WATER RESEARCH

80/

[redacted]

TREATMENT AND DISINFECTION OF SMALL WATER SUPPLIES

Final Report 551-S

Contract PECD 7/7/06-50/82

WRc Project PWT 1526/9826

CONTRACT REPORT 551-S

WARNING OF CONFIDENTIALITY

This report has been prepared as a result of the work done under a contract from the Department of the Environment.

The contents must not be published in any way nor discussed with a third party unless the prior permission of the client has first been obtained by the senior staff member responsible for the work, namely Mr J H Warden.

This sheet will be detached before issue of the report to the client or when general permission to publish has been given.

C O N T E N T S

## LIST OF FIGURES



## LIST OF TABLES

SECTION 1 SUMMARY

Laboratory evaluations were made on 17 pumps and other dosers used for hypochlorite dosing on small water supplies and the features in their designs which made for reliability and effectiveness were identified. A specification listing detailed recommendations for the selection of dosing pumps and more general guidance on other types of doser is appended. While calcium hypochlorite tablets are attractive for use on small supplies, having long shelf life and carrying a high charge of chlorine, the simple dosers available are not as accurate or versatile as liquid dosers.

Gas chlorination using vacuum injectors is technically viable for supplies down to about 50 cu.m/d where there is a minimum water head of 2m available to drive the injector. Gas chlorination could be applied to lower flows if measurement of the gas flow could be made more accurate.

On-site generation of hypochlorite is reviewed. There are not many units available for small supplies and there is little technical or economic justification for any substantial adoption of the process.

Ultraviolet irradiation is a proven method of disinfection and a survey of users has shown it to be reliable and satisfactory in practice although not in widespread use.

Preliminary investigations reported here demonstrated the need for further developments in chlorine monitors and in the hydraulic design of contact tanks.

Many small supplies require pH elevation and this can often be achieved by letting the water pass through a contact bed of suitable material. There are several semi-manufactured materials available but, where long enough contact can be given, natural calcium carbonate has the advantage that it will saturate without raising pH excessively.

Where electricity is required to monitor or control the treatment of a supply of variable quality, all the necessary equipment can be obtained for battery operation. A range of hydraulic, wind and solar powered generators is available for keeping the batteries charged from natural energy supplies.

Sodium hypochlorite is reputed to have a short shelf life. Tests have shown that exposure to light is the main agent of decomposition and that temperature is also a significant factor. Since these depend upon conditions of storage and are not under suppliers' control, a "use-by" date labelling system is not feasible. Recommendations are made for care in storage and regular turnover of stocks which should help to ensure that the loss of available chlorine up to the point of use would be negligible.

## Objectives

In 1982 WRc Processes was awarded a contract by the Department of the Environment tostudy the treatment and disinfection of small water supplies. The total work under this contract proceeded in two phases, the first running from 1 September 1982 until 31 August 1984. The objectives were;

(1) To evaluate operational experience of equipment currently available for the disinfection of small water supplies.

(2) To test means of hypochlorite dosing and identify the factors that make for reliability and effectiveness.

(3) To develop processes and equipment specifications for treating water at small remote installations.

The programme of work was to

- make a survey of equipment available and user experience (at the same time looking for information on the extent to which water quality could vary),
- test methods of hypochlorite dosing with regard to reliability and effectiveness,
- test other methods of disinfection,
- report.

It became clear at the outset that the main concern of the operators of small supplies was the reliabilty of the quality of the water they supplied. and that so far as this rested upon equipment, they were looking for performance and reliability of the whole system. Since the third objective was to develop processes, the programme was expanded to include some consideration of chlorine monitoring and the effectiveness of contact tanks.

The second phase of the contract extended the completion date to 1986 with the following objectives.

1a. Evaluate available equipment for disinfection of small water supplies not covered by previous review of water undertakings' operational experiences.

2a. Investigate and report on potential value and factors that make for reliability of electrochlorination equipment and halogen releasing agents.

3a. To complete specification for treatment processes, investigate specifications of commercial grades of sodium hypochlorite solutions, with special investigation of their storage life to establish "use by" date labelling for water treatment applications.

3b. To complete development of processes for treating water at small remote installations, investigate requirements for, and availability and suitability of power supply units.

3c. To complete development of specifications for treatment processes for small remote installations, evaluate in the field the use of proprietary and natural solid materials in fixed beds for adjustment of pH of supplies.

4. Prepare report on guidance for selection of processes and equipment for disinfection of small water supplies.

The programme of work was to

- complete evaluation of disinfection units; this to include UV radiation, dry chlorine gas and hypochlorite tablet units,
- carry out a study of electrochlorination and halogen release agents for disinfection,
- study shelf life of hypochlorite solutions and investigate specification of commercially-available material for waterworks application, with a view to advising on "use by" date labelling,

- carry out field trials for evaluation of fixed beds of solid materials for pH adjustment,
- complete 'process and equipment selection guide' for disinfection and treatment of small water supplies,
- provide final comprehensive contract report to DoE.

## Introduction

This is the final comprehensive contract report. Its purpose is to give an account of all the work done under this contract and to present the knowledge gained in the context of the objectives.

An important objective was to identify the design features of hypochlorite dosers which made for accuracy and reliability. This involved testing and evaluation of several units. Some of these could be described anonymously by type but some were made by only one manufacturer, and so the report openly refers to all units by their trade names or numbers. However the objectives did not include making a comprehensive survey of the market or reporting the suitability of particular units. While some remarks are made on suitability where they seem to be natural or helpful, the authors have tried to avoid making comparisons between different makes of similar units and have chosen not to present anything which might be mistaken for a buyers' guide.

It is admitted that there is a need for information which will help in the selection of equipment and processes and a report by WRc is in preparation under the title "Upgrading Small Public Water Supplies". This will draw on the knowledge gained in this contract, acknowledging the permission of the Department of the Environment to do so, and on other work done by WRc.

A major part of the work under this contract was to be performance testing of chemical dosers. Since there were no published standards available the first action was to circulate a draft specification (WRc report 209-S, March 1983) to interested parties for comment and approval. This draft is included as an Annex, Section 16. It describes a complete water treatment plant and so provides the context for as well as a statement of the performance requirements of the chemical dosers.

It should be noted that the specification does not call for a given degree of bacterial kill or a specified water quality because these things are beyond the capability of a doser. A doser can only be evaluated in terms of the volume of chemical dosed at the specified operating conditions.

The requirements were drafted with broad tolerances, giving those consulted the opportunity to call for closer limits. The sections relating to the performance of disinfection equipment are reproduced below. As a result of the work done on this contract it has been possible to add recommendations on the design of hypochlorite dosers as shown in Section 13.

## 2. GENERAL

2.3 The plant must be capable of running unattended for a normal period of one week and a maximum of two.

3.3 Materials of construction of equipment and surface finishes must be resistant to damp atmospheres and corrosion by substances to which they will be exposed, both in normal use and also in the case of accidental spillage. They should comply with the relevant BS specifications and if necessary, have WAA* approval. Any chemicals used should be approved for use by the CCM**.

3.4 Preference will be given to equipment which can be adjusted and whose renewable parts can be cleaned and replaced without the use of tools by an operator with gloved hands.

## 5. CHLORINATOR

5.1 The chlorinator must be able to deliver free chlorine into a flow of water at a rate controllable between 0.1 and 3mg/l under steady flow conditions, the dose not altering by more than 10% from one hour to the next or between the second hour of continuous operation and the 350th hour(i.e. after two weeks).

5.2 This performance must be maintained notwithstanding any change in temperature of the water dosed from zero to 30 degrees centigrade or, if dosing into a closed system, any change in water pressure from 1 bar negative to 10 bar positive and at all stages from full to empty chemical container whether this is a part of the chlorinator or not.

5.3 Where an adjustment is provided to change the delivery, the alterations must be smoothly continuous or (where stepwise) in equal steps and whenever the adjuster is moved to any position from the full range setting, the dose should be within 10% of the average for that setting.

* Water Authorities' Association

** Committee on Chemicals and Materials of Construction for Use in Public Water Supply and Swimming Pools, Department of the Environment.

6. CHLORINE MONITOR

6.1 Where a chlorine residual monitor is provided it must be able to detect a residual of 0.1mg/l free chlorine and to indicate this to within plus or minus 0.05mg/l. At a free chlorine level of 1mg/l the indication must be within 0.2mg/l and at a residual of 5mg/l, within 1mg/l. In performance tests these measurements should be taken in samples at pH 5.5 although the instrument will be expected to operate with the same accuracy at the natural pH of the water.

7. CONTACT TANK

7.1 Where a chlorine contact tank is provided, its design must be such that when water is flowing steadily through at the maximum design rate, 95% of the water discharged has remained in the tank for the minimum required contact time.

## SECTION 4 HYPOCHLORITE DOSERS

### Introduction

Performance tests were carried out on 17 hypochlorite dosing devices. This Section reports their main features, how widely they are used, their methods of operation and the findings of the performance tests. Details of the testing procedures and the results obtained are given in Section 15.

No evaluation was considered complete before the results had been made known to the manufacturer or supplier and his comment invited. In some cases there was no comment; generally the results were accepted as true and fair, and in the few cases where there were anomalies or points of misunderstanding, they were resolved.

### Choice of Units

Altogether 17 units were evaluated of which 13 could be classified as pumps,though with wide variations within that classification. Some units were purchased, some were obtained on loan, some donated and three were taken from WRc stock, having seen previous duty. The aims of selection were to include examples of alltypes of equipment available on the market which were in current use on small water supplies.

Immediate candidates on account of their widespread use and simplicity were the Mariotte Jar, Dosatron, Self Powered Chemical Doser, Meter Controlled Reagent Feeder and the Schuco peristaltic pump.

Of the wide range of standard precision dosing pumps the MPL KV type was taken (though obsolescent) as typical of an indistrial motor driven unit capable of being fitted with a variety of pump heads. The Prominent range of pumps was also widely used for hypochlorite dosing and offered a contrast to the KV units in that the displacers were solenoid operated with electronic control of stroking rate as well as adjustment of stroke length. Three units were taken from the range; a mains operated pump with automatic or manual speed adjustment, a pump with speed control by a water meter and a battery powered pump. An Alldos pump was tested: of similar size and output to the Prominent pumps and with a similar diaphragm head, it was driven by a motor and crank. The Jesco was another meter controlled solenoid pump with the additional feature of an impulse divider which enabled a very wide range of dosing to be provided by a single unit. While each of these pumps had individual design features, they also had many in common ans this enabled assessments of the design features making for reliability and effectiveness to be made without tham being associated with a particular marque.

Two new water-powered units became available during the contract, the Aragonite and the Elados. Both were included in the programme to evaluate their potential.

Calcium hypochlorite tablets are used on some small supplies and are attractive because 70% of the weight of material carried to site is available chlorine. In many cases the means of using the tablets is very primitive. Only two dosing devices were available in the UK and both were tested.

## Test Procedures

A standard method of testing was evolved for pumps. It had been hoped to be able to collect the discharges of individual pump strokes so as to get an ultimate measurement of the regularity of operation, but it was not possible to do this when the pump was working at pressure and so delivery was measured out of a calibrated suction container, usually over a counted number of strokes.

Putting steady pressure on a pump outlet was not simply a matter of discharging through a loading valve; in this case the delivery pressure started at zero on each stroke and rose to the valve setting pressure. The pressure gauge showed such wide fluctuations that it was impossible to measure the effective delivery pressure. When a surge damper was connected into the delivery line it was found that it did not pass a steady flow, but discharged intermittently, opening at one pressure and closing at a slightly lower one. Two methods were used in the tests. Small pumps delivered into a 10 litre pressure vessel which was pre-pressurised up to a maximum of 10 bar by a compressed air cylinder. During the period of a test the volume of water added to the cylinder was not enough to change the pressure significantly. Where a pump had too great a delivery for testing in this way it was connected to a water line flowing at pressure. This was a direct simulation of working conditions but the laboratory water supply pressure was limited to 3 bar.

However, measuring the accuracy and regularity of dosing at different pressures was only a part of the tests. An investigation of the factors making for reliability and effectiveness called for an analysis of the operation of eachdevice, identification of all the elements contributing to its performance and then the assessment of each. The detailed considerations given to each unit are described in the respective parts of Section 15.

## 4.1 MARIOTTE JAR

### Introduction

The Mariotte Jar is about the simplest acceptable gravity feeder and is well known in laboratory practice. It has found general use for disinfecting small water supplies. It is illustrated at Fig 1. This doser would be assembled locally and the cost is nominal.

### Method of operation

The unit is assembled from standard laboratory apparatus and is usually based on a 20-litre glass aspirator. When liquid flows through the capillary outlet tube, air is drawn into the jar through the central vent pipe and bubbles up into the air space above the liquid. Atmospheric pressure exists at the foot of the vent pipe. This means that all the liquid above this level is stored at reduced pressure and there is a constant head above the outlet tube. Therefore the dose rate does not decrease as the jar empties and, further, it can be easily adjusted by rotating the capillary tube to raise or lower the outlet. Where the feeder doses the flow into a reservoir, the vent pipe may be extended to terminate at the reservoir top water level. Then when the reservoir is full the air inlet will be stifled and dosing will stop. Cutoff may be rather sluggish, depending on the length of the tube and the amount of air in the jar. The doser is installed above the top level of the water to be treated and so all the energy required for its operation is stored in the hypochlorite by virtue of its elevation.

### Factors making for reliability and effectiveness

The reliability and effectiveness of this simple doser depend in the first place on the construction; the rigidity of the solution container (if a glass aspirator is not used) and the airtightness of the outlet and vent tube connections.

Because solution is dosed through a small nozzle at low pressure, the doser can not tolerate any solid particles in the solution. If the hypochlorite solution is to be diluted before use, precautions must be taken to avoid the deposit of calcium carbonate from any hardness in the diluting water and the feeder should be protected from evaporation and crystallisation at the nozzle. Variations in atmospheric temperature and pressure make the dose vary about its average and hypochlorite solutions lose strength rapidly when exposed to light. For these reasons the doser operates best in a cool, dark and humid place.

### Range of application

The smallest reliable delivery is about 1 litre/day. The greatest delivery is limited by the capacity of the aspirator and the period between visits to refill it. Performance tests have shown that adjustment of the dose is simple and reliable and that the dosing rate is not dependent on the amount of solution in the jar. However changes in temperature and atmospheric pressure can cause temporary disturbances in the rate of dosing as they affect the pressure drop across the capillary tube. The unit should not be used, therefore, unless there is a reservoir of at least 12 hours' capacity beween it and the first consumer.

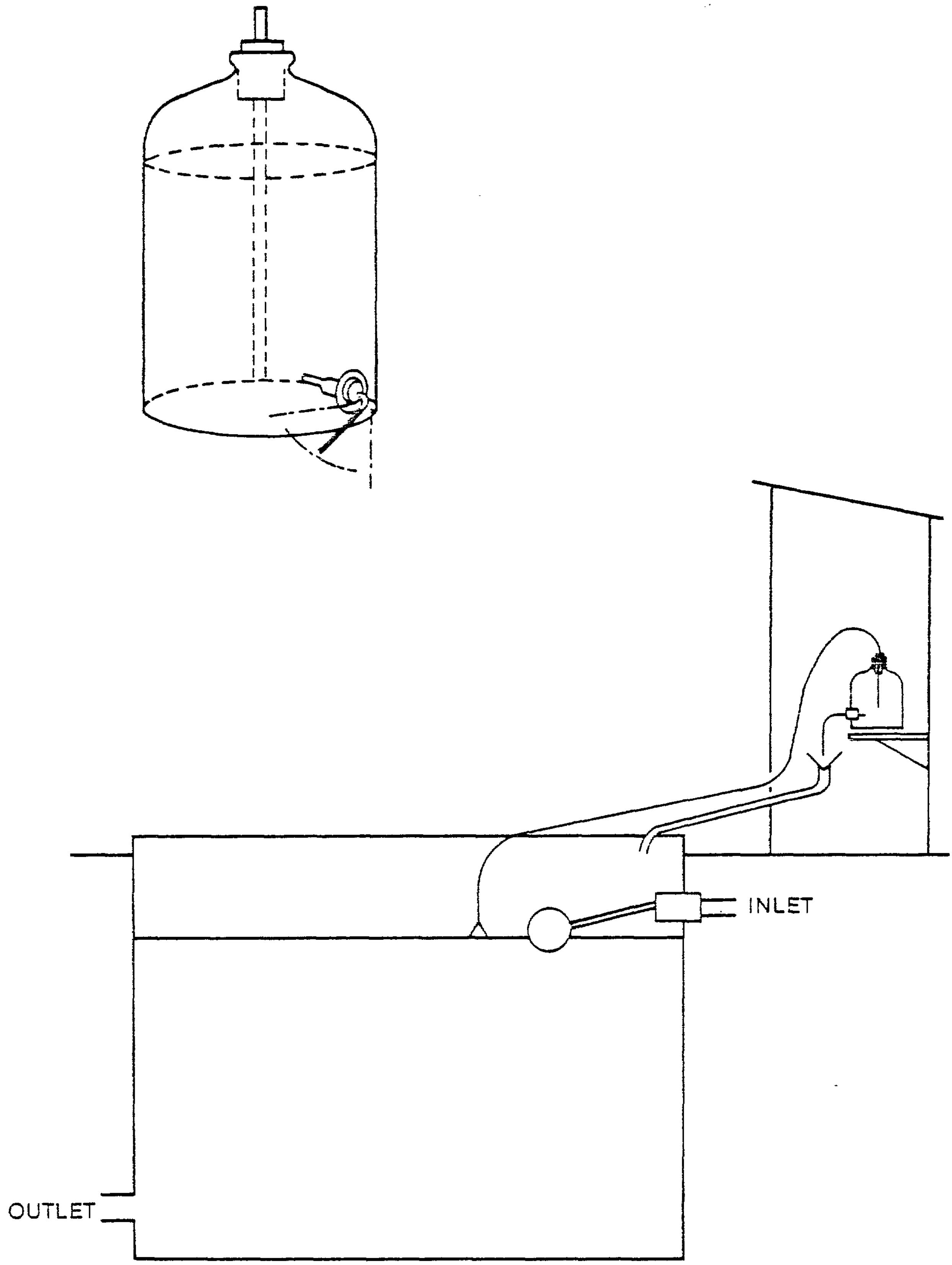



Fig. 1 Mariotte jar

Introduction

This unit is understood to be manufactured in France and marketed by an agent in the UK. It was included among the units tested because it was inexpensive and found to be in use on the rural supplies of more than one public supply undertaking. The unit is readily available, inexpensive to buy and easy and compact to instal.

Method of operation

Water flows through a positive displacement motor unit, driving a piston up and down. The piston is connected to an auxiliary piston which delivers hypochlorite solution from a container into the water flowing through the motor unit. A cross-section is shown in Fig 2 and it can be seen that piston is stepped and works in two bores. Valves in the piston head connect the the main bore to either the inner bore or the outer annulus. One valve is open while the other is closed and they are changed over with a snap action at each end of the stroke when a push rod operates a spring-loaded toggle mechanism. Both body and piston are moulded in plastic and the piston is made watertight in its bores by lip seals which are part of the piston moulding.

The dose ratio of the unit is fixed. Six models are available with ratios ranging from 1:500 to 1:10.

Factors making for reliability and effectiveness

In tests over a wide range of flows the doser was found to work to well within the limits of accuracy required for drinking water treatment. The piston, moving freely between the ends of its travel and relying on a piston-mounted mechanism to reverse the direction of travel, might have been expected to show a lengthening of stroke as the speed increased. In fact there was little variation over the operating range and the dose per stroke was constant, suggesting that reversal at the bottom of the stroke was at the same point at all speeds. This was attributed to the rapid action of the spring-loaded toggle mechanism which operated the valves in the piston head and to the fact that the maximum rate was limited to about two reversals per second.

Reliability of the unit depends on the durability and wear-resisting properties of the moving parts. This unit could not be described as of robust construction and the fact that the piston seals were part of the piston meant that when they were worn, the whole unit needed replacement. It was reported from the field and confirmed in laboratory tests that the unit was susceptible to premature wear if its axis were not set truly vertical.

Although most dosers use ball valves, this one relied on lip seals in the dosing cylinder and they gave consistent performance.

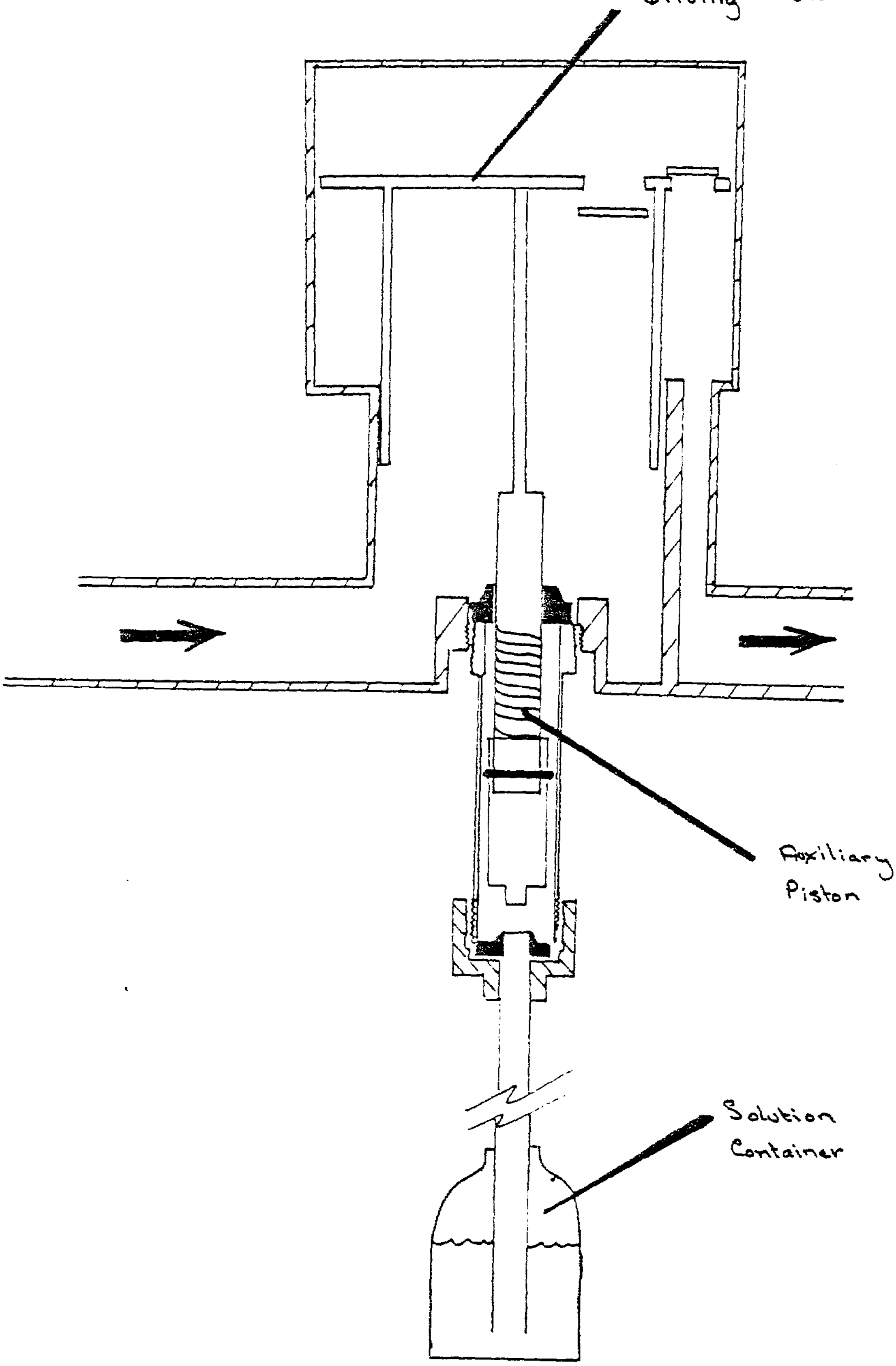



Fig 2 - DOSATRON DISPENSER

## 4.3 THE SCHUCO PERISTALTIC PUMP

### Introduction

Although designed primarily for laboratory applications, this unit is used for hypochlorite dosing on small supplies in several parts of the country. The pump is readily available at low cost.

### Method of Operation

A small 3-12V dc geared motor drives a rotor at a maximum speed of 100rpm. The rotor carries a triangular head over which a length of silicone tubing is stretched (Fig 3). As the head is rotated liquid is squeezed along the tube. The delivery may be varied either by controlling the voltage applied to the motor to change its speed or by changing to a different tube diameter. Tubes of 1, 2.5 and 5mm bore are available, permitting a delivery range of 0.2-38.5ml/min. The pump is designed to operate against a maximum back pressure of 0.34bar (5psi).

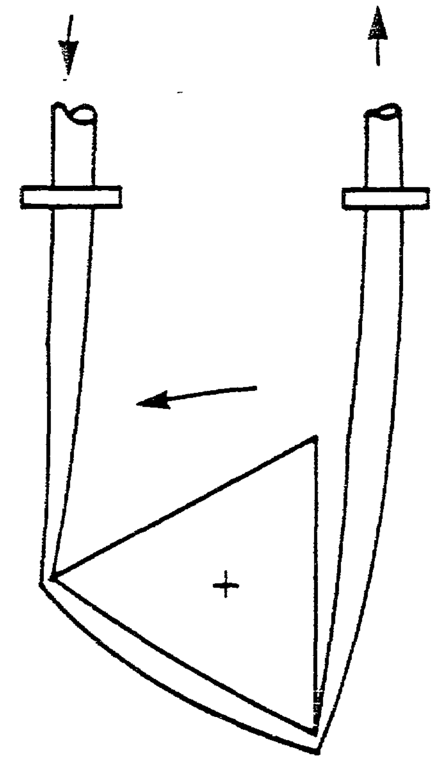
The power source may be either a 12V motor vehicle type battery or, via a specially designed control unit, 240V ac mains.

### Factors Making for Reliability and Effectiveness

The pump is of simple construction and should provide reliable service.

Because the tube must be occluded at the corners of the triangular rotor head, it is soft walled and flexible. This probably contributes to tube life but at the same time it limits the height to which the liquid can be lifted into the pump and causes variation in delivery if the outlet pressure varies.

Routine maintenance is essential but straightforward; the length of tube over which the rotor works requires replacement ideally every week and the battery (if used) needs regular recharging.



Schuco
Fig. 3 Peristaltic pump

## 4.4 ARAGONITE PROPORTIONAL FEEDER

### Introduction

This feeder is manufactured in Germany and distributed through agents in the UK. It has become available only recently and is not in wide use. The unit is readily available in a number of sizes.

### Method of Operation

The feeder is a compact, cylindrical self-powered unit with water inlet and outlet on opposite sides and the dosing solution inlet on the underside as shown in Fig 4. The feeder is divided into two chambers separated by a diaphragm to which a dosing piston is rigidly attached. Part of the water flow is directed through a bistable mechanism which induces periodic up/down movement of the diaphragm and hence the piston. Dosing solution is drawn into the feeder on the upstroke and dosed into the water on the downstroke.

The volume of solution dosed can be varied by adjusting the control knob, located on the underside of the feeder, over a graduated scale. The scale was not calibrated and the marks were labelled as settings 0-6 for the purposes of this evaluation. Each graduation required two complete turns of the knob. The range of adjustment of the control knob actually extends half a graduation beyond setting 6 and a similar amount below setting 0. The knob is marked to allow precise adjustment in eighths of a graduation.

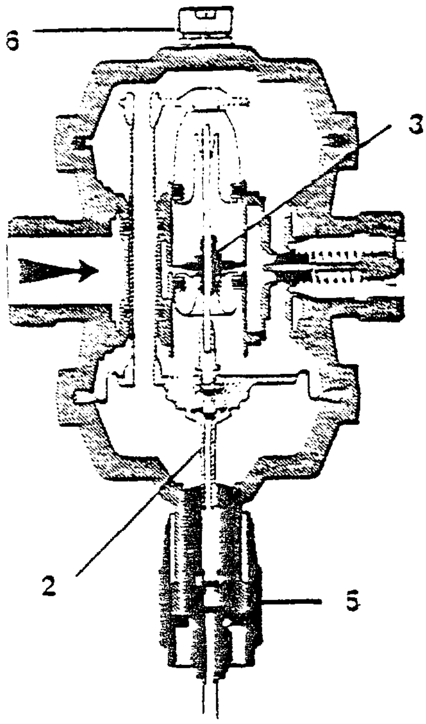
### Factors making for reliability and effectiveness.

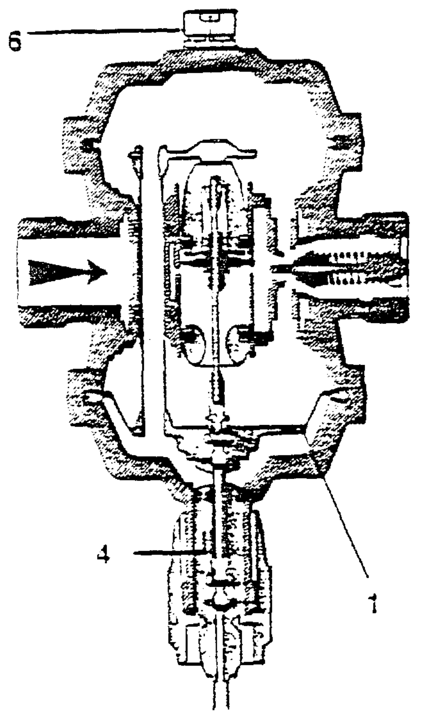
The unit was of robust construction, well made and mechanically sound; fundamental requirements for satisfactory long-term performance. The dosing cylinder appeared in tests to work well and there was no doubt that the double ball valves sealed well and contributed to effective performance.

Performance tests showed that the actual dose delivered per stroke depended on the rate of stroking although the variation was not excessive. The reason for this was not clear. The variation was regular, indicating that it was inherent in the design rather than being a result of the construction of the particular unit tested.

Furthermore, the stroke rate did not vary in strict proportion to the flow rate of water through the unit. This appeared to depend on the performance of a spring loadad valve whose function was to divert a constant proportion of the water flow to the motor unit. The result of this was that, although the unit was found to perform reliably and repeatably in the tests, its effectiveness as measured by flow proportional dosing was variable and was judged acceptable for drinking water treatment over only a part of its operating range.

There was no provision on this unit to reset the control knob so that zero setting corresponded with zero dose. Thus, although the dose varied linearly with setting there was little chance that an operator would use this to advantage when making dose adjustments.




1 Diaphragm
2 Dosing piston
3 Hydraulic bistable
4 Pumphouse
5 Control knob
6 Aeration and de-aeration

FIGURE 4.

THE ARAGONITE PROPORTIONAL FEEDER

4.5

## SELF-POWERED CHEMICAL DOSER

### Introduction

This unit was brought on to the market in 1981. It does not use electricity in its operation and can be applied to gravity supplies or to a pumped system at a point where head is broken.

The unit is manufactured in the UK. Several have been installed in rural areas by Water Undertakings and others such as the Youth Hostels Association and the Forestry Commission.

### Method of Operation

The unit Fig.5 is based on a 150 litre water tank fitted with a siphon which rapidly empties the tank when it has filled to the top level. A ball float, operating in vertical guides, raises and lowers a cup as the water level moves, but within a smaller range of travel limited by mechanical stops. At its lowest position the cup is immersed in a well of hypochlorite solution. A displacement plunger is mounted vertically above the cup, and as it rises to its upper stop the plunger enters the cup and displaces hypochlorite solution over the lip and into the water filling the tank. The cup reaches its topmost position before the siphon operates.

Thus, the cup being filled to the same level on each cycle, every volume of water discharged from the tank is dosed with the same volume of hypochlorite solution. The dose can be altered by raising and lowering the stop which limits the upward travel of the cup. The cup, plunger and setting scale can be provided to deliver up to 5, 10 or 20 ml hypochlorite per cycle and these sets of parts are interchangeable according to the duty required of the unit.

The volume of water discharged per cycle is the volume of the tank between the upper and lower siphon levels plus the volume which flows into the tank while the siphon is operating. Thus although the hypochlorite dispensed per cycle is constant, the volume of water into which it is dosed will vary slightly according to flow rate into the tank. This effect is discussed below.

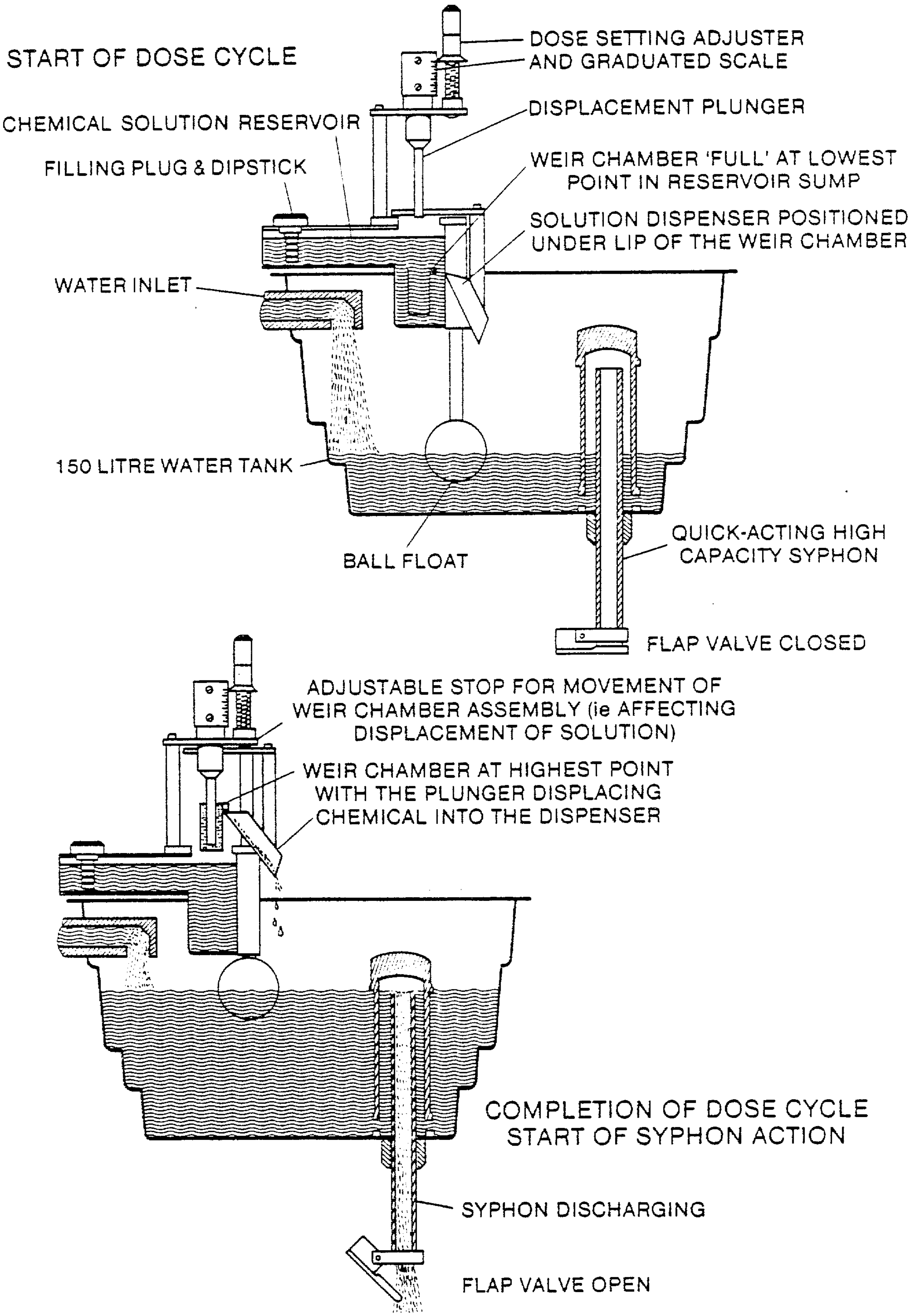



Fig. 5 Self powered chemical doser

Factors making for reliability and effectiveness

This unit has been designed in recent years with the specific aim of being reliable and effective for extended periods on remote sites where resources are minimal. The main features are as follows.

- The hypochlorite life is conserved by making the container closed and opaque.
- The dose is measured out by a plunger working in an open cup. Small doses can thus be dispensed accurately without the use of small orifices.
- Water is positively metered through the unit so that dosing is regular over the whole operating range.
- The unit does not allow trickle flows to pass untreated.

## 4.6 KV TYPE DIAPHRAGM DOSING PUMP

### Introduction

The KV type chemical dosing pump was well known and widely used in the water industry. Although in process of being replaced by a new design, it was tested as being representative of a well established type and capable of helping identify the design features making for good performance.

This type of pump provided a basic driving unit on to which different types of pumphead could be mounted, some units capable of taking more than one pump head of more than one type at the same time. In this test a diaphragm head was fitted to a single drive unit.

### Method of operation

A wormwheel on the shaft of a vertically-mounted electric drive motor drove a spur gear which ran in an oil bath. A crank on the spur gear drove a connecting rod whose small end drove a plunger in a guide bush. On every rotation of the spur wheel the plunger was driven forward to the full extent of the crank, but its return travel was powered by a spring and limited by the position of a stroke adjusting unit. Thus the travel of the plunger could be adjusted from zero to 12.7mm (0.5 inch) but the outward stroke was always to the same point. A section of the drive unit is shown in Fig 6.

In this test a diaphragm pump head was fitted to the drive unit. The pumphead was made in plastic with single ball valves on inlet and outlet. The plunger head was sealed from the pumping chamber by a circular diaphragm made of a plastic similar to that used for credit cards; thinner and more flexible but with a degree of rigidity. This was the largest diaphragm pump head in the range, rated at 45 l/h at full stroke and a maximum pressure stipulated as 2.8 bar.

### Factors making for reliability and effectiveness

The laboratory tests and extended experience of use of the unit on WRc pilot plant proved that the robust construction and well-lubricated, slow moving parts made the pump very reliable in operation.

Consistent dosing, however, required that the delivery pressure should be steady and that the inlet head should not change from positive to negative. These shortcomings were attributed to the design of the diaphragm chamber and choice of diaphragm material.

In a dosing pump the work of pumping belongs to a displacer, usually in the form of a piston, and the purpose of the diaphragm is to seal the pumping chamber. If the diaphragm is attached to the centre of the displacer, it will take up a conical shape on the suction stroke and, having a large unsupported area, will be prone to flex and enclose a space whose volume depends on the pressure of the liquid enclosed. The lesson drawn here is that for accurate and consistent dosing the diaphragm should have a small unsupported area. This must be an annulus close to its edge, where the material must be very flexible and have high tensile strength.

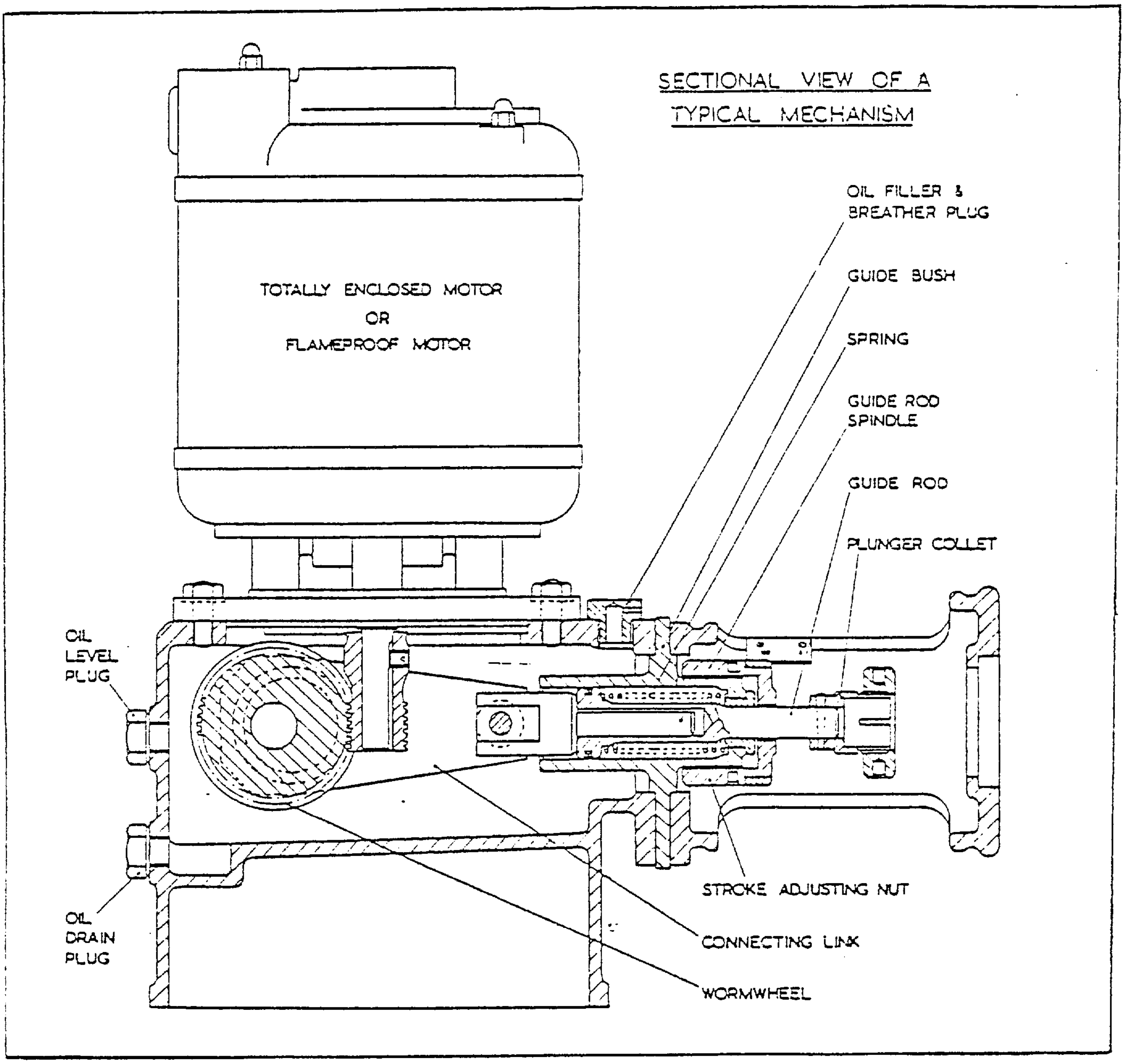



Figure 6. The KV Type Drive Unit

## 4.7 KVPG PISTON DOSING PUMP

### Introduction

This pump utilised the same KV drive unit as used for the KV Diaphragm Dosing Pump reported previously (section 4.6). It was however fitted with a different type of pump head.

### Method of Operation

The PG13G pumphead fitted on this unit had a glass piston reciprocating in a lip seal. Single ball valves were fitted in the inlet and outlet lines. Stroke length was adjustable.

### Factors Making for Reliability and Effectiveness

This unit was of robust construction, and the relatively slow movement of the working parts should make it mechanically reliable.

The piston pump head fitted to this pump proved to be less sensitive to suction head and delivery pressure than the diaphragm pump head fitted on the same motor (section 4.6). This demonstrated one advantage of having a rigid piston rather than a flexible diaphragm, the curvature of which can change and thus alter the swept volume per stroke.

## 4.8 MPL PUMPS LTD AG SUPER SOLENOID DIAPHRAGM PUMP

Method of Operation

The pump had a diaphragm type head with single 'duckbill' valves on suction and delivery. The diaphragm was driven by a solenoid motor activated by a solid-state electronic timer. Unlike most other pumps of this type, the length of stroke was not adjustable and all the adjustment of dose was controlled by using the timer to adjust the stroke rate.

Factors Making for Reliability and Effectiveness

This pump could only be considered adequate for small water supplies in situations where the pressure remained constant. The sensitivity to pressure, particularly at the lower end of the operating range, was typical of solenoid pumps. The relatively powerful solenoid and long stroke were features of this unit tending to increase this sensitvity.

The use of an electronic timer demonstrated how a pump could be controlled accurately over a wide range of doses without the need for mechanical adjustment of the stroke length.

The use of duckbill valves was unusual. They sealed well, as shown by the consistency of dose per stroke at all flow rates, but in this test one failed very quickly. They appeared to be more expensive to manufacture than the standard ball type valve without offering any improvement in performance.

## 4.9 PROMINENT A1002P DIAPHRAGM PUMP

### Method of Operation

The Prominent A1200P was an electronically controlled diaphgram dosing pump. The drive unit was a solenoid armature, the stroke of which could be adjusted between 10 and 100% by means of a control knob. The frequency of the stroke could also be adjusted via a potentiometer with a turn down ratio of 10:1.

### Factors Making for Reliability and Effectiveness

Unlike some other solenoid type pumps, the 'supercharging' effect was restricted to the lowest 10-15% of the delivery pressure range, after which delivery was virtually independent of pressure. The short stroke length (maximum 1.25mm) was a major contributing factor to this.

The electronic control allowed for precise adjustment of delivery across the full range.

Delivery was found to vary during continuous running, the limits being just inside those recommended for drinking water applications.

## 4.10 PROMINENT A2001N 12V DC DIAPHRAGM DOSING PUMP

### Introduction

This was one of three dosing pumps from the same manufacturer, but unlike the others was designed to operate from a 12V dc supply rather than the mains.

### Method of Operation

This was an electronically controlled, solenoid driven, diaphragm dosing pump. Both the length of stroke and the stroke rate were adjustable. The pump was designed with a short stroke length (1.25mm).

Like the other pumps from this manufacturer, the A2001N had twin ball valves in the inlet and outlet ports of the diaphragm.

### Factors Making for Reliability and Effectiveness

The performance of this pump was found to be acceptable for drinking water applications. Delivery was independent of suction head and only slightly influenced by back pressure; 'supercharging' was limited to the 0 - 1 bar pressure range, largely as a result of the pump having a short stroke length.

The electronic control allowed for linear adjustment of stroke length and frequency.

The pump maintained a constant delivery during continuous operation; battery life during the test was however limited, so attention should be given to ensuring that sufficient capacity is available.

## 4.11 PROMINENT E2001N METER-CONTROLLED DIAPHRAGM DOSING PUMP

### Method of Operation

This was an electronically controlled, solenoid driven pump. The dose per stroke could be adjusted between 10 and 100% by means of a control knob. The frequency of stroking was controlled by pulses from a NG5 flow meter mounted in the pipe carrying the water to be chlorinated.

### Factors Making for Reliability and Effectiveness

The short stroke length (maximum 1.25mm) contributed to the relative insignificance of the 'supercharging' effect when compared to other solenoid pumps.

The combination of an accurate water meter and electronic control allowed for precise adjustment of delivery across the full range.

Delivery was found to remain stable during continuous running, demonstrating that the pump was reliable and suitable for drinking water treatment.

## 4.12 ALLDOS P201-105

### Method of Operation

The ALLDOS M200 series pump was a diaphragm metering pump with mechanical control of stroke length and electronic frequency control. A water meter, on which the pump was mounted, provided a pulsed signal to a UNIDOS controller which switched the pump on/off. The frequency at which the pump was turned on was proportional to the water flow rate through the meter, as the flow increased the frequency of dosing increased. When the pump was working it had a stroke rate of 60 strokes per minute (spm).

The rotary action of the electric motor was transformed to a stroke action by an eccentric shaft which moved a cam that effected the pressure stroke. A spring created the suction stroke. Both the outlet and inlet valves on the pumphead had double ball-valves.

### Factors Making for Reliability and Effectiveness

The combination of an electronic controller with a precise water flow meter appeared to contribute to the generally good performance of this unit. The output range was adequate and dose adjustment linear. However, the length of time the pump operated for each pulse signal received from the meter was too long, resulting in the dose rate being flow proportional for only 60% of the operating range.

The provision of two ball valves was found to be beneficial in preventing backkflow through the pumphead

The pump provided reliable service throughout the test programme.

## 4.13 JESCO MAGDOS MD2 SOLENOID PUMP WITH MX3 FLOW METER

### Method of Operation

The pump consisted of a diaphragm dosing head driven directly by a solenoid, with an electronic control unit at the rear. The volume delivered on each stroke was adjusted by a stroke control knob. The pump was designed to deliver into metered flow and the dose rate could be adjusted by setting a frequency control knob or automatically according to the pulse rate from a water flow meter. Further, the whole range of adjustment could be changed by an impulse fractionator which divided the number of pulses from the meter, per unit volume passed, by any number from 1 to 255.

### Factors Making for Reliability and Effectiveness

The performance of this pump was found to be satisfactory for drinking water applications. The dose was sensitive to back pressure at the lower end of its pressure range because of supercharging, but was relatively insensitive to suction head.

In common with other solenoid driven pumps the maximum frequeny was limited by the time required for the armature to complete its forward and back strokes.

An accurate flow meter and linear adjustment of stroke length and frequency allowed for precise setting of desired dose.

The impulse fractionator was a very useful feature, considerably extending the range of the pump to the point where it could effectively dose neat sodium hypochlorite solution.

The use of a rubber bush to connect the meter magnet to the drive spindle appeared to result in slippage at high flow rates.

## 4.14 ELADOS 'C' WATER POWERED FLOW PROPORTIONAL DOSING PUMP

Introduction

This West German manufactured dosing pump was newly available in the UK and there was interest in evaluating it as another example of a water-powered unit.

The device was designed to dose liquids such as calcium hypochlorite solution which might contain suspended solids prone to settle out and cause blockages in pipes and stirring tanks. This was achieved with a dual pumphead in which a diaphragm maintained a circulating flow while a small piston, driven by the same actuator, dosed a small part of the flow into the water to be treated. It is described more fully in Appendix 4.14.

Factors Making for Reliability and Effectiveness.

During the tests both the drive and the dosing head had to be replaced, suggesting that there may be reliability problems with this unit. The dose head contained a diaphragm, piston seal and three valves but was designed as a sealed unit so that if any component failed to work correctly, the only remedy was to replace the whole unit. This was considered to be a disadvantage.

A dosing pump for use with small supplies should provide flow proportional dosing. This unit was found to be flow proportional for only the first 30% of its flow range.

The dose per unit volume of water was fixed, a feature considered to be a major limitation on its effectiveness for drinking water treatment.

## 4.15 FEEDER TYPE AHWM

### Introduction

The AHWM feeder is a water driven hypochlorite doser which is manufactured in the UK and has been in widespread use for many years.

### Method of Operation

This feeder is designed for dosing chemical solution into a flow of water under pressure. It has two main parts, a dose pump and a water meter. The pump obtains its driving energy by taking a small flow from the pressurised system and discharging it to the atmosphere.

Fig 7 represents a cross section of the water driven dosing pump which has a conventional diaphragm dosing head (10) with inlet and outlet check valves (12). Operating water is usually taken from the main adjacent to the dosing point and is applied to the outer side of the diaphragm so that only a small net force is needed to drive it forward on the pumping stroke. This force is obtained from a second, power diaphragm (7) to which water is supplied through a flow control valve (8).

Stroking of the pump is controlled by a four-lobed cam (24) which is driven by the water meter in the main and thus rotates at a speed proportional to the flow of water. In the diagram the cam rotates clockwise forcing the roller follower (22) forward and closing valve (4) through which the power water had been flowing to waste. As pressure builds up the power diaphragm moves forward compressing spring (16) and closing bleed valve (19) which balances the pumping diaphragm. The whole assembly now moves forward, controlled by the cam follower (22) and hypochlorite is injected into the main.

As the cam continues to rotate the follower is released from the high point and returns immediately to the low point. Valve (4) opens, depressurising the power diaphragm, the spring expands opening bleed valve (19) and pulling the dosing diaphragm back to recharge the dosing head. The rearward movement of the diaphragm is limited by a stop (3) behind the power diaphragm whose position is controlled by a setting knob (1). The maximum stroke is 1/2" and the minimum is one quarter of this. The knob has a pointer which moves over a scale calibrated from 10 (full stroke) to 2.5 (quarter stroke).

### Factors Making for Reliability and Effectiveness

The AHWM works within the limits of accuracy required for drinking water treatment across its wide operating flow rate range (rated turndown ratio is in excess of 300:1). Reliability should not be a problem. The unit is of robust construction and the parts move slowly, with all necessary lubrication provided by the water. The pump is designed such that the pressures on each side of the diaphragm are balanced, thereby minimising the energy needed to inject the chemical into the water flow and reducing the stresses on working parts of the pump, especially the diaphragm.

Maintenance is simplified by the ease with which the major components can be removed by hand without tools, and by the comprehensive notes included in the service manual supplied with each unit. Being able to zero the control knob is a very useful feature of the dose setting control.

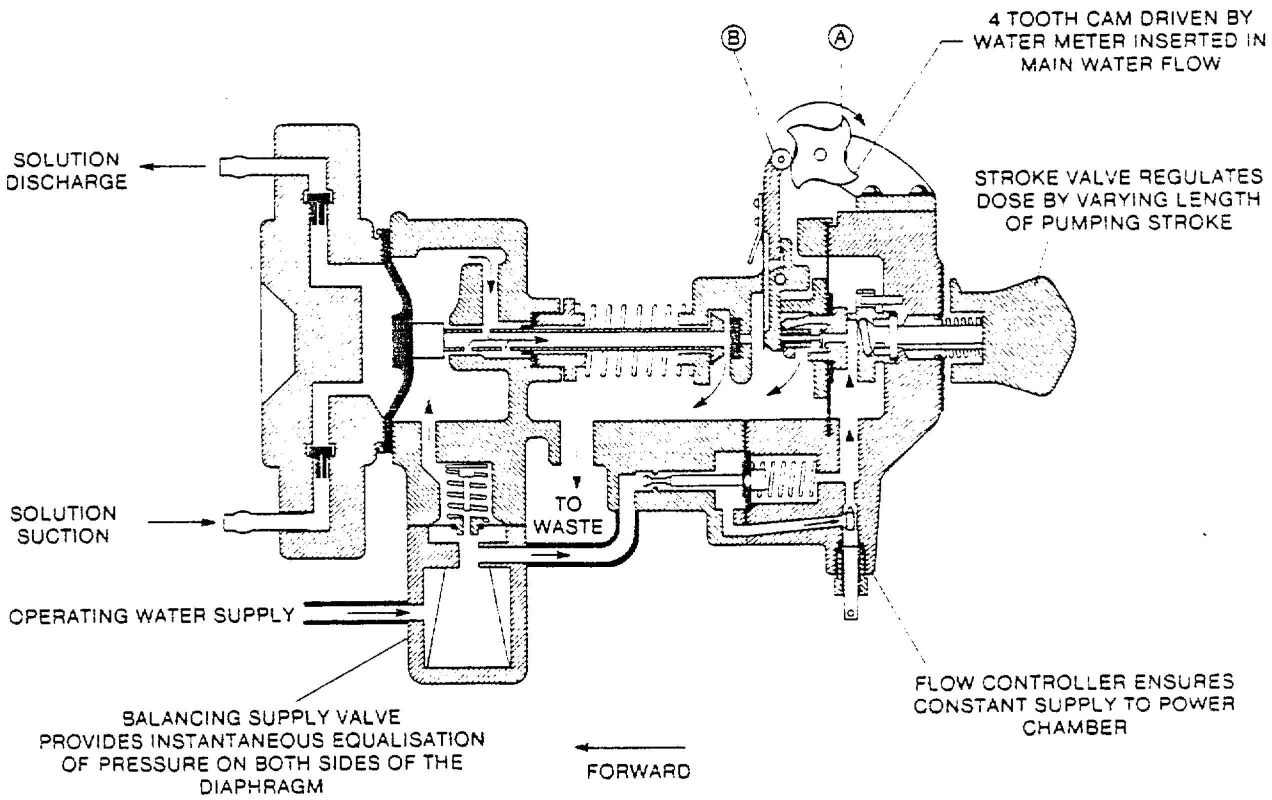



Fig. 7 AHWM reagent feeder

## 4.16 SANURIL TABLET CHLORINATOR

### Introduction

This US manufactured device was designed originally for disinfecting sewage. With the provision of a bypass in the water line, it should also be suitable for use with potable water. Only the actual chlorinator was supplied bythe maker, it being left to the user to provide the necessary pipework.

An essentially similar unit called 'Aquaward' was later introduceded by the same company specifically for potable water applications. Again, the user was required to provide a bypass line.

### Method of Operation

The Sanuril Tablet Chlorinator (Fig 8) consisted of a plastic trough with a large inlet in one end, in front of which was a baffle, and a weir outlet at the other. Disinfecting tablets were held in tubes with support grids at the bottom to keep the tablets slightly above the floor of the trough. Six slots cut in the lower part of the tube allowed the tablets to be wetted by water flowing through the trough. The tubes were lowered into the trough through two holes in its lid, one near the inlet and one near the outlet. Because of the weir the water level in the trough rose if the flow rate was increased. A greater area of tablets was then wetted.

For potable water treatment the unit was supplied with the weir cut down to base level and a recommendation that only the tube nearest the outlet be filled with tablets.

The 'Aquaward' was exactly similar to the Sanuril in operation. The tablets used differed in that they were pure calcium hypochlorite whereas the Sanuril tablets contained a binding agent.

### Factors Making for Reliability and Effectiveness

This unit was of a simple design, requiring no power supply and virtually no maintenance. However, it clearly demonstrated the problems associated with using solid calcium hypochlorite for potable water disinfection.

The tablets tended to dissolve not only too quickly but also irregularly and so delivered an excessive and variable concentration even when the flow was steady. The requirement is for a smaller tablet with a much reduced solubility rate and a fine-grained composition that will release chlorine at a predictable,uniform rate. Controlled release tablets are well known in medicine and perhaps the same could be available for water treatment if the demand could be demonstrated.

The unit had no means of adjusting the dose; this depended on setting the external bypass. It was considered unsatisfactory that such an important factor in the success of the device was not an intrinsic part of its design.

The dose was found to surge periodically as the remnant of one tablet crumbled away and a new tablet came into use. So long as the doser delivered into a reservoir of sufficient capacity, this would not necessarily cause undue variations of the residual in supply, but it would be very unsatisfactory for a visiting operator. If he found that the residual in the reservoir was outside the set limits, he would have to readjust the bypass and remain for at least one whole tablet to dissolve to be able to check the new dose level.

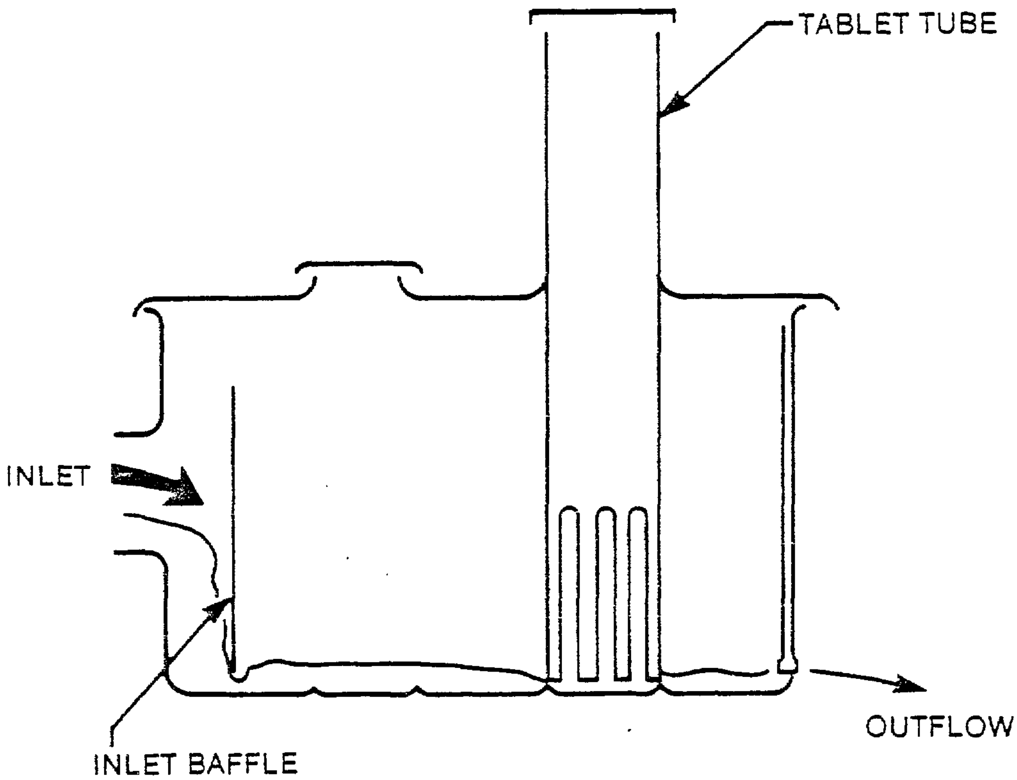



Fig. 8 Sanuril tablet chlorinator

## 4.17 GRAMPIAN TIPPING TRAY

### Introduction

The tipping tray chlorinator was designed to use calcium hypochlorite tablets and to deliver batches of chlorinated water into a service reservoir of several hours retention time. It could operate from sources of minimal head, and was conceived with particular supply situations in mind.

The unit was constructed from fibre-glass and uPVC and so was corrosion resistant. The unit was reported to be in use on supplies up to 400 cu.m/day; however only a small proportion of the flow, approximately 5%, actual passed through the unit.

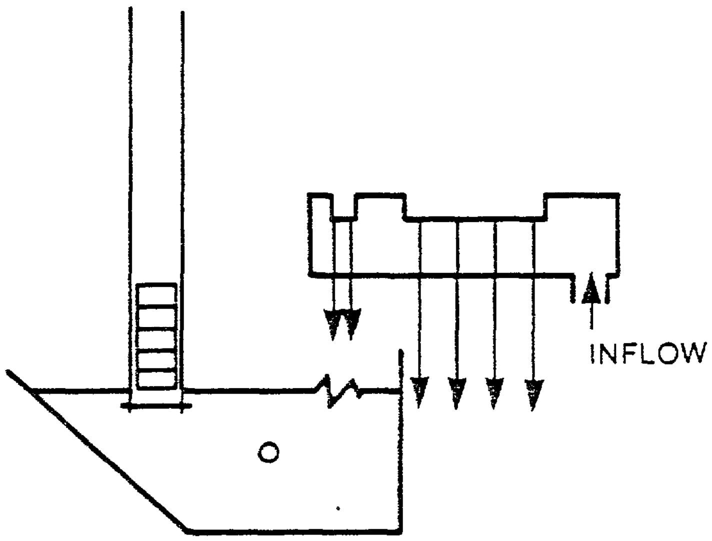
### Operation

The unit produced batches of chlorinated water, and is shown in Fig 9. The water entered the rear chamber where it took one of two routes, either overflowing the by-pass weir in the rear of the unit or syphoning over through a half-inch PVC pipe which directed the water into the middle of the trough. As the level of water in the trough built up the hypochlorite tablets, which were suspended above in a PVC tube, became immersed in the water and dissolved. Due to the shape of the trough it over-balanced when nearly full thus releasing a batch of chlorinated water into the service reservoir. The chlorine residual was adjusted by varying the height of the tablet tube above the bottom of the trough, the nearer to the bottom the larger the residual obtained.

### Factors Making for Reliability and Effectiveness

The limiting factor with this device was the unpredictable nature of the dissolving characteristics of the calcium hypochlorite tablets. The dose at a given depth of immersion and flow rate varied significantly between one batch and another although the long-term mean was steady. The mean dose, however, was not proportional to flow rate.

The general operation of the device was reliable. The tip cycle time was a regular function of flow rate and the proportion of water directed into the tiptray was reasonably constant at all flow rates. The maintenance requirement was low. The device had been designed for a particular supply situation and, while it appeared to be reasonable for this case, it was found to be flow proportional only over a limited range of flow rates.



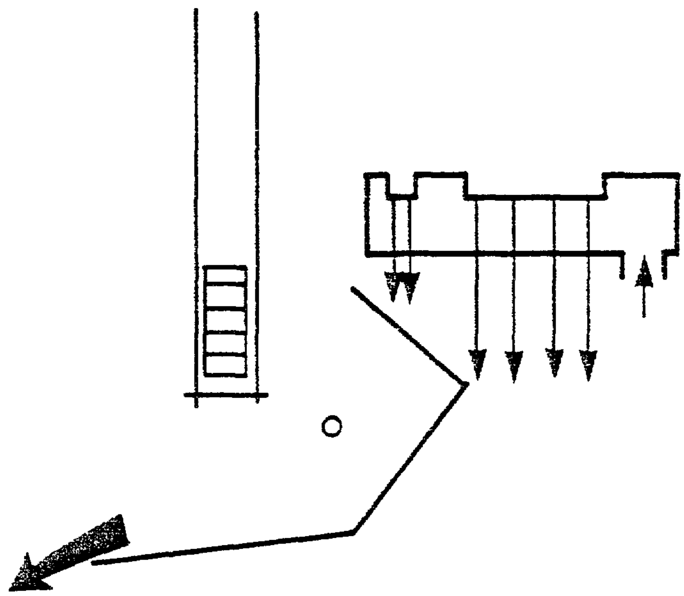



Fig. 9. Tipping-tray chlorinator

4.18 NOTE ON SUPERCHARGING

It was noted in all tests on diaphragm pumps that the output reduced as the delivery pressure increased and it was assumed in the first place that this was simply due to deflection of the diaphragm at high back pressures, as suggested in Fig 10. At high pressure, it was assumed that the diaphragm stretched into the annular space between the displacer and the sealed edge and so increased the volume of liquid left in the chamber at the end of the pumping stroke.

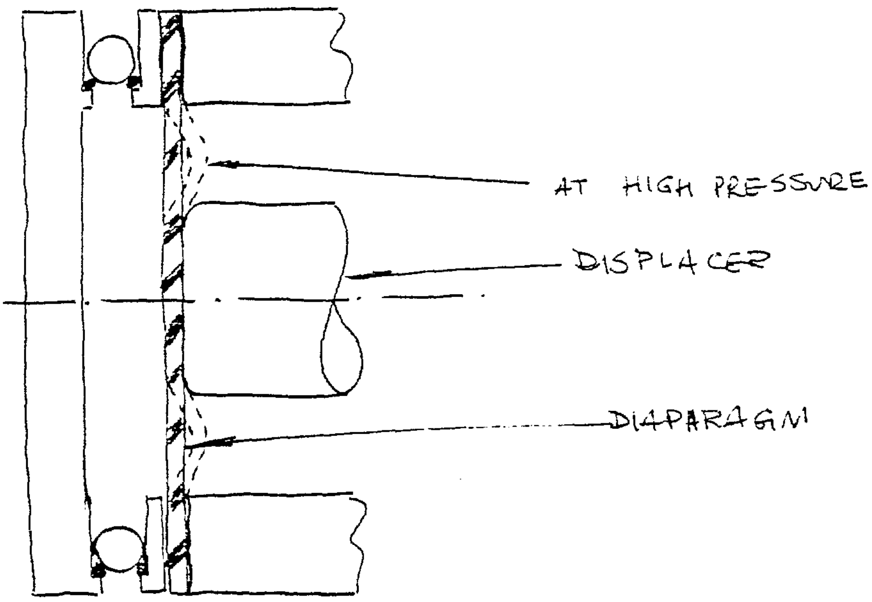



Fig 10. Deflection of pump diaphragm at pressure

This effect was seen on all pumps and was quite separate from any change in output caused by different deflections of the diaphragm on the suction stroke due to differences in inlet head.

The effect was particularly marked, however, on diaphragm pumps with solenoid drives. Rather than a decrease in delivery as pressure increased, it appeared as a sharp increase in delivery at low pressures especially when delivering direct to atmosphere, hence the use of the term 'supercharging'.

The force acting on the armature of a soleniod is greatest when it is fully home in the coil. This means that the liquid displacer moves with increasing acceleration towards the delivery end of its stroke and comes to a sudden halt, in contrast to the movement of a crank-driven piston which approaches the end of its stroke with an increasing acceleration backwards. The practical effect of this is that the column of liquid in the delivery line from a solenoid pump may at the end of the stroke have sufficient momentum to draw additional liquid through the pumphead after the displacer has come to rest. The magnitude of this effect would depend on several factors such as the mass of liquid in the delivery line, and that in the suction line, the inlet head and frictional forces. It would be most marked where the delivery line was unrestricted and not too short and the inlet was short with low suction.

Testing for Supercharging

It was not possible to measure the swept volume of a diaphragm pump by taking the dimensions of the pumping chamber and measuring the stroke length. To do so required operating the pump slowly and measuring the delivery of a counted number of strokes. The construction of most of the solenoid pumps made this very difficult but it was possible with the Jesco Magdos.

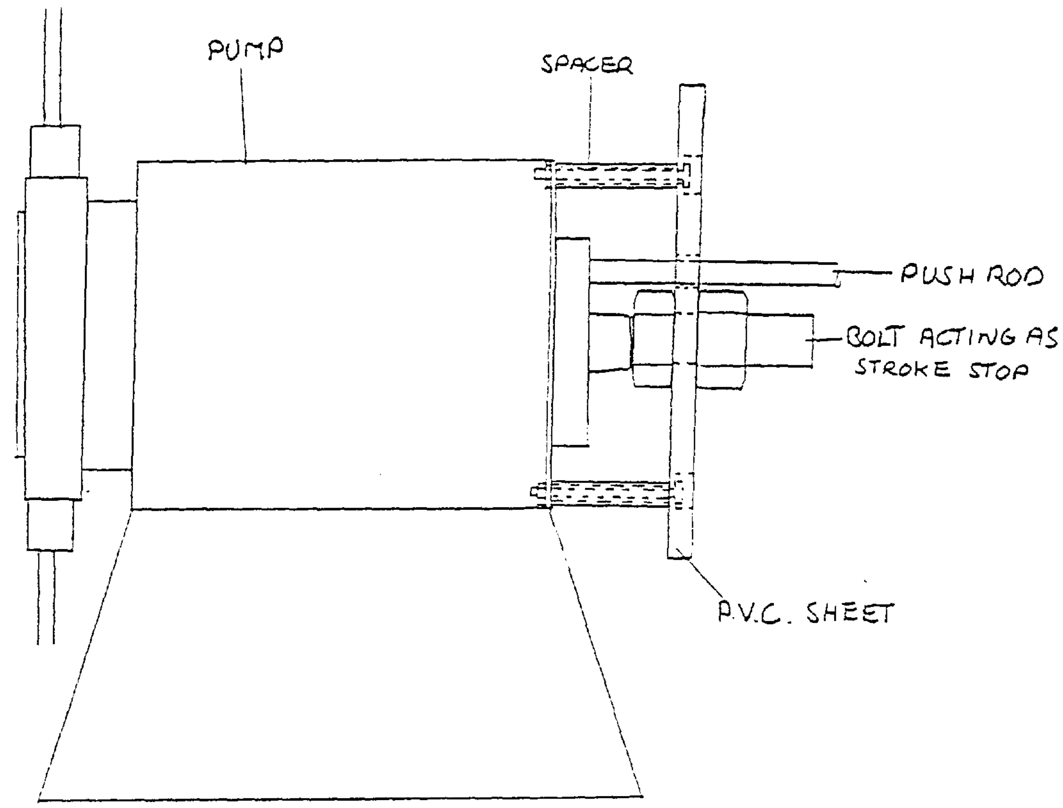
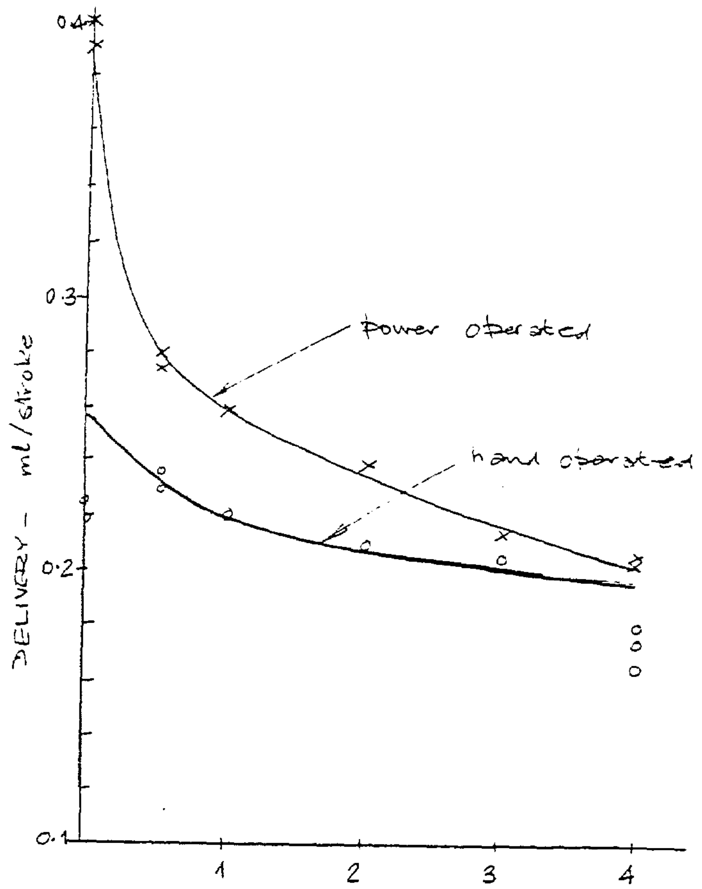



Fig 12 Solenoid pump test results



The electronic control section was removed from behind the solenoid and replaced by a rigid plastic plate, see Fig 11, with a bolt in the centre which could be adjusted to set the stroke length. A hole was drilled close to the bolt to give access to a push rod by which the armature could be operated by hand. In this way the pump could be operated electrically and by hand alternately without any need for reassembly or readjustment when changing from one means to the other.

The stroke length was set at 2mm, within the normal operating range, and the output of the pump was measured at pressures up to 4 bar for both hand and power operation. It was very difficult to drive the pump by hand to a full stroke at 4 bar and impossible at higher pressures. The hand results showed some scatter but it is thought the curves shown in Fig 12 are fair.

## Discussion

The results of this test and similar information from the tests on other pumps are brought together in Table 1 below.

TABLE 1 Increase in Output of Diaphragm Pumps on Release of Delivery Pressure

| PUMP | DRIVE | OUTPUT PER STROKE ml at pressure | open | PERCENT INCREASE ON PRESSURE RELEASE |
|---|---|---|---|---|
| Prominent 1000 | solenoid | 0.5 | 1.1 | 120 |
| Prominent 2000 | solenoid | 0.17 | 0.25 | 47 |
| Alldos | rotary | 0.4 | 0.5 | 25 |
| Magdos | solenoid | 0.2 | 0.39 | 95 |
| Magdos | hand | 0.2 | 0.26 | 30 |

It appears that the change in output of diaphragm pumps with changes in delivery pressure has two main causes,

- increasing deflection of the diaphragm as pressure increases,
- the effect of supercharging at low pressures.

The former may be consistent and relatively slight but, according to circumstances, supercharging can have a significant effect as shown in Fig 13. It is an inherent feature of solenoid pumps and can be overcome by correct plant design. It is not a problem with rotary drive pumps.

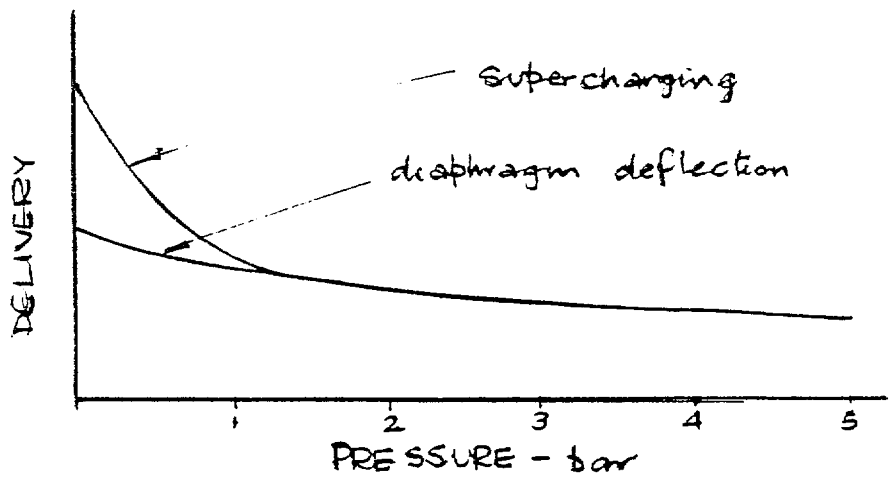



Fig 13. The effect of supercharging on the delivery of a solenoid-drive diaphragm pump

## SECTION 5 GAS CHLORINATION

### Introduction

Gaseous chlorine is used widely for the disinfection of water on a large scale but is not much used on small supplies, due to the reputed unreliability of the equipment at low flow rates. This series of tests was undertaken to investigate the low range performance of one of the commercially available systems.

Commercial systems offer two approaches to dosing the chlorine into the water. One way is to supply the gas to the dosing point at a low positive pressure and the alternative is to use the water flow to draw the gas under vacuum. The system evaluated was a vacuum type. The tests are reported in detail in Appendix 5.

### Method of Operation

The basic gas chlorinator system is shown in Fig 14. Water to be chlorinated is passed through an ejector (1) under pressure. The ejector is in essence a waisted section of pipe so arranged that as water accelerates to pass through the constriction its pressure falls below atmospheric. A tapping at the waist draws a vacuum in the pipe leading to the chlorine cylinder.

No chlorine can be drawn from the cylinder unless the correct vacuum exists in the system. If the vacuum is broken or even reduced, the chlorine flow stops. The vacuum created at the ejector must be sufficient to overcome the spring in the check valve (2). The whole chlorine pipe is then evacuated and the inlet safety valve (3) opens. This valves provides a constant supply pressure to the flow meter (5) and rate valve (6). The latter is set by hand to the required rate.

### Factors Making for Reliability and Effectiveness

There are inherent advantages in having a vacuum operated system rather than dosing chlorine under pressure. The vacuum system will stop the flow of gas at the point at which the water flow is insufficient to maintain the required vacuum. Also if there are any leaks in the chlorine line air will enter and dilute the chlorine - chlorine will not escape. This provides safety in operation and also a method of stopping the gas flow when the water stops.

Accurate control of chlorine dose is difficult to achieve at the lowest flows with only the variable area meter to rely on. This is due to the small size of the meter, and to the tendency of the ball to stick as a result of the organic impurities in the chlorine.

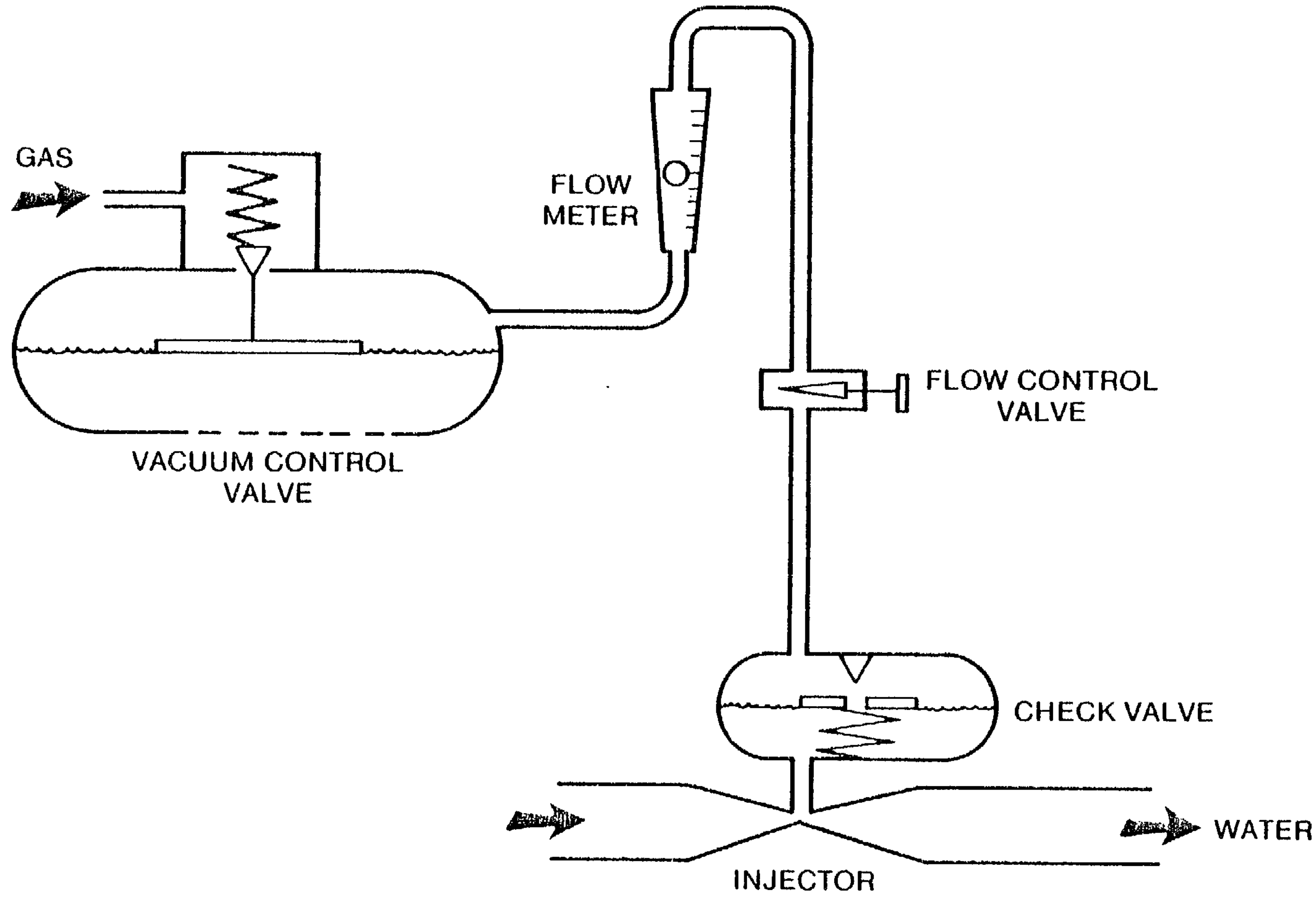



Fig. 14 Vacuum gas chlorinator

## Introduction

On-site production of chlorine for the disinfection of drinking water has been proposed in recent years for large waterworks on the grounds of safety. Incidents in other countries drew attention to the risks involved in the transport of liquid chlorine in bulk and the dreadful consequences of an accident. At the same time several small incidents at swimming pools highlighted the fact that while chlorine could be handled safely by trained operators, the modern practice of reducing manning levels and skills had increased risks. This led to a withdrawal of gas supplies to swimming pools and it was feared that small water supplies might also be affected. A general study of the feasibility of electrochlorination for water supplies was made at WRc by R.J.Lawrence in 1983 (Laboratory Record 242-S).

Electrolysis of brine has been the method of manufacturing chlorine since the end of the 19th century. It is produced as a gas, compressed to a liquid and delivered in cylinders, 1 ton drums and in bulk by tankers. It has many uses; 96% of UK production is used in chemical manufacture, 1.5% for water treatment. At coastal power stations and on shipboard, where electricity is available at cost price and brine is free, chlorine is generated electrolytically as a matter of routine and used to prevent fouling of power and cooling water systems with a marginal use for treating drinking water. Thus it can be seen that on-site electrochlorination is not novel. Its application to drinking water, however, and to small supplies particularly, would count as a special application of present technology.

## Basic principles

A solution of sodium chloride in an electrolytic cell will be decomposed fundamentally to produce chlorine at the anode and sodium at the cathode.

In most cells the sodium released reacts immediately with water to produce sodium hydroxide and release hydrogen as gas.

These reaction can be summarised as

$$2NaCl + H_2O + \text{electric current} = 2NaOH + Cl_2 + H_2$$

If the brine contains impurities, other elements will also be released at the electrodes. Seawater, for instance, contains many other substances and the chlorine may be accompanied by bromine and iodine. Calcium and magnesium may appear at the cathode and the cell must take this into account with a design that avoids fouling.

Even if the brine is pure there may be other reactions. The water may be electrolysed to produce oxygen at the cathode, chlorine reacts with water to produce hypochlorous acid and this may oxidise further to make chlorate. The most significant counter-productive reaction is reduction of hypochlorous ion to chloride at the cathode.

## Types of Electrolyser

The efficient manufacture of chlorine requires cells with electrodes close together so that electrical resistance is low. At the same time the electrode products must not be allowed to react together, so they must be kept apart and removed from the cell quickly.

In the *mercury* cell this is done by making the cathode a film of mercury flowing down the sloping floor of the cell. Sodium released here does not react with the water, but dissolves in the mercury (at less than 1% concentration) and is recovered outside the cell before the mercury is recycled.

In the *diaphragm cell* the electrodes are separated by an asbestos diaphragm. Brine enters the anode side of the cell and chlorine is released from the electrode. The depleted brine flows through the diaphragm to a lower level where hydrogen is released at the cathode and a solution of caustic soda is withdrawn.

Physical separation of the products is also the feature of the *membrane cell* which uses an impermeable cation transfer membrane which will allow the positive sodium ions only to pass through to the cathode compartment. The cathode needs a separate water feed and produces pure caustic soda.

In contrast to these, where the product required is sodium hypochlorite, the chlorine produced at the anode is encouraged to react with the caustic soda and it is necessary only that the cell should release hydrogen efficiently. Here simple *undivided* cells are normally used. There are many manufacturers now offering electrochlorination for waterworks with units delivering from 50kg to 1000kg chlorine per day. Typically the unit requires to be supplied with softened water and purified vacuum dried salt. The salt is put into a saturator and saturated brine is diluted to about 3% sodium chloride for electrolysis producing a 0.8% solution of sodium hypochlorite. The use of softened water prevents scaling on the cathode and reduces the maintenance required.

## Electrochlorinators for Small Supplies

A small supply at the upper end of the size range, say, 1000 cu.m/d requiring a chlorine dose of 3mg/l would require 3kg chlorine per day. The normal range of demands will be downwards from this to a minimum of, say, 3 g/d. There are a few electrochlorinators on the market and under development to operate in this range.

The smallest range of electrochlorinators is designed with the needs of small supplies in mind. It is supposed that the purchaser, whether a public undertaking or a private proprietor, will require something that only needs unskilled attention, and not much of that. It is assumed that the local water will be used, whether it is softened or not, but the the salt used will be the pure vacuum dried grade, which happens to be the cheapest commercial grade.

The total number of electrochlorination installations on water supplies is very small; perhaps about a dozen. On small supplies there are no more than trial installations on a few private premises. Firm performance data is scant; as might be expected the small units are not as efficient as the larger ones as appears from Table 2 overleaf.

TABLE 2 PERFORMANCE OF SMALL ELECTROCHLORINATORS

| | LARGE UNIT | SMALL UNIT |
|---|---|---|
| Size range kg chlorine/day | 50 - 1000 | 0.2 - 2 |
| Brine feed concentration | 3% | 3% |
| Hypochlorite concentration | 0.8 - 1% | 0.3 - 0.5% |
| Salt:chlorine weight ratio | 3 - 3.5 | 6 - 10 |
| Energy kWh/kg chlorine | 3 - 6 | 7 - 11 |
| Temperature limits deg.C | 5 - 30 | 5 - 50 |

## The Potential for Electrochlorination

At the time of writing there is interest in electrochlorination for small supplies and, since it mirrors the main manufacturing process, there was never any question about its technical feasibility.

The units that have been developed and tested on small supplies have shown that equipment can be designed and built which is easy enough to operate, reliable enough in operation and is not obviously expensive in either capital or running costs.

To become established in current practice, however, the process needs to be able to show significant advantages over the alternatives, at least in some commonly occurring circumstances. The discussion below compares on-site generation with delivery of sodium hypochlorite solution to site. The solution is manufactured at a little over 15% concentration and would normally be delivered to site at the same.

*Transport to site:* Hypochlorite requires about 7kg per kg chlorine and salt requires between 6 and 10kg; about the same.

*Material cost:* In the form of sodium hypochlorite, chlorine costs about £1 per kg compared with about 11p per kg in salt.

*Handling:* Sodium hypochlorite is alkaline and corrosive and the operator should wear gloves and goggles while handling it. Careful design of plant and provision of proper equipment, however, should mean that this is not a problem. Salt is chemically neutral but it is corrosive over time. Being a flowing solid, it is harder to handle than a liquid and must be kept dry if severe handling problems are to be avoided. Since it will be used as a solution, extra plant is needed to make the solution. Apart from the slight safety consideration, the advantage lies with hypochlorite.

*Dosing:* Hypochlorite can be dosed with a variety of dosers according to site conditions. Where there is no electricity on site, there are gravity and water-powered dosers available. On-site chlorination requires electricity. This might generated on site. Using the data from Section 11, it is estimated that it would require a 13m head loss of all the water treated to generate a chlorine dose of 1mg/l, or an inverse proportion if a larger flow could be tapped. Under all circumstances it appears that the advantage lies with hypochlorite. On-site generation always requires greater energy and, even if this could be obtained free by, say, tapping the wind, it would involve greater capital cost and more plant to be maintained.

*Temperature:* At low temperatures electrolysis is slowed and requires a higher voltage to maintain output. This not only increases power consumption but can damage the anode and some cells have heaters or cutouts to operate at about 5 degrees centigrade. This is a factor which might affect the choice of electrochlorination for some remote sites where occasional heating cannot be provided.

Conclusions

On-site generation of chlorine is simply a technical extension of present practice to move the manufacture of chlorine from a central facility to the point of use. On no scale is this cost advantageous to the water industry which, in any case, buys only about 1.5% of the chlorine manufactured in the UK. However on very large waterworks where the chlorine storage is measured in tons (or tonnes), especially where the liquid is delivered by bulk tankers, there is tremendous potential for a major disaster if there should be an accident. On-site generation of chlorine would remove this risk for a negligible change in operating costs.

The major danger lies in the use and handling of elemental chlorine. Electrochlorination produces the required tonnage, but in modified form as sodium hypochlorite and at a safely low concentration.

When small water supplies are considered, the main advantage of electrochlorination is lost immediately because very few small supplies use liquid chlorine. Although the technique is technically feasible and there is equipment on the market, it appears that the capital and operating costs of the process are such that there is a high additional price to pay for a very small safety benefit compared with using centrally-manufactured sodium hypochlorite.

# DISINFECTION WITH ULTRAVIOLET IRRADIATION

## Introduction

Ultraviolet irradiation can be used for the disinfection of small water supplies. The potential advantages are attractive;

- cheaper equipment
- no bother with chemicals
- equipment has no moving parts needing maintenance
- it is impossible to overdose
- no effect on the taste of the water
- the effect is instantaneous - no contact time needed.

Because it has no moving parts and uses no chemicals however, it is harder to tell by inspection whether it is working correctly. One disadvantage relative to chlorine is that it does not carry a residual downstream. Chlorine gives continued protection to the water after treatment and can also disinfect a distribution system that may have been contaminated by the occasional passage of untreated water.

## How it works

It has been known for many years that sunlight inactivates bacteria and F.L.Gates reported in 1929 that the most effective wavelength for disinfection, 265 nm, corresponded to the wavelength for maximum absorption by nucleic acids. Mercury vapour discharge tubes produce most of their output at a wavelength of 254 nm and so are highly effective. The tubes are separated from the water by quartz sleeves which are transparent to the ultraviolet light. A sufficient dose of radiation is required to destroy the nuclei of bacteria and viruses. Dose is the product of intensity and exposure time, and the effectiveness of a unit depends upon keeping the dose above the required minimum. The US Department of Health stipulates a minimum dose of 16mWs/sq.cm and many manufacturers rate their units to give about twice this dose.

- The intensity of radiation at any point falls off at the square of its distance from the source and so high intensities are required at the tubes to ensure adequate levels throughout the water.

- The transparency of water to ultraviolet wavelengths can be affected by substances in solution, especially iron. Turbidity present in the water will also have a marked effect on the intensity transmitted. Because of the 'square law' effect any diminution in transmissivity of the water has a marked effect on the intensity at points remote from the sources of radiation.

- Bacteria may be attached to turbidity particles and shielded by them from the radiation.

- As the UV tube ages the intensity of 254 nm radiation declines even though the tube continues to run.

The manufacturers take account of these factors by installing ample radiant power, fitting turbulence inducers to make any suspended particles spin, recommending that units should only be installed where the water's UV transmittance has been checked and that the tubes should be renewed at regular intervals before the intensity has declined.

It is important that the rated flow of a unit should be greater than the expected peak flow and it may be prudent to fit a flow limiting valve to prevent over-running.

Some units have the facility for provision of a UV intensity monitor which may close down the unit when the radiation falls below the set limit, or switch in standby tubes. This ensures that the maximum useful life is obtained from every tube but, more importantly, provides a continuous check on performance. However even monitors have failure rates and can more than double the cost of a small unit and so for the smallest units the usual recommendation is to change the tubes regularly.

A survey was made to find the extent to which UV was used in the disinfection of small public supplies and to collect the experiences of the users. This is reported in Appendix 7.

## Factors Making for Reliability and Effectiveness

Where it is satisfactory and convenient to disinfect drinking water immediately before use, ultraviolet irradiation can be reliable and effective. However, because the process does not confer any protection to the water against contamination after treatment it should be installed in a place where there will be no break of pressure between treatment and consumption. Its effectiveness depends on the optical properties of the water being treated and the reliability of the process cannot be better than that of the water quality.

Given a water appropriate for the process and a suitable location for installation the equipment available for UV treatment requires only simple routine maintenence. It is important to remember that the light tubes become ineffective before they expire and they should be replaced at regular time intervals or else the equipment should be fitted with a monitor to ensure that exposure levels remain effective. It is also important to remember that the efficiency of a unit can be impaired by deposits of dry dust or dirt in places where they obstruct the passage of the rediation.

Ultraviolet disinfection can be particularly effective in places where there are problems using chlorine, for instance, where there is insufficient contact time for chlorine or where chlorination would cause taste or odour complaints.

## SECTION 8 CHLORINE RESIDUAL CONTROL

### Introduction

It became clear at an early stage of the contract that reliability of disinfection would be greatly improved on small supplies if a battery-operated residual chlorine monitor could be developed. The feasibility of such a development was established and work began to acquire the understanding necessary for writing a specification.

Chlorine residual monitoring and control was standard practice on large waterworks, was well proven and gave reliable results. All the available equipment, however, was mains-powered, required a certain minimum pressure in the stream to be sampled (or else the provision of a sample booster pump), included equipment to control the sample flow rate and discharge the monitored sample to waste; all features which were difficult or costly to provide on small supplies. The sensor at the heart of these systems, however, was a fairly simple copper-platinum electrochemical cell which actually generated a signal proportional to the concentration of free chlorine.

There was also a new generation of membrane-type electrodes finding application for chlorine monitoring. The best of these was found to be as accurate and reliable as existing electrochemical equipment for about the same initial cost, but it was judged that this type of equipment was not yet robust or reliable enough for use on small supplies on remote sites.

The work therefore centred on obtaining a thorough understanding of the copper-platinum cell to find whether and how existing equipment could be simplified to suit small supplies while maintaining the necessary level of accuracy and reliability.

### Laboratory studies

A detailed account of the tests is given in Appendix 8.

The first tests were done with two different designs of simple flow cell having copper and platinum electrodes. When a stream of water flowed through a cell the electrochemical potential difference between the metals of the electrodes caused a current to flow. The current soon fell to a low value when the cell polarised. Free chlorine in the water depolarised the cell and caused an increase in current which was proportional to the concentration of free chlorine. Tests were aimed at finding how the cell current was related to free chlorine, rate of flow and sample pH.

Using the local tap water supply dosed with hyochlorite at about neutral pH, the cells were found to pass currents which changed in direct proportion to changes in free chlorine concentration and flow.

It was expected that when the water flow was dosed with caustic soda or sulphuric acid to change its pH, the change of signal would reflect the well-known curve describing how the degree of ionisation of HOCl changed with pH. In fact, although the result was partly as expected, other effects appeared as well. At high pH the copper electrode became coated with a white deposit and the signal reduced. At low pH it was etched clean and the signal increased. Both these effects were time-dependent and so it appeared that in cases where pH was likely to vary, the cell signal would be affected not only by the pH at the time but also the history of recent pH excursions.

The cell signal did not appear to be much affected by total ionic concentration but it was affected by light.

## Conclusion

It had become clear that further progress required resources beyond the scope of this contract. Although investigations and development continued at WRc, they were funded from subscription income.

# 9. CONTACT TANK DESIGN

## 9.1. INTRODUCTION

There is increasing interest in the use of closed cylindrical vessels as chlorine contact tanks for small supplies. On the small scale, a closed steel tank or a length of large-bore pipe can be economically competitive with the more common rectangular concrete tank and it has the advantage of not requiring a break of head. Yorkshire WA installed such a tank at Gayle in 1982 and Thames WA installed one at Eynsford.

The essential requirement of a contact tank is that there should be no mixing between elements that have entered the tank at different times, so that all the water leaving the tank at any time has, as nearly as possible, been exposed to the required level of chlorine for the full nominal residence time. This is a subject that has received little attention in waterworks design and it is suspected that short-circuiting and mixing are widespread in all sizes of contact tank. The problem is often exacerbated by the fact that these tanks often serve also for flow balancing and so their levels fluctuate.

Thames WA had in 1981 invited WRc to advise on the best arrangement of inlet and baffles to ensure the desired 'plug flow' in a set of tanks proposed for installation at Upper Swell in the then Cotswold Division. Model tests were made and it was reported(2) that the best way of spreading the flow over the whole cross-sectional area of the tank was to direct the inlet backwards against the end of the tank, as, for example, in Fig 15. Baffles were not effective. Subsequently the Western Division decided to instal nine tanks of a uniform design in the year 1983/84 and took WRc advice on the design of the inlet arrangements. The first of these was installed at West Hagbourne in April 1983 and was commissioned in October.

The model work reported was based on the particular proportions of the tanks proposed for Upper Swell and the recommendations were largely descriptive. It was felt that a worthwhile advance could be made by conducting some further simple tests to put the design principle on a quantitative basis. The purpose was to define the practical range of flows and the degree of plug flow possible with the backward-directed inlet.

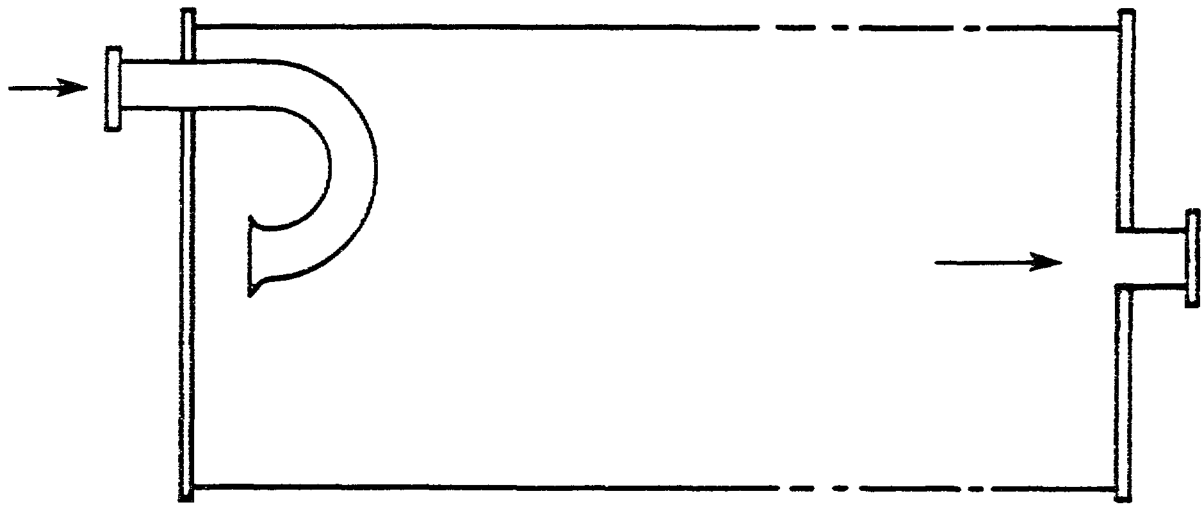


Fig. 15. Closed cylindrical contact tank

## 9.2. PROCEDURE

The model tank was assembled from disused model filter columns 305 mm in diameter and 1220 mm long. The outlet was taken from a radial branch at one end. The inlet pipe was introduced at the centre of the outlet end and was extended down the axis of the tank to within a short distance of the inlet end.

For each test a small amount of fluorescein dye was injected quickly into the inlet pipe and its appearance at the outlet was detected by a fluorometer. The fluorometer signal was fed to a chart recorder which produced a continuous graph of dye concentration against time. The dye was injected at such a low concentration that its movement down the tank was not visible and a few tests were made with massive injections so that the progress of the dye could be seen and photographed.

This tracer technique is widely used in the study of flow. The dye injection produces a hump shaped graph and it can be shown that the area under the curve is proportional to the amount of dye used and that the centroid of the area corresponds to the average residence time after the dye was injected. A tall, narrow shape to the curve indicates a high degree of plug flow and a curve extending over a long time indicates a high degree of longitudinal mixing, but there are no universally accepted criteria for expressing these phenomena numerically.

The previous report accepted the method published by Rebhun and Argaman(3) which is based on the conceptual model of the tank whose volume is divided into three idealised zones. The first is dead space which takes no part in the flow; the second is a perfectly mixed zone in which each fresh element entering is distributed throughout the whole volume and begins to exit the zone instantaneously and the third zone is given to perfect plug flow. A method of analysis is given where the area under the graph up to any time 't' is subtracted from the total area and the logarithm of the difference is plotted against the time 't'. Theoretically the plot is a straight line with negative slope. In practice it starts as a curve which becomes straight. The slope of the line and its intercept on the time axis are used to calculate the relative proportions of dead space, perfect mixing and plug flow. This is a most attractive concept for contact tank analysis.

For a given flow, a small diameter tank will operate at a high velocity. The turbulent flow associated with the high velocity gives a good degree of plug flow, but the pipe needs to be long to give a desired residence time. The same volume contained in a short pipe of large diameter, if it operates at too low a speed, may go into laminar or streamline flow which gives little transverse mixing but a high degree of longitudinal dispersion. The purpose of the tests was to evaluate the properties of the model and to find the lower limit of velocity for turbulent flow.

## 9.3. RESULTS

The first traces obtained were analysed and it was found that the centroid of the graph suggested an average residence time 20-25% higher than that calculated from the flow rate and tank volume. Careful re-measurement of the tank and checking flow rates confirmed this. As a last resort the fluorometer was checked. It was found that the measuring cell was large compared with the sample flow. While the instrument responded instantly to a change in sample concentration, it was several seconds before this change was fully registered, either as an increase or a decrease. Thus the traces indicated falsely extended residence times. When the measuring cell volume was reduced, there was a satisfactory correspondence between residence times calculated from flow rates and those from the trace areas.

When the Rebhun and Argaman analysis was applied to the results, the tank appeared to have a negative dead space; that is, it had the behaviour of a theoretical tank with a larger volume. No logical explanation could be found for this. However when the straight line from the logarithmic plot was plotted back on the original dye trace, it was seen that the conceptual model described only the latter part of the actual trace and bore no resemblance to the very important first signal and the rising part of the curve, Fig. 6.

While it was felt possible that the Rebhun and Argaman model might be modified to represent these results more closely, such development was judged to be outside the scope of this contract. The proposed specification suggested that 95% of the flow through a contact tank should remain within the tank for the specified

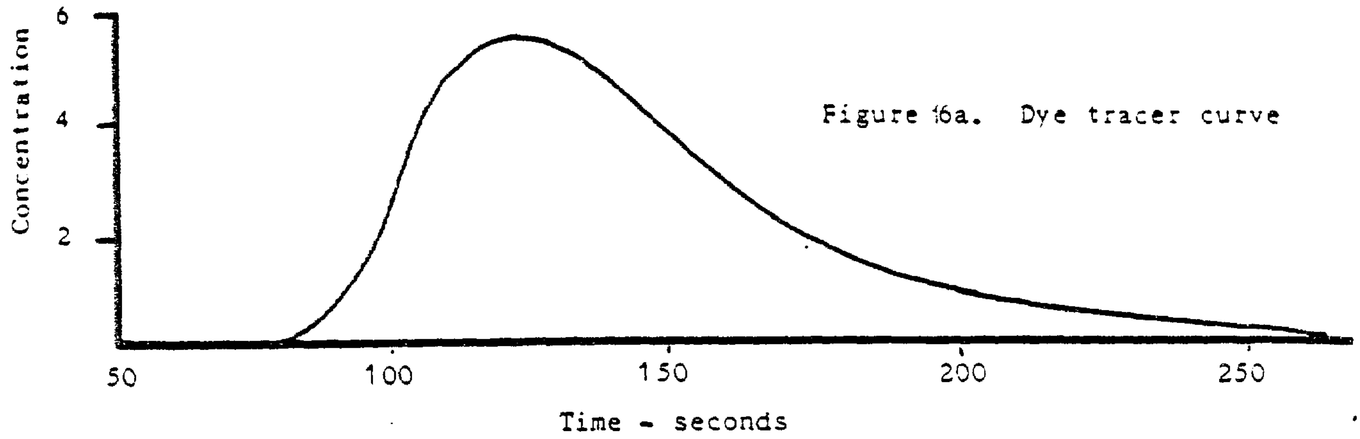



Figure 16a. Dye tracer curve

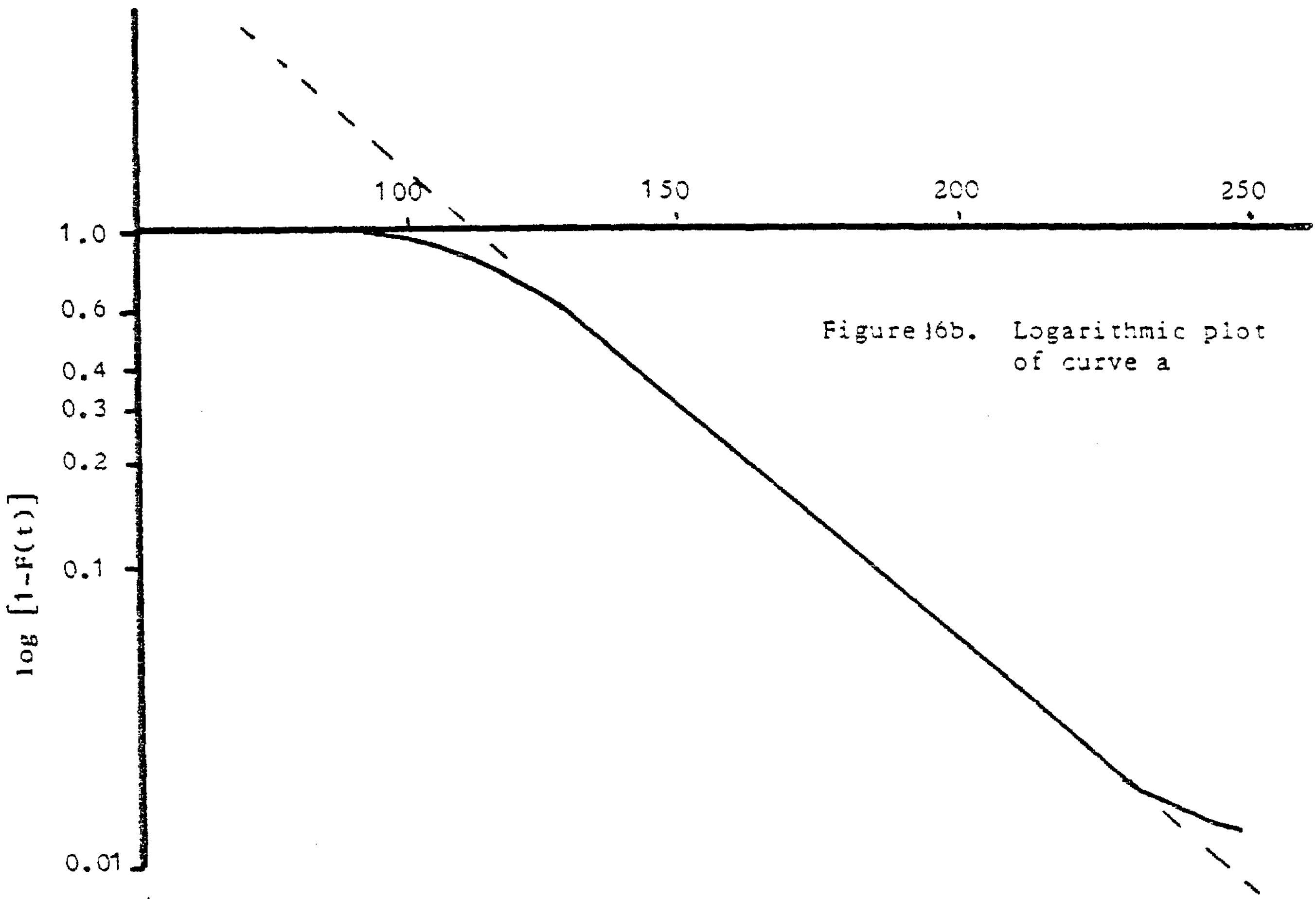



Figure 16b. Logarithmic plot of curve a

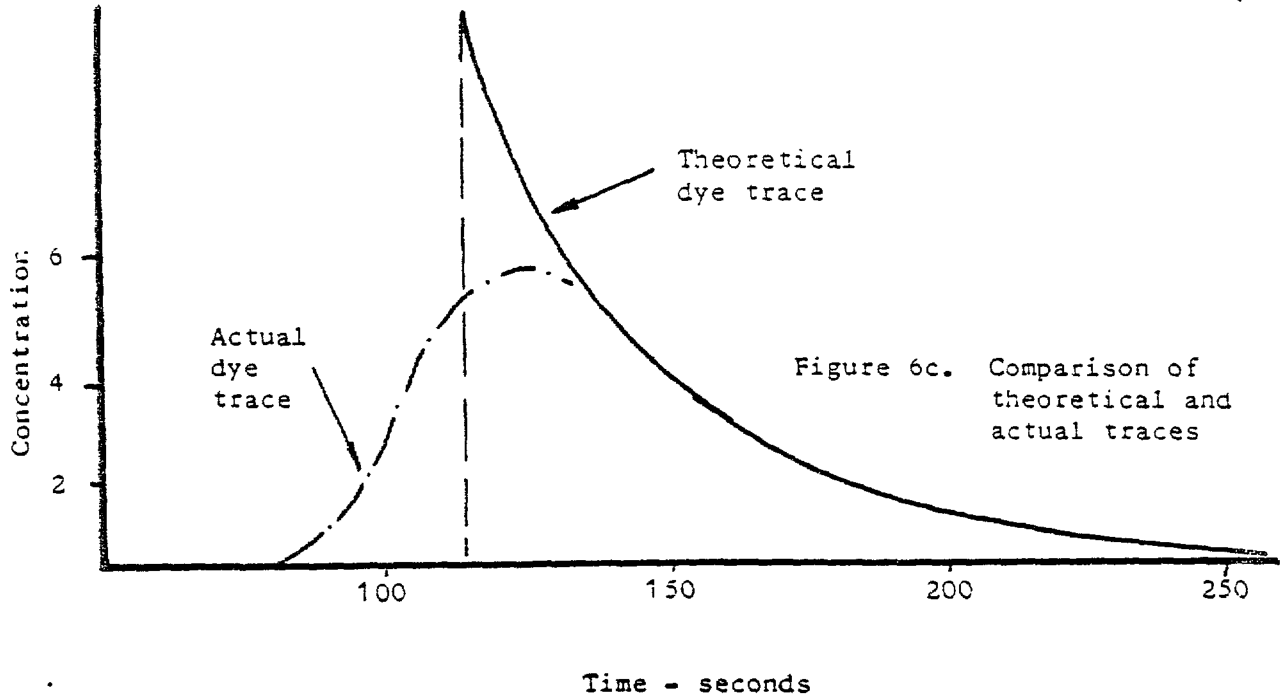



Figure 6c. Comparison of theoretical and actual traces

residence time. In other words, if a dye were injected at the tank inlet, no more than 5% of the amount injected should emerge before the specified contact time had expired. This amount corresponds to the first 5% of the area under the curve. This time was called '$t_5$'. It was determined for every run and a relationship was sought between this time and the average residence time 'T' defined by the tank volume divided by the flow rate.

Tracer curves were obtained for two lengths of tank; 2640 mm and 1420 mm at flow rates ranging from 20 l/min to 130 l/min, corresponding to Reynolds Numbers of 1100 to 7000. Every tracer curve was examined and the area under the curve and $t_5$ were measured. Graphs of $t_5$ against T, Fig. 7, appeared as straight lines passing through the origin except at the lower flow rates, the linear portion corresponding to values of $R_e$ greater than 2500.

The usual method of presenting tracer curves is to 'normalise' them by dividing the measured concentration by the concentration $C_o$ that the dye would have if diluted into a single tank volume, and by dividing the time by the average residence time T. This makes both co-ordinates dimensionless, the area under the curve should be unity and curves obtained under widely differing conditions should be directly comparable.

Because the usual theoretical model of flow had been discounted, however, it was decided to examine the tracer curves showing actual concentrations and times. Fig. 8 shows traces obtained at a flow of 36 l/min, one in the 2640 mm tank and one in the 1420 mm. It can be seen that the curves have similar shape and this is confirmed in Fig. 9 where they are overlaid, the respective values of T being subtracted from every abcissa. This similarity was not noticed on the normalised curves.

The conclusion from this is that the dispersion pattern of the dye is established in a mixed zone at the inlet end of the tank and that when the dye moves out of this zone there is negligible longitudinal dispersion. The fixed value of the ratio $t_5$:T at all rates of flow confirm this idea, that the $t_5$ and T elements of dye move down the tank at the same speed and with a fixed distance between them. Unfortunately it has not yet been possible to put this theory into a model that fits the experimental data.

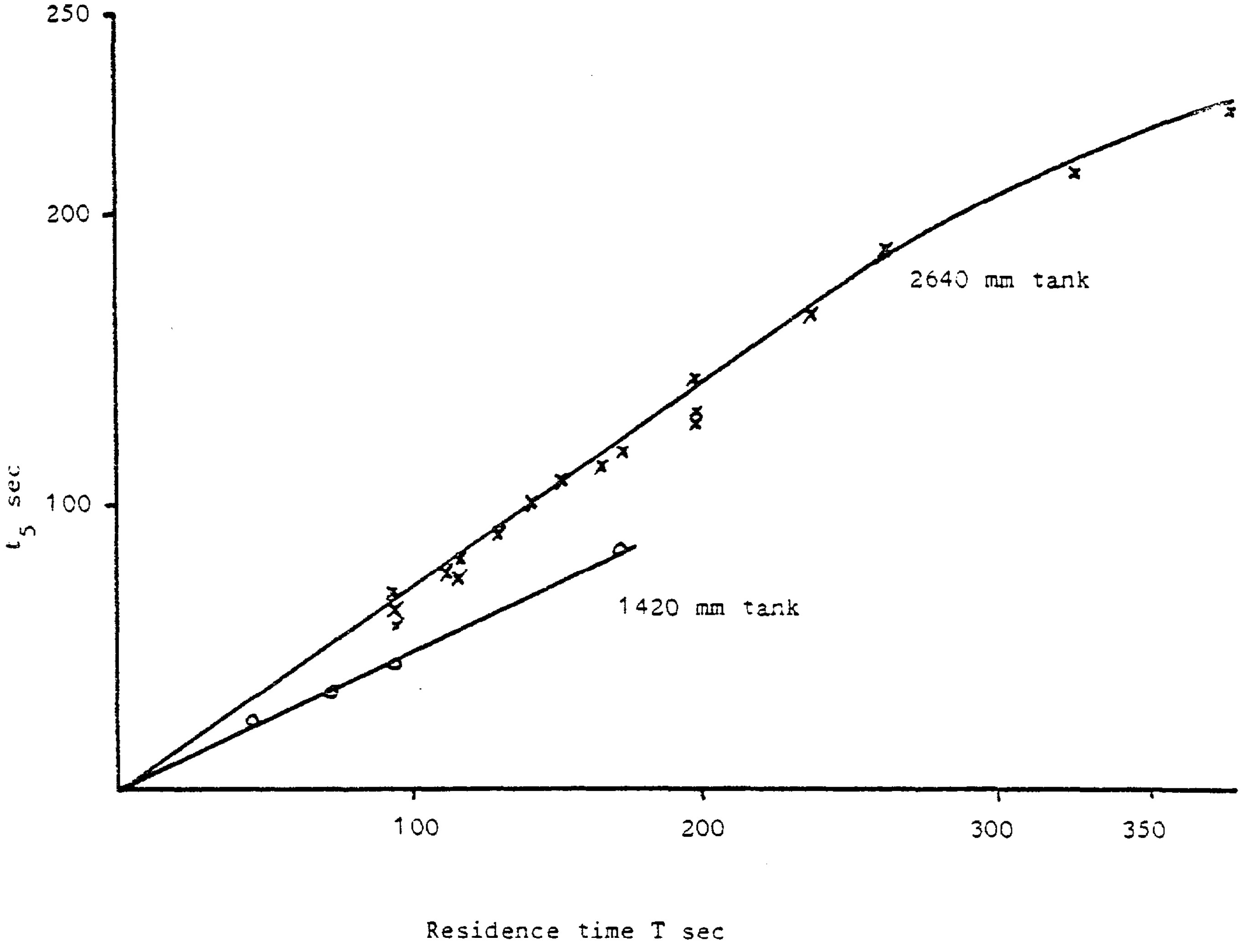



Figure 17. $t_5$ graphed against T

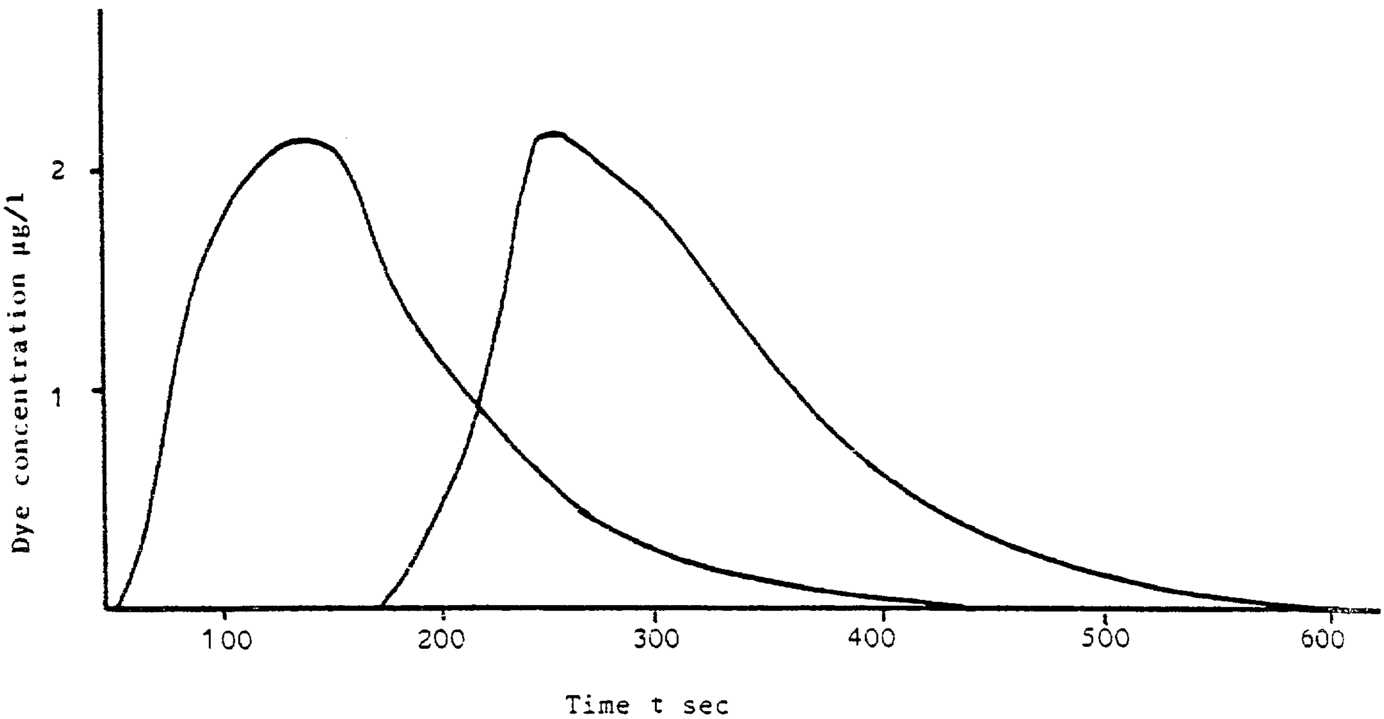



Figure 18. Dye traces for long and short tank

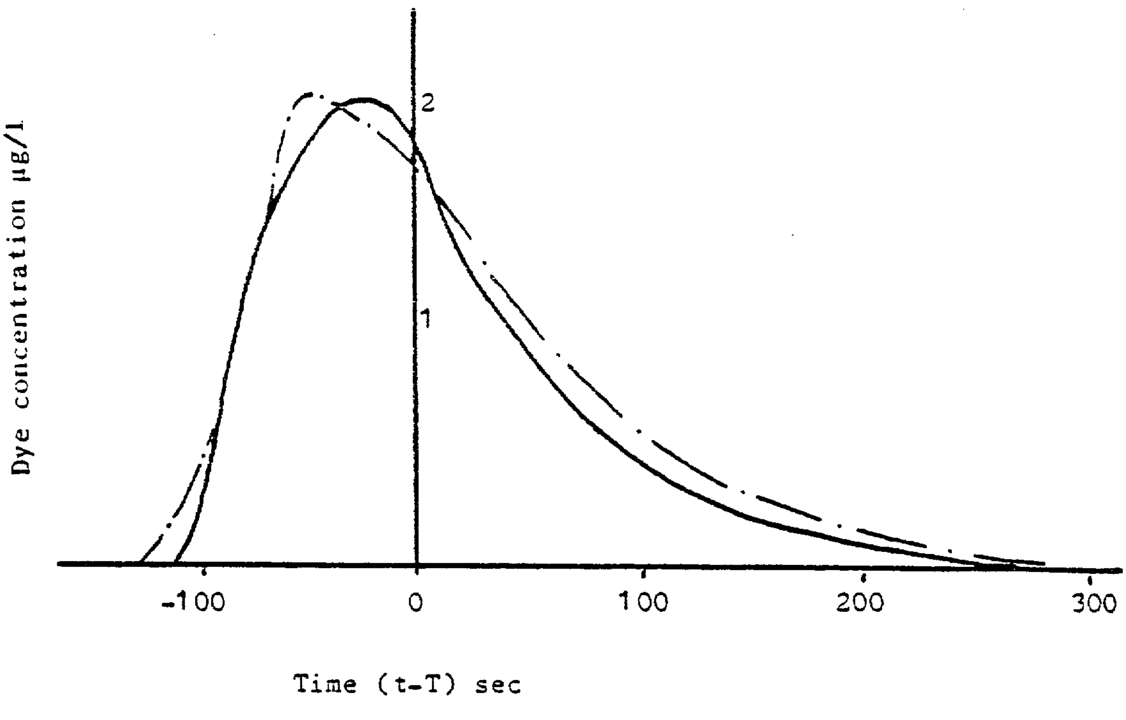



Figure 19. Traces overlaid

Tracer tests have been made on the contact tank at West Hagbourne which has a diameter of 1.2 m, a length of 44 m and a volume of 50 $m^3$. When operated at a flow rate of 680 $m^3/d$ the average residence time is 106 min and $R_e$ is 7700. The tracer tests showed that $t_5$ was 13 min earlier than T. According to the terms of the proposed specification, this means that the 50 $m^3$ tank appears to have an effective contact volume of 44 $m^3$.

## 9.4. CONCLUSIONS

Although the full-scale contact tank at West Hagbourne appears to have a high efficiency and the WRc advice can be regarded as successful, the knowledge is still largely descriptive. A recommendation that the flow should exceed a minimum Reynolds Number of 2500 is the only numerical result so far. Further effort is needed to combine the information gained in recent tests into a satisfactory quantitative model of tank performance.

## SECTION 10 CONTACT BEDS FOR pH ADJUSTMENT

### Introduction

Superficially the main reason for pH adjustment may be to bring a supply into compliance with the EC Directive which requires pH to be between 6.5 and 8.5. The main practical reason for pH adjustment in a small supply will probably be to reduce corrosion in the distribution system; either of iron in the mains or lead in connecting pipes or soldered plumbing. Corrosion control, however, is not simply a matter of pH adjustment; it is important to have sufficient buffer capacity as well.

In virtually every instance, where pH has to be altered it has to be increased. It may be necessary to accept that this may

- intensify the colour of the water and
- increase the corrosion of zinc coatings and fittings.

The pH value of a water on or in the ground will depend mainly upon the amounts of carbon dioxide and alkalinity in solution. A soft moorland water with no alkalinity may have a pH as low as 4.5 with quite a small carbon dioxide content. The same pH can exist in a water of higher alkalinity but requires a greater concentration of carbon dioxide, such as may be found in a groundwater or deep in a lake. In contrast the water in the upper layer of a lake may have its carbon dioxide content depleted during daylight due to algal activity and the pH may rise as high as 10.

Thus control of carbon dioxide is the key to pH adjustment. The chemical effect can be achieved by

- caustic dosing to neutralise the carbonic acid,
- removing excess carbon dioxide,
- adding a weak alkali which neutralises the acid and also adds alkalinity.

In some cases it is practicable to add alkali to a hypochlorite solution and use a single doser for both disinfection and pH adjustment, but often it is necessary to control both processes separately. Dosing alkali would then seem to require a duplicate dose but an alternative is to let the water flow over or through a bed of solid alkali material. There is a range of natural and manufactured media available in a range of particle sizes. The simplest contact bed is formed by loading granular material into a channel down which the water flows. Alternatively, suitable material can be loaded into a filter. Here it may be added to the filter sand simply for its chemical effect or, if the particle size is appropriate, it may contribute to filtration. Indeed, in principle at any rate, the particle size may be chosen so that the contact medium replaces the sand entirely.

### Media available

*Calcium carbonate* is the source of most natural hardness and a contact bed may be loaded with chalk, limestone or marble chips. These materials are only very slightly soluble however and relatively long contact times are needed in large beds.

Both *magnesite* (magnesium carbonate) and *magnesium hydroxide* have been used as pH adjusting media. Although ten times as soluble as calcium carbonate, magnesite reacts equally slowly with dissolved carbon dioxide. However it can be burned to magnesium oxide which is much more reactive, and then hydrated into magnesium hydroxide. Whereas hydrated lime (calcium hydroxide) comes as a powder and thus needs to be put into suspension for dosing, magnesium hydroxide can be produced in granular form and used in a contact bed.

*Dolomite* is a rock containing both calcium and magnesium; $MgCO_3.CaCO_3$. When this is half burned, or semi-calcined, a nearly equimolecular mixture of magnesium oxide and calcium carbonate is produced which has properties intermediate between those of its components.

Reactivity

Calcium carbonate is only slightly soluble;

$$CaCO_3 \rightleftharpoons Ca^{2+} + CO_3^{2-}$$

and in this equilibrium the product of the concentrations of calcium and carbonate ions is constant. If, during the pH adjustment of a water with some calcium hardness, this solubility product is exceeded then calcium carbonate can be precipitated. This results in softening of the water and loss of alkalinity and buffering capacity, not to mention the deposition of a troublesome white deposit in filters, pipes and valves.

This can happen in a contact bed with the more reactive *magnesium oxide* materials if, for instance a filter flow rate is cut back to give excessive contact time. The calcium materials, on the other hand will simply cease to dissolve when the solubility product is reached. It should be noted that in both cases the equilibrium point for the dissolving of these materials may result in a higher pH than required unless the contact time is controlled or limited in some way.

The suppliers publish information on the performance of their contact media which enable beds to be sized for the neutralisation of a known excess of carbon dioxide. The tables give the amount of medium required as kilograms per hourly or daily flow of water. This is a practical answer which enables the right amount to be ordered, but is is of interest to look at it in another way. Given the bulk density, the weight of medium can be converted to a volume in cu.m and then, by cancellation of units, to a contact time. For example;

Weight required per hourly cu.m water = 142.6 kg
Volume at 1.1 ton/cu.m (kg/l) = 129.6 litres = 0.13 cu.m

$$\text{Contact time} = \frac{0.13 \text{ cu.m}}{1 \text{ cu.m per hour water}} = 0.13 \text{ hour} = 7\text{m } 48\text{s}$$

Strictly speaking the time above is called Empty Bed Contact Time. It is actually the time that would be required for a cubic metre of water to pass through a tank of 0.13 cu.m capacity. In fact the 'tank' is to be filled with medium and so the volume available for flow is only the pore space; about a half of the total. Thus the physical contact time is only half the EBCT. It is the convention to quote EBCT as contact time and it enables plant to be sized for different media without reference to porosity data.

Table 3 lists contact times for several solid media and the corresponding bed depths for slow filters and rapid filters. The first three lines are based on the suppliers' data and the last four on laboratory tests at WRc. It can be seen that contact time is affected by particle size and also, for natural materials, by its hardness.

TABLE 3 CONTACT TIMES AND BED DEPTHS FOR pH ADJUSTMENT MEDIA for the neutralisation of 40mg/l carbon dioxide in a water containing 20mg/l alkalinity at 20 °C.

| MATERIAL | SIZE | CONTACT TIME | FILTER BED DEPTH | |
|---|---|---|---|---|
| | | | slow (0.2m/h) | rapid (6m/h) |
| | mm | minutes | millimetres | |
| Magnaspheres | 1 - 2 | 3 | 9 | 300 |
| Akdolit Grade 0 | 0.5 - 1.2 | 4 | 12 | 400 |
| Akdolit Grade 1 | 0.5 - 2.5 | 7 | 21 | 700 |
| Skye marble | 1 - 4 | 30 | 90 | 3 000 |
| Soft chalk | 4 - 12 | 24 | 72 | 2 400 |
| Hard chalk | 4 - 12 | 40 | 120 | 4 000 |
| Skye marble | 4 - 12 | 100 | 300 | 10 000 |

The activity of a bed is also affected by temperature. In the example given here the temperature does not represent normal field conditions and lower temperatures require greater depths. The correction is as follows.

$$\text{Depth required} = \text{depth from data} \times \frac{(\text{data temperature}) + 5\,^{\circ}\text{C}}{(\text{required temperature}) + 5\,^{\circ}\text{C}}$$

Thus the bed depth required for operation at 7.5 °C would be exactly twice that shown in the Table.

The design engineer's questions are

- natural or manufactured medium?
- how much is needed?
- what kind of structure is needed to house it?

These questions may not have a single answer and in order to find the most economic solution it may be necessary to cost more than one technically viable possibility.

Choice of medium

Table 3 shows clearly that the manufactured materials are required in small enough amounts for them to be incorporated within the depth of sand in a filter. If a filter already exists, or if the water quality is such that one is required, then manufactured medium is a viable option. However once a bed is installed, changes in water temperature will affect the required contact time and changes in flow rate will affect the actual contact time causing variable and occasionally excessive pH elevation. Field experience reported to date indicates that results can be satisfactory so long as the filter is not allowed to stagnate.

As a general rule, for consistent performance on a small supply where the flow rate may vary or even stop at times, crushed marble is the most desirable material. Reaction time is significantly longer than for the manufactured media and will probably rule out a rapid filter, but this disadvantage might be outweighed by the fact that pH cannot be over-adjusted.

Design of contact bed

All media are subject to fouling by deposition and precipitation and so however simply the bed is constructed, provision must be made for routine cleaning by backwashing or flushing. There is no material that will work indefinitely without some attention and replenishment. The usual recommendation is to replenish a bed when 10% of the medium has been dissolved. When a layer of medium has been added to a sand bed, it may become dispersed during backwashing. This does not alter its effectiveness but it is difficult to monitor the rate of solution. The usual practice, therefore, is to replenish when there are signs that the pH is beginning to drop. However it is done, the designer must allow adequate means of cleaning the medium and of loading and spreading fresh material.

Where a bed of natural material is contemplated it is very desirable to obtain samples for assessment. Design data would be generated in the laboratory by contacting a sample of the water with a sample of the proposed medium in a stirred vessel and noting how pH changes with time at the temperature of the test. The vessel could be a litre beaker and the stirrer should keep the water in brisk circulation without making a strong vortex. The vessel should be covered to restrict air circulation and a water-only test would check whether carbon dioxide uptake from the atmosphere was significant under test conditions. The water sample should be as representative as possible of the raw water. If the water quality is changeable, a series of samples would be advisable. For the laboratory tests a sample would be crushed and screened to the same particle size as proposed for the contact bed. It should be soaked overnight and rinsed several times before use to remove any dust or other material which might have a significant once-only effect on pH.

If possible the test, or at least one of a series, should be done at 10 $^{o}$C or some other temperature representative of the source. These tests will show how long the water needs to be in contact with the medium to achieve the required pH, or to come into equilibrium with the medium. The bed can then be designed to give a similar 'physical' contact time.

The volume of water in the bed is calculated by dividing the flow rate by the required contact time. The volume of solid medium will add the same volume again - because the crushed rock will lay to a porosity of about 50%. The volume so calculated can be adjusted, if necesary by applying the temperature correction given above. If there is any question about the design minimum temperature for a surface source, zero should be assumed.

Where only pH adjustment is required a simple upflow bed of crushed marble might be appropriate for a very small supply with cleaning by downflow at the times of routine visits.

Where filtration is required in addition to pH adjustment, then there are the options of separate filter and contact bed or a filter with mixed media. The decision will be made on the basis of cost and reliability of the alternatives.

## SECTION 11 POWER SUPPLY UNITS FOR REMOTE SITES

### Introduction

Those small supply sites which lack mains electricity are remote, rural and generally serve small communities through local isolated distribution systems. The sources may be springs, streams, lakes or reservoirs chosen originally because they gave the best quality water in the locality and were deliverable to the community under gravity. A reservoir was usually built between the source and the consumers to help provide continuity of supply at times of peak demand or low flow from the source. Most of these small supplies were established long ago and water was distributed without treatment. This meant that in some districts the water was very hard and in others it was very soft and possibly corrosive to pipes and utensils. In many cases the water carried some colour which became stronger in rainy weather. Now under the management of the Regional Water Authorities all public supplies are examined periodically and all receive the treatment necessary to protect public health. Few small supplies, however, are treated to remove colour, turbidity or aggressive properties. Many sources, at one time quite pure, are now subject to contamination because of changes in land use, increasing use of agrochemicals and intensive animal rearing.

A survey made in 1981 showed that streams and lakes each provided about 40% of such supplies and springs 20%. Half the sites were more than 50m from the nearest vehicle access, the furthest was 1600m. At half the sites the nearest electricity was more than 400m away and it could be up to 2500m. Almost all supplies had a service reservoir; the average capacity was 11 hours' flow. 40% of sites were attended once per week, 30% daily and 30% were atended two or three times per week. At that time 42% of supplies were reported not to be using any disinfection, 23% used chlorine gas, 4% used hypochlorite tablets and 31% hypochlorite solution (20% used dosing pumps and 10% gravity feeders)

Since that time the industry has been more actively concerned to improve standards on small supplies and the EC Directive on Drinking Water Quality has come into force. The advice in "Water Supply Hygiene" is not only that all drinking water should be disinfected, but that (in the section dealing with protection of sources) "Reliance should not be placed on a single line of defence, such as disinfection"

### Power requirements

The heart of the disinfection plant for a small water supply is usually a dosing pump for sodium hypochlorite. For supplies ranging up to 1 Ml/d, 10% sodium hypochlorite would be dosed at rates between 5 ml/h and 1 l/h. Pumps rated in this range consume very small powers; manufacturers' catalogues quote figures from 7 W to 60 W. Normally both figures would be so low as to be negligible, but not in this case. The smallest pump tested in the WRc programme was a very simple peristaltic type with a d.c.motor which consumed less than 0.5 W. On this basis the nominal 15 W suggested by one manufacturer appears to be realistic for a conventional motor or solenoid-driven diaphragm pump.

If a site were set up to superchlorinate and dechlorinate the water with residual control and dialling out the steady power demand may be as much as 50 W with a peak up to 75 W while dialling.

For the purpose of sizing a power source it is required to know the total energy expressed, say, in Wh required for one day's operation, this figure to include the peak instantaneous demands and the times of no load. If there were some load that imposed at longer intervals such as for operating valves for filter washing, this should be expressed as an average daily load. It should be taken that the electrical supply unit would be supported by a battery pack capable of supplying 10 days' demand.

Battery Power

Under emergency conditions a 40 AH motor vehicle battery would run a single dosing pump safely for a single day but for normal duties batteries are best used as buffer capacity and backup to an appropriately rated generator.

While standard lead-acid batteries may be used, they have certain drawbacks. They contain acid which is a hazard in handling. Once fully charged, they electrolyse the water in them producing oxygen and hydrogen. This provides an explosion hazard and the batteries should be kept in a vented room separate from other equipment.

The nickel-cadmium type batteries are generally more appropriate. They

- are filled with a gel electrolyte which cannot be spilled
- do not need topping up
- release gas only insignificantly on charging
- lose less charge on standing
- need less maintenance
- can be discharged to lower levels between charges
- have longer life as measured in recharge cycles
- cost more.

All batteries give best service if charged with a steady current, though this is unlikely to be convenient when generating from natural energy sources. Because system demands are generally steady and must be met at all times, a power unit must be sized to meet this demand even when the natural energy supply is near its minimum. Thus for much of the time, and for substantial periods, the unit will be producing excess power.

Proper provision must be made to discharge this excess power by means of voltage or current regulators or dump resistors. Disconnecting the generator on a water or wind powered unit could cause dangerous overspeeding when the load is removed unless this is allowed for in the design.

Water Power

Since drinking water supplies are generally taken from sources which run all the year round it is natural to enquire whether the flow from the source, or just the part abstracted for drinking, might be able to generate enough power to control its own treatment.

The potential energy released by one cubic metre falling through one metre (which might be called a "metre to the fourth") is 9.81 kJ or 2.725 Wh. Converting this potential energy into electricity would require a turbine and a generator. Allowing for a little more than 50% efficiency of energy conversion in each, one metre to the fourth might be expected to generate, say, 0.75 Wh of electrical energy. Thus it is possible to calculate hydraulic head requirements. For example, to generate 10 W for a particular process on a site where the flow is 500 cu.m/d, the daily electrical requirement is 240 Wh. This is equivalent to about 320 metres to the fourth, or the daily flow of 500 cu.m/d falling through 64cm head.

The greatest operating efficiency is obtained in a generating system when it runs under steady conditions. Put another way, if it can be arranged that the head and flow of water are constant, the generating system can be tailored to give the required output quite precisely with no need to add extra capacity to allow for variations. However this might not be the most economic solution if the water flow varies and an expensive reservoir has to be built to provide a constant flow.

## Waterwheels

The simplest and earliest means of obtaining mechanical power from a stream of water was the waterwheel and much of the engineering development was done by the Romans. The earliest design was a horizontal shaft with flat radial paddles which dipped into the stream at the bottom of their travel. This was found to generate very little power and so the undershot wheel was developed. Here a weir was constructed to build a head of water upstream of the wheel. The water was released from below a gate in a high velocity stream aimed at the bottom of the wheel. This drove the wheel faster but the efficiency was only about 25%.

To improve efficiency, the overshot wheel was developed. In this the flat blades were replaced by buckets which were filled at the top of the wheel and emptied at a low point. By the late 19th century efficiencies of 75% were obtained from wheels of up to 25m diameter. They generally needed substantial civil works, however, and were superceded by turbines.

## The Pelton Wheel

The earliest Pelton wheel was like the first water wheel with flat radial blades, but it was driven at high speed by a jet of water ejected from a nozzle under pressure. It was found that the greatest torque was obtained when the wheel was stationary and the water exerted the greatest force on the wheel, but the power was nil. The greatest speed attainable was when the blades travelled at the same speed as the water, but this was only approached at no load and again the power was nil. The greatest power was obtained when the blades travelled at half the water jet speed, and the efficiency was 50%.

Efficiency could be improved by curving the blades so that the water was ejected backwards (and to one side) relative to the blade and was maximised when it left the wheel with no net forward or backward velocity. Modern Pelton wheel turbines are made with twin cups, each taking half the flow, to balance the sideways forces. For maximum efficiency it is essential that the spent water should have free passage from the machine.

## Impulse Turbines

The impulse turbine uses a jet of water angled at about 20 degrees to the plane of rotation of the wheel. The wheel has curved blades and the water enters at one side and leaves at the other. This is a more compact design than the Pelton wheel and runs at about twice the speed.

Like the Pelton wheel, the impulse turbine runs in air and the spent water must have free egress from the wheel to obtain maximum efficiency.

## Reaction Turbines

This type of machine does not use a jet and runs with the casing flooded. The commonest design is the Francis Turbine, developed in the USA by J B Francis in the 18th century. Water is directed on to the rotor by a series of of controllable guide vanes and all the rotor buckets are in continuous operation. The machine runs at high speed and is significantly smaller for a given power than any impulse turbine. As with the other designs, this requires an unrestricted passage for the spent water.

## Water Turbines for Small Supplies

While large water turbines driving alternators need expensive gear to control speed precisely, this is much less important for small d.c. generators. However some provision should be made, either in the design to limit "run away" (no load) speed, or for power dumping resistors to avoid overcharging batteries or underloading the turbine.

High heads and low flows favour the selection of impulse turbines while if the head is low and the flow sufficient, the reaction turbine is to be favoured. While the bare shaft turbine may cost as little as £300 - £900, the total cost of an installation including the civil works will be very much more.

Generally speaking water turbines are not regarded as efficient for delivering powers of less than about 250 W but a turbine can be supplied for any output required so long as it is accepted that it may be operating under conditions far removed from the optimum.

Although it may be assembled largely from standard parts, the configuration of a water turbine will be specific to the power requirement and the site conditions. All the suppliers in this field offer a full range of both impulse and reaction types and will recommend the most effective for a particular duty.

If a high head is available, a particular power requirement may be met by a low flow operating an impulse turbine. For instance if a power of 20W were required at a site where a head of 20m could be made available, an impulse turbine would only need a flow of 32 cu.m/d.

On the other hand, if a head of only 2m were available, the choice would probably be a reaction turbine provided that a minimum flow of 320 cu.m/d could be assured.

Whatever type of turbine is selected, it is necessary to take steps to ensure that the driving water is free of silt and other abrasive solids as well as coarser materials like dead leaves which could block nozzles and passages.

## WIND POWER

The daily cycle of heating and cooling as the earth turns to face the sun causes the atmosphere to be in constant motion. Any tendency to regularity in this motion is affected by the irregular disposition of land and water areas which control the heating and cooling of the air above them. While there are general patterns of air flow high in the atmosphere, they become broken and modified near the earth's surface, especially over land.

The energy of the wind can be expressed in the normal form for kinetic energy, 1/2 mv2 where v is the speed of the wind and m is the mass passing a fixed point in unit time. Since this mass is clearly proportional to the speed it can be seen that the power in a wind stream is proportional to the cube of its speed. The power available from a machine depends also directly upon the area it presents to the wind.

The meteorological data for open sites on the UK mainland shows a fairly even distribution of wind direction and no association of speed with direction. While the mean wind speed at 10m above ground level is 5-7m/s (18-25km/h), the range is from 0 to 70km/h and may peak at over 100km/h. This very wide range poses a problem to the designers of wind mills.

### Horizontal Axis Machines

Horizontal axis wind machines have been known since the 17th century BC in the middle east and were brought to the west at the time of the crusades. Large diameter windmills and small diameter wind pumps are familiar.

Design problems relate to the variability of the wind and the need to support the turbine on a tower. It must be possible in the first place for the turbine to be able to turn to face the wind and this requires a bearing at the top of the tower. The tower must also be able to withstand not only the direct wind load on its body but the much greater horizontal thrust of the wind on the turbine. The actual fluctuations in this load depend on the severity of gusts and on the ability of the turbine to accelerate (and so 'ride' the gust) or to shed the load in some way. Surplus power may be spilled by allowing the blades to bend or cone, by turning them edgwise to the wind (feathering) or by turning the whole turbine away from the wind. Coning is easier if the rotor is downwind of the tower but then the blades are subject to fluctuating loads as they pass through the wind shadow of the tower.

Vertical Axis Machines

The main advantage of vertical axis machines is that they do not have to be reoriented when the wind changes direction and this simplifies machine construction, eliminating one axis of rotation and the slip rings usually mounted at the top of the tower. The penalty is that the blades only produce energy while moving downwind and require energy to drive them back upwind.

There are several designs. The Darrieus rotor has blades of aerofoil section. In the original machine the blades were straight and subject to great bending forces when rotating at speed. The modern design with flexible blades, Fig 20, enables a much more efficient and lighter structure. This type of rotor can generate considerable power but it is not self-starting.

The Savonius rotor, Fig 21, is more often used for small machines; it is self-starting and cheap to manufacture though its efficiency falls to 30%.

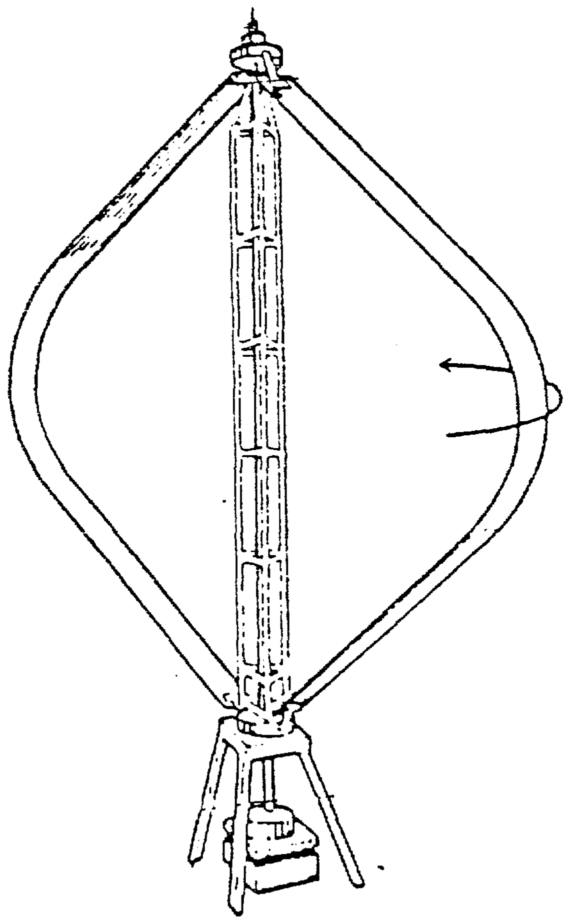


Fig 20 Darrieus rotor

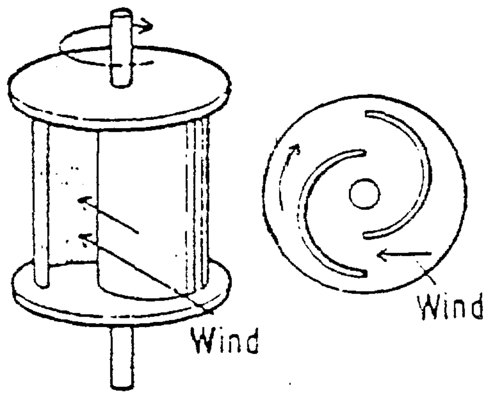



Fig 21 Savonius rotor

System efficiencies may be low but offset against this is that the source of power is free.

A wind generator will have an effect on the visual environment and this must be an important consideration in selection. The main technical consideration is wind strength. The site mean wind speed should be taken as the wind velocity occurring for 50% of the time throughout the year. The actual power available will vary with weather and season but an overall 50% yield should be achievable.

The generator would normally give a 12v or 24v d.c. output with batteries to provide for continuity of supply and some means of protecting the supplied system from any irregularities or disturbances in the generated voltage or current.

## SOLAR POWER

Ultimately the sun is the source of almost all the energy available to mankind; coal, oil, firewood, hydroelectricity, direct sunlight. Electricity generation from sunlight is both immediate and also moderately efficient when compared with the traditional conversion systems.

The photo-electric effect was first observed in the 19th century but was not put to effective commercial use until the 1950's. Development was spurred on by its application to the American space programme which required low weight high power systems to operate satellites. Initial costs were very high but continued development has broadened the range of materials and reduced costs.

### Operating principle

In a pure crystal structure each atom shares negatively charged valence electrons with adjacent atoms in covalent bonding. If the pure crystal is 'doped' with a compatible material which has an excess of valency electrons, the result is an 'n' type semiconductor. If the excess electrons are supplied with enough energy they will escape their weak restraining forces and drift in the crystal lattice and so make the crystal electrically conductive.

If a similar crystal is doped with with a compatible material which is electron deficient the result is a 'p' type semiconductor. If the electron in thge crystal are excited they will "fill" adjacent holes thus creating a vacancy in the original lattice. If the excitation continues these holes drift inside the atomic structure. This material exhibits a positive charge characteristic.

There is no overall charge in or on on any crystal. But if the two materials, p type and n type were joined, the free electrons would diffuse across the junction from n to p and the holes would drift the other way. When the transfer of holes and electrons has taken place, the nuclear charges within each crystal will no longer be in balance and this leads to a potential difference across the junction with the p type material exhibiting a negative charge and the n type material a positive charge.

If light of sufficient energy falls on the crystal and excites an electron to leave its parent atom the electron will drift towards the p type conductor. The hole created by by the departing electron will migrate towards the n type conductor. This process leads to the development of a potential across the semiconductor which can drive a current in an external circuit.

## Theoretical Efficiency

The ability of light to excite the electrons in a solar cell depends on its wavelength and different cell materials respond to different wave bands. When using silicon as the cell material, 77% of the solar spectrum is convertible into electricity. When other materials are developed with smaller "band gaps", it will be possible to make use of more of the solar spectrum.

Of the light incident on a solar cell, a proportion is lost in reflection and in absorption on the cell's outer protective layer. Skilful selection of surface coating can minimise these losses. There is also a proportion of light that will pass right through the cell, depending on its thickness. Other losses are caused by internal resistance, junction loss, losses due to recombination (of electrons and holes) and the effect of temperature. The efficiency of a cell falls as the temperature rises and all cells have a "rated" temperature (usually 25 degrees Centigrade) at which their performance characteristics are measured. It is desirable to mount the cells in a situation which, while allowing peak illumination, will limit heat build up in the enclosure.

The silicon cells generally available have an efficiency of 10% to 12%. So long as the temperature is controlled, cells will work at this efficiency over a wide range of lighting levels. Higher efficiency cells are available at greatly increased costs.

The life of a cell is theoretically infinite, but is limited in practice by the failure of the encapsulation. Design life is usually 10 years.

## Practical Considerations

The available solar power on a clear day at noon is about 1 kW/sq.m. at the equator. This is a peak figure and the realisable available energy will depend on latitude, time of year, location of site and atmospheric pollution. Available data shows that the total radiation received in the UK is about 3200 MJ/sq.m per year, equivalent to an average of about 200 W/sq.m for the daylight hours. Currently available commercial solar panels will yield peak powers of about 80 W/sq.m.

Orientation of a solar panel has an important effect on the amount of energy that can be recovered. The histogram Fig 22 shows the mean daily radiation on a horizontal surface at a site in West London, averaged over six years. Although a horizontal surface is open to the whole sky, light incident at a low angle will tend to be lost by reflection. This is illustrated by the dotted line which shows the radiation on a vertical surface facing south. It can be seen that in summer the vertical surface is at a disadvantage because it is only open to half the sky. However in winter it collects more energy than the horizontal surface because it gathers the low-angle radiation from the south more efficiently and suffers no penalty from not looking north. The Table 4 shows the variation in mean daily radiation for surfaces inclined at different angles to the horizontal. It can be seen that the highest annual mean is obtained with a southerly slope of about 40 degrees, but to obtain the highest value for the annual minimum, the slope should be 60 degrees.

A cell panel should be mounted high enough not to be shadowed by buildings or trees, and should not be subject to masking by fallen leaves. The southerly inclination will allow rain runoff and thus a little natural cleaning but little can be done to avoid obscuration by snow. Vandalism or theft may be a problem at remote sites and it may be advisable to make the panel inconspicuous or inaccessible.

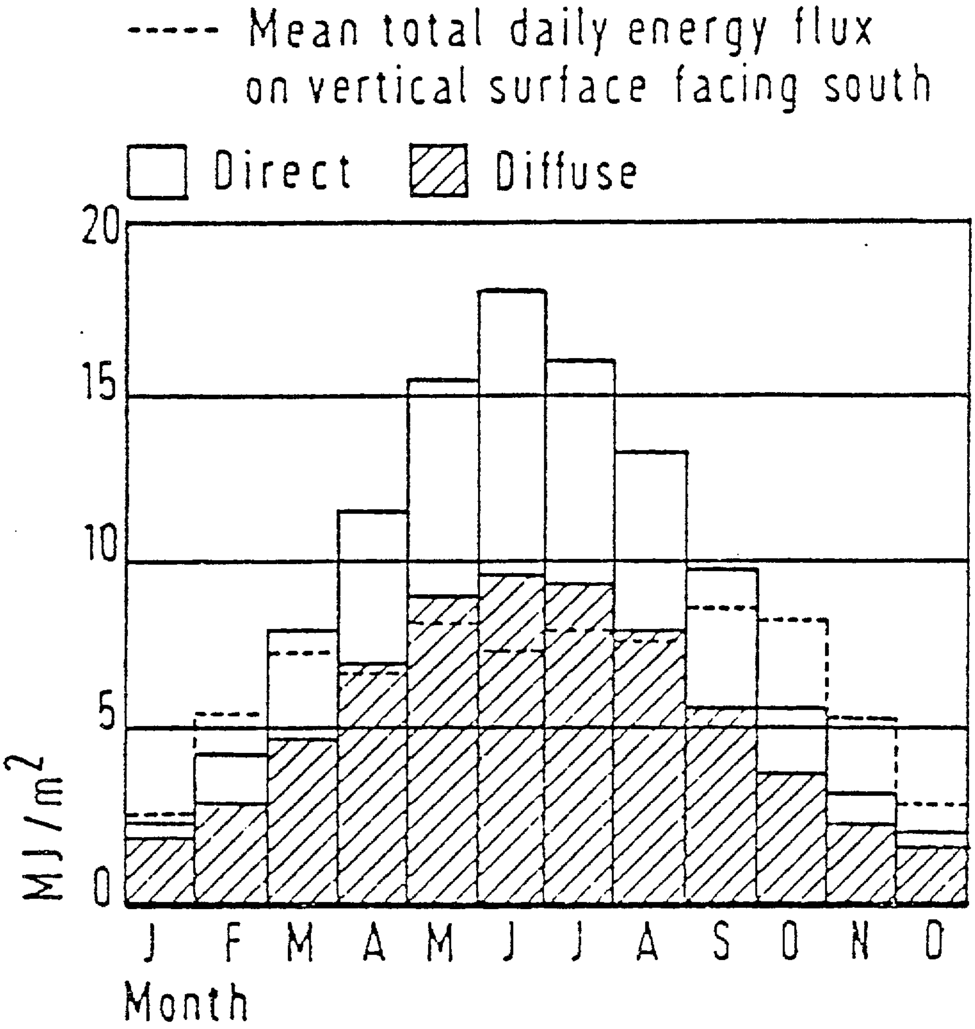



*Fig 22. Mean daily radiation on a horizontal surface in West London, averaged over 6 years.*

*Table 4. Total radiation on South facing surfaces under average conditions, MJ/m² day*

| Position of surface | Winter period Oct 16-Feb 26 | Spring and Autumn Feb 27-Apr 12 and Aug 31-Oct 15 | Summer Apr 13 Aug 30 | Annual mean |
|---|---|---|---|---|
| Horizontal | 2.49 | 7.47 | 14.51 | 8.35 |
| S 20° | 3.28 | 8.52 | 14.96 | 9.09 |
| S 40° | 3.79 | 8.99 | 14.50 | 9.20 |
| S 60° | 3.81 | 8.52 | 12.51 | 8.32 |
| S Vertical | 3.52 | 6.47 | 8.57 | 6.19 |

Maintenance on solar cells normally consists only of annual inspection and cleaning.

Solar cells produce direct current and can charge batteries without rectification. Some systems take advantage of the characteristics of the cell to limit battery charging currents. Since peak powers can be determined exactly, control circuitry is simple.

A wide range of cells is available and the manuacturers offer advice on how to provide for particular voltage and current loads. When an enquiry is made the manufacturer will need to know

- Electrical load, voltage and curent
  This should be the *average* amp.hr per day. It should include cyclic loads and an accurate assessment of total load including any local indication of battery condition.

- Type of storage batteries to be used

- Latitude and aspect of site
  Obtainable from a suitable map.

- Degree of security of supply required.
  This is important as it will govern the storage battery size and the cell panel capacity.

## SECTION 12 SPECIFICATION AND STORAGE OF SODIUM HYPOCHLORITE

### Introduction

Sodium hypochlorite solution is the most important chemical used in the disinfection of small supplies. Of those reporting to WRc's 1981 survey, the ratio of hypochlorite to gas was about 6:4 and expected to increase.

While much of the concern about unreliable disinfection was focussed on dosing equipment, it was also said that the sodium hypochlorite solutions were unstable and liable to rapid deterioration. Thus, even with faultless equipment the reliability of disinfection would be at the mercy of a fickle chemical. It was said that hypochlorite solutions would lose strength in storage and could have deteriorated even to half strength before delivery to site. Once there, deterioration was even more rapid, especially if the solution had to be diluted with the local water before use.

It was because of these comments that the objectives of the second phase of the contract were extended to a study of the shelf life of hypochlorite solutions, the specifications of commercial grades and recommendations on "use-by" dates.

### Manufacture and Specification

There were three main manufacturers of sodium hypochlorite for general industrial use and they supplied several distributors. The chemical was made by bubbling chlorine gas through caustic soda solution and the industrial product, distributed at about 15% by weight of available chlorine, had the following typical composition.

| | |
|---|---|
| Specific gravity | 1.262 |
| pH value | >11.5 |
| Available chlorine | 15% |
| Sodium carbonate | 0.32% |
| Sodium hydroxide | 0.54% |
| Sodium chloride | 15.5% |
| Sodium chlorate | 0.2% |
| Iron oxide (FeO) | 1.0 ppm |
| Copper | <0.1 ppm |
| Nickel | <0.1 ppm |

Decomposition was said to be accelerated by heat, light, acidity and the presence of metallic impurities and so, to ensure product quality and stability, the manufacturing plant was built with contact parts of PVC and titanium, high quality raw materials were used and the product was filtered and distributed at high pH.

The distributors received bulk supplies in 11 or 20 cu.m tankers and repacked, usually into 50 litre plastic drums although according to demand the chemical could be supplies in containers of any required size from 1 litre to 2.5 cu.m. Although the standard concentration was 14-15%, lower strengths could be supplied down to [illegible] if the demand justified it. Some distributors marked their drums with the month and year of packing and they all issued product notes pointing out the proneness of the chemical to decomposition, the need to rotate stocks and the advisability of ordering only to current requirements.

## Decomposition

Literature on the decomposition of sodium hypochlorite is scant and inconsistent. Some authors say that on heating, three molecules of hypochlorite produce one of chlorate and two of chloride. Others quote a reaction which evolves oxygen. On the other hand everyday experience is that hypochlorite solutions smell of chlorine, so there must be a decomposition route involving the loss of chlorine directly.

The main authority, G.C.White in his "Handbook of Chlorination" makes no reference to decomposition products. He quotes from a 1960 technical bulletin published by the Allied Chemical Co. which shows how the half life of a solution depends on its concentration, increasing as concentration decreases, as indicated in Fig 23. The term 'half life' implies first-order exponential decay to the average reader but it is not at all clear that the term is used in this sense. White quotes exposure to sunlight as reducing the half life of a 15% solution three or four times and that of a 20% solution about six times. It is stated very clearly that exposure to sunlight will accelerate decomposition. This should therefore reduce its strength and so increase the half life.

It can only be said that there is confusion about the actual reactions by which sodium hyopochlorite solutions lose strength and about the rates of deterioration.

## Laboratory Studies

This account is a summary of the work reported in Appendix 12.

Two 50 litre drums of sodium hypochlorite solution were obtained from one of the major suppliers. One of them was opened and samples, filtered to 40 microns were treated as follows.

- diluted 100, 10, 2-fold and not at all,
- put in clear or amber glass bottles,
- left on a window ledge, in a dark cupboard or a cool store.

They were all titrated for available chlorine immediately and then at intervals which increased as time passed up to a total time of nine months.

The samples exposed to light at a north facing window lost half their chlorine in about a fortnight, those kept in the dark at about 15OC dropped to half strength in six months while those kept in the dark at about 5OC lost only about 10% of their available chlorine in nine months. There was no evidence that this behaviour depended on concentration. After what had been reported, these results were surprising.

It was expected at first that the decay would be exponential and time constants were calculated for some samples after 50 days. Later results showed the samples to be losing strength more slowly than expected, as though the products of decomposition were having a preservative effect on the remaining chlorine. Simple checks to see whether the hydroxyl ion concentration changed during decomposition were inconclusive but the tests were not continued when it began to appear that the outcome would have little practical significance.

## Conclusions

The results of this work suggest that although sodium hypochlorite solutions tend to decompose, they can be managed in such a way that most of the chlorine purchased is used for disinfection. Effective management is simple and does not require expensive equipment.

The work done here has not identified the mechanisms by which hypochlorite solutions decompose or quantified the main controlling factors, though it has shown that decomposition is not first order. Samples kept under different conditions lost strength at different rates. While some of the experimental results showed scatter, the consistency within sets was generally good and it is concluded therefore that hypochlorite solutions lose strength by more than one reaction and that the separarate reactions are influenced to different degrees by the controlling factors; light, temperature, catalysis, for example.

It would require a more comprehensive study to enumerate and quantify these factors to the point at which the decomposition could be calculated and it is not obvious that such knowledge would enable more economic management than can be achieved by adherence to the recommendations listed below.

Finally it is concluded that while it is helpful for distributors to mark their containers with the date of filling, they should not be asked to quote "use by" dates. This is because the period of viable storage depends entirely on the purchaser and there is nothing a supplier can do to control it.

## Recommendations

In order to get the best economic performance from sodium hypochlorite solutions, water supply undertakings should adopt operating rules for their storage and use. The details of these rules should depend on local circumstances such as the annual usage of hypochlorite, location of suppliers, methods of distribution from store to site, suitability of store, costs of storage and the extent to which deliveries may be affected by winter weather.

The general features of the rules would be as follows.

1. Check each new delivery for gassing. Stir each container well and draw a sample into a 250ml cylinder. Any spontaneous evolution of bubbles indicates nuclei for decomposition and the container should be rejected.

2. Mark new stock with date of receipt.

3. Check strength of every delivery. Keep records and act on anomalies.

4. Keep as little hypochlorite as possible in central stock. Two weeks' supply is suggested as a reasonable minimum which might be increased where storage conditions are good and inexpensive.

5. Consider holding minimum stocks in summer when deliveries can be relied on and increased amounts in winter if transport is more difficult.

6. Consider whether the range of container sizes should be changed.

7. Always keep stock in a cool, dark place.

8. Always isue the oldest material in stock.

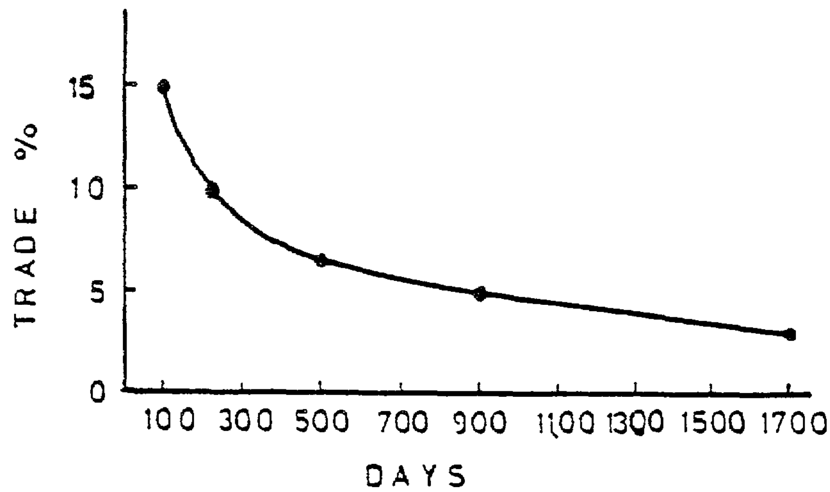
9. Make periodical checks on the strength of solutions in stock. If it found that strengths change quickly, it may be desirable to reduce stocks, re-order more often and make more frequent checks. If it is found that strengths are stable, sampling frequency can be reduced until containers are checked only on receipt and issue.

10. Review records annually and consider whether to change stock levels or sampling frequencies.

11. Make deliveries to sites as small and frequent as possible within the economic constraints.

12. Use solutions on site undiluted if possible to avoid the chance of contamination, and try to avoid unnecessarily transferring the solutions between containers.

13. If a small supply requires to dose solution at less than the standard 15% concentration, consider whether to prepack the dilute solution centrally.




N.B. Industrial grade under average storage conditions

Fig 23 Half-life of sodium hpochlorite related to initial concentration

## SECTION 13 RECOMMENDATIONS ON EQUIPMENT DESIGN

Drawing on the reports of the doser tests, and particularly the "factors making for reliability and effectiveness", the following recommendations are made.

### Design of dosers

They must be of robust, simple construction with few moving parts. Wherever possible sliding joints and sliding seals should be avoided.

Although the draft specification does not call for very precise dosing, the best long-term consistency of performance is obtained from accurate units.

The accuracy of dosing must not depend upon precise levelling of a doser or its setting at an exact height.

For satisfactory service on drinking water supplies a doser must have as part of its construction some means of adjusting the flow of hypochlorite relative to the flow of water being dosed.

The dose adjuster should have a marker moving over a calibrated scale. The scale should be numbered so that zero (even if it is not marked) would correspond to zero dose and there should be some way of setting the marker relative to the scale to allow the zero to be adjusted.

Many pumps have facilities for both manual setting and automatic control. Traditionally the operator was given manual control of stroke length and the automatic control was used to adjust stroking rate; each working in a 10:1 range and giving the pump an overall 100:1 range. However modern electronic controls are very accurate and can operate over ranges even wider than 100:1. More accurate overall performance is to be obtained by reducing or even eliminating the mechanical variation of stroke length and exercising all control electronically. This would not entail depriving the operator of the facility for making a manual setting; it would simple be done by electronic instead of mechanical proportioning.

With many pumps, dosing is more reliable and consistent when the pump works against a steady moderate pressure. It should be remembered that although pressure duties may vary widely from one site to another, the head variation on any single small supply site may be no more than 3 or 4 metres according to the level in the service reservoir.

For a slow stroking pump, double action may be advantageous.

Reliable disinfection requires adequate mixing of hypochlorite into the dosed stream. On a large works the flow of chlorine gas is continuous, mixing into the main flow is virtually instantaneous and the contact tank, designed simply to give disinfection contact may be separate from the service reservoir capacity. On a small supply the doser will probably give a pulsating flow of hypochlorite; a Mariotte jar, for instance may be set to give one drop every ten seconds. Such an interval may appear insignificant but it draws attention to the principle of intermittent dosing which would provide a means of treating very small flows with relatively large but accurately measured pulses of hypochlorite. In order to set a standard it is proposed that the longest pulse interval should be no more then 1% of the residence time in the contact tank or service reservoir.

For a small electrical pump a rotary drive motor is to be preferred to a solenoid. Although the solenoid is simple and reputedly cheap, there is no great price difference between pumps of the two types. All the solenoid pumps tested showed much increased deliveries at very low pressures, or supercharging. This would not be a problem at all sites and can be eliminated by the provision of a pressure loading valve on the pump delivery line. However supercharging is not a problem at all with rotary drive pumps.

Where hydraulic power is used to drive a doser, the motor should be of the positive displacement type. However an inferential type of flow meter is acceptable to provide control.

Although piston pumps are generally more precise than diaphragm types, the sealed diaphragm offers a better promise of leak-free operation when handling hypochlorite and it is not subject to frictional forces at the shaft seal. The tests have shown that a diaphragm head can be designed which gives satisfactory accuracy over a wide range of relevant operating conditions. As a guide, the volume swept by the diaphragm's annular seal must be a small proportion of the total swept volume and its change over the full rated range of inlet and delivery pressures should not be greater than 5% of the maximum swept volume.

There is inevitably some degree of reverse flow at the end of a pump stroke as the displacer changes direction and the valves drop on to their seats. The fundamental way of maximising the volumetric efficiency of a pump is to deliver as much liquid as possible on each stroke so that the loss on reversal is the smallest possible fraction of the delivery.

Valves with metallic return springs are to be avoided for pumping hypochlorite which is corrosive.

While lip seal valves give good service, gravity operated ball valves using glass balls on O-ring seats are simple, cheap and very effective. Double valves in series on both suction and delivery give better sealing than single valves.

Flow proportional dosers must not allow trickle flows to pass untreated although there must be some limit of acceptability. If, for example, the treated water were to pass to a 24 hour storage tank and a 10% dilution of residual chlorine were acceptable over a maximum 8 hour trickle period, then the maximum acceptable trickle rate would be 2.4 in 8 or 30% of the average hourly flow rate. As a general rule the untreated trickle flow should not exceed 1% of the average hourly flow for each hour's storage in the reservoir. So, for example, the allowable untreated trickle for a 24 cu.m/d (1000 l/h) supply with 18 hours' storage would be 18% of 1000 l/h, or 3 l/min.

Every doser should be supplied with clear literature describing its method of operation, installation and adjustment and the recommended servicing procedures. Where the information supplied applies to a range of units, it must be easy for the user of a particular unit to identify and discard what is irrelevant. Where servicing involves routine replacement of components, the unit should be supplied with enough of these for the first year's operation.

Energy demands for dosing into a pressurised system can be reduced if the system pressure can be tapped to pressurise the hypochlorite solution before it is dosed. This involves wasting a volume of water rather greater than the volume of hypochlorite dosed. The technique is not applicable in all cases but should be considered favourably where it is.

Hypochlorite handling

Operating at rates between 1ml/h and 5l/h, dosers pass hypochlorite solutions at low speeds, often through narrow passages or constrictions, and they can be susceptible to restriction or blockage if the solution contains any solid particles. Because sodium hypochlorite is alkaline it can, if diluted with hard water, precipitate calcium carbonate. For this reason it should be dosed straight from the supplier's container if possible. Not only will this prevent scale formation, it will

- help avoid adventitious contamination on re-handling,
- help avoid premature loss of solution strength
- contribute to safety at work.

The hypochlorite solution storage container should be located in a cool dark place. Pipes and tubes carrying hypochlorite solution must be made of opaque materials and flow indicators should be kept covered.

SECTION 14 CONCLUSIONS

1. The studies on dosers succesfully identified the factors making for reliability and effectiveness in a wide range of equipment and have provided the basis for a considerable enhancement of the plant specification drafted at the beginning of the work. They have provided information on which can be based

- advice on the purchasing of reliable and effective equipment
- design standards for treatment works for small supplies
- information on the situations in which different methods of disinfection are appropriate for small supplies.

2. The public water supply undertakings are interested in the findings of this work and have financed the publication of a design manual for the improvement of their small supplies. There is also information here which would be to the benefit of the proprietors of private water supplies. This might be made available directly through appropriate publications or else through the services of local Environmental Health Officers. However EHO's have wide ranging responsibilities and while they might be briefed to give general advice to the owners of private supplies, they should not be expected to give a complete technical advisory service. The Department of the Environment has a responsibility to see that such advice is made available and an alternative route might be through approved contractors. This would require the setting up of a system such as the gas industry CORGI.

3. The desirability of a battery operated residual chlorine monitor was identified early in the study and created some interest. Although a simple extension of existing technology was thought at first to be feasible, problems were met in obtaining reliable readings in samples of varying pH. There is still the need for such a device .

4. The work has identified many desirable features in small electrical hypochlorite dosing pumps. None was found which combined all the best features, so there is scope for further development either through the enterprise of a manufacturer or else sponsored in some way by the water industry.

5. Calcium hypochlorite tablets provide a very attractive way of delivering chlorine to a small, possibly remote, supply site. At 70% by weight active chlorine it is by far the most concentrated form of deliverable chlorine and it is stable in storage. There is however, a distinct lack of dosing equipment able to use this material effectively.

6. A part of the work highlighted the need for effective hydraulic design of contact tanks - on large waterworks as well as small ones - and showed that considerable imrovements could be obtained by simple means. There is a need for this work to be carried further.

7. Work on this contract began in September 1982 and was effectively completed in September 1986. In the meantime the EC Directive on the Quality of Water Intended for Human Consumption came into legal effect in the UK in July 1985. The practices and policies of the public water undertakings are changing. More money is being spent on improving standards of disinfection generally and improving the facilities on small supplies; in treatment, service and monitoring. The situation has changed since the first surveys and site visits and it would be important, therefore, before engaging in any further work, to ensure that the objectives have not shifted.

## SECTION 15 ANNEXES

APPENDIX 1 SPECIFICATION FOR SMALL WATER TREATMENT PLANT

## TREATMENT PLANT FOR SMALL WATER SUPPLIES

## PROPOSED TERMS OF SPECIFICATION

### 1. PURPOSE

1.1 The purpose of a water treatment plant is to deliver potable water which is wholesome, that is, water which is not injurious to health and is aesthetically acceptable with regard to taste, odour and appearance. In addition it is required that it will not deteriorate in the distribution main and will not affect the main by deposition or corrosion. To this end, the water may require to be treated by chemical and physical methods. A separate treatment specification may stipulate these methods and this specification describes the plant by which the treatment is to be applied.

### 2. GENERAL

2.1 The treatment plant shall be capable of delivering a flow of water into a distribution pipe (which may already exist) at the specified flow rate against the maximum pressure prevailing at the inlet point.

2.2 The plant must be designed on the basic premise that there is no supply of energy or material available at the site. Where solar, wind, hydraulic or electrical energy are available, the plant may be designed to use these provided that it can be shown that the Present Value (calculated according to the purchasing authority's method) will be lower than otherwise.

2.3 The plant must be capable of running unattended for a normal period of one week and a maximum of two.

2.4 In the case of failure of a unit of the treatment plant in normal circumstances,

- either a standby unit must be automatically brought into use
- or, PROVIDED THAT THERE IS SUFFICIENT RESERVOIR CAPACITY TO MAINTAIN PRESSURE IN THE DISTRIBUTION SYSTEM FOR 48 HOURS, the supply must be stopped and a signal must be given. In this case sufficient spare parts and units must be supplied to ensure that repairs can be made within the stipulated time.

## 3. DESIGN

3.1 The plant shall be designed so that all procedures required for its normal operation and monitoring can be carried safely out by a person working alone. The design documentation, to be delivered at the beginning of construction, shall include operation and maintenance information on all equipment.

3.2 The handling of chemicals must be safe and easy. Rinsing and washing facilities must be provided for both the plant and the operator. Raw water is acceptable for this purpose if treated water is not conveniently available.

3.3 Materials of construction of equipment and surface finishes must be resistant to damp atmospheres and corrosion by substances to which they will be exposed, both in normal use and also in the case of accidental spillage. They should comply with the relevant BS specifications and if necessary, have WAA approval. Any chemicals used should be approved for use by the CCM.

3.4 Preference will be given to equipment which can be adjusted and whose renewable parts can be cleaned and replaced without the use of tools by an operator with gloved hands.

3.5 Equipment shall be located so that pipe runs are short and direct.

3.6 The equipment shall be installed in a building with sufficient space for normal attention and repair and adequate lighting, preferably natural. Enough space shall be provided for the convenience of the operator and any accessories which may be used in carrying out duties on the site. Protection should be provided where freezing is likely which could damage equipment or prevent adequate treatment of the water. This may consist of insulation, heating or the use of anti-freeze agents in chemical solutions.

3.7 The exterior design of the building should be vandal resistant and its appearance should be in keeping with its surroundings.

## 4. FILTERS

4.1 Preference will be given to designs showing ease of operation. Valve operations should be minimised by using multiported or ganged valves. Adequate means of inspecting the sand bed during washing is very important, especially in shell filters, and easy access for sand replacement is required.

## 5. CHLORINATOR

5.1 The chlorinator must be able to deliver free chlorine into a flow of water at a rate controllable between 0.1 and 3mg/l under steady flow conditions, the dose not altering by more than 10% from one hour to the next or between the second hour of continuous operation and the 350th hour(i.e. after two weeks).

5.2 This performance must be maintained notwithstanding any change in temperature of the water dosed from zero to 30 degrees centigrade or, if dosing into a closed system, any change in water pressure from 1 bar negative to 10 bar positive and at all stages from full to empty chemical container whether this is a part of the chlorinator or not.

5.3 Where an adjustment is provided to change the delivery, the alterations must be smoothly continuous or (where stepwise) in equal steps and whenever the adjuster is moved to any position from the full range setting, the dose should be within 10% of the average for that setting.

6. CHLORINE MONITOR

7.1 Where a chlorine residual monitor is provided it must be able to detect a residual of 0.1mg/l free chlorine and to indicate this to within plus or minus 0.05mg/l. At a free chlorine level of 1mg/l the indication must be within 0.2mg/l and at a residual of 5mg/l, within 1mg/l. In performance tests these measurements should be taken in samples at pH 5.5 although the instrument will be expected to operate with the same accuracy at the natural pH of the water.

7. CONTACT TANK

7.1 Where a chlorine contact tank is provided, its design must be such that when water is flowing steadily through at the maximum design rate, 95% of the water discharged has remained in the tank for the minimum required contact time.

APPENDIX 4.1 MARIOTTE JAR

Tests

A Mariotte Jar was built similar to those used in the field using a 20-litre aspirator, 10mm vent tube and a capillary outlet tube 240 mm long whose bore was measured to be 1.8mm. This tube was bent to give a horizontal length of 155 mm and an inclined length of 85mm.

The first test was to investigate the relationship between flow and head. The head over the outlet tube was altered by raising or lowering the bottom of the vent tube in steps. At each setting smaller variations were made by rotating the capillary outlet. At each measurement the discharge was collected in a measuring vessel for a timed period and sufficient amount was collected to allow its volume to be measured to an accuracy of about 1%. The graph Fig 411 shows the flow varying continuously from 65ml/min at a maximum head of 159mm to 1.9ml/min at a head of 21mm. In order to keep the drops falling cleanly from the end of the tube it was recommended that its slope should not exceed 1 in 2. Within this limit and the construction of the jar it was not possible to obtain a head less than 21mm, but it was clear from the results that the flow was likely to stop at a head very close to 20mm.

The graph shows six series of results each with a range of capillary positions, one for each setting of the vent tube. These small sections overlap to show a well-defined curve which has been drawn together with two similar curves, one 10% higher, the other 10% lower. This figure shows that all heads were replicated two or three times and that the dose was within 10% of the average over the whole of the range.

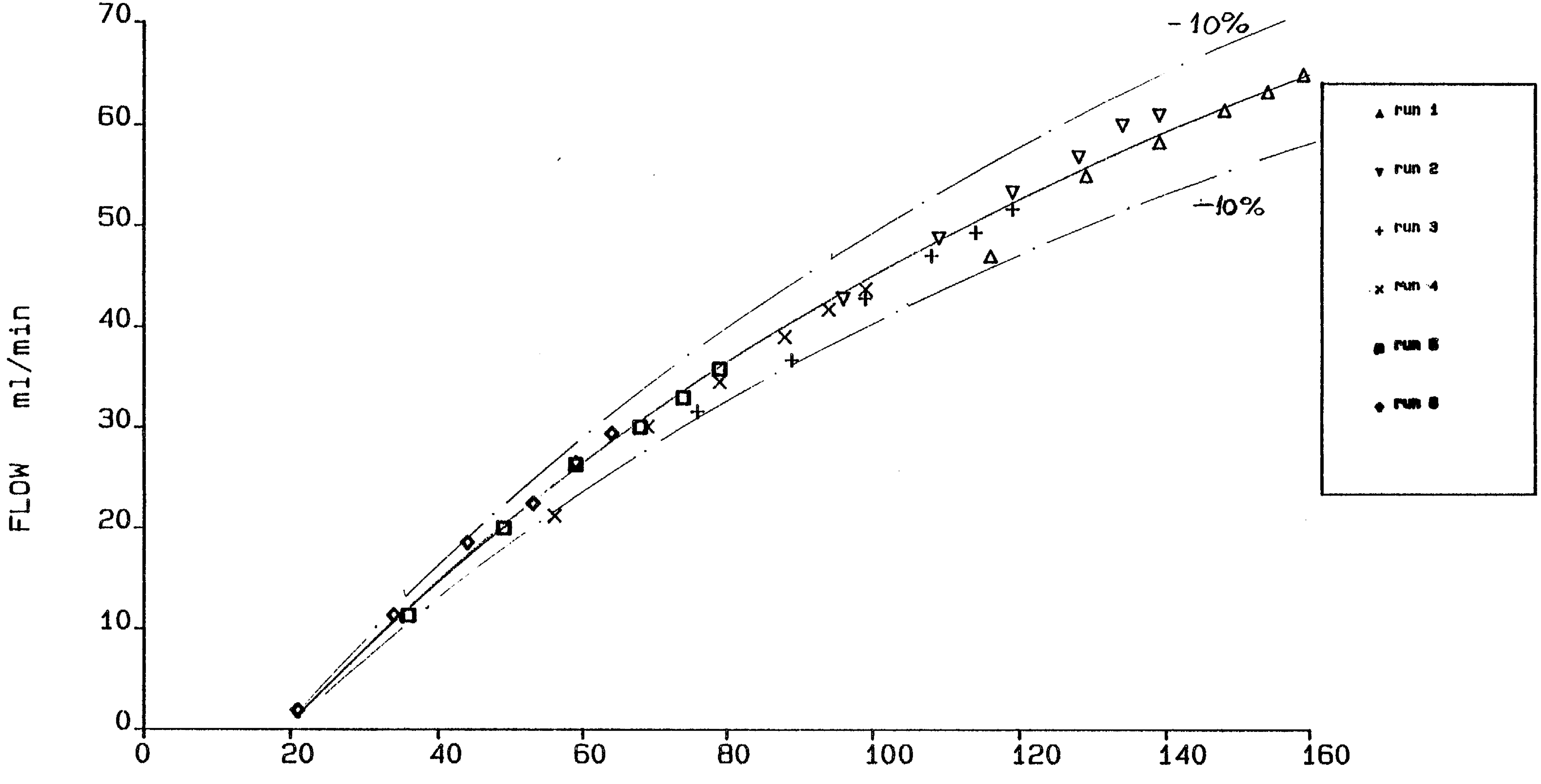
It had been reported from the field that the doser worked reliably at flows down to 1 litre/day (0.7 ml/min). It was felt that the usefulness of this simple doser would be much greater if it could be made to operate at even lower flows and so further work was done with this in view.

As a first step the capillary outlet was replaced by one of the same bore but almost twice as long, 430mm. It was bent 50mm from the end and this shorter limb made lower heads possible without reducing the minimum slope. The previous tests were repeated and the results are shown in Fig 412. They show clearly that flow stops at a threshold head of about 17mm. The first results are included on the graph to show that although the change in tube length has changed the head-flow relationship, the minimum head to obtain flow is the same in both cases.

It was felt that the cessation of flow at positive head was a result of surface tension and capillary action. A piece of this tube dipped in a beaker of water supported a column of water about 15mm high. Adding detergent to the beaker reduced the capillary head to 4mm and in the jar it was found that the minimum head for flow was 4mm. The lowest flow obtained was about 0.1 ml/min (0.14 l/d) but the results were erratic. This line of investigation was not pursued because it was not felt that adjusting surface tension would be a practical way of obtaining low flows.

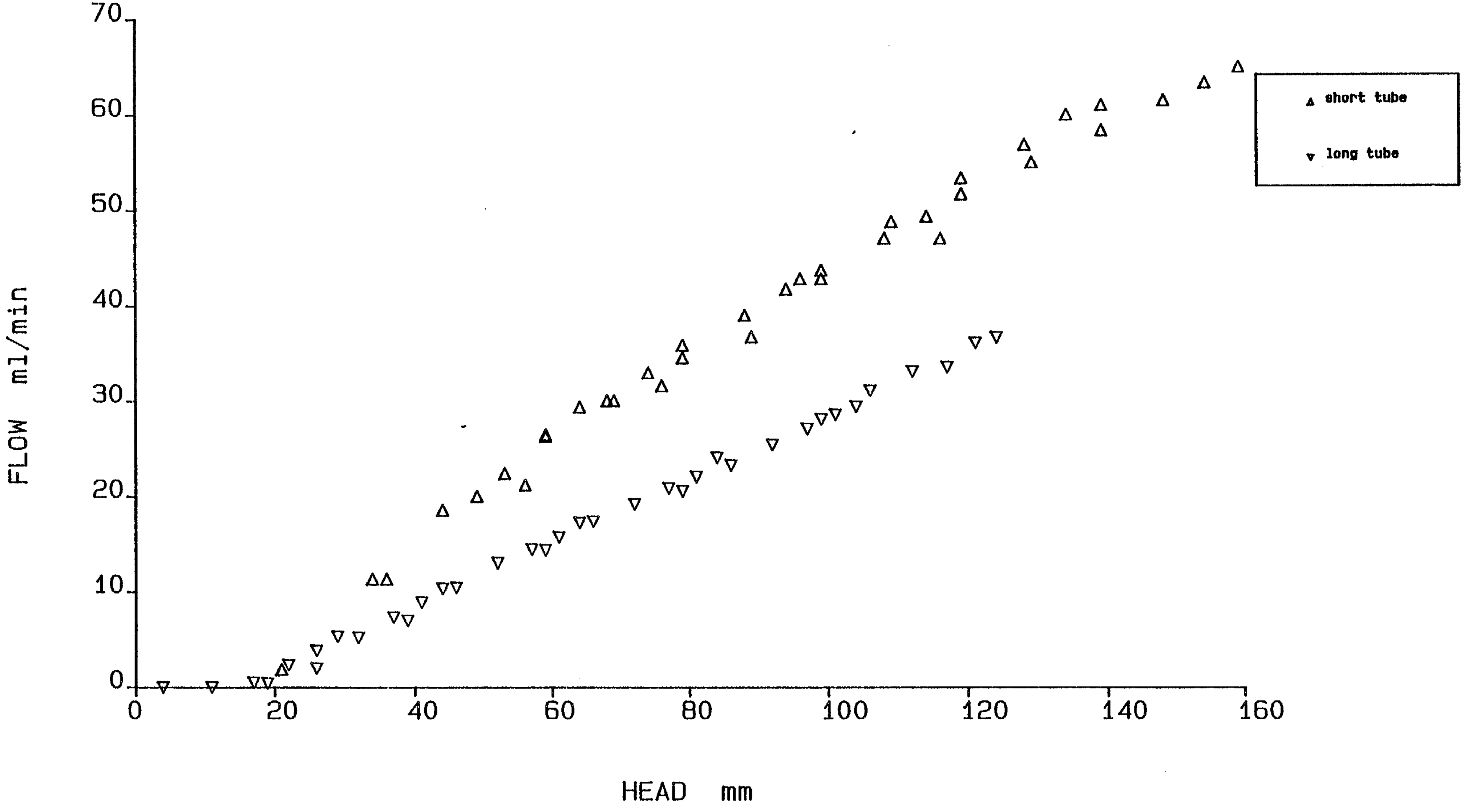
The effect of surface tension is to create a pressure difference across the surface of a developing droplet at the end of the capillary or a developing bubble at the foot of the vent tube. With no bubble the air/water interface is flat and there is no pressure difference. As a bubble starts to form the interface becomes curved and a pressure drop develops rising to a maximum when the bubble is a hemisphere at the end of the tube bore. As the bubble continues to grow its radius increases and the internal pressure drops, but it will stop growing if there is not enough pressure potential available to exceed the maximum.

Fig 4.11
MARIOTTE JAR TESTS 13-19 SEPTEMBER 1984




WARDEN 26-NOV-1986 11:10

Fig 4.12
MARIOTTE JAR TESTS SEPT 1984




WARDEN 19-NOV-1986 14:05

Several modifications were made to the capillary nozzle and the end of the vent tube to try and make droplets and bubbles at lower pressures, but with no significant success.

It was noticed during this period of intensive examination of low flow conditions that sometimes there would be a rapid bubbling of air into the jar with no corresponding discharge of liquid. This often coincided with the opening of a door and an influx of cold air to the laboratory. At other times flow would start after a long period of inactivity and water would rise in the vent tube. This could be caused by laying a warm hand on the jar. It was also realised that changes in atmospheric pressure would cause fluctuations in flow as the air in the jar responded. The effects would be more marked when the jar contained more air.

## Results and discussion

Copies of the experimental results are appended.

## Conclusions

The Mariotte Jar is an essentially simple gravity doser which is accurate and reliable enough for use on water supplies down to doses of 1 litre/day. After a series of experiments it was concluded that the unit could not be refined to operate a lower flows without losing its essential simplicity. Changes in atmospheric temperature and pressure would cause corresponding temporary fluctuations in the dose rate and so it was desirable to deliver dosed water into a reservoir having at least 12 hours' capacity.

# MARIOTTE JAR TESTS SEPTEMBER 1984

| SHORT TUBE 13-19.9.84 outlet 85mm plus 155mm horizontal | | | | | LONG TUBE 26.9.84 outlet 50mm plus 380mm horizontal | | | | |
|---|---|---|---|---|---|---|---|---|---|
| outlet | heads mm | | | flow | outlet | heads mm | | | flow |
| angle | outlet | vent | total | ml/min | angle | outlet | vent | total | ml/min |
| 90 | 85.00 | 74 | 159 | 65.00 | 90 | 50.00 | 74 | 124 | 36.58 |
| 70 | 79.87 | 74 | 154 | 63.33 | 70 | 46.98 | 74 | 121 | 36.00 |
| 60 | 73.61 | 74 | 148 | 61.50 | 60 | 43.30 | 74 | 117 | 33.47 |
| 50 | 65.11 | 74 | 139 | 58.33 | 50 | 38.30 | 74 | 112 | 33.00 |
| 40 | 54.64 | 74 | 129 | 55.00 | 40 | 32.14 | 74 | 106 | 31.00 |
| 30 | 42.50 | 74 | 116 | 47.00 | 30 | 25.00 | 74 | 99 | 28.00 |
| 90 | 85.00 | 54 | 139 | 61.00 | 90 | 50.00 | 54 | 104 | 29.33 |
| 70 | 79.87 | 54 | 134 | 60.00 | 70 | 46.98 | 54 | 101 | 28.50 |
| 60 | 73.61 | 54 | 128 | 56.83 | 60 | 43.30 | 54 | 97 | 27.00 |
| 50 | 65.11 | 54 | 119 | 53.33 | 50 | 38.30 | 54 | 92 | 25.33 |
| 40 | 54.64 | 54 | 109 | 48.75 | 40 | 32.14 | 54 | 86 | 23.20 |
| 30 | 42.50 | 54 | 96 | 42.75 | 30 | 25.00 | 54 | 79 | 20.50 |
| 90 | 85.00 | 34 | 119 | 51.66 | 90 | 50.00 | 34 | 84 | 24.00 |
| 70 | 79.87 | 34 | 114 | 49.30 | 70 | 46.98 | 34 | 81 | 22.00 |
| 60 | 73.61 | 34 | 108 | 47.00 | 60 | 43.30 | 34 | 77 | 20.80 |
| 50 | 65.11 | 34 | 99 | 42.75 | 50 | 38.30 | 34 | 72 | 19.14 |
| 40 | 54.64 | 34 | 89 | 36.66 | 40 | 32.14 | 34 | 66 | 17.33 |
| 30 | 42.50 | 34 | 76 | 31.54 | 30 | 25.00 | 34 | 59 | 14.33 |
| 90 | 85.00 | 14 | 99 | 43.66 | 90 | 50.00 | 14 | 64 | 17.20 |
| 70 | 79.87 | 14 | 94 | 41.66 | 70 | 46.98 | 14 | 61 | 15.68 |
| 60 | 73.61 | 14 | 88 | 38.95 | 60 | 43.30 | 14 | 57 | 14.40 |
| 50 | 65.11 | 14 | 79 | 34.48 | 50 | 38.30 | 14 | 52 | 13.00 |
| 40 | 54.64 | 14 | 69 | 30.00 | 40 | 32.14 | 14 | 46 | 10.42 |
| 30 | 42.50 | 14 | 56 | 21.17 | 30 | 25.00 | 14 | 39 | 7.00 |
| 90 | 85.00 | -6 | 79 | 35.81 | 90 | 50.00 | -6 | 44 | 10.33 |
| 70 | 79.87 | -6 | 74 | 32.93 | 70 | 46.98 | -6 | 41 | 8.88 |
| 60 | 73.61 | -6 | 68 | 30.00 | 60 | 43.30 | -6 | 37 | 7.33 |
| 50 | 65.11 | -6 | 59 | 26.26 | 50 | 38.30 | -6 | 32 | 5.20 |
| 40 | 54.64 | -6 | 49 | 20.00 | 40 | 32.14 | -6 | 26 | 2.00 |
| 30 | 42.50 | -6 | 36 | 11.33 | 30 | 25.00 | -6 | 19 | 0.42 |
| 90 | 85.00 | -21 | 64 | 29.33 | 90 | 50.00 | -21 | 29 | 5.33 |
| 70 | 79.87 | -21 | 59 | 26.45 | 70 | 46.98 | -21 | 26 | 3.83 |
| 60 | 73.61 | -21 | 53 | 22.40 | 60 | 43.30 | -21 | 22 | 2.33 |
| 50 | 65.11 | -21 | 44 | 18.54 | 50 | 38.30 | -21 | 17 | 0.50 |
| 40 | 54.64 | -21 | 34 | 11.33 | 40 | 32.14 | -21 | 11 | 0.00 |
| 30 | 42.50 | -21 | 21 | 1.90 | 30 | 25.00 | -21 | 4 | 0.00 |

APPENDIX 4.2 DOSATRON DISPENSER

Tests

The unit obtained for evaluation was rated as follows.

| | |
|---|---|
| maximum flow | 25 l/min |
| minimum flow | 0.5 l/min |
| maximum operating pressure | 6 bar |
| minimum operating pressure | 0.5 bar |
| dose ratio | 2 : 1000 |

The unit was installed as shown in Fig 421, taking into account the recommendation of the suppliers that it should be installed in an upright position with the solution container normally below the unit but raised to give a positive head of 10-15cm while priming. A filter was fitted at the end of the inlet tube to prevent ingress of any solid particle which may damage the unit or its seals.

The first test was to pass water at 15 l/min and 2.5 bar pressure through the unit and measure the volume dosed in 3 minutes. It was noted that the dose ratio was 3.77:1000; a dose 88% larger than specified. This placed the unit within 30% of the one next larger rated at 5:1000 and the suppliers suggested that perhaps the wrong dosing plunger may have been fitted during assembly. The plunger was measured and found to be the correct size. The dose ratio was checked at other flows from 0.5 l/min to 25 l/min and was found to vary from 2.8:1000 to 4:1000. It was felt that perhaps this unit was not typical and it was exchanged for another.

In the first series of tests the solution level was kept 25cm below the doser and the flow was varied in stages up to 25 l/min at line pressures of 1, 2 and 3 bar. In each test a note was made of the volume drawn from the dosing cylinder in a measured time and the stroking rate of the piston. Since line pressure appeared to have no effect on performance, this was not varied in other tests. Later in the series the flow was raised to 30 l/min; above the rating of the unit.

In the second series of tests the height of the dosing cylinder was altered. When this was completed the pressure loss was measured using a mercury manometer connected across the doser while the flow was varied. Finally the doser was run continuously for two weeks at a steady flow.

Results and discussion

The test results are given on pages 4.2.7 and 4.2.8. For all measurements except those for pressure drop it was possible to calculate the actual dose delivered per stroke of the unit and also the ratio of dose to flow in parts per thousand (or ml per litre).

Fig 422 shows a plot of all measurements of stroke rate against flow. They appear to lie on a straight line with a positive intercept although in fact at lower flows the points depart from the straight line and indicate that stroking would cease at some small positive flow. This point was not investigated in detail although it was noted that there was no dosing at a flow of 0.5 l/min. The inverse slope of the curve is a measure of the volume of flow required to drive the pump by one stroke. The slope of the straight part indicates a volume of 500 ml per stroke and this is supported by measurements of the bore and stroke length. There seems to be no explanation for the positive intercept except that the flowmeter was not correctly zeroed.

Fig 423 shows that the delivery per stroke of the dosing piston was steady at all values of flow where the inlet head was 25cm negative.

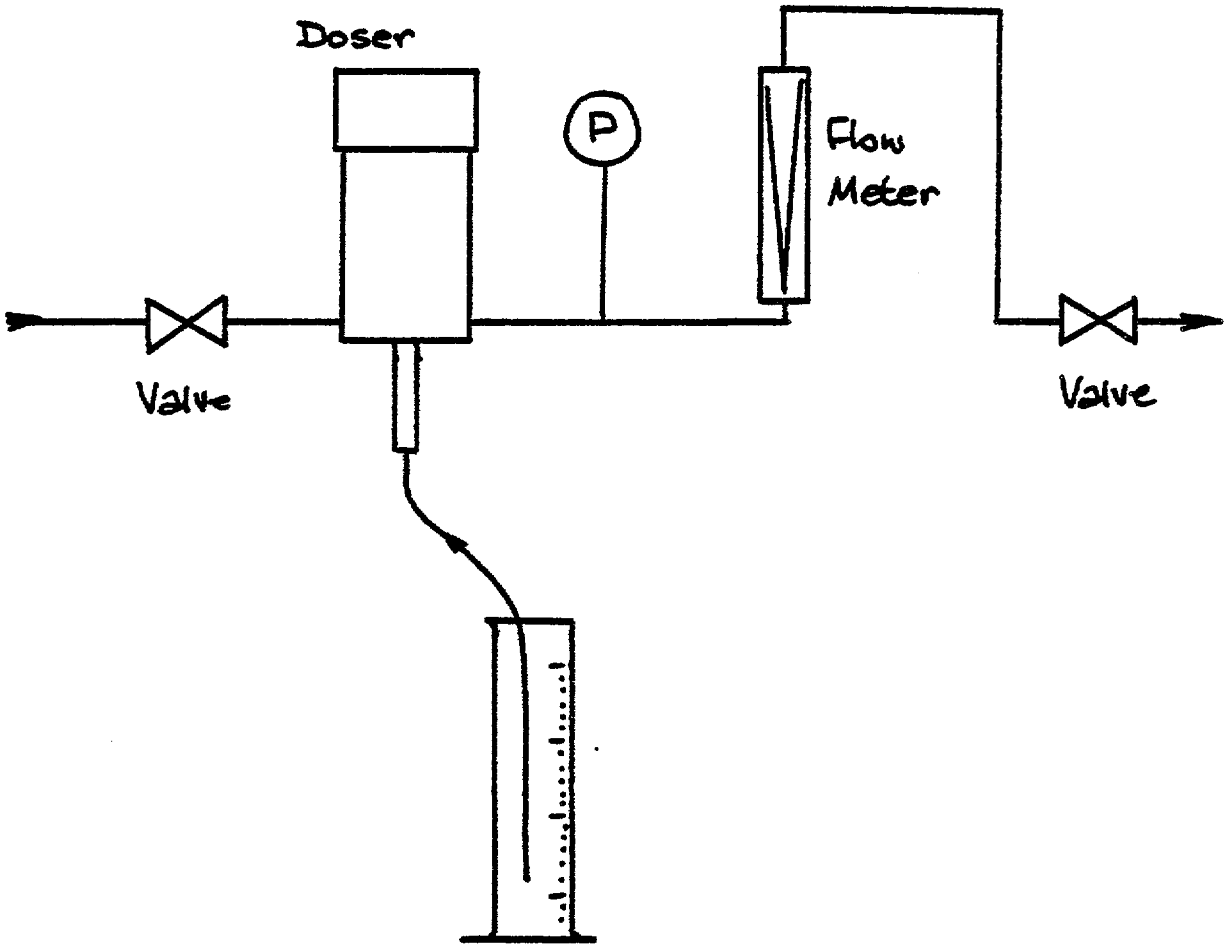
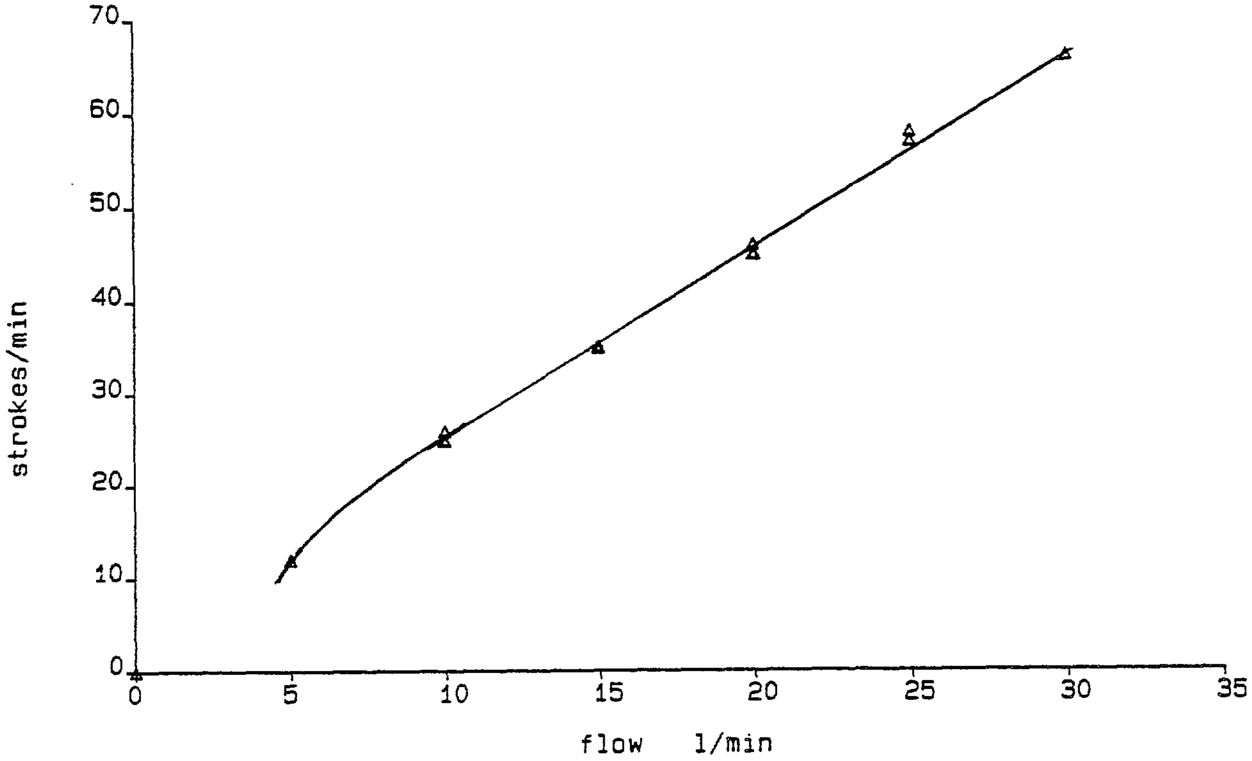



Fig 421

Fig 422 DOSATRON TESTS FEB 1984




WARDEN 5-DEC-1986 15: 47

Fig 423 DOSATRON TESTS FEB 1984

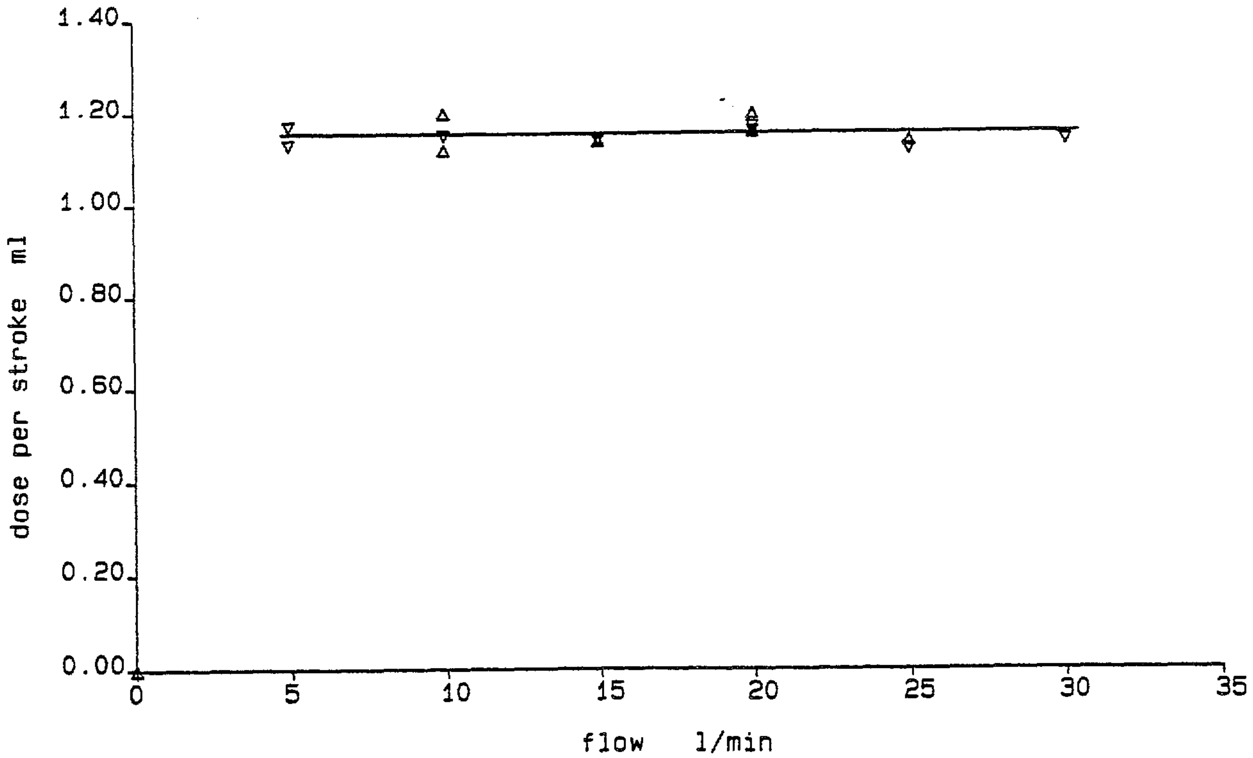


Fig 424 combines the two previous figures to report dose ratio in ml/litre of flow against flow. It follows the form described for the volume of flow per stroke with a slight decline at higher flows but an overall range within 10% of the mean.

Fig 425 reports two sets of data from the tests where the dosing cylinder level was varied. The results show some scatter but no general variation of dose with head from 100cm negative to 50cm positive.

Finally, Fig 426 shows pressure drop across the unit related to flow and the two points claimed by the makers; 0.4 bar at 1 l/min and 1.2 bar at 20 l/min. Actual pressure losses were lower.

## Conclusions

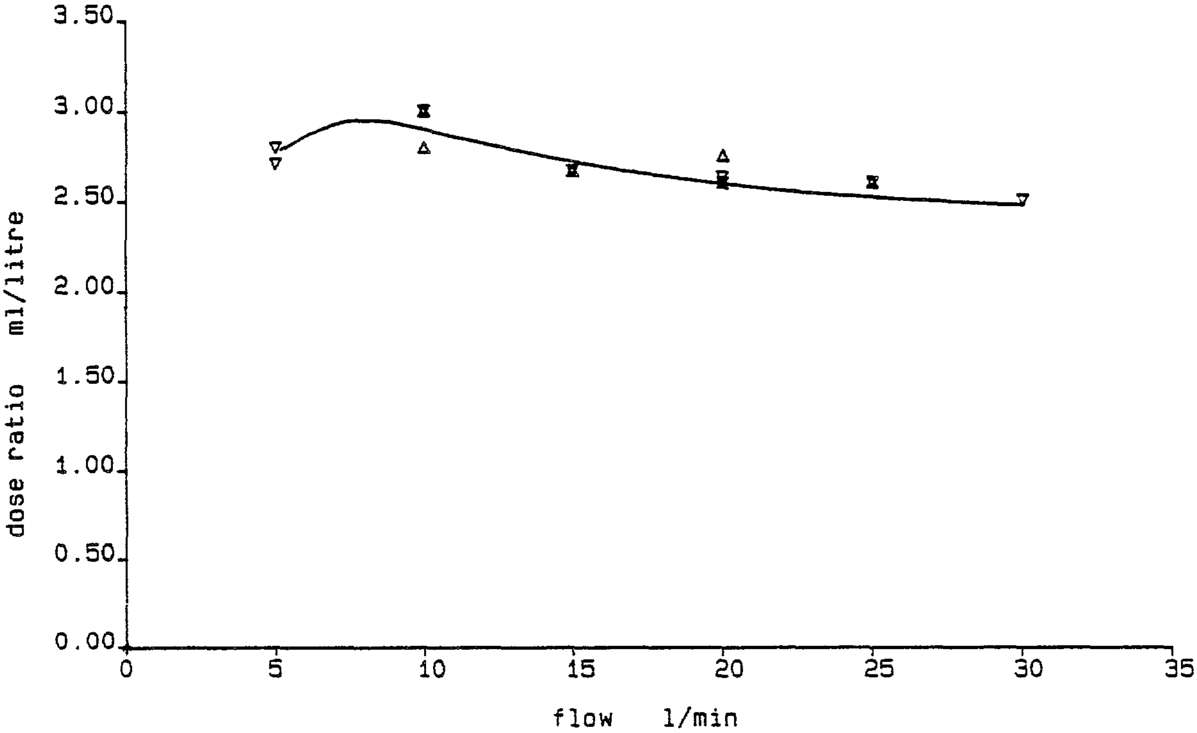
The WRc draft specification for hypochlorite dosers for drinking water treatment calls for units to dose to an accuracy within 10% of their mean and to be able to maintain this performance for an unattended period of two weeks. The doser tested met this requirement with a margin to spare. Nevertheless unit is considered not to be fully satisfactory for the following reasons.

1. Although the unit tested was consistent and maintained accuracy, the dose, which averaged about 2.6 ml/litre was 30% higher than the rating of the unit. The first unit tested dosed 88% high. This suggests a wide range of variation between units.

2. The dose rate is not adjustable except by changing the concentration of the hypochlorite. This is not acceptable for general use especially when, should a unit be replaced, there is a risk that the new unit will give a significantly different dose.

3. Slight misalignment of the unit from vertical could cause heavy wear of the seals and rapid deterioration of performance in a two-week period.

Fig 424 DOSATRON TESTS FEB 1984




WARDEN 8-DEC-1986 11:34

Fig 425 DOSATRON TESTS FEB 1984

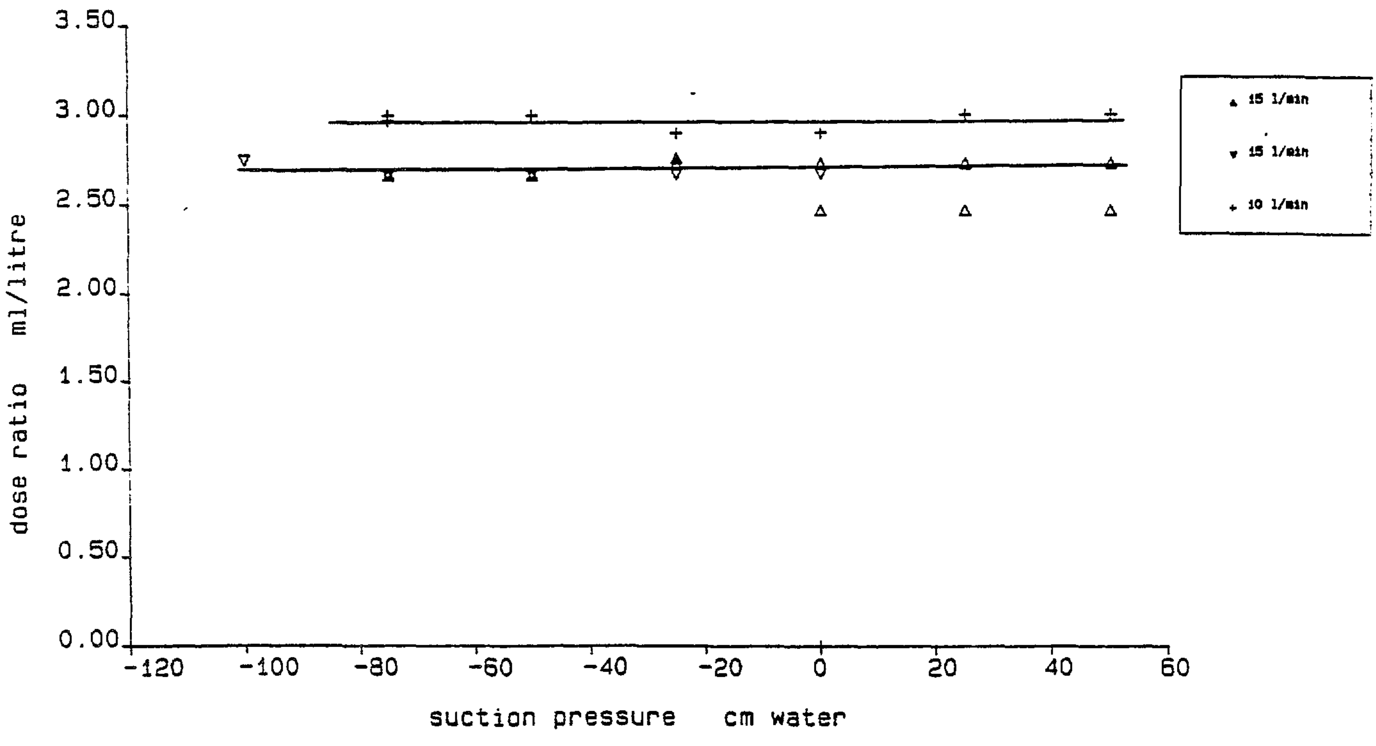
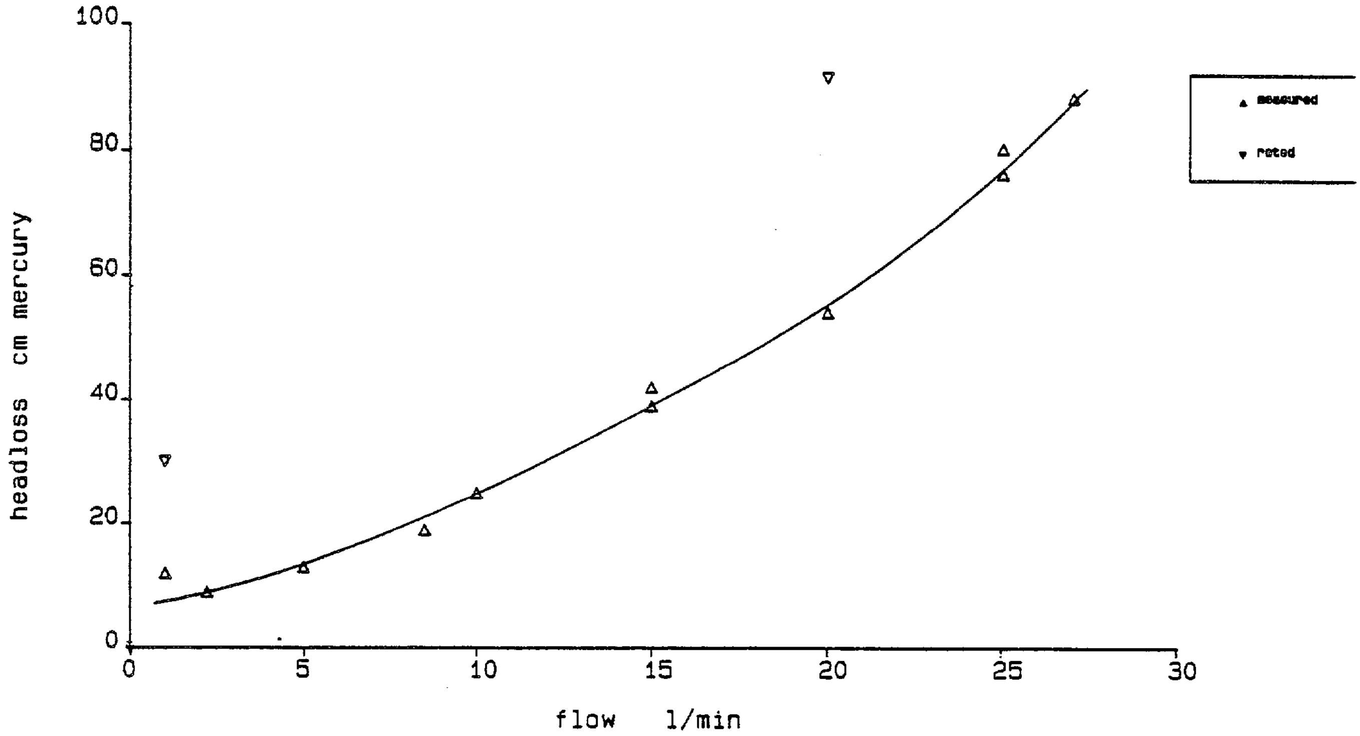


Fig 4.2.6 DOSATRON TESTS FEB 1984




WARDEN 8-DEC-1986 11:55

DOSATRON TESTS FEB 1984

| | | suct | R E A D I N G S | | | dose | dose | |
|---|---|---|---|---|---|---|---|---|
| l/min | P bar | head | dose | mins | stk/m | ml/sk | :1000 | |
| 25 | 1 | -25 | 65 | 1 | 57 | 1.14 | 2.60 | Feb 7th |
| 25 | 1 | -25 | 65 | 1 | 57 | 1.14 | 2.60 | Varying flow and |
| 20 | 1 | -25 | 55 | 1 | 46 | 1.20 | 2.75 | line pressure |
| 20 | 1 | -25 | 55 | 1 | 46 | 1.20 | 2.75 | |
| 15 | 1 | -25 | 40 | 1 | 35 | 1.14 | 2.67 | |
| 15 | 1 | -25 | 40 | 1 | 35 | 1.14 | 2.67 | |
| 10 | 1 | -25 | 30 | 1 | 25 | 1.20 | 3.00 | |
| 10 | 1 | -25 | 30 | 1 | 25 | 1.20 | 3.00 | |
| 25 | 2 | -25 | 65 | 1 | 57 | 1.14 | 2.60 | |
| 25 | 2 | -25 | 65 | 1 | 57 | 1.14 | 2.60 | |
| 20 | 2 | -25 | 55 | 1 | 46 | 1.20 | 2.75 | |
| 20 | 2 | -25 | 55 | 1 | 46 | 1.20 | 2.75 | |
| 15 | 2 | -25 | 40 | 1 | 35 | 1.14 | 2.67 | |
| 15 | 2 | -25 | 40 | 1 | 35 | 1.14 | 2.67 | |
| 10 | 2 | -25 | 28 | 1 | 25 | 1.12 | 2.80 | |
| 10 | 2 | -25 | 28 | 1 | 25 | 1.12 | 2.80 | |
| 25 | 3 | -25 | 65 | 1 | 57 | 1.14 | 2.60 | |
| 25 | 3 | -25 | 65 | 1 | 57 | 1.14 | 2.60 | |
| 20 | 3 | -25 | 52 | 1 | 45 | 1.16 | 2.60 | |
| 20 | 3 | -25 | 52 | 1 | 45 | 1.16 | 2.60 | |
| 15 | 3 | -25 | 40 | 1 | 35 | 1.14 | 2.67 | |
| 15 | 3 | -25 | 40 | 1 | 35 | 1.14 | 2.67 | |
| 10 | 3 | -25 | 30 | 1 | 25 | 1.20 | 3.00 | |
| 10 | 3 | -25 | 30 | 1 | 25 | 1.20 | 3.00 | |
| | | | | | | | | |
| 15 | 2 | -50 | 40 | 1 | 35 | 1.14 | 2.67 | Varying suction |
| 15 | 2 | -50 | 40 | 1 | 35 | 1.14 | 2.67 | head |
| 15 | 2 | 0 | 37 | 1 | 35 | 1.06 | 2.47 | |
| 15 | 2 | 0 | 37 | 1 | 35 | 1.06 | 2.47 | |
| 15 | 2 | 25 | 37 | 1 | 35 | 1.06 | 2.47 | |
| 15 | 2 | 25 | 37 | 1 | 35 | 1.06 | 2.47 | |
| 15 | 2 | 50 | 37 | 1 | 35 | 1.06 | 2.47 | |
| 15 | 2 | 50 | 37 | 1 | 35 | 1.06 | 2.47 | |
| 15 | 2 | -75 | 120 | 3 | 35 | 1.14 | 2.67 | Feb 22nd,23rd |
| 15 | 2 | -75 | 120 | 3 | 35 | 1.14 | 2.67 | |
| 15 | 2 | -50 | 120 | 3 | 35 | 1.14 | 2.67 | |
| 15 | 2 | -50 | 120 | 3 | 35 | 1.14 | 2.67 | |
| 15 | 2 | -25 | 124 | 3 | 35 | 1.18 | 2.76 | |
| 15 | 2 | -25 | 123 | 3 | 35 | 1.17 | 2.73 | |
| 15 | 2 | 0 | 123 | 3 | 35 | 1.17 | 2.73 | |
| 15 | 2 | 0 | 123 | 3 | 35 | 1.17 | 2.73 | |
| 15 | 2 | 25 | 123 | 3 | 35 | 1.17 | 2.73 | |
| 15 | 2 | 25 | 123 | 3 | 35 | 1.17 | 2.73 | |
| 15 | 2 | 50 | 123 | 3 | 35 | 1.17 | 2.73 | |
| 10 | 2 | 50 | 90 | 3 | 25 | 1.20 | 3.00 | |
| 10 | 2 | 50 | 90 | 3 | 25 | 1.20 | 3.00 | |
| 10 | 2 | 25 | 90 | 3 | 25 | 1.20 | 3.00 | |
| 10 | 2 | 25 | 90 | 3 | 25 | 1.20 | 3.00 | |
| 10 | 2 | 0 | 87 | 3 | 25 | 1.16 | 2.90 | |
| 10 | 2 | 0 | 87 | 3 | 25 | 1.16 | 2.90 | |
| 10 | 2 | -25 | 87 | 3 | 25 | 1.16 | 2.90 | |
| 10 | 2 | -25 | 87 | 3 | 25 | 1.16 | 2.90 | |
| 10 | 2 | -50 | 90 | 3 | 25 | 1.20 | 3.00 | |
| 10 | 2 | -50 | 90 | 3 | 25 | 1.20 | 3.00 | |
| 10 | 2 | -75 | 180 | 6 | 25 | 1.20 | 3.00 | |
| 10 | 2 | -75 | 535 | 18 | 25 | 1.19 | 2.97 | |

| l/min | P bar | suct head | R E A D I N G S dose | mins | /min | dose ml/sk | dose :1000 | |
|---|---|---|---|---|---|---|---|---|
| 20 | 2 | -75 | 155 | 3 | 45 | 1.15 | 2.58 | |
| 20 | 2 | -75 | 155 | 3 | 45 | 1.15 | 2.58 | |
| 20 | 2 | -50 | 155 | 3 | 45 | 1.15 | 2.58 | |
| 20 | 2 | -50 | 205 | 4 | 45 | 1.14 | 2.56 | |
| 20 | 2 | -25 | 155 | 3 | 45 | 1.15 | 2.58 | |
| 20 | 2 | -25 | 155 | 3 | 45 | 1.15 | 2.58 | |
| 20 | 2 | 0 | 420 | 8 | 45 | 1.17 | 2.63 | |
| 20 | 2 | 0 | 205 | 4 | 45 | 1.14 | 2.56 | |
| 20 | 2 | 25 | 155 | 3 | 45 | 1.15 | 2.58 | |
| 20 | 2 | 25 | 155 | 3 | 45 | 1.15 | 2.58 | |
| 20 | 2 | 50 | 420 | 8 | 45 | 1.17 | 2.63 | |
| 20 | 2 | 50 | 420 | 8 | 45 | 1.17 | 2.63 | |
| 15 | 2 | -25 | 120 | 3 | 35 | 1.14 | 2.67 | Feb 23rd |
| 15 | 2 | -25 | 120 | 3 | 35 | 1.14 | 2.67 | |
| 15 | 2 | -50 | 120 | 3 | 35 | 1.14 | 2.67 | |
| 15 | 2 | -50 | 120 | 3 | 35 | 1.14 | 2.67 | |
| 15 | 2 | -75 | 120 | 3 | 35 | 1.14 | 2.67 | |
| 15 | 2 | -75 | 120 | 3 | 35 | 1.14 | 2.67 | |
| 15 | 2 | -100 | 165 | 4 | 35 | 1.18 | 2.75 | |
| 15 | 2 | -100 | 165 | 4 | 35 | 1.18 | 2.75 | |
| 15 | 2 | 0 | 400 | 10 | 35 | 1.14 | 2.67 | |
| 15 | 2 | 0 | 400 | 10 | 35 | 1.14 | 2.67 | |
| 30 | 2 | -25 | 150 | 2 | 66 | 1.14 | 2.50 | Varying flow |
| 30 | 2 | -25 | 150 | 2 | 66 | 1.14 | 2.50 | |
| 25 | 2 | -25 | 130 | 2 | 58 | 1.12 | 2.60 | |
| 25 | 2 | -25 | 130 | 2 | 58 | 1.12 | 2.60 | |
| 20 | 2 | -25 | 525 | 10 | 45 | 1.17 | 2.63 | |
| 20 | 2 | -25 | 260 | 5 | 45 | 1.16 | 2.60 | |
| 15 | 2 | -25 | 80 | 2 | 35 | 1.14 | 2.67 | |
| 15 | 2 | -25 | 160 | 4 | 35 | 1.14 | 2.67 | |
| 10 | 2 | -25 | 150 | 5 | 26 | 1.15 | 3.00 | |
| 10 | 2 | -25 | 90 | 3 | 26 | 1.15 | 3.00 | |
| 5 | 2 | -25 | 70 | 5 | 12 | 1.17 | 2.80 | |
| 5 | 2 | -25 | 380 | 28 | 12 | 1.13 | 2.71 | |

| l/min | P bar | l leg | r leg | head | |
|---|---|---|---|---|---|
| 27 | 1 | 9 | 97 | 88 | Apl 2nd Pressure loss measurements |
| 25 | 1 | 11 | 87 | 76 | |
| 25 | 1 | 13 | 93 | 80 | |
| 20 | 1 | 26 | 80 | 54 | |
| 15 | 1 | 39 | 81 | 42 | |
| 15 | 1 | 34 | 73 | 39 | |
| 10 | 1 | 41 | 66 | 25 | |
| 5 | 1 | 47 | 60 | 13 | |
| 5 | 1 | 47 | 60 | 13 | |
| 2.2 | 1 | 50 | 59 | 9 | |
| 1 | 1 | 48 | 60 | 12 | |
| 8.5 | 1 | 45 | 64 | 19 | |

APPENDIX 4.3 THE SCHUCO PERISTALTIC PUMP

Tests

The pump obtained for evaluation was rated as follows.

| Tube Bore (mm) | Minimum Flow (3V supply) (ml/min) | Maximum Flow (12v supply) (ml/min) |
|---|---|---|
| 1.0 | 0.2 | 2.0 |
| 2.5 | 1.5 | 12.0 |
| 5.0 | 3.5 | 38.5 |

Maximum back pressure is 0.34bar.

The pump was installed in the laboratory with a 12V car battery as the power source, an arrangement commonly used in the field.

In the first test the delivery of the pump was measured over the supply voltage range, 3-12V, for each of the three tube sizes. Inlet and delivery heads were both set as close as possible to zero.

The second test investigated how delivery was effected by increasing the back pressure from atmospheric to 0.7bar, twice the rated pressure. The pump was operated at its maximum speed and the inlet head set at -0.25mwg.

For the next test the inlet head was varied from -1mwg to +1mwg while back pressure was kept constant at 0bar. The pump was again operated at its maximum speed.

Finally, the pump was left running at maximum speed over a period of several weeks. During this time delivery was monitored and the durability of the pump components observed.

Results and Discussion

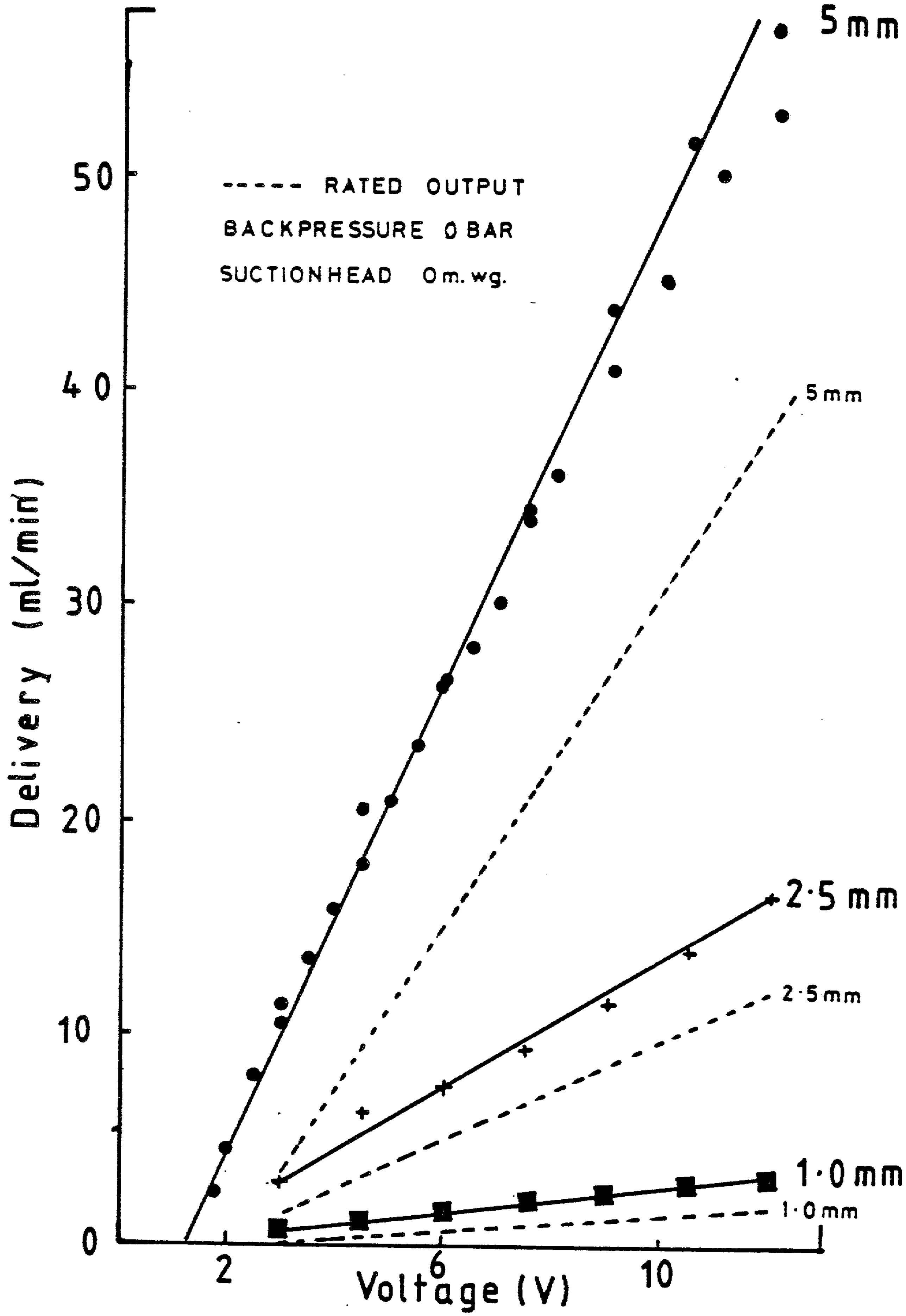
A complete table of experimental results is appended.

Pump delivery exceeds that that specified by the manufacturer for all sizes of tube and at all voltages (Fig 1). The increase of delivery with voltage is linear.

Delivery is only affected by back pressure when a 5mm tube is used (Fig.2), declining by 10% as the back pressure increases over the rated range of 0-0.34bar. A greater inlet head results in a higher delivery (Fig 3) when either a 5mm or a 2.5mm is used, but does not have a noticable effect when a 1mm tube is fitted. This reflects the relative stiffness of the smaller tube.

Variation in delivery over the life of a tube is small, within +/- 10%. Tube life can vary quite significantly, anything from 1 week to 3 weeks of continuous operation; longer life is achieved by lubricating the tube. Fig 4 shows delivery over a 16 day period. At the end of its life the tube lost its suppleness and developed a longtitudinal split, usually resulting in total loss of delivery. Delivery seemed to increase as the tube neared the end of its life perhaps because the tube wall began to break down.

Running from an 18Ah capacity car battery the pump will run for 3-4 weeks before it begins to slow down.



----- RATED OUTPUT
BACKPRESSURE 0 BAR
SUCTIONHEAD 0m.wg.
5mm
5mm
2·5 mm
2·5mm
1·0 mm
1·0mm
Delivery (ml/min)
0
10
20
30
40
50
2
6
10
Voltage (V)

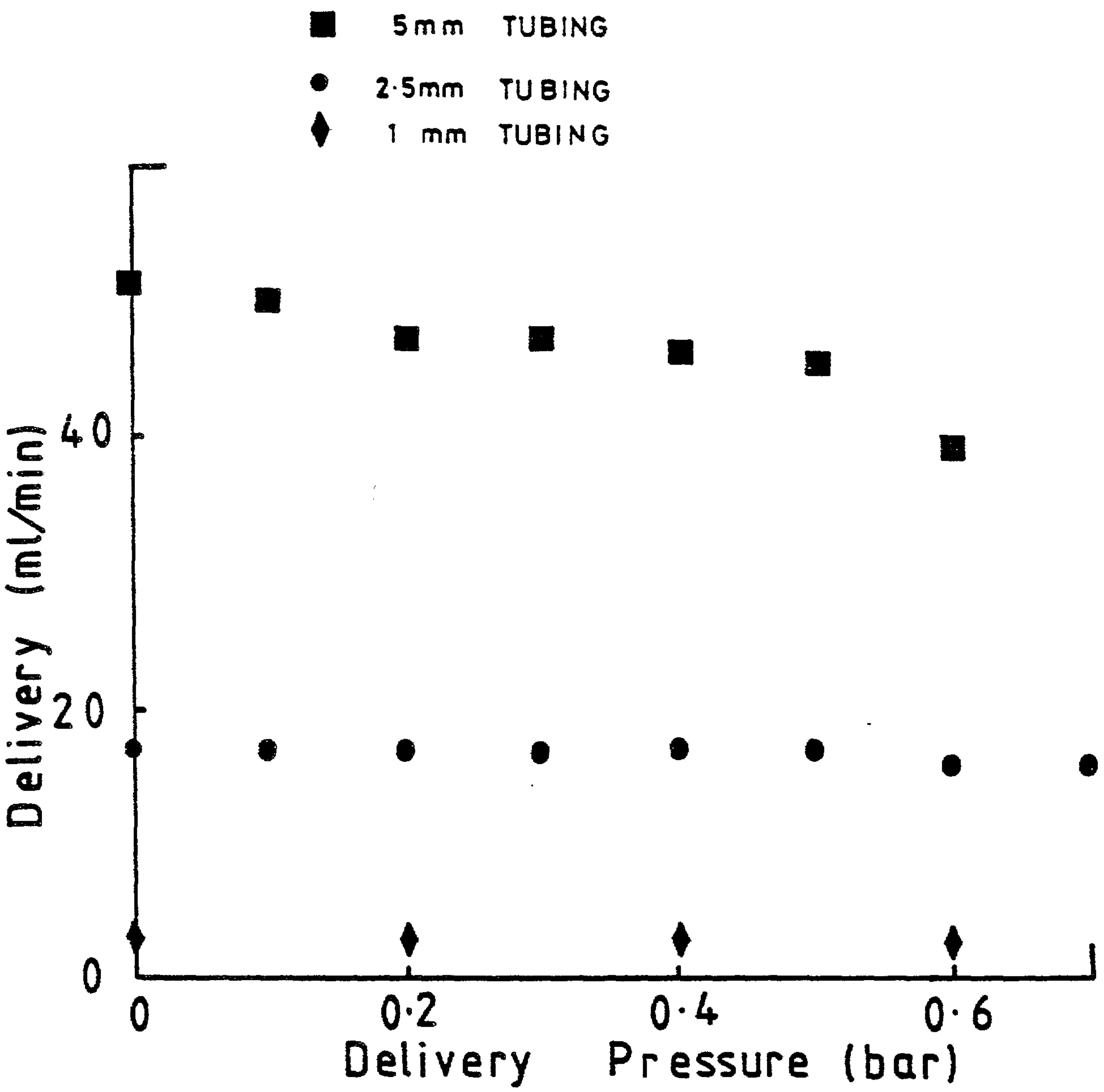

5mm TUBING
2·5mm TUBING
1 mm TUBING
Delivery (ml/min)
40
20
0
0
0·2
0·4
0·6
Delivery Pressure (bar)

Fig 4.3.2

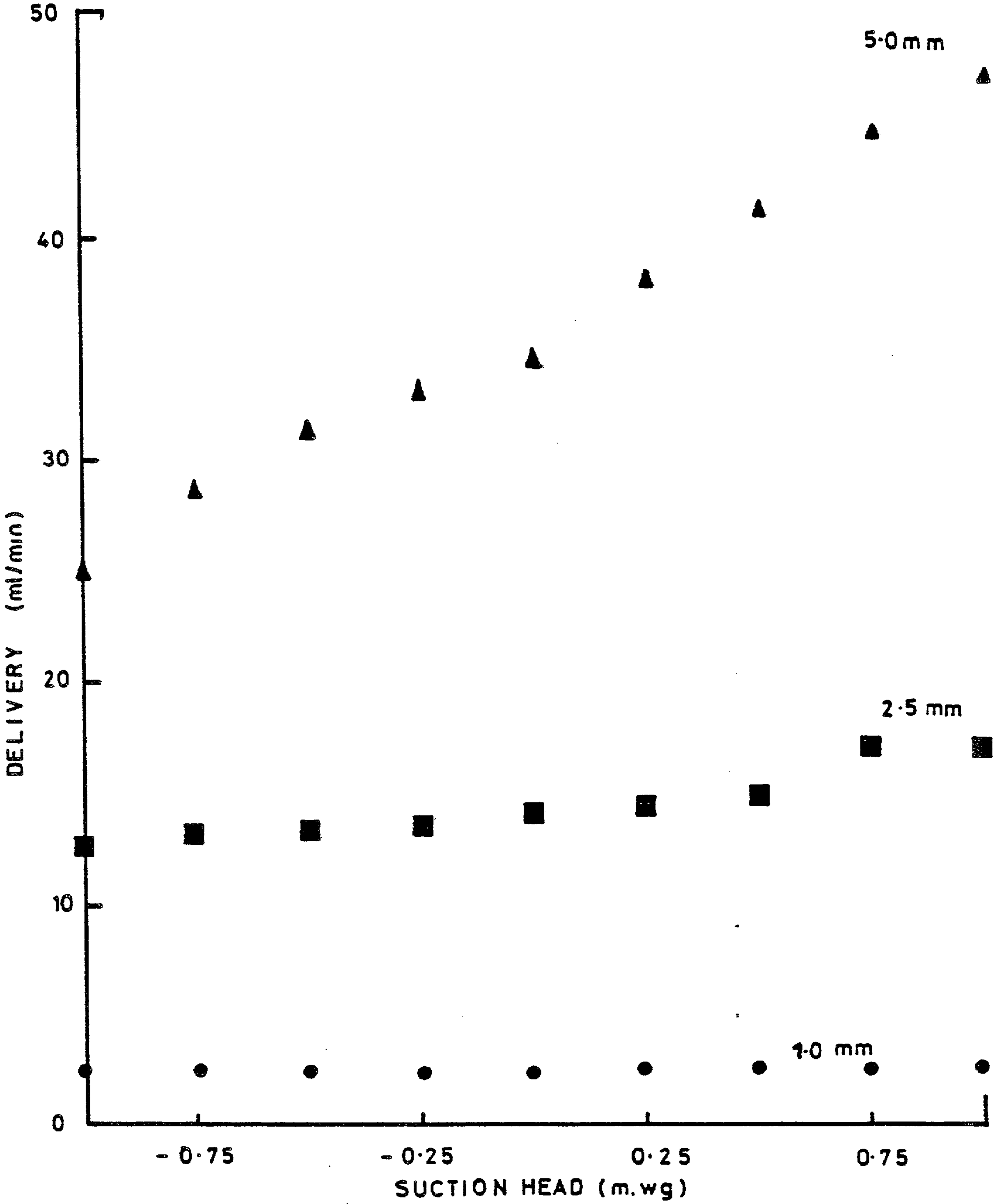



Figure 4.33 Influence of Suction Head

## Conclusions

This simple and inexpensive pump is satisfactory for use on small water supplies provided the limitations on pressure and inlet head are recognised.

Ideally, back pressure should not exceed the advertised maximum of 5psi. Although the pump will deliver against pressures up to double this, the adverse effect on performance becomes significant, particularly when 5mm tubing is fitted.

It would be a sensible precaution always to mount the pump on a higher level than the solution container (to minimise leakage in the event of tube failure). The maximum inlet head to the bottom of the container should be no more than 1m, or 0.5m if 5mm tubing is fitted.

Since the effect of tube failure is to stop dosing completely, the tube should be renewed at least fortnightly, preferably weekly, and greased when fitted.

The pump can be satisfactorily operated from a car battery where mains power is not available. Speed control can be achieved simply by connecting a variable resistor in series with the motor, although energy will be conserved by the use of an electronic voltage-reducing circuit.

SCHUCO PUMP TESTS 3SCH.DAT APRIL 84

| OUTPUT ml/min | TUBE DIAMETER mm | VOLTS |
|---|---|---|
| 0.84 | 1 | 3.0 |
| 1.28 | 1 | 4.5 |
| 1.72 | 1 | 6.0 |
| 2.20 | 1 | 7.5 |
| 2.60 | 1 | 9.0 |
| 3.04 | 1 | 10.5 |
| 3.40 | 1 | 12.0 |
| 3.04 | 1 | 10.5 |
| 2.60 | 1 | 9.0 |
| 2.20 | 1 | 7.5 |
| 1.72 | 1 | 6.0 |
| 1.28 | 1 | 4.5 |
| 0.80 | 1 | 3.0 |
| | | |
| 10.00 | 5 | 3.0 |
| 18.00 | 5 | 4.5 |
| 26.33 | 5 | 6.0 |
| 34.50 | 5 | 7.5 |
| 43.75 | 5 | 9.0 |
| 51.66 | 5 | 10.5 |
| 57.00 | 5 | 12.0 |
| 51.25 | 5 | 10.5 |
| 43.12 | 5 | 9.0 |
| 35.00 | 5 | 7.5 |
| 27.00 | 5 | 6.0 |
| 18.66 | 5 | 4.5 |
| 10.33 | 5 | 3.0 |
| | | |
| 3.00 | 2.5 | 3.0 |
| 5.12 | 2.5 | 4.5 |
| 7.50 | 2.5 | 6.0 |
| 9.33 | 2.5 | 7.5 |
| 11.56 | 2.5 | 9.0 |
| 14.00 | 2.5 | 10.5 |
| 16.66 | 2.5 | 12.0 |
| 14.00 | 2.5 | 10.5 |
| 11.80 | 2.5 | 9.0 |
| 9.57 | 2.5 | 7.5 |
| 7.57 | 2.5 | 6.0 |
| 5.37 | 2.5 | 4.5 |
| 3.08 | 2.5 | 3.0 |

| BACK PRESSURE barg | OUTPUT ml/min | TUBE DIAMETER (mm) |
|---|---|---|
| 1.0 | 14.00 | 2.5 |
| 0.9 | 16.25 | 2.5 |
| 0.8 | 16.25 | 2.5 |
| 0.7 | 16.25 | 2.5 |
| 0.6 | 16.25 | 2.5 |
| 0.5 | 17.00 | 2.5 |
| 0.4 | 17.00 | 2.5 |
| 0.3 | 17.00 | 2.5 |
| 0.2 | 17.00 | 2.5 |
| 0.1 | 17.00 | 2.5 |
| 0.0 | 17.00 | 2.5 |
| | | |
| 0.6 | 39.00 | 5 |
| 0.5 | 45.00 | 5 |
| 0.4 | 46.00 | 5 |
| 0.3 | 47.00 | 5 |
| 0.2 | 47.00 | 5 |
| 0.1 | 50.00 | 5 |
| 0.0 | 51.00 | 5 |
| | | |
| 1.0 | 1.23 | 1 |
| 1.0 | 1.20 | 1 |
| 1.0 | 1.23 | 1 |
| 0.8 | 2.25 | 1 |
| 0.8 | 2.25 | 1 |
| 0.6 | 3.00 | 1 |
| 0.6 | 3.00 | 1 |
| 0.4 | 3.30 | 1 |
| 0.4 | 3.30 | 1 |
| 0.2 | 3.35 | 1 |
| 0.2 | 3.35 | 1 |
| 0.0 | 3.40 | 1 |
| 0.0 | 3.40 | 1 |

| INLET HEAD m.wg | OUTPUT ml/min | TUBE DIAMETER mm |
|---|---|---|
| -1.00 | 2.35 | 1 |
| -1.00 | 2.35 | 1 |
| -0.75 | 2.38 | 1 |
| -0.75 | 2.38 | 1 |
| -0.50 | 2.33 | 1 |
| -0.50 | 2.33 | 1 |
| -0.25 | 2.25 | 1 |
| -0.25 | 2.21 | 1 |
| 0.00 | 2.28 | 1 |
| 0.00 | 2.38 | 1 |
| 0.25 | 2.47 | 1 |
| 0.25 | 2.52 | 1 |
| 0.50 | 2.44 | 1 |
| 0.50 | 2.50 | 1 |
| 0.75 | 2.41 | 1 |
| 0.75 | 2.40 | 1 |
| 1.00 | 2.37 | 1 |
| 1.00 | 2.66 | 1 |
| | | |
| -1.00 | 12.75 | 2.5 |
| -1.00 | 12.75 | 2.5 |
| -0.75 | 13.30 | 2.5 |
| -0.75 | 13.28 | 2.5 |
| -0.50 | 13.66 | 2.5 |
| -0.50 | 13.57 | 2.5 |
| -0.25 | 13.80 | 2.5 |
| -0.25 | 13.80 | 2.5 |
| 0.00 | 14.00 | 2.5 |
| 0.00 | 14.00 | 2.5 |
| 0.25 | 14.40 | 2.5 |
| 0.25 | 14.33 | 2.5 |
| 0.50 | 14.80 | 2.5 |
| 0.50 | 14.80 | 2.5 |
| 0.75 | 17.00 | 2.5 |
| 0.75 | 17.00 | 2.5 |
| 1.00 | 17.00 | 2.5 |
| 1.00 | 16.80 | 2.5 |
| | | |
| -1.00 | 26.66 | 5 |
| -1.00 | 23.33 | 5 |
| -0.75 | 28.66 | 5 |
| -0.75 | 28.66 | 5 |
| -0.50 | 31.33 | 5 |
| -0.50 | 31.50 | 5 |
| -0.25 | 33.00 | 5 |
| -0.25 | 33.00 | 5 |
| 0.00 | 34.50 | 5 |
| 0.00 | 34.50 | 5 |
| 0.25 | 38.00 | 5 |
| 0.25 | 38.00 | 5 |
| 0.50 | 41.00 | 5 |
| 0.50 | 41.00 | 5 |
| 0.75 | 44.50 | 5 |
| 0.75 | 44.50 | 5 |
| 1.00 | 47.00 | 5 |
| 1.00 | 47.00 | 5 |

| TIME days | OUTPUT ml/min | NOTES |
|---|---|---|
| 0 | 3.57 | 1mm tube |
| 1 | 3.71 | |
| 2 | 4.00 | |
| 2 | 3.95 | |
| 2 | 3.95 | |
| 5 | | Tube failure,replacement |
| 5 | 3.70 | |
| 6 | 3.70 | |
| 7 | 4.31 | |
| 13 | | Tube failure,replacement |
| 13 | 3.25 | |
| 14 | 3.37 | |
| 15 | 3.63 | |
| 19 | | Tube failure |

APPENDIX 4.4 ARAGONITE PROPORTIONAL FEEDER

Tests

The Aragonite Proportional Feeder was supplied free of charge by MSR GmbH for reevaluation. An earlier unit tested by WRc had not functioned well but on examination it was found to have been fitted with an incorrect spring.

Manufacturer's Information
Four models of the feeder are available (July 1986) with dose ranging from 0.025 ml/l to 7.5 ml/l. The feeder provided for evaluation was model H305D0.4, serial number 861194, rated as follows:-

| | |
|---|---|
| Maximum flow rate | 83 l/min |
| Minimum flow rate | 2 l/min |
| Range of adjustment(dose) | 0.025 ml/l to 0.4 ml/l |
| Self priming,maximum height | 3 m |
| Maximum pressure loss | 1 bar |
| Maximum working temperature | 60°C |

The manufacturer claims that delivery of dosing solution is in proportion to water flow rate and that adjustment is precise and progressive.

Experimental Programme
The feeder was installed as shown in Fig 441. The filter was provided to remove particulate matter, which could damage the internal components of the feeder. Provision was made to measure directly the volume of dosing solution drawn into the feeder. Flow rate of water was controlled by a valve.

A series of experiments was undertaken to determine the operating characteristics of the feeder.

Stroke Rate
The number of strokes of the dosing piston in a set time was noted for several flow rates over the operating range.

Delivery per Stroke
By noting the volume of dosing solution drawn into the feeder in a set number of strokes, the volume of solution delivered per stroke was determined. The variations in delivery per stroke with flow rate and setting were investigated.

Dose
Dose (millilitres of solution dosed per litre of water) was measured indirectly by determining the volumetric feedrate of dosing solution and dividing by the water flow rate. Variations with setting and flow rate were investigated.

Pressure Drop
The pressure drop across the feeder was measured for a series of flow rates over the operating range, by the inclusion of a second pressure gauge immediately downstream of the feeder.

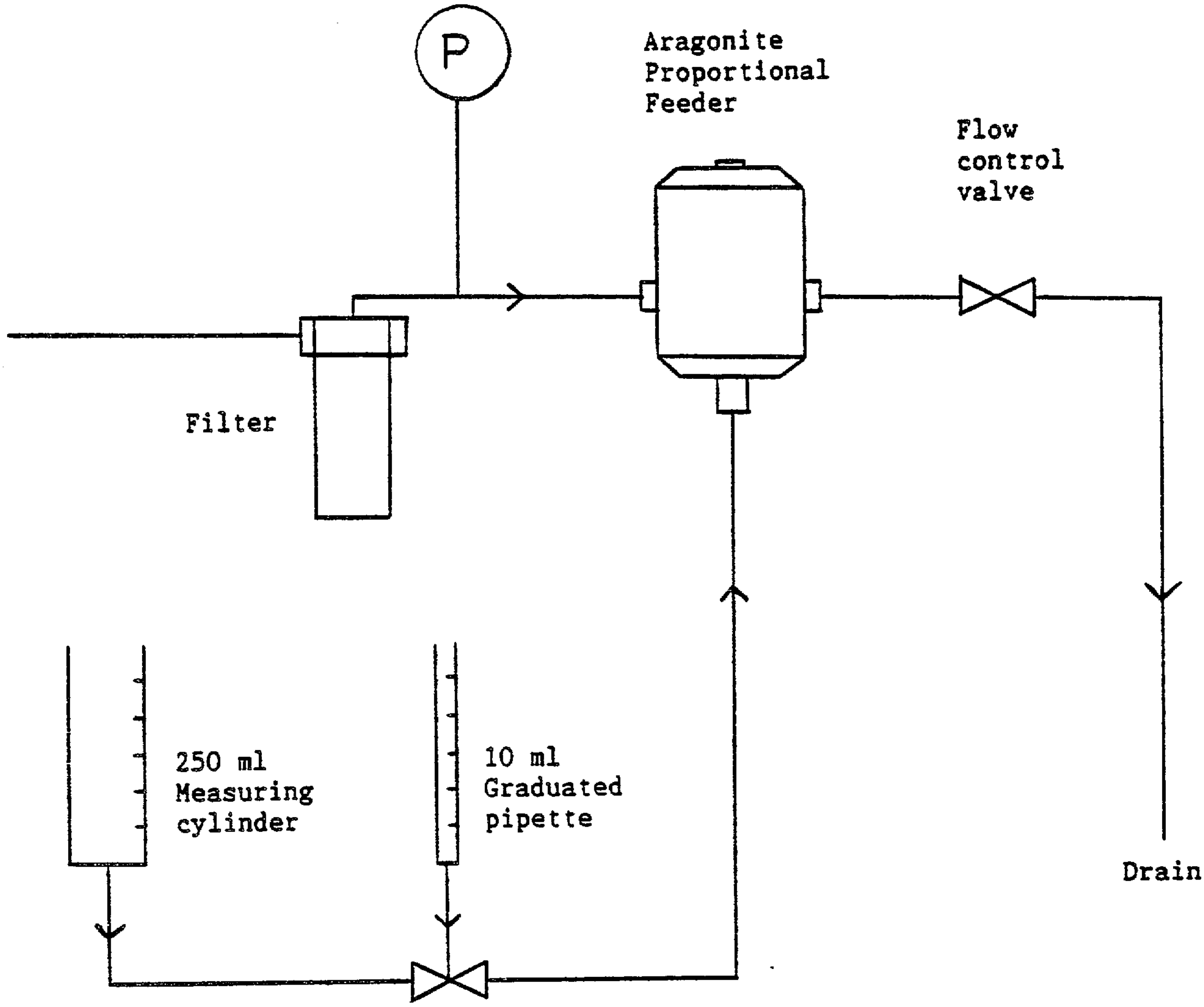



FIGURE 44i

EXPERIMENTAL APPARATUS

Results and Discussion

A complete table of experimental results is appended (page 4.4.10). It should be noted that most of the experimental data shows the delivery per stroke related to flow rate and setting. Only relatively few timed measurements were made of the dose rate. Because of experimental error, the two sets of data do not correspond exactly and it should be noted that while the former appear in figures 442a and 4.2b, it is the latter that appear in figures 443a and 443b.

Dose may be seen to depend on setting and flow rate. The actual dose at a given setting is a function of the delivery of each stroke of the dosing piston and the stroke rate induced by the flow.

To assist interpretation of the experimental results, mathematical models were derived for the different elements of the feeder's performance and these are shown in the curves drawn through the experimental data points (figures 441, 442a, 442b, 443a and 443b). The models are empirical and cannot be extrapolated beyond indicated ranges.

Flow Rate

The maximum flow rate attainable through the feeder was 75 l/min, and the minimum 1.18 l/min. This range compares to the manufacture's information for flow rate range of 2 - 83 l/min.

Stroke Rate

The relationship between stroke rate and flow rate is shown in Fig 441. Superimposed on the experimental data points is the model curve corresponding to a fifth order polynomial:

$$\underset{(str/min)}{\text{Stroke rate}} = a + a_1F + a_2F^2 + a_3F^3 + a_4F^4 + a_5F^5$$

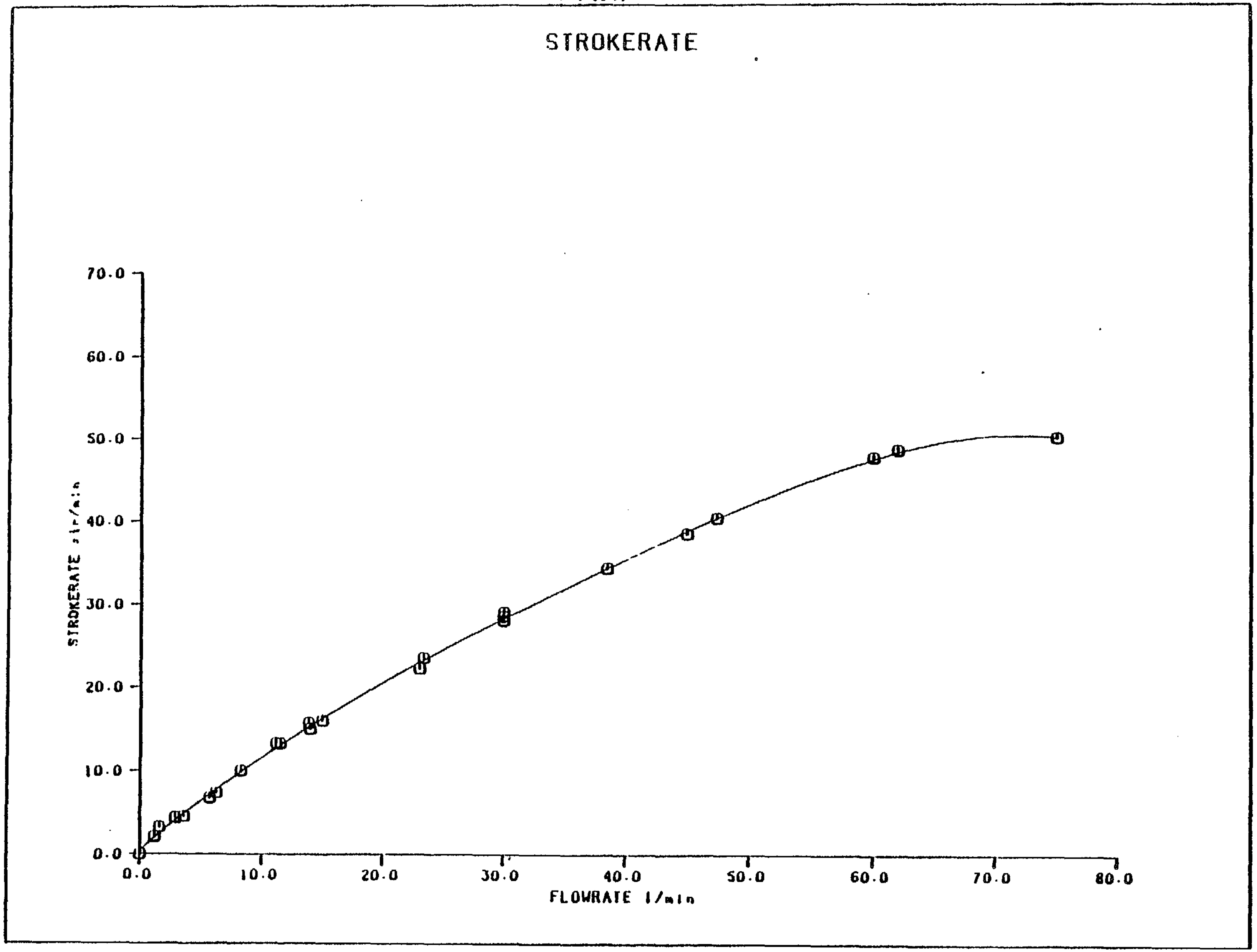
(0 l/min <F< 75 l/min)

where
F = flow rate (l/min)
a0 = 4.71787 E-1
a1 = 1.25625
a2 = -1.61860 E-2
a3 = 1.80107 E-4
a4 = 2.51350 E-7
a5 = -1.58454 E-8

The model was derived using optimised polynomial regression analysis. Although providing a good fit to the experimental data across the flow rate range, some inaccuracy exists at very low flow rates because the polynomial does not give a zero stroke rate corresponding to the minimum operating flow rate.

The relationship between stroke rate and flow rate is linear only as operating flow rate tends to the minimum. The rate of increase in stroke rate falls as flow rate increases, with a significant drop above 60 l/min.

FIGURE 441'



STROKERATE
STROKERATE s/min
FLOWRATE l/min
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0

Delivery per Stroke

Figures 442a and 442b relate delivery per stroke to flow rate for settings 0-6. All the experimental data points are shown together with continuous lines representing the mathematical model. Since the performance of the feeder is claimed to be linear, some effort was made to derive a model that was linear and uniform over all settings. The following was found to be satisfactory over most of the flow rate range:

$$\text{Delivery per stroke (ml/str)} = 0.04228 + (0.0004918 * \text{Flow rate}) + (0.052 * \text{Setting})$$

$$(15\ \text{l/min} < \text{Flow rate} < 75\ \text{l/min})$$

It had been thought that the variation of delivery per stroke with flow rate may depend on setting but this was not found to be the case.

Each rotation of the control knob corresponds to a constant change in delivery per stroke. It should be noted however that because zero on the graduated scale is not equivalent to a zero delivery per stroke, the delivery per stroke is not doubled when adjustment is made for example from setting 2 to setting 4 as would otherwise be expected.

Delivery per stroke is also seen to vary with flow rate, the effect apparently being linear and independent of setting at flow rates above 15 l/min. For an increase in flow rate to result in a greater delivery per stroke requires each stroke of the dosing piston to be longer. This would happen if for instance a fixed time were required for the piston reversing mechanism to operate.

Behaviour of delivery per stroke at flow rates below 15 l/min is less certain due to the scatter in the experimental data. The dashed lines extending from the model lines in figures 442a and 442b attempt to follow the data. It appears that at setting 6 the variation of delivery per stroke is linear but there is a fall-off at lower settings which becomes increasingly marked as the setting is reduced. At the lowest setting the delivery per stroke appears to approach zero as flow rate approaches zero. The logical implication of this is that under these conditions the valves in the dosing piston do not seal instantly when the piston reverses at the end of its stroke.

Dose

Figures 443a and 443b relate dose to flow rate and setting. The continuous lines refer to the modelled flow rate range 15 - 75 l/min. It can be seen that for settings 1,3 and 6 the model corresponds particularly well with the experimental results. The dashed lines extending from the model curves correspond to the delivery per stroke behaviour at flow rates below 15 l/min as discussed above.

As noted above, settings 0 and 6 do not correspond to the limits of delivery per stroke. Neither the minimum dose (0.025 ml/l) nor the maximum dose (0.4 ml/l) claimed by the manufacturer were therefore reached. However, figures 443a and 443b suggest that these claimed dose limits are realistic. It is desirable that dose should remain constant at a given setting. A quantitative indication of deviation from ideality (constant dose) at each setting is given in tables 4.1 below.

FIGURE 442a

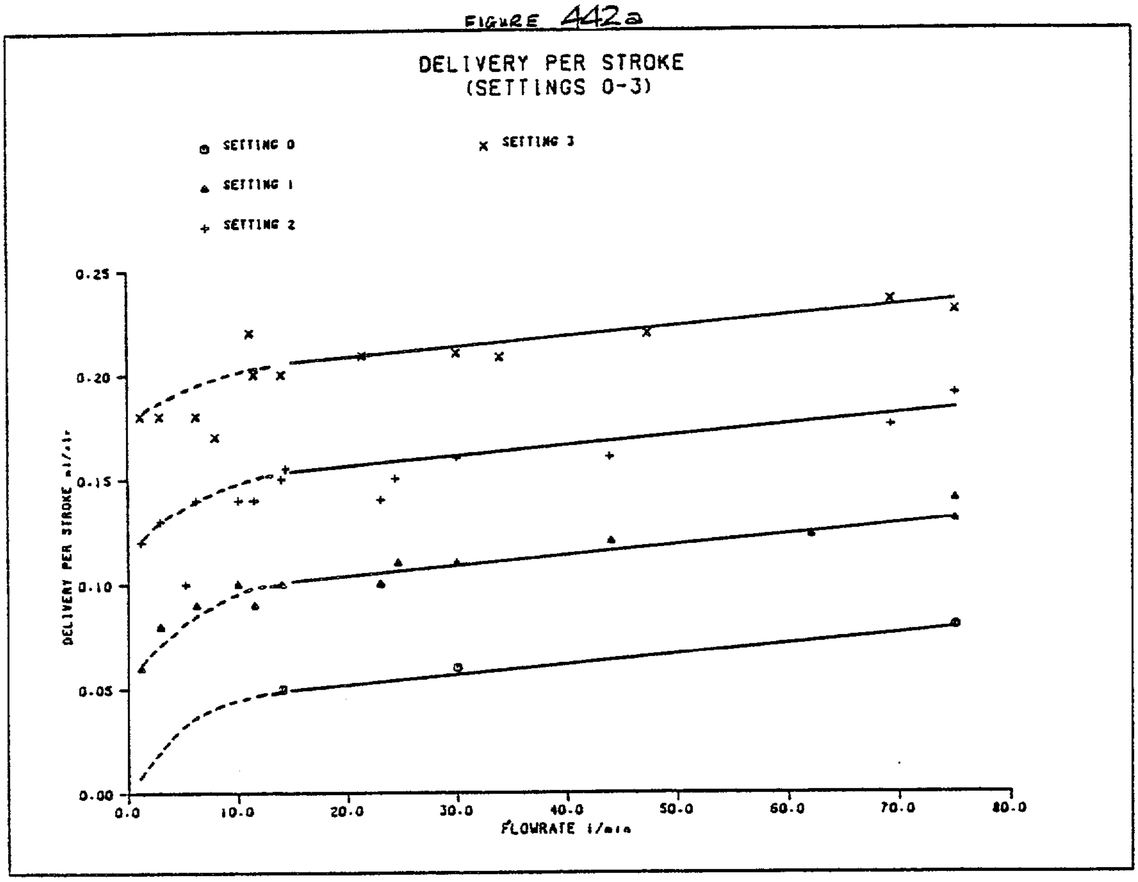



FIGURE 442b

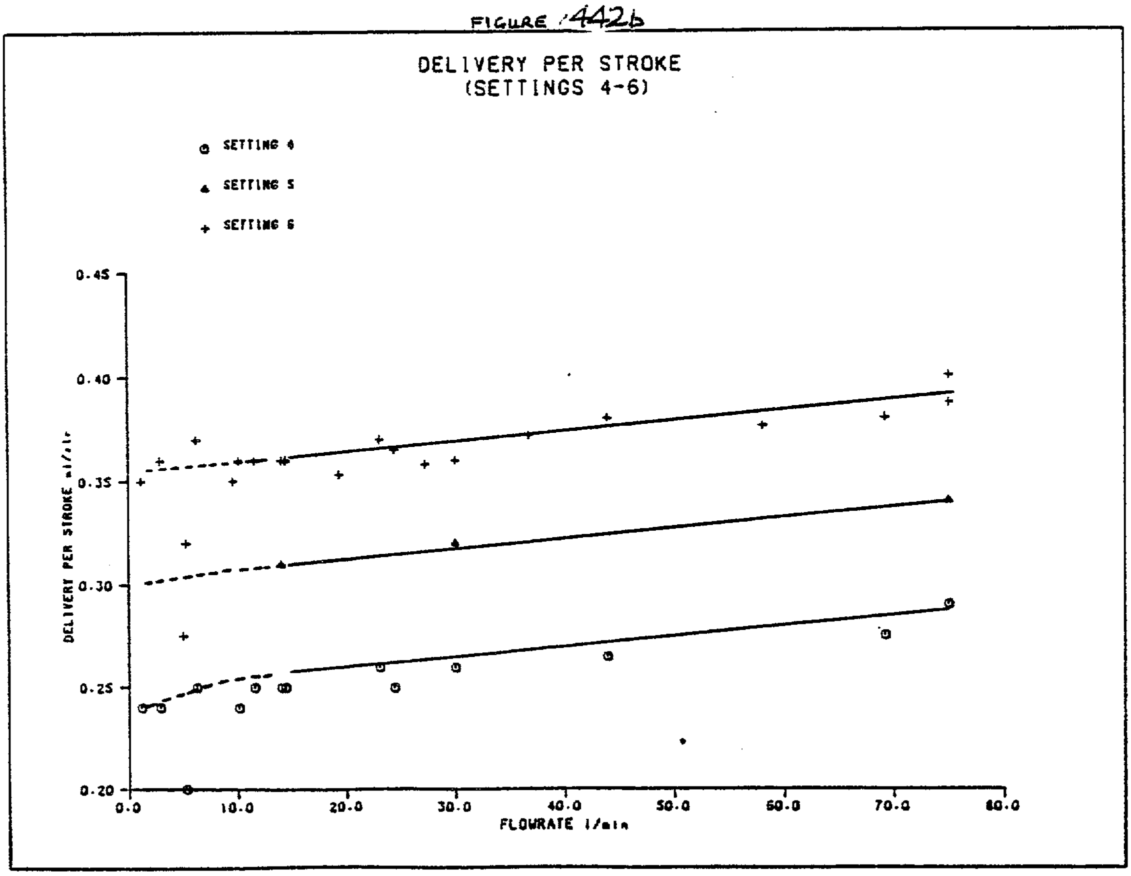


FIGURE 443a

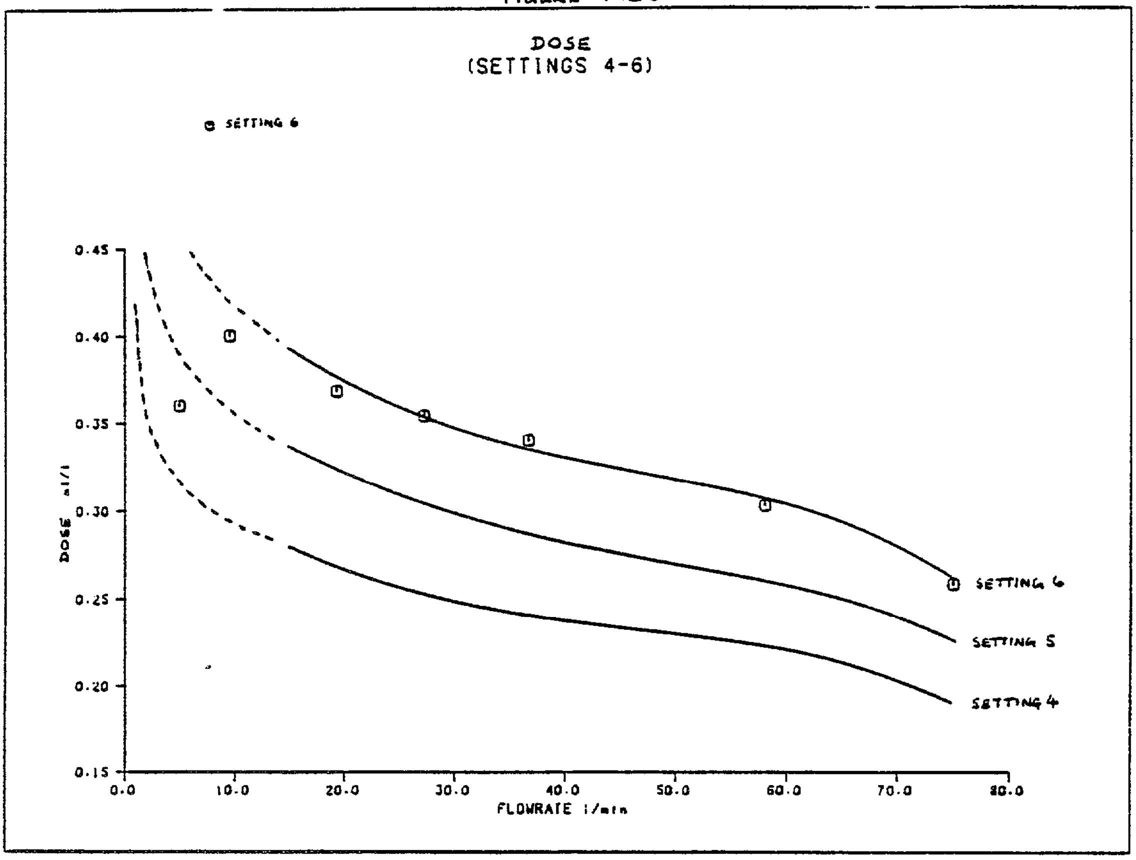
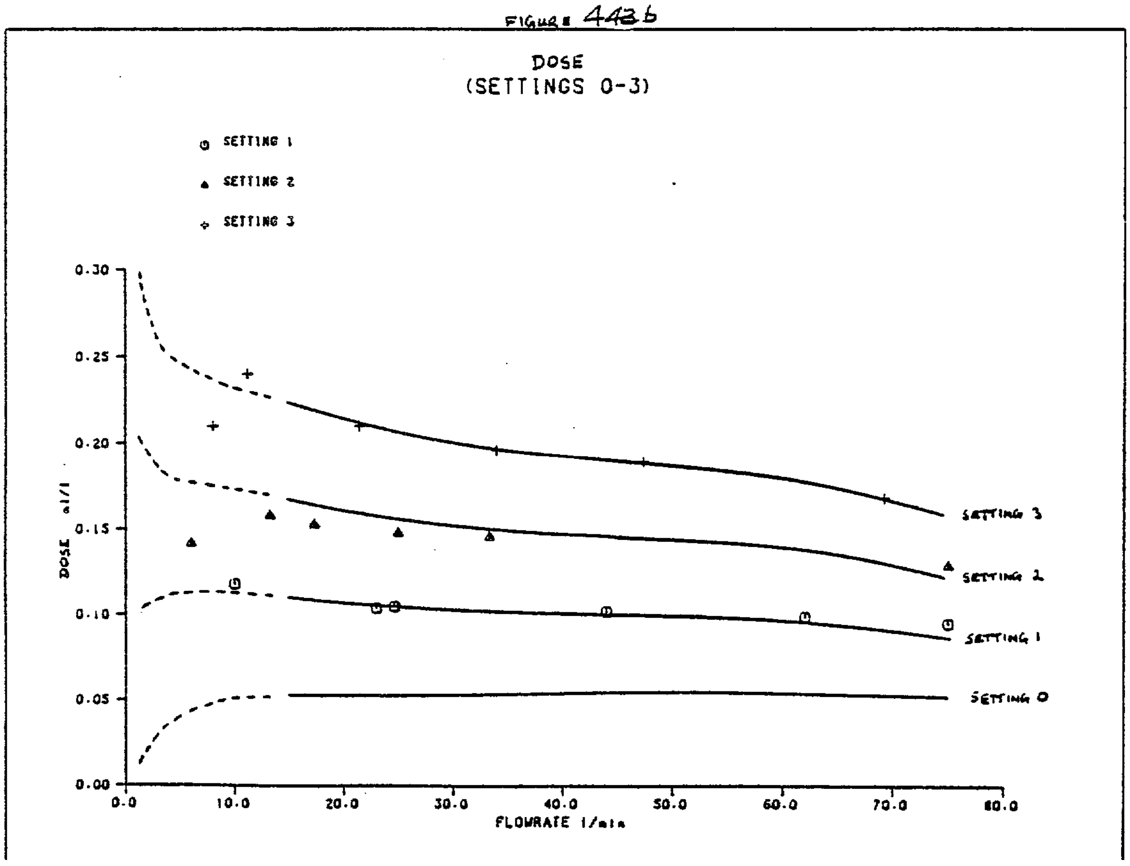



FIGURE 443b



| Setting | Dose 15 l/min (ml/l) | Dose 75 l/min (ml/l) | Mean dose (ml/l) | Deviation from mean (%) | Change in mean dose with setting (ml/l) |
|---|---|---|---|---|---|
| 0 | 0.054 | 0.053 | 0.0535 | +/- 1 | |
| 1 | 0.110 | 0.087 | 0.0985 | +/- 12 | 0.045 |
| 2 | 0.167 | 0.122 | 0.1445 | +/- 16 | 0.046 |
| 3 | 0.223 | 0.157 | 0.1900 | +/- 18 | 0.0455 |
| 4 | 0.280 | 0.191 | 0.2355 | +/- 19.5 | 0.0455 |
| 5 | 0.336 | 0.226 | 0.2810 | +/- 20 | 0.0455 |
| 6 | 0.393 | 0.261 | 0.3270 | +/- 21 | 0.046 |

Table 4.1 Characteristics of Dose Curves

The values shown in table 4.1 are approximate. Based on the model, the mean quoted is the arithmetic mean of dose at 15 l/min and 75 l/min. The trends are of more significance than the absolute values. The change in mean dose induced by unit change in setting is constant. Deviation from the mean, over the flow range 15 l/min $<F<$ 75 l/min, is negligible at setting 0 but rises rapidly as setting number increases. Table 4.2 shows the limits imposed on a flow rate of 44 l/min by stipulating a maximum deviation in dose of +/- 10%. This flow rate corresponds approximately with the mean dose.

| Setting | Dose (ml/l) | Flow rate limits Maximum (l/min) | Flow rate limits Minimum (l/min) |
|---|---|---|---|
| 0 | 0.053 | 75.0 | 15.0 |
| 1 | 0.100 | 72.2 | 15.0 |
| 2 | 0.145 | 70.0 | 20.8 |
| 3 | 0.190 | 67.4 | 24.2 |
| 4 | 0.235 | 65.7 | 24.4 |
| 5 | 0.280 | 65.6 | 25.1 |
| 6 | 0.325 | 64.9 | 25.6 |

Table 4.2 Deviation in Flow Rate Corresponding to a Maximum Permissible Deviation in Dose of +/-10%.

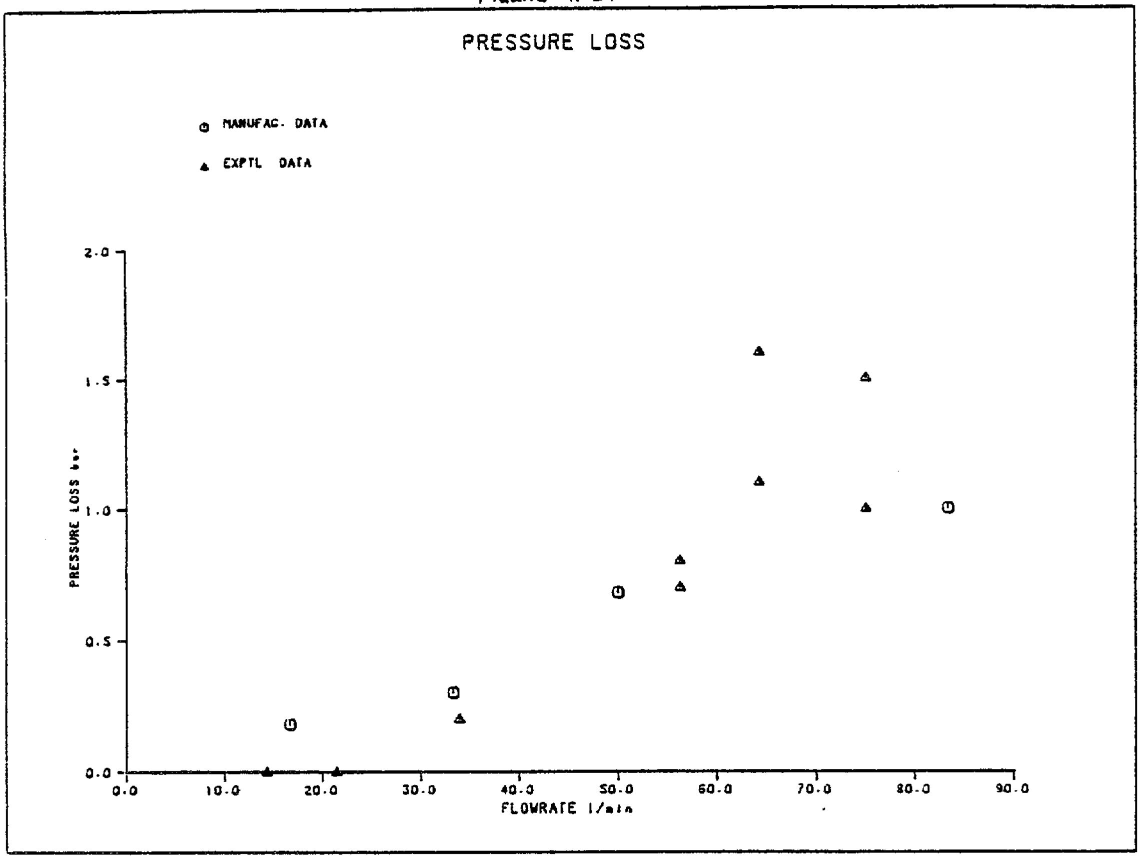
Table 4.2 indicates that it is possible to maintain a reasonably constant dose even at higher settings, provided the average flow rate is around 40 l/min (near the middle of the operating range) and the expected deviations in flow rate are less than +/- 20 l/min.

Pressure Drop

Pressure drop data is shown in figure 444 . The experimental results are compared with manufacturer supplied data. The scatter in the experimental data is such that modelling was not attempted.

Figure 444 indicates that the actual pressure drop across the feeder exceeds the manufacturer's data at flow rates above 60 l/min

FIGURE 444


PRESSURE LOSS
MANUFAC. DATA
EXPTL DATA
PRESSURE LOSS bar
FLOWRATE l/min
0.0
0.5
1.0
1.5
2.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0
90.0

Conclusions

The feeder is compact, simple to operate and well made.

The range of flow rates over which the feeder operates is 1.2 - 75 l/min, not 2 - 83 l/min as claimed by the manufacturer.

At flow rates above 15 l/min the delivery of dosing solution per stroke of the dosing piston is a linear function of setting; the lowest setting on the graduated scale does not however correspond to the end point of adjustment of the control knob.

Delivery per stroke also increases at a contant rate with flow rate, at any setting.

The stroke rate of the dosing piston is not a linear function of flow rate, but tends to a maximum at 75 l/min. The levelling off is particularly rapid above 60 l/min.

The last two effects work in opposite senses so that the actual dose is steadier than it would be il one were absent. Even so, over the flow rate range 15 - 75 l/min the dose is only maintained at a (virtually) constant value at setting 0. At higher settings the dose can be kept within +/- 10% of the mean provided the flow rate range is restricted to 25 - 65 l/min.

Below 15 l/min the performance characteristics of the feeder are less certain. It is apparent that dose varies more significantly with flow rate, particularly at lower settings.

Pressure drop is higher than indicated by the manufacturer at flow rates above 60 l/min.

ARAGONITE DOSER TESTS A.DAT OCT 86

| | EXPERIMENTAL DATA | | | | | MODELLED DATA | | |
|---|---|---|---|---|---|---|---|---|
| SET | L/MIN | STR/MIN | ML/STR | ML/MIN | ML/L | STR/MIN | ML/STR | ML/L |
| 0 | 14.00 | | 0.050 | | | 15.38 | 0.049 | 0.054 |
| 0 | 30.00 | | 0.060 | | | 28.27 | 0.057 | 0.054 |
| 0 | 75.00 | | 0.080 | | | 49.98 | 0.079 | 0.053 |
| 1 | 1.18 | | 0.060 | * | * | 1.93 | 0.095 | 0.155 |
| 1 | 2.94 | | 0.080 | * | * | 4.03 | 0.096 | 0.131 |
| 1 | 6.25 | | 0.090 | * | * | 7.74 | 0.097 | 0.120 |
| 1 | 10.00 | | 0.100 | 1.180 | 0.118 | 11.60 | 0.099 | 0.115 |
| 1 | 11.54 | | 0.090 | * | * | 13.09 | 0.100 | 0.113 |
| 1 | 14.00 | | 0.100 | * | * | 15.38 | 0.101 | 0.111 |
| 1 | 23.00 | | 0.100 | 2.400 | 0.104 | 22.96 | 0.106 | 0.105 |
| 1 | 23.07 | | 0.100 | * | * | 23.02 | 0.106 | 0.105 |
| 1 | 24.65 | | 0.110 | 2.600 | 0.105 | 24.25 | 0.106 | 0.105 |
| 1 | 30.00 | | 0.110 | * | * | 28.27 | 0.109 | 0.103 |
| 1 | 44.00 | | 0.120 | 4.480 | 0.102 | 38.08 | 0.116 | 0.100 |
| 1 | 62.00 | | 0.123 | 6.120 | 0.099 | 48.26 | 0.125 | 0.097 |
| 1 | 75.00 | | 0.130 | * | * | 49.98 | 0.131 | 0.087 |
| 1 | 75.00 | | 0.140 | 7.140 | 0.095 | 49.98 | 0.131 | 0.087 |
| 1 | 75.00 | | 0.140 | * | * | 49.98 | 0.131 | 0.087 |
| 2 | 1.18 | | 0.120 | * | * | 1.93 | 0.147 | 0.240 |
| 2 | 2.94 | | 0.130 | * | * | 4.03 | 0.148 | 0.202 |
| 2 | 5.26 | | 0.100 | * | * | 6.66 | 0.149 | 0.188 |
| 2 | 6.00 | | * | 0.850 | 0.142 | 7.47 | 0.149 | 0.186 |
| 2 | 6.25 | | 0.140 | * | * | 7.74 | 0.149 | 0.185 |
| 2 | 10.11 | | 0.140 | * | * | 11.71 | 0.151 | 0.175 |
| 2 | 11.54 | | 0.140 | * | * | 13.09 | 0.152 | 0.172 |
| 2 | 13.24 | | * | 2.100 | 0.158 | 14.69 | 0.153 | 0.169 |
| 2 | 14.00 | | 0.150 | * | * | 15.38 | 0.153 | 0.168 |
| 2 | 14.40 | | 0.155 | * | * | 15.74 | 0.153 | 0.168 |
| 2 | 17.31 | | * | 2.650 | 0.153 | 18.30 | 0.155 | 0.164 |
| 2 | 23.07 | | 0.140 | * | * | 23.02 | 0.158 | 0.157 |
| 2 | 24.40 | | 0.150 | * | * | 24.06 | 0.158 | 0.156 |
| 2 | 25.00 | | * | 3.700 | 0.148 | 24.52 | 0.159 | 0.156 |
| 2 | 30.00 | | 0.160 | * | * | 28.27 | 0.161 | 0.152 |
| 2 | 33.33 | | * | 4.880 | 0.146 | 30.69 | 0.163 | 0.150 |
| 2 | 43.90 | | 0.160 | * | * | 38.02 | 0.168 | 0.145 |
| 2 | 54.55 | | * | * | * | 44.64 | 0.173 | 0.142 |
| 2 | 69.23 | | 0.175 | * | * | 50.20 | 0.180 | 0.131 |
| 2 | 75.00 | | 0.190 | * | * | 49.98 | 0.183 | 0.122 |
| 2 | 75.00 | | * | 9.680 | 0.129 | 49.98 | 0.183 | 0.122 |

| | EXPERIMENTAL DATA | | | | | MODELLED DATA | | |
|---|---|---|---|---|---|---|---|---|
| SET | L/MIN | STR/MIN | ML/STR | ML/MIN | ML/L | STR/MIN | ML/STR | ML/L |
| 3 | 1.18 | | 0.180 | * | * | 1.93 | 0.199 | 0.326 |
| 3 | 2.94 | | 0.180 | * | * | 4.03 | 0.200 | 0.274 |
| 3 | 6.25 | | 0.180 | * | * | 7.74 | 0.201 | 0.249 |
| 3 | 8.00 | | 0.170 | 1.670 | 0.210 | 9.58 | 0.202 | 0.242 |
| 3 | 11.18 | | 0.220 | 2.680 | 0.240 | 12.75 | 0.204 | 0.232 |
| 3 | 11.54 | | 0.200 | * | * | 13.09 | 0.204 | 0.231 |
| 3 | 14.00 | | 0.200 | * | * | 15.38 | 0.205 | 0.225 |
| 3 | 21.43 | | 0.209 | 4.550 | 0.210 | 21.71 | 0.209 | 0.212 |
| 3 | 30.00 | | 0.210 | * | * | 28.27 | 0.213 | 0.201 |
| 3 | 33.96 | | 0.208 | 6.670 | 0.196 | 31.14 | 0.215 | 0.197 |
| 3 | 47.37 | | 0.219 | 8.960 | 0.189 | 40.29 | 0.222 | 0.188 |
| 3 | 69.23 | | 0.235 | 11.760 | 0.168 | 50.20 | 0.232 | 0.168 |
| 3 | 75.00 | | 0.230 | * | * | 49.98 | 0.235 | 0.157 |
| 4 | 1.18 | | 0.240 | | | 1.93 | 0.251 | 0.411 |
| 4 | 2.94 | | 0.240 | | | 4.03 | 0.252 | 0.345 |
| 4 | 5.26 | | 0.200 | | | 6.66 | 0.253 | 0.320 |
| 4 | 6.25 | | 0.250 | | | 7.74 | 0.253 | 0.314 |
| 4 | 10.11 | | 0.240 | | | 11.71 | 0.255 | 0.296 |
| 4 | 11.54 | | 0.250 | | | 13.09 | 0.256 | 0.290 |
| 4 | 14.00 | | 0.250 | | | 15.38 | 0.257 | 0.283 |
| 4 | 14.40 | | 0.250 | | | 15.74 | 0.257 | 0.281 |
| 4 | 23.07 | | 0.260 | | | 23.02 | 0.262 | 0.261 |
| 4 | 24.40 | | 0.250 | | | 24.06 | 0.262 | 0.259 |
| 4 | 30.00 | | 0.260 | | | 28.27 | 0.265 | 0.250 |
| 4 | 43.90 | | 0.265 | | | 38.02 | 0.272 | 0.235 |
| 4 | 69.23 | | 0.275 | | | 50.20 | 0.284 | 0.206 |
| 4 | 75.00 | | 0.290 | | | 49.98 | 0.287 | 0.191 |
| 5 | 14.00 | | 0.310 | | | 15.38 | 0.309 | 0.340 |
| 5 | 30.00 | | 0.320 | | | 28.27 | 0.317 | 0.299 |
| 5 | 75.00 | | 0.340 | | | 49.98 | 0.339 | 0.226 |
| 6 | 1.18 | | 0.350 | * | * | 1.93 | 0.355 | 0.581 |
| 6 | 2.94 | | 0.360 | * | * | 4.03 | 0.356 | 0.488 |
| 6 | 5.00 | | 0.275 | 1.820 | 0.360 | 6.37 | 0.357 | 0.455 |
| 6 | 5.26 | | 0.320 | * | * | 6.66 | 0.357 | 0.452 |
| 6 | 6.25 | | 0.370 | * | * | 7.74 | 0.357 | 0.442 |
| 6 | 9.57 | | 0.350 | 3.850 | 0.400 | 11.17 | 0.359 | 0.419 |
| 6 | 10.11 | | 0.360 | * | * | 11.71 | 0.359 | 0.416 |
| 6 | 11.54 | | 0.360 | * | * | 13.09 | 0.360 | 0.408 |
| 6 | 14.00 | | 0.360 | * | * | 15.38 | 0.361 | 0.397 |
| 6 | 14.40 | | 0.360 | * | * | 15.74 | 0.361 | 0.395 |
| 6 | 19.35 | | 0.353 | 7.140 | 0.368 | 20.02 | 0.364 | 0.376 |
| 6 | 23.07 | | 0.370 | * | * | 23.02 | 0.366 | 0.365 |
| 6 | 24.40 | | 0.365 | * | * | 24.06 | 0.366 | 0.361 |
| 6 | 27.27 | | 0.358 | 9.670 | 0.354 | 26.25 | 0.368 | 0.354 |
| 6 | 30.00 | | 0.360 | * | * | 28.27 | 0.369 | 0.348 |
| 6 | 36.73 | | 0.372 | 12.500 | 0.340 | 33.10 | 0.372 | 0.336 |
| 6 | 43.90 | | 0.380 | * | * | 38.02 | 0.376 | 0.325 |
| 6 | 58.06 | | 0.376 | 17.650 | 0.303 | 46.50 | 0.383 | 0.307 |
| 6 | 69.23 | | 0.380 | * | * | 50.20 | 0.388 | 0.282 |
| 6 | 75.00 | | 0.400 | * | * | 49.98 | 0.391 | 0.261 |
| 6 | 75.00 | | 0.387 | 19.350 | 0.258 | 49.98 | 0.391 | 0.261 |

| E X P E R I M E N T A L D A T A | | | | | | M O D E L L E D D A T A | | |
|---|---|---|---|---|---|---|---|---|
| SET | L/MIN | STR/MIN | ML/STR | ML/MIN | ML/L | STR/MIN | ML/STR | ML/L |
| | 0.00 | 0.00 | | | | 0.47 | | |
| | 1.18 | 2.04 | | | | 1.93 | | |
| | 1.60 | 3.20 | | | | 2.44 | | |
| | 2.94 | 4.29 | | | | 4.03 | | |
| | 3.60 | 4.50 | | | | 4.79 | | |
| | 5.70 | 6.70 | | | | 7.14 | | |
| | 6.25 | 7.31 | | | | 7.74 | | |
| | 8.30 | 10.00 | | | | 9.89 | | |
| | 11.20 | 13.30 | | | | 12.77 | | |
| | 11.54 | 13.33 | | | | 13.09 | | |
| | 13.90 | 15.70 | | | | 15.29 | | |
| | 14.00 | 15.00 | | | | 15.38 | | |
| | 15.00 | 16.00 | | | | 16.28 | | |
| | 23.07 | 22.22 | | | | 23.02 | | |
| | 23.40 | 23.50 | | | | 23.28 | | |
| | 30.00 | 28.00 | | | | 28.27 | | |
| | 30.00 | 28.50 | | | | 28.27 | | |
| | 30.00 | 29.00 | | | | 28.27 | | |
| | 38.50 | 34.30 | | | | 34.34 | | |
| | 45.00 | 38.40 | | | | 38.75 | | |
| | 47.40 | 40.30 | | | | 40.31 | | |
| | 60.00 | 47.60 | | | | 47.42 | | |
| | 62.00 | 48.50 | | | | 48.26 | | |
| | 75.00 | 50.00 | | | | 49.98 | | |
| | 75.00 | 50.00 | | | | 49.98 | | |
| | 75.00 | 50.00 | | | | 49.98 | | |

---

| L/MIN | PRESSURE DROP,BAR |
|---|---|
| 14.29 | 0.0 |
| 21.43 | 0.0 |
| 33.96 | 0.2 |
| 56.25 | 0.7 |
| 56.25 | 0.8 |
| 64.29 | 1.1 |
| 64.29 | 1.6 |
| 75.00 | 1.0 |
| 75.00 | 1.5 |

APPENDIX 4.5 SELF-POWERED CHEMICAL DOSER

. Maker's Information

The sales prospectus BP.80.050 points out that the unit can be used for dosing solutions of several kinds, not only hypochlorite, and states particularly:

i) The unit can accommodate, within acceptable limits, variable flows in the range of 500 to 22 000 UK gal/d (2.5 to 100 $m^3/d$) and will stop dosing under 'no flow' conditions. Units can be ganged together for higher flow rates.

ii) The unit can apply a dose of more than 2 mg/l at maximum water throughput using 10% sodium hypochlorite.

iii) The chemical reservoir has 10 litres capacity which will last for more than four and a half days at maximum water flow with maximum chemical dose.

iv) The unit has an adjustable dose setting range of 10:1.

v) The unit is manufactured from corrosion resistant materials throughout.

vi) The unit can be stripped and reassembled in minutes using only the most simple tools.

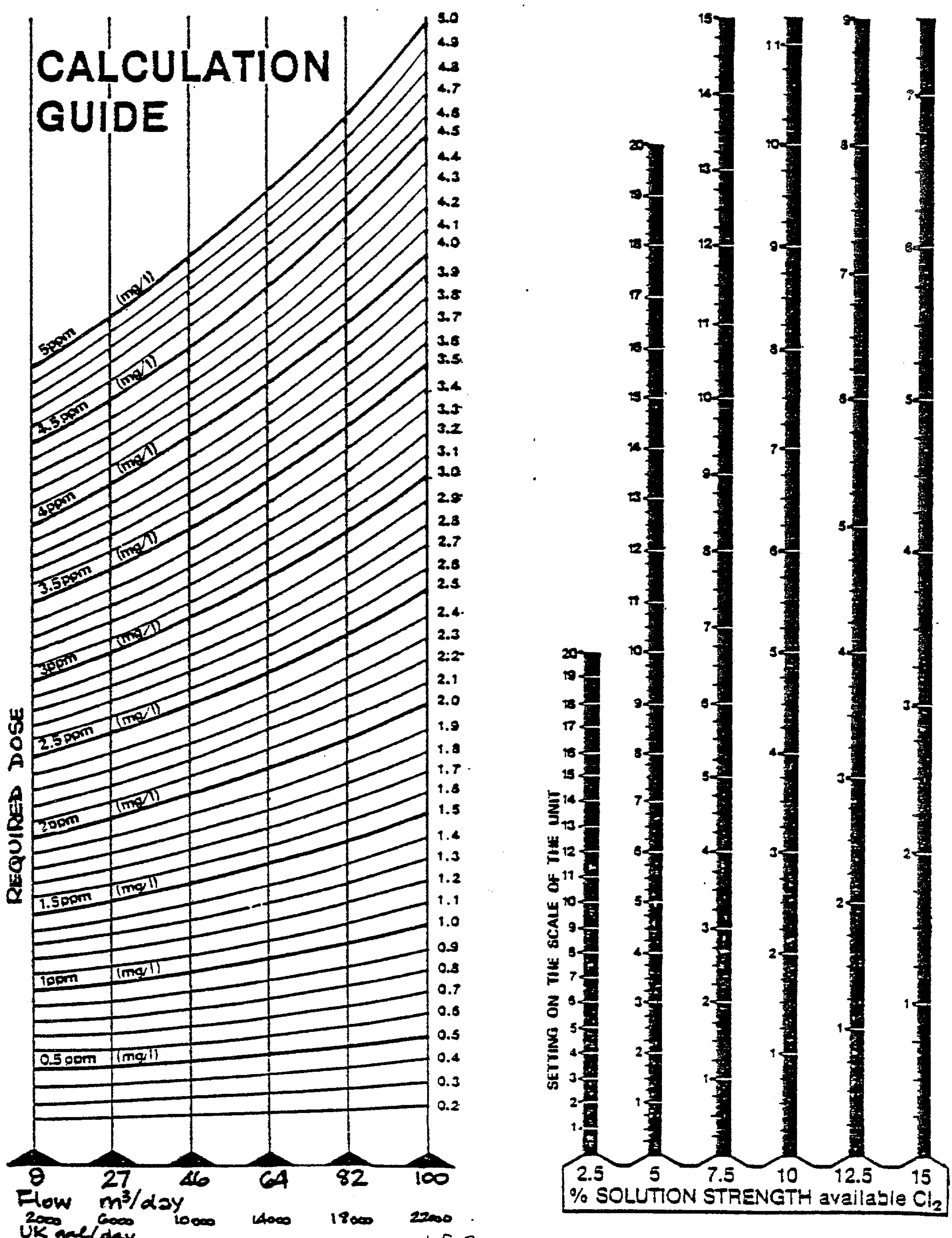
The sales prospectus also includes all the information needed for a draughtsman to make an installation drawing.

One unit was purchased for the trial complete with all parts necessary to operate over the three dose ranges. It was delivered with a fully detailed packing list of all items including an instruction manual BM.80.050, setting chart Fig. 2 and ready reckoner. The ready reckoner gave a formula for calculating the hypochlorite dose per cycle.

$$\text{Dose} = \frac{\text{Dose rate in ppm} \times 1\,000\,000}{\text{Solution strength \%} \times (66\,000 - 0.967 \text{ flow rate UK gal/d})}$$

# SELF POWERED CHEMICAL DOSER

First determine the required dose and establish where the curve for ppm (mg/l) crosses the vertical line which indicates the anticipated flow in m³/day (UK GAL/day). Follow horizontally across to the solution strength and read off the scale setting.



Both reckoner and chart show doses required to give 13 dose rates ranging from 0.5 to 5 mg/l with hypochlorite at 5 concentrations from 5% to 15% and at 6 flowrates from 2000 to 22 000 UK gal/d. The reckoner gives discrete figures while the charge shows continuous curves enabling interpolations to be made.

2.2.3. Test Procedure

The SPCD is designed to deliver into a free water surface about 1.5 m below the inlet pipe. For the tests, each batch of dosed water was collected in a 200 litre capacity tank which stood on the platform of a 0 - 500 kg weighing machine. The SPCD was supported above the collecting tank on a steel structure with access platform. A microswitch was mounted on the unit and connected to a counter to indicate the number of cycles made in each run. The unit was piped to the laboratory water supply through two variable area flowmeters connected in parallel to allow the flowrate to be set roughly at the beginning of each run.

The laboratory water supply was checked occasionally and never showed a detectable chlorine residual or chlorine demand. Residuals were measured in the trial with a Wallace and Tiernan Residometer which had proved to be accurate in previous work. The instrument's zero was checked before almost every reading and the reading was checked monthly against DPD ferrous ammonium sulphate titration.

Each test was made at a steady flowrate which was set roughly by the flowmeters and measured accurately by timing the operating cycle and weighing the water discharged. The siphoning time was also measured. After a number of cycles, the dose dispensed on each of ten consecutive cycles was collected in a small beaker for weighing. A further number of cycles were made, at least ten in number, in which the water was dosed with hypochlorite and the residual was measured by taking samples from the collecting tank. This procedure was followed for each dose setting on each of the three scales, 0-5, 0-10 and 0-20 ml. The hypochlorite concentration was changed as necessary to keep the residual in the range 0.5 - 2 mg/l to correspond with the range used in the field. Flowrates through the unit were not changed in an orderly way but were altered so that at the end of the trial the unit had been operated over the whole of its range.

### 2.2.4. Results

Flow Rate

At the minimum flow rate, when the tank has filled the water will trickle over the siphon without causing it to operate. The flap valve at the bottom of the discharge tube plays an important part in accumulating this trickle until, when the weight of water overcomes the weight of the flap, the sudden discharge starts the siphon. Without the flap valve, the minimum flow rate required to operate the siphon was 13.2 $m^3/d$ gal/d but with the valve in position, the maker's figure of 2.5 $m^3/d$ gal/d was confirmed. Any deposit which changed the balance weight or wedged the valve open could allow a small flow of untreated water to pass through into supply but the action of the unit is such as to minimise the likelihood of this happening.

When the inflow rate approaches the siphon rate, the siphon may run continuously without breaking and this too could allow untreated water to flow into supply. The trials showed that the siphon rate was 300 $m^3/d$; just 3 times the maximum rating of the unit. There is nothing about the unit that prevents its being operated at flowrates well above its rated maximum. In the laboratory trial the water supply available enabled the maximum rating to be exceeded marginally but no more. It was thus possible to confirm the maker's claim for maximum and minimum flow rates, but not to explore this above range.

Dosing

Table 1. Experimental Results: SPCD

Run No 3 Setting 2 ml/cycle Solution Concentration 8.1%

| Cycle | Filling time sec | Emptying time sec | Batch weight kg | Residual mg/l | Cycle | Solution weight g |
|---|---|---|---|---|---|---|
| 1 | 805 | 59 | 154.1 | 0.95 | 17 | 1.967 |
| 2 | 808 | 60 | 154.9 | 1.09 | 18 | 1.893 |
| 3 | 807 | 59 | 154.5 | 1.00 | 19 | 1.907 |
| 4 | 805 | 59 | 154.0 | 1.07 | 20 | 1.910 |
| 5 | 807 | 60 | 154.4 | 0.99 | 21 | 1.898 |
| 6 | 806 | 59 | 154.5 | 1.23 | 22 | 1.919 |
| 7 | 807 | 59 | 154.3 | 0.87 | 23 | 1.955 |
| 8 | 806 | 59 | 154.5 | 0.87 | 24 | 1.541 |
| 9 | 806 | 59 | 154.5 | 1.02 | 25 | 1.885 |
| 10 | 806 | 59 | 154.7 | 0.84 | 26 | 1.908 |
| 11 | 804 | 59 | 154.1 | 1.01 | 27 | 1.910 |
| 12 | 806 | 60 | 154.0 | 1.07 | 28 | 1.906 |
| 13 | 806 | 58 | 154.1 | 1.01 | 29 | 1.899 |
| 14 | 807 | 59 | 154.1 | 1.05 | 30 | 1.910 |
| 15 | 808 | 58 | 154.5 | 1.03 | 31 | 1.905 |
| 16 | 807 | 58 | 154.3 | 0.99 | 32 | 1.892 |

Average filling time 806 s )
) Average cycle time 865 s
Average emptying time 59 s )

Average batch weight 154.5 Kg
Average solution weight 1.913 g
Water flow rate 15.4 $m^3/d$ (3395 UK gal/d)

Chlorine Dose - actual 1.00 g/l predicted 1.02 g/l

In most runs, two sets of cycles were performed. On Run 3 shown here hypochlorite was dosed into the tank on cycles 1 to 16 and on cycles 17 to 32, the dose was collected and weighed. Both filling and emptying times show a high degree of consistency. The check measurements of residual show some variation which is probably associated with the precision of the measuring instrument. The variations in dose from one cycle to the next are small.

The calculated chlorine dose in this run, based on an average dose of 1.913 g of 8.1% solution in 154.5 Kg water is 1.00 mg/l.

The average filling time and the average emptying time added together give the average cycle time which, divided into the verage batch weight gives a flow rate of 15.4 $m^3/d$. Using this figure, the maker's formula predicts a chlorine concentration of 1.02 mg/l.

Table 2 summarises the results from all runs where the doses of solution were collected for weighing.

Table 2. Summary of Results: SPCD

| Run No | Flow Rate | Scale | Setting | Dose | Error | Variation (standard deviation) |
|---|---|---|---|---|---|---|
| | $m^3/d$ | | ml/cycle | ml | % Setting | % dose |
| 1 | 28.7 | 0-5 | 1 | 0.651 | -44.9 | 5.8 |
| 2 | 29.0 | 0-5 | 2 | 1.988 | - 0.6 | 2.1 |
| 3 | 15.4 | 0-5 | 2 | 1.913 | - 4.3 | 1.2 |
| 4 | 39.2 | 0-5 | 3 | 3.125 | + 4.2 | 0.7 |
| 5 | 58.5 | 0-5 | 4 | 4.304 | + 7.6 | 1.8 |
| 6 | 15.3 | 0-10 | 9 | 8.952 | - 0.5 | 0.4 |
| 6B | 14.3 | 0-10 | 7 | 6.507 | - 7.0 | 0.3 |
| 7 | 20.1 | 0-10 | 10 | 9.596 | - 4.0 | 1.5 |
| 7B | 19.9 | 0-10 | 5 | 3.786 | -24.3 | 0.9 |
| 9 | 28.5 | 0-20 | 5 | 4.997 | - 0.0 | 1.0 |
| 10 | 29.0 | 0-20 | 10 | 10.563 | + 5.6 | 1.1 |
| 11 | 11.1 | 0-20 | 15 | 16.412 | + 9.5 | - |
| 12 | 57.8 | 0-20 | 19 | 19.085 | + 0.4 | 0.5 |
| 13 | 70.5 | 0-20 | 19 | 18.457 | - 2.8 | 0.3 |
| 14 | 81.0 | 0-20 | 15 | 14.444 | - 3.7 | 1.1 |
| 15 | 92.1 | 0-20 | 9 | 7.964 | -11.5 | 1.5 |

Error: taking all results — Average = -4.8%; SD = 12.9%
omitting 2 outliers, — Average = -0.6%; SD = 5.5%

Variation: average of standard deviations = 1.3%

It can be seen from this table that with two exceptions, the doses dispensed were close to the scale setting. The average error of less than 1% and standard deviation of 5.5% would count as meeting the proposed specification for accuracy. The larger errors in Runs 1 and 7B are attributed to operator error but, as in the othe runs, the consistency of dosing was acceptable.

The precision of dosing was much better. The variation of dose on any particular setting showed an average standard deviation of 1.3%. This implies the expectation that 95% of all doses would fall within ± 2.7% from one dose to the next and a very much smaller variation would be expected from hour to hour.

Other Observations

The calibration chart and reckoner take Imperial gallons as their prime unit and then give the nearest metric equivalents in cubic metres. Since all the UK Water Authorities have now adopted the metric system completely it would have been more convenient if the calculators had been fully metric with Imperial equivalents as alternatives.

The variation in dose with flow rate has already been noted and the calculators take this into account. However the settings are given to achieve a required dose based on the <u>instantaneous</u> flow rate into the unit. This is not stated explicitly, and because the rates are quoted in volume <u>per day</u> the operator might be inclined to think of the average daily flow. In some cases the difference may not be significant but where the unit serves a tank fitted with a ball valve, large differences can arise.

To take an extreme example, the design maximum demand from a community may be 100 $m^3/d$. Allowing for no draw-off at night, the daily flow into the tank may be at an average rate of 150 $m^3/d$, but it could be that when the ball valve is open, the actual flow is at an instantaneous rate of 200 $m^3/d$. If, as the makers recommend, the ball valve is of the quick acting type, then all the flow through the unit will be at the 200 $m^3/d$ rate. Under these conditions, the setting to give a dose of 2 mg/l would in fact only give a dose of 1 mg/l. The practical consequence of this is that the operator would find the residual to be low and he would increase the setting as necessary. Although the unit is not rated for this flow, it will accept it, and it can be adjusted to dose at 2 mg/l as required.

This effect is always present though at the lower flows normally to be expected it is not so pronounced. The illustration is used to show the limitation of the calculators. In practice the operator may not have a direct measurement of daily flow and it may be satisfactory and more accurate to calculate settings on the basis of the cycle time of the unit which the operator can measure on the spot.

In the laboratory trials the recommended maintenance procedures were followed. As claimed, the unit was easy to strip and assemble. The metering head was cleaned weekly, removed and washed monthly and after three months (or when the solution concentration was changed) the reservoir was removed and washed. It was found that the knurled plastic screws on the metering head soon broke although only made thumb tight, and the reservoir was difficult to empty completely if it had not emptied naturally. A drain plug or cock would be very useful.

The guide tube, provided to ensure that the float assembly rose smoothly and evenly, fell out of its socket in the mounting plate and was glued back in position. It appears that it was manufactured to be a push fit in the socket and that this is a design weakness.

Site Evaluations

Visits were made to North Yorkshire and Wales to obtain direct evidence of performance in the field by examining dosers in use and questioning the operators on three sites.

Although the doser is provided with setting scales and calibration charts, it was found that these were not used in practice. From the operators' accounts it appears that the units were installed, and then the settings obtained by trial and error. By the time a satisfactory residual had been established in the system, the operator had the 'feel' of the adjuster and no attempt was made to correlate the results to the numbers on the scale.

In every case the doser gave better and more reliable results than the previous equipment and required less attention. The recommended routine dismantling and cleaning was not done, although neither of the two units which had been in use for eighteen months showed any deposits requiring removal. Neat hypochlorite was dosed on all sites although at one site it was diluted tenfold in summer when the chlorine demand was low.

As in the laboratory, the knurled plastic screws securing the metering head had broken on one unit in the field, but not on the other two. Although this unit was acknowledged to be much more reliable than the previous equipment it was still visited daily.

## 2.2.5. Summary

The Self Powered Chemical Doser has been found in laboratory tests to come up to its maker's claims and its accuracy and precision of dosing are well within the limits of the WRC proposed specification. It was not convenient to run the unit for the extended time of 350 hours in the laboratory and this aspect of performance will be examined on units operating in the field.

The unit was found to be easy to instal, adjust and maintain. Minor criticisms could be made of the chemical reservoir which could not be drained easily, the fixing of the float assembly guide and the strength of the plastic fixing screws.

Information provided with the unit was very good. Instructions for setting the required dose were accurate but would be improved if the flow rate through the unit were expressed in terms of the cycle time.

## APPENDIX 4.6 KV TYPE DIAPHRAGM DOSING PUMP

### Tests

The pump was installed in a rig where it drew from a calibrated container and delivered into a pressurised cylinder of sufficient capacity to ensure that there was no significant change in pressure during a test run due to the volume of liquid pumped in.

The first test was to check the maximum and minimum flowrates and the stroke rate of the pump. The feed tank was situated to give a positive inlet head of 2cm water gauge, the delivery presure was set at 0.7 bar and the stroke adjusting nut was then turned until the pump rod made zero stroke. The indicator plate was adjusted to read zero percentage stroke. The adjusting nut was then set at 100% stroke and the volume delivered by the pump and its stroke rate were measured. The results are shown in Table 4.3, which shows that the hourly flow rate was correct. However the stroke rate was slightly faster than the rated value.

Table 4.3. KV pump - main characteristics

| Characteristic | Specified | Observed |
|---|---|---|
| flow at 0% stroke | zero l/h | zero l/h |
| flow at 100% stroke | 45.0 l/h | 45.45 l/h |
| stroke rate (per min) | 24 | 25 |

The influence of inlet head on pump delivery was investigated. For heads of -73, -25, +2, +25, +50 and +75 cm water gauge, measurements were made of volume pumped in 3 minutes. This procedure was repeated for delivery pressures of 0, 1, 2 and 3 bar. The results are plotted in Fig 462 and show that at each operating pressure there was a sudden increase in output from the pump when the inlet head was increased from zero to +25cm water gauge. On each side of this step the output was constant. It was also noted from these results that the output decreased as delivery pressure increased.

Next, the output was measured at a series of pressures while the stroke setting was changed over the range from 20% to 100% stroke. The inlet head was kept constant at 50cm water. The results are shown in Fig 463 on which is also shown the manufacturer's calibration. It can be seen that the output is not a linear function of stroke setting and that the maker's calibration appears not to take account of the loss of delivery with increasing back pressure.

In the final test the pump was run continuously for 15 days at 50% stroke, inlet head of 50cm water and delivery pressure of 0.7 bar. Every day a measurement was made of the volume pumped in 15 minutes. There was some variation within 5% of the mean and no overall change in this period.

### Discussion

The delivery of the pump was not proportional to the stroke setting. While this might have been thought to be a feature of the drive mechanism, later tests using a different head on the same drive did not show the same results. It must therefore be a feature of this diaphragm chamber that its volume changes with stroke in a non-linear way.

The reducing output with increasing delivery pressure suggests that the diaphragm can flex to allow significant changes in chamber volume according to pressure.

The stepwise increase of output with change from negative to positive inlet head also indicates flexure of the diaphragm. Fig 461 suggests how when the inlet head is negative the diaphragm may keep the same convex shape for the whole pumping cycle, but when it is positive the diaphragm may click to the opposite curvature on the suction stroke, enclosing a suddenly larger volume.

## Conclusions

In the extended running test the pump maintained its performance well. This confirms long experience of the use of this type of pump in WRc pilot plant work on continuous running for periods of months under conditions where the inlet and delivery pressures were steady and low. However the tests also showed that in circumstances where the pressure regime was variable or could change, this type of pump would not give consistent dosing.

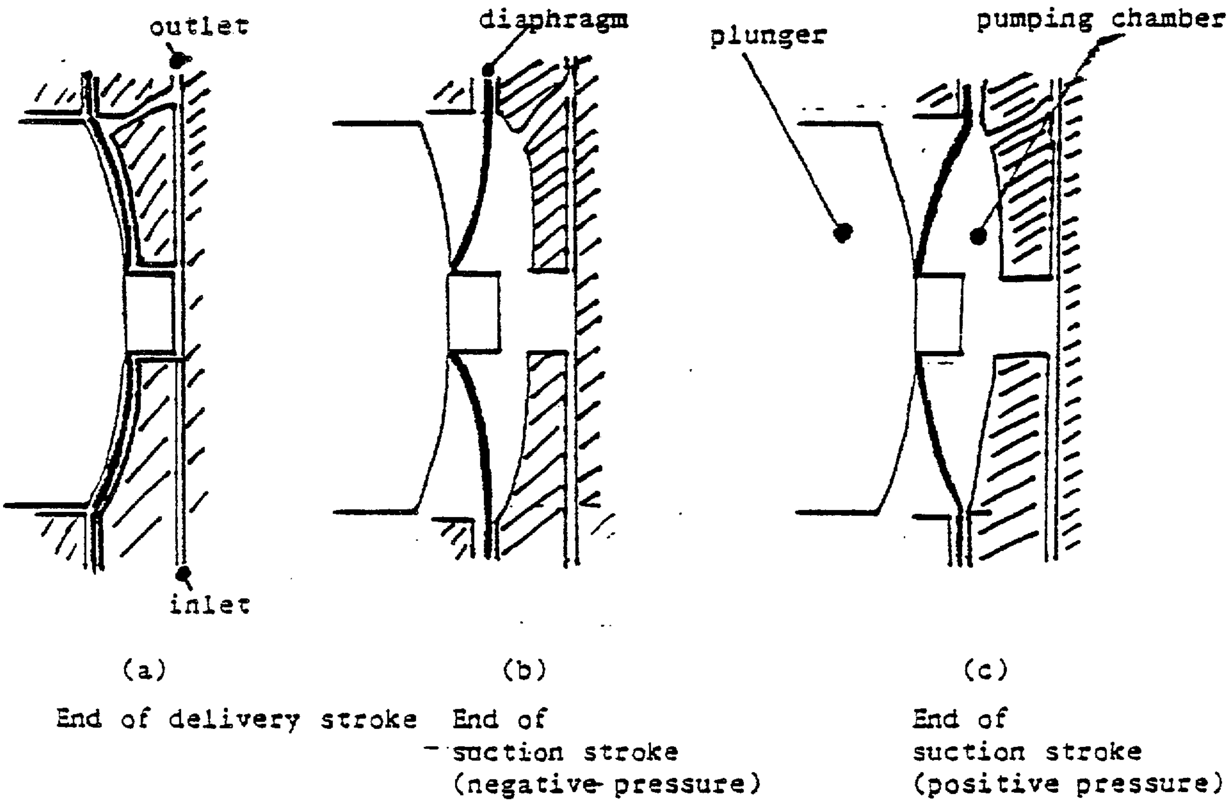



Figure 461 Change in Diaphragm Curvature with Suction Pressure

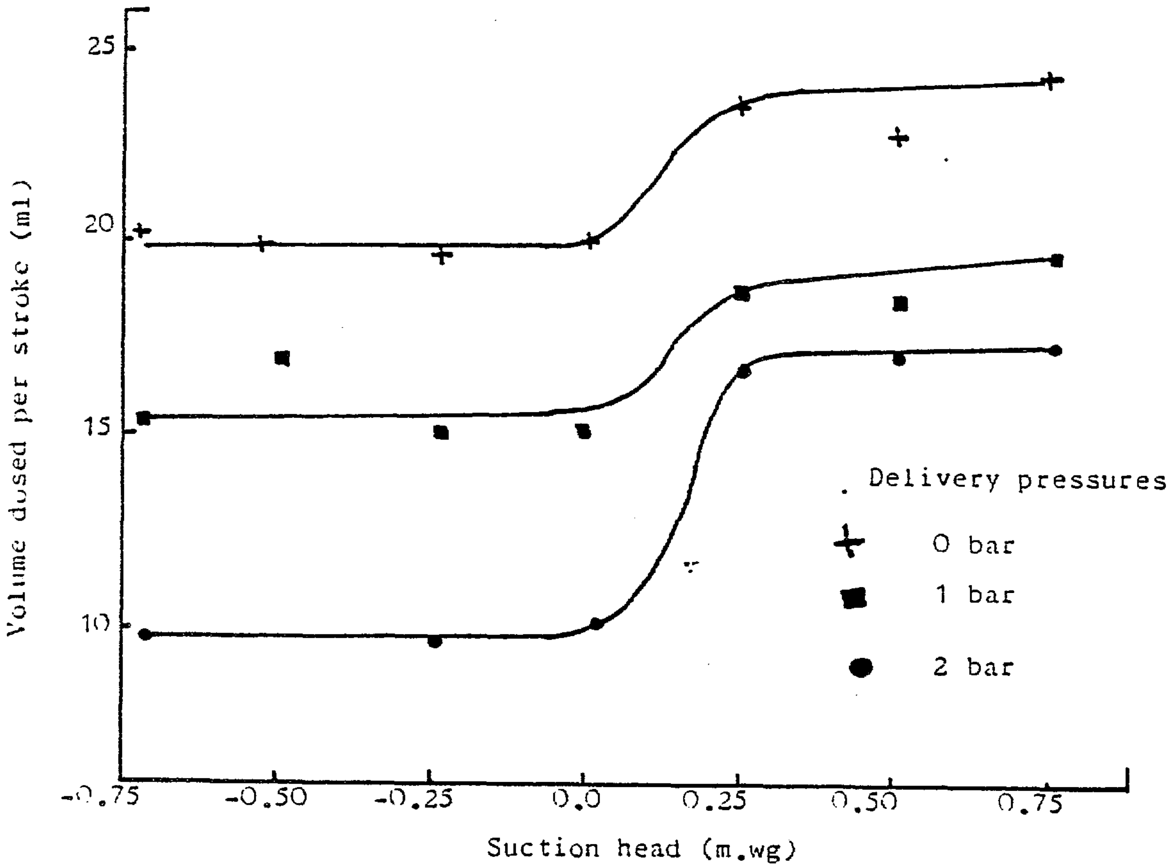



Figure 4.6.2 KVDP: Variation of output with suction head

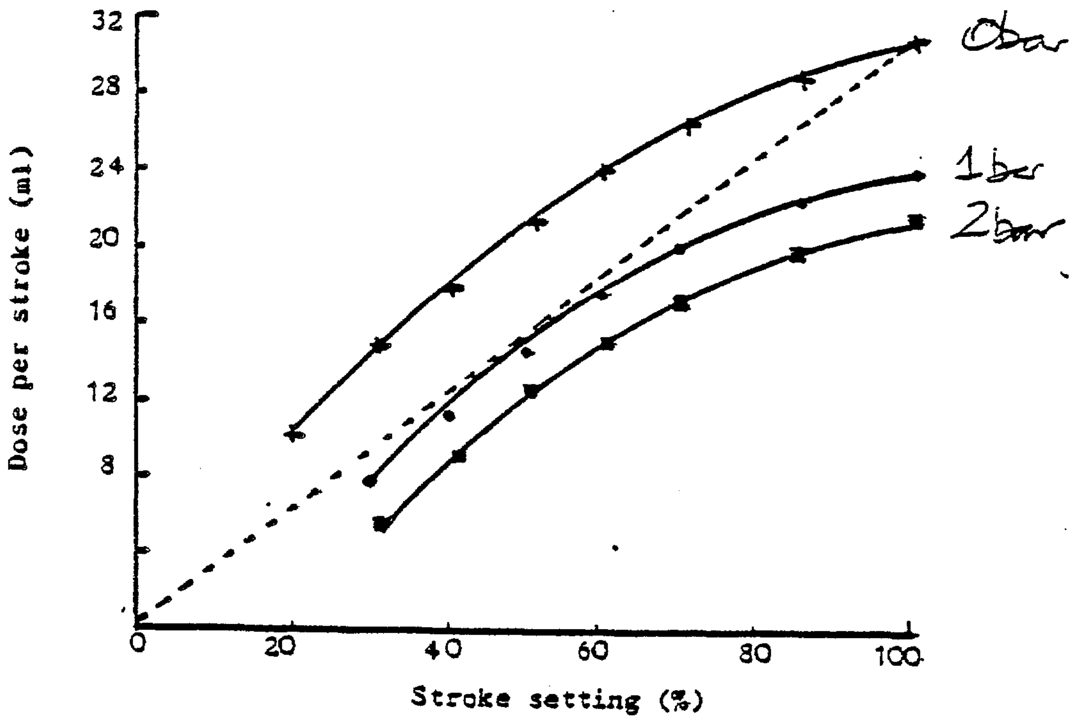



Figure 4.6.3 KVDP - Calibration Curves

APPENDIX 4.7

KVPG PISTON DOSING PUMP

## Tests

The pump was rated as follows:

| | |
|---|---|
| Delivery at full stroke | 5.46 l/h @ 24 str/min |
| Max delivery pressure | 14 bar |

The same test apparatus was used as on the other KV pump tested previously (Appendix 4.6). Calibrations were made of pump delivery against stroke setting at delivery pressures of 0, 1 and 2 bar with a positive suction head of 25cm wg (Fig 471) and a negative suction head, -75cm wg, (Fig 472).

It was found that delivery was proportional to stroke setting and was unaffected by the variations in suction head and delivery pressure. However, the calibration graphs did not pass through the origin. This implied a small loss of delivery on each stroke, perhaps due to the time needed for the valves to seat and seal.

Figure 2 has been marked with two heavy dashed lines, the higher showing the delivery to be expected from the measured stroke and diameter of the piston, and the lower showing the manufacturer's rating. This makes it clear that even a precision dosing pump may be subject to some inefficiency due to (for instance) the time required for the valves to seal on reversal of the piston. The loss per stroke appears to be reasonably constant over the range, which suggests a reasonably constant loss of fluid through the valves on each stroke.

When the pump was operated continuously for two weeks the output was found to decline from 45 ml/min to 38.6 ml/min. There did not appear to be any obvious reason for this.

## Conclusions

The precision of the pump was found to be well within acceptable limits for drinking water applications, and at all stroke settings above 10% the accuracy was good. There was a small loss of delivery on each stroke which appeared to be the result of the finite time taken for the valves to seat as the piston reversed.

The long term consistency of the unit tested was unsatisfactory, the output declining by 14% over a two week period.

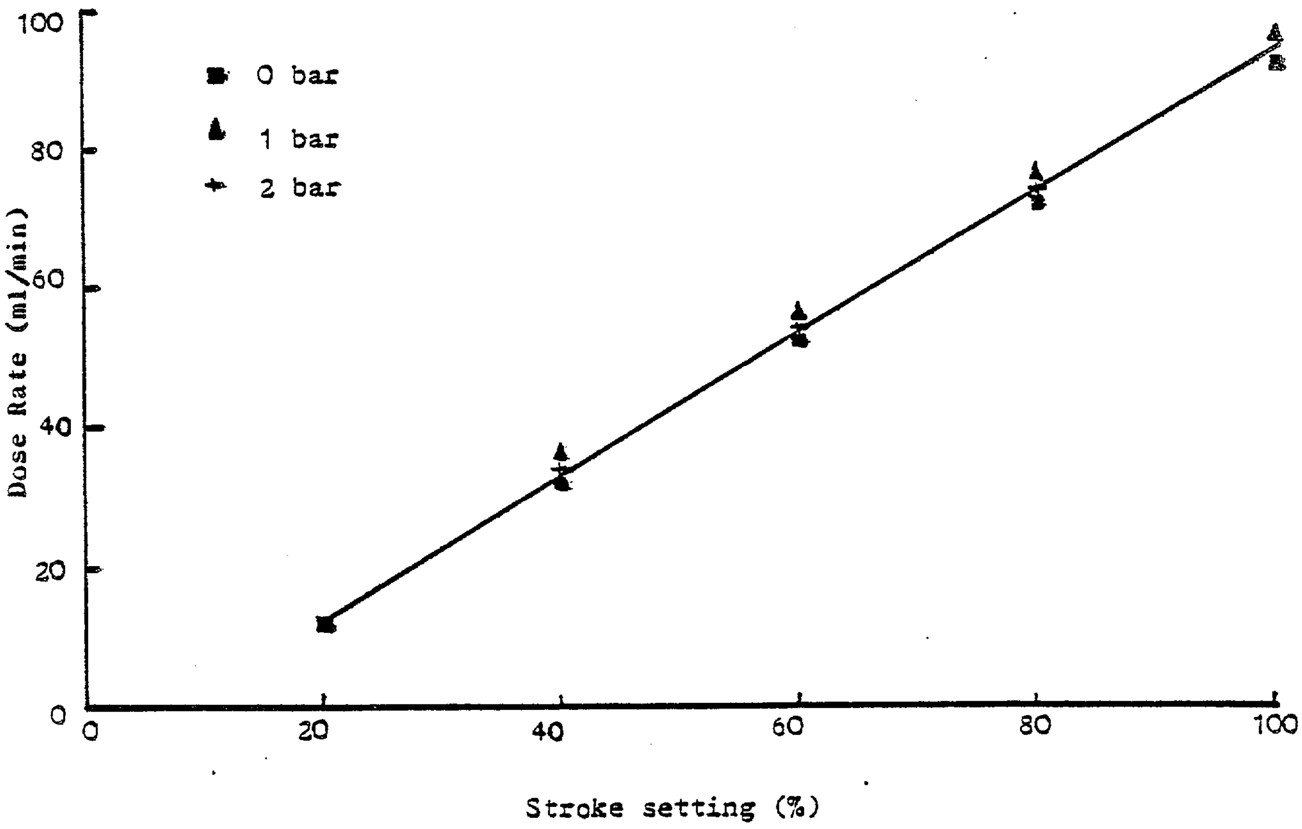



Figure 4.71 KVPG Calibration, Positive Suction

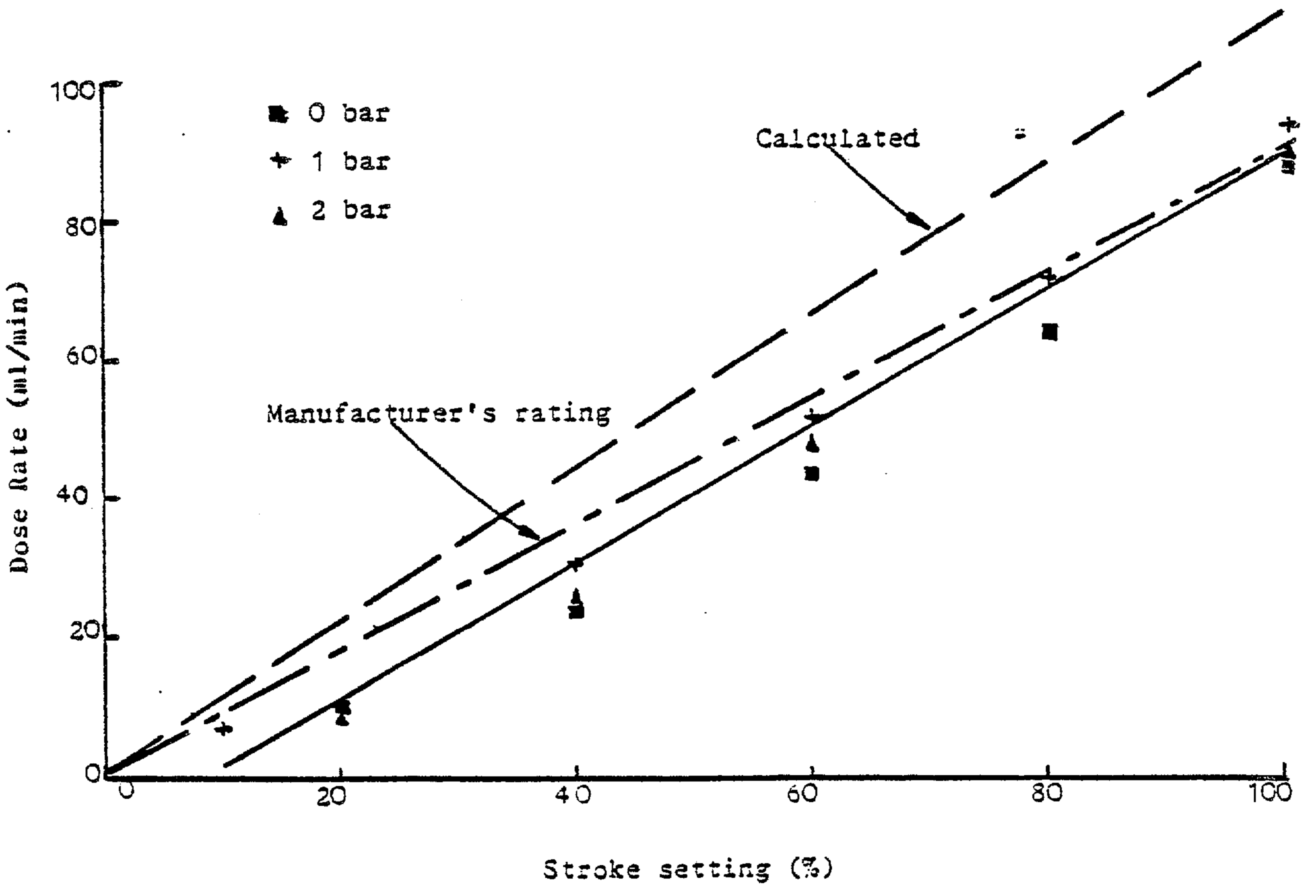



Figure 4.72 KVPG Calibration: Negative Suction

## Conclusions

The test showed that electronic timing of a solenoid actuator could give flow variations with a turndown ratio of 30:1 without the need to provide adjustment of stroke length. For many applications this range would be adequate. However, the calibration of the flow control knob did not permit very precise setting and there was no facility for locking the knob.

The variation of dose delivered per stroke of the pump was well within required limits at stroke rates above 25 per min, and just acceptable at the lowest flows, but only if the delivery pressures were kept constant.

The actual output of the pump was very sensitive to pressure especially in the range 0-3bar; it appeared that in this range 'supercharging' occured that resulted in the delivery per stroke being greater than the swept volume of the diaphragm cell. This could have a serious effect on the accuracy of dosing into water mains where the pressure may vary according to demand on the system.

The duckbill valve appeared to be more expensive to manufacture than a ball valve and there was no evidence in the unit tested that its performance was in any way better.

APPENDIX 4.8 MPL

MPL PUMPS LTD SUPER SOLENOID DIAPHRAGM PUMP

Tests

The timer was calibrated 0 to 100% with a separate switch to select one of four ranges; to 2, 5, 10 and 15 l/h. A turndown ratio of 10:1 was claimed for each range.

The nominal capacity was quoted as that obtained when working against 1bar pressure and a graph was given, Fig 481, showing how this was reduced as the total head across the pump increased.

Although the dose control knob was calibrated 0 to 100% and came to a definite stop at zero, it was possible to make a setting a little over 100%. The knob projected about 15mm from the panel, with the setting mark on top of the knob and the calibrations marked on the panel. Care was needed therefore to avoid parallax error in setting the dose. Fig 482 shows that the control was linear between 20% and 100%. It appeared that the maximum rate corresponded to a setting of 104%. There was a cut-off at a point between 10% and 20% at which the pump stopped stroking.

The pump was set at 100% on the 2 l/h range delivering into a pressure of 3bar while the suction head was varied from 1m negative to 1m positive. As the suction changed from negative to positive, the delivery increased from 28 to 29ml/min but otherwise there was no change over the range.

The delivery pressure was increased from 0 to 7 bar with a suction head of 0.25m. Fig 483 shows the result compared with the maker's claimed performance. Delivery was greater over the whole range but more affected by pressure than predicted. It seems likely that the output above about 2bar relates to the actual swept volume of the diaphragm cell and that at lower pressures there is some degree of 'supercharging'.

The variation in stroke delivery was measured at 3bar backpressure, -0.25m suction head and 0-100% flow. The results were plotted as delivery per stroke against strokes per minute, Fig 484. The average dose was 1.58ml/stroke. At stroke rates above 25spm, the variation was from 1.50 to 1.68ml/stroke (-5% to 6%) but at lower stroke rates there were variations up to 14%.

The pump was set up to run at 100% flow, -0.25m suction head and 1 bar backpressure on the 2 l/h range for a fortnight. However, after two days it was noted that the delivery had dropped to 50% of the initial value and on closer inspection a piece of rubber was seen in the delivery tube. The valves were then disassembled and it was found that the suction valve had a hole in it. The test was discontinued.

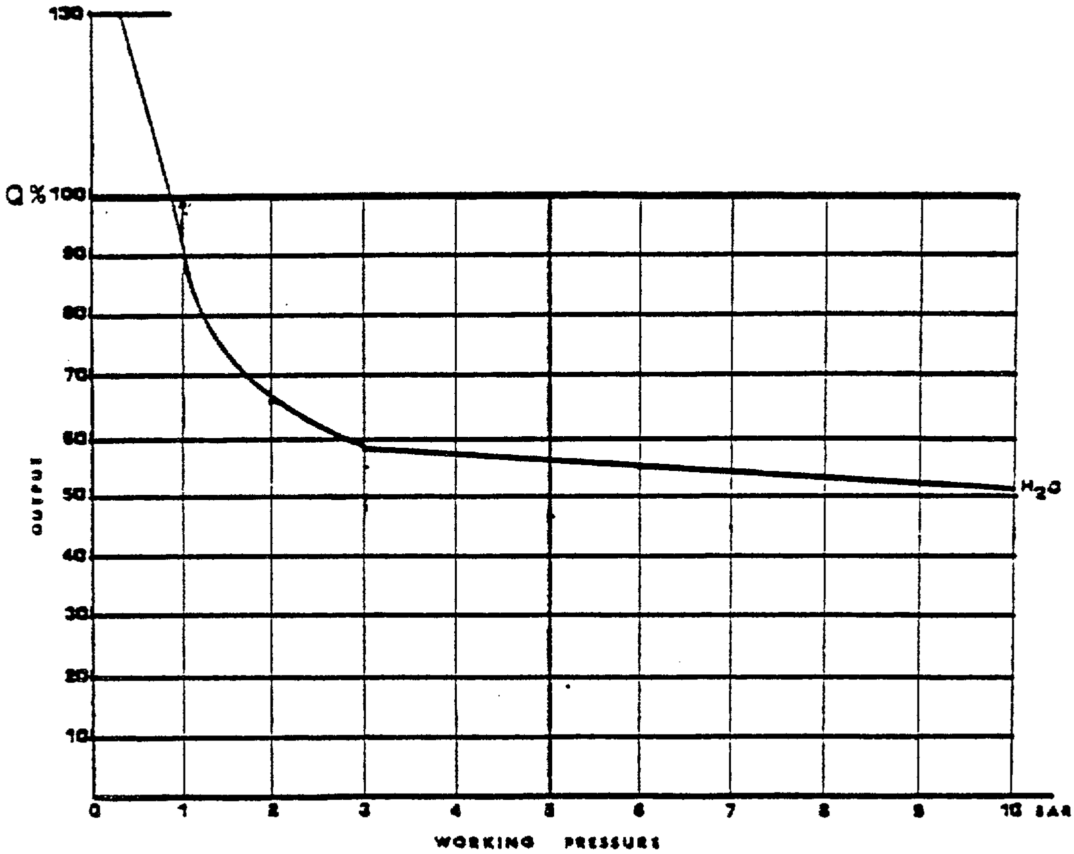



Fig.4.81. Typical characteristic of AG Super Pump

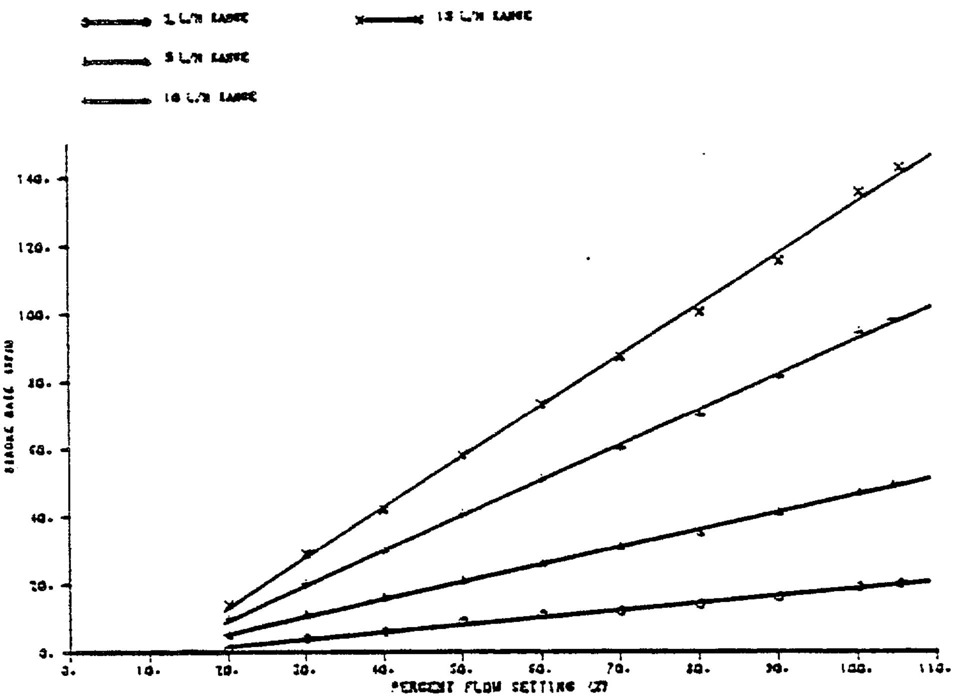



Fig.4.82. Frequency calibrations - AG Super Pump

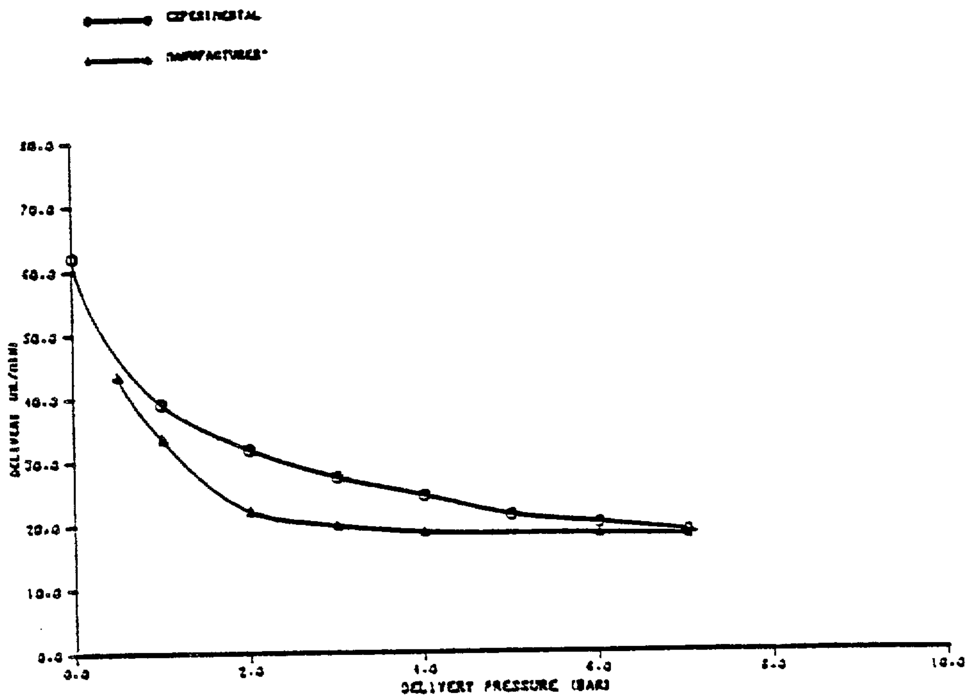


Fig 4B3. AG Super Pump - Claimed and Actual Performance

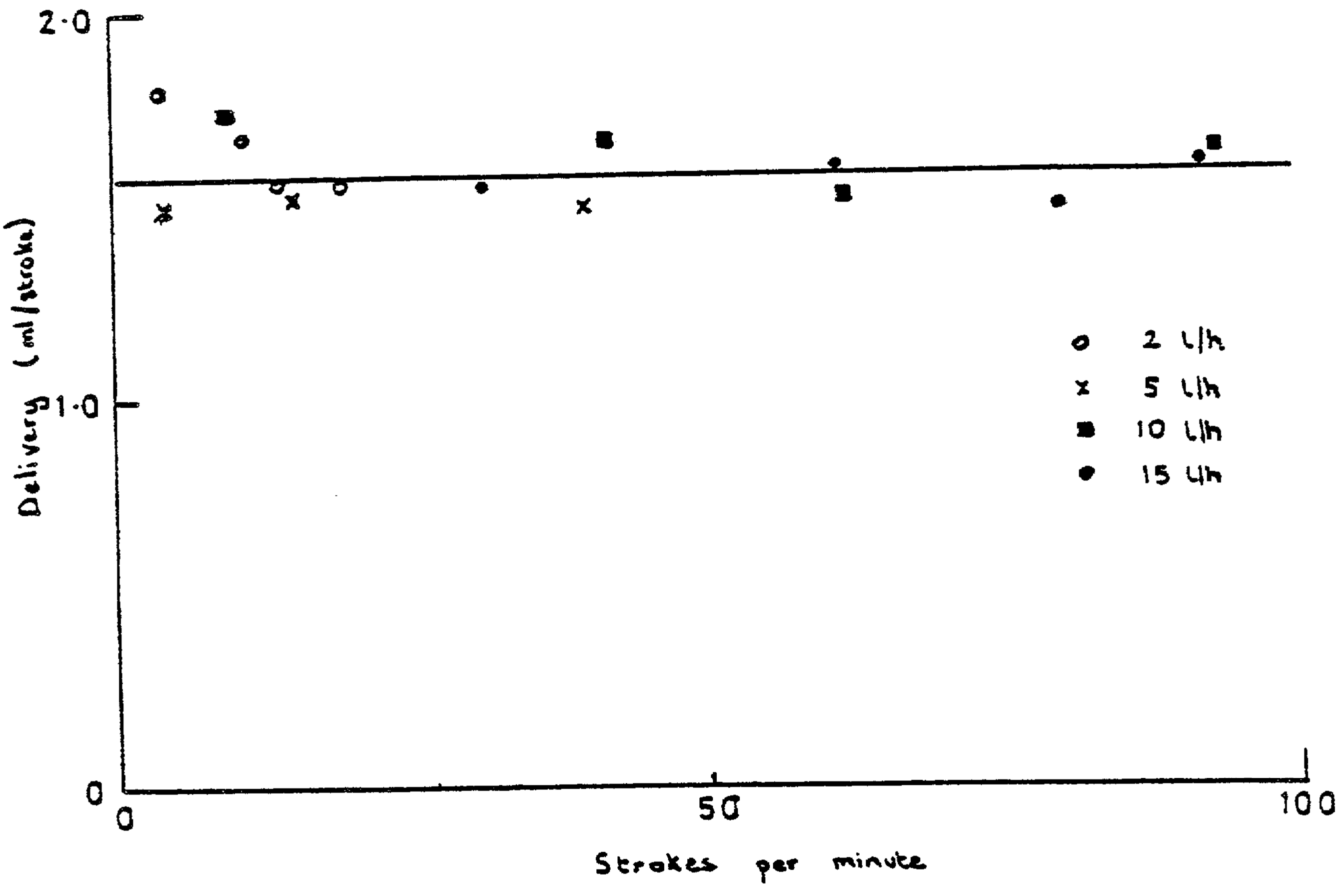



Figure 4B4 Variation in Stroke Delivery

## Introduction

The pump was rated by the manufacturer as follows:

| | |
|---|---|
| Maximum stroke rate | 120 str/min |
| Max delivery, 6bar | 0.33 ml/str |
| Max delivery, 10bar | 0.275 ml/str |

The pump was installed in the test rig shown schematically in Fig 491.

## Tests

The inital test carried out measured the maximum stroke frequency which was 112 SPM, the rated value being 120 SPM. The next test was to compare the delivery at 6 bar with the rated value of 0.33 ml/stroke. With a positive suction of 25 cm wg and maximum stroke rate, the delivery was measured as 0.47 ml/stroke.

The influence of suction head on pump delivery was investigated over the range -1.50 to +0.75 m wg at 100% stroke, maximum frequency and a delivery pressure of 2 bar. The results are shown on Fig 492 from which it can be seen that the delivery is independent of suction head.

Increasing delivery pressure had the effect of decreasing the pump output. The delivery pressure was varied from 0 to 7 bar at 100 % stroke, maximum frequency and a suction head of +0.25 cm wg. The results are shown on Fig 493. They indicate that at low pressures 'supercharging' occurs. The manufacturer recommends the fitting of a loading valve downstream of the pump for applications below 0.5bar.

The linearity of the stroke control was investigated at a delivery pressure of 6 bar, a suction head of +0.25 cm wg and max. stroke frequency. The results are plotted on Fig 494, from which it can be seen that the delivery is directly proportional to the stroke setting within 3 %. On the same figure is plotted the maker's rated delivery of the pump. At all stroke settings the actual delivery is greater than the rated value.

The pump was left running for three weeks at 100% stroke, maximum frequency and a delivery pressure of 2bar. The delivery was found to vary up to +/-8% about the mean, with variations noted in both stroke rate and delivery per stroke.

## Conclusions

The pump delivery was independent of suction head over the range -1.5 to 0.75m wg.

Between 1 and 6 bar the delivery was virtually independent of delivery pressure. Below 1 bar the delivery increased rapidly from 0.55 to 1.1 ml/str at 0bar, this being due to the 'supercharging' effect typical of solenoid driven pumps. A loading valve should be fitted for applications at low pressures.

The stroke control allowed for linear adjustment of delivery. Delivery exceeded the maker's rating by about 25% at all settings. During continuous running the delivery varied by up to +/-8%, approaching the limit of +/- 10% recommended for drinking water applications.

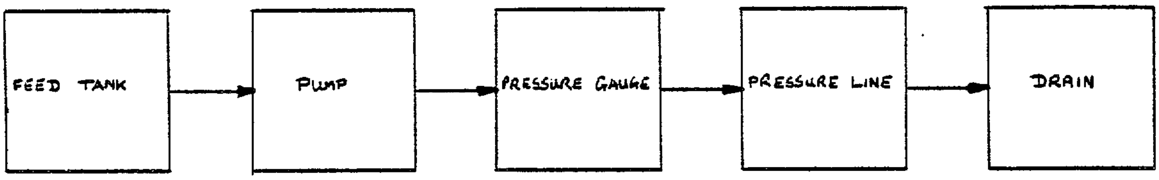
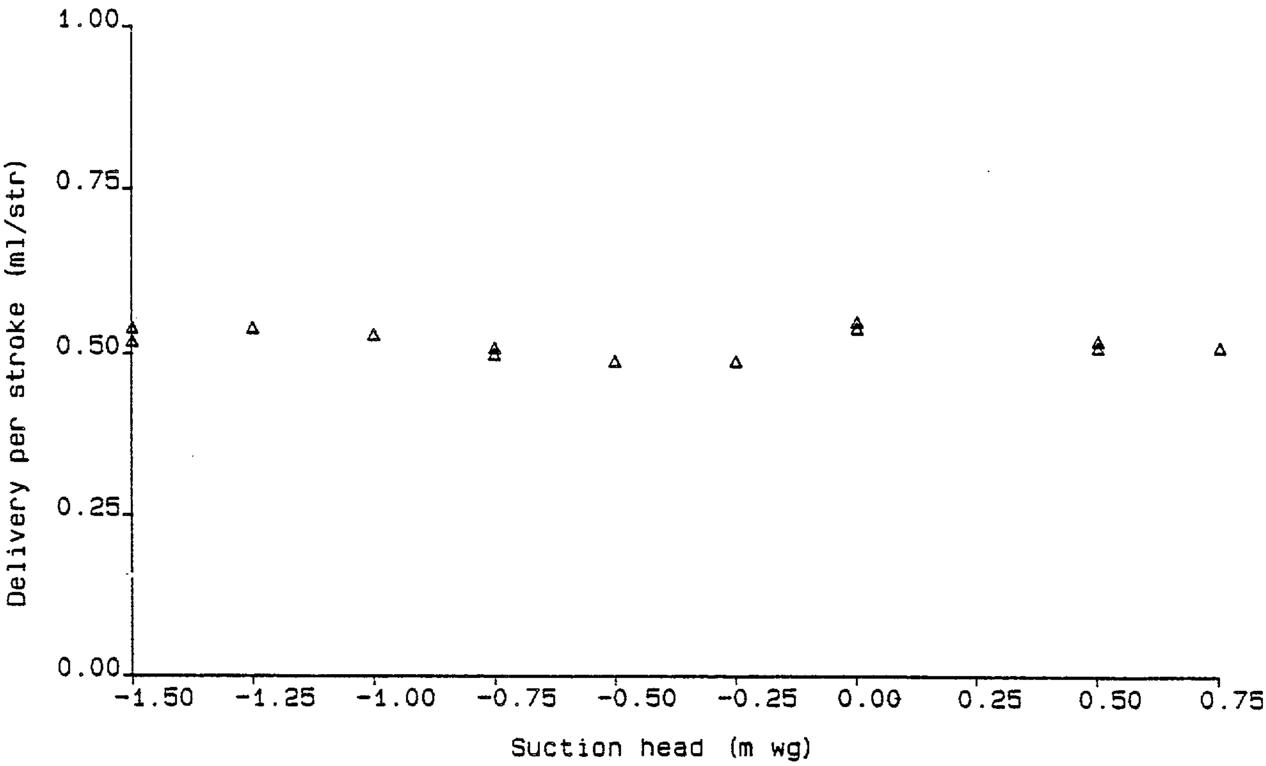



FIG 4.9.1 SCHEMATIC DIAGRAM OF TEST APPARATUS

Fig 4.9.2 Effect of Suction Head on Delivery



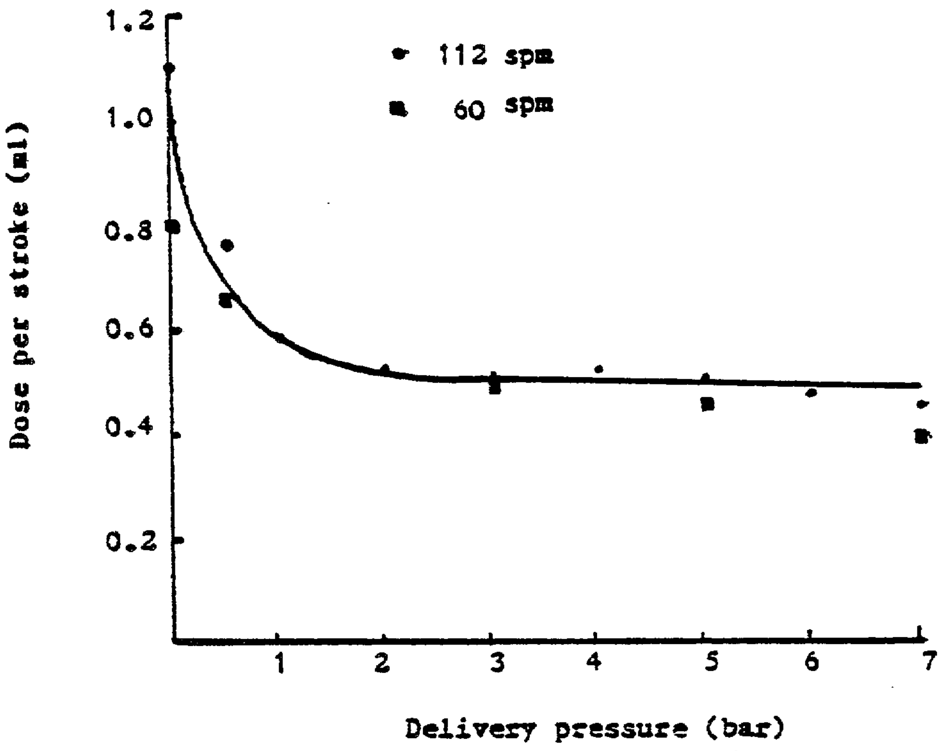



Figure 493 Prominent - Variation of dose with delivery pressure

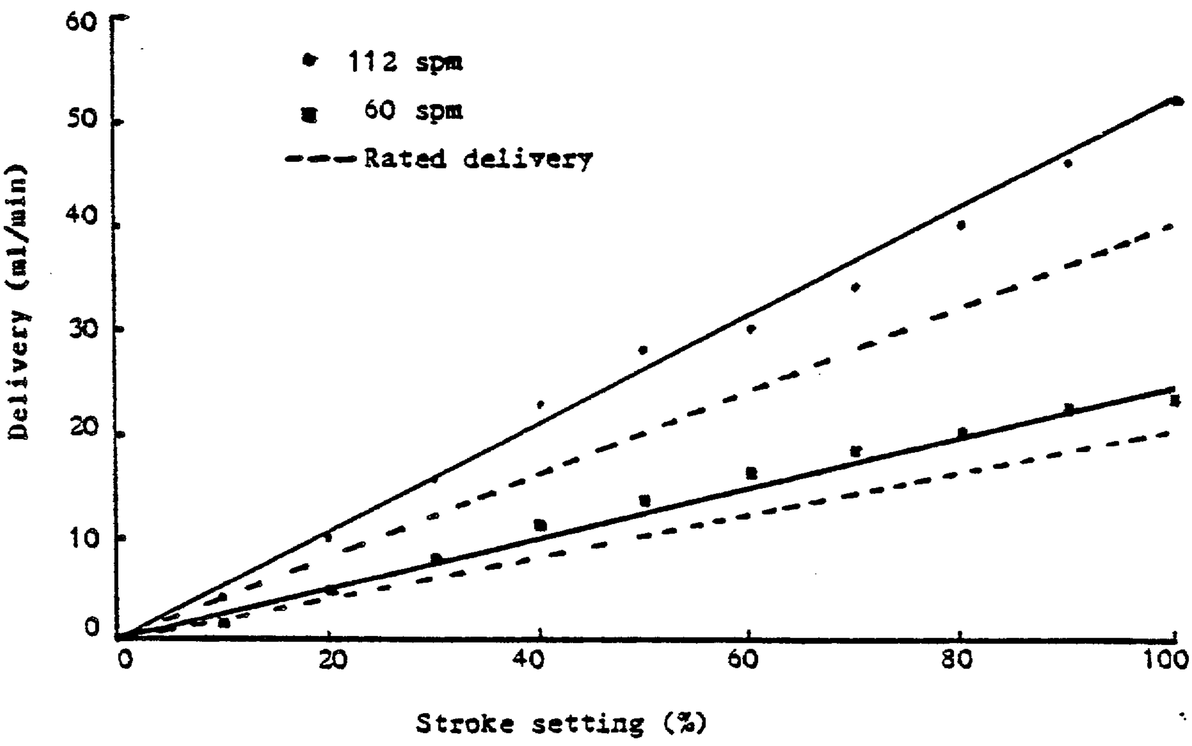



Figure 494 Prominent - Calibration

## APPENDIX 4.10 PROMINENT A2001N 12V DC DIAPHRAGM DOSING PUMP

Manufacturer's Rating

| | | |
|---|---|---|
| Maximum stroke rate | 120 | str/min |
| Max. delivery, 14 bar | 0.11 | ml/str |
| Max. delivery, 20 bar | 0.09 | ml/str |

Tests

The inital test on the pump measured the maximum stroke frequency which was 113 str/min, the rated value being 120 str/min. Next, the dose at 6 bar and 100% stroke and frequency was measured, 0.176 ml/stroke; from a calibration chart in the handbook the rated dose per stroke was estimated as 0.177 ml.

The effect of suction head on delivery was determined over the range -0.75m wg to +0.75m wg, at 100% stroke & frequency and 3 bar delivery pressure. The results, Fig 4101, indicate that over the tested range the delivery was independent of suction head.

The influence of delivery pressure, over the range 0 to 6 bar, was investigated at 50% stroke & frequency and -0.25 m.wg. suction head. The results, Fig 4102, show that there was a decrease in delivery with increasing delivery pressure. Also plotted on figure 2 is the rated delivery, showing that the actual delivery was less than the rated values over the test range.

The linearity of the stroke control was investigated at 3 bar, 50 % frequency and -0.25 m.wg. The results, Fig 4103, show that the delivery was directly proportional to the stroke setting.

The linearity of the frequency control was also investigated. At a delivery pressure of 3 bar, 50% stroke and suction head of -0.25 m.wg. The results, Fig 4104, show that the delivery is proportional to the frequency setting, however the curve showed a large jump between 30% and 40%. From a discussion with the makers it was concluded that the pump had not been correctly set-up in the factory. The test was repeated when the pump was returned from the factory; the results showed a linear relationship between frequency and delivery.

The pump was then put on a continuous running test, powered by a fully charged 12V 18Ah car battery. It was set at 100% frequency and 100% stroke. The test was started midweek and the pump ran steadily for 2 days but the battery was flat after the weekend. Allowing for a minimum of 50 hours' running, the average current taken by the pump would have been 0.36A, corresponding to a load of 4.32W. It may have been, however, that the running period was closer to 100 hours. Unfortunately this test was not repeated.

## Conclusions

The pump delivery was independent of suction head, while the influence of back pressure was less than with some other solenoid type dosing pumps. After a peak delivery at zero back pressure, due to 'supercharging', delivery fell about 25% by 1 bar, but only by about 15% between 1 and 7 bar. The delivery was however found to be lower than the maker's rating.

Adjustment of both stroke length and frequency was linear.

The continuous running test showed the pump to be capable of maintaining a constant delivery over several days, although attention must be given to providing sufficient battery capacity.

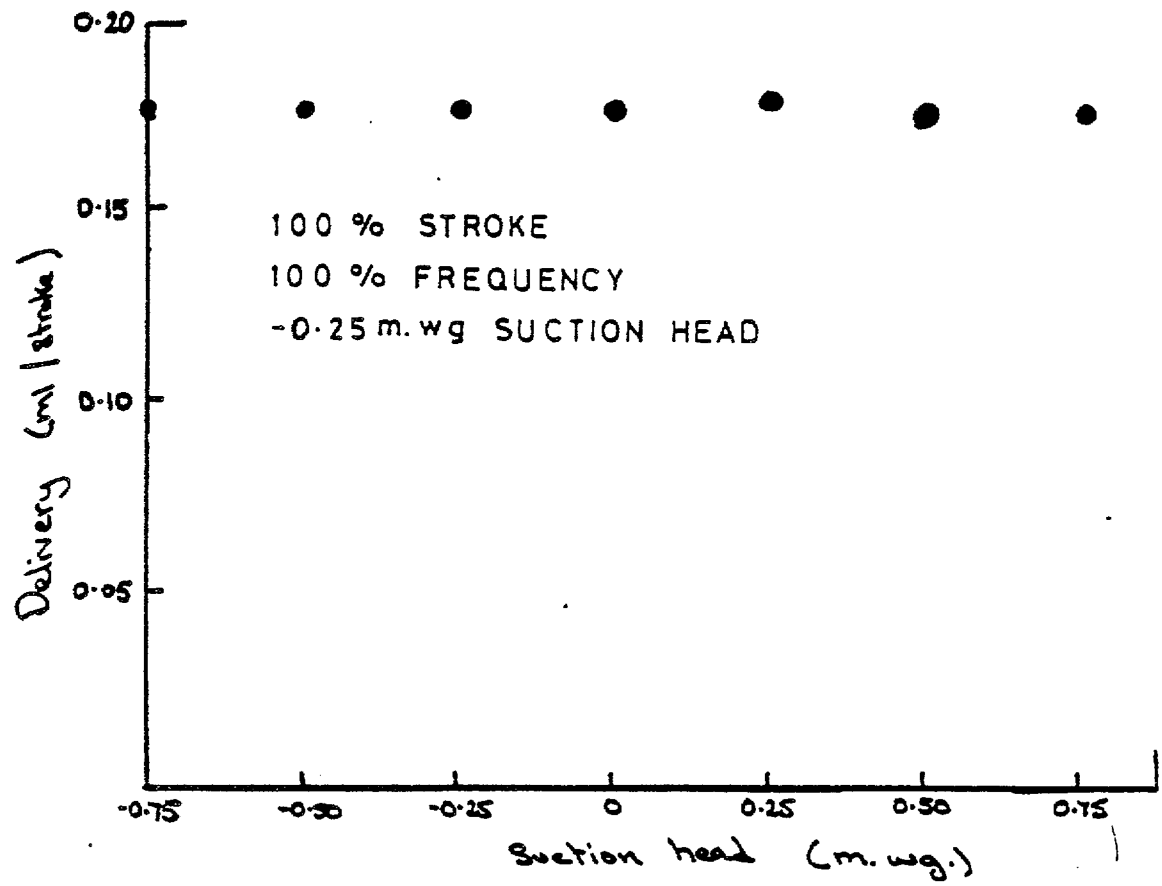



Figure 4101 Influence of Suction head on Delivery

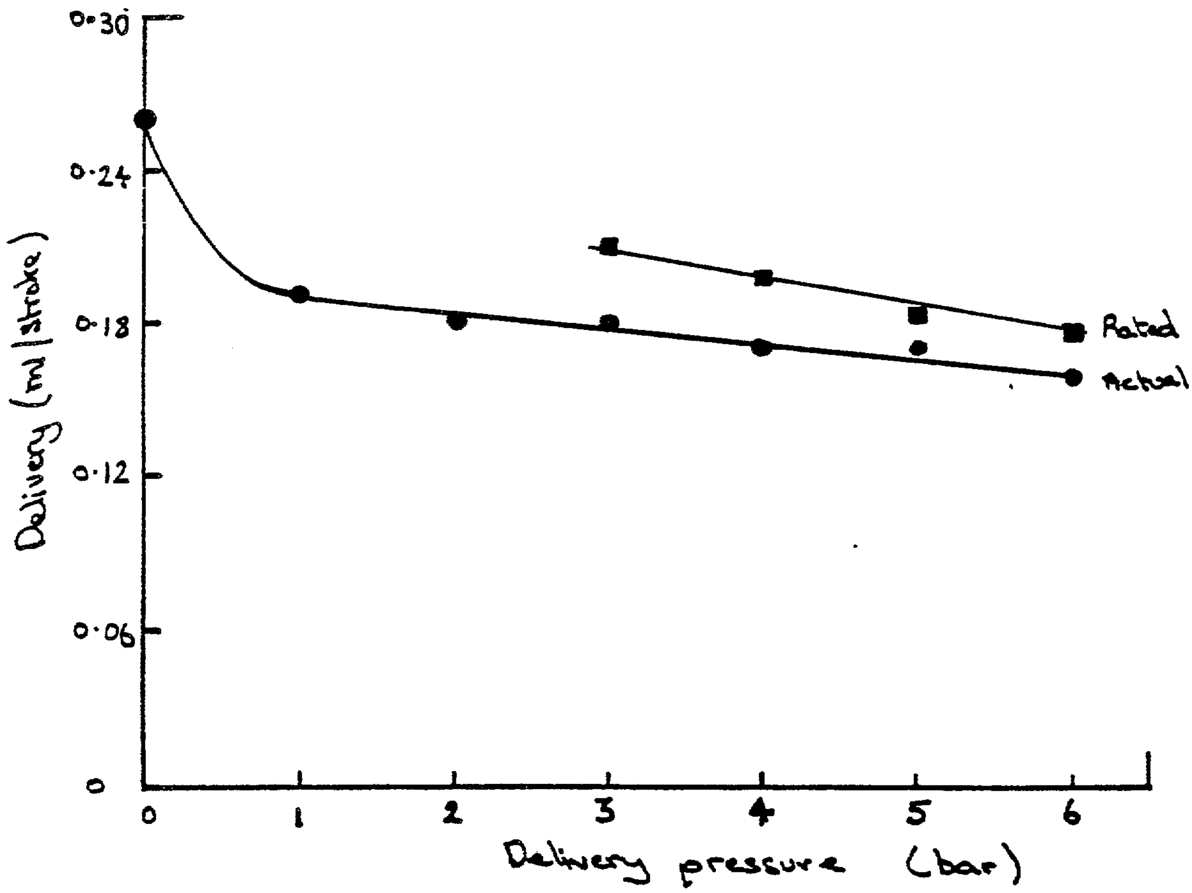



Figure 4102 Influence of Delivery Pressure

Fig 4.103 Calibration of Stroke

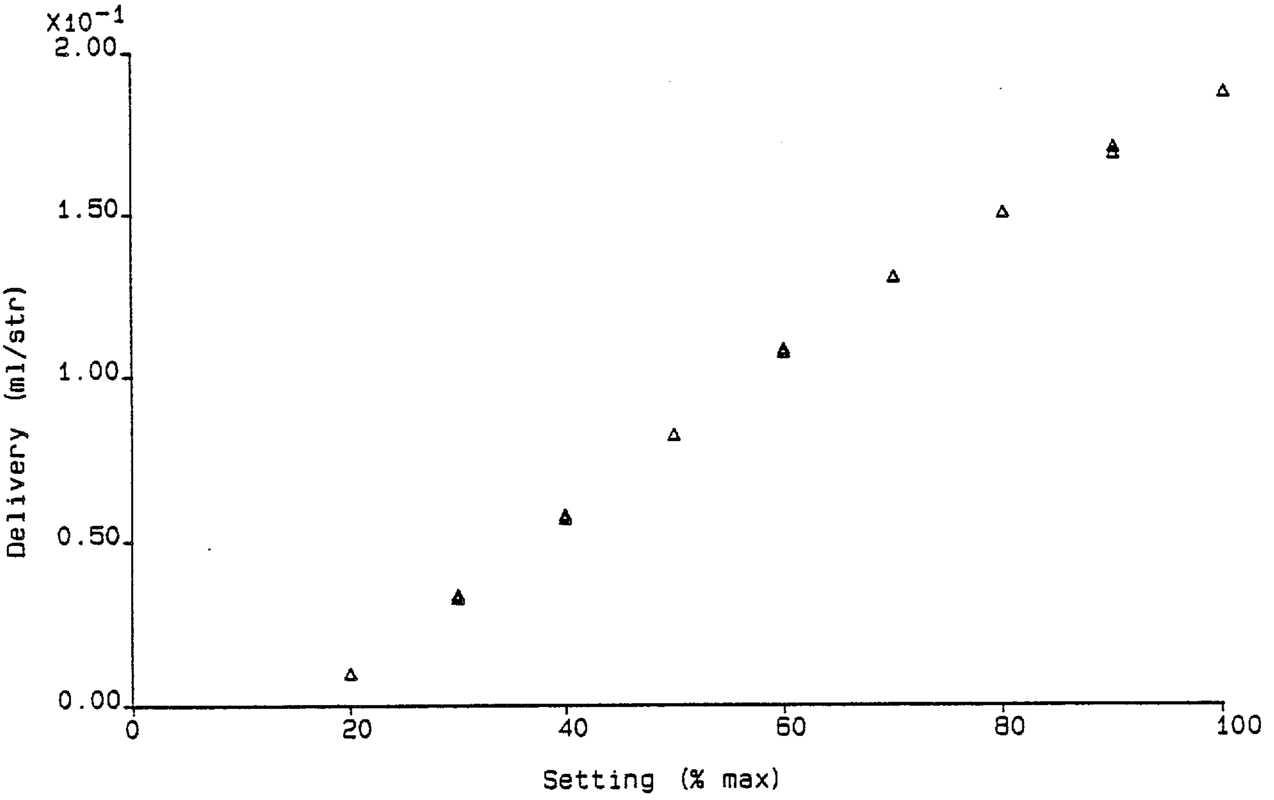
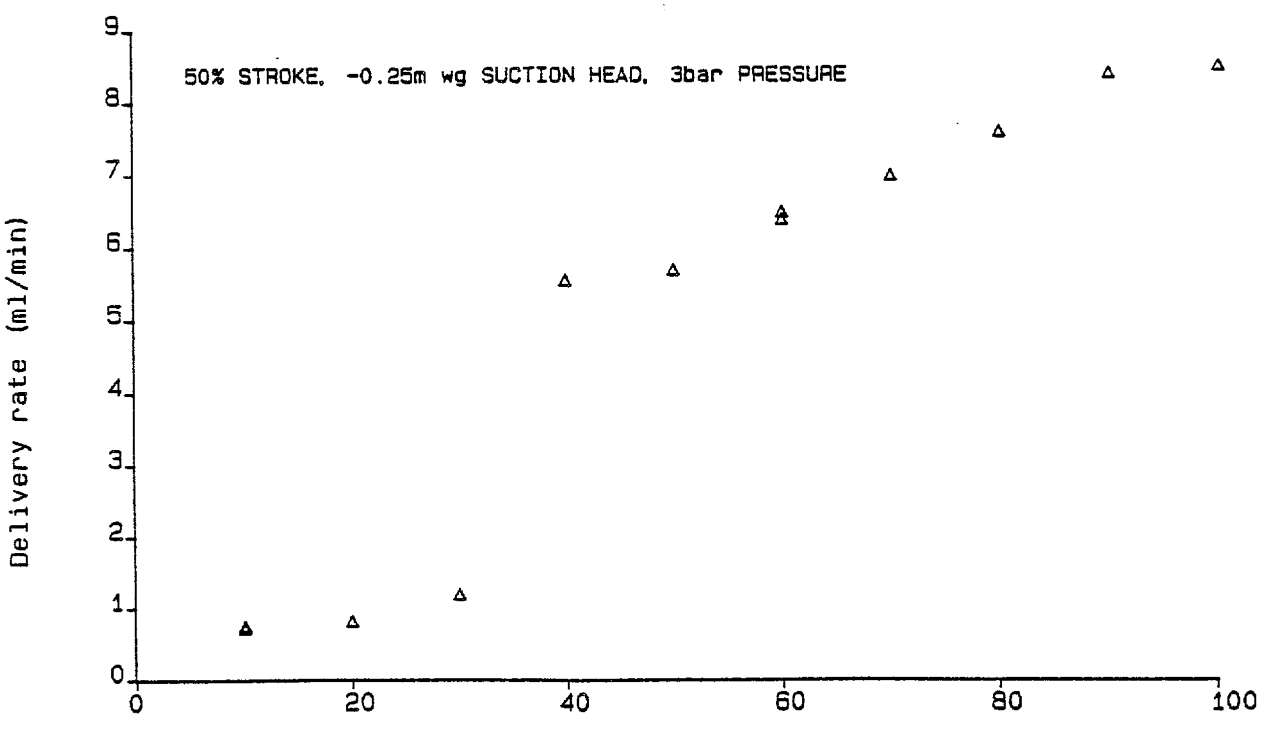



Fig 4.104 Calibration of Frequency
(Before Factory Reset)



APPENDIX 4.11 PROMINENT E2001N METER-CONTROLLED DIAPHRAGM DOSING PUMP

Introduction

The pump was rated as follows:

| | | |
|---|---|---|
| Maximum back pressure | 20 | bar |
| Max.delivery, 20bar | 0.54 | l/h |
| | 0.09 | ml/str |
| Max. delivery, 14bar | 0.66 | l/h |
| | 0.11 | ml/str |
| Max. stroke rate (frequency) | 100 | str/m |
| Min. stroke rate | 4 | str/min |

The NG5 meter was rated:

| | | |
|---|---|---|
| Minimum flow rate | 20 | l/h |
| Maximum flow rate | 5000 | l/h |
| Dosing interval | 2 | l/pulse |
| Dosing rate | 25-250 | ml/cu m |
| Nominal pressure drop | 0.8 | bar |

TESTS

The Meter

In order to test the meter, water at known flows between 10 and 90 litres per minutes was passed through it and the number of pulses per minute recorded on an electronic counter. The results, shown on Fig 4111, show that the number of pulses remained constant at one per every two litres over the range tested.

The Pump

For most of the following tests the meter was detached and the stroke rate (frequency) set manually, in order to isolate the different factors in the pump's performance.

The inital test on the pump was to measure the maximum stroke rate; it was 103str/min, the rated value being 100str/min. The minimum frequency was 4str/min. Next, the dose at 7 bar and 100% stroke and frequency was measured as 0.186 ml/stroke. From a calibration chart in the handbook the rated dose per stroke was estimated as 0.148 ml.

The influence of delivery pressure, over the range 0 to 7 bar, was investigated at 100% stroke & frequency and -0.25m wg suction head. The results, Fig 4112, show that there is a decrease in delivery with increasing delivery pressure. The reduction in delivery from 1 to 7 bar was 10% but from 0 to 1 bar was over 20%. This is indicative of the 'supercharging' that usually occurs in solenoid pumps at the lower end of their operating pressure ranges. Also plotted on Fig 4112 is the rated delivery, showing that the actual delivery was greater that the rated values over the test range.

The effect of suction head on delivery was determined over the range -0.75m wg to +0.75m wg, at 100% stroke & frequency and 5 bar delivery pressure. The results, Fig 4113, indicate that over the tested range the delivery is independant of suction head.

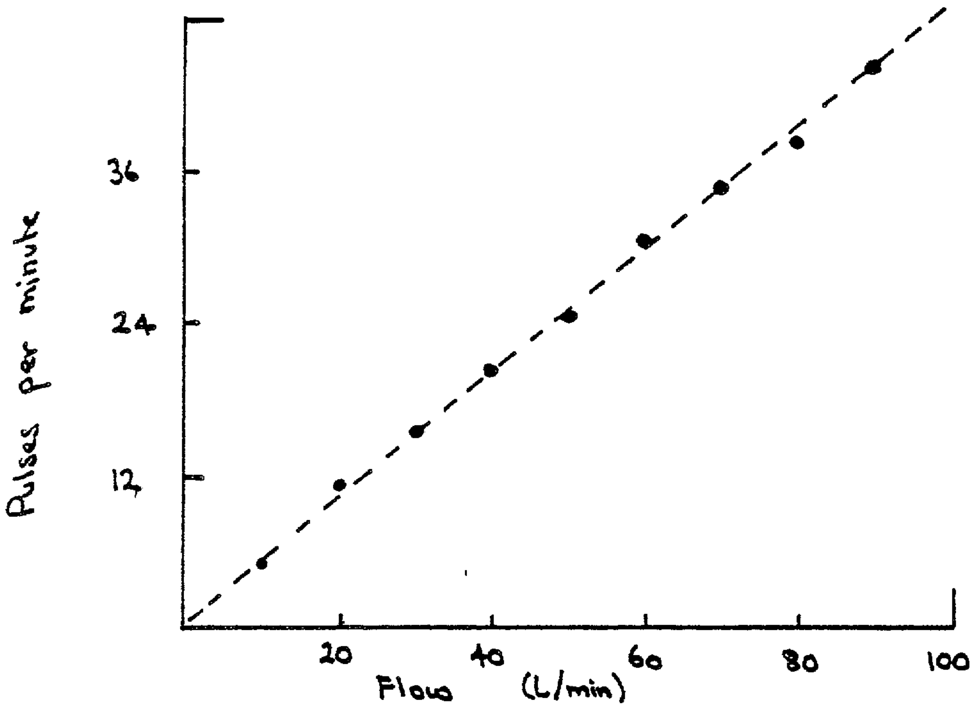



Figure 4.11.1 Calibration of Water meter

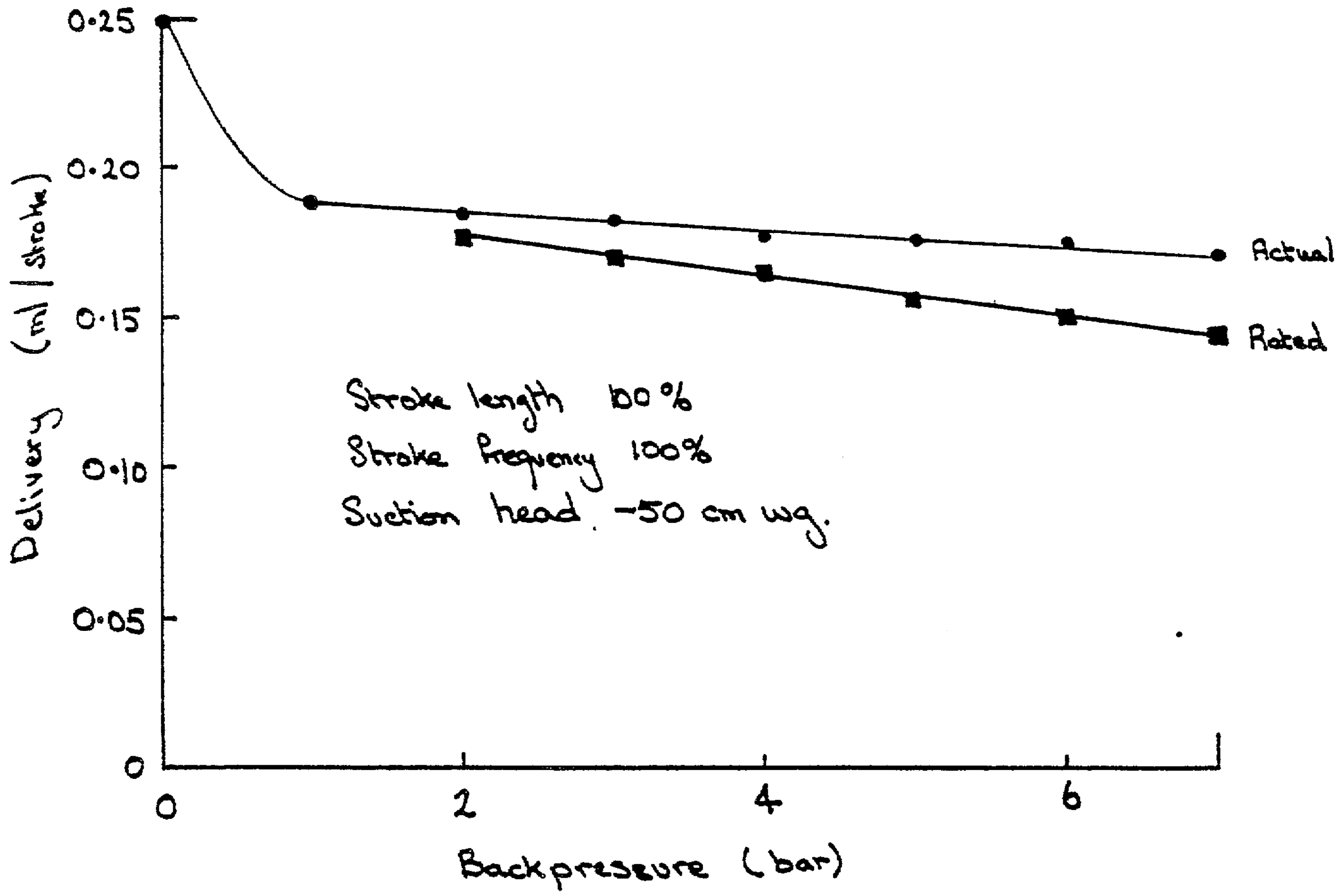



Figure 4.11.2 Influence of Backpressure on Delivery

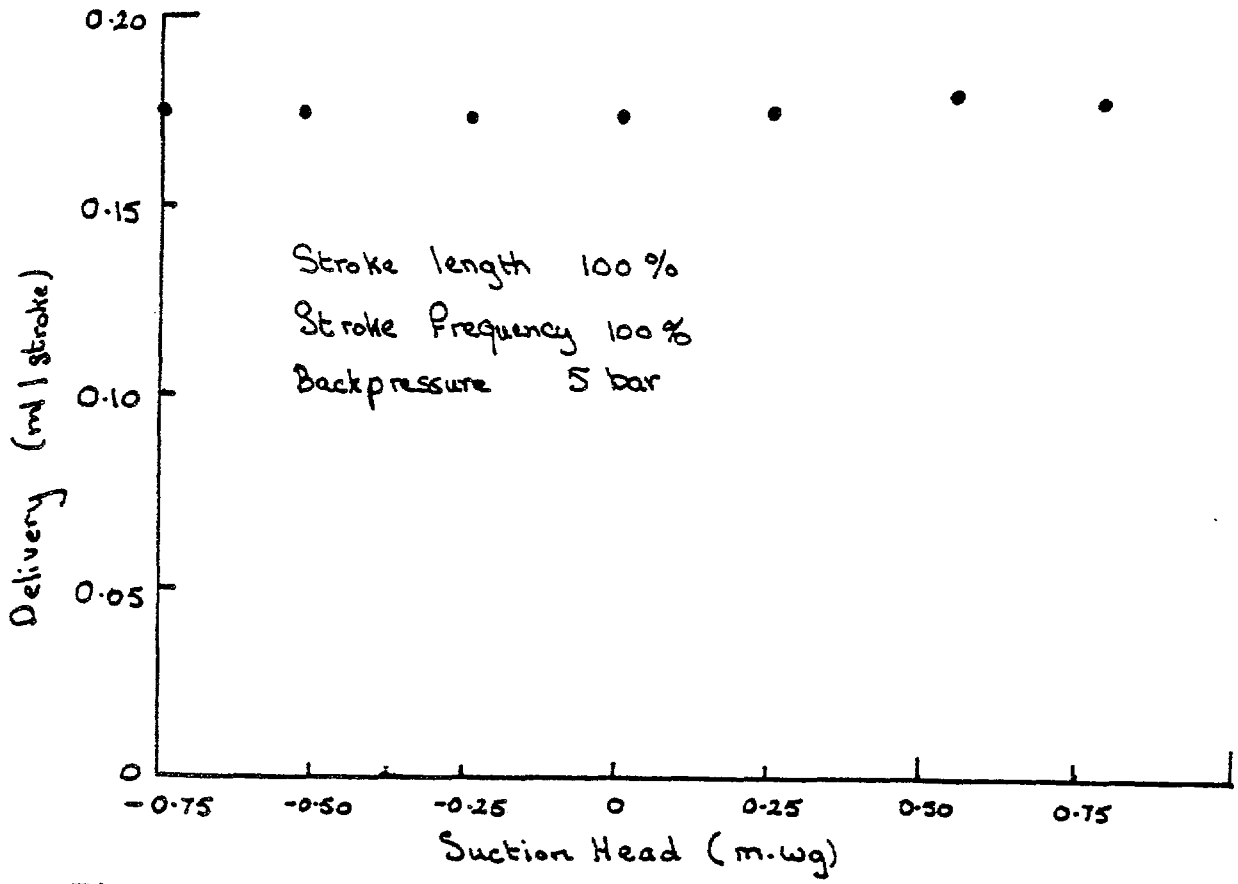



Figure 4113 Influence of Suction Head

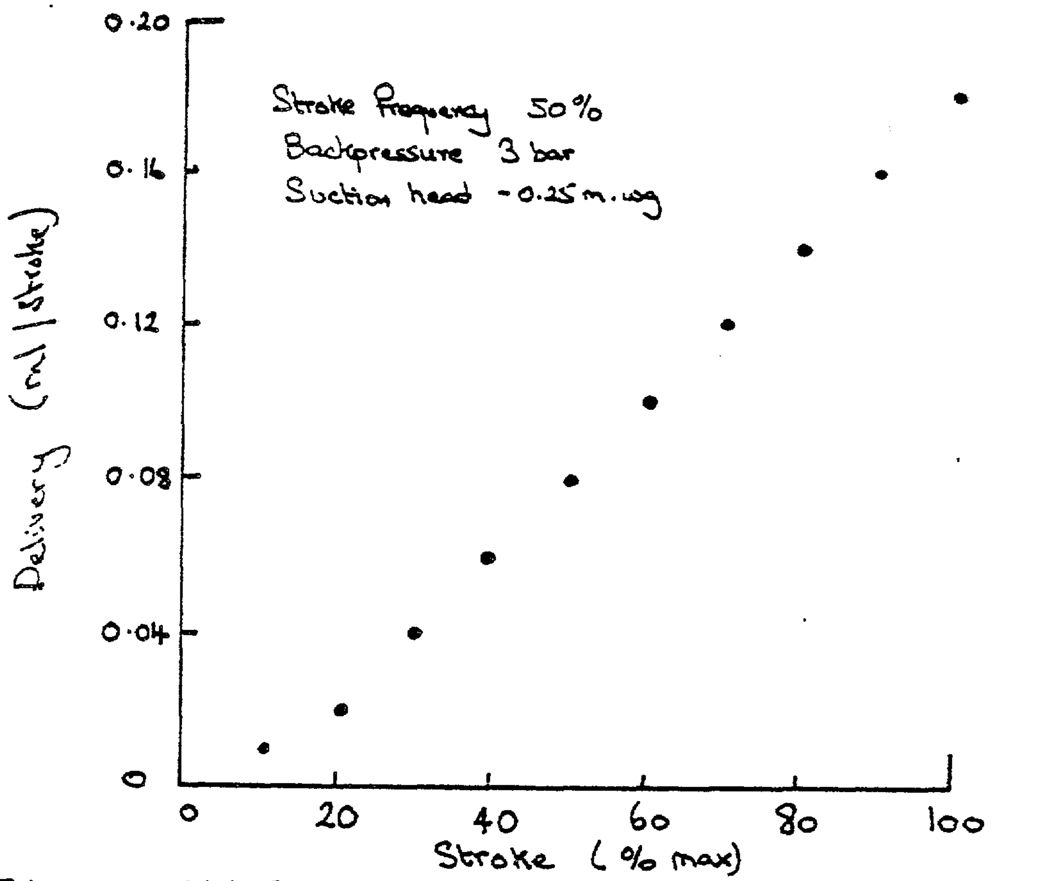



Figure 4114 Calibration of Stroke Setting

The linearity of the stroke control was investigated at a delivery pressure of 3 bar, 50 % frequency and -0.25 m.wg. The results, Fig 4114, show that the delivery is linear to the stroke setting but not quite proportional to flow.

The linearity of the frequency control was also investigated. At a delivery pressure of 3 bar, 50% stroke and suction head of -0.25 m.wg. The results, Fig 4115, show that the delivery is directly proportional to the frequency setting.

Finally, the pump was run continuously for 1 month at 50% stroke, -0.25mwg suction head and 0.5 bar delivery pressure. No delivery measurement varied by more than 2% over this period.

## Conclusions

For maximum precision the manufacturer recommends a loading of at least 1.5bar and a stroke setting of more than 30%. The tests showed that acceptable performance extended beyond these limits, although if dosing into an open line a loading valve should be fitted to the pump.

The flow meter output signal was proportional to flow rate

Pump delivery was independent of suction head and decreased only slightly with increasing pressure. 'Supercharging' was limited to the 0 to 1 bar range, the delivery rising by 20% between 1 and 0 bar.

Both the stroke length and frequency adjustments were linear

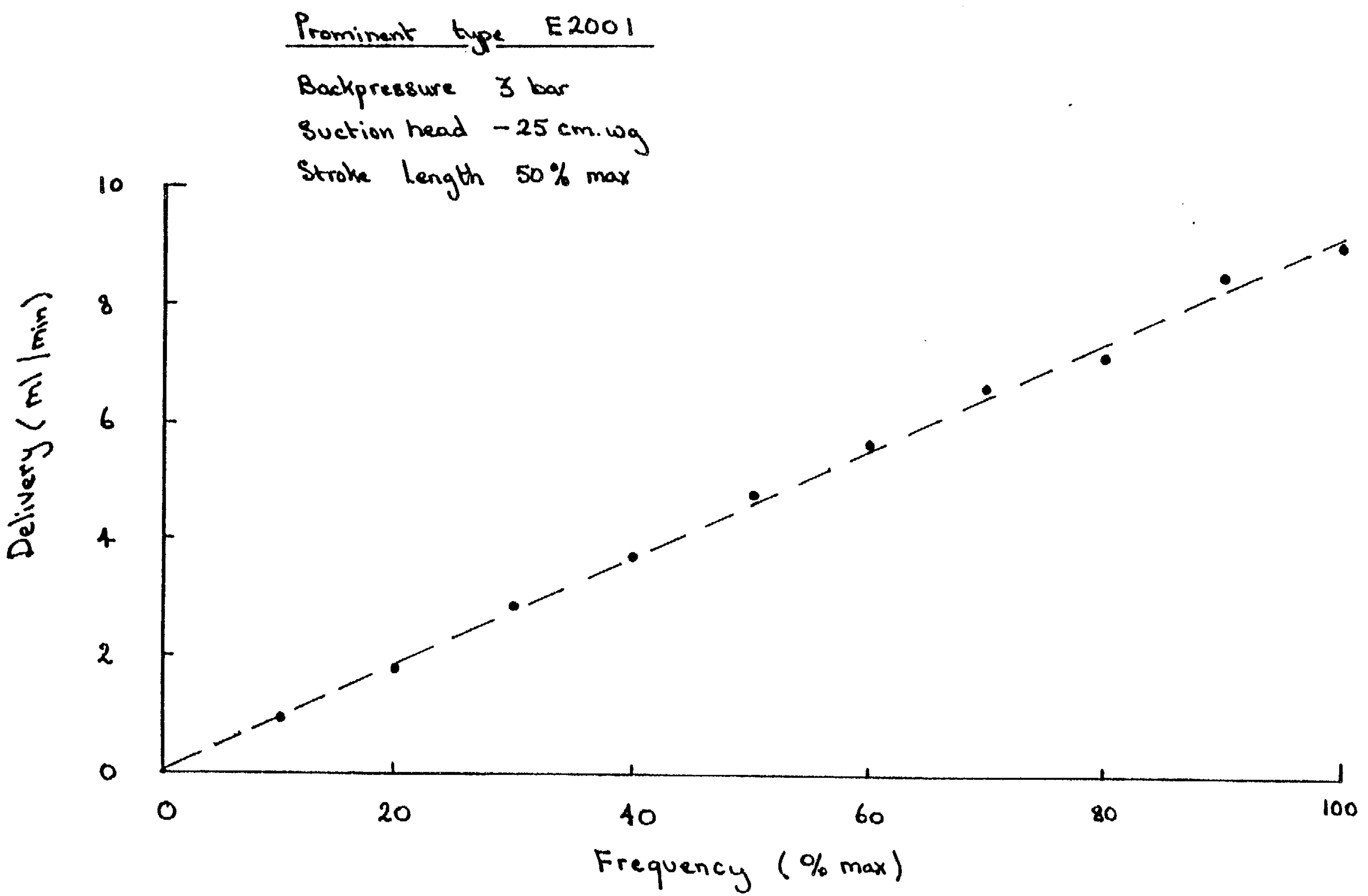



Figure 4.15 Calibration of Frequency Control

## APPENDIX 4.12 TESTS ON ALLDOS P201-105

Introduction

The manufacturer claimed that the pump had a virtually unvarying characteristic curve when compared against backpressure. The mechanical variation of the pump output range was 10:1 and when used in conjunction with the UNIDOS controller this was increased to 100:1. A summary of the manufacturer's technical specification is shown in Table 4.4.

Table 4.4 Maker's Specifications

| | |
|---|---|
| Strokes per minute | 60spm maximum |
| Stroke capacity | 0.4ml/str minimum |
| Accuracy | +/-4% at max output |
| Suction lift | 1.0m w |
| Back pressure | 10bar maximum |
| Maximum capacity per cu m of water at 10bar back pressure | 400ml |
| Max water throughput | 83.3 l/min |
| Min water throughput | 0.5 l/min |

The Dosing Pump

The dosing pump was installed in accordance with the manufacturer's recommendations, Fig 4121. The maximum stroke rate was confirmed as 60 spm by passing water at 83 l/min (rated maximum water flow rate) through the meter and measuring the number of strokes over 3 minutes.

The influence of backpressure was then investigated over the range 0 to 7 bar, at a suction head of -0.25 m wg. The results are shown on Fig 4122, together with the manufacturer's characteristic curve. Extrapolation of the experimental results indicate that a dose of 0.40 ml/stroke could be expected at a backpressure of 10 bar. This corresponds with the manufacturer's technical data. Over the tested range the experimental results coincide well with the rated performance.

The rated maximum suction head of the pump is stated as 1.00 m wg. When dosing against a backpressure of 1 bar the dose was found to remain constant at 0.49 ml/stroke +/- 2% over the range of -1.00 to +0.50 m wg suction head whilst at 5 bar backpressure the dose remained constant at 0.41 ml/stroke over the same range. The results are shown on Fig 4123.

The stroke length was varied from 0 to 100% at backpressures of 1 and 5 bar and a suction head of -0.25 m wg. The results are plotted on Fig 4124. Both sets of results exhibit a directly proportional relationship between dose rate and stroke setting. The experimental results at 5 bar coincide with the maker's rated delivery.

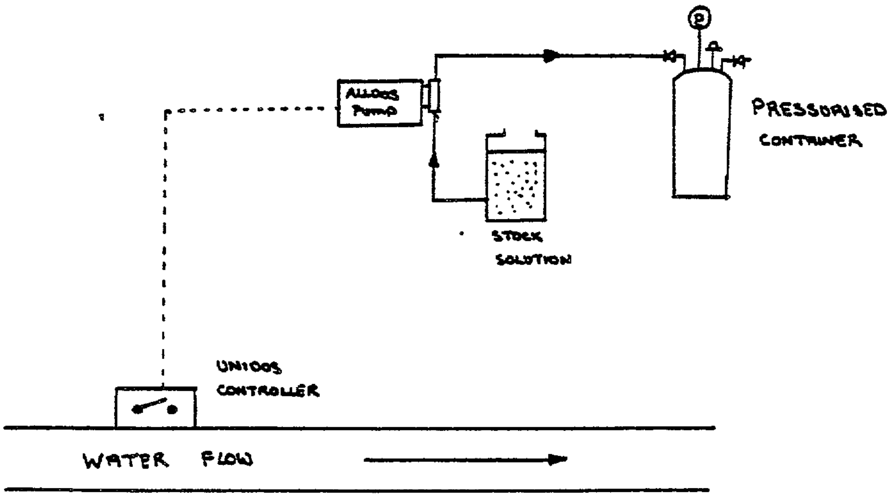



FIGURE 4121 EXPERIMENTAL APPARATUS

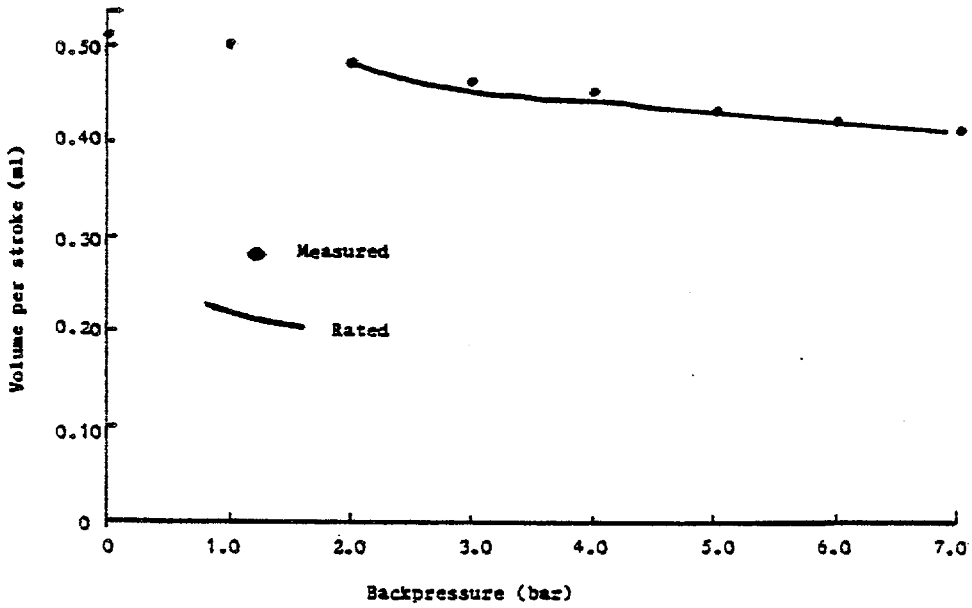
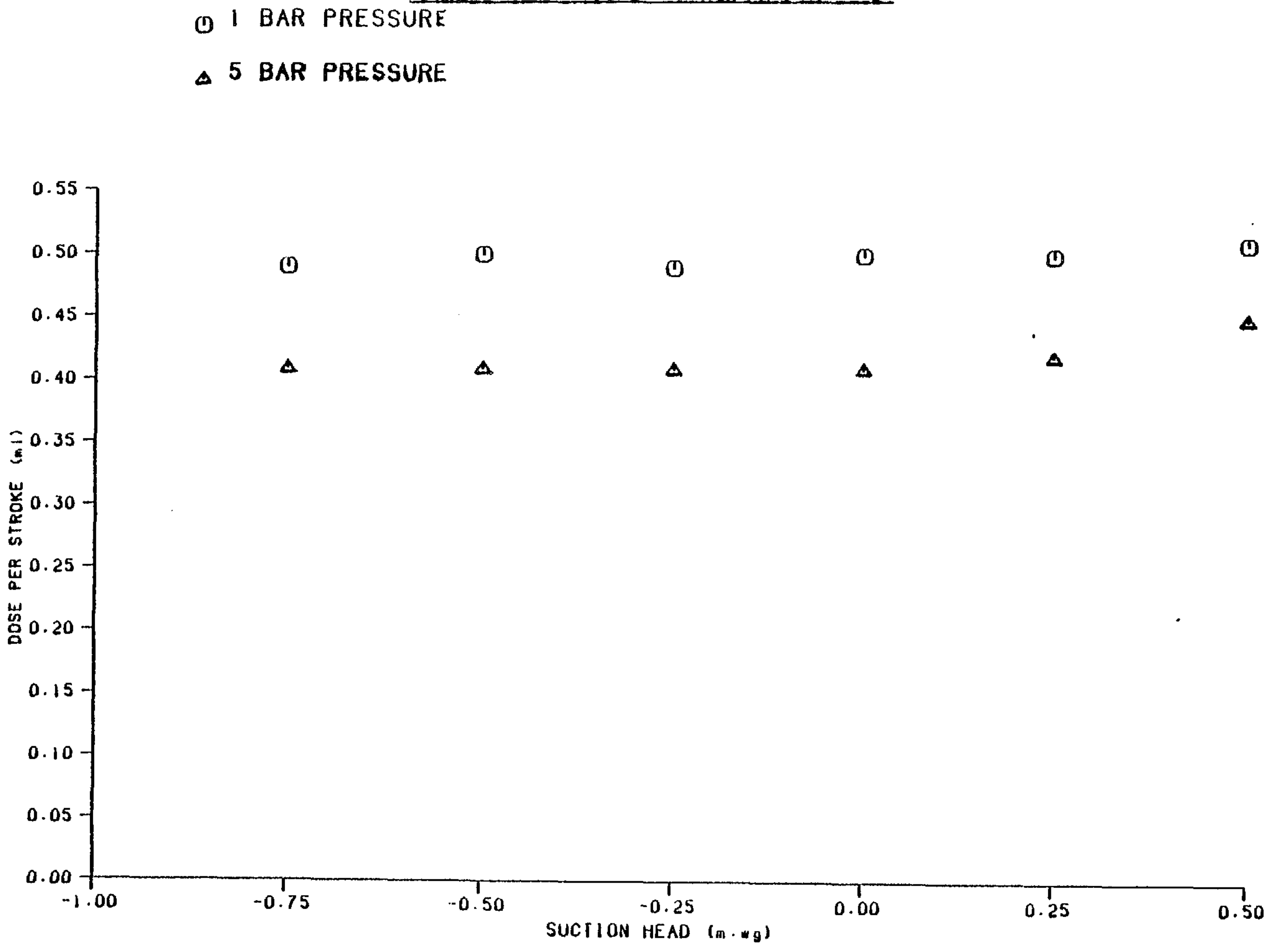



Figure 4122 Alldos - Variation of delivery with pressure

FIGURE 4.12.3 EFFECT OF SUCTION HEAD ON DOSE




4.12.3

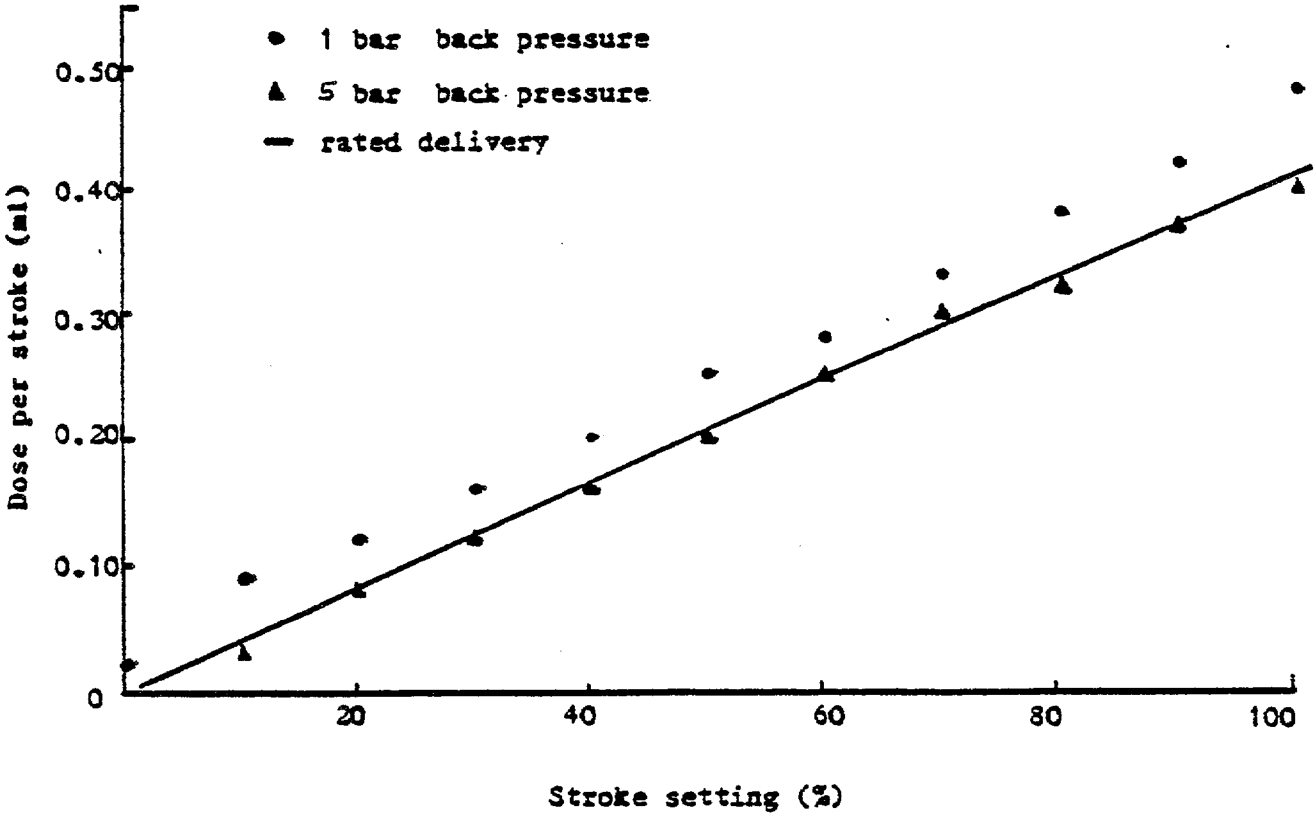



Figure 4.124 Alldos - Calibrations

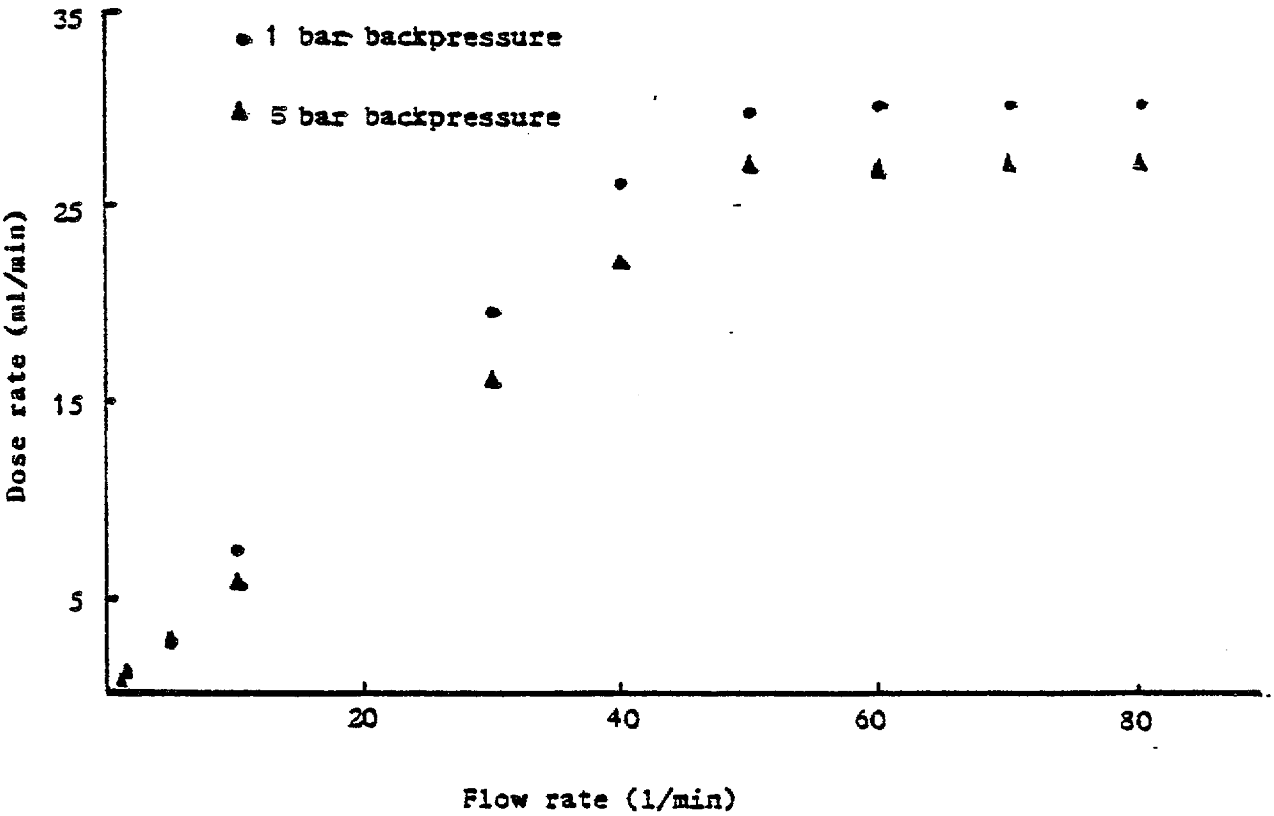



Figure 4.125 Alldos - Variation of dose with flow

In order to investigate the frequency controller the water flow through the meter was varied between 0.35 and 70 l/min. The suction head was -0.25 m wg and backpressures of 1 bar and 5 bar were used. The results are plotted on Fig 4125. From 0.35 to 50 l/min the points lie on a straight line with the dose rate increasing with flow however, above 50 l/min the dose rate remains constant at 30 ml/min; this would mean that at the maximum rated flow of 80 l/min the pump would only deliver 375 ml/cu.m compared with the rated value of 400 ml/cu.m

The number of ball-valves in the inlet and outlet valves were reduced to one in each in order to investigate the necessity of two sets. The pump was set at 100 % stroke continuously and the delivery was measured over backpressures of 0, 2, 4 and 6 bar. The results are plotted on Fig 4126. The removal of one set of ball-valves appears to have decreased the output of the pump when it is subjected to a backpressure, at 4 bar the output is down from 0.45 ml/stroke to 0.41 ml/stroke. This indicated that the presence of two sets of valves was benefical in preventing back flow through the pumphead.

The pump was run continuously for a fortnight during which time its delivery remained constant.

Unidos Controller

The sensing element was mounted within a die-cast housing which was fixed directly into the pipeline with the pump on top. Inside the casing the unit was sub-divided by a brass plate into a 'wet section' containing a turbine and a 'dry section' containing a magnetic switch which was used to effect the pulsed control signal.

As the flow through the meter increased the turbine rotated faster. A magnetic coupling transmitted the rotary motion to a spindle in the dry section on which was mounted a small wheel. Two magnetic strips were set into the wheel and as they rotated they moved pass and activated a switch thus causing a pulsed signal to be sent to the controller. The controller on receiving the signal tripped a delay circuit which ran the pump for a fixed period of time; it was approximated to be just over one second as the pump stopped after just over one stroke. It was therefore estimated that for the pump to run continuously the controller would have to receive approximately 50 pulses per minute (assuming 1 stroke = 1.2sec). From the technical literature one pulse is equivalent to one litre of water through the meter hence the pump will run continuously at flow rates of 50 l/min and greater. The meter was disengaged from the controller and water at known flowrates was passed through it in order to calibrate the meter. The results are shown in Fig 4127. The output from the meter remained linear at one pulse per litre up to 80 l/min.

This pumping system was quoted as providing a proportional dose up to 83.3 l/min, however this would not be possible unless the period of time for which the pump ran on receiving a pulse was decreased from 1.2 seconds to 0.72 seconds.

Conclusions

This dosing pump proved to be relatively insensitive to changes in both back pressure and suction head. Adjustment of dose setting was linear.

Although the water meter output signal was proportional to flow rate across the full rated range, the dose rate was proportional to flow only up to 50 l/min, after which it remained constant. This was because the length of time the pump operated for each pulse signal it received from the UNIDOS controller was too long.

FIGURE 4.26 PERFORMANCE WITH SINGLE BALL VALVES

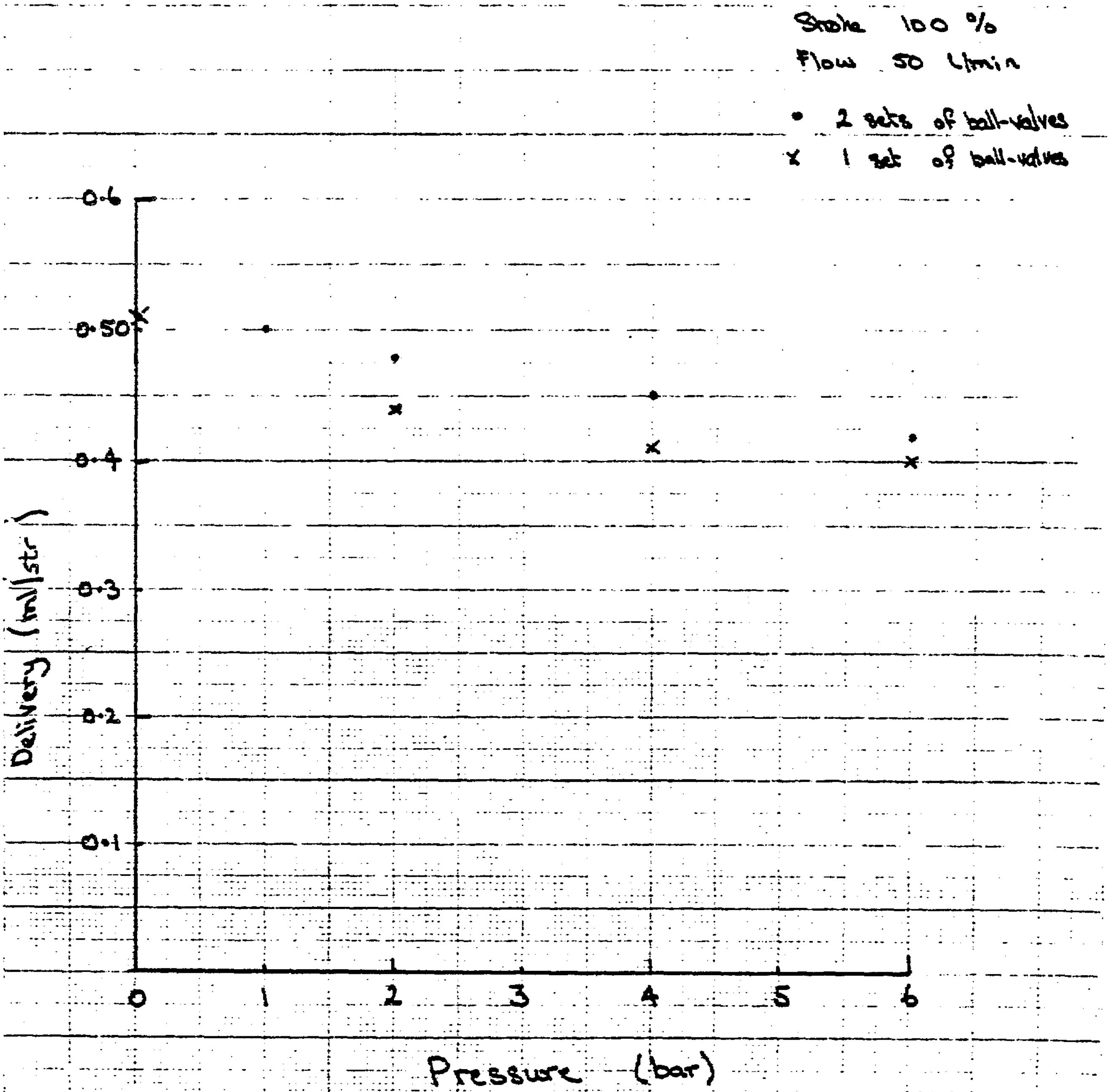
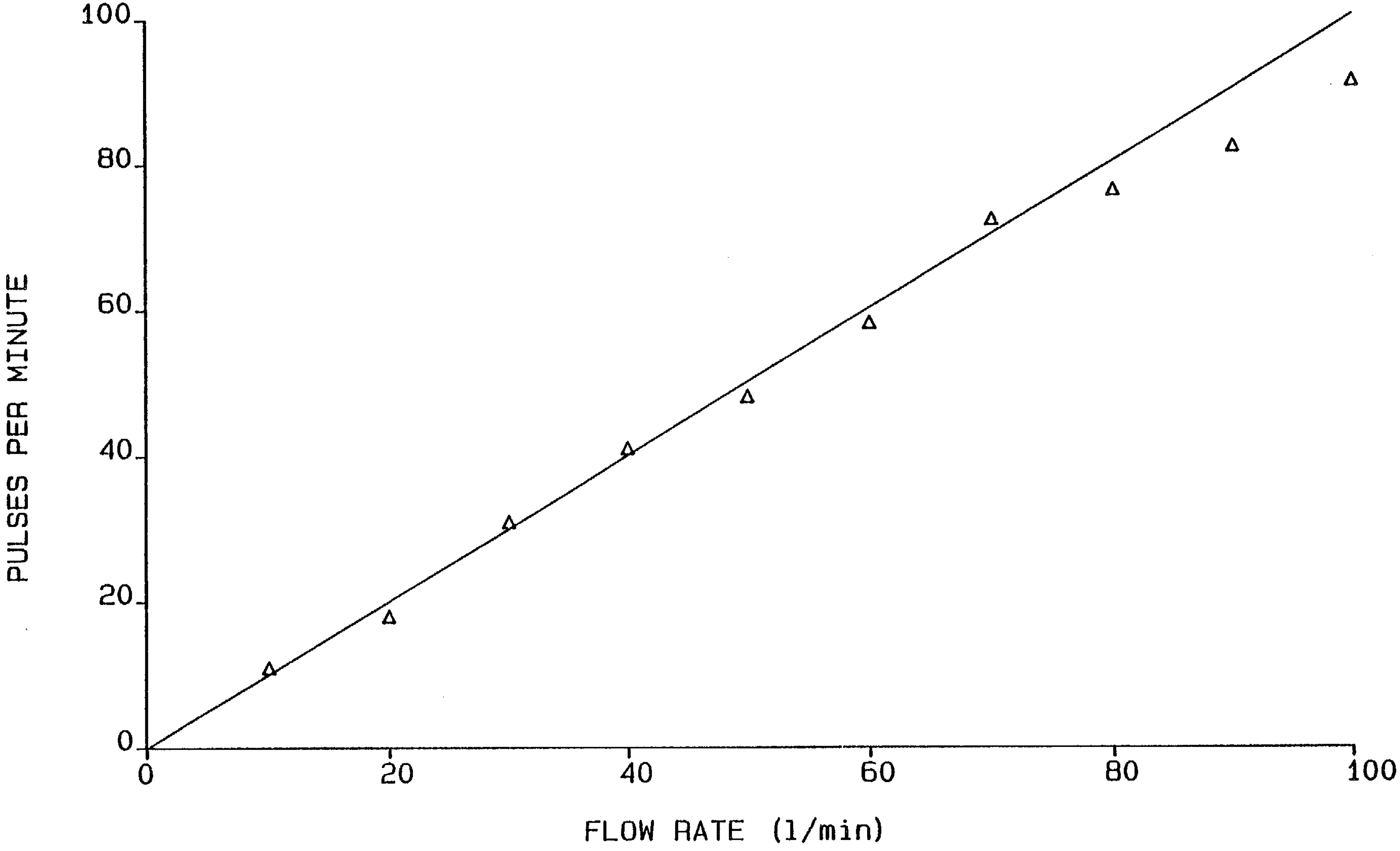


*FIG A127 CALIBRATION OF WATER METER*



TESTS ON ALLDOS P201 DOSING PUMP APRIL 1984

ALLDOS VARIABLE FLOW RATE, 5 BAR, 100% STROKE

| FLOW (l/min) | DOSE (ml/min) |
|---|---|
| 0.35 | 0.04 |
| 0.60 | 0.37 |
| 1.00 | 0.58 |
| 5.00 | 2.93 |
| 10.00 | 5.70 |
| 30.00 | 16.00 |
| 40.00 | 22.00 |
| 50.00 | 27.00 |
| 60.00 | 26.70 |
| 70.00 | 27.00 |
| 80.00 | 27.00 |

ALLDOS VARIABLE FLOW RATE, 1BAR, 100% STROKE

| FLOW (l/min) | DOSE (ml/min) |
|---|---|
| 1.00 | 0.71 |
| 1.50 | 1.09 |
| 5.00 | 2.76 |
| 10.00 | 7.37 |
| 30.00 | 19.41 |
| 40.00 | 26.00 |
| 50.00 | 29.60 |
| 60.00 | 30.00 |
| 70.00 | 30.00 |
| 80.00 | 30.00 |

ALLDOS VARIABLE PRESSURE, 100% STROKE, -0.25 M wg, 50 l/min

| BAR | DOSE PER STROKE (ml/str) |
|---|---|
| 0.00 | 0.51 |
| 1.00 | 0.50 |
| 2.00 | 0.48 |
| 3.00 | 0.46 |
| 4.00 | 0.45 |
| 5.00 | 0.43 |
| 6.00 | 0.42 |
| 7.00 | 0.41 |

ALLDOS STROKE SETTING (% MAX) AGAINST DOSE @1 BAR, 50 l/min

| SS | DOSE PER STROKE (ml/str) |
|---|---|
| 0.00 | 0.02 |
| 10.00 | 0.09 |
| 20.00 | 0.12 |
| 30.00 | 0.16 |
| 40.00 | 0.20 |
| 50.00 | 0.25 |
| 60.00 | 0.28 |
| 70.00 | 0.33 |
| 80.00 | 0.38 |
| 90.00 | 0.42 |
| 100.0 | 0.48 |

ALLDOS STROKE SETTING (% MAX) AGAINST DOSE @5 BAR, 50 l/min

| SS | DOSE PER STROKE (ml/str) |
|---|---|
| 0.00 | 0.00 |
| 10.00 | 0.03 |
| 20.00 | 0.08 |
| 30.00 | 0.12 |
| 40.00 | 0.16 |
| 50.00 | 0.20 |
| 60.00 | 0.25 |
| 70.00 | 0.30 |
| 80.00 | 0.32 |
| 90.00 | 0.37 |
| 100.0 | 0.40 |

ALLDOS SUCTION HEAD (m.wg) V DOSE 100% STROKE @1 BAR, 50 l/min

| SUCTION | DOSE PER STROKE (ml/str) |
|---|---|
| -0.75 | 0.49 |
| -0.50 | 0.495 |
| -0.25 | 0.49 |
| 0.00 | 0.50 |
| 0.25 | 0.50 |
| 0.50 | 0.51 |

ALLDOS SUCTION HEAD (m.wg) V DOSE 100% STROKE @5 BAR, 50 l/min

| SUCTION | DOSE PER STROKE (ml/str) |
|---|---|
| -0.75 | 0.41 |
| -0.50 | 0.41 |
| -0.25 | 0.41 |
| 0.00 | 0.41 |
| 0.25 | 0.42 |
| 0.50 | 0.45 |

CONTINUOUS RUNNING TEST

| DAYS | STROKE RATE (str/min) | DOSE (ml/min) |
|---|---|---|
| 0 | 60 | 32.66 |
| 6 | 60 | 32.66 |
| 10 | 60 | 32.66 |
| 14 | 60 | 32.66 |
| 15 | 60 | 32.66 |
| 22 | 60 | 32.66 |

CALIBRATION OF WATER METER

| FLOW (l/min) | PULSE COUNT (per min) | PULSE PER LITRE |
|---|---|---|
| 10 | 11 | 1.10 |
| 20 | 18 | 0.90 |
| 30 | 31 | 1.03 |
| 40 | 41 | 1.03 |
| 50 | 48 | 0.96 |
| 60 | 58 | 0.97 |
| 70 | 72 | 1.03 |
| 80 | 76 | 0.95 |
| 90 | 82 | 0.91 |
| 100 | 91 | 0.91 |

APPENDIX 4.13 TESTING OF JESCO MAGDOS MD2 SOLENOID PUMP WITH MX3 FLOW METER

Introduction

The pump was specified as follows:

| | |
|---|---|
| Max pressure | 10 bar |
| Output at max pressure | 0-0.35 ml/str |
| Max stroke rate | |
| Internal control | 0-120 str/min (revised to 0-100 str/min) |
| External control | 0-130 str/min |
| Max suction | 122 cm wg |
| Adjustability ratio | 1:300 |

The Flow Meter MX3 was rated:

| | |
|---|---|
| Min flow | 0.5 l/min |
| Max flow | 33 l/min |
| Peak | 50 l/min |
| Pressure range | 1-10 bar |
| Frequency output | 96 pulse/l of driving flow |

Experimental Apparatus

The apparatus used for evaluation of the pump is shown in Fig 4131. The delivery from the pump was fed into the flow via a check valve injection fitting. Line pressure was maintained using the valve downstream of the meter to vary the flow. For most of the tests the pump delivered into a large pressure vessel so that the back pressure could be held constant.

Diaphragm Dosing Head

The body of the head was constructed from PVC with a PTFE faced rubber diaphragm. The suction and delivery valves consisted of ground glass balls on soft rubber seats. Although the diaphragm was capable of 7mm movement the adjustment was only over a range of 1.5mm

The literature on the pump suggested that the delivery should drop linearly with back pressure. In fact the pump performed differently as shown in Fig 4132. At low back pressures the pump showed a supercharging effect where the liquid in the head was given enough momentum to keep the check valves open and carry on flowing when the solenoid armature had reached the end of its stroke. A separate test showed that the effect was most marked at 0bar, but could still be observed to a lesser degree at 3bar. When back pressure was applied the dose dropped sharply and then decreased at a lesser rate than suggested by the makers, although it still varied by as much as 25% from 1 to 6 bar.

Against a back pressure of 6bar, the dose remained constant with negative suction heads up to -25cm wg. At 0cm wg it jumped by 0.01 ml/str and remained constant thereafter (Fig 4133).

## The Solenoid

The movement of the solenoid armature was transmitted directly to the diaphragm via a push rod which worked against a spring. The range of movement of the armature was quoted as being 4mm, which was reduced to approximately 1.5mm by the MD2 control unit. Without the control unit attached a stroke of 7mm was obtained. The energisation period on each stroke was given as 0.13s. The actual time for the delivery stroke and spring return for maximum travel was measured at 0.5s. At 120str/min the time allowed for each stroke would be 0.5s; a stroke rate higher than this would not allow the armature to return fully before the solenoid was reenergised. The manufacturers, recognising this, had reduced the maximum rate to 100str/min. Fig 4134 shows how, at maximum stroke length, the delivery began to diminish with increase of frequency at about 50str/min.

## Stroke Control

The pump was set to a rated delivery and the stroke control knob was adjusted to the appropriate point on its scale. Figs 4135 and 4136 show that the delivery varied linearly with the settings on the scale, but that the gradient was less than specified.

The knob could be turned well passed the end of the scale so that over twice the rated delivery could be obtained. As far as could be determined with no markings, the adjustment still seemed to be linear in this range.

## Frequency Control

Although the pump was rated up to 120str/min on manual control, it was found to be factory set to a maximum of 101str/min. The stroke rate varied linearly between 1 and 10 on the scale after which it levelled off at 101str/min (Fig 4137). The lowest stroke rate obtained was 3str/min which when combined with the minimum stroke setting of 0.03ml/str (at 6bar back pressure) gave a delivery of 0.09ml/min. The maximum flow obtainable was 100str/min at 0.3ml/str (again at 6 bar back pressure) giving 30ml/min. This adjustability of 1:333 was greater than the maker's rating.

## Water Meter

The water meter was found to be acceptably accurate at measuring flows between 0.03 and 3.4cu m/h which was slightly greater than the rated range. Although rated to give 96 pulse/l of driving flow, the unit tested gave only 75pulse/l over the working range of flows and 57pulse/l above this (Fig 4138). The frequency varied linearly at both of these gradients, changing slope at 30 l/min (1.8cu m/h). Later experiments showed the pulse rate falling above 20 l/min.

The pulses were produced by a reed switch which was operated by an annular magnet on top of the meter spindle. Two pulses were given per revolution. The magnet was attached to the spindle by means of a rubber bush in its centre. At high flows the reduction in pulse frequency might have been due to either the magnet slipping on the spindle or the reed switch being unable to respond to the magnetic pulses. Above 42 l/min (2.52cu m/h) the magnet rotated faster than the reed switch was able to move and so the pulse rate became very variable and dropped with increasing flow.

## Impulse Fractionator

The impulse fractionator was found to operate correctly up to a maximum output rate of about 150pulse/min, which was higher than required to drive the pump (Fig 4139). When attempts were made to drive it faster it appeared to give a submultiple of the correct frequency.

The impulse fractionator was potentially of great benefit in extending the range of the pump. For example, it would enable the number of pulses to be reduced sufficiently to dose neat hypochlorite into the flow (see appendix) provided adequte mixing equipment was installed with the pump.

## Conclusions

The variation of dose with back pressure was not linear as indicated by the manufacturer. Rather, dose fell from a maximum at zero back pressure and then levelled off. This peak dose at zero pressure was typical of solenoid driven diaphragm pumps, largely being due to supercharging.

The pump was relatively insensitive to suction head. Provided the head was maintained either negative or positive dose remained constant. The dose with positive head was however slightly greater than with negative head.

The adjustability of the pump was good. Both stroke length and frequency setting controls were linear, with the range of the former extending significantly beyond the marked scale. The impulse fractionator was an unusual but potentially very useful feature; it provided the pump with a sufficiently high turndown ratio for it to be able to be used with neat hypochlorite solution.

A limitation with this type of pump was that the maximum stroke frequency was dependent on the time required for the armature to complete its forward and back stroke. Such a limitation would not apply to a pump with a crank driven piston.

A weak point in this particular pump seemed to be the use of a rubber bush to connect the meter magnet to the drive spindle, resulting in slippage at high flow rates.

In general the pump appeared to be well designed and constructed, and simple to install and operate.

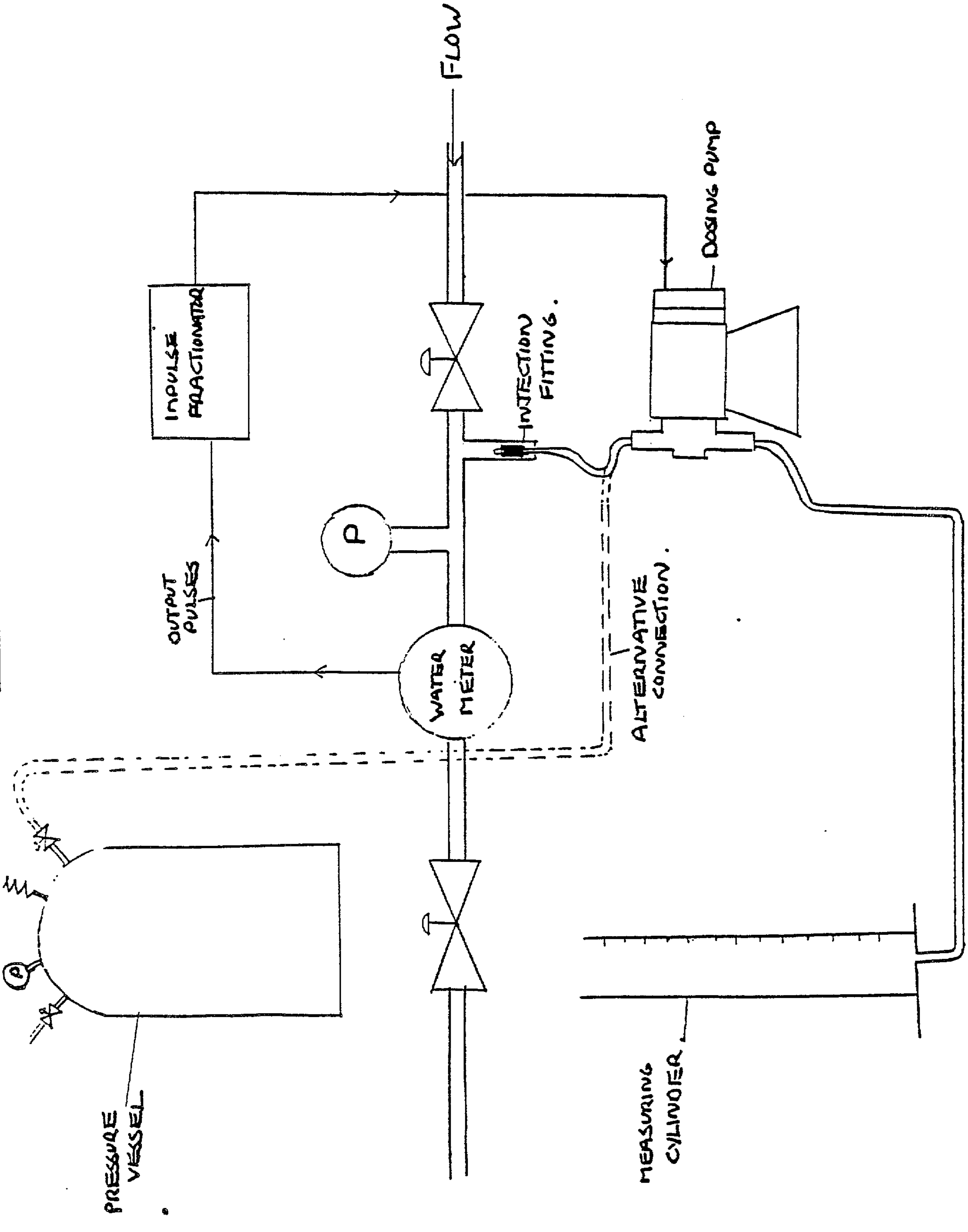
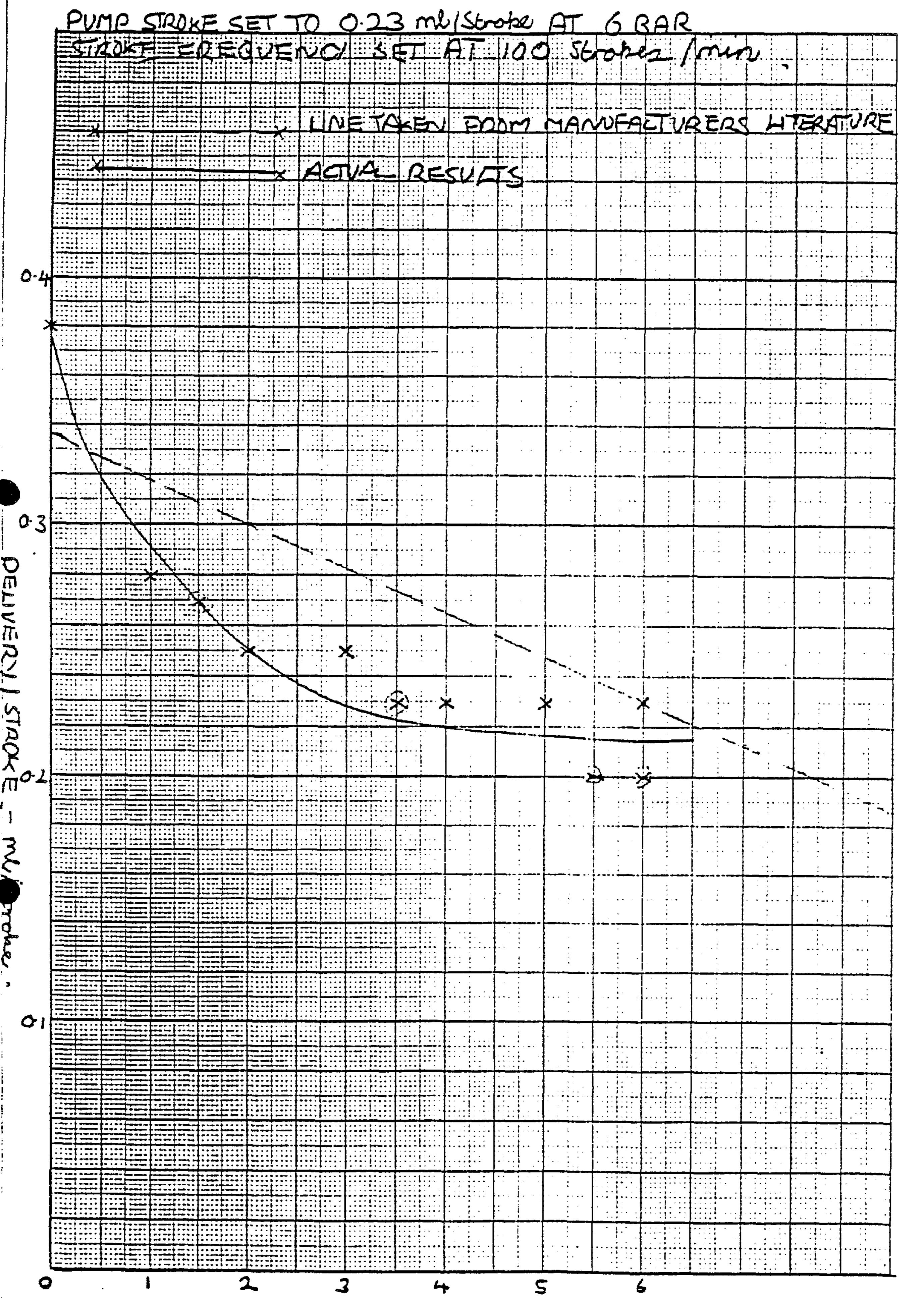



FIG 4.13.1 EXPERIMENTAL APPARATUS

21/5/85 . FIG 4132

JESCO - VARIATION OF DELIVERY WITH BACKPRESSURE

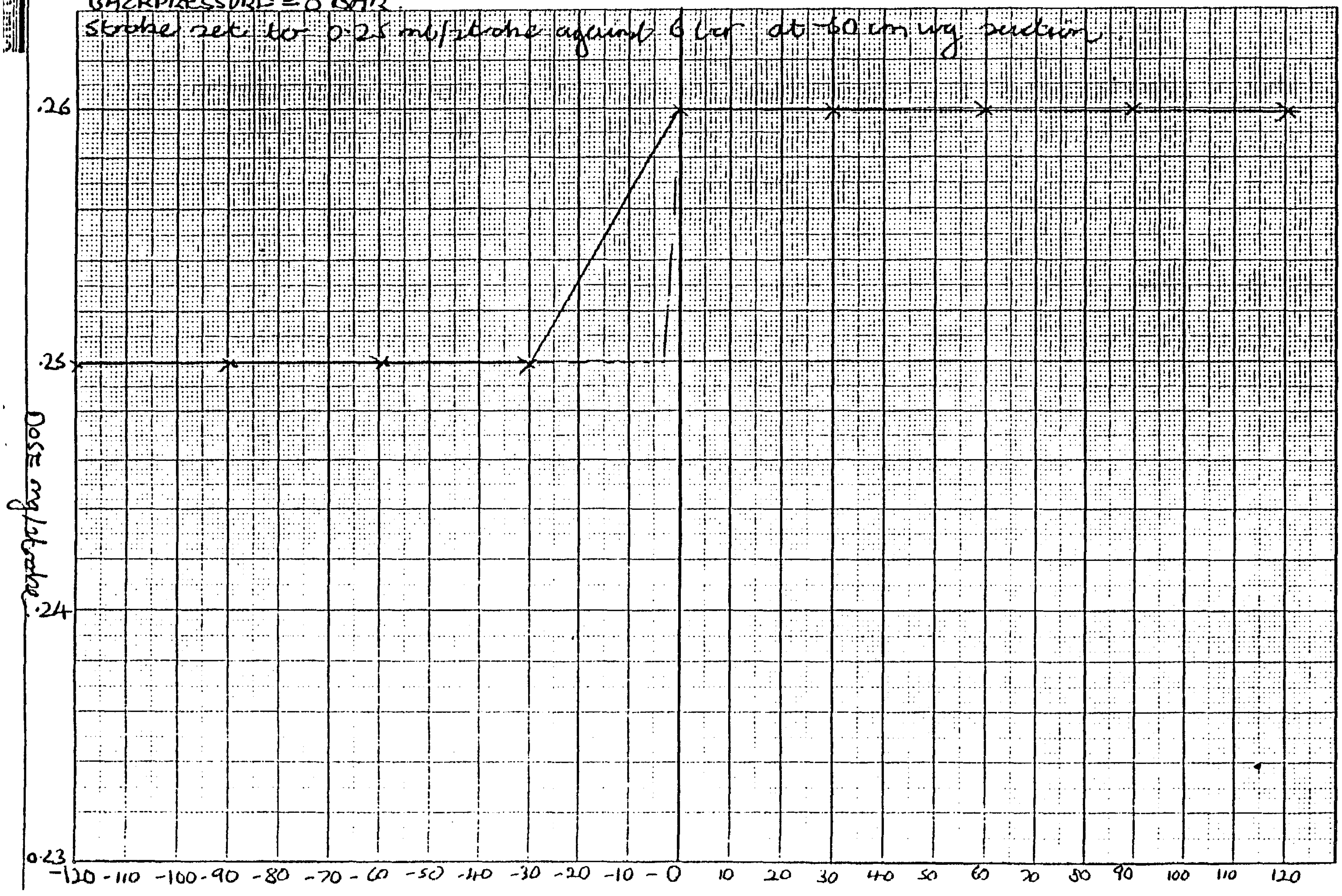


JESCO - VARIATION OF DOSE WITH SUCTION HEAD. FIG. 4133 22/5/05

MAX FREQ = 100 Strokes/min

BACKPRESSURE = 6 BAR

Stroke set to 0.25 ml/stroke against 6 bar at 60 cm wg suction.



3/6/85 JESCO - VARIATION OF DOSE WITH FREQUENCY AT MAX STROKE LENGTH,

FIG 4.134

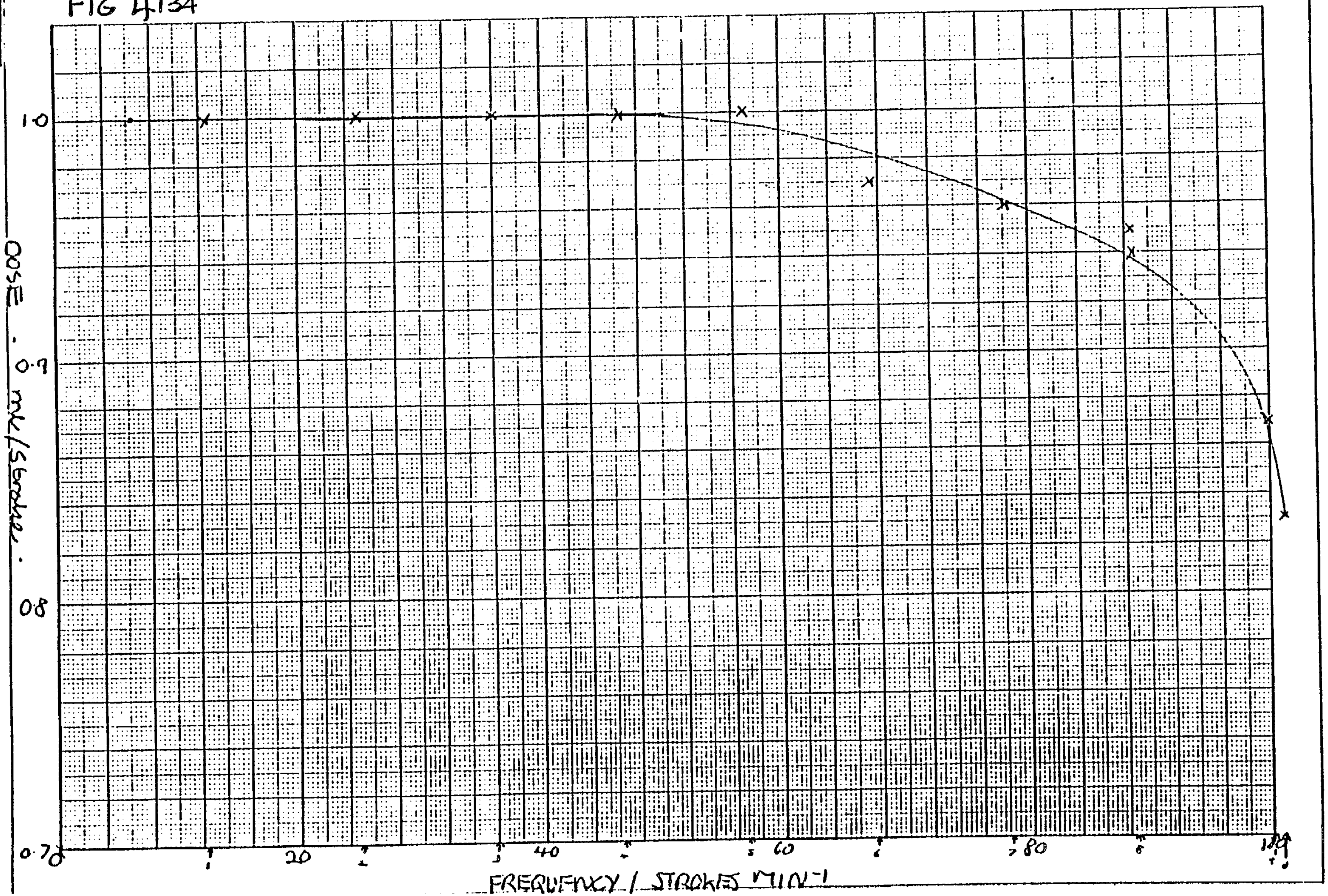
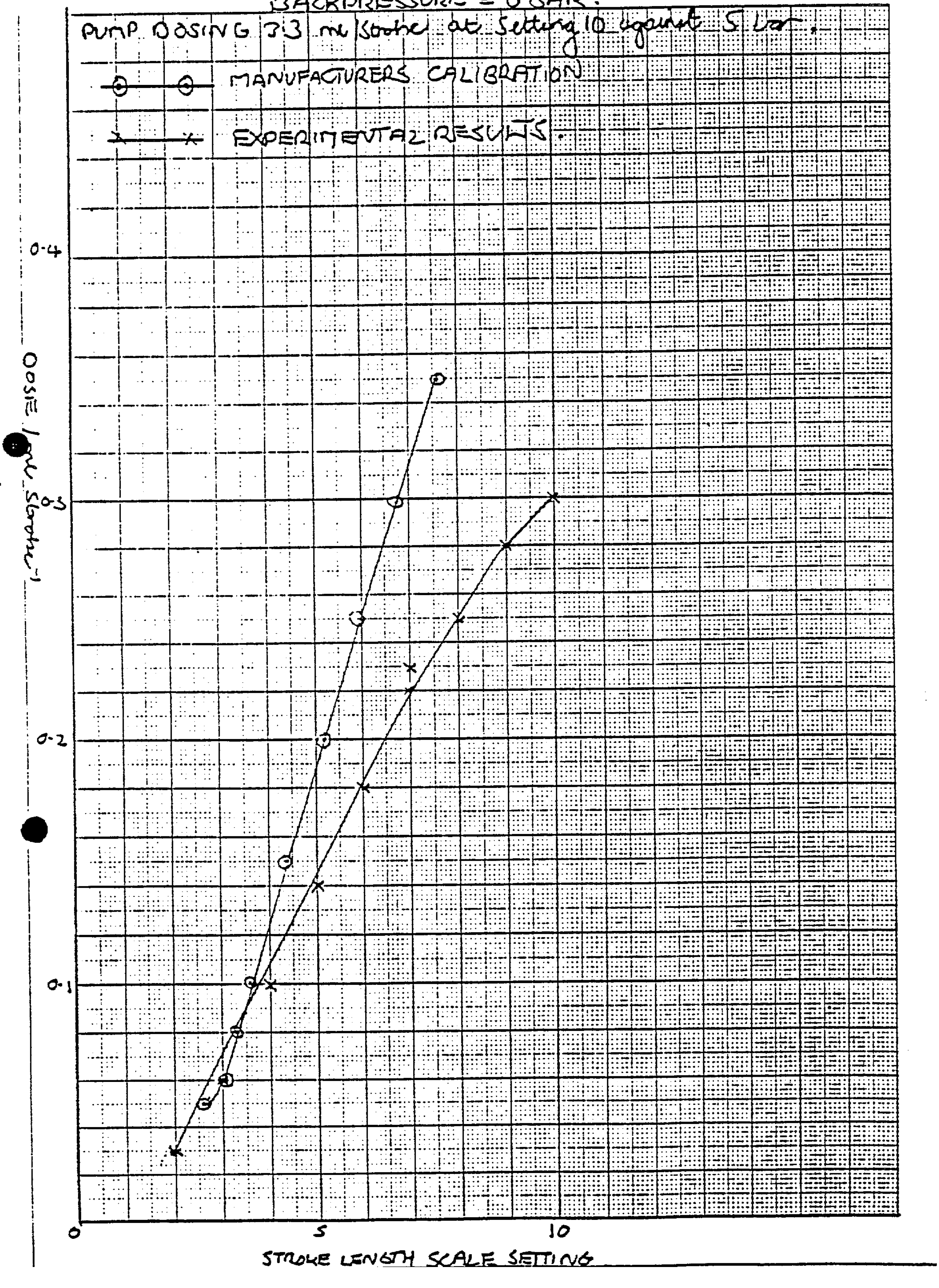


FIG 4135

11/6/85 JESCO - CALIBRATION OF STROKE LENGTH ADJUSTER.
PUMP WITH NEW CAM (4mm) + DIAPHRAM ROD.
BACKPRESSURE = 6 BAR.



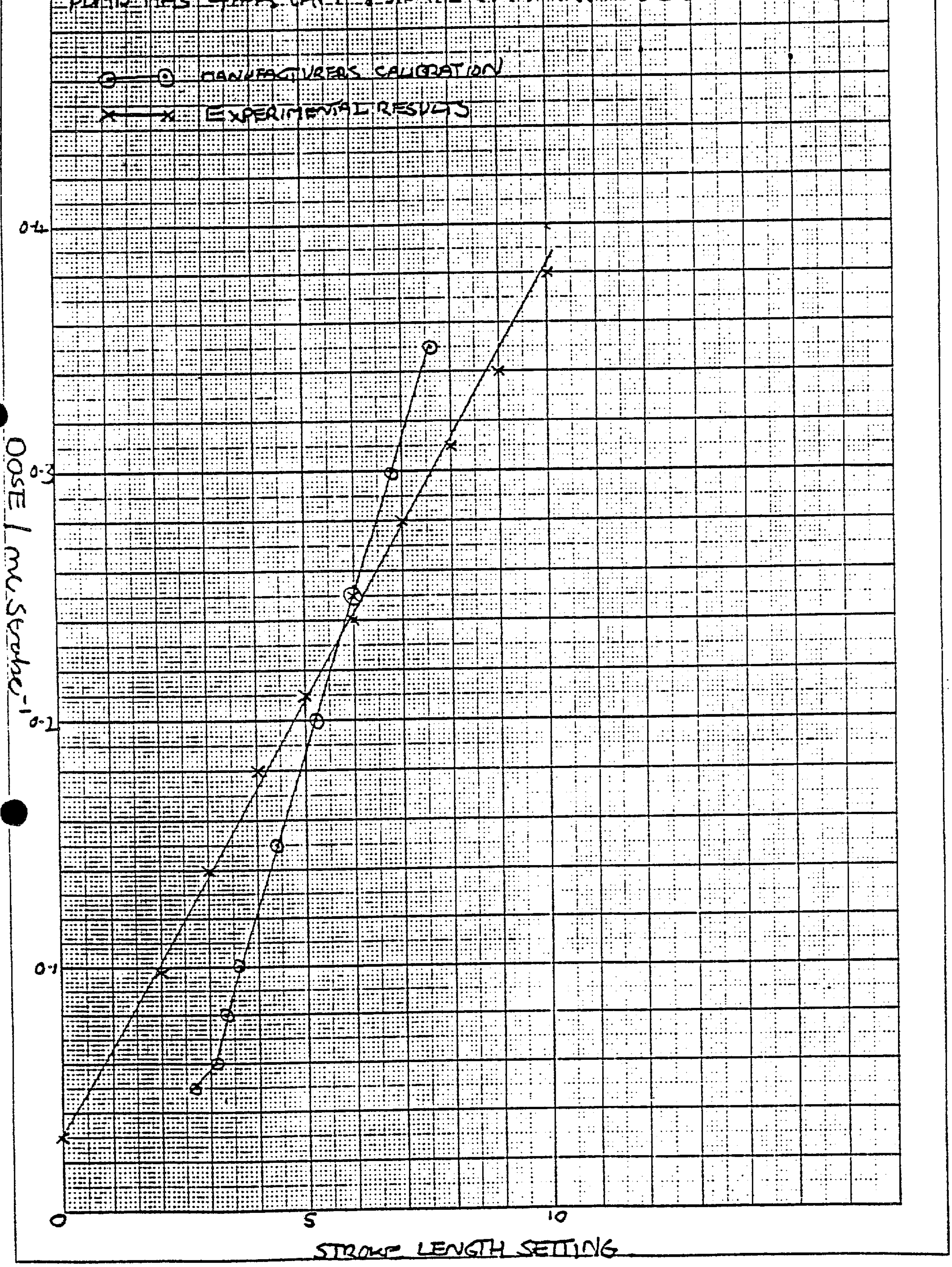
F16 , A136

12/6/83 JESCO - CALIBRATION OF STROKE LENGTH ADJUSTER.

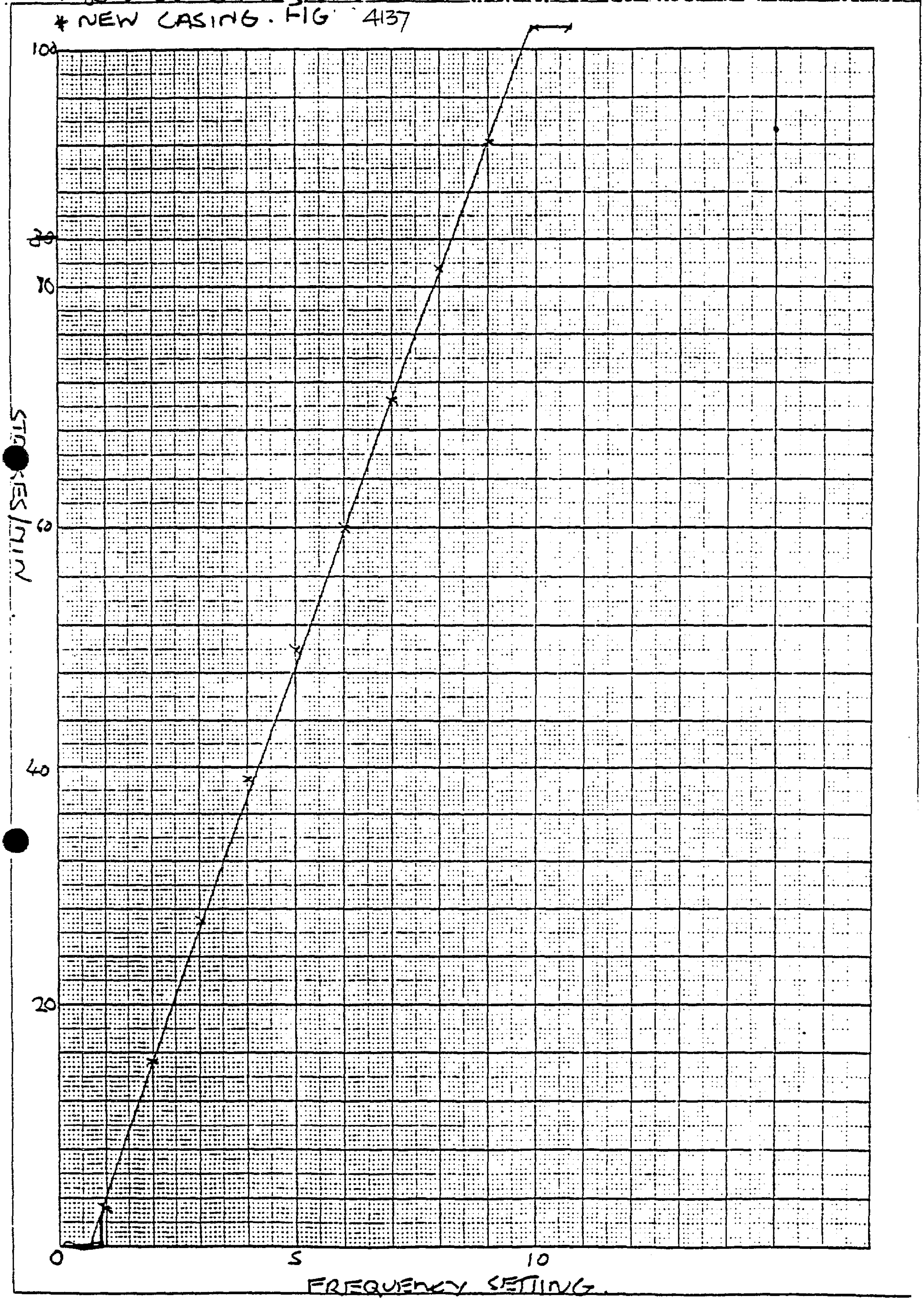
PUMP SET TO DOSE 0·25 ml/stroke AT SETTING 6 AGAINST 6 BAR.

BACK PRESSURE = 6 BAR.

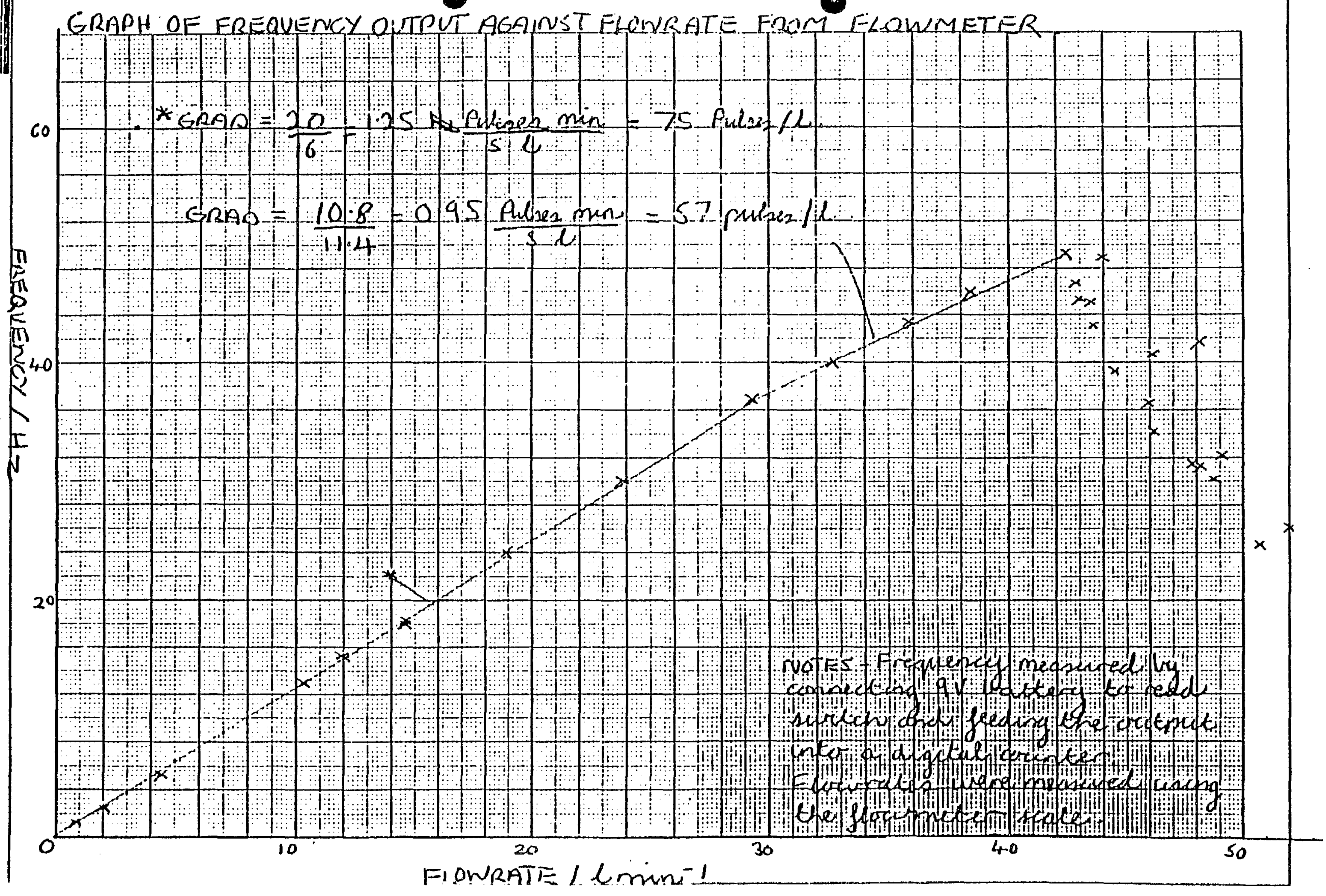
PUMP HAS 4mm CAM & SHORTER DIAPHRAM ROD.



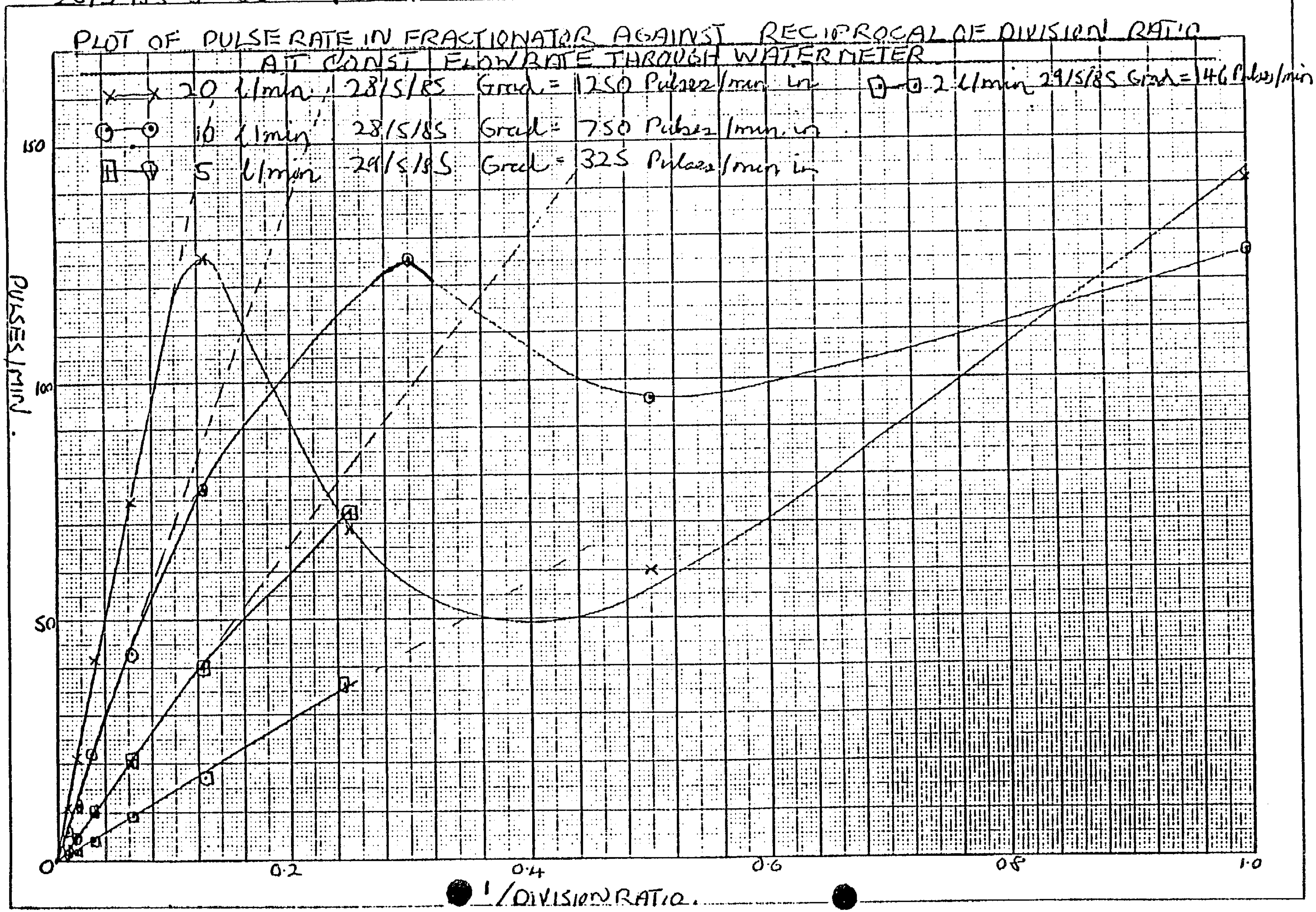
10/6/85 JESO - CALIBRATION OF FREQUENCY CONTROL KNOB



JESCO - PUMP 3015/85 FIG 4138



28/5 IPS JESCO. FIG. 4139



FRACTIONATOR DIVISION RATIO FOR NEAT HYPOCHLORITE

Required dose = 0.5mg/l

Hypochlorite concentration = 100g/l (@10%)

Minimum dose per stroke = 0.03ml/str

Flow meter pulse rate = 75pulse/l

One stroke delivers $\frac{0.03 \times 100}{1000} = 0.003$g

No. of strokes/litre required for a dose of 1mg/l

$$= \frac{1}{3}$$

or 1 stroke for every 3 litres of flow

Therefore,

Fractionator division ratio

$$= 3 \times 75$$

$$= 225$$

## APPENDIX 4.14 TESTS ON ELADOS 'C' WATER POWERED FLOW PROPORTIONAL DOSING PUMP

### Method of Operation

The pump consisted of two sections, the dosing head and the water powered drive (Fig 4141). It was designed to dose liquids such as calcium hypochlorite solution, which may contain suspended solids. The chance of solids settling and blocking valves was reduced by circulating a relatively large amount of liquid and only dosing a small proportion of it. The dose was delivered into the water line through an injection fitting, which also acted as a check valve.

The flow through the drive turned a crank which powered the dosing head. Fig 4142 shows a cross section of the dosing head. The diaphragm cell had an inlet port and two outlets - a return line down which most liquid was recirculated, and a delivery line. The plastic hexagonal piston rod was attached to the diaphragm, which drew liquid in through the inlet and expelled most of it into the return line. A small titanium piston attached to the diaphragm stroked into a cylinder sealed by an 'O' ring. When fully drawn back the piston was clear of the seal and liquid was free to enter the cylinder. On the forward stroke the piston moved into the cylinder and made a seal with the 'O' ring. Liquid was forced out through a hole in the cylinder wall, under a rubber ring that acted as a check valve, and into the delivery line.

### Tests

The pump was rated to operate on water flow rates of 0.15 to 6 cu m/hr (2.5 to 100 l/min) at a maximum pressure of 10bar and to dose 100ml of solution per cubic meter of water.

The experimental apparatus is shown in Fig 4143. The delivery line led to a vessel which could be pressurised from an air cylinder. The volume of the vessel was large relative to the volume of solution dosed so that back pressure remained effectively constant once set.

Before commencing the test programme, some general observations were made of the pump in operation. It was noticed that when the head at the delivery outlet was greater than at the liquid inlet, and the piston was not sealing with the 'O' ring, liquid would flow back into the pump from the delivery line. Liquid was also drawn back from the delivery line during the piston back stroke. This suggests that either the rubber ring was inefficient as a non-return valve or that there was a relief channel provided to prevent cavitation in the dosing cylinder on the suction stroke.

### Drive

The first test was to determine how the speed of the crank varied with water flow rate. For this test the pump was operated with the dosing head detached. A flow meter was installed downstream of the pump. The results, illustrated in Fig 4144, showed that the crank speed was only proportional to flow rate at flows below about 40 l/min.

Some time later the speed/flow rate relationship was rechecked as the pump performance appeared to be deteriorating at some flow rates. The relationship was found to have changed significantly (Fig 4145) and so a new drive was fitted. The speed/flow rate relationship of this new drive was similar to the original curve for the old drive (Fig 4146). Since it is not known how the drive operates no comment can be made on the form of the relationship or why it altered.

Effects of Back Pressure

The next test was to determine the variation of pump delivery with back pressure. The dosing head was attached and the stroke rate set at 132 str/min (note each revolution of the crank corresponded to one stroke). The inlet head was set at -25cm wg.

Four runs were carried out without the injection fitting on the delivery line. The results are shown in Fig 4147, along with a similar run done with a new dosing head; this had to be fitted after the original dosing head stopped dosing against all but the lowest back pressures. A general pattern was followed, a sharp fall in delivery from 0 to 1 bar after which dose increased with pressure. There was however significant differences between the deliveries at a given pressure measured during each run.

The high delivery at 0bar was thought to be due to the lack of any loading on the delivery line such that liquid was being forced into this line before the piston had entered the cylinder. Runs were therefore carried out with the injection fitting inserted in the delivery line. The results (Fig 4148) indicated that this fitting had little effect other than to reduce the delivery at 0bar slightly and to shift the minimum delivery to 2bar.

Runs were carried out at 180 str/min (118 l/min flow rate through the drive) with and without the injection fitting. The results are shown in Fig 4149. The run without the injection fitting showed the same trend as before but the addition of the fitting reduced the delivery at 0bar such that the delivery increased with back pressure from the start. This may have been a result of the speed/flow rate relationship rather than the effect of the fitting itself.

Effects of Inlet Pressure

The next test investigated the variation of delivery with suction head. The flow rate was set at 50 l/min and the suction head varied from -75cm wg to 100cm wg. Back pressure was atmospheric. The results are shown in Fig 41410. Delivery remained at 5 ml/min at suction heads up to -25cm wg, after which it increased linearly. It is assumed that with a positive head on the suction line liquid will free flow into the delivery line before the piston enters the cylinder.

Delivery per Stroke

The final test was to determine the variation of delivery with stroke rate. Back pressure was set at 0bar and suction head at -25cm wg. The results are shown on Fig 41411. The relationship is apparently proportional with the delivery per stroke constant at 0.033ml/str. Due to the characteristics of the pump drive the delivery will not be flow proportional above 40 l/min.

Conclusions

In these tests this pump did not show the consistency of performance or reliability that would be required for a small drinking water supply. The two fold variation in delivery over the pressure range 0 to 6bar is not acceptable and a rising output with pressure is considered suspect. In addition the drive does not give an output speed proportional to flow. Further to all this, the fixed ratio of dose to driving flow is considered to be a severe limitation on the applicability of the unit to small water supplies.

FIG 4141 DIAGRAM OF PUMP

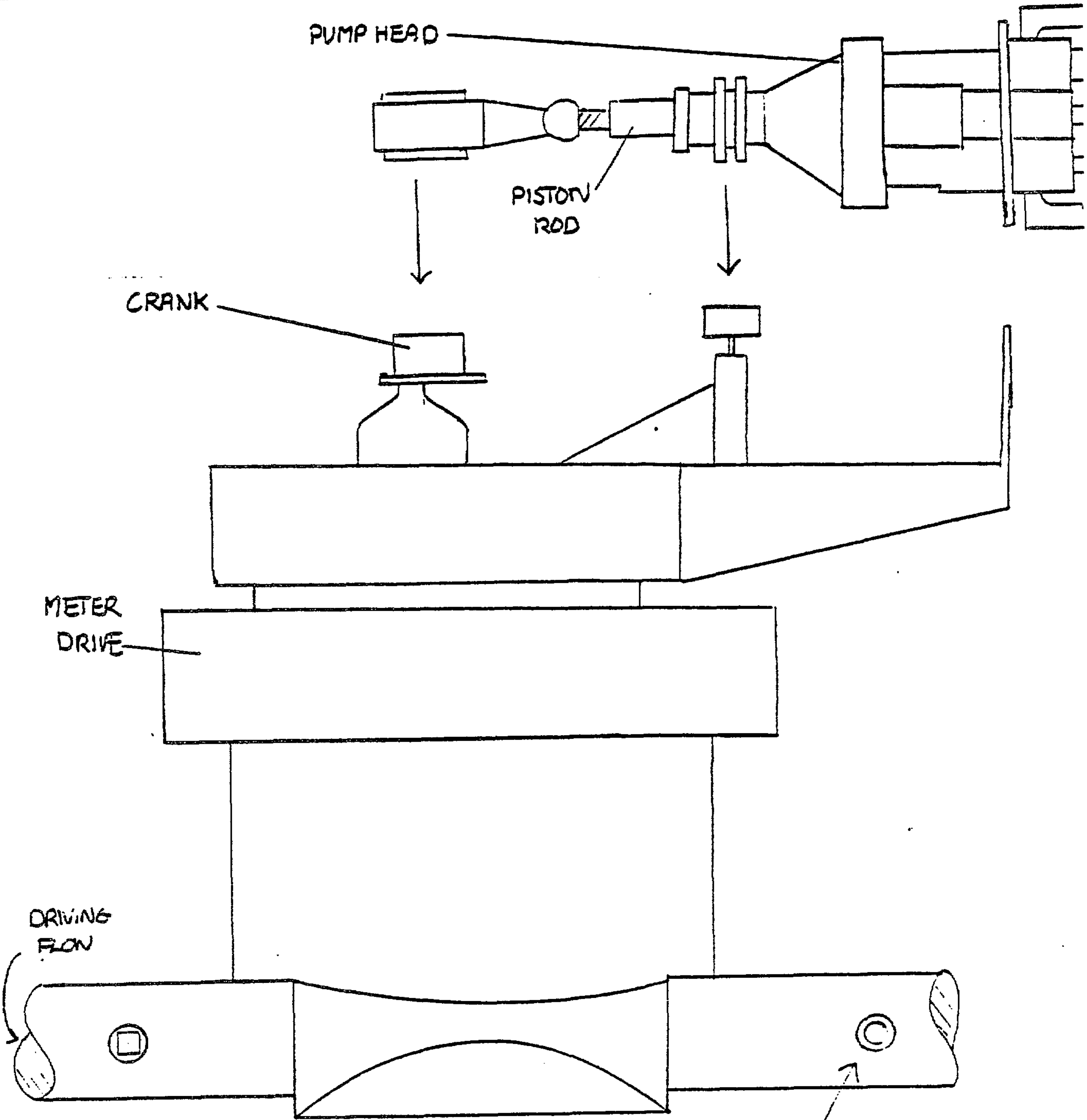



FIG 1a

INJECTION FITTING

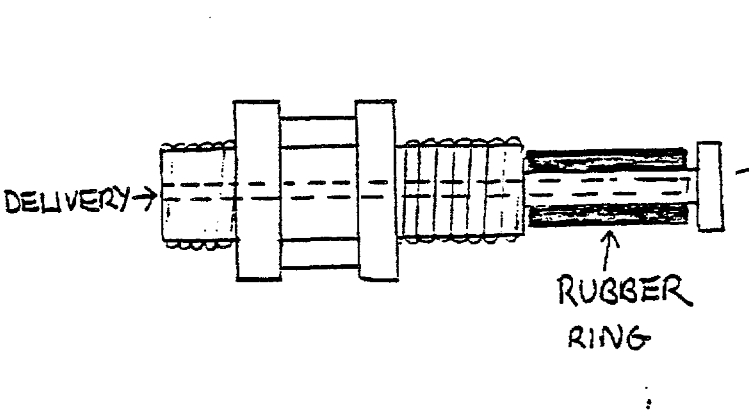


FIG 4.42

SIMPLIFIED DIAGRAM OF DOSING HEAD.

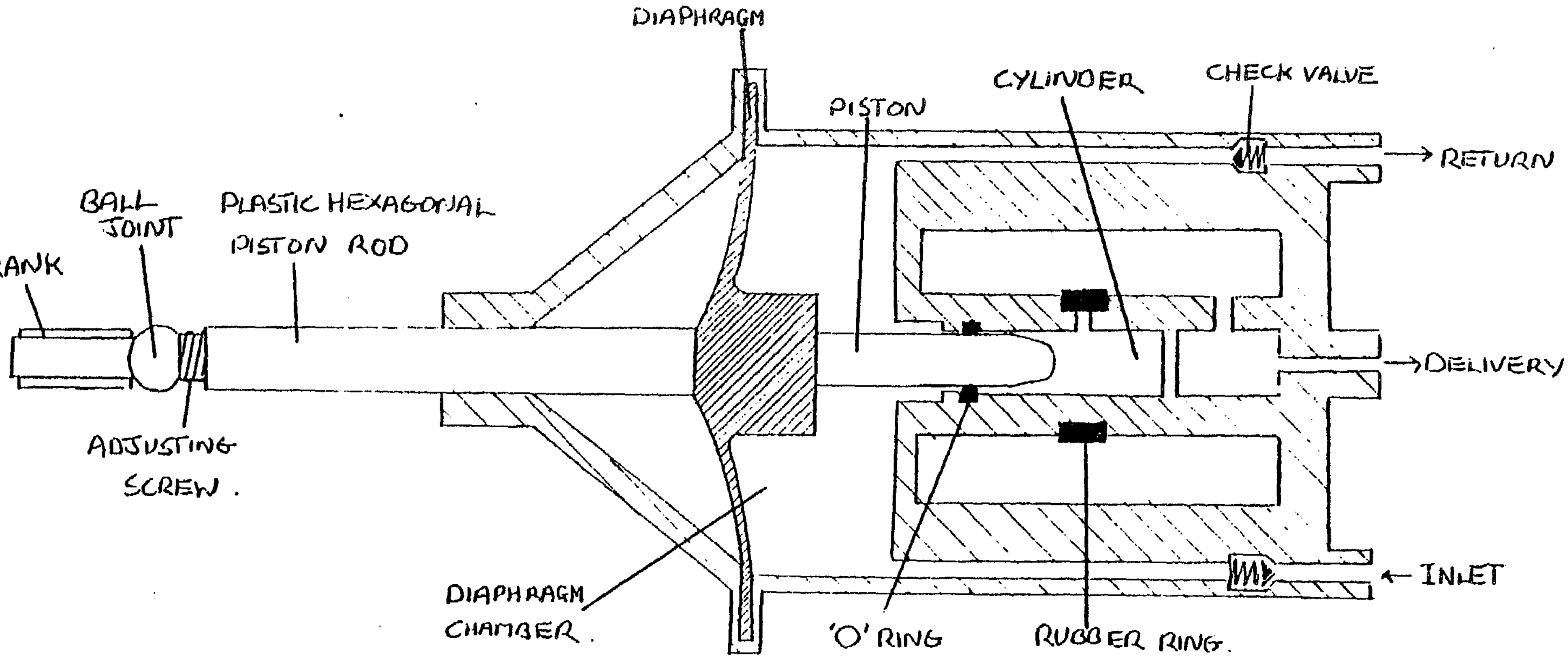
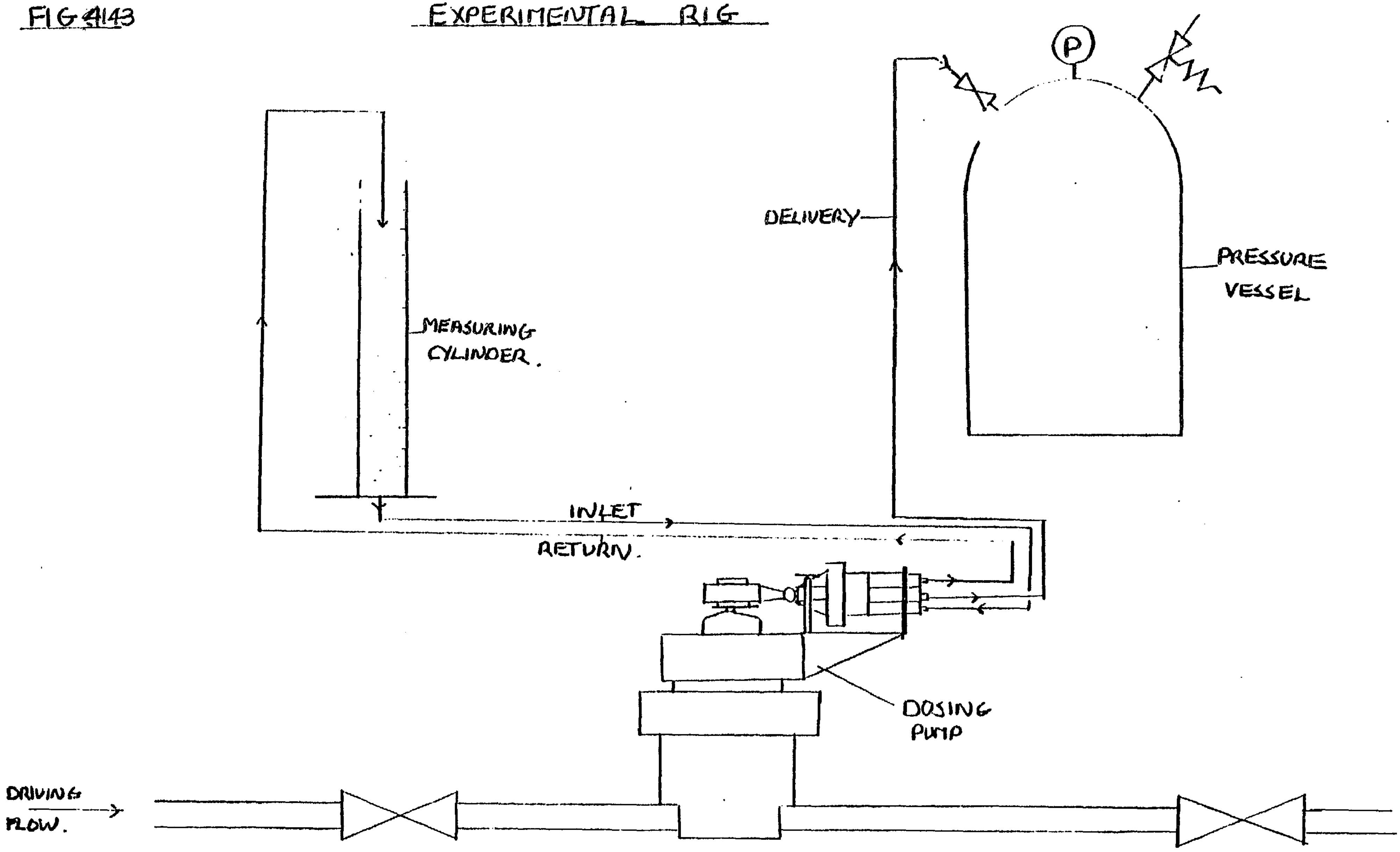


FIG 4143

# EXPERIMENTAL RIG



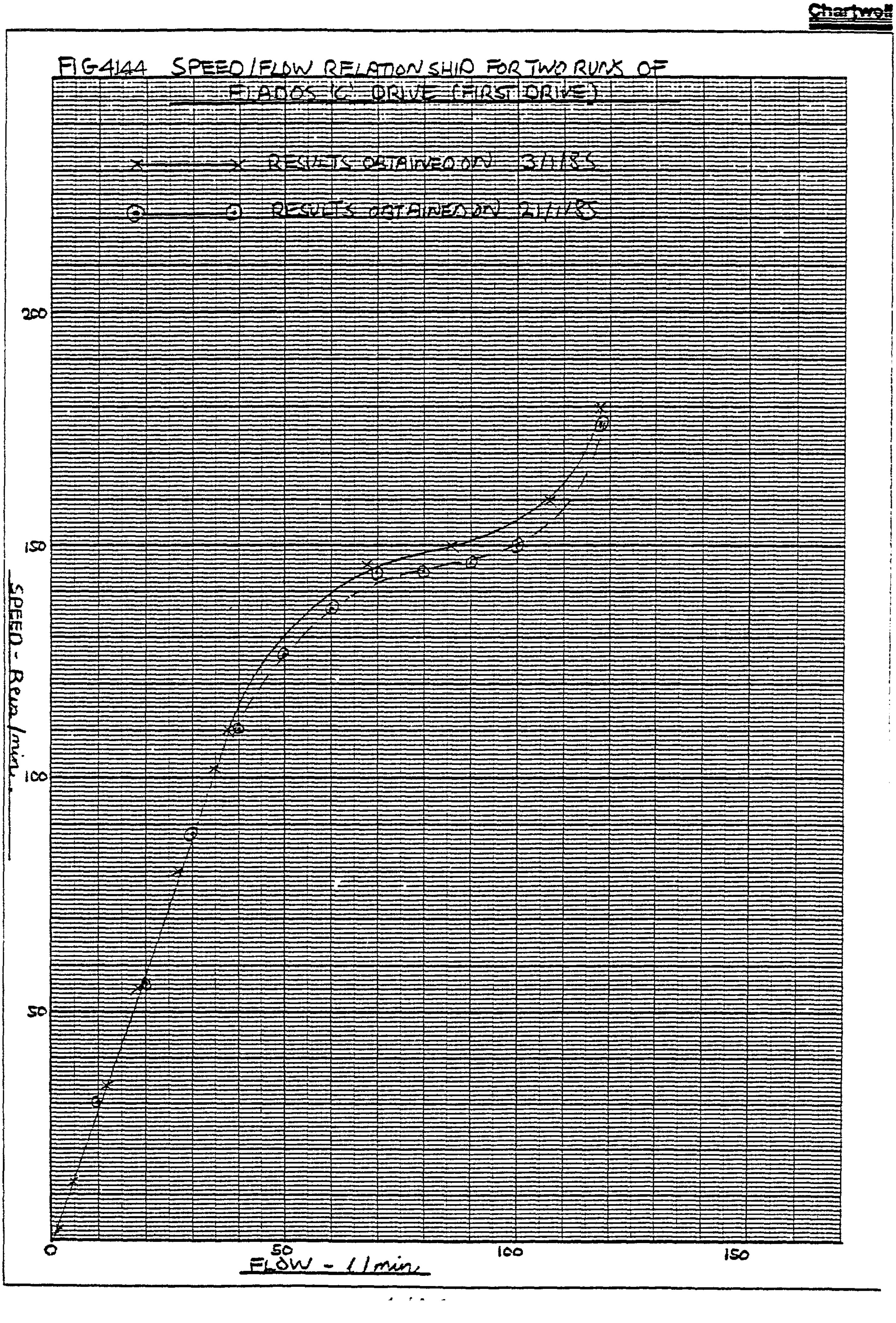

Chartwell
FIG 4.14.4 SPEED/FLOW RELATIONSHIP FOR TWO RUNS OF FLADOS 'C' DRIVE (FIRST DRIVE)
RESULTS OBTAINED ON 3/1/85
RESULTS OBTAINED ON 2/1/85
200
150
100
50
0
SPEED - Revs/min.
50
100
150
FLOW - l/min.

FIG 4.14.5. COMPARISON OF ELANDS 'C' DRIVE SPEED / FLOW RELATIONSHIPS OBTAINED ON 15/3/85 & 21/1/85. (FIRST DRIVE)

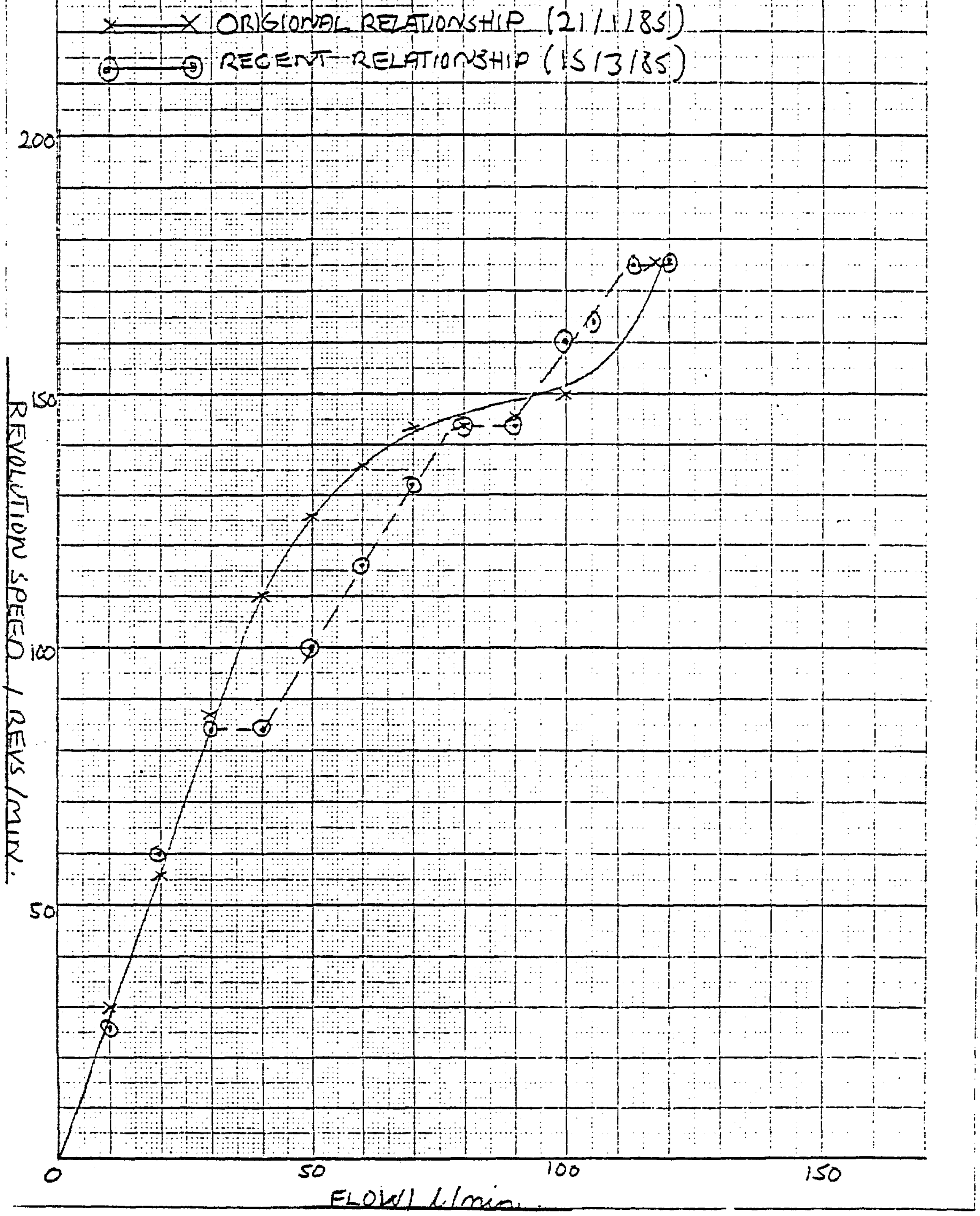


FIG 4.14.6 SPEED/FLOW RELATIONSHIP FOR NEW DRIVE

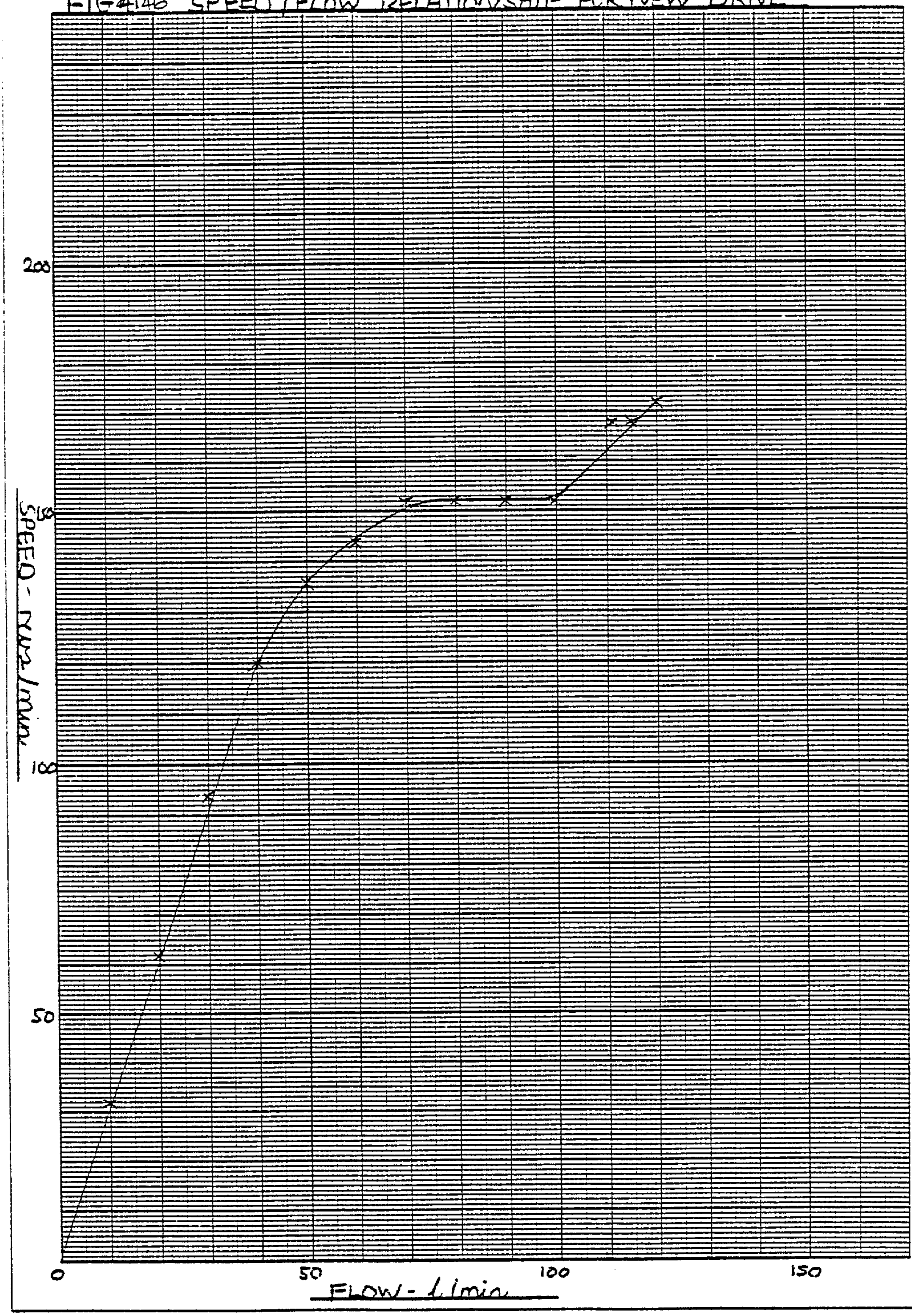
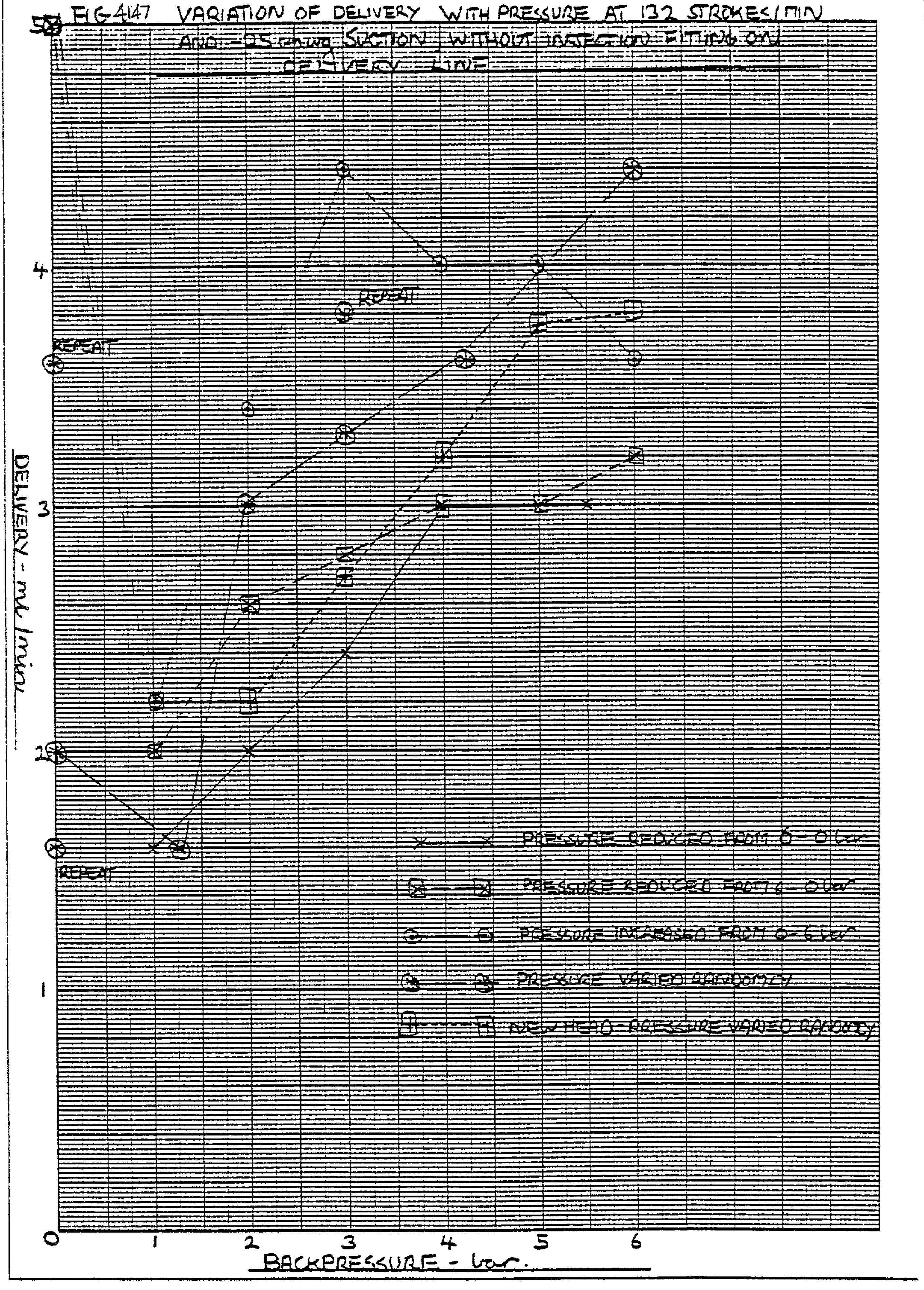


FIG 4.14.7 VARIATION OF DELIVERY WITH PRESSURE AT 132 STROKES/MIN AND -25 mmWG SUCTION WITHOUT INJECTION FITTING ON DELIVERY LINE



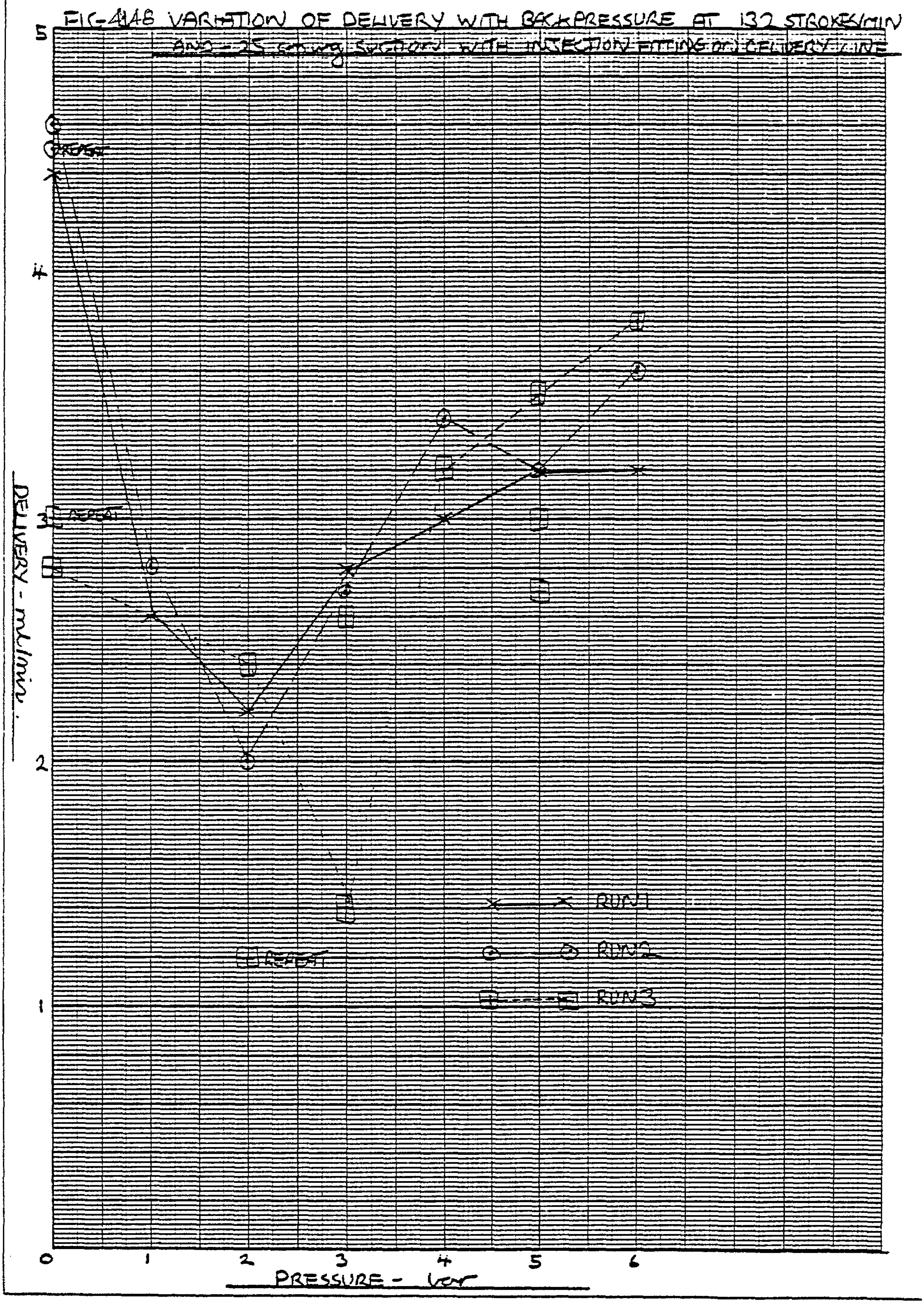
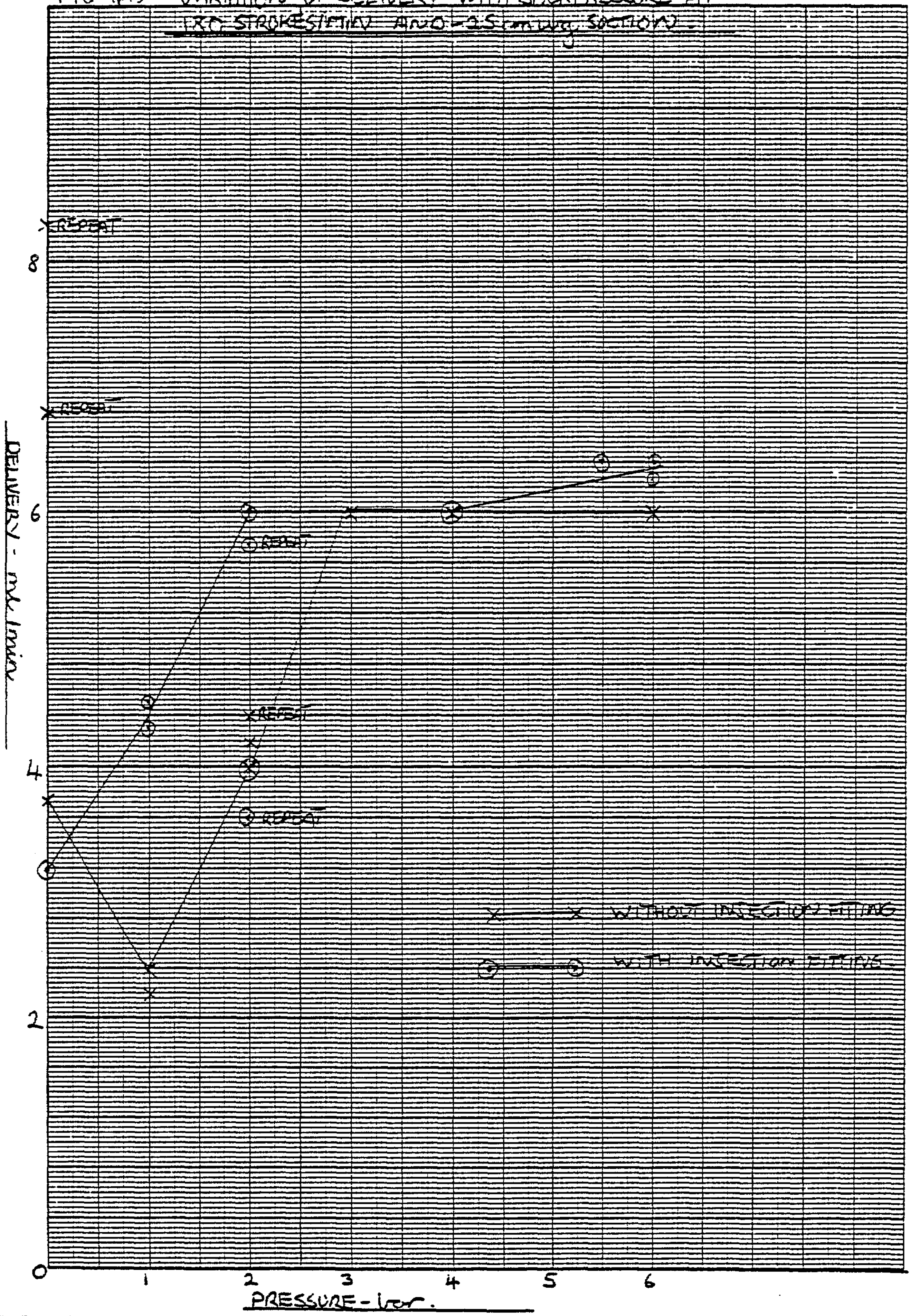


FIG 4.14.8 VARIATION OF DELIVERY WITH BACKPRESSURE AT 132 STROKES/MIN
AND -25 cm wg SUCTION WITH INJECTION FITTING ON DELIVERY LINE
DELIVERY - ml/min.
PRESSURE - bar
0
1
2
3
4
5
6
REPEAT
REPEAT
REPEAT
RUN 1
RUN 2
RUN 3

FIG 4.14.9 VARIATION OF DELIVERY WITH BACKPRESSURE AT 130 STROKES/MIN AND 2.5 (mm dia) SECTION.



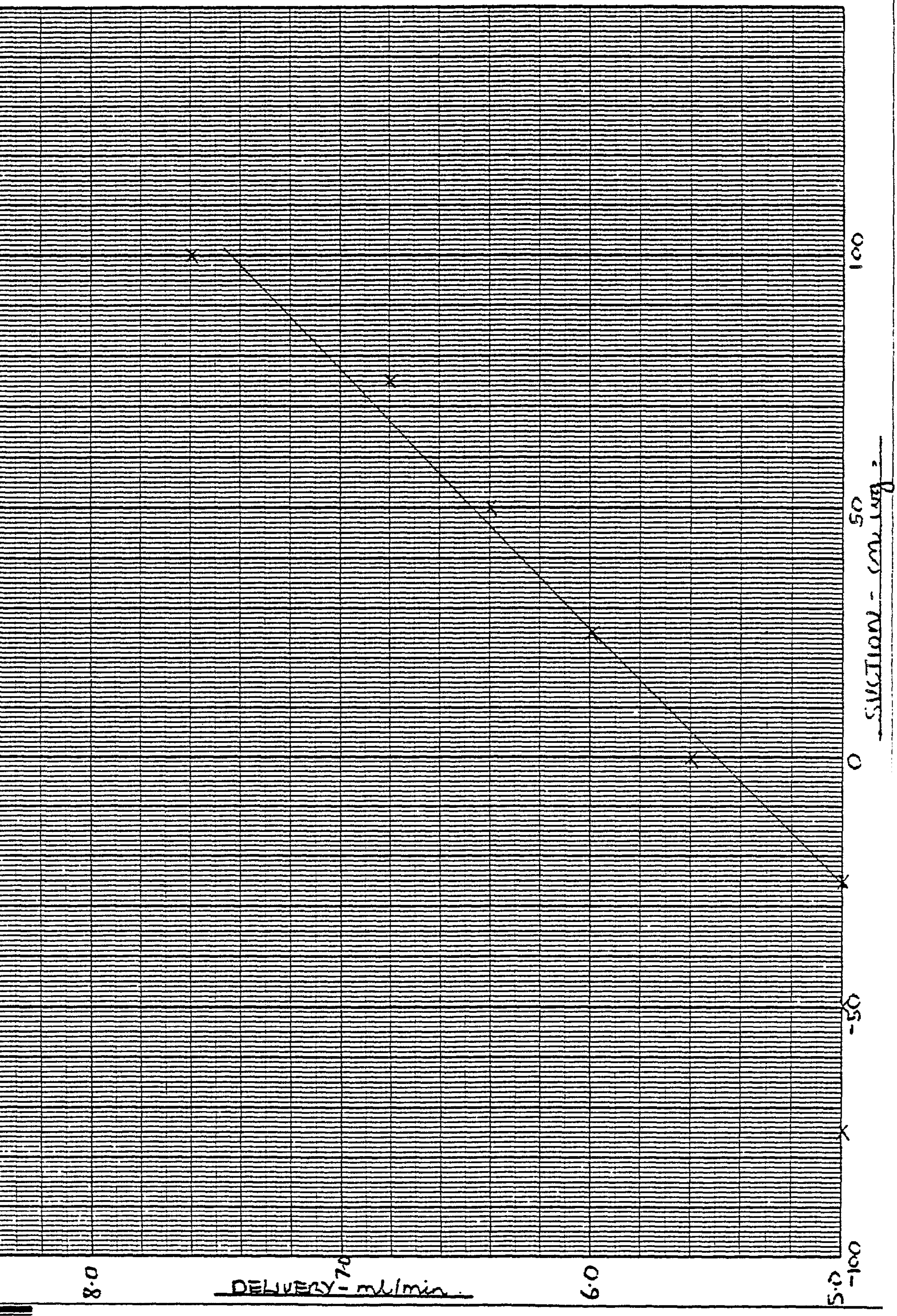
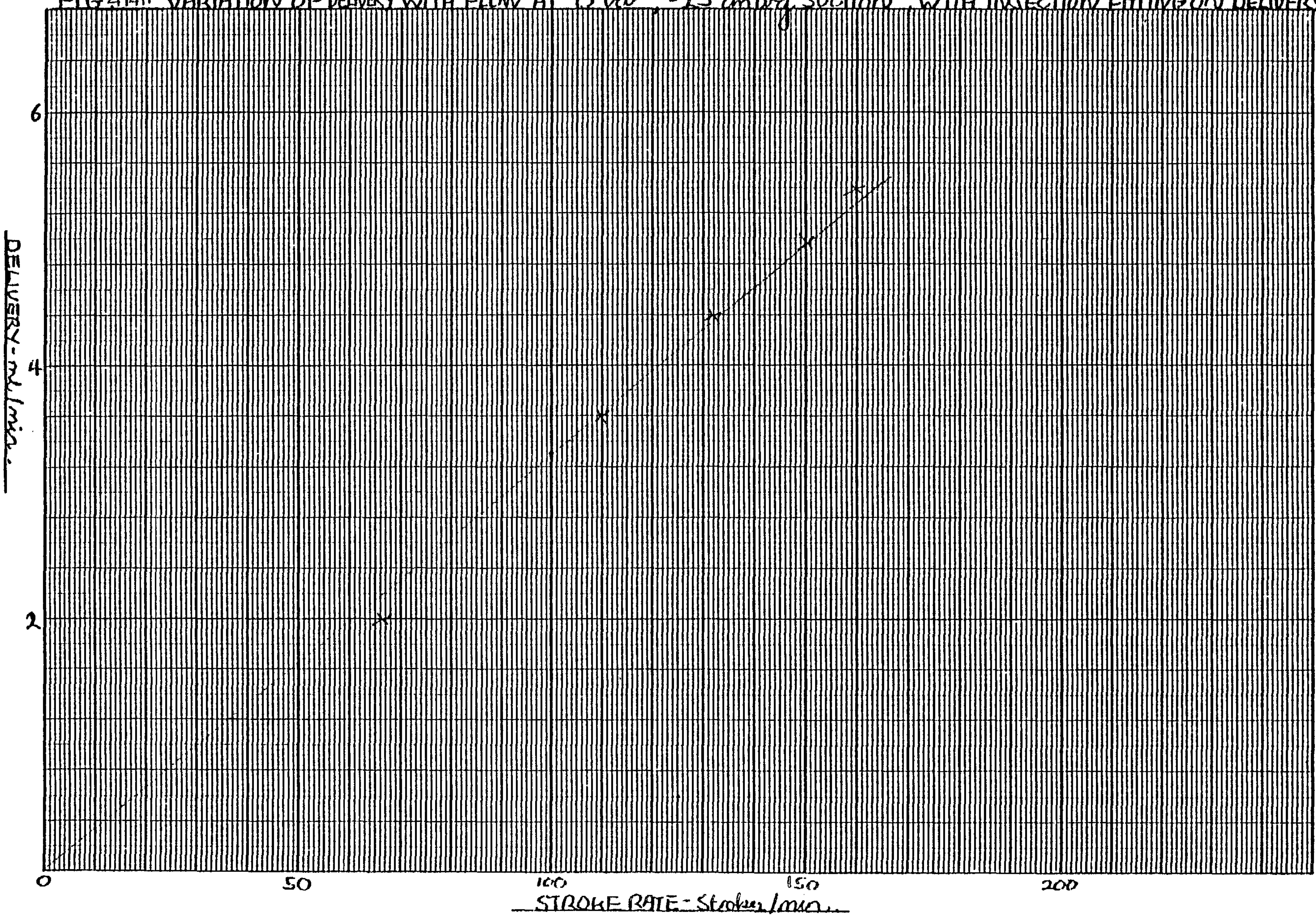



FIG 4.14.10 VARIATION OF DELIVERY WITH SUCTION HEAD AT 0 cm BACKPRESSURE AND 133 STROKES/MIN

FIG 4.14.11 VARIATION OF DELIVERY WITH FLOW AT 0 bar, -25 cm wg SUCTION, WITH INJECTION FITTING ON DELIVERY



## Tests

The AHWM feeder is rated as follows.

| | |
|---|---|
| Maximum hypochlorite dose | 2.6ml/s |
| Maximum delivery per pump stroke | 13.5ml |
| Manual adjustment range | 4:1 |
| Automatic range | 20:1 |
| Maximum pressure | 8.6bar |
| Minimum pressure | 0.7bar |
| Maximum water usage (for power) | 30.0ml/s |
| Maximum water temperature | 38 C |
| Minimum water temperature | 4 C |
| Maximum solution suction head | 2.5m |
| Maximum flow through meter | 2954 l/h |
| Minimum flow through meter | 9 l/h |
| Headloss at maximum flow | 1.4m |

The laboratory water supply was connected to drain through the flowmeter with a gate valve upstream to control flow and a gate valve downstream to control pressure. Since the accuracy of the whole unit depended upon both the accuracy of the meter and the accuracy of the dosing pump, it was decided to test each part separately.

## The Meter

The meter had a needle that made one revolution for every 10 litres passed and a six digit revolution counter, giving a reading up to 10000 cubic meters between zeros. It was checked by timing batches of about 300 l into a tank standing on the platform of a weighing machine. Flow rates of 75 to 8000 l/h were measured, the latter being 2.7 times the rated maximum. In a separate run it was found that the meter registered a flow of 9l/h.

The graph Fig 4151 shows a plot of the ratio, meter reading:measured throughput against flow rate. It indicates that over the rated range up to 3000 l/h the meter reads 2-3% high, but that above this range the ratio decreases slightly. This level of accuracy is satisfactory for the duty.

Next, it was required to know how much water passed the meter for each stroke of the pump. Tests were undertaken at 2800 l/h, 1320 l/h and 280 l/h, noting the volume passed for 50 pump strokes. For each of 24 results the volume was 187 or 188 litres, or 3.75 l per stroke. Hence the stroke rate is proportional to flow rate.

To see how this response might be affected by friction or by dirt in the cam bearing, the drive spindle was gripped lightly. It required firm pressure between thumb and forefinger to stop the spindle turning, suggesting that the doser would not be easily affected by adverse operating conditions.

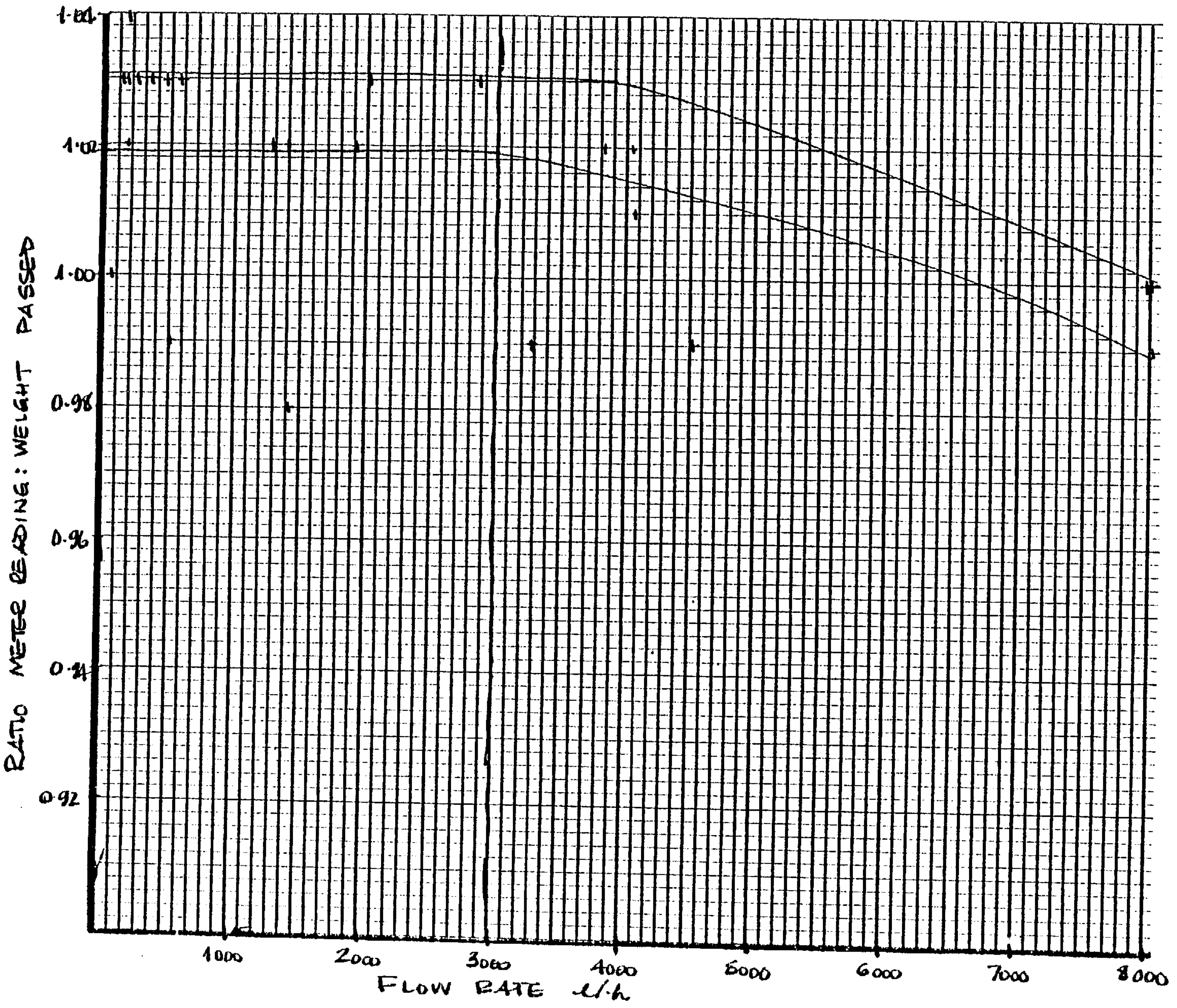



Figure 4.15.1 AHWM meter performance graphed against flow rate

## Dosing Pump

To check the performance of the dosing pump measurements were made of dose per stroke. At first, the output from the dosing head was collected but it was found the quantity depended very much upon the suction and delivery pressures. This was attributed to the fact that the dosing diaphragm was pressurised on one side from the water main, and that accurate dosing would only be obtained when this diaphragm was balanced as intended. Therefore water, representing dose solution, was taken from a measuring cylinder and the volume drawn in a known number of strokes (usually 10) noted.

A series of calibrations was made at system pressures of 0.5, 1, 2 and 3 bar at a flow rate of 2800 l/h, and then at 3 bar pressure at flow rates of 280, 1320, and 2800 l/h. All these results plotted on to a single line showing that dose per stroke was not affected by flow or pressure in the ranges tested. There was no difficulty in aligning the pointer with any required setting on the scale and successive runs adjusting upwards and then downwards showed that there was no backlash in the setting mechanism. However, as can be seen in Fig 4152, the dose was not proportional to setting and did not increase above setting 8.

This indicated that the setting knob was not correctly positioned on its shaft. It was loosened and repositioned. A repeat calibration, Fig 4153 showed that dosing was now proportional to setting number.

## Conclusions

The Feeder Type AHWM provides flow rate-proportional dosing across a wide flow rate range and is sufficiently precise for use with potable water. It is well made, and should provide reliable service provided routine maintenance is performed as advised by the manufacturer.

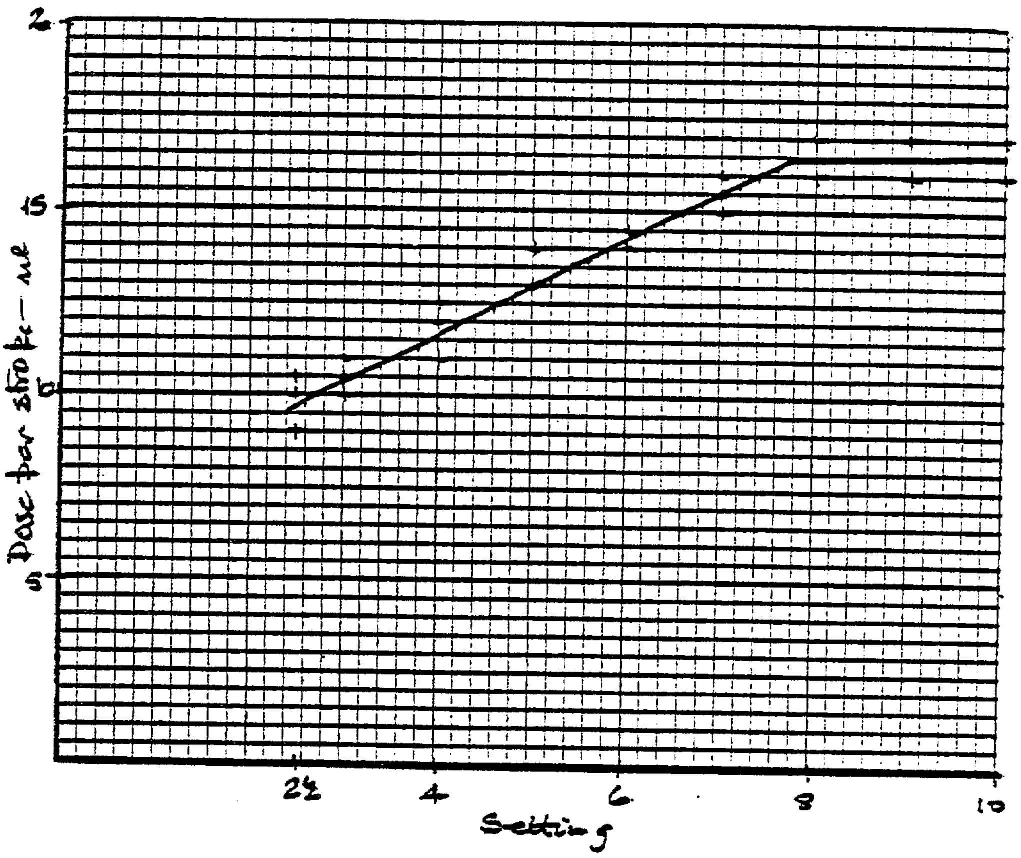
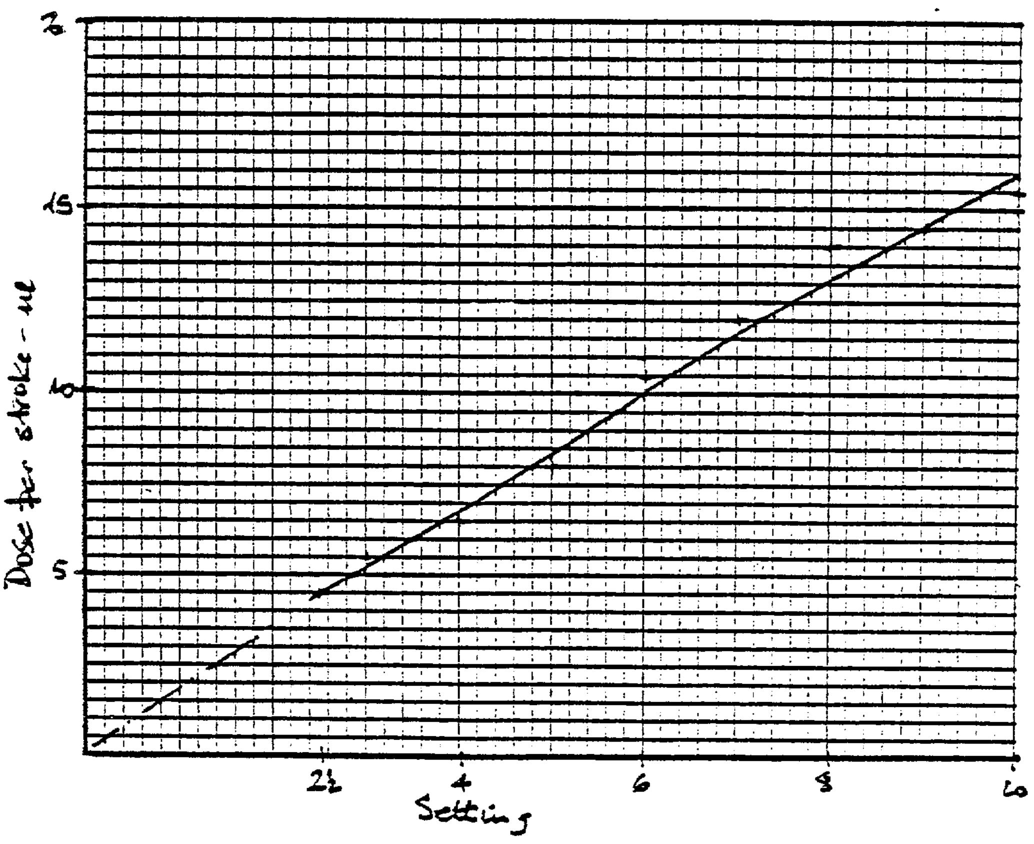



Figure 4.52 Calibration – Pump as delivered



INITIAL CALIBRATION OF SETTING KNOB

| SETTING | DOSE PER STROKE ml (2800l/h) | (1320l/h) | (280l/h) |
|---|---|---|---|
| 2.5 | 9.0 | 10.0 | 10.0 |
| 3 | 10.0 | 11.0 | 11.0 |
| 4 | 12.0 | 12.0 | 12.0 |
| 5 | 14.0 | 13.0 | 13.0 |
| 6 | 14.5 | 14.5 | 14.0 |
| 7 | 15.0 | 16.0 | 16.0 |
| 8 | 16.0 | 16.0 | 17.0 |
| 9 | 16.0 | 16.0 | 17.0 |
| 10 | 16.0 | 17.0 | 17.0 |

CALIBRATION AFTER RESETTING KNOB

| SETTING | DOSE PER STROKE ml (2800l/h) | (280l/h) |
|---|---|---|
| 2.5 | | 4.5 |
| 3 | 5.5 | |
| 4 | | 6.5 |
| 5 | 8.0 | |
| 6 | | 11.0 |
| 7 | 12.0 | |
| 8 | | 14.0 |
| 9 | 14.5 | |
| 10 | | 15.0 |

## DETERMINATION OF METER ACCURACY

| DELIVERY RECORDED BY METER litres | WEIGHT OF WATER COLLECTED kg | TIME OF COLLECTION min:sec | FLOW RATE l/h | RATIO OF METERED TO COLLECTED |
|---|---|---|---|---|
| 300.0 | 299.8 | 2:15 | 7994.0 | 1.00 |
| 300.0 | 300.0 | 2:15 | 8000.0 | 1.00 |
| 300.0 | 300.2 | 2:15 | 8005.0 | 0.99 |
| 300.0 | 300.0 | 2:15 | 8000.0 | 1.00 |
| 300.0 | 300.2 | 2:15 | 8005.0 | 0.99 |
| 300.0 | 300.6 | 4:00 | 4509.0 | 0.99 |
| 300.0 | 300.2 | 4:00 | 4503.0 | 0.99 |
| 300.0 | 300.4 | 4:00 | 4506.0 | 0.99 |
| 300.0 | 300.6 | 4:00 | 4509.0 | 0.99 |
| 300.0 | 300.2 | 4:00 | 4503.0 | 0.99 |
| 310.0 | 301.4 | 14:20 | 1273.0 | 1.02 |
| 310.0 | 300.8 | 9:00 | 2005.0 | 1.03 |
| 310.0 | 299.2 | 6:30 | 2761.0 | 1.03 |
| 310.0 | 303.2 | 9:30 | 1914.0 | 1.02 |
| 300.0 | 300.6 | 5:30 | 3279.0 | 0.99 |
| 310.0 | 303.0 | 4:45 | 3827.0 | 1.02 |
| 310.0 | 302.8 | 4:30 | 4037.0 | 1.02 |
| 290.0 | 285.6 | 4:20 | 4079.0 | 1.01 |
| 280.0 | 283.4 | 12:00 | 1417.0 | 0.98 |
| 290.0 | 282.0 | 12:00 | 1410.0 | 1.02 |
| 290.0 | 280.6 | 36:00 | 467.0 | 1.03 |
| 290.0 | 281.2 | 29:15 | 578.0 | 1.03 |
| 140.0 | 140.0 | 1:51 | 75.0 | 1.00 |
| 290.0 | 280.0 | 2:03 | 136.0 | 1.03 |
| 290.0 | 280.0 | 50:00 | 348.0 | 1.03 |
| 289.0 | 278.6 | 67:00 | 249.4 | 1.03 |
| 229.0 | 218.8 | 70:00 | 187.5 | 1.04 |
| 290.6 | 280.0 | 113:00 | 148.6 | 1.03 |
| 290.7 | 282.4 | 87:00 | 194.7 | 1.02 |
| 290.0 | 280.2 | 33:30 | 501.8 | 0.99 |

## DETERMINATION OF VOLUME OF WATER PER STROKE

| ATER FLOW ATE l/h | 2800 | 1320 | 280 |
|---|---|---|---|
| OLUME FOR O STROKES litres | 188 | 188 | 188 |
| | 188 | 188 | 188 |
| | 188 | 188 | 188 |
| | 187 | 187 | 188 |
| | 188 | 188 | |
| | 187 | 188 | |
| | 188 | 188 | |
| | 188 | 187 | |
| | 188 | 188 | |
| | 187 | 188 | |

APPENDIX 4.16 SANURIL TABLET CHLORINATOR

## Introduction

The unit was rated as follows:

| | |
|---|---|
| Dose at 12 l/min | 4.6 mg/l |
| Dose at 35 l/min | 5.4 mg/l |

It was recommended that the chlorinator should be mounted with its base horizontal.

## Evaluation Under Normal Operating Conditions

Experiments were carried out to determine the variability of the dose during normal operation. The flow rate was increased in steps to 20 l/min and it was clear that the dose was flow sensitive and higher than specified by the manufacturer (Figs 4161, 4162). The dose was found to vary according to the following relationship,

Dose(mg/l) = 59/Flow Rate(l/min) + 12.7

This curve is plotted on Figs 4161 and 4162.

## Variation of Dose From Different Tablets

When the chlorinator was running continuously at a set flow rate, the dose showed a periodic variation as one tablet dissolved away and another was wetted. Usually the dose from a particular tablet was reasonably constant, showing a random variation of +/-1 mg/l; however, as the tablet approached the end of its life the dose decreased by 2 to 3 mg/l due to the reduction in surface area, and then rose rapidly by as much as 10 mg/l as the remaining fragment crumbled away (Figs 4163, 4164). Some tablets gave a very variable dose due to premature crumbling.

## Effect of Chlorinator Angle

One suggested way of producing a lower and hopefully steadier dose was tipping the whole unit forward. This divided the flow into two sections, a thin film of fast moving water along the floor of the trough and a pool caused by the hold up at the weir. Fig 4165 shows the dose/flow rate relationship for a 5 degree tilt angle. At very low flow rates, with a tilt angle of 5 degrees or more, most of the flow was below the support grid and it was assumed that the tablet was dissolved very slowly by splashes as the water flowed past the tube supports. The dose was very flow variable,decreasing rapidly with rising flow rate. At a certain flow, depending on the tilt angle, the water level rose above the grid. The dose then showed a slight increase after which it tended towards a constant level as the tablet immersion increased with flow rate. At very high flows the dose tended to increase again, due either to greater tablet erosion or to the tablet becoming immersed in the backwash from the front wall of the trough.

In general the dose at a given flow rate decreased with the degree of forward tilt until a minimum dose was obtained after 10 degrees (Fig 4166). At flow rates below 2 l/min tilting the unit more than 8 degrees increased the flow velocity to such an extent that the wash created against the front of the tube (Fig 4167a) was large enough to penetrate the support grid. The graph of dose against tilt angle at 2 l/min is shown in Fig 4167b. It can be seen that dose increased again after this point.

With the tube in the rear position, near the inlet, the effects of velocity erosion occured sooner resulting in the flow range of constant dose being significantly reduced (Fig 4168, curve b)

The chlorinator was also tested with a 5 degree backward tilt and the tube in the front position. At low flows the increased hold-up caused a longer immersion time and thus larger dose (Fig 4169). At flows above 15 l/min the tube was immersed to a similar depth as in level operation, but the actual volume of water was greater. Dose therefore fell below the level operation case.

## Effect of Tube Position

The effect of tube position was examined at a 5 degree forward tilt. The results are shown in Fig 41610. The dose was compared with the tubes in the normal position, with the tablet tube only at the front and with the tablet tube only at the rear. There was no overall change in dose with the tube position, although the movement of the tube between readings produced more scattered dose measurements. At higher tilt angles the shape of the curve changed when the tablet tube was moved from front to rear, as explained above. With the chlorinator tilted forward and the tablet tube in the front position an increased dose could be obtained at high flows, as the tablet became immersed in the hold-up at the outlet.

## Effect of Blocking the Back Half of the Tablet Tube

Under normal operation with the chlorinator level and the tablet tube in the front position, there was no change in the level of dose or the shape of the curve (Fig 41611). When the chlorinator was tipped forward, blocking the back of the tube reduced, to some extent, the dose at low flows, by decreasing the wash under the grid. Also, when the tube was in the rear position, it reduced the effects of velocity erosion (Fig 4168, curve c).

## Effect of Wicking

A short test was carried out to investigate the claim that the tablets showed no tendency to absorb water by capillary action (wicking). A stack of tablets was immersed to a depth of 10mm in a large tray of water for 48 hours. Over the first 8 hours the water was drawn up to a height of 8mm. The tablets also showed a slight yellowish colour suggesting that some water had been drawn up through the whole stack. After 23 hours the tablets had started to dissolve, reducing the wicking height to 6mm where it remained until the stack had dissolved away to this level.

The test showed that the anti-wicking properties of the tablets were effective in limiting wetting to a height of 10mm.

## Conclusions

Although this chlorinator was of very simple design, the factors determining the dose were complicated and difficult to identify. The chlorine output was erratic and this added to the difficulties.

Under normal operating conditions, with the trough level and tablets in one tube only, the chlorine concentration delivered by the unit was too high for potable water treatment and the unit could only be used in a situation where a large part of the flow was diverted through a bypass. For example, when operated in the normal manner the minimum rate of chlorine release was about 50mg/min at a flow rate through the trough of 1 l/min. This would provide a dose of 1 mg/l in a flow of 72 cu.m/d. To achieve this, the bypass would need to take 98% of the flow..

From the experimental results it was concluded that the best arrangement for a steady low dose was:

1) To have the chlorinator angled above 10 degrees forward

2) To have the tablet tube in the rear position (near the inlet) to keep it from being immersed in the hold up at the outlet.

3) To have the back half of the tube slots blocked in order to reduce velocity erosion and the wash against the front of the tube

Under the above conditions the Sanuril chlorinator should give a dose of between 1.6 and 0.6mg/l over the flow range 2 to 20 l/min. The Sanuril gave little scope for adjusting dose once set up.

The provision of adequate mixing or a sufficiently large service reservoir would be advisable, to even out the periodic high doses obtained as the last fragments of a tablet crumbled into the water flow. Apart from these peaks the dose could be expected to remain reasonably steady. For use with potable water the device would require a well designed adjustable bypass (such is meant to be fitted with the Aquaward chlorinator) but even then would not be recommended where the flow is likely to vary to any great extent.

The device was of simple design and operation and virtually maintenance free.

26/2/85 (RESULTS) SAVRIL TABLET DOSER - FLOW WITH DOSE WITH 4 TABLETS CHARGED TO TUBE IN POSITION.. TUBE AT BOTTOM OF TROUGH.

FIG 4161

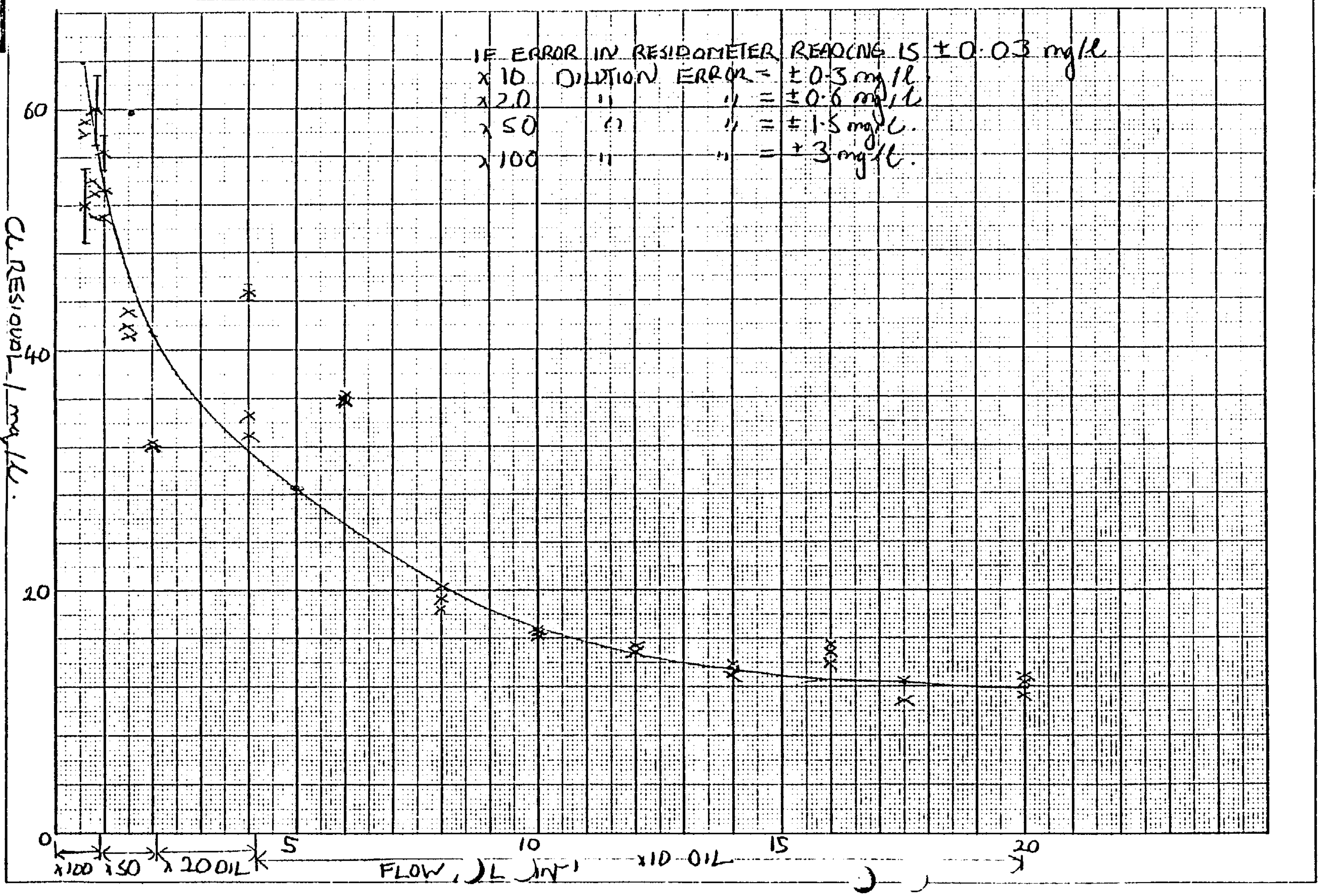
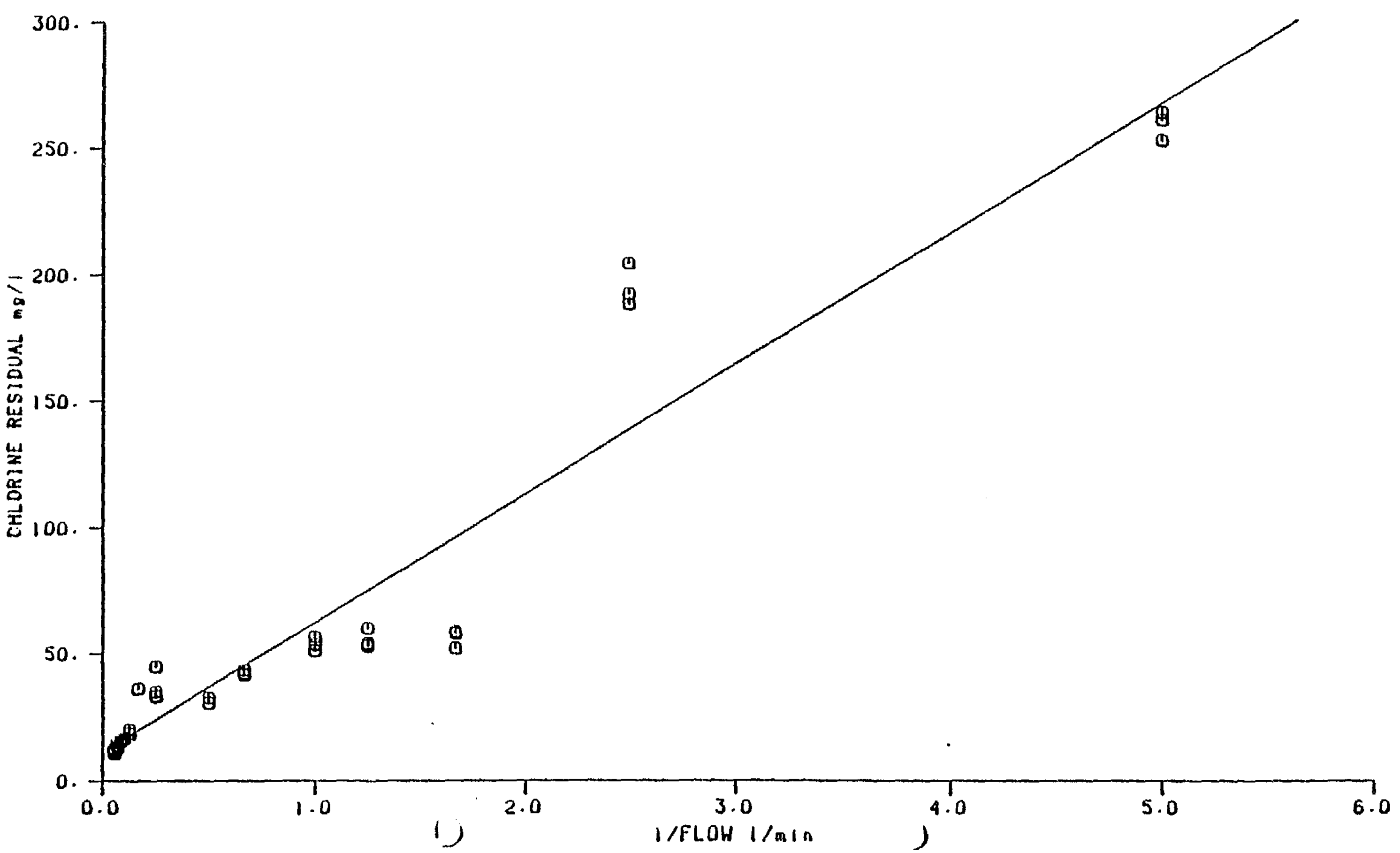


FIG 4.16.2

SANURIL TABLET CHLORINATOR

26/2/85 (RESULTS)



12/4/85 FIG 4.16.3

VARIATION OF DOSE WITH TIME AT 10 l/min 5'F Slope.

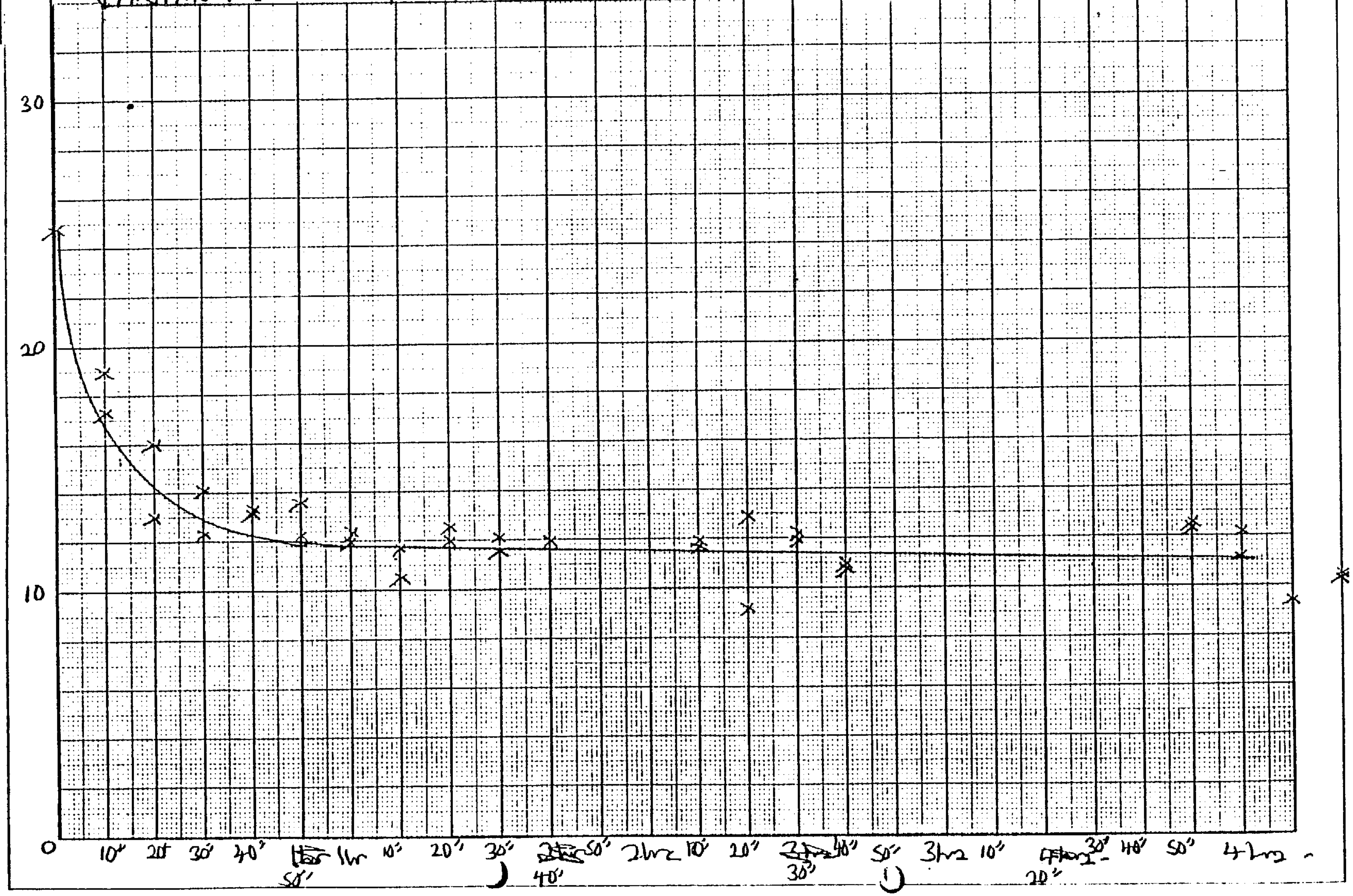


FIG 4.6.4

SANURIL CHLORINATOR - CONTINUOUS RUNNING AT 5° Forward Slope FLOW = 20 l/min.
TABLETS IN POSITION 1, EMPTY TUBE IN POSITION 2. FLOW →

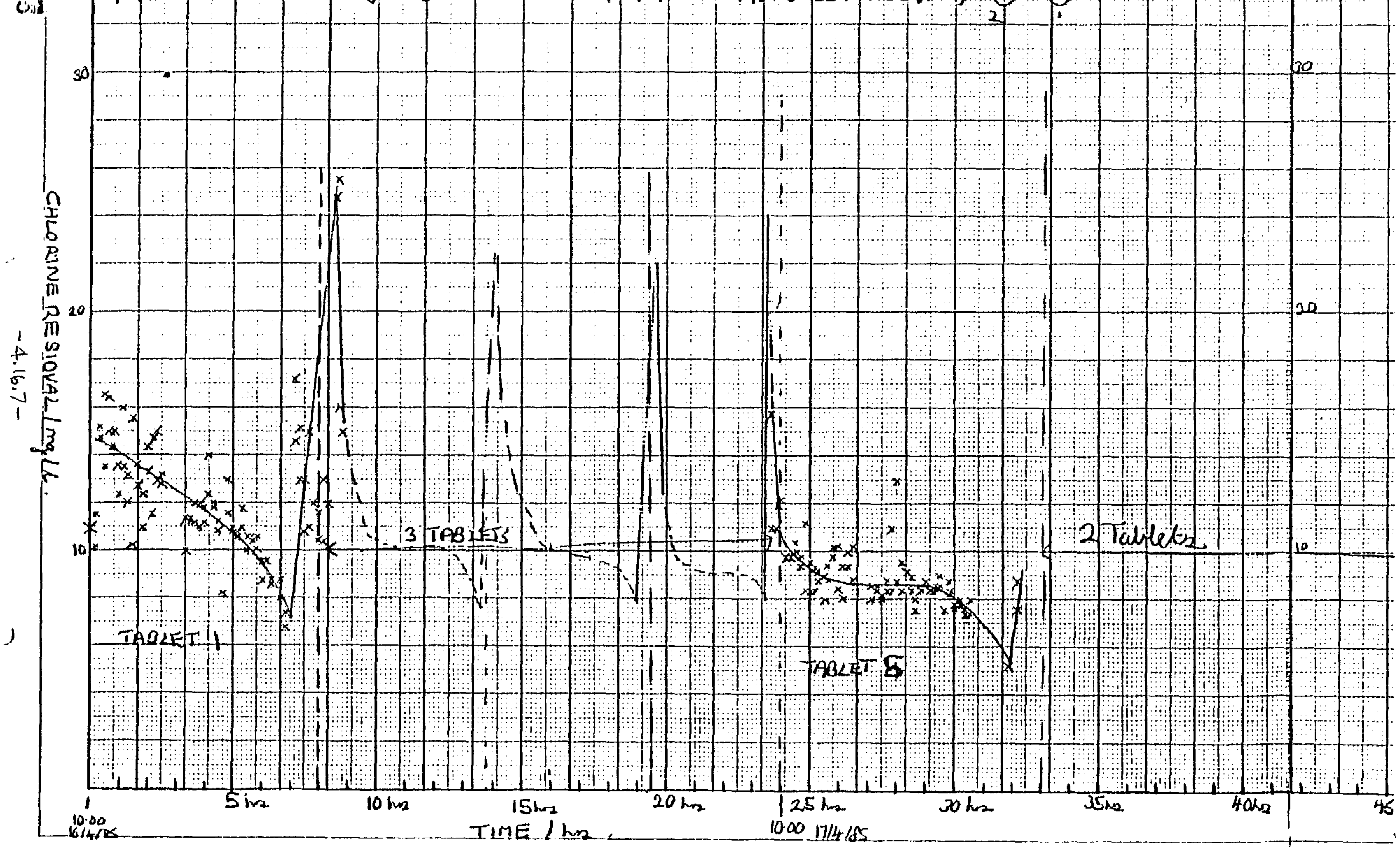
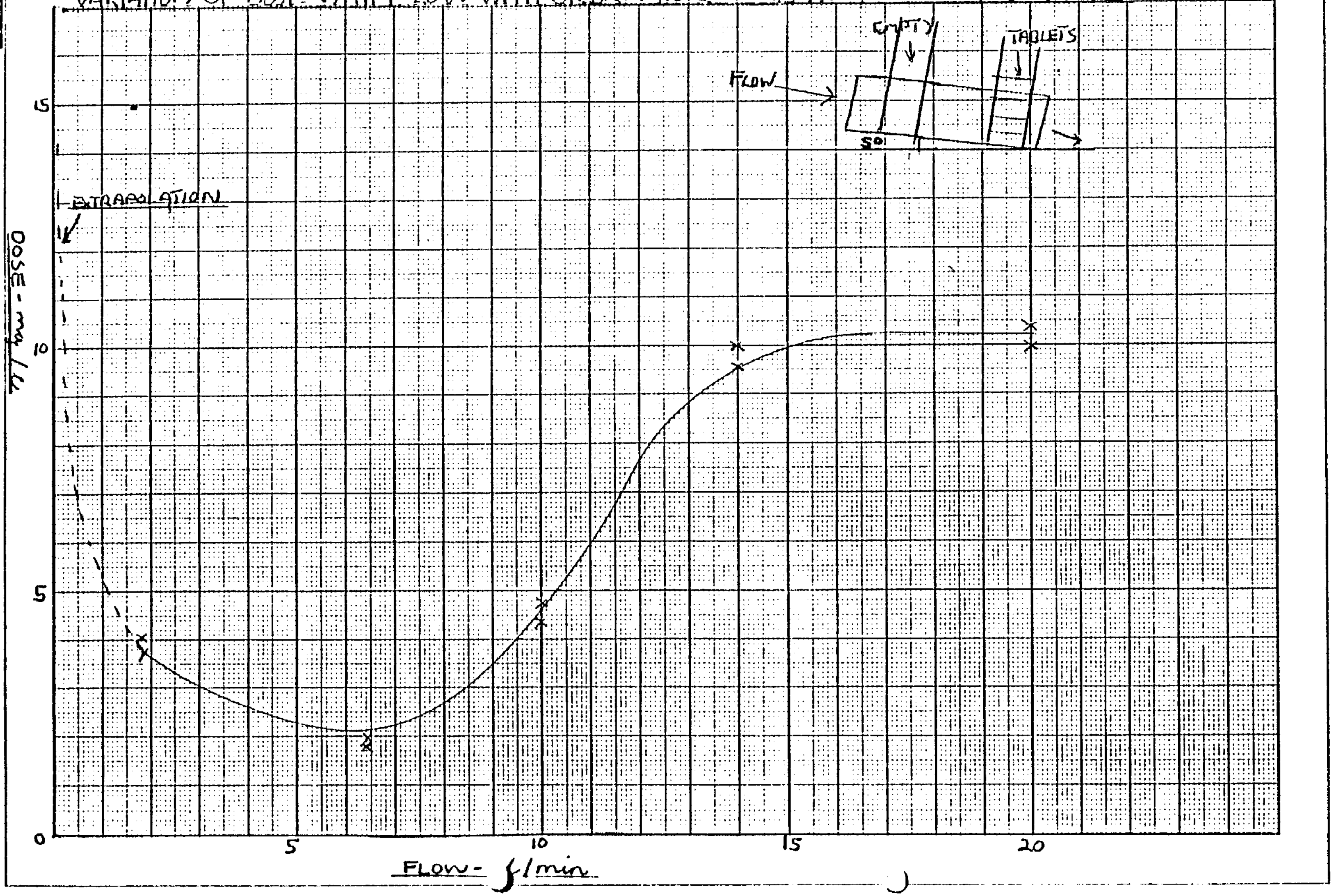
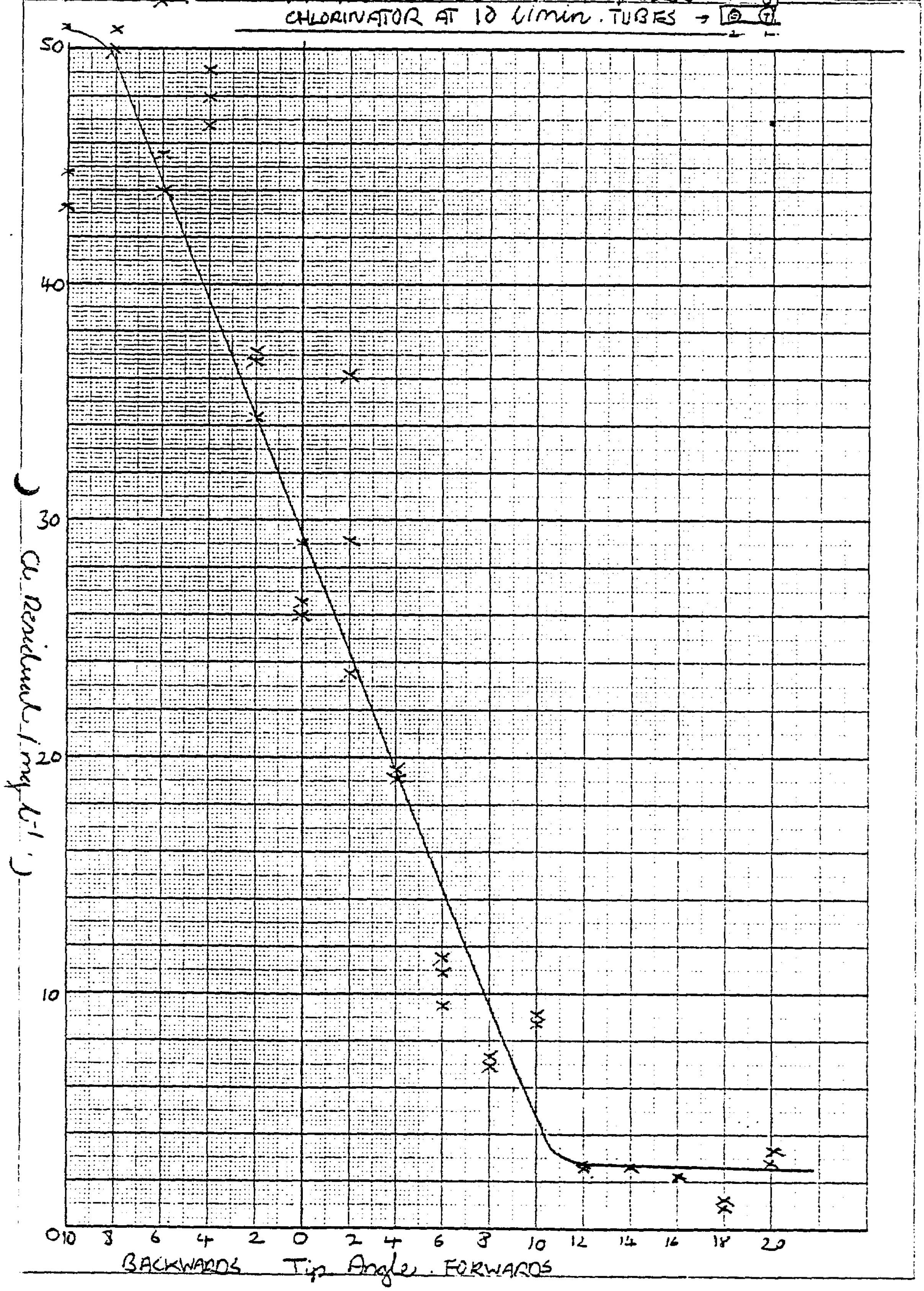


FIG A165

VARIATION OF DOSE WITH FLOW WITH CHLORINATOR TIPPED AT A 5° FORWARD ANGLE

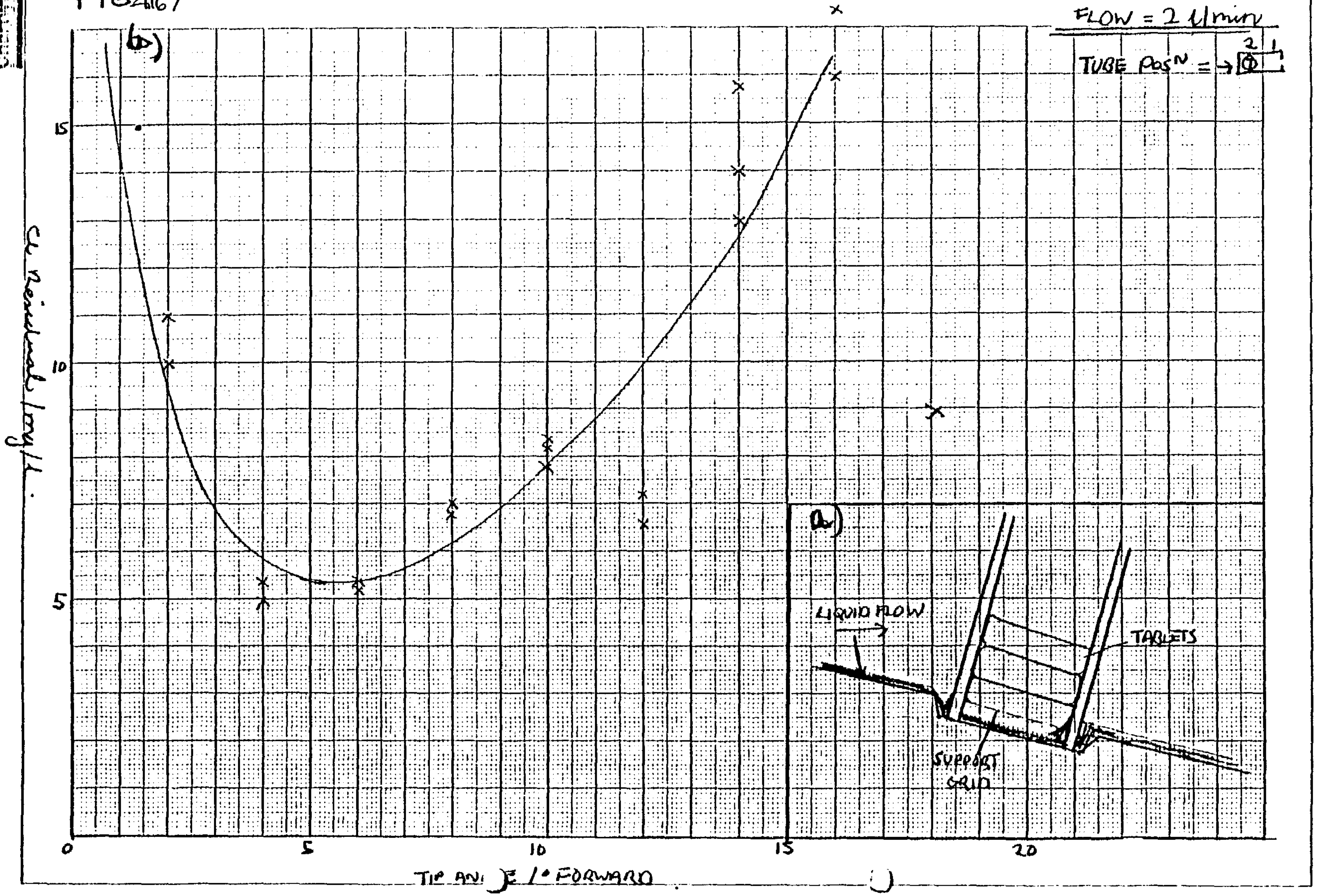


3/4/85. FIG. 4.16 VARIATION OF DOSE WITH ANGLE OF TIP OF CHLORINATOR AT 10 l/min. TUBES →

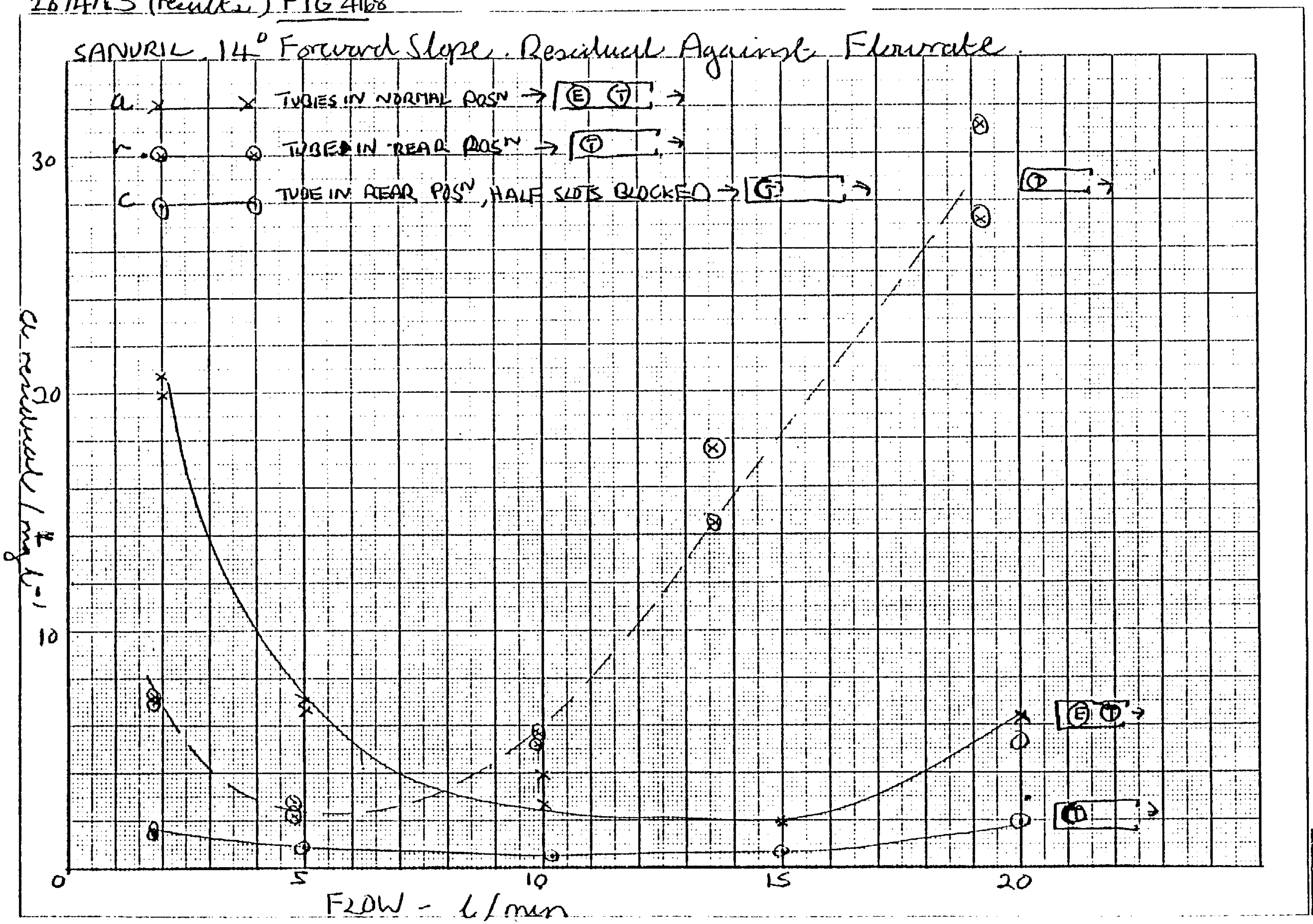


1.15185 VARIATION OF DOSE WITH TIP ANGLE OF SANURIL CHLORINATOR.

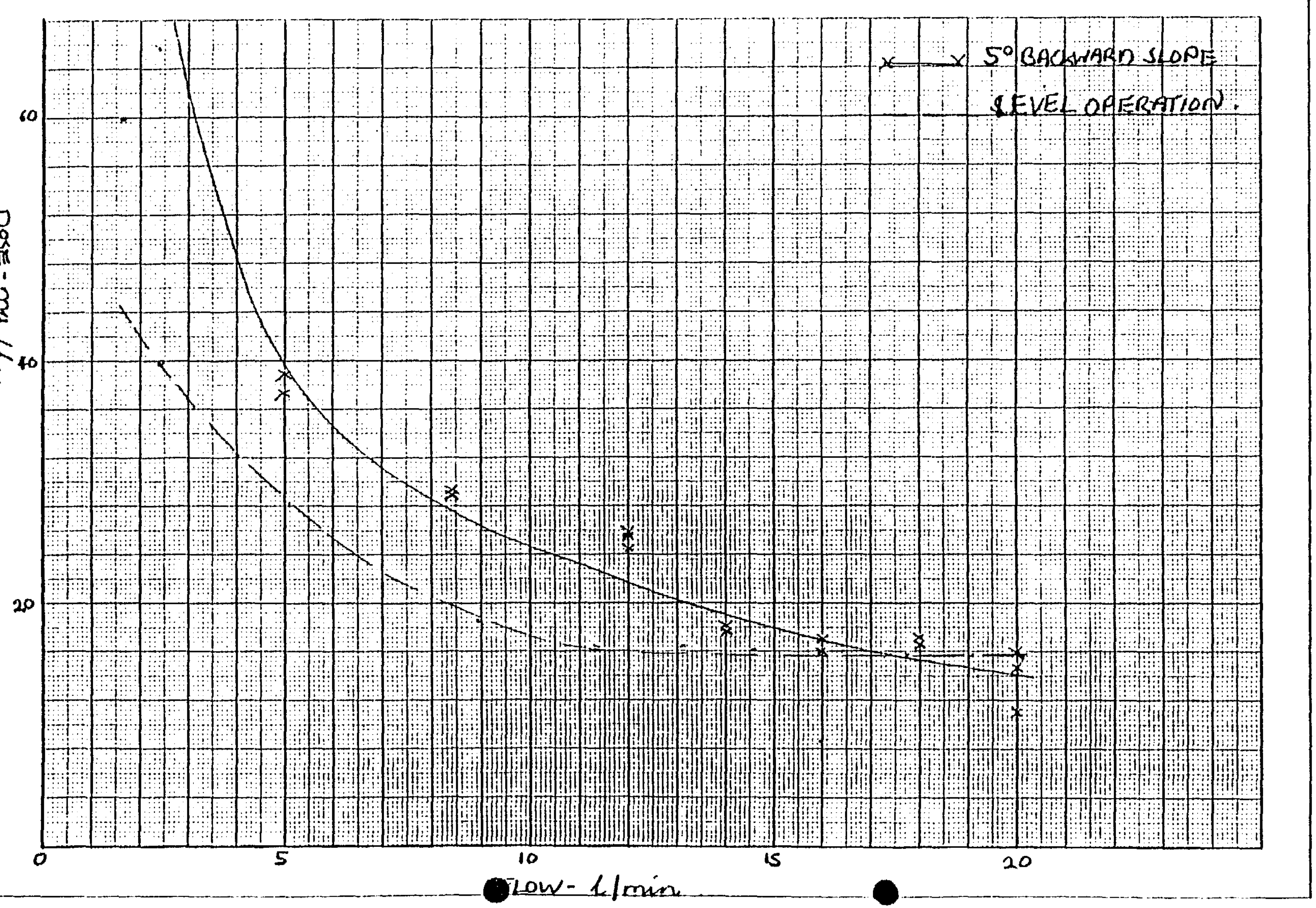
FIG 4.167



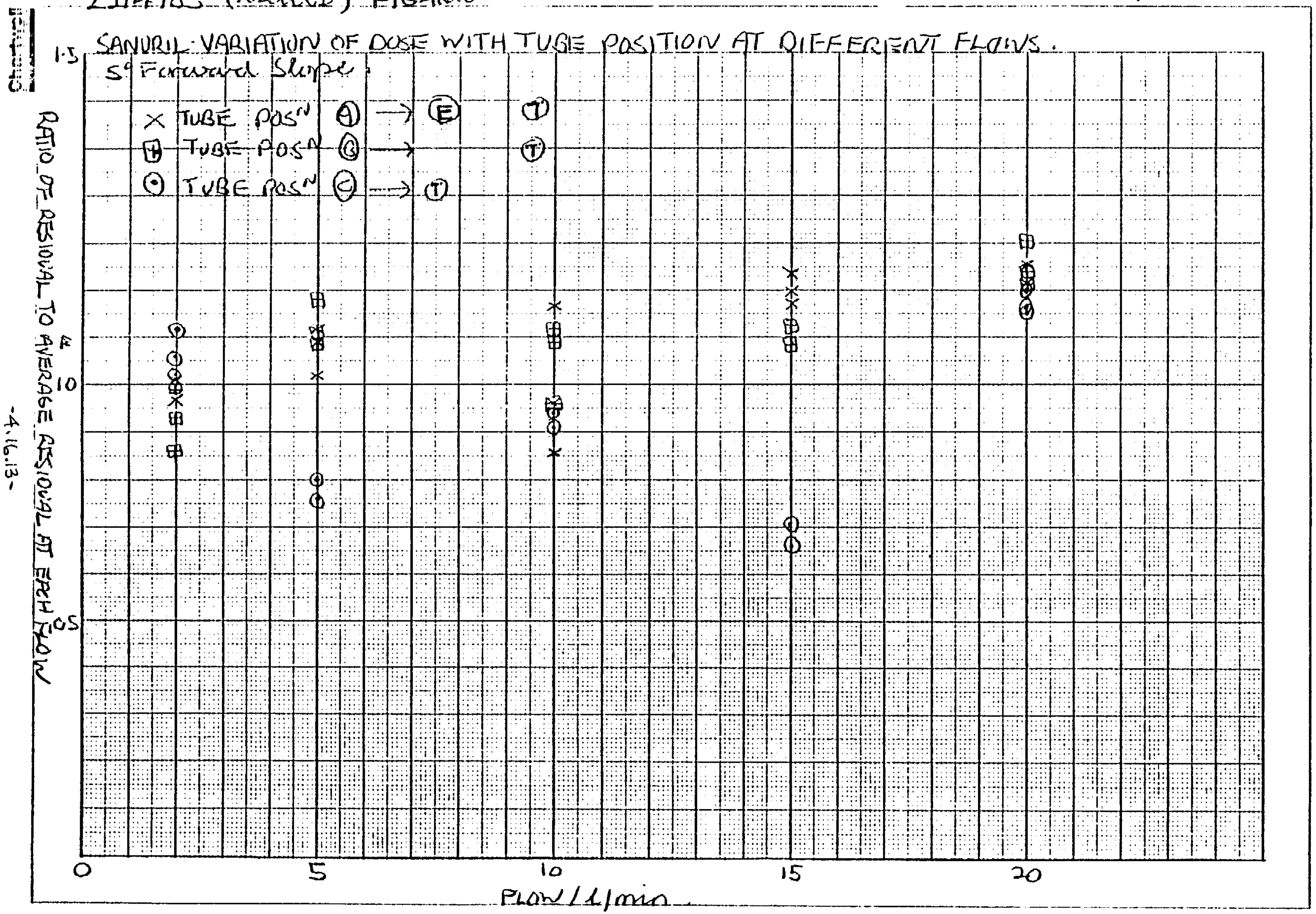
26/14/ES (results) FIG 4.1.68



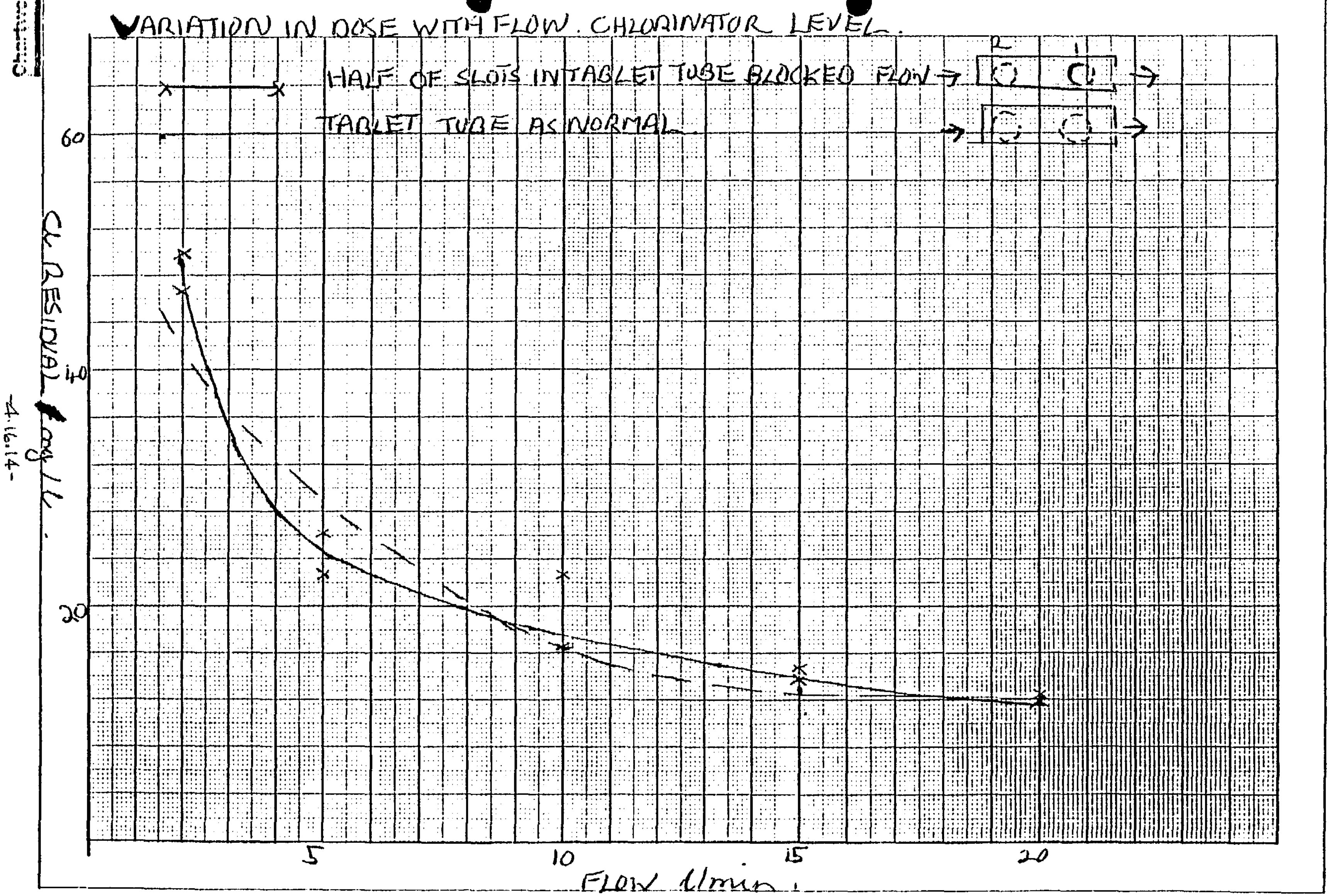
VARIATION OF DOSE WITH FLOW FOR SANURIL-CHLORINATOR TIPPED 5° BACKWARDS FIG 4.16.9



2214/185 (results) FIG4.16.10



24/7/80 SANURIL CHLORINATOR FIG 4.16.11



APPENDIX 4.17 TESTS ON GRAMPIAN TIPPING TRAY

Rate of Solution of Calcium Hypochlorite Tablets

In order to determine the effect of immersion time on the dose obtained from the chlorinator, tests were carried out to find the solution rate of the tablets. The effect of temperature was also investigated.

The solubility rate was estimated by immersing the tablet tube, which contained three tablets, 5 mm into a continually stirred beaker containing three litres of de-ionised water and sampling the water at intervals for chlorine. During each test the solution temperature was held constant by means of a water bath. For temperatures of 10, 18 and 25 C two runs were done using a fresh tablet for each temperature, while at 5 C a fresh tablet was used for the second run as well.

Runs were then done at 18 and 25 C during which the tablet was allowed to dry overnight before repeating the experiment.

The results were then plotted as residual against time with the gradient giving solubility rate, Figs 4171, 4172. The general trend seemed to be an initial rise in chlorine concentration over the first minute after which it increases in proportion with time.

The value of this initial rise varied randomly between runs. It was thought that this was due to a layer of loose dust around new tablets and a layer of saturated solution around old tablets rapidly going into solution. This was supported by the runs at 18 and 25 C (Figs 4173, 4174) where the tablets were allowed to dry before re-use. The initial rise on these runs was much less than for the other cases.

The gradients of the proportional part of the curves are listed in table 1 (appended). The discrepancies between repeated runs indicated that the dissolution process was not a simple one. However, the gradients did in general increase with temperature, as would be expected.

Variation of Dose With Flow

For the doser tests, the chlorinator was mounted on a steel frame above the collecting tank. The water to the unit was piped through a variable orifice flowmeter to aid setting of the flow. The discharged water from each tip was collected in a tank which stood on the platform of a weighing machine. At 20mm immersion depth, the flow through the unit was varied and the fill time, empty time, batch weight and residual were measured for 10 tips at each flow rate.

The mean chlorine residual was found to vary in proportion to the reciprocal of flow rate (Figs 4175, 4176);

$$\text{Residual(mg/l)} = 1.1 + 9.0*[1/\text{Flow(l/min)}]$$

The residual in repeated tips at the same flow rate showed a large variation. The % standard deviation for the 10 samples taken at each flow rate are listed in table 2 (appended).

The experiment was repeated with the tube arranged such that the tablet was in contact with the water only at the moment the tray tipped ie at virtually zero immersion depth. Fig 4177 shows that the residual did not decrease much as compared to the 20 mm immersion case. This appeared to be due to the fact that tablet deposits built up on the support grid.

The average dose and % standard deviation at each flow rate are listed in table 3 (appended). These results suggest that the chlorine concentration in the dose given by the chlorinator is mainly due to a discharge of saturated solution from the tablet when it is first immersed in the water. It was observed that a cloudy solution came from the tube the moment it was in contact with the water.

The maximum flow through the trough was measured as 5 l/min, above this the water overflowed the weir in the reservoir of the unit. The constricting factor on the maximum flow through the trough is the size of the syphon pipe feeding the water into the trough. The empty time remained constant at 2 seconds over the flow range 0.8 to 5.2 l/min.

Fig 41710 shows the variation of average dose, collected in a tank over a number of tips, with flow rate at different tablet immersion depths. The gradient (ie solution rate) of each curve is plotted on Fig 41711. In general, the solution rate increases with immersion.

Continuous Running of the Chlorinator

In a continuous running test spot samples from the tray varied randomly over a period of 28days. Fig 4178 shows that the standard deviation was 56%. To obtain a more realistic appreciation of the overall variation of the dose over a number of days the chlorinator was arranged to dose into a 300 l collecting tank, with a baffle and overflow to allow the batches of chlorinated water to mix. Samples were then taken daily from the overflow. Fig 4179 shows the results obtained with a line representing the linear regression best fit drawn through the points. The standard deviation is 17%, much less than before but still significant.

Flow Splitting Tests

It was found that the proportion of flow directed to the tray remained constant over a reasonable range of flows (2 to 20 l/min, Fig 41712), as long as the inlet to the tube leading to the tray was pointing vertically upwards. Below 2 l/min the proportion flowing to the tray increased due to the liquid being held up at the outlet weir by surface tension.

Conclusions

This doser did not meet the proposed standards for drinking water chlorination; the dose varied by more than +/-10% at a given setting and also varied with temperature changes of less than 30 C. It was not flow proportional. The limiting factor appeared to be the dissolving characteristics of the tablets which, on short time scales were erratic.

However, the doser was designed for use with supplies where it was not critical to keep a constant residual, and there was a service reservoir of several of several hours retention time to even out variations in dose. The general operation of the tiptray was found to be reliable.

In conclusion, the device was designed for, and is in service with, particular water supply situations. It was not meant to be more widely applicable, and the tests supported this view.

FIGURE 1 - TIPPING TRAY CHLORINATOR

Figure 1 (a)
Tray filling with water

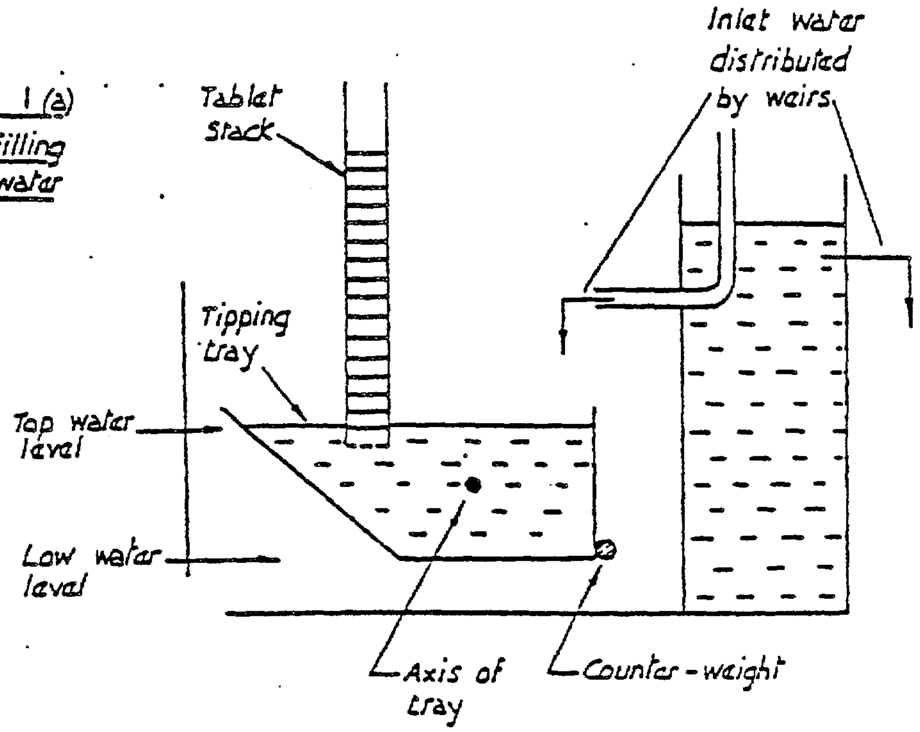



Figure 1 (b)
Discharge of chlorinated water

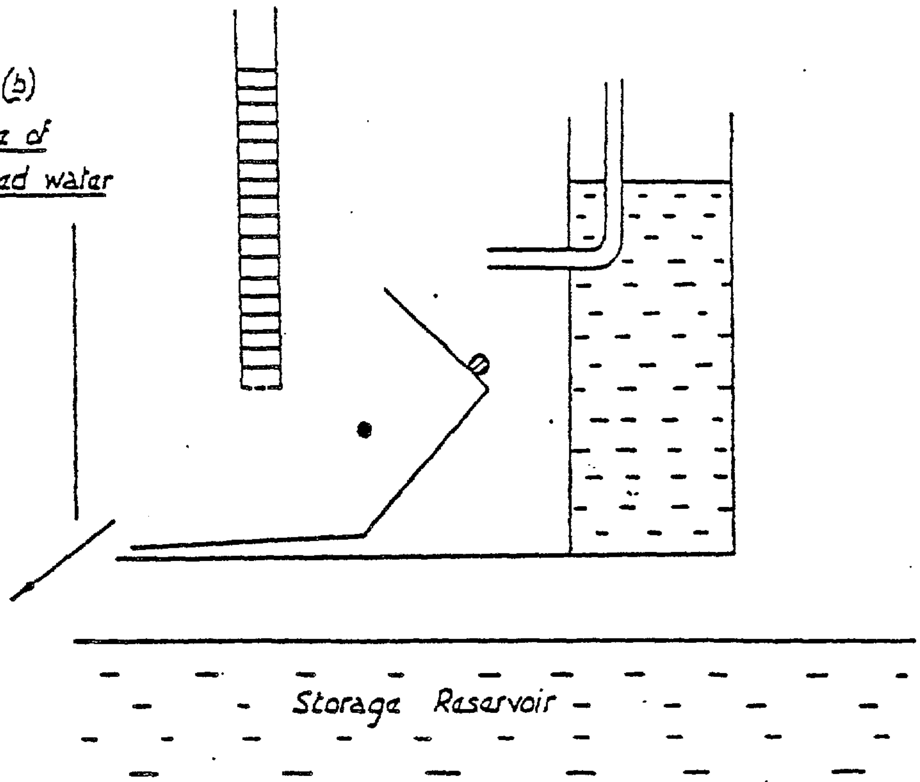


FIG 4171 SOLUTION RATE OF STEADICHLOR-NS TABLETS IN 3 l OF DISTILLED WATER AT 5 mm IMMERSION.

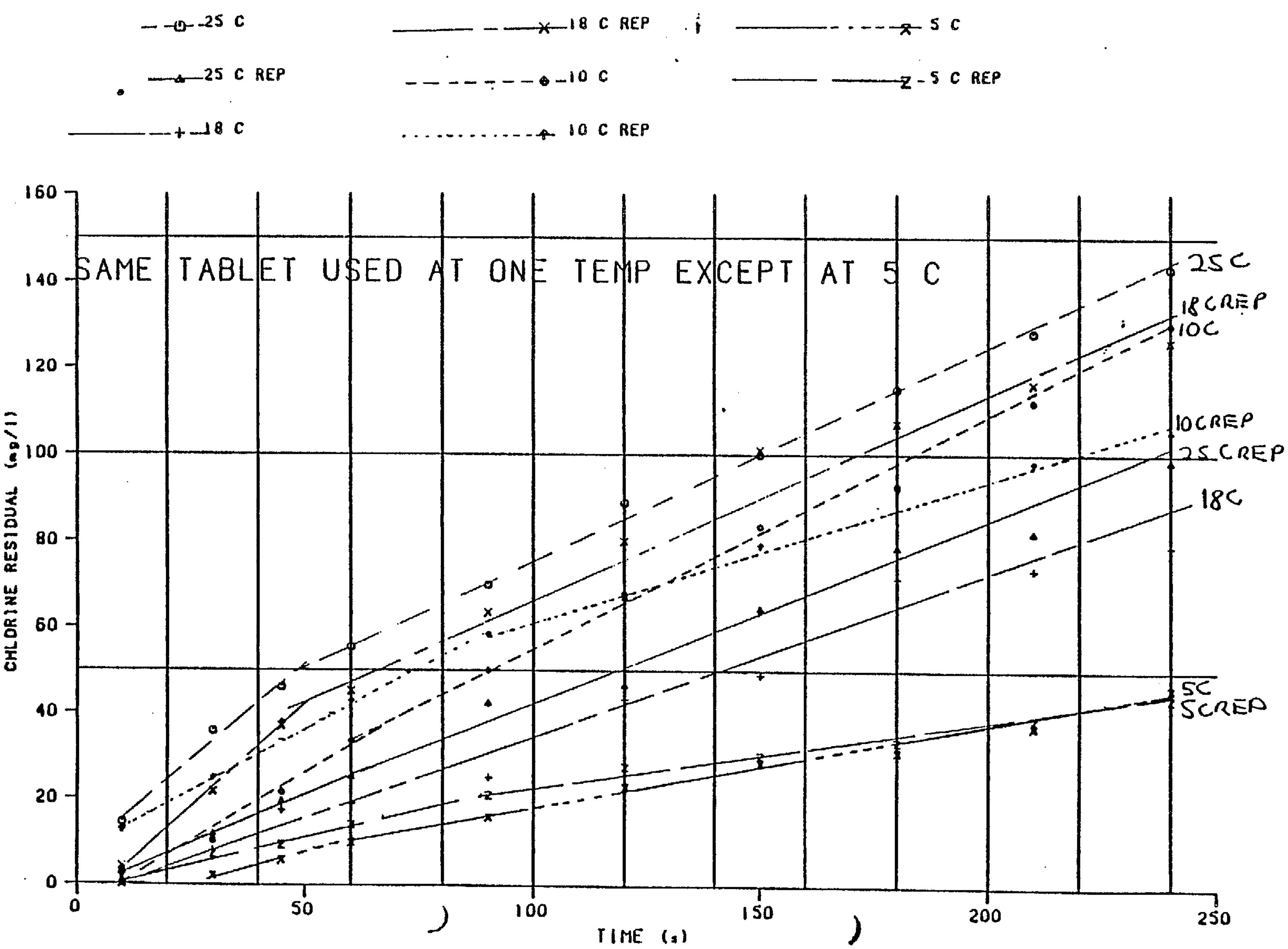
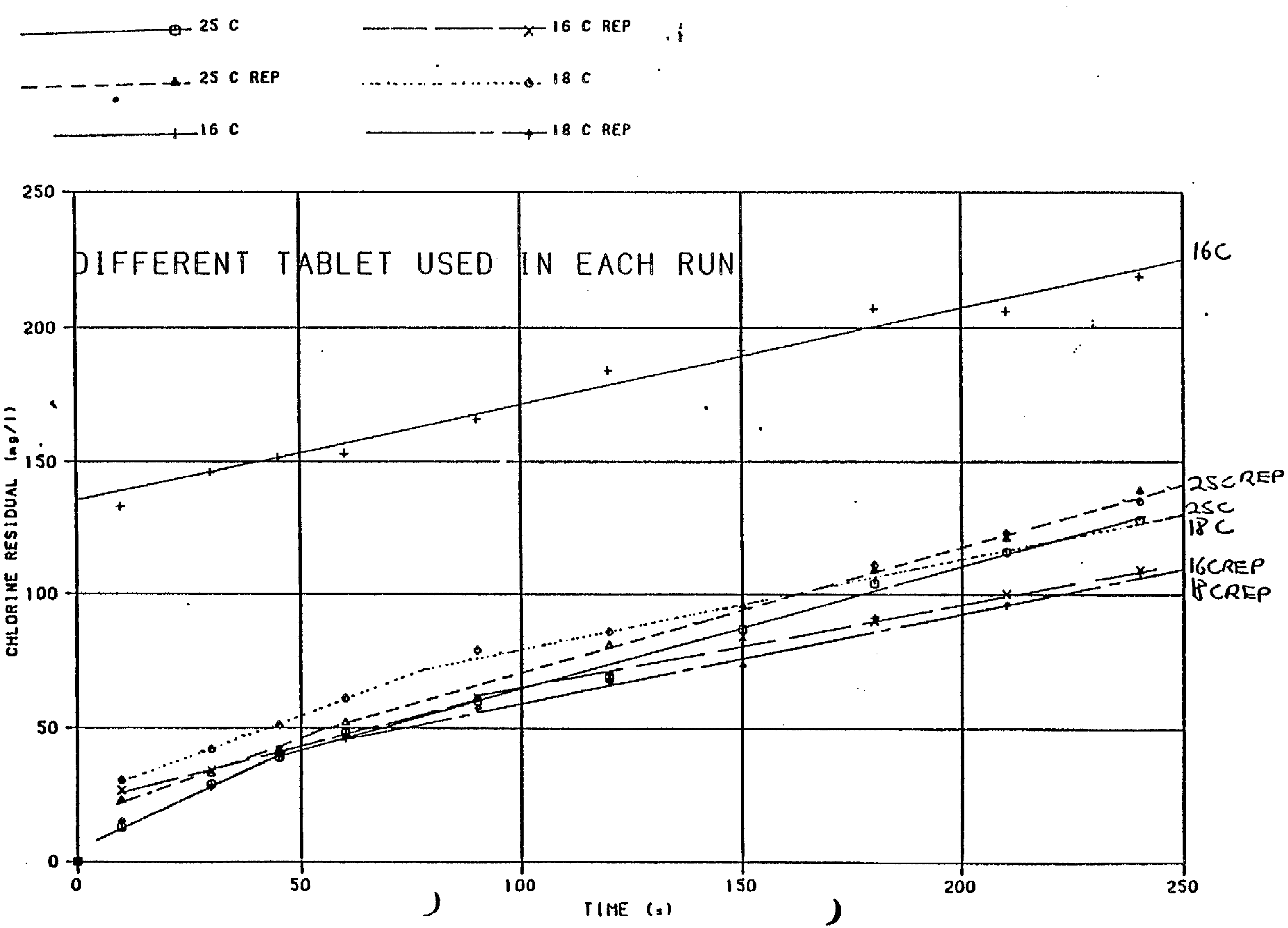
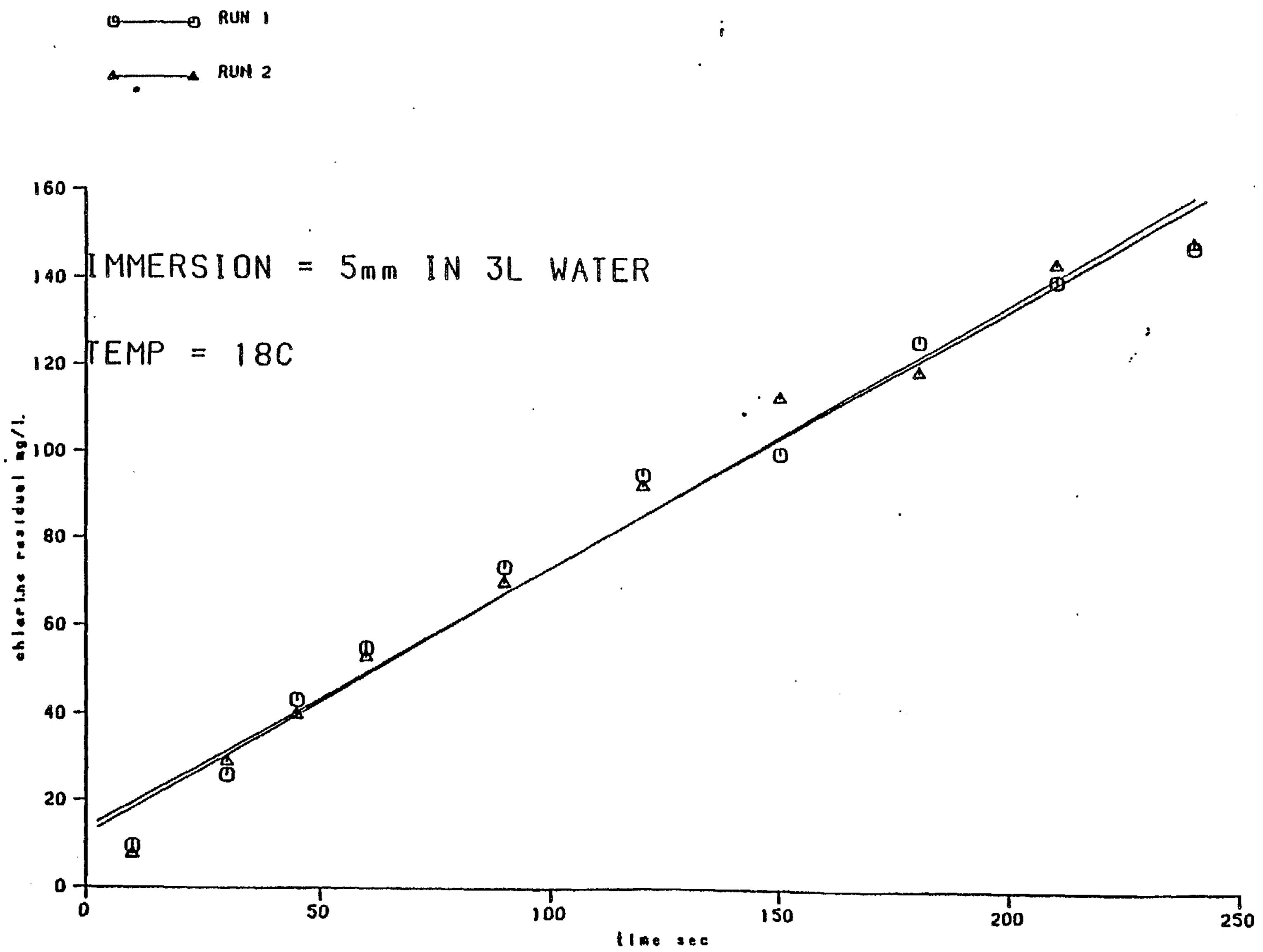


FIG SOLUTION RATE OF STEADICHLOR-NS TABLETS IN 5 l OF DISTILLED WATER
FIG 4.17.2 AT 5 mm IMMERSION. TABLETS WETTED BEFORE RUN.



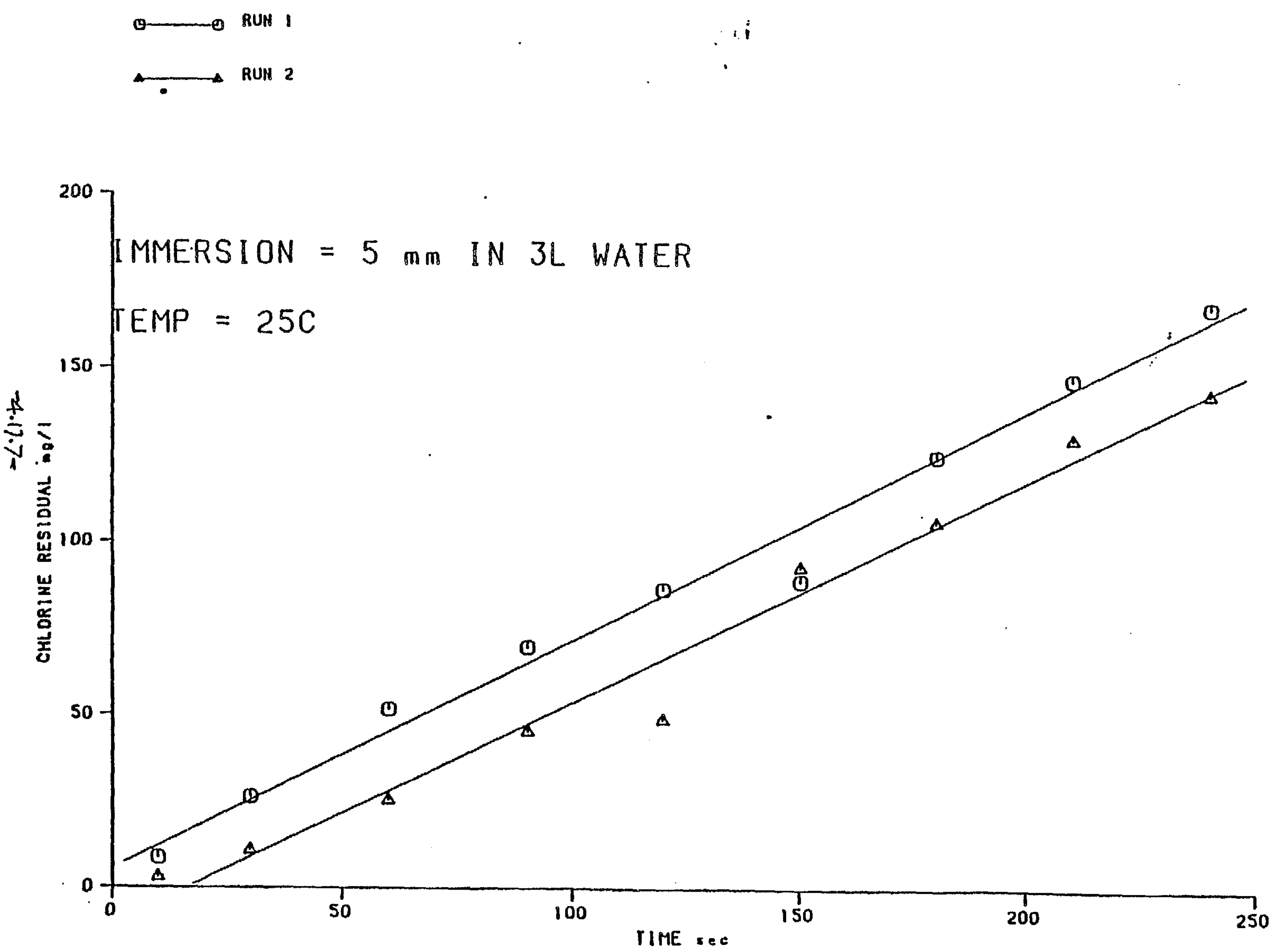
CALCIUM HYPOCHLORITE TABLET SOLUTION RATE. TABLETS DRIED BETWEEN RUN 1 AND RUN 2

FIG 4.17.3



CALCIUM HYPOCHLORITE TABLET SOLUTION RATE. TABLETS DRIED BETWEEN RUN 1 AND RUN 2

FIG 4.17.4



## APPENDIX 4.17

### TABLE 1

Gradients Of Tablet Curves After 60s At 5 mm Immersion

| TEMP °C | COMMENT | GRADIENT mg/l.s | DOSE RATE mg/min |
|---|---|---|---|
| 25 | First Run - New Tablet. | 0·47 | 84·6 |
| | Repeat of above using same tablet | 0·38 | 68·4 |
| | Tablet immersed In Water 60s before Run | 0·46 | 82·8 |
| | " " " " " " " | 0·49 | 88·2 |
| 18 | First Run - New Tablet | 0·37 | 66·6 |
| | Repeat Of Above Using Same Tablet | 0·41 | 73·8 |
| | Tablet Immersed In Water 60s Before Run | 0·40 | 72·0 |
| | " " " " " " " | 0·34 | 61·2 |
| 16 | Tablet Immersed In Water 60s Before Run | 0·36 | 64·8 |
| | " " " " " " | 0·34 | 61·2 |
| 10 | First Run - New Tablet | 0·52 | 93·6 |
| | Repeat Of Above Using Same Tablet | 0·32 | 57·6 |
| 5 | First Run - New Tablet | 0·19 | 34·2 |
| | Repeat Of Above Using Different Tablet | 0·18 | 32·4 |

### TABLE 2

Average Residuals And Standard Deviations For The Dose From The Tray Of The Tipping Tray Chlorinator With Tablet Immersed To 20mm.

| FLOW TO TRAY (l/min) | AVERAGE Cl RESIDUAL (mg/l) | STANDARD DEVIATION OF 10 SAMPLES | % STANDARD DEVIATION. |
|---|---|---|---|
| 0·8 | 12·3 | 2·22 | 18% |
| 2·5 | 4·8 | 0·40 | 8·3% |
| 3·4 | 3·6 | 0·53 | 14·6% |
| 5·2 | 2·8 | 0·46 | 16·7% |

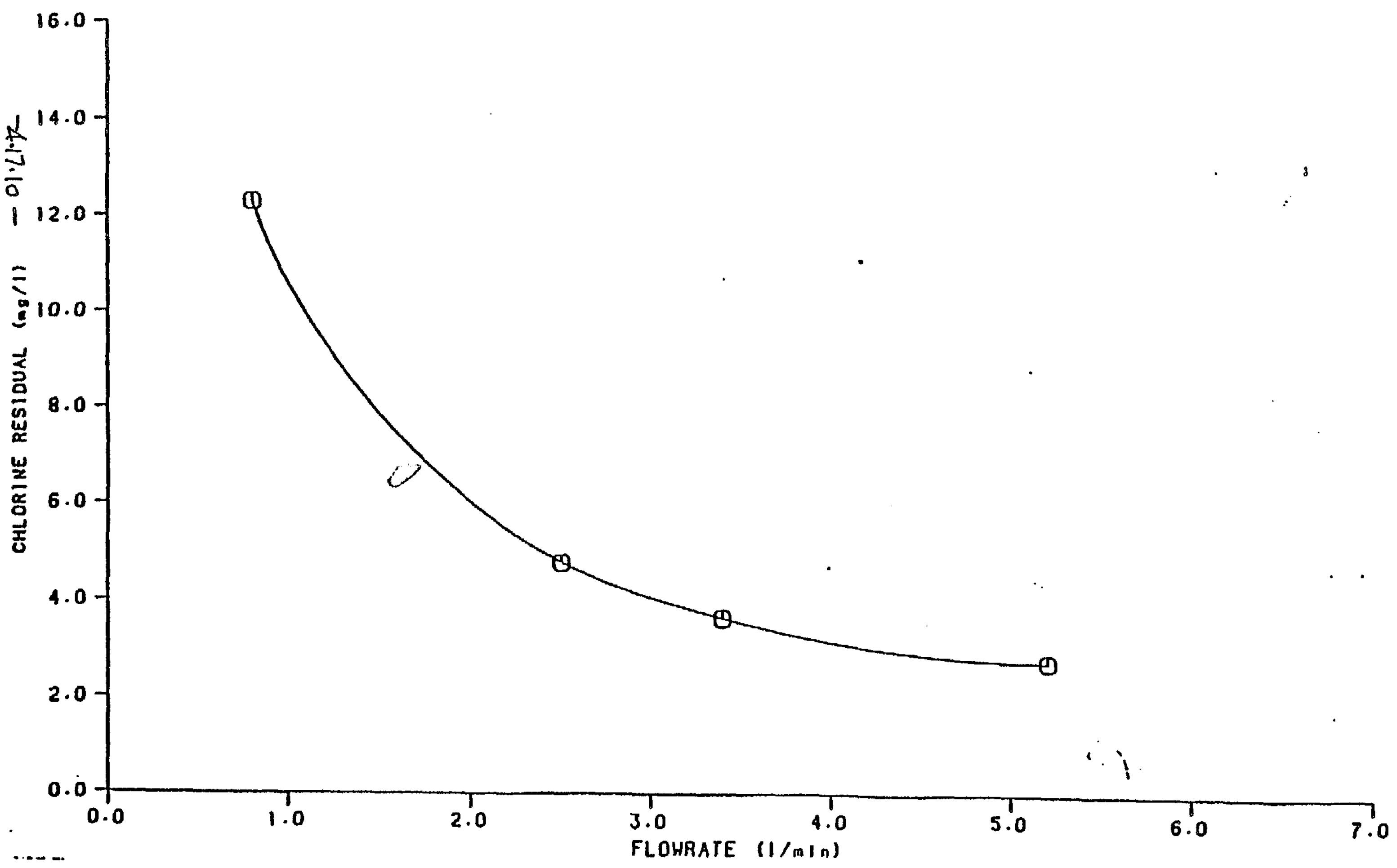
## Table 3

Average Cl Residual And Standard Deviation For Sample From The Tray And Collecting Tank In The Tipping Tray Chlorinator With Virtually Zero Tablet Immersion.

| FLOW l/min. | AVE RES FROM TRAY (mg/l) | S.D. FOR TRAY | % S.D. FOR TRAY | AVE RES IN COLLECTING TANK (mg/L) | S.D. IN COLLECTING TANK | % S.D. IN COLLECTING TANK |
|---|---|---|---|---|---|---|
| 0.95 | 17.88 | 5.58 | 31.2 | 13.45 | 0.80 | 6.0 |
| 1.86 | 10.38 | 1.87 | 18.0 | 12.82 | 1.61 | 12.6 |
| 2.8 | 6.90 | 1.18 | 17.1 | 7.39 | 0.68 | 9.2 |
| 3.75 | 2.95 | 0.61 | 20 | 2.84 | 0.14 | 5 |

FIG CHLORINE RESIDUAL AGAINST FLOWRATE FOR TIPPING TRAY CHLORINATOR
IMMERSION = 20mm

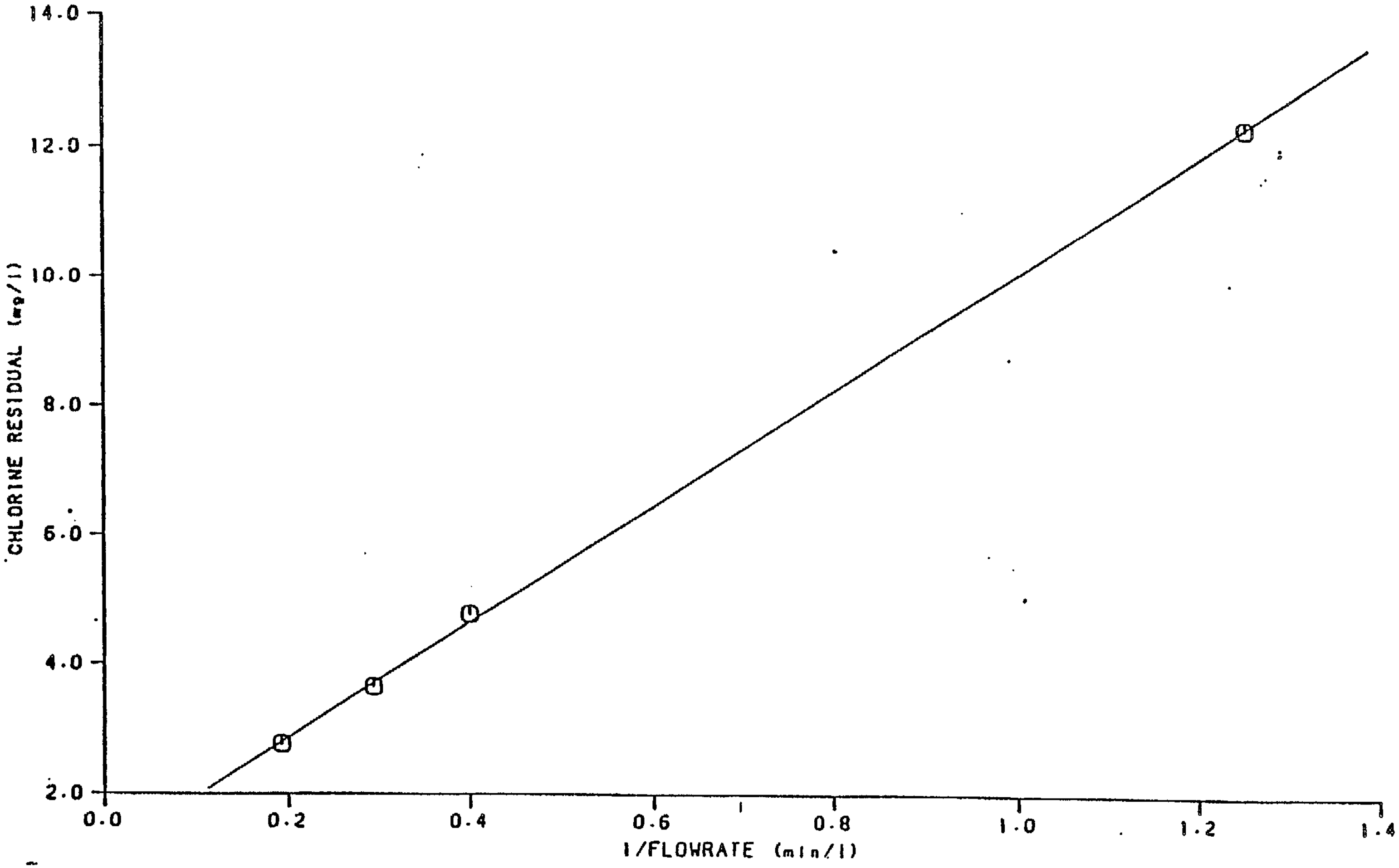
Fig 4.175



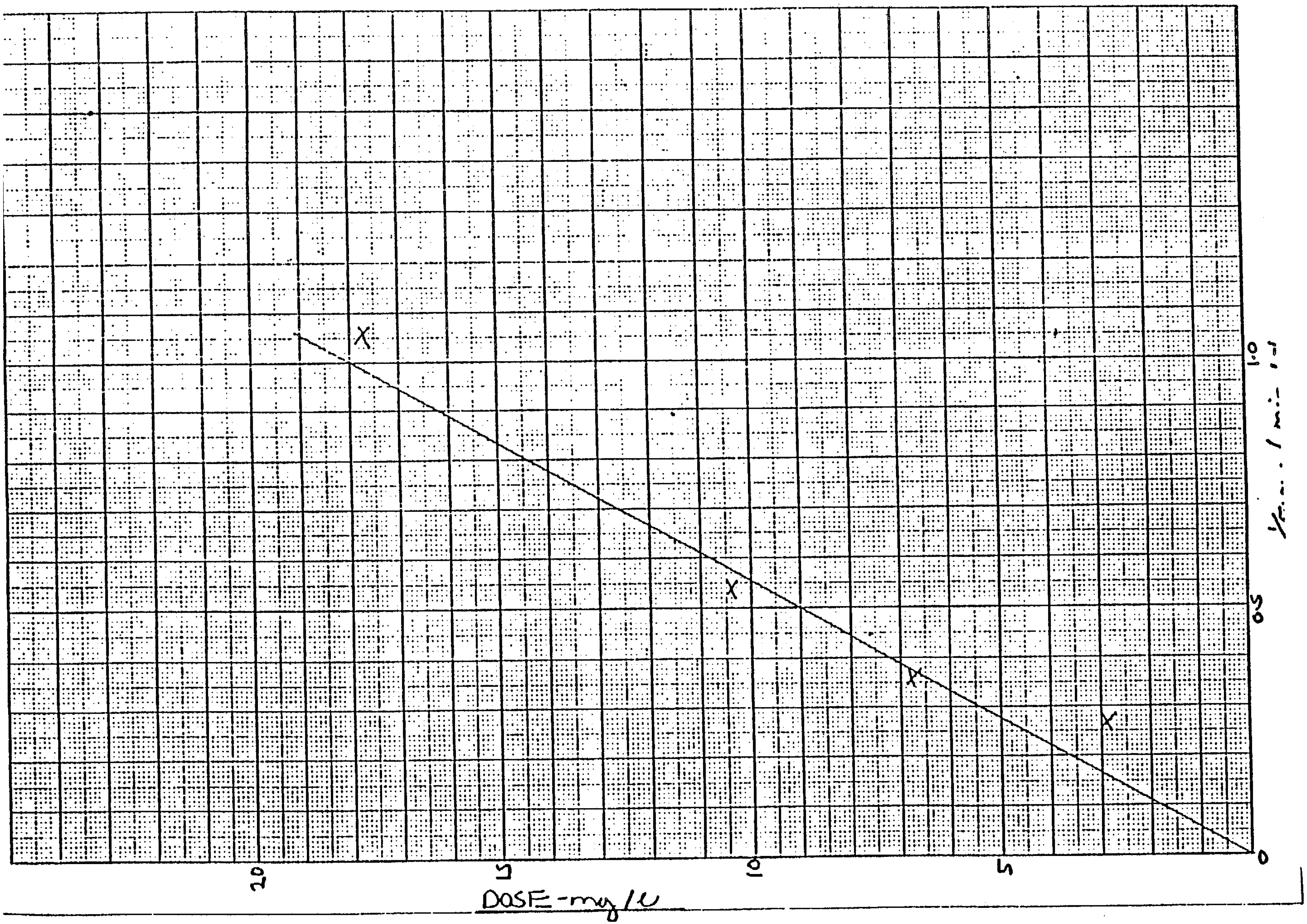

— 4.17.10 —

FIG CHLORINE RESIDUAL AGAINST RECIPROCAL OF FLOWRATE FOR TIPPING TRAY CHLORINATOR. IMMERSION = 20mm

FIG 4.17b



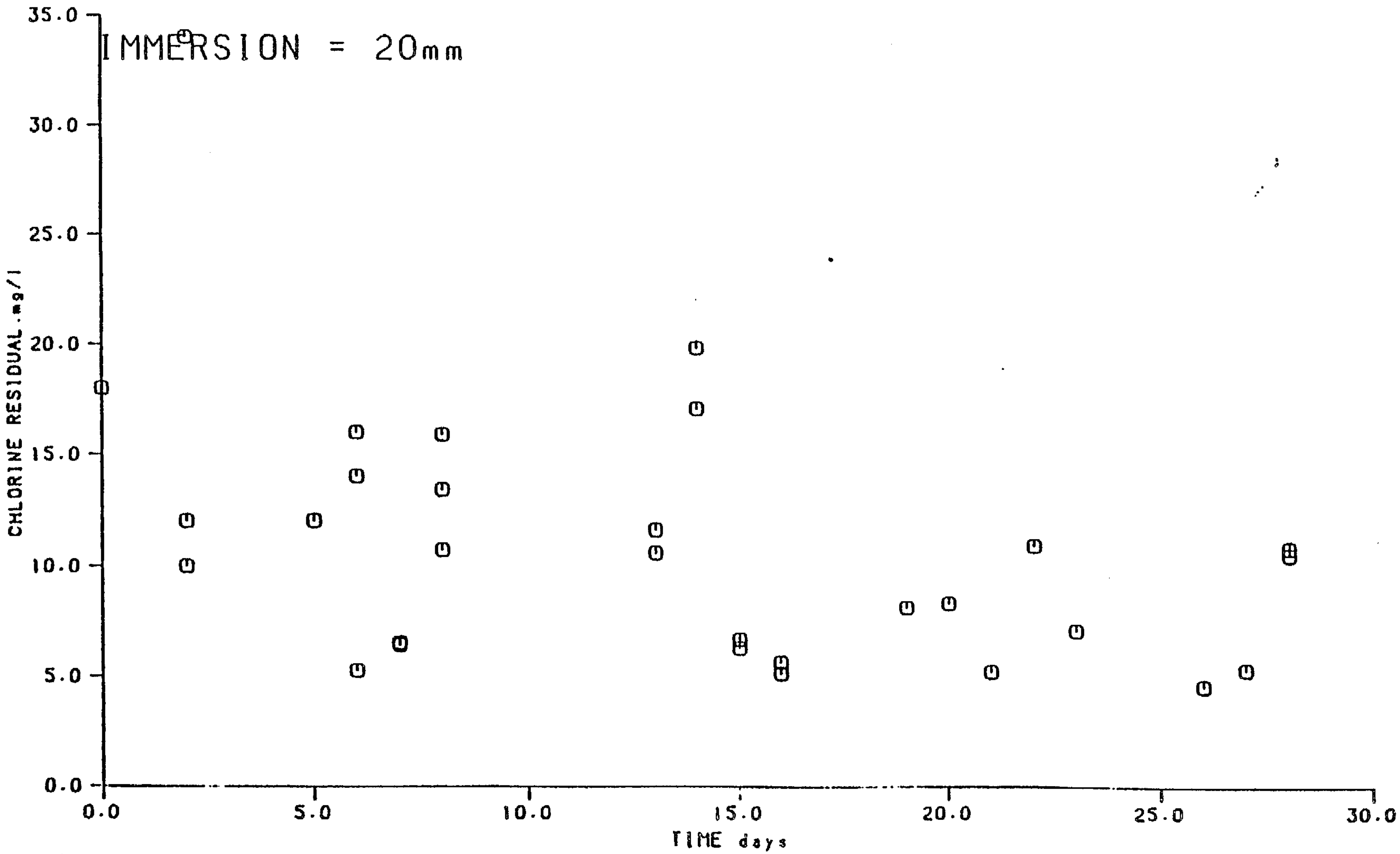

-4.17.11-



DOSE-mg/kg
0
5
10
15
20
0.5
1.0

TIPPING TRAY CHLORINATOR
VARIATION OF DOSE IN TRAY WHEN RUNNING CONSTANTLY FOR 28 DAYS

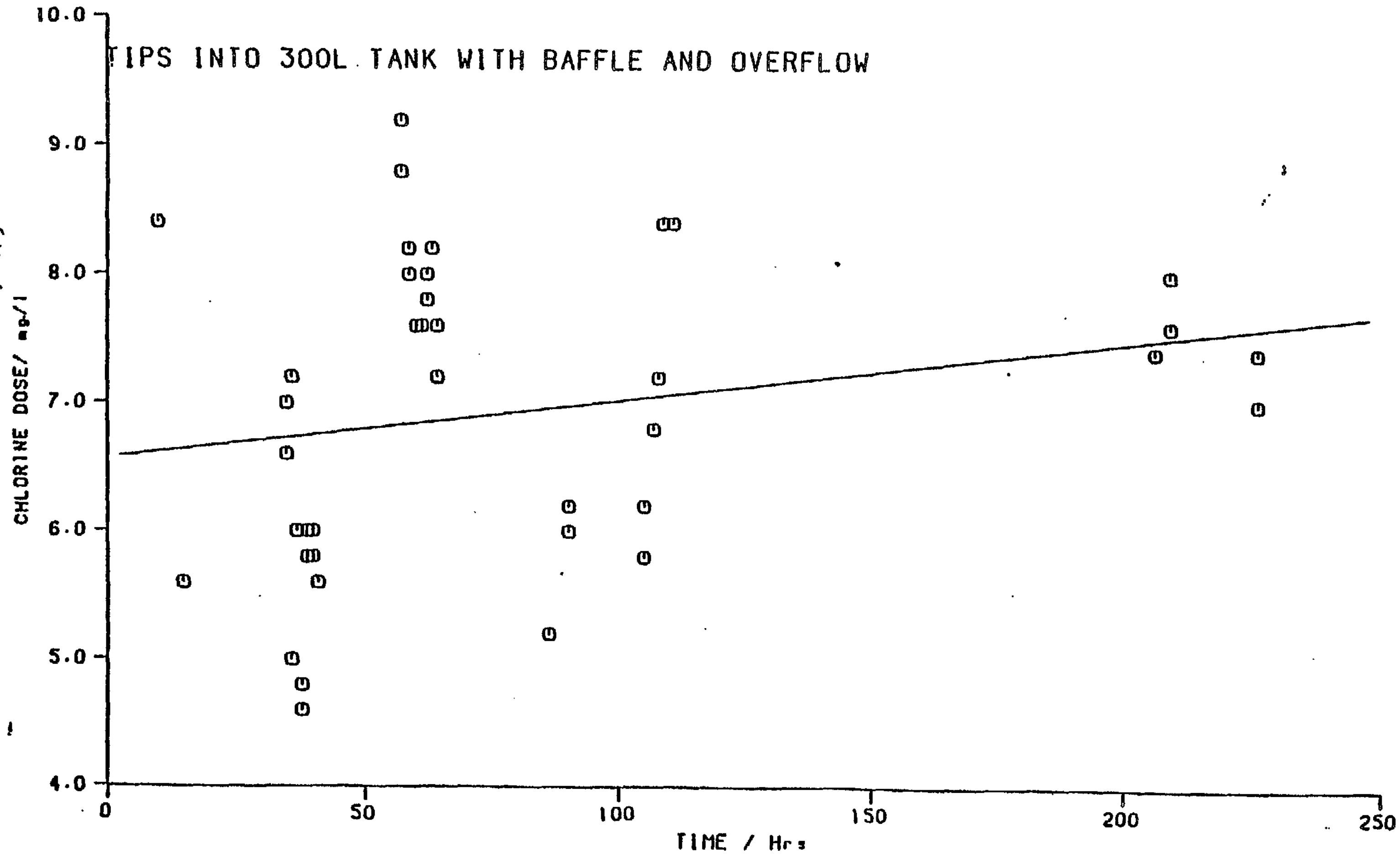
Fig 4.17.8



TIPPING TRAY CHLORINATOR

VARIATION OF DOSE AT A STEADY 2L/MIN AND 10 s IMMERSION TIME

FIG 4179




-4.17.14-

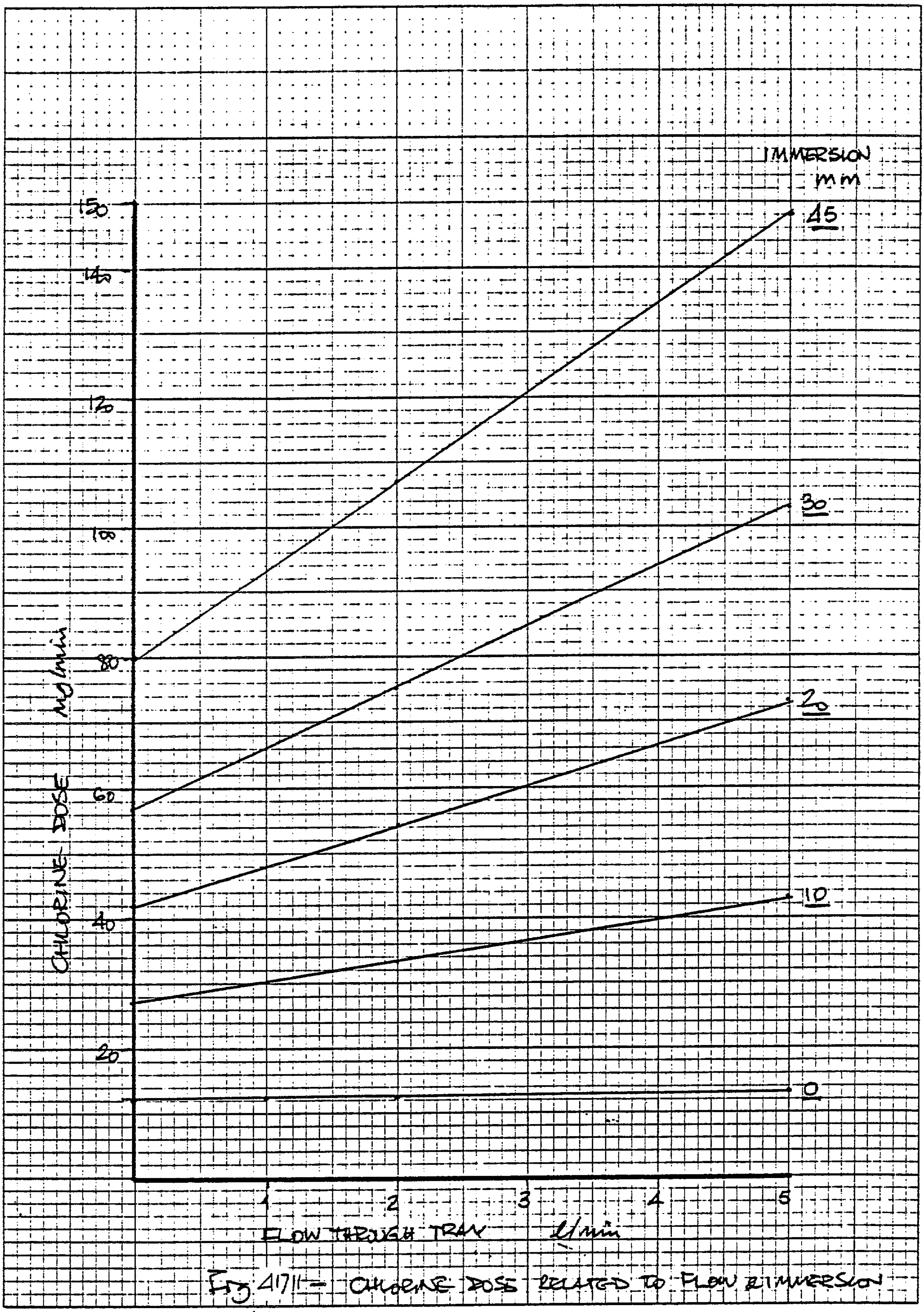
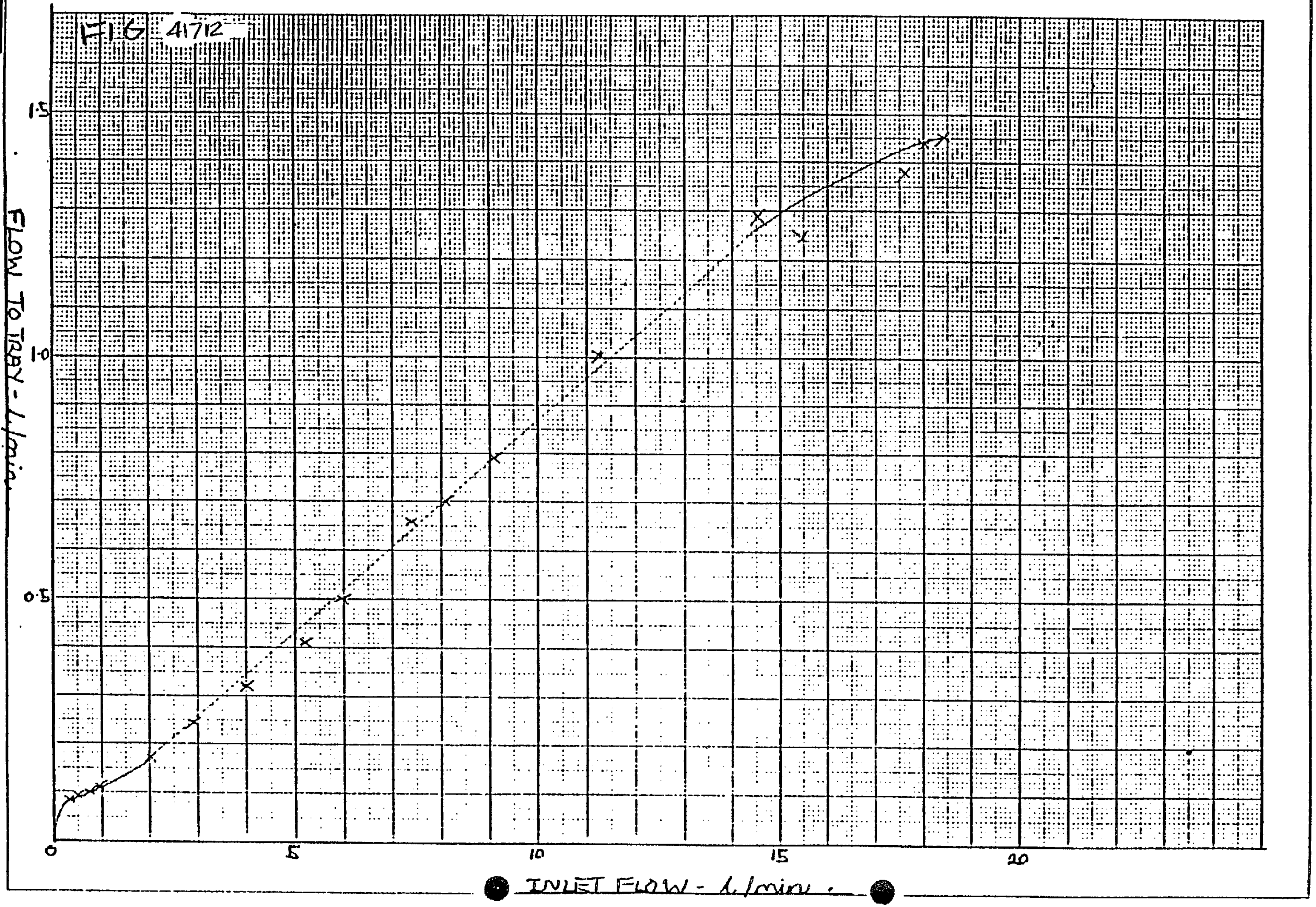



Fig 4.17.1 – CHLORINE DOSE RELATED TO FLOW & IMMERSION

L.T.C. 1110105 RATIO OF FLOW TO TRAY AGAINST INLET FLOW. WEIR HALF CLOSED (50.5mm ...)
INLET TO SYPHON TUBE POINTING VERTICALLY

FIG 41712



APPENDIX 5 GAS CHLORINATOR

Tests

The experimental apparatus is shown in Fig 51. As the chlorine cylinder was isolated for safety reasons, a second variable area flow meter with a rate control valve included was inserted in the line to enable local control. A sample was taken from the chlorinated water main to detemine the chlorine residual using a residometer. Some of the chlorinated water was diverted to a chlorine monitor connected to a voltmeter and chart recorder. This was done primarily so that a continuous record was available and secondly to investigate the accuracy and consistency of the chlorine monitor cell.

The first test was to measure pressure drop across the ejector and vacuum drawn as functions of water flow rate. The manometers were used for this purpose.

For the second test the variation of chlorine dose with water flow rate was measured. The water inlet valve was fully opened and the gas flow adjusted to 7g/h. The readings on the local gas flow meter were recorded as the water flow rate was reduced. It was noticed that the gas flow was not cut off even at low water flow rates, so this test was repeated with a stiffer spring fitted in the check valve.

Test number three was a calibration of the gas flow meters and chlorine monitor cell. The local gas rate valve was opened in steps of 1g/h as read on the local chlorine flow meter, and the corresponding reading on the cylinder mounted flow meter noted. A residometer reading was also taken of the chlorinated water from which the chlorine flow rate could be calculated.

The voltmeter connected to the chlorine monitor cell was calibrated against the residometer in a similar way.

Test number four was a constant running test and was repeated for three chlorine flow rates. Throughout the series of experiments the water flow rate was set at the maximum attainable, 10.3 l/min. Initially the chlorine flow rate was set at 2g/h on the local flow meter, and readings of the flow meter, residometer and voltmeter recorded at intervals over a five day period; 2g/h was the lowest flow rate to which it was possible to adjust the flow meter. At the end of the first day the flow meter was reset to 2g/h as the flow had fallen; it was not altered at any time after this. The flow rate was then reset to 4g/h and monitored over nine days. Finally it was set at 5g/h; it was noticed that the ball in the flow meter fluctuated between 4 and 5g/h if the flow meter was gently tapped.

The last test, number five, was a check on the response of the chlorinator to cessation of water flow. The gas flow was adjusted to about 6g/h and the water turned off. The time for the gas flow to fall to zero was recorded. After a three hour interval the water was turned on again - the gas flow was 9 g/h. After a further two hours the water was again turned off and the time for zero gas flow to be reached recorded. In both cases this took about 40s. These tests showed that there were no immediate gas leaks when the water flow stopped; the final check was to leave the equipment overnight with the chlorine cylinder valve open but with no water flow.

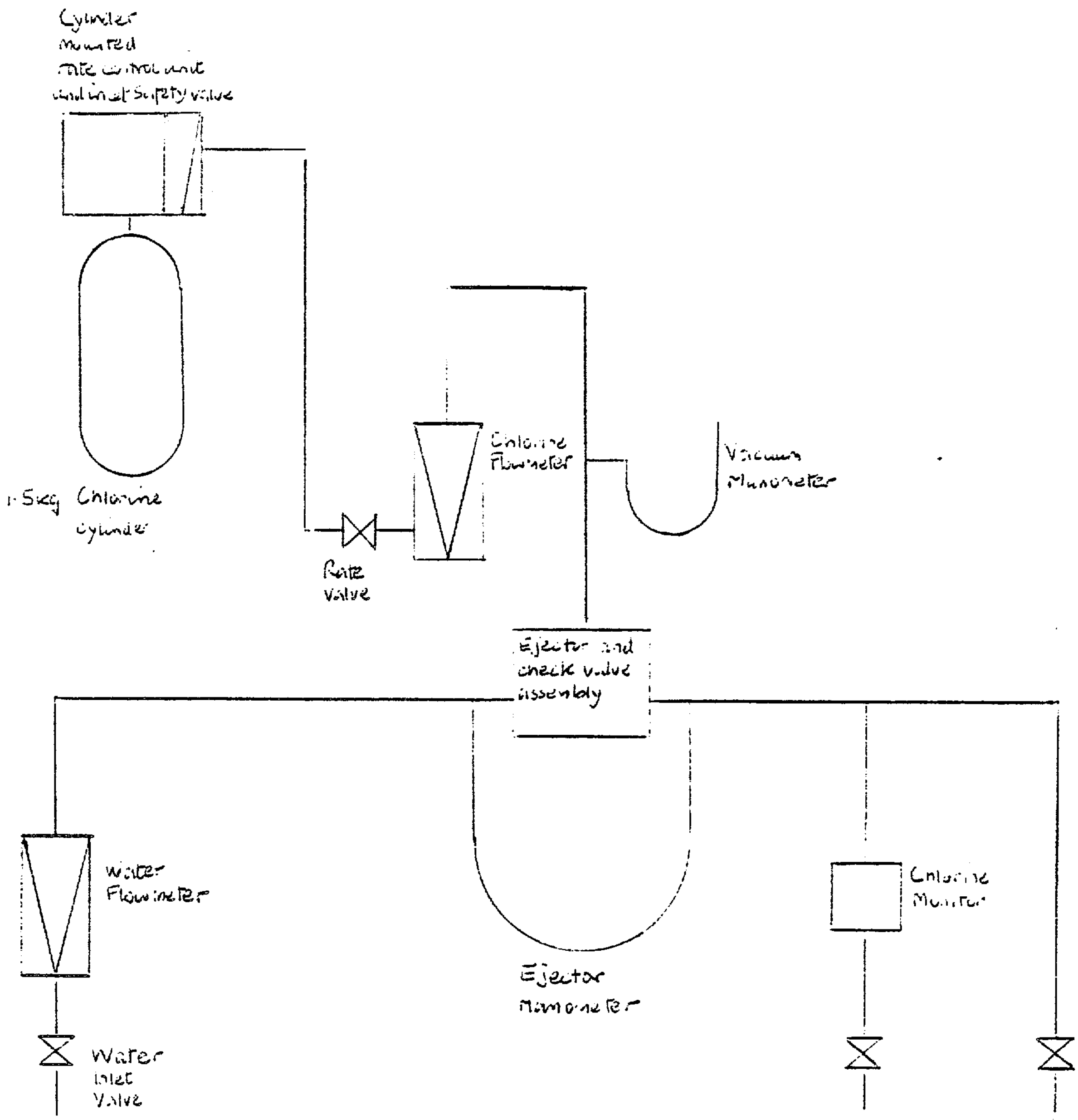



FIG 5.1
EXPERIMENTAL APPARATUS

Results and Discussion

The results of the first test are shown in Fig 52. The vacuum is seen to reach a maximum of about 71cmHg at 5l/min: at this flow rate a change in sound of the water passing through the ejector indicated the onset of cavitation at the waist.

Fig 53 shows the variation of gas flow rate with water flow rate. The stiffer spring is seen to increase the rate of change of gas flow rate but also to provide a clear cut off at about 4 l/min. The gas flow rate appears to be approaching a maximum, suggesting that at higher water flow rates than tested (the upper experimental limit being about 10.3 l/min) it is independent of the water rate.

Fig 54 compares the gas flow meter readings, taking the residometer as the standard. Differences between the two meters never exceeded +/-20%, and it should be noted that they could only be read to +/-0.3g/h because of fluctuations of the ball. These fluctuations were on occasions fairly regular, with a period of about 15s; this was thought to be due to the inlet safety valve sticking. The ball was also observed to stick, probably due to organic impurities in the gas; the flow meter was dismantled and cleaned with acetone and methanol after the experiment. Fig 55 shows that the chlorine cell readings were not proportional to the gas flow.

Figs 56, 57 and 58 show the constant operation tests for gas flow rates of 2,4 and 5g/h respectively. Readings are expressed as percentages of the readings at time zero. In the 2g/h case the gas flow meter gave a steady reading after the initial drop, but there were significant fluctuations in the residometer reading. At 4g/h all the instrument readings decreased by about 40% in 9 days. At 5g/h the flow meter reading dropped by 20% after 4 days, the same decrease as the 4g/h case after the same time, and the residometer fell by 40%.

The results of this test indicate a fall off in chlorine flow rate. For the tests a 1.5kg chlorine cylinder was used; at rates of 4 or 5 g/h over several days the pressure in such a cylinder will fall significantly, and depending on the effectiveness of the regulating valves a fall in the flow rate would be expected.

Conclusions

The gas chlorination equipment is inherently safe. If the gas line develops a leak the result is ingression of air into the line rather than the escape of chlorine to the atmosphere. The flow of chlorine stops if water flow drops below a minimum; this minimum depends upon the stiffness of the spring in the check valve.

This equipment will provide a constant flow of chlorine provided the water flow is constant and the gas cylinder is not close to being empty. Gas flow increases with water flow but is not proportional to it.

The variable area flow meter only provides for coarse control of chlorine dose rate. The lowest dose rate to which it can be adjusted is 2g/h and for field use the minimum reliable rate is recommended to be 3g/h. The dose can only be set to +/-0.3g/h. The main problems are the small size of the flow meter, fluctuations of the ball, and sticking of the ball due to impurities in the gas.

FIG 52A VARIATION OF EJECTOR SUCTION PRESSURE WITH FLOW RATE

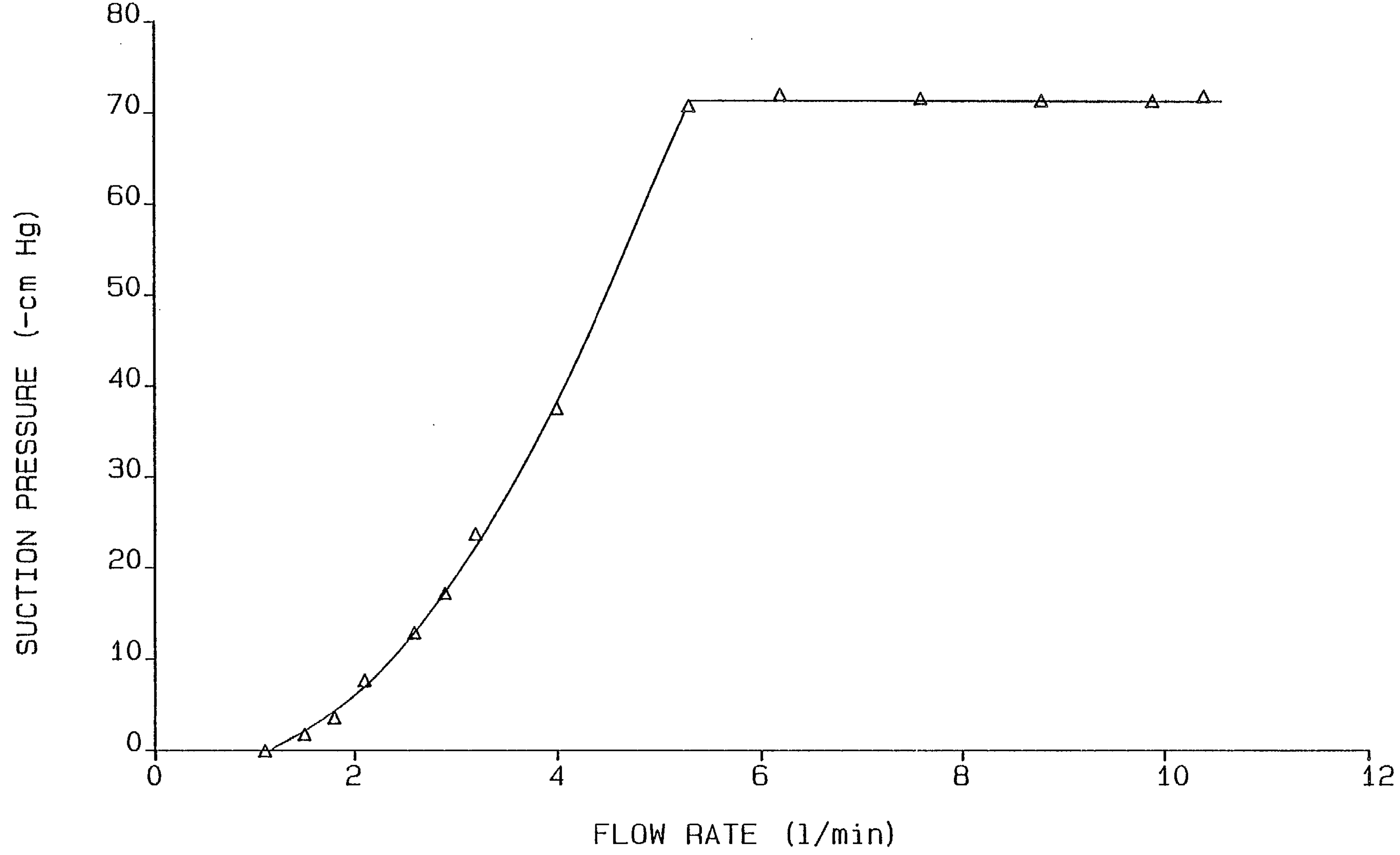


FIG 5.2B VARIATION OF PRESSURE DROP
WITH FLOW RATE

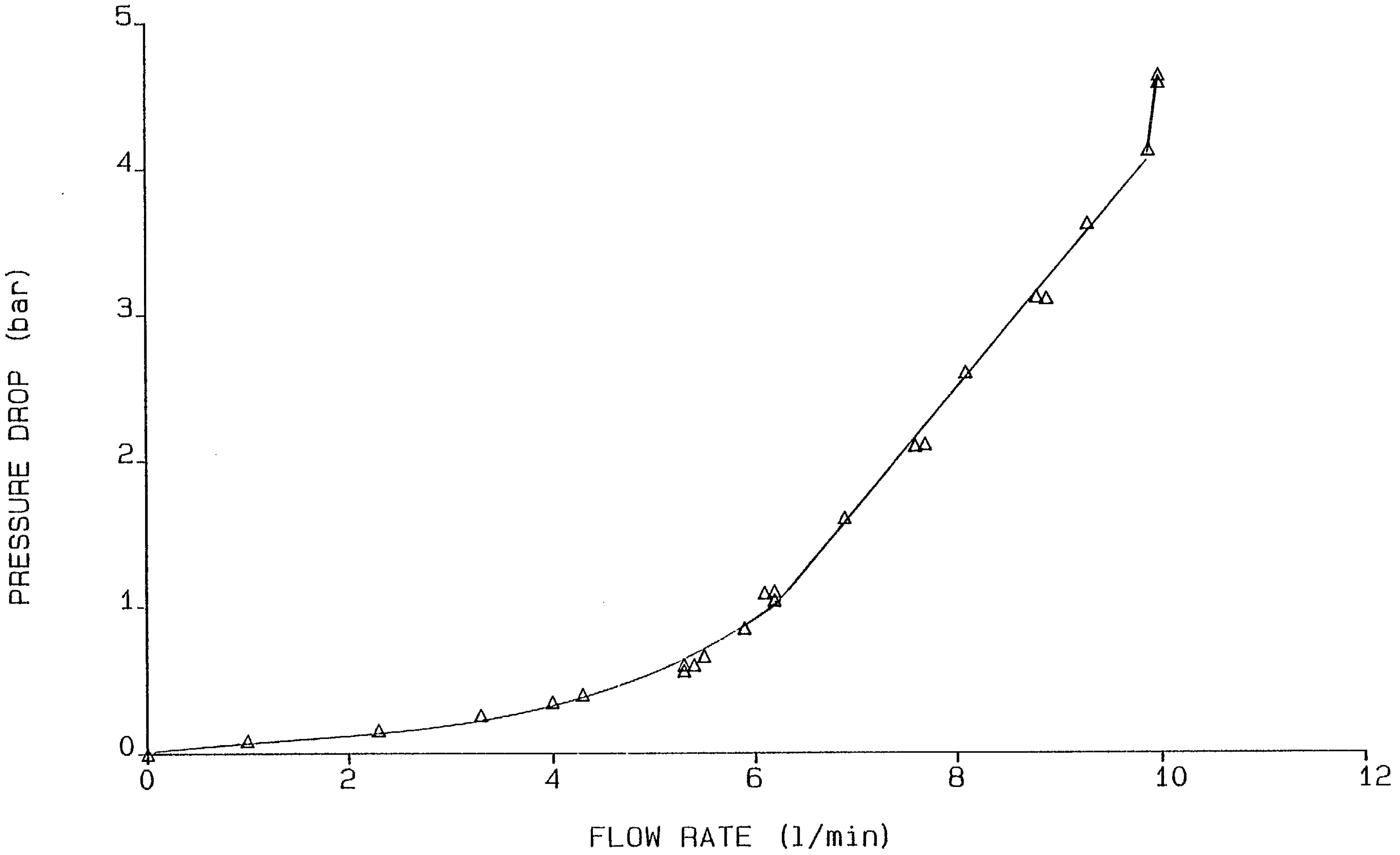


*FIG 53 VARIATION OF CHLORINE DOSE WITH FLOW RATE*

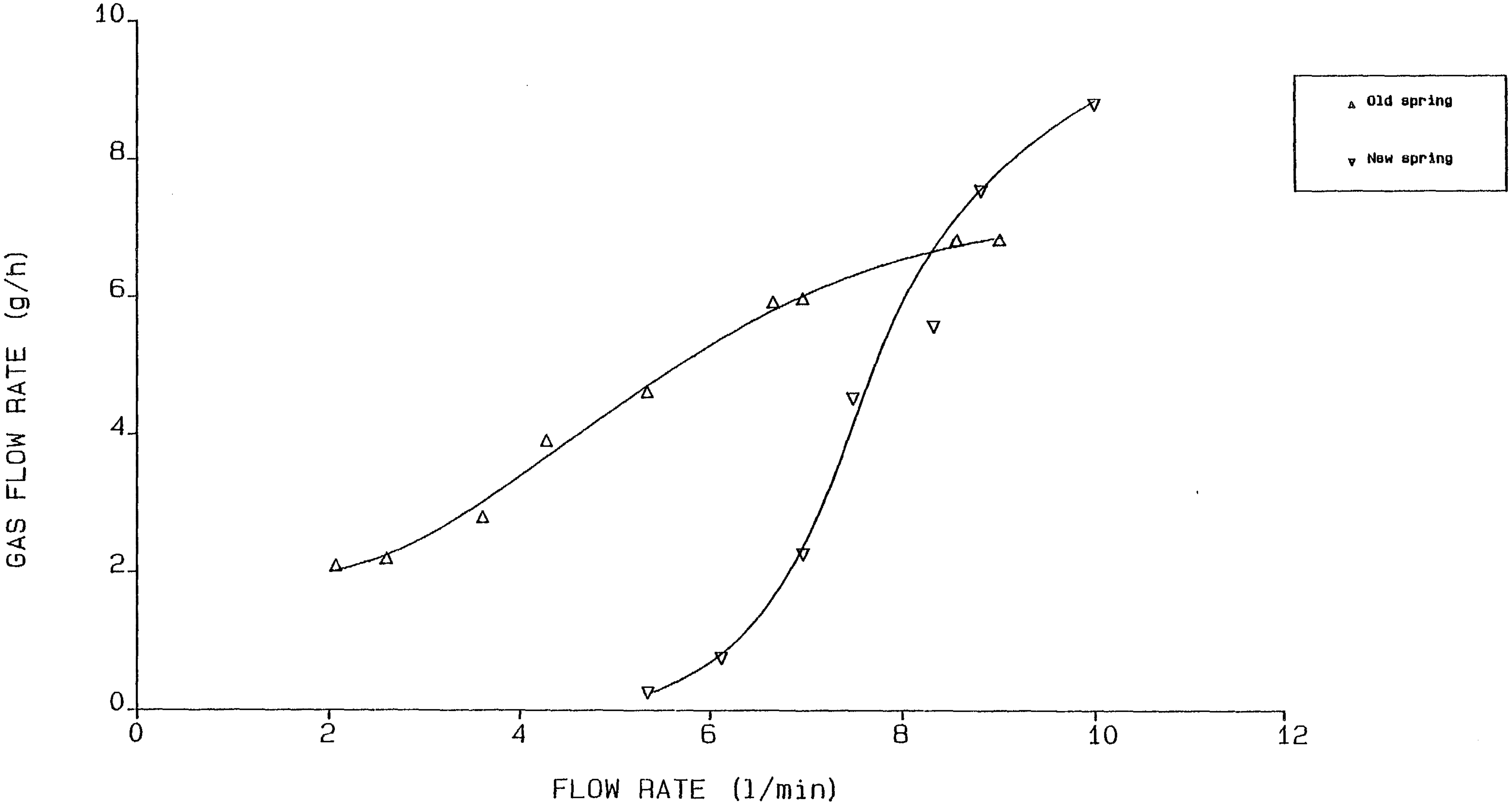


FIG 54 CALIBRATION OF FLOW METERS

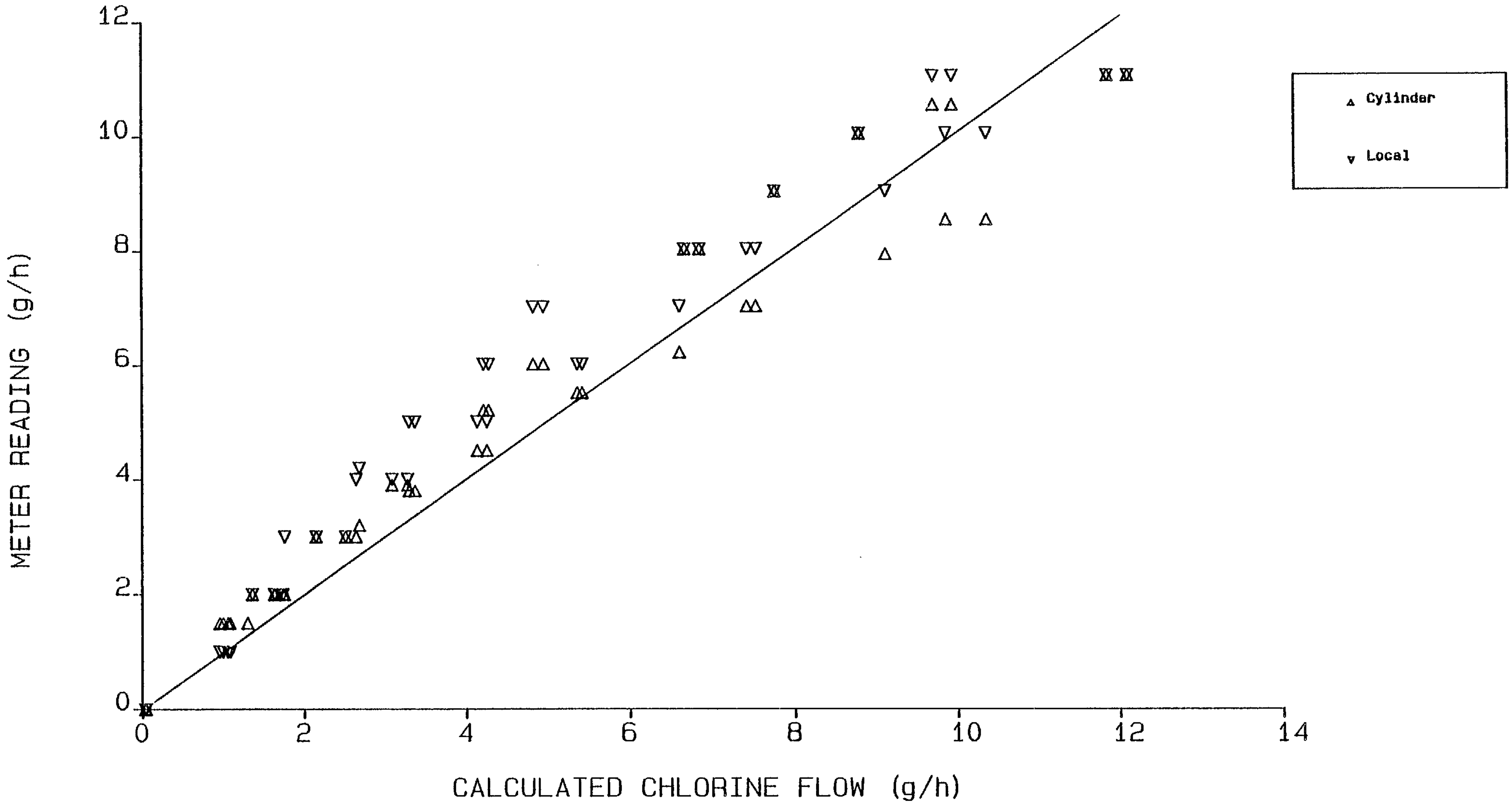


FIG 55 CALIBRATION OF CHLORINE CELL

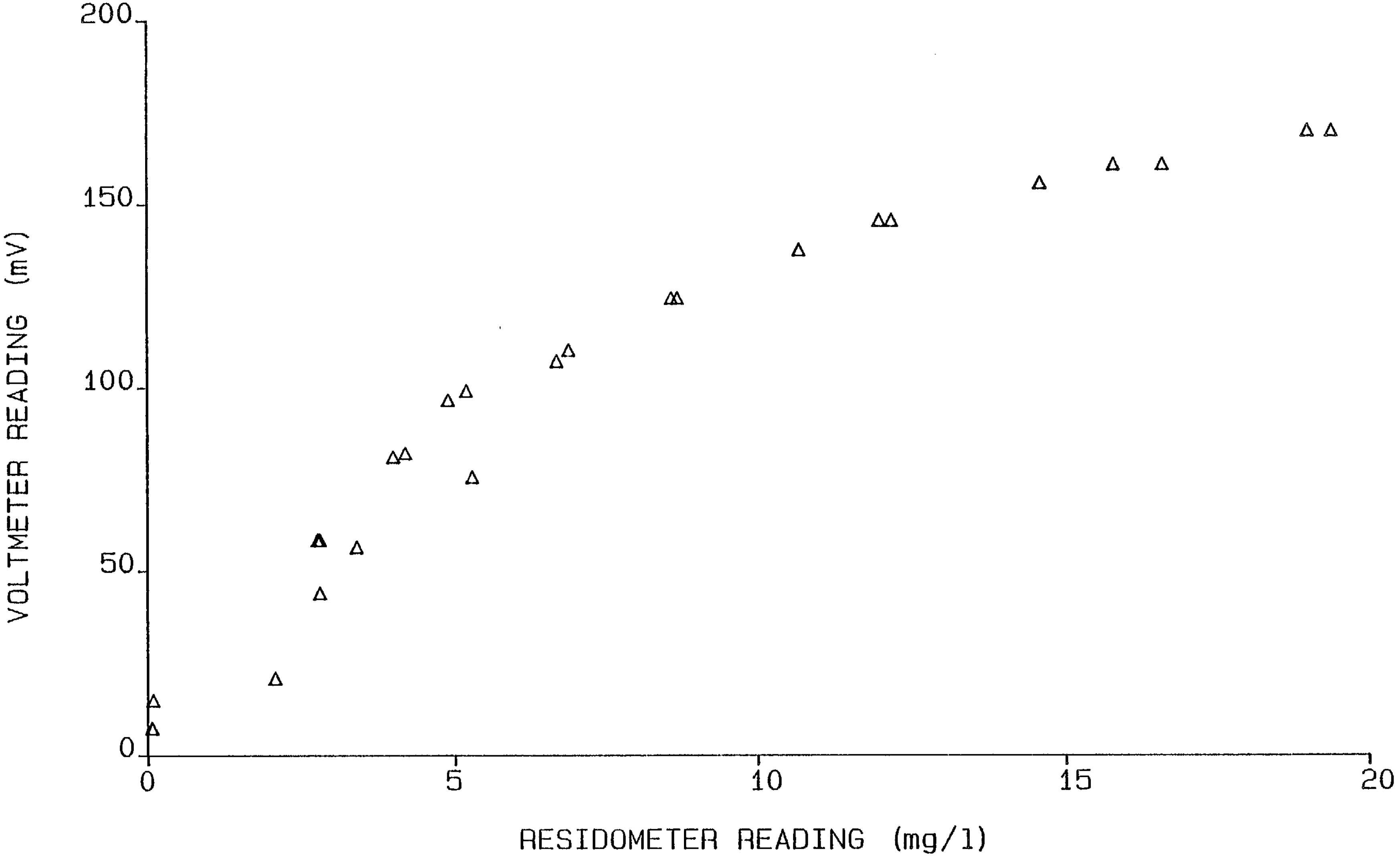


FIG 56 CONTINUOUS RUN AT 2g/h

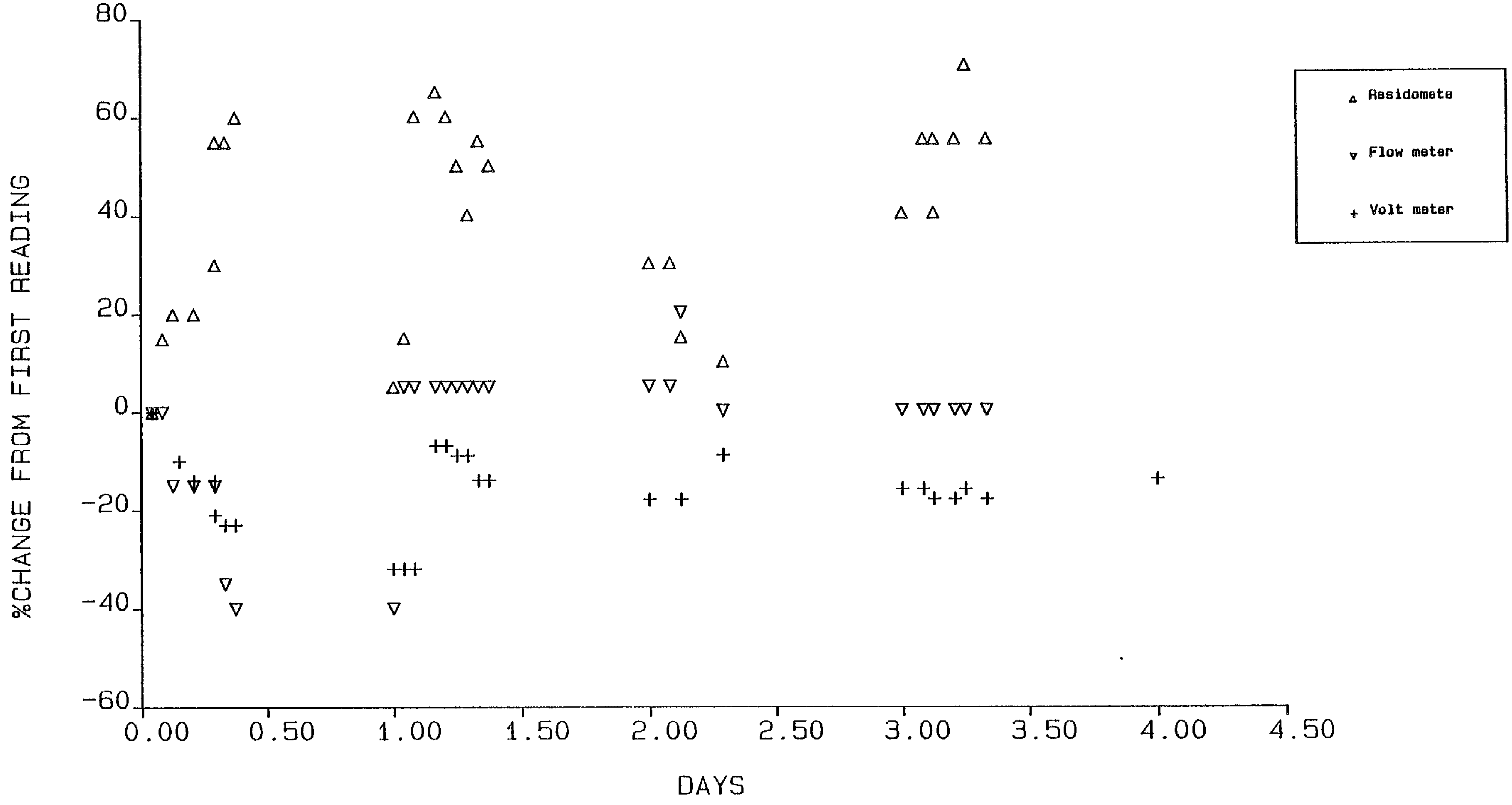


FIG 57 CONTINUOUS RUN AT 4g/h

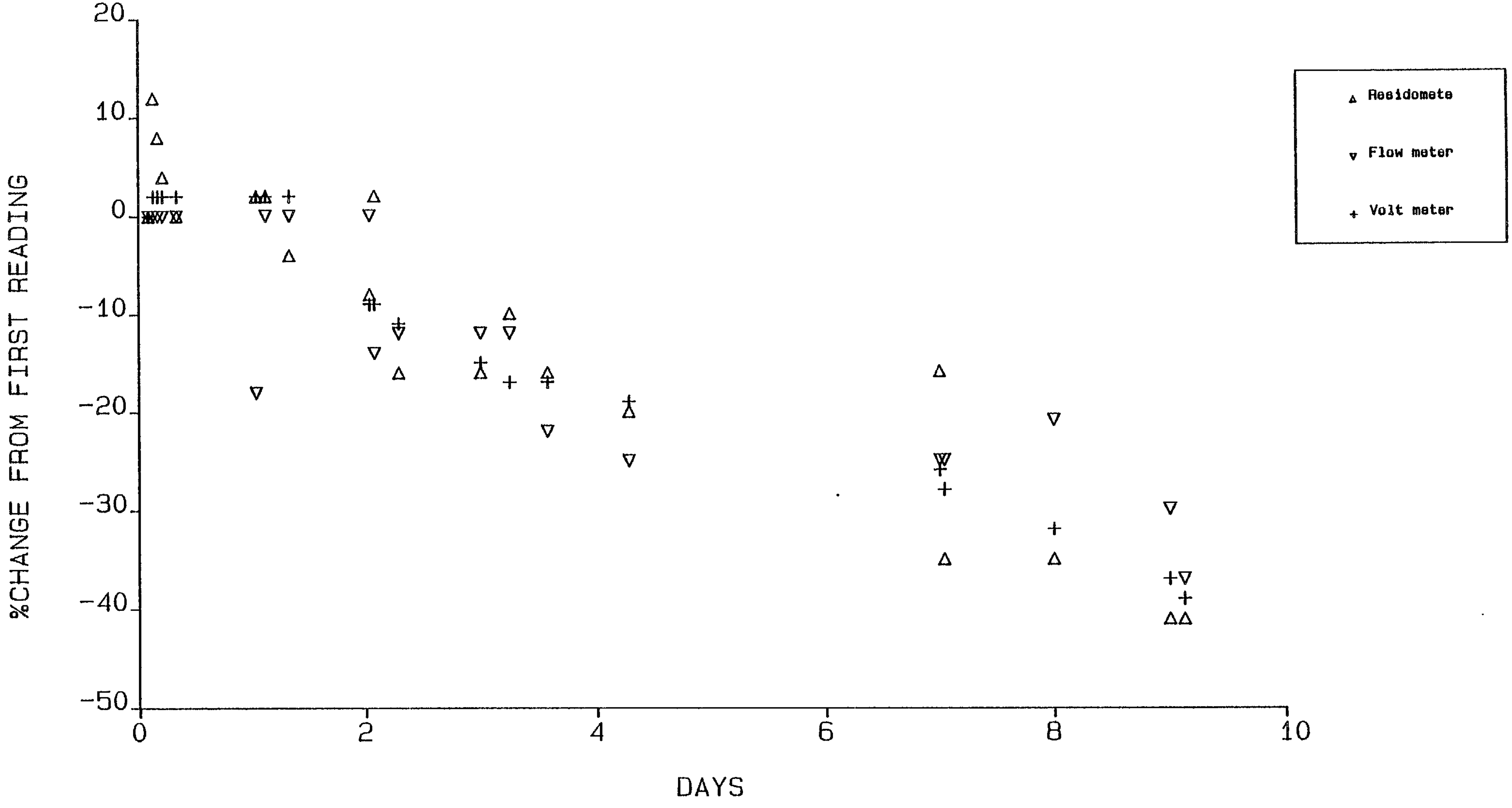
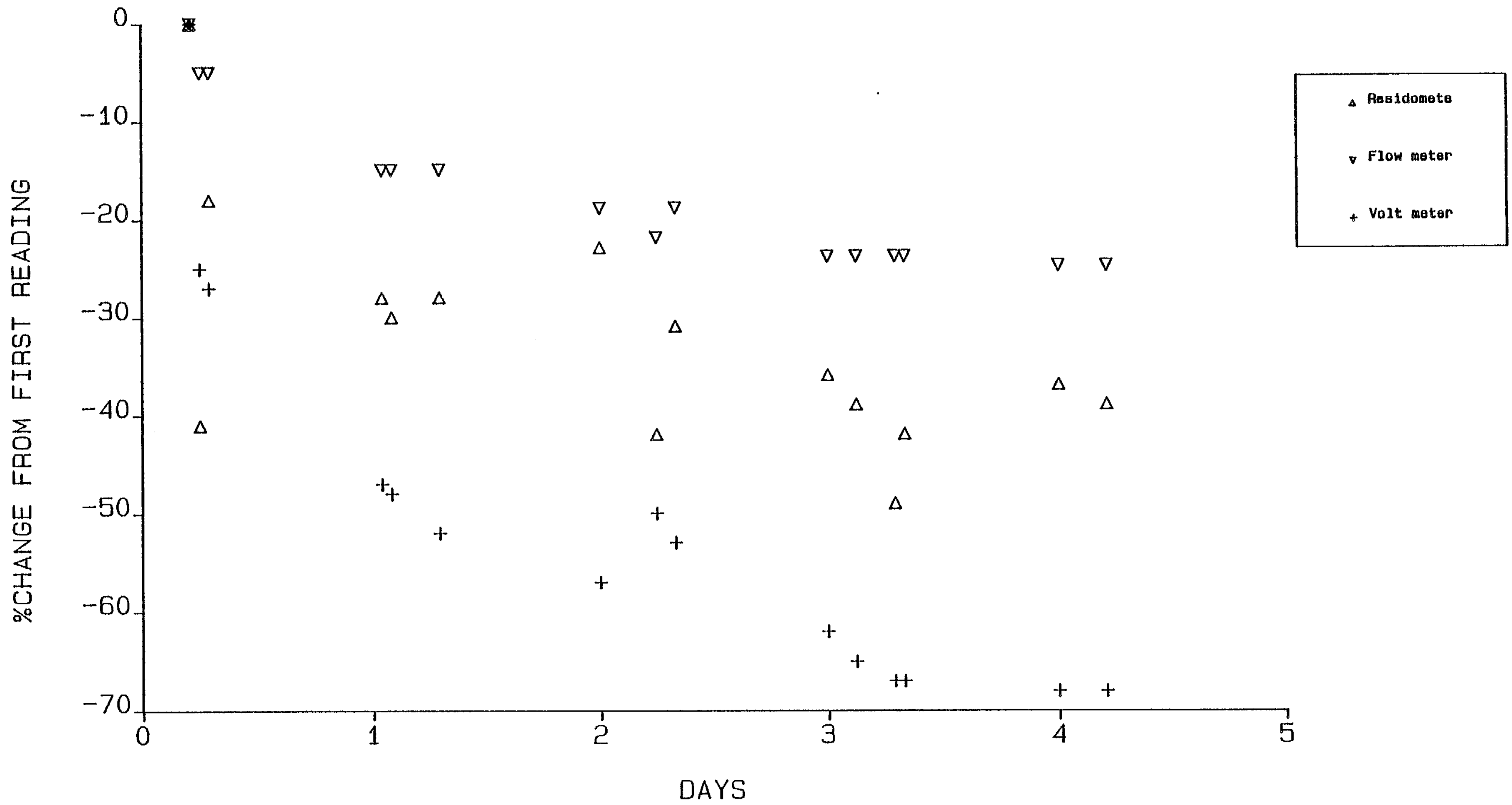


FIG 56 CONTINUOUS RUN AT 5g/h



GAS CHLORINATOR

VARIATION OF EJECTOR SUCTION WITH FLOW

| FLOW | SUCTION |
|---|---|
| l/min | -cm Hg |
| 1.1 | 0.0 |
| 1.5 | 1.8 |
| 1.8 | 3.6 |
| 2.1 | 7.7 |
| 2.6 | 12.9 |
| 2.9 | 17.2 |
| 3.2 | 23.7 |
| 4.0 | 37.4 |
| 5.3 | 70.5 |
| 6.2 | 71.7 |
| 7.6 | 71.2 |
| 8.8 | 70.9 |
| 9.9 | 70.8 |
| 10.4 | 71.3 |

VARIATION OF PRESSURE DROP WITH FLOW

| FLOW | PRESSURE DROP |
|---|---|
| l/min | bar |
| 0.00 | 0.00 |
| 1.00 | 0.09 |
| 2.30 | 0.16 |
| 3.30 | 0.26 |
| 4.00 | 0.35 |
| 4.30 | 0.40 |
| 5.30 | 0.60 |
| 5.30 | 0.56 |
| 5.40 | 0.60 |
| 5.50 | 0.66 |
| 5.90 | 0.85 |
| 6.10 | 1.09 |
| 6.20 | 1.10 |
| 6.20 | 1.04 |
| 6.90 | 1.60 |
| 7.60 | 2.09 |
| 7.70 | 2.10 |
| 8.10 | 2.59 |
| 8.80 | 3.10 |
| 8.90 | 3.09 |
| 9.30 | 3.60 |
| 9.90 | 4.10 |
| 10.00 | 4.56 |
| 10.00 | 4.61 |

VARIATION OF CHLORINE DOSE WITH FLOW

| ORIGINAL SPRING | | NEW SPRING | |
|---|---|---|---|
| FLOW | DOSE | FLOW | DOSE |
| l/min | g/h | l/min | g/h |
| 2.07 | 2.10 | 5.35 | 0.25 |
| 2.60 | 2.20 | 6.12 | 0.75 |
| 3.61 | 2.80 | 6.98 | 2.25 |
| 4.29 | 3.90 | 7.50 | 4.50 |
| 5.35 | 4.60 | 8.33 | 5.54 |
| 6.67 | 5.90 | 8.82 | 7.50 |
| 6.98 | 5.95 | 10.00 | 8.75 |
| 8.57 | 6.80 | | |
| 8.57 | 6.80 | | |
| 9.01 | 6.80 | | |

CALIBRATION OF: GAS FLOW METERS

| CYLINDER METER CALC'ED DOSE g/h | CYLINDER METER METER READIMG g/h |
|---|---|
| 0.03 | 0.00 |
| 0.04 | 0.00 |
| 0.95 | 1.50 |
| 0.99 | 1.50 |
| 1.05 | 1.50 |
| 1.08 | 1.50 |
| 1.30 | 1.50 |
| 1.36 | 2.00 |
| 1.63 | 2.00 |
| 1.64 | 2.00 |
| 1.74 | 2.00 |
| 1.76 | 2.00 |
| 2.15 | 3.00 |
| 2.15 | 3.00 |
| 2.52 | 3.00 |
| 2.65 | 3.00 |
| 2.69 | 3.20 |
| 2.69 | 3.20 |
| 3.09 | 3.90 |
| 3.28 | 3.90 |
| 3.30 | 3.80 |
| 3.37 | 3.80 |
| 4.14 | 4.50 |
| 4.22 | 5.20 |
| 4.26 | 4.50 |
| 4.28 | 5.20 |
| 4.83 | 6.00 |
| 4.96 | 6.00 |
| 5.37 | 5.50 |
| 5.43 | 5.50 |
| 6.61 | 6.20 |
| 6.67 | 8.00 |
| 6.85 | 8.00 |
| 7.42 | 7.00 |
| 7.53 | 7.00 |
| 7.76 | 9.00 |
| 8.79 | 10.00 |
| 8.79 | 10.00 |
| 9.11 | 7.90 |
| 9.70 | 10.50 |
| 9.86 | 8.50 |
| 9.94 | 10.50 |
| 10.36 | 8.50 |
| 11.86 | 11.00 |
| 12.11 | 11.00 |

| LOCAL METER CALC'ED DOSE g/h | LOCAL METER METER READIMG g/h |
|---|---|
| 0.03 | 0.00 |
| 0.04 | 0.00 |
| 0.04 | 0.00 |
| 0.95 | 1.00 |
| 0.99 | 1.00 |
| 1.05 | 1.00 |
| 1.08 | 1.00 |
| 1.36 | 2.00 |
| 1.63 | 2.00 |
| 1.64 | 2.00 |
| 1.74 | 2.00 |
| 1.74 | 2.00 |
| 1.76 | 3.00 |
| 2.15 | 3.00 |
| 2.15 | 3.00 |
| 2.52 | 3.00 |
| 2.65 | 4.00 |
| 2.69 | 4.20 |
| 2.69 | 4.20 |
| 3.09 | 4.00 |
| 3.28 | 4.00 |
| 3.30 | 5.00 |
| 3.37 | 5.00 |
| 4.14 | 5.00 |
| 4.22 | 6.00 |
| 4.26 | 5.00 |
| 4.28 | 6.00 |
| 4.83 | 7.00 |
| 4.96 | 7.00 |
| 5.37 | 6.00 |
| 5.43 | 6.00 |
| 6.61 | 7.00 |
| 6.67 | 8.00 |
| 6.85 | 8.00 |
| 7.42 | 8.00 |
| 7.53 | 8.00 |
| 7.76 | 9.00 |
| 8.79 | 10.00 |
| 8.79 | 10.00 |
| 9.11 | 9.00 |
| 9.70 | 11.00 |
| 9.86 | 10.00 |
| 9.94 | 11.00 |
| 10.36 | 10.00 |
| 11.86 | 11.00 |
| 12.11 | 11.00 |

CHLORINE CELL

| RESIDO-METER READING mg/l | CHLORINE CELL READING mV |
|---|---|
| 0.055 | 7.60 |
| 0.07 | 7.40 |
| 0.08 | 15.10 |
| 0.08 | 15.10 |
| 2.07 | 21.00 |
| 2.76 | 58.50 |
| 2.80 | 58.50 |
| 2.80 | 44.00 |
| 3.40 | 56.50 |
| 4.00 | 81.00 |
| 4.20 | 82.00 |
| 4.90 | 96.50 |
| 5.20 | 99.00 |
| 5.30 | 75.50 |
| 6.70 | 107.00 |
| 6.90 | 110.00 |
| 8.60 | 124.00 |
| 8.70 | 124.00 |
| 10.70 | 137.00 |
| 10.70 | 137.00 |
| 12.00 | 145.00 |
| 12.20 | 145.00 |
| 14.60 | 155.00 |
| 14.60 | 155.00 |
| 15.80 | 160.00 |
| 16.60 | 160.00 |
| 19.00 | 169.00 |
| 19.40 | 169.00 |

CONTINUOUS RUN AT 2g/h

| DAYS | %CHANGE FROM FIRST READING RESIDO-METER | FLOW METER |
|---|---|---|
| 0.0416 | 00.00 | 0.00 |
| 0.0833 | 15.00 | 0.00 |
| 0.1250 | 20.00 | -15.00 |
| 0.2083 | 20.00 | -15.00 |
| 0.2916 | 30.00 | -15.00 |
| 0.2917 | 55.00 | -15.00 |
| 0.3333 | 55.00 | -35.00 |
| 0.3750 | 60.00 | -40.00 |
| 1.0000 | 5.00 | -40.00 |
| 1.0416 | 15.00 | 5.00 |
| 1.0830 | 60.00 | 5.00 |
| 1.1666 | 65.00 | 5.00 |
| 1.2083 | 60.00 | 5.00 |
| 1.2500 | 50.00 | 5.00 |
| 1.2916 | 40.00 | 5.00 |
| 1.3333 | 55.00 | 5.00 |
| 1.3750 | 50.00 | 5.00 |
| 2.0000 | 30.00 | 5.00 |
| 2.0830 | 30.00 | 5.00 |
| 2.1250 | 15.00 | 20.00 |
| 2.2900 | 10.00 | 0.00 |
| 3.0000 | 40.00 | 0.00 |
| 3.0830 | 55.00 | 0.00 |
| 3.1250 | 40.00 | 0.00 |
| 3.1250 | 55.00 | 0.00 |
| 3.2083 | 55.00 | 0.00 |
| 3.2500 | 70.00 | 0.00 |
| 3.3333 | 55.00 | 0.00 |
| 4.0000 | 0.00 | 0.00 |

| DAYS | %CHANGE VOLT METER |
|---|---|
| 0.0416 | 0.00 |
| 0.1500 | -10.00 |
| 0.2083 | -14.00 |
| 0.2916 | -14.00 |
| 0.2917 | -21.00 |
| 0.3333 | -23.00 |
| 0.3750 | -23.00 |
| 1.0000 | -32.00 |
| 1.0416 | -32.00 |
| 1.0830 | -32.00 |
| 1.1666 | -7.00 |
| 1.2083 | -7.00 |
| 1.2500 | -9.00 |
| 1.2916 | -9.00 |
| 1.3333 | -14.00 |
| 1.3750 | -14.00 |
| 2.0000 | -18.00 |
| 2.1250 | -18.00 |
| 2.2900 | -9.00 |
| 3.0000 | -16.00 |
| 3.0830 | -16.00 |
| 3.1250 | -18.00 |
| 3.1250 | -18.00 |
| 3.2083 | -18.00 |
| 3.2500 | -16.00 |
| 3.3333 | -18.00 |
| 4.0000 | -14.00 |

CONTINUOUS RUN AT 4g/h

| DAYS | %CHANGE FROM FIRST READING RESIDO-METER | FLOW METER | VOLT METER |
|---|---|---|---|
| 0.0830 | 0.00 | 0.00 | 0.00 |
| 0.1250 | 12.00 | 0.00 | 2.00 |
| 0.1666 | 8.00 | 0.00 | 2.00 |
| 0.2083 | 4.00 | 0.00 | 2.00 |
| 0.3333 | 0.00 | 0.00 | 2.00 |
| 1.0416 | 2.00 | -18.00 | 2.00 |
| 1.1250 | 2.00 | 0.00 | 2.00 |
| 1.3333 | -4.00 | 0.00 | 2.00 |
| 2.0416 | -8.00 | 0.00 | -9.00 |
| 2.0830 | 2.00 | -14.00 | -9.00 |
| 2.2916 | -16.00 | -12.00 | -11.00 |
| 3.0000 | -16.00 | -12.00 | -15.00 |
| 3.2500 | -10.00 | -12.00 | -17.00 |
| 3.5800 | -16.00 | -22.00 | -17.00 |
| 4.2800 | -20.00 | -25.00 | -19.00 |
| 7.0000 | -16.00 | -25.00 | -26.00 |
| 7.0416 | -35.00 | -25.00 | -28.00 |
| 8.0000 | -35.00 | -21.00 | -32.00 |
| 9.0000 | -41.00 | -30.00 | -37.00 |
| 9.1250 | -41.00 | -37.00 | -39.00 |

CONTINUOUS RUN AT 5g/h

| DAYS | %CHANGE FROM FIRST READING RESIDO-METER | FLOW METER | VOLT METER |
|---|---|---|---|
| 0.2083 | 0.00 | 0.00 | 0.00 |
| 0.2500 | -41.00 | -5.00 | -25.00 |
| 0.2900 | -18.00 | -5.00 | -27.00 |
| 1.0416 | -28.00 | -15.00 | -47.00 |
| 1.0833 | -30.00 | -15.00 | -48.00 |
| 1.2916 | -28.00 | -15.00 | -52.00 |
| 2.0000 | -23.00 | -19.00 | -57.00 |
| 2.2500 | -42.00 | -22.00 | -50.00 |
| 2.3333 | -31.00 | -19.00 | -53.00 |
| 3.0000 | -36.00 | -24.00 | -62.00 |
| 3.1250 | -39.00 | -24.00 | -65.00 |
| 3.2916 | -49.00 | -24.00 | -67.00 |
| 3.3333 | -42.00 | -24.00 | -67.00 |
| 4.0000 | -37.00 | -25.00 | -68.00 |
| 4.2083 | -39.00 | -25.00 | -68.00 |

APPENDIX 7 ULTRAVIOLET IRRADIATION

## SURVEY OF USERS

Manufacturers of UV equipment were approached for lists of public water undertakings which had installed their equipment. The list of contacts thus obtained included 3 Regional Water Authorities, 3 Scottish Regional Councils, 3 Water Companies and one District Council. The contact in the last was the Environmental Health Officer who had recommended UV disinfection for a number of private supplies.

No attempt was made to identify large numbers of private users. To do so would have involved considerable correspondence with dealers such as local plumbers through whom equipment is sold for private use. When the users were eventually identified it was probable that their replies would only be descriptive. The advantage of restricting the survey to public undertakings was that each might have several installations and that each one would have been installed and monitored by knowledgable officers who could give useful information and figures on water quality.

The survey form is shown on page 7.3 and the main findings are tabulated on the following pages.

## FINDINGS

Completed questionnaires were received from all 10 contacts and described 29 installations using equipment from 7 different manufacturers. Although battery powered units were available, all the units reported were mains powered.

### Sources

Sources were usually groundwater; springs or boreholes. There were only 5 surface water sources reported. At 4 of these the water was filtered before disinfection and in the other it was screened and then chlorinated before entering the mains.

Supplies ranged from a 10Ml/d supply down to a single household. Two thirds of the number reported were smaller than 500 cu.m/d and one third smaller than 20 cu.m/d.

### Locations

Most units were situated quite close to the user. Distances were usually less than 200m or else described as small; in two cases the units were installed on the premises supplied. One unit was 3000m from the nearest consumer, but chlorine was also used in this case. The greatest distance reported where chlorination was not used was 1500m.

### Other Treatment

For about half the supplies reported, UV disinfection was the only treatment. Two undertakings used UV as a second line of defence to back up chlorination on 7 installations, some where the contact tank was too small to give sufficient retention for chlorine alone.

## Monitoring

Most users relied solely upon the routine bacteriological sampling to monitor the performance of a unit. Others used units with built-in UV monitors either to maintain a constant radiation level or to activate an alarm when the radiation fell below a set level. One of these monitors was reported not to function properly while there were colour variations in the water and the manufacturer was designing a new monitor. Some respondents also mentioned weekly visual checks as a monitoring procedure to supplement the bacterial inspection.

## Water Quality

In most of the supplies the raw water was of good bacteriological quality and there was no improvement to be reported due to the UV disinfection. In some cases the UV units had no effect on plate counts during periods of high colour or turbidity. In one case this happened after prefiltration because after heavy rain the filter became overloaded.

One user had carried out an evaluation of an UV unit running alongside chlorination. Both UV and chlorination gave 100% inactivation of bacteria. However, the UV unit occasionally interrupted the supply when, due to a drop in UV transmission, the unit was automatically shut down.

## Cleaning Frequency and Tube Life

Most of the units were cleaned regularly every 2 or 3 months, though the frequency varied between installations from twice weekly to annually and the time for cleaning varied from 5 mins to 6 hrs per year. One user reported problems due to corrosion products causing a brown deposit on the window of the UV sensor so that it was not known whether the lamp was operating correctly. Another reported frequent brown deposits on the dry side of the lamp sleeve.

Where it was reported, the lamp life normally equalled or exceeded its guaranteed life, sometimes by as much as 67%. In two cases the lamp was changed as a matter of routine every time the unit was cleaned.

## Consumer Reaction

It was generally reported that the installation of UV disinfection had provoked no consumer reaction. One exception was an installation where there had been seasonal taste complaints due to chlorination of water containing phenols. These ceased after UV was installed. The other exception was where a consumer had said he was very satisfied with the unit.

## Conclusion

In general, UV disinfection appeared to have been used where the bacteriological quality of the water was known to be good and the low frequency of attention required by the process could be matched with a low frequency of sampling. It had also proved effective, when used in conjunction with chlorination, to give rapid disinfection and so remove the need for contact time on site.

Units were available to suit a wide range of demands. They required less frequent attention than chlorinators or hypochlorinators, but they did not operate reliably in supplies which exhibited high colour or turbidity.

# WRc PROCESSES - Water Group
## Small Supplies Project
# SURVEY OF UV DISINFECTION PRACTICE NOV 84

## SITE

| | |
|---|---|
| NAME OF SUPPLY: | LOCATION (GRID) |
| UNIT MAKE&MODEL | UV UNIT COST :<br>INSTALLED COST : |
| PREVIOUS DISINFECTION METHOD | |
| IS THERE FLOW CONTROL? YES/NO | DATE INSTALLED |
| POWER SUPPLY: MAINS/BATTERY | DISTANCE OF UNIT FROM CONSUMER |

## WATER QUALITY

| | |
|---|---|
| SOURCE: BOREHOLE/RIVER/STREAM/SPRING/WELL (CIRCLE) | |
| IS THE QUALITY CONSTANT ? YES/NO | PRETREATMENT<br>SCREENING/FILTER-RAPID/SLOW |
| DEMAND (cu.m/d) | PEAK FLOW (cu.m/h) |

## PERFORMANCE

| | |
|---|---|
| HOW IS PERFORMANCE MONITORED ? | |
| HOW IS IT KNOWN WHEN UNIT IS NOT OPERATING CORRECTLY ? | |
| WHAT IMPROVEMENT IN BACTERIAL RESULTS HAS THERE BEEN ? | |
| CLEANING FREQUENCY | CLEANING TIME |
| TUBE LIFE (HRS) | TUBE GUARANTEE PERIOD (HRS) |

| |
|---|
| HAS THERE BEEN ANY CHANGE IN CONSUMER REACTION ? |

## RETURN COMPILED BY

| | |
|---|---|
| NAME: | DATE : |
| JOB TITLE: | |
| UNDERTAKING : | ARE MORE SITES INTENDED YES/NO |

20/09/85

USER SURVEY ON ULTRA VIOLET DISINFECTION UNITS
SUMMARY OF RETURNS RECEIVED TO DATE

| SENDER AND ORGANISATION | MAKE AND MODEL No | POWER | DISTANCE FROM USER | SOURCE | PRE-TREATMENT | DEMAND CU M PER DAY | HOW IS PERFORMANCE MONITORED | HOW IS UNIT FAILURE DETECTED | BACTERIOLOGICAL CHANGE | CLEANING FREQUENCY | TUBE GARANTEE LIFE | CONSUMER REACTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| D.B. JAMES NEWCASTLE AND GATESHEAD W Co | HANOVIA No 12 | MAINS | 700m | BOREHOLE (ISLAND SUPPLY) | MECHANICAL FILTRATION | 55 | REGULAR SAMPLING | POOR SAMPLE OR VISUAL INSPECTION SHOWS LAMP — DIMING | NONE AS RAW QUALITY WAS ALREADY GOOD | WEEKLY | 2500-3000 Hrs | NONE |
| " | JABAY No 500 2SF | MAINS | 220m | SPRING | - | 20 | REGULAR BACTERIOLOGICAL SAMPLING | INDICATOR LAMP | NONE, ONLY GOOD WHEN RAW WATER QUALITY IS GOOD | WEEKLY | 7500 Hrs | NONE |
| " | JABAY No 2000 SF | MAINS | - | SPRING | - | 56 | REGULAR BACTERIOLOGICAL SAMPLING | INDICATOR LAMP | NONE, AS RAW QUALITY WAS ALREADY GOOD | WEEKLY | 7500 Hrs | NONE |
| " | HANOVIA No 12 | MAINS | 20m | SPRING | - | 2 | REGULAR BACTERIOLOGICAL SAMPLING | POOR SAMPLE OR VISUAL INSPECTION SHOWS LAMP - DIMING | SLIGHT, BUT NOT SATISFACTORY WHEN RAW COLI COUNT INCREASES | WEEKLY | 2500 3000 Hrs | NONE |
| " | HANOVIA No 12 | MAINS | 10m | SPRING | - | 1.5 | REGULAR BACTERIOLOGICAL SAMPLING | POOR SAMPLE OR VISUAL INSPECTION SHOWS LAMP DIMNIG | NONE, ONLY GOOD WHEN RAW WATER QUALITY IS GOOD | WEEKLY | 2500 3000 Hrs | NONE |
| R. HUNTER BORDERS R.C. | JABAY No 2000 | MAINS | 100m | SPRING | NONE | 227 | FORTNIGHTLY BACTERIOLOGICAL SAMPLING | SAMPLING + INDICATOR LAMP | RAW QUALITY IS ALREADY GOOD | ANUAL | 7300 Hrs | NONE |
| N GROOCOCK SEVERN TRENT W.A. | HANOVIA | MAINS | 1 MILE | SPRING | NONE | 105 | BACTERIOLOGICAL SAMPLING | ON/OFF CONTROL WITH ALARM | NONE. U.V. USED DUE TO TASTE COMPLAINTS WITH CHLORINE | QUARTERLY | 1000 Hrs | NO TASTE COMPLAINTS |
| " | LAMP & MACHINE PROD'S | MAINS | 200m | SPRING | NONE | 60 | BACTERIOLOGICAL SAMPLING | ON/OFF CONTROL WITH ALARM | NONE | QUARTERLY | 1000 Hrs | NONE |
| D.C.WATSON NORTH WEST WATER AUTHORITY | WILLAND WB 18 | MAINS MAINS | 2-3m | SPRING | NONE | 6.5 | BACTERIOLOGICAL SAMPLING | - | COMPLETE DISINFECTION | NONE SELF CLEANSING | 4000 Hrs | NONE |

| SENDER AND ORGANIS-ATION | MAKE AND MODEL No | POWER | DIST-ANCE FROM USER | SOURCE | PRE-TREATMENT | DEMAND CU M PER DAY | HOW IS PERFORMANCE MONITORED | HOW IS UNIT FAILURE DETECTED | BACTERIOLOGICAL CHANGE | CLEAN-ING FREQU-ENCY | TUBE GARA-NTEE LIFE | CONS-UMER REAC-TION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| " | BBC No UAC13 | MAINS | - | BOREHOLE | CHLORINATION | 7250 | SAMPLING + DAILY U.V. STRENGTH READING | VISUAL ALARM WHEN OUTPUT FALLS BELOW 60% | UNITS USED WITH CHLORINATION TO OBVIATE CONTACT TIME | - | 4000 Hrs | NONE |
| " | BBC No UAC13 | MAINS | - | BOREHOLE | CHLORINATION | 7250 | SAMPLING + DAILY U.V. STRENGTH READING | VISUAL ALARM WHEN OUTPUT FALLS BELOW 60% | UNITS USED WITH CHLORINATION TO OBVIATE CONTACT TIME | - | 4000 Hrs | NONE |
| " | HANOVIA | MAINS | - | BOREHOLE | CHLORINATION | 10600 | TRIAL PHASE - NO DATA AVAI;ABLE | | | | | |
| " | HANOVIA | MAINS | - | BOREHOLE | CHLORINATION | 10600 | TRIAL PHASE - NO DATA AVAI;ABLE | | | | | |
| P. DUFF NORTH WEST WATER AUTHORITY | HANOVIA No 12 | MAINS | 46m | STREAM | RAPID FILTER | - | WEEKLY VISUAL INSPECTION | WEEKLY SAMPLING AND VISUAL INSPECTION | IMPROVEMENT EXCEPT AFTER HEAVY RAIN | ONCE EVERY 3000 Hrs | 3000 Hrs | NONE |
| " | HANOVIA No 12 | MAINS | 805m | STREAM | RAPID FILTER | 20 | WEEKLY VISUAL INSPECTION | WEEKLY SAMPLING AND VISUAL INSPECTION | IMPROVEMENT EXCEPT AFTER HEAVY RAIN | ONCE EVERY 3000 Hrs | 3000 Hrs | NONE |
| J. WATT GRAMPIAN R. C. | HANOVIA No 111 | MAINS | - | SPRING | NONE | 30 | WEEKLY BACTERIOLOGICAL SAMPLING | TWICE WEEKLY VISUAL INSPECTION | SLIGHT. NOT SATISFACTORY DURING STORM CONDITIONS | NOT NEEDED | 1000 Hrs | NONE |
| J. LEACH ROCHDALE E.H. DEPT | PURAQ No 15/3 | MAINS | 1m | SPRING | NONE | - | REGULAP BACTERIOLOGICAL SAMPLING | LAMP DIMING | COMPLETELY FREE OF BACTERIA | - | - | VERY SATIS-FIED |
| " | AQUA-FINE | MAINS | IN BUIL-DING | STREAM/ WELL | RAPID FILTFR | VAR-IABLE | WEEKLY SAMPLING | ON/OFF CONTROL FROM MONITOR | SUBSTANTIAL | WEEKLY | 6000 | - |
| " | MAR-SHALL PUMP SYSTEMS | MAINS | 6m | SPRING | RAPID FILTER | - | SAMPLING EVERY 4 MONTHS | ON/OFF CONTROL WITH ALARM | SUBSTANTIAL 100% KILL | DAILY | 6000 | - |

| SENDER AND ORGANISATION | MAKE AND MODEL No | POWER | DISTANCE FROM USER | SOURCE | PRE-TREATMENT | DEMAND CU M PER DAY | HOW IS PERFORMANCE MONITORED | HOW IS UNIT FAILURE DETECTED | BACTERIOLOGICAL CHANGE | CLEANING FREQUENCY | TUBE GARANTEE LIFE | CONSUMER REACTION |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| " | WILLAND WB 18 | MAINS | 2-3m | SPRING | NONE | 7.05 | MONTHLY BACTERIOLOGICAL SAMPLING | SAMPLING + INDICATOR LIGHT | BACTERIAL COUNT WITHIN EEC LIMITS | NONE SELF CLEAN- | 4000 Hrs | NONE |
| " | WILLAND WB 18 | MAINS | 2-3m | SPRING | LIMESTONE CHIPS FOR pH ADJUSTMENT | 4.9 | MONTHLY BACTERIOLOGICAL SAMPLING | SAMPLING + INDICATOR LIGHT | BACTERIAL COUNT WITHIN EEC LIMITS | 3-4 MONTHS | 4000 Hrs | NONE |
| " | WILLAND WB 18 | MAINS | 2-3m | SPRING | LIMESTONE CHIPS FOR pH ADJUSTMENT | 0.75 | MONTHLY BACTERIOLOGICAL SAMPLING | SAMPLING + INDICATOR LIGHT | BACTERIAL COUNT WITHIN EEC LIMITS | NONE SELF CLEANSING | 4000 Hrs | NONE |
| " | WILLAND WB 18 & WB 35 | MAINS | SMALL IN BUILING | SPRING TO DAIRY | NONE | 5.2 | MONTHLY BACTERIOLOGICAL SAMPLING | SAMPLING + INDICATOR LIGHT | BACTERIAL COUNT WITHIN EEC LIMITS | NONE SELF CLEANSING | 4000 Hrs | NONE |
| " | WILLAND WB 18 | MAINS | SMALL | SPRING | NONE | 9.9 | REGULAR BACTERIOLOGICAL SAMPLING | SAMPLING + INDICATOR LIGHT | REDUCTION IN No E-COLI BUT NOT COMPLETE DISINFECTION | 3-4 MONTHS | 4000 Hrs | NONE |
| C.J.ACKERS CENTRAL R.C. | HANOVIA No 131A | MAINS | 50m | STREAM | CHLORINATION & SCREENING | 470 | MONITOR CAMERA (DOES NOT WORK PROPERLY) WEEKLY SAMPLING | WEEKLY SAMPLING | NONE, U.V. IS A BACKUP IF CHLORINATION FAILS | ONCE - TWICE WEEKLY | 1000 Hrs | NONE |
| P. BODDINGTON WELSH WATER | HANOVIA No 131A | MAINS | 2 MILES | STREAM INTO RESERVOIR | RAPID FILTER | 2000 | BACTERIOLOGICAL SAMPLING | ALARM SOUNDS IF TRANSMISSION FALLS BELOW 30% | OPERATING WITH CHLORINATION. U.V. ON OWN GAVE 100% KILL | ONCE A FORTNIGHT | 1000 Hrs | NONE |
| D.J. BELLAMY BRISTOL WATER Co | 3X HANOVIA No 12 | MAINS | 1/4 MILE | BOREHOLE\ SPRING | NONE | 400 | SAMPLING | SAMPLING AND WEEKLY VISUAL INSPECTION | NONE | ONCE EVERY 2 MONTHS | 1000 Hrs | NONE |
| A.F.BEND RICKMANSWORTH WATER Co | BBC No UAC13 | MAINS | - | BOREHOLE | CHLORINATION | 3600 | SAMPLING + DAILY U.V. STRENGTH READING | VISUAL ALARM WHEN OUTPUT FALLS BELOW 60% | UNITS USED WITH CHLORINATION TO OBVIATE CONTACT TIME | - | 4000 Hrs | NONE |
| " | BBC No UAC13 | MAINS | - | BOREHOLE | CHLORINATION | 3600 | SAMPLING + DAILY U.V. STRENGTH READING | VISUAL ALARM WHEN OUTPUT FALLS BELOW 60% | UNITS USED WITH CHLORINATION TO OBVIATE CONTACT TIME | - | 4000 Hrs | NONE |

## . TESTS

### . Free Chlorine

Laboratory tests with two different designs of flow cell supplied by Croft Pools Ltd have been made to find how cell current is related to free chlorine, rate of flow and sample pH.

The cell current (in the range up to 0.1 mA) was measured by passing it through a resistance connected in parallel with a recording voltmeter. This resistance was made adjustable so that the measured voltage could be brought into a convenient range. A small counter-current was applied from a battery to cancel the component of the signal due to the natural conductances of the water, so that only the depolarising action of the chlorine was measured. The electrical circuit is shown in Fig. . It can be seen that this system is essentially simple. The cell generates its own current and external power is needed only to take the measurement, drive the recorder (if required) and take any control actions.

### . Flow

The tests showed, Fig. 3, that the cell signal was proportional to free chlorine over the range tested; up to 10 mg/l, and it was possible to measure concentrations as low as 0.05 mg/l.

At a constant chlorine level the signal was proportional to the flow through the cell. Fig. 4 shows the results of measurements at several levels of free chlorine.

### pH

The dissociation of hypochlorous acid into hypochlorite and hydrogen ions depends on pH in a well-known way. A series of tests using a constant concentration of sodium hypochlorite at a range of pH values from 2.9 to 9.45 showed that the signal varied with pH in a similar way to the concentration of hypochlorous acid.

The graph Fig. 5 shows the first set of results obtained. The highest meter reading was obtained at pH 2.9 and all the other readings are expressed as percentages of that value.

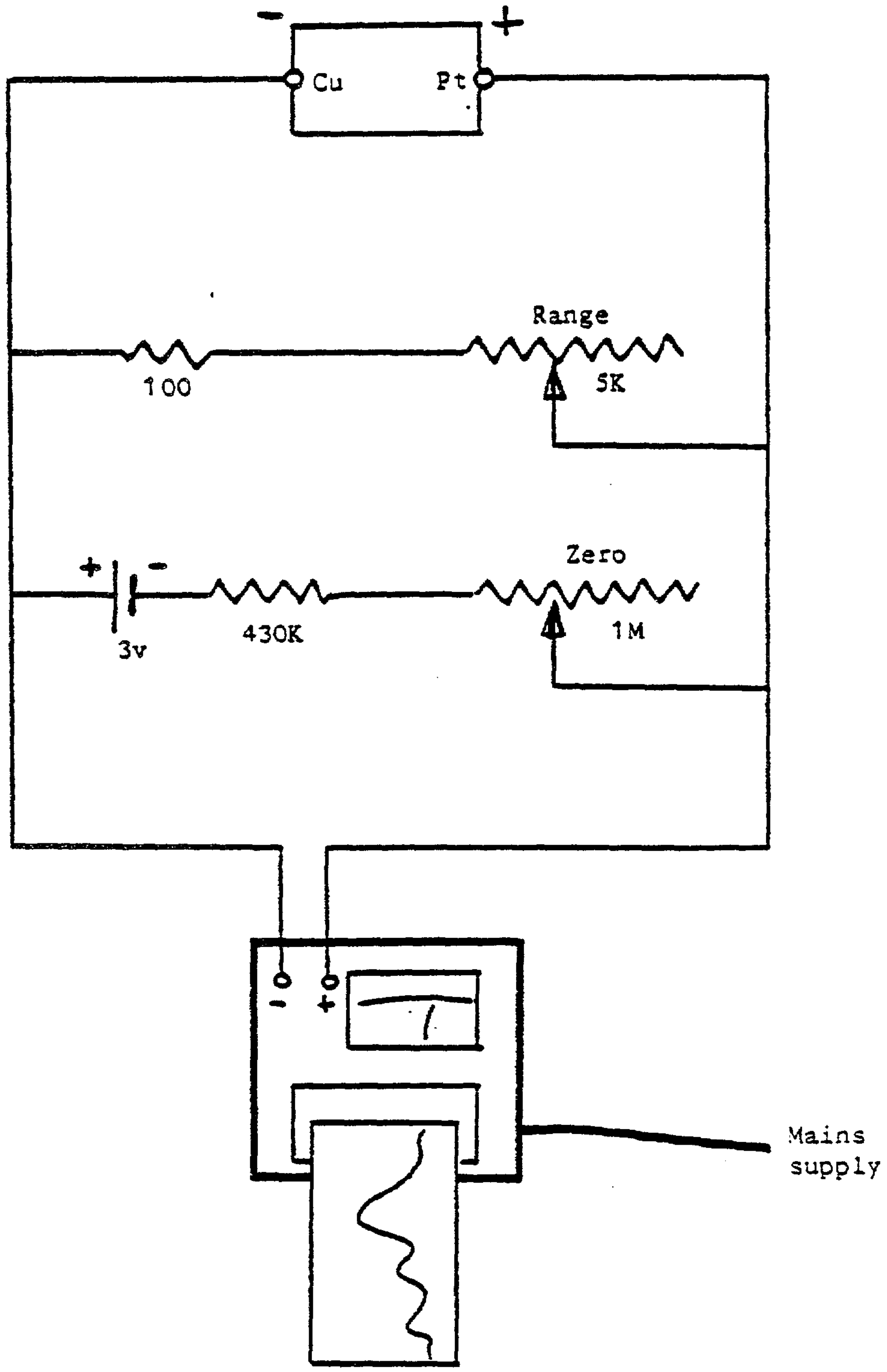



Figure . Electrical circuit to Copper-Platinum cell

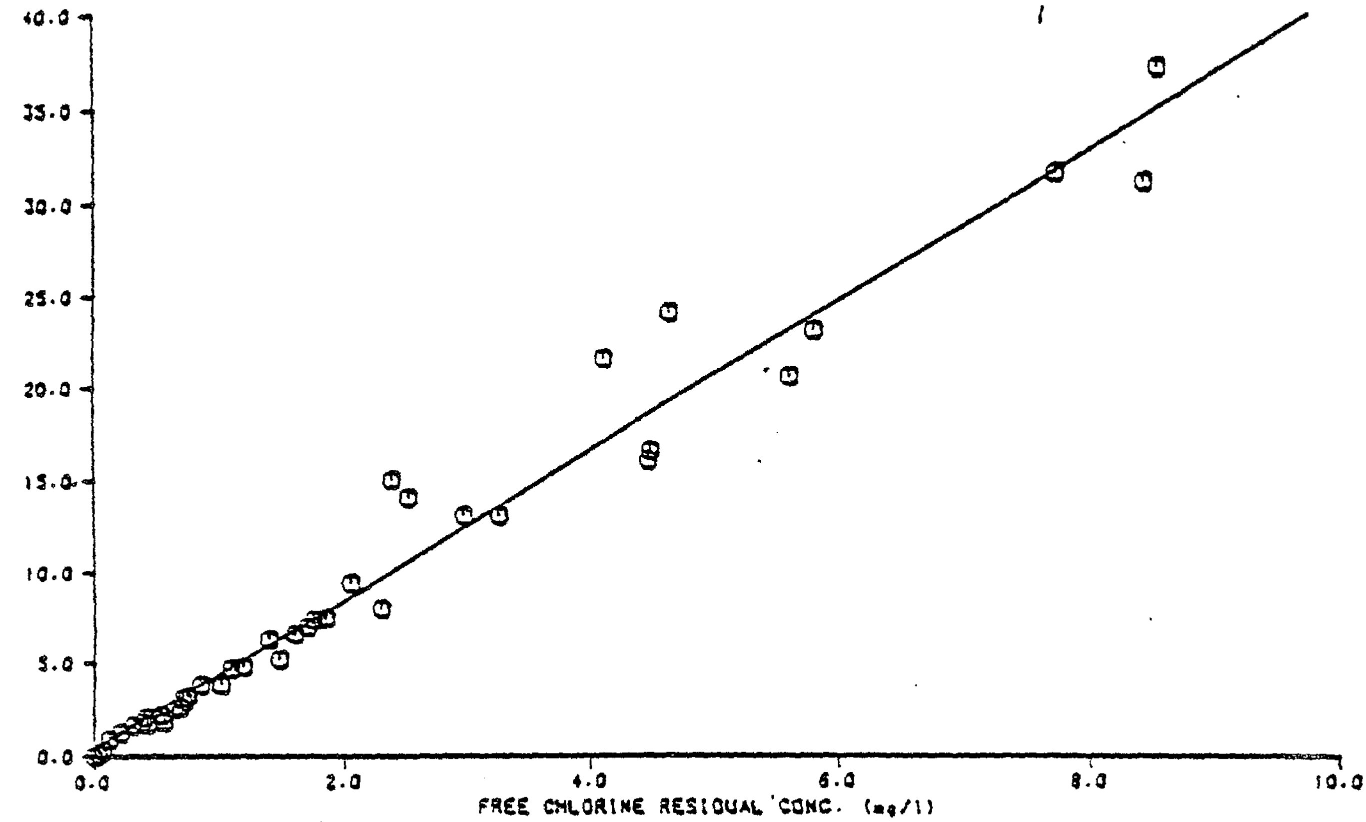



Figure 3. Variation of meter reading with free chlorine

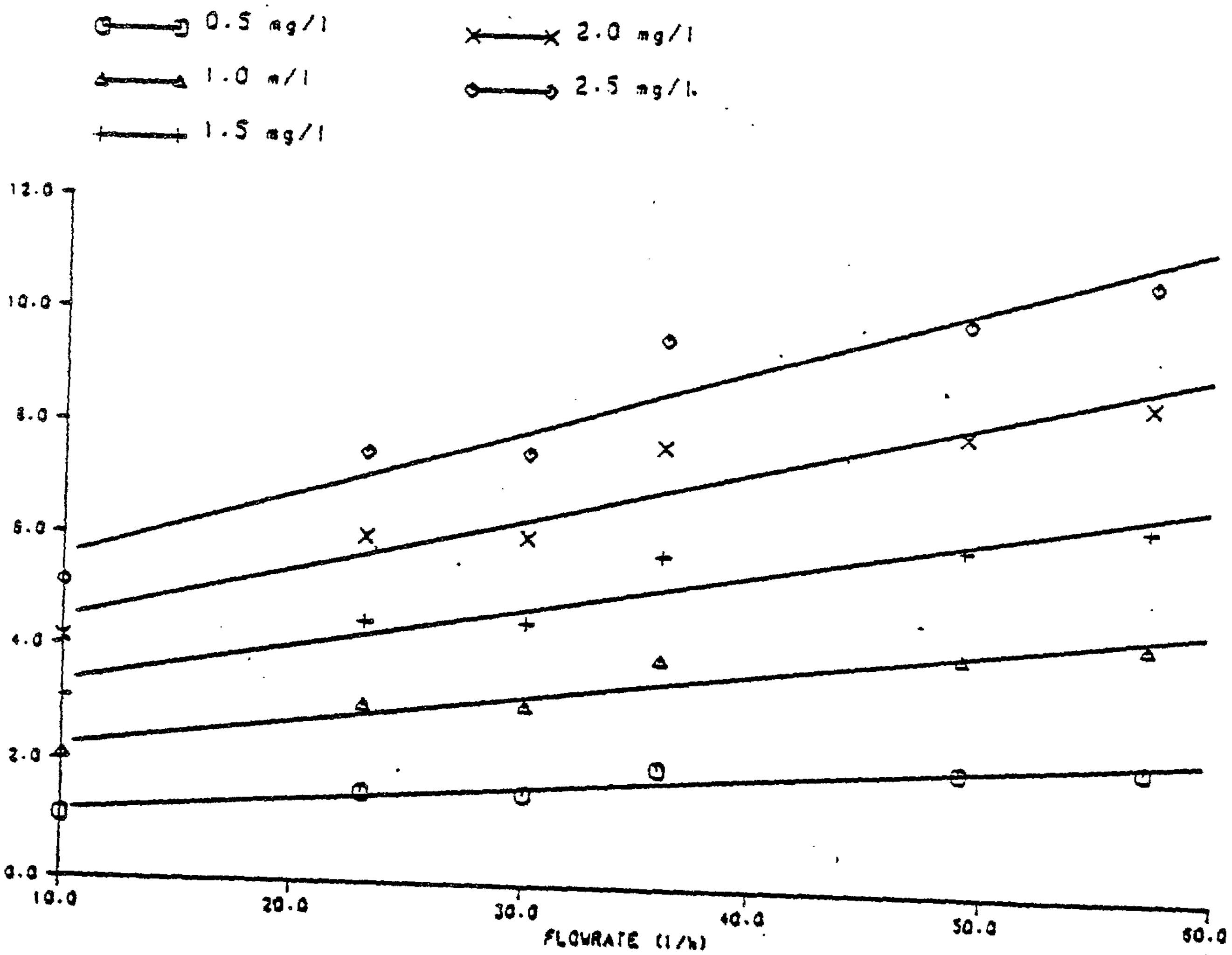



Figure 4. Variation of meter reading with flow rate

Plotted on the same axes, the chain-dotted line shows how the percentage of hypochlorous acid varies with pH as it dissociates over the same range into hypochorite and hydrogen ions. Although the two curves are not close, they are not dissimilar and strongly suggest that the electrode system is more sensitive to hypochlorous acid than to hypochlorite ion.

It can also be seen how greatly the hypochlorous acid fraction varies at about neutral pH; from 97% at pH 6 to 80% at pH 7, to 56% at pH 7.5 and to 29% at pH 8. This explains why buffered measuring cells are recommended for waters where the pH is likely to vary more than a point upwards or downwards.

It is understood that on small supplies taking surface waters the pH varies during the year and with changes in the weather. However the use of buffer solutions on small supply monitors is not desirable and thought has been given to making some electrical alteration to the cell signal based on pH. Therefore detailed attention has been given to this effect.

In a performance test of seven proprietary chlorine cells carried out in association with South Staffordshire Waterworks Company, the Wallace and Tiernan unit was found to be the most consistently reliable and accurate. One of these was therefore mounted into a flow line passing laboratory water at a controlled rate. Electronically controlled dosing pumps were used to add a sodium hypochlorite, sulphuric acid and caustic soda solutions into the flow which was then monitored for pH, conductivity and temperature (which remained sensibly constant). At a series of chlorine doses ranging from (and including) 0 to 1.5 mg/l, the pH was altered from about 5 to 8.5. Examination of the comprehensive data produced has not yet yielded an explanation of how the meter signal is affected by pH changes. It was also noted that the cell signal was affected by incident light.

. DISCUSSION

The variation of chlorine cell signal with changes in pH has not proved to be as readily comprehensible as had been expected but the problem should not yet be considered insoluble. Even if ultimately no alternative to buffering can be found, it is not certain that a simple unbuffered cell would be unacceptable.

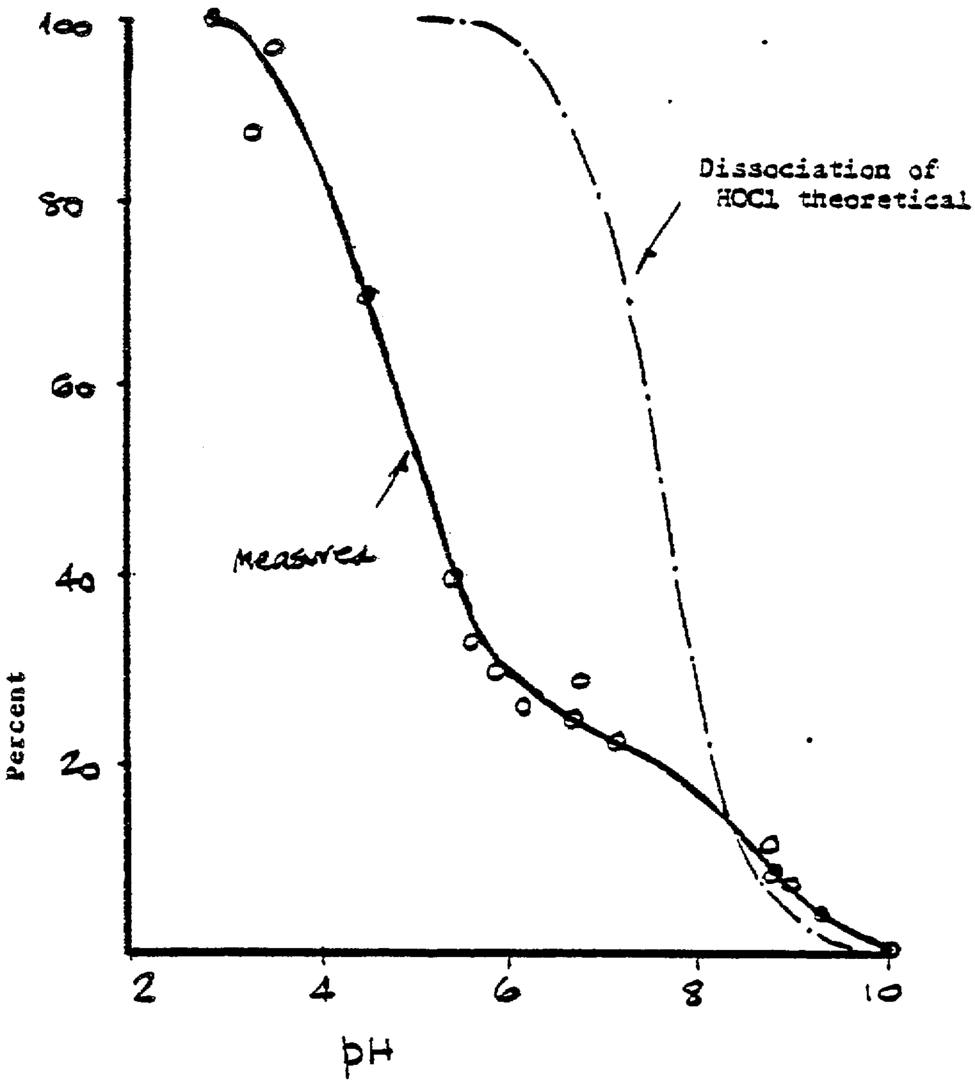



Figure 10. Variation of meter reading with pH

There is still far too little field data available on pH changes over short time scales and on the extent to which chlorine residuals may be allowed to vary. There is still no doubt that some form of simple residual controller will in many places be of enormous benefit in improving standards of service.

This work has turned out not to be nearly so simple and straightforward as had been expected, and clearly beyond the resources of this contract. Because of the great demand by Water Authorities for a battery-operated chlorine controller for small supplies, the work has continued but has been financed by members' subscription income.

## APPENDIX 12 SODIUM HYPOCHLORITE SHELF LIFE TESTS

### Objective

To determine the variation of concentration with time of sodium hypochlorite solution under varying conditions.

### Introduction

Sodium hypochlorite is in common use for the disinfection of potable water supplies. It is especially popular in small supplies which have to be left unattended for long periods of time. One major drawback of its use, however, is that in storage, the available chlorine content of the solution decreases with time. According to the literature, the main route of decomposition of commercial solutions (which are alkaline) is to sodium chlorate and sodium chloride with the release of some oxygen.

The rate of decomposition is catalysed by sun light and the presence of copper, nickel, cobalt and iron ions. Increased temperature and concentration of solution also have adverse affects on the stability. The stability is thought to be enhanced by keeping the solution in dark bottles at low temperature.

### Procedure

Industrial grade sodium hypochlorite was passed through a 40 micron membrane filter to remove as many impurities as possible. Twenty samples were prepared at varying dilutions using either deionised or distilled water and decanted into clear or amber glass winchester bottles with vented caps.

To test the effect of sun light, a set of 5 samples were stood on a north facing window ledge in clear bottles as well as another set of 5 in amber bottles. As a control, another set was put in a dark cupboard. To examine the effect of temperature a set in amber bottles were put in a cool store. Also, two portions of unfiltered hypochlorite were left in their original drums; one stored at room temperature in the laboratory and one in the cool store. Table 1 lists all the samples.

TABLE 1 LIST AND LOCATIONS OF SAMPLES

| SAMPLE NO | CODE | DILUTION WATER: HYPOCHLORITE | WATER FOR DILUTION | LOCATION | COLOUR OF BOTTLES |
|---|---|---|---|---|---|
| 1 | NCW | None | - | Window ledge | Clear |
| 2 | 10DEIONCW | 10:1 | Deionized | Window ledge | Clear |
| 3 | 100DEIONCW | 100:1 | Deionized | Window ledge | Clear |
| 4 | 21DEIONCW | 1:2 | Deionized | Window ledge | Clear |
| 5 | 10DISTCW | 10:1 | Distilled | Window ledge | Clear |
| 6 | NAW | None | - | Window ledge | Amber |
| 7 | 10DEIONAW | 10:1 | Deionized | Window ledge | Amber |
| 8 | 100DEIONAW | 100:1 | Deionized | Window ledge | Amber |
| 9 | 21DEIONAW | 1:2 | Deionized | Window ledge | Amber |
| 10 | 10DISTAW | 10:1 | Distilled | Window ledge | Amber |
| 11 | NCDC | None | - | Dark cupboard | Clear |
| 12 | 10DEIONCDC | 10:1 | Deionized | Dark cupboard | Clear |
| 13 | 100DEIONCDC | 100:1 | Deionized | Dark cupboard | Clear |
| 14 | 21DEIONCDC | 1:2 | Deionized | Dark cupboard | Clear |
| 15 | 10DISTCDC | 10:1 | Distilled | Dark cupboard | Clear |
| 16 | NACS | None | - | Cool store | Amber |
| 17 | 10DEIONACS | 10:1 | Deionized | Cool store | Amber |
| 18 | 100DEIONACS | 100:1 | Deionized | Cool store | Amber |
| 19 | 21DEIONACS | 1:2 | Deionized | Cool store | Amber |
| 20 | 10DISTACS | 10:1 | Distilled | Cool store | Amber |
| 21 | DRUMLAB | None | - | Back of lab | Original drum |
| 22 | DRUMCOOL | None | - | Cool store | Original drum |
| 23 | SBUSKDC | 10:1 | Stallingbusk | Dark cupboard | Clear |
| 24 | SBUSKLA | 10:1 | Stallingbusk | Back of lab | Clear |

Samples were taken from each bottle at intervals, which increased as time went on, and were titrated for available chlorine using the iodometric method with starch indicator.

## Results

The variation of concentration with time is shown for some typical samples in Fig 1. Those in the cool store hardly deteriorated at all. Those exposed to light decayed completely in about 50 days and those at ambient temperature in the dark decayed to almost half strength over 8 months. Fig 1 shows only how the neat samples behaved. The diluted samples decayed in a similar way. There was no detectable difference between those diluted 10:1 with distilled water and those with deionized water. The results for the samples diluted 100:1 showed considerable scatter and no firm conclusion could be drawn in this case.

It was expected that the decay would be exponential.

$$dC/dt = -kC$$

$$C = Co * EXP(-k*TIME)$$

or

$$Ln (C) = -k*(TIME) + Ln (Co)$$

where C is the concentration of chlorine at any time t and Co is the initial concentration. Time is measured in days and k represents the reciprocal of the time constant.

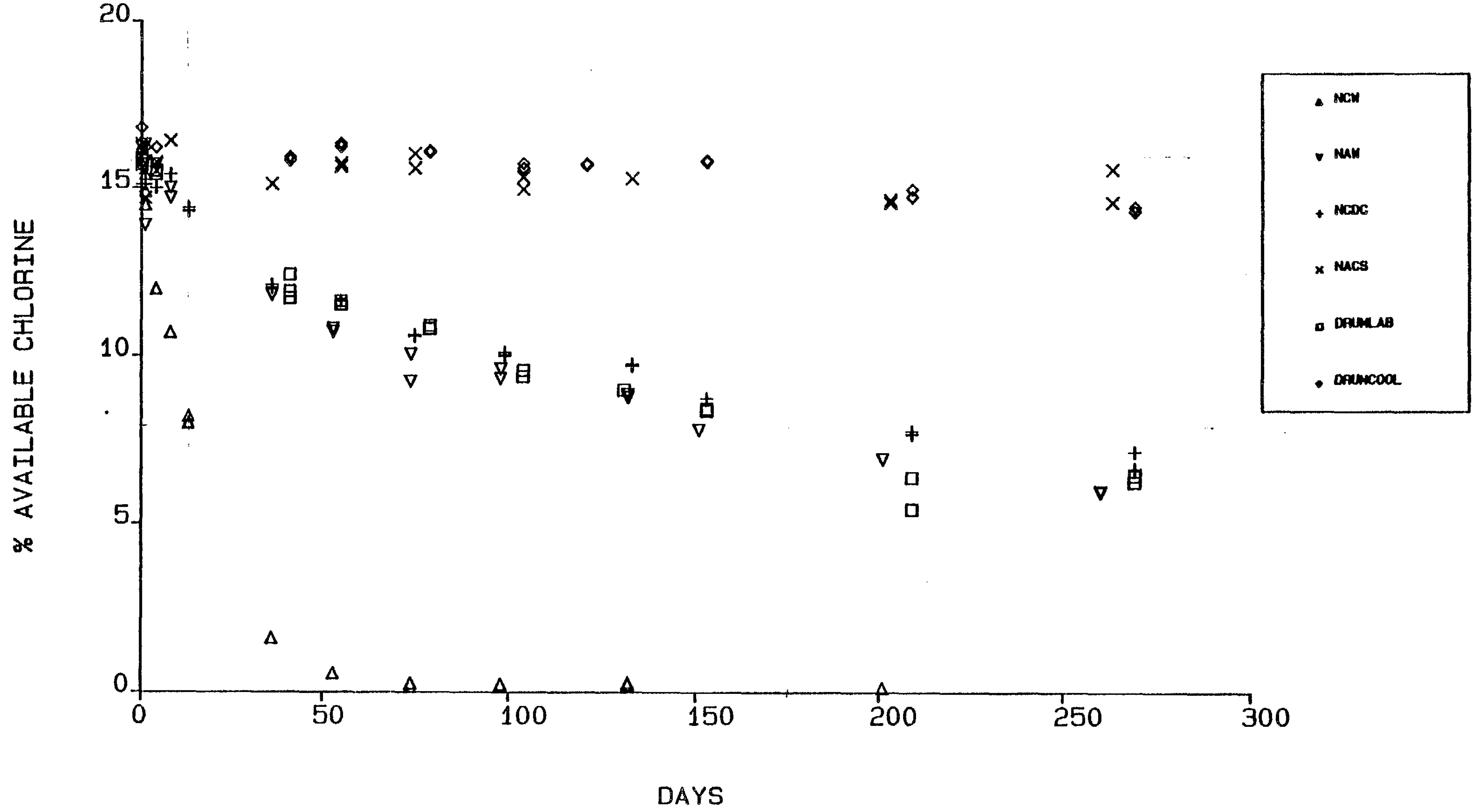
When the graphs were drawn after about 50 days, the above relationship appeared to be true and the following time constants were calculated for some of the samples.

TABLE 2 DECAY OF SODIUM HYPOCHLORITE SOLUTIONS

| STORAGE | CODE | INITIAL CONCENTRATION | TIME CONSTANT |
|---|---|---|---|
| Clear bottles placed at the north facing window | 10DEIONCW<br>21DEIONCW<br>NCW | 1.64%<br>10.8%<br>16.2% | 14 days<br>21 days<br>16 days |
| Orignal drum in lab | DRUMLAB | 15.8% | 180 days |
| Neat sample in colourless bottle placed in dark | NCDC | 15.4% | 162 days |

With the exception of samples exposed to light, there had been little loss of strength of the solutions. This appeared to be at odds with the general experience reported from the field that solutions deteriorated rapidly. Therefore, as a spot check, neat sodium hypochlorite was also diluted with raw water from Stallingbusk, a small source in the Yorkshire Dales. The dilution used was 10:1 and the samples were placed in clear bottles. One was placed in the dark cupboard while the other was put at the back of the lab.

FIG 1 SODIUM HYPOCHLORITE SHELF LIFE



In order to measure the chlorine demand of the Stallingbusk water, a 1 litre sample and a litre of distilled water were each dosed with 3 ml of weak hypochlorite solution. The distilled water sample had a residual of 4.8 mg/l while that in the Stallingbusk sample was only 2.4 mg/l. It was concluded that the Stallingbusk water had a chlorine demand of 2.4 mg/l.

In a sample of hypochlorite diluted 10:1 the chlorine concentration would be 15,000 mg/l. A demand of 2.4 mg/l in the diluting water would have negligible effect on the chlorine concentration.

However, as the trial progressed beyond 70 days, it was found that the samples did not continue to decay at the expected rate, but more slowly. This is shown in Fig 2.

After about 250 days, a new mathematical model was tested on one sample which had shown significant decay over the whole period, DRUMLAB.

The following relationship was used to construct the mathematical model.

dC/dt = -k(C**n)

Ln (dC/dt) = -Ln (k) + n(Ln (C))

An example calculation showing how the values of n and k were calculated is as follows. The sample used in this example is DRUMLAB.

A graph was plotted of % available chlorine (C) against number of days (Fig 3). A smooth curve was drawn by hand through the data points and five points were choosen which lay close to the curve (arrowed). They were joined with straight lines and the relationship of dC/dt with C was based on the gradient of these lines and the co-ordinates of their mid-points.

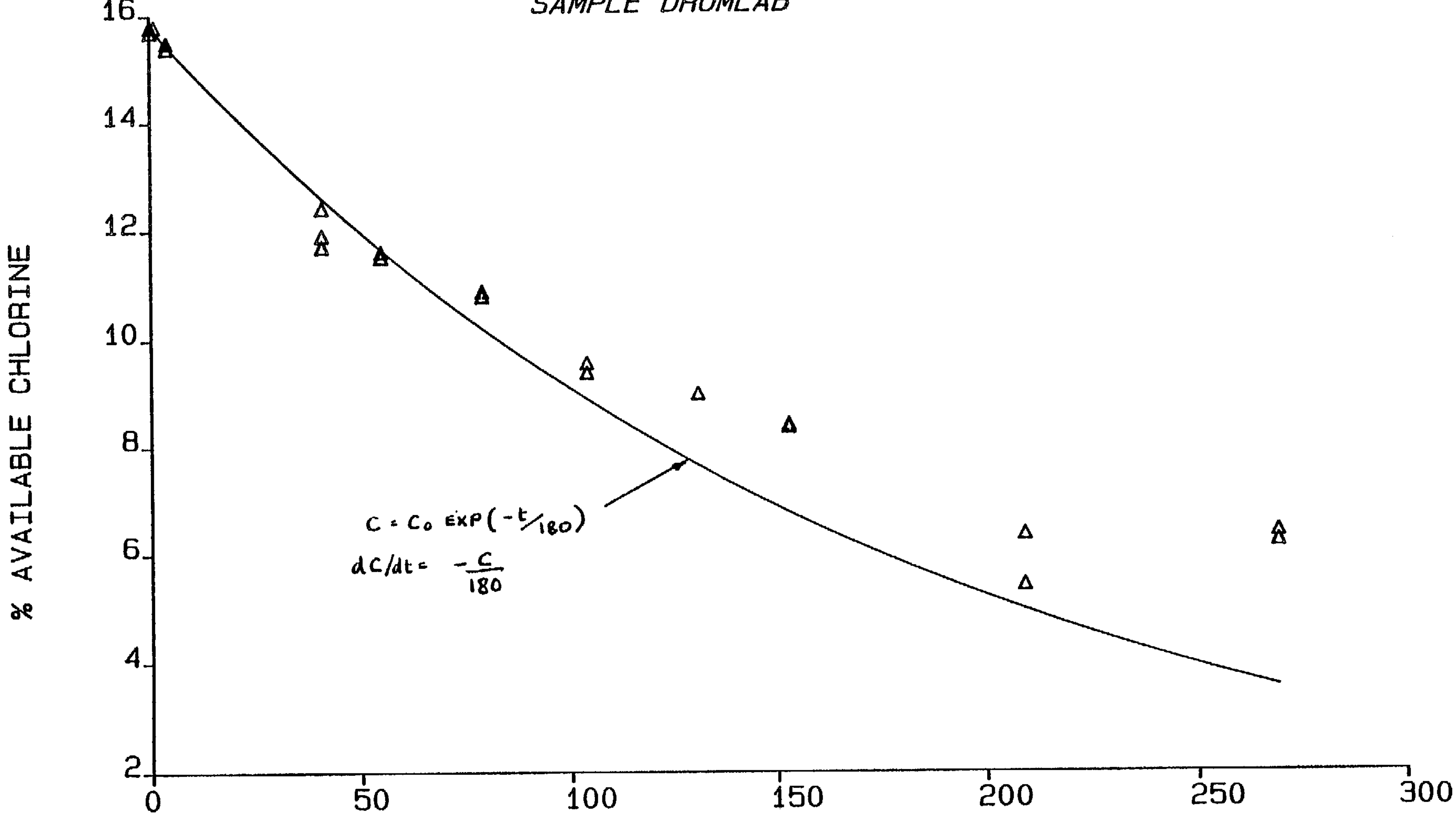
The data are tabulated in Table 3. From these, a graph was drawn of Ln (dC/dt) against Ln (C), (Fig 4). It was found that the graph was a straight line and the slope and intercept were found to be:

n = 2.75
k = 6.64 E-5

TABLE 3 SAMPLE DRUMLAB

| t | C | dC | dt | dC/dt | t' | c' | Ln (C) | Ln (dC/dt) |
|---|---|---|---|---|---|---|---|---|
| 0 | 15.70 | | | | | | | |
| | | 3.70 | 41 | 0.090 | 20.50 | 13.85 | 2.62 | -2.40 |
| 41 | 12.00 | | | | | | | |
| | | 0.85 | 14 | 0.061 | 48.00 | 11.98 | 2.48 | -2.79 |
| 55 | 11.55 | | | | | | | |
| | | 2.10 | 49 | 0.043 | 79.50 | 10.50 | 2.35 | -3.14 |
| 104 | 09.45 | | | | | | | |
| | | 3.15 | 165 | 0.019 | 186.5 | 7.88 | 2.06 | -3.96 |
| 269 | 06.30 | | | | | | | |

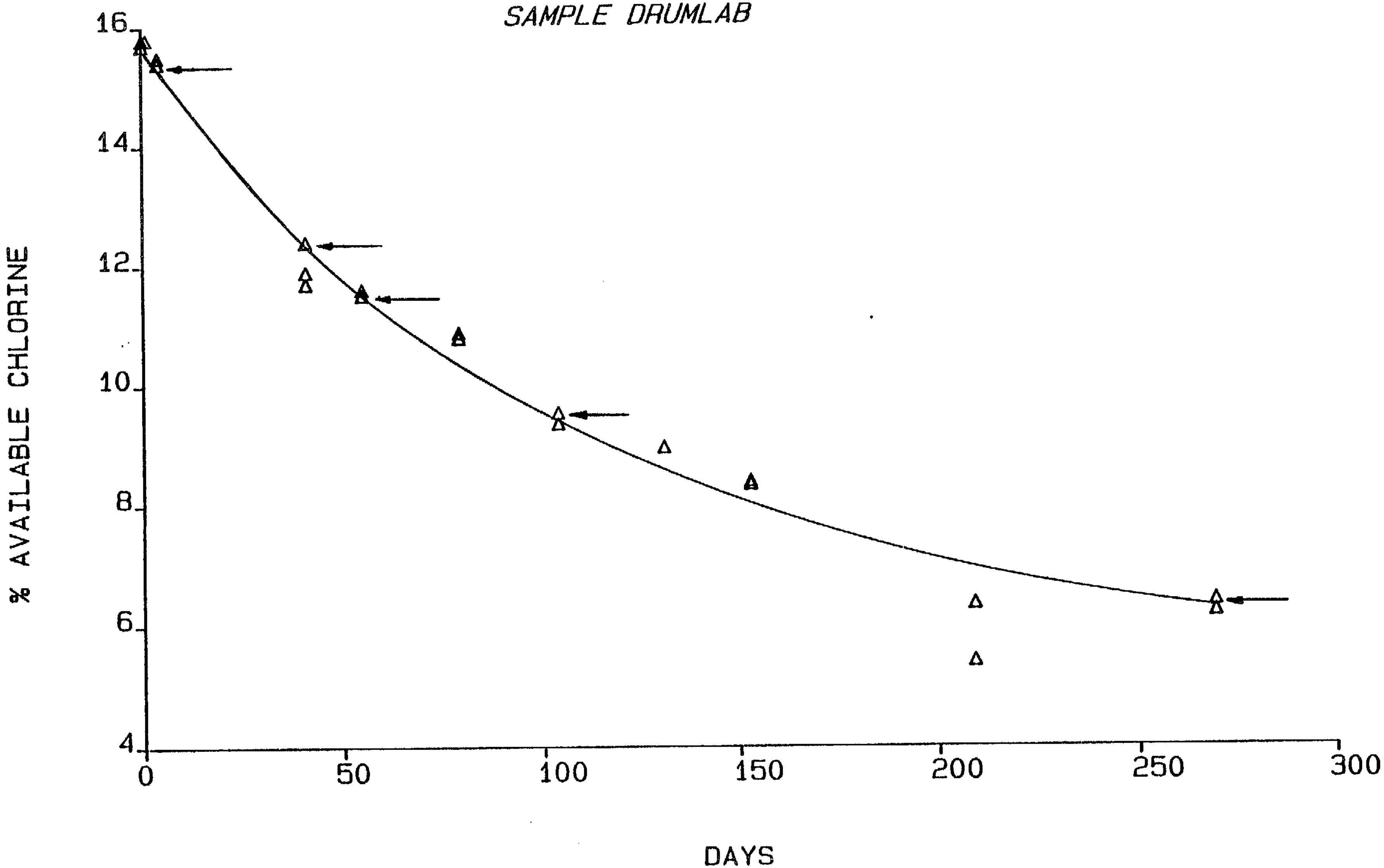
FIG 2 SODIUM HYPOCHLORITE SHELF LIFE
SAMPLE DRUMLAB




SHEPHERD 3-DEC-1986 14:14

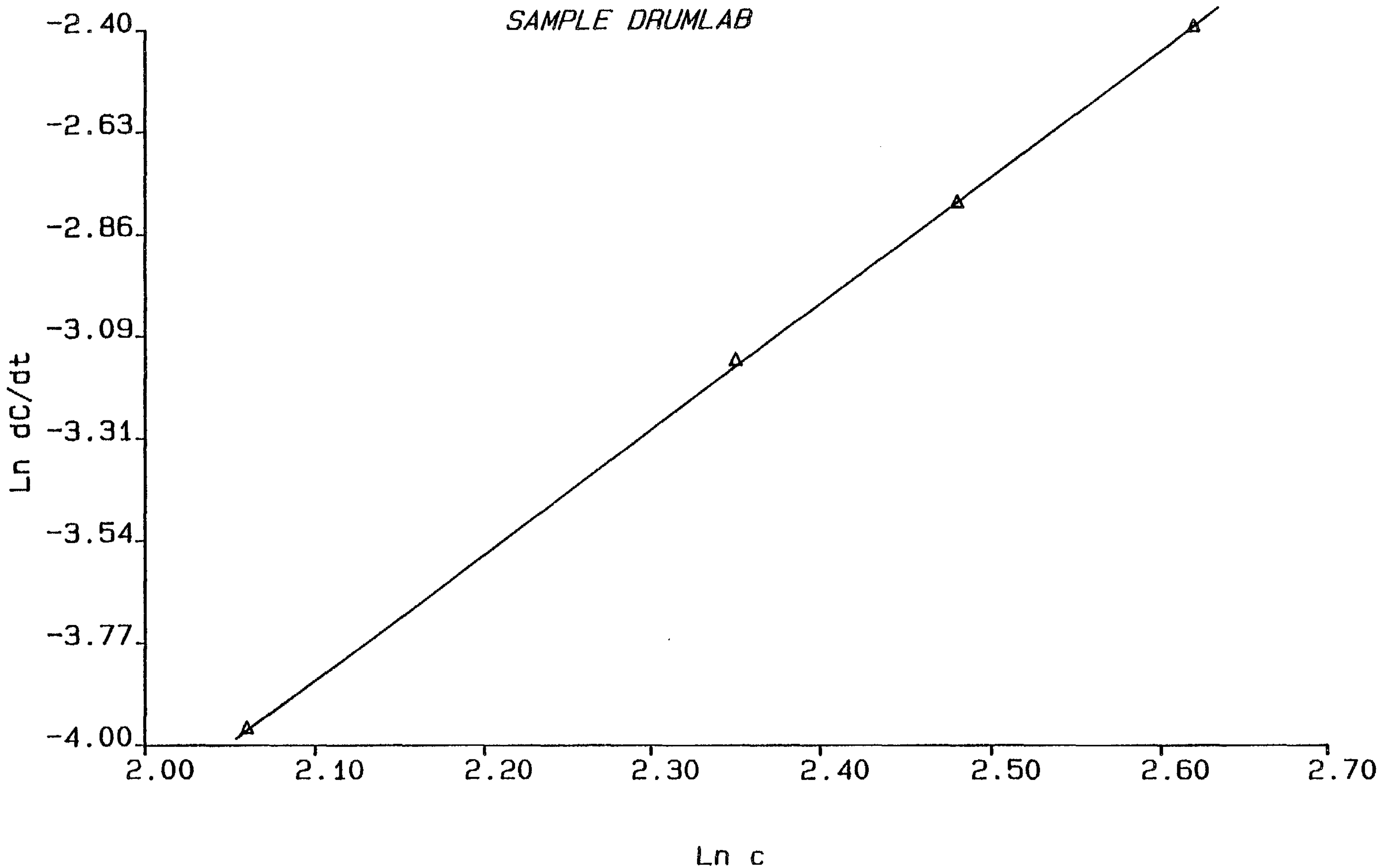
12.6

FIG 3 SODIUM HYPOCHLORITE SHELF LIFE
SAMPLE DRUMLAB




SHEPHERD 3-DEC-1986 14:00

FIG 4 DERIVATION OF MODEL PARAMETERS
SAMPLE DRUMLAB




SHEPHERD 3-DEC-1986 14:20

The following values of n and k were obtained for other samples:

TABLE 4 VALUES OF n AND k

| SAMPLE | n | k |
|---|---|---|
| DRUMLAB | 2.75 | 6.64E-5 |
| NAW | 2.65 | 1.04E-4 |
| NCDC | 3.70 | 5.50E-4 |
| 21DEIONCDC | 1.50 | 5.00E-4 |
| 10DEIONCDC | 12.75 | 1.40E-6 |
| 100DEIONCDC | 3.91 | 0.60 |

When the model for DRUMLAB was plotted against the experimental data, it was found to correspond closely (Fig 5). However, the values of n and k of the other samples appeared to vary widely and showed little pattern.

A sensitivity analysis was carried out on the values of n for one of the samples (DRUMLAB). The value of n was altered by +/-20% and the graphs of % available chlorine against the number of days were redrawn using the model as well as the altered values of n (Fig 6). It can be observed that altering the value of n did not cause much change in the shape of the curve.

Although a clear picture had not emerged and precise values of n and k had not been determined, it was obvious at least that decomposition was not first-order.

It was therefore postulated that some other compounds present in solution might be affecting the decomposition; perhaps hydroxyl ions. To check this, a number of samples were titrated with 0.02N hydrochloric acid to measure the hydroxyl ion concentration. The procedure was as follows.

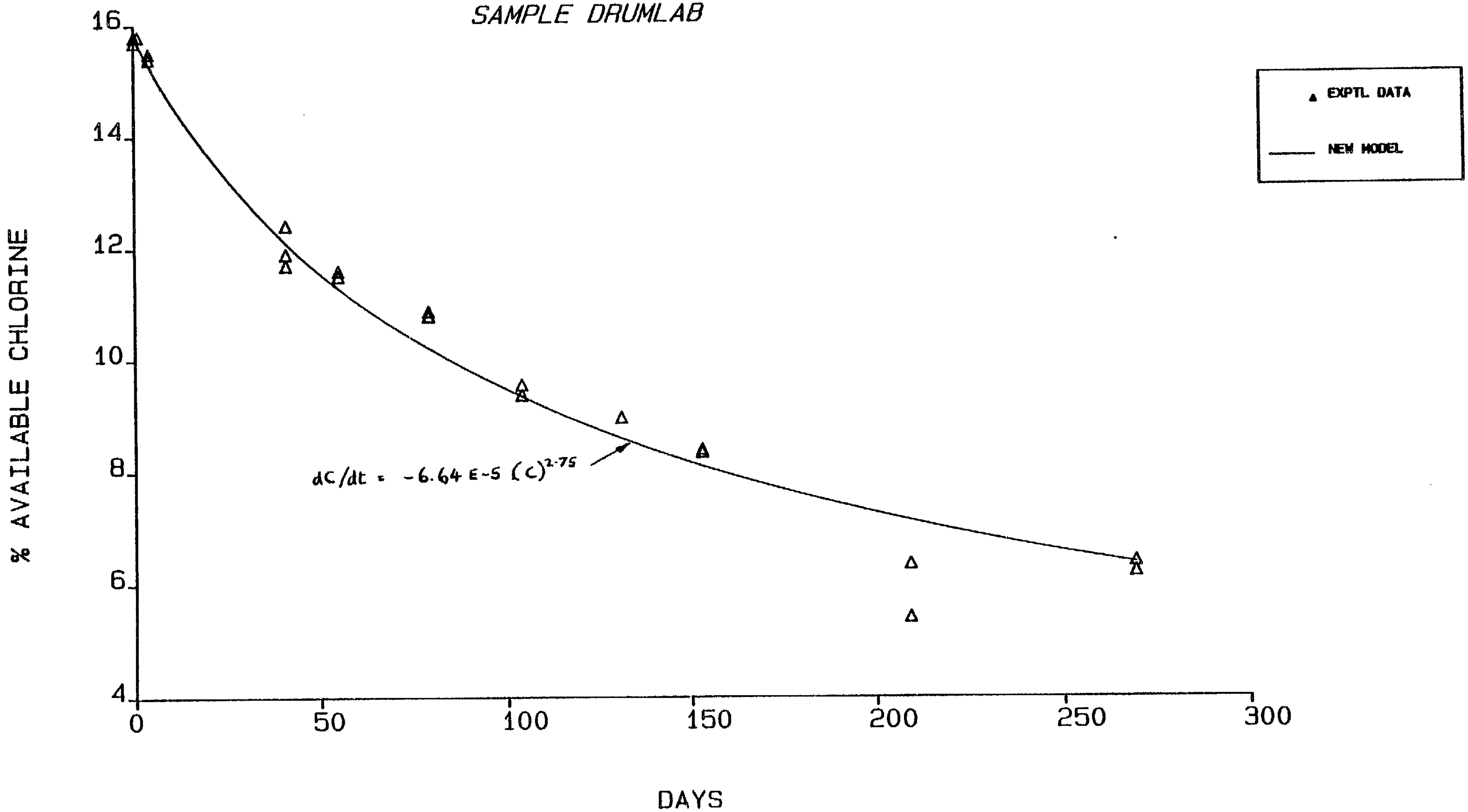
A 1 ml sample was diluted to 100ml and titrated with hydrochloric acid from the burette. A continuous plot of pH against volume of acid added was obtained. The graph for one of the samples is shown in Fig 7.

At an initial pH value of about 11, all the hypochlorite ions existed in the fully ionized form. The first addition of acid rapidly neutralized the excess hydroxyl ions to about 9.5. As more acid was added the change of pH became slower as the hypochlorite ions began to associate;

$$H^+ \quad + \quad OCl^- \quad \text{-------->} \quad HOCl$$

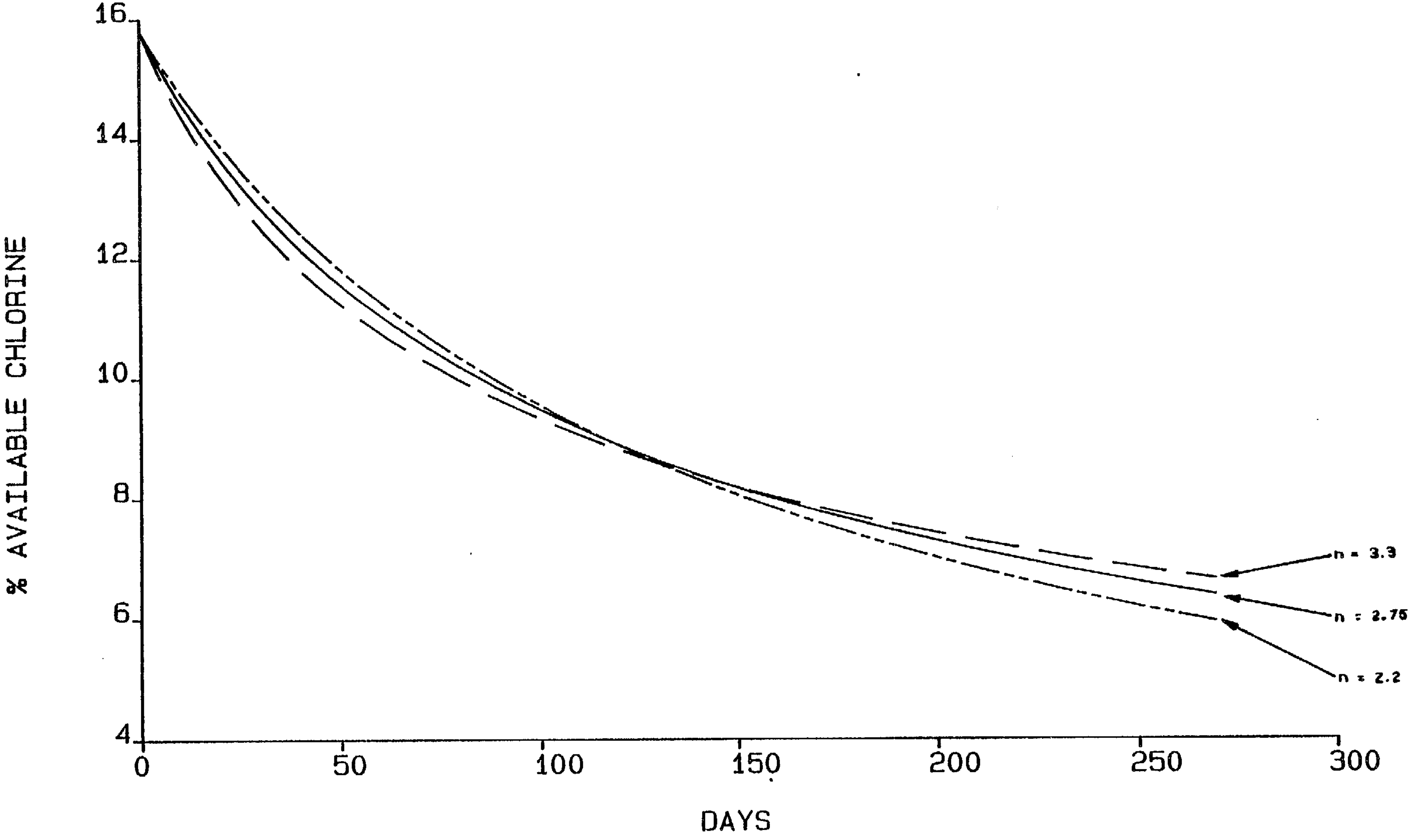
This continued to about pH 5 at which the hypochlorite was fully associated and the pH again changed quickly as further acid was added. The points of inflection were noted.

FIG 5 SODIUM HYPOCHLORITE SHELF LIFE
SAMPLE DRUMLAB




SHEPHERD 3-DEC-1986 14:26

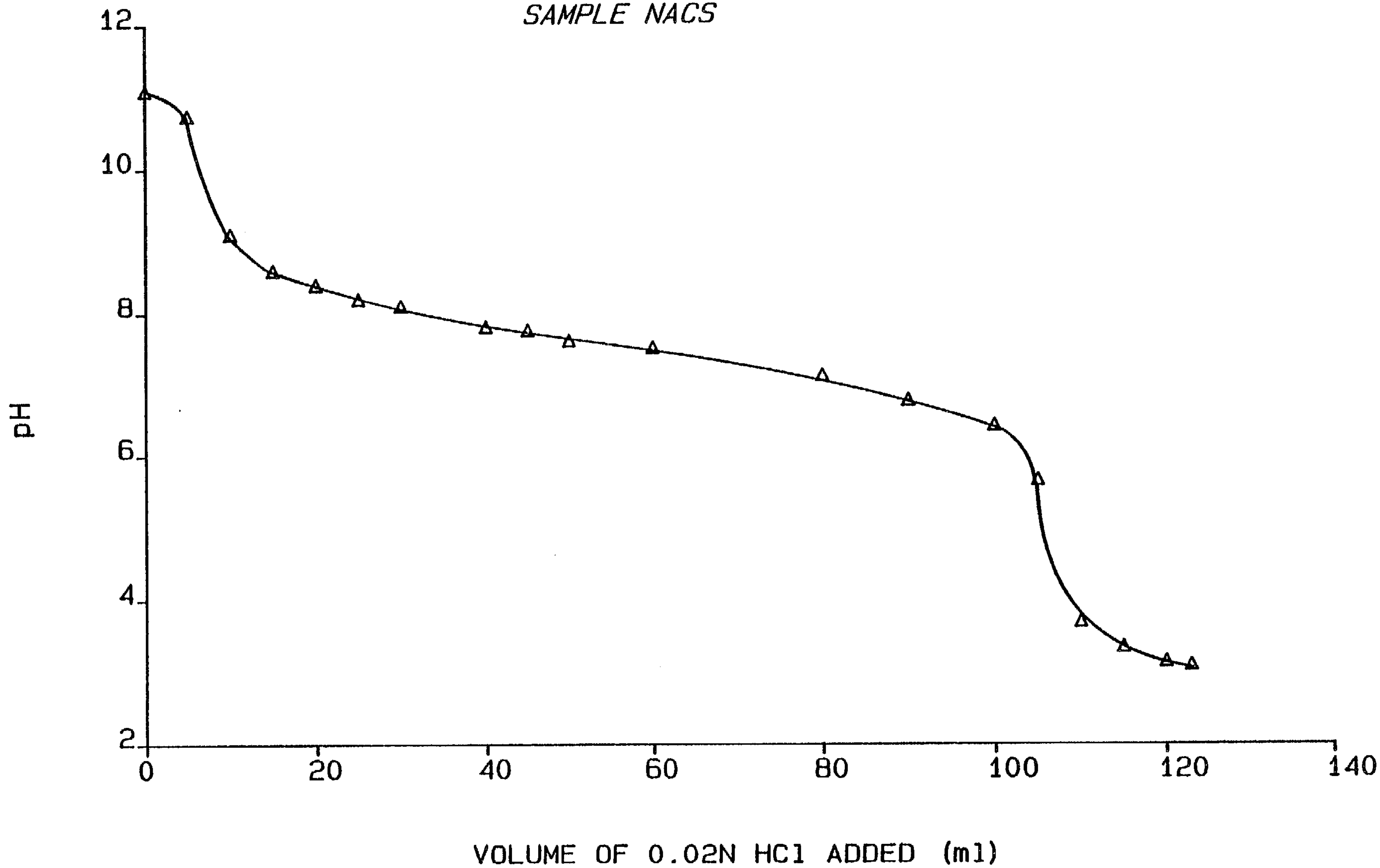
*FIG 6 SENSITIVITY OF MODEL*
*SAMPLE DRUMLAB*




SHEPHERD 8-DEC-1986 13:47

12·11

FIG 7 VARIATION OF pH WITH VOLUME OF ACID ADDED
SAMPLE NACS




SHEPHERD 3-DEC-1986 14:36

Table 5 lists the samples and their available chlorine contents. Against each is shown the acid addition to neutralise excess $OH^-$ to pH 9.5 (in terms of excess hydroxyl ion per litre) and that required to associate the hypochlorite to hypochlorous acid. The latter is expressed as equivalent % chlorine and it can be seen that these figures correspond closely with the chlorine contents measured by thiosulphate titration. This gave confidence in the results.

TABLE 5 TITRATION RESULTS

| SAMPLE | % AVAILABLE CHLORINE | EXCESS $OH^-$ to pH 9.5 (mg/l) | HOCL ASSOCIATED pH 9.5-5 (as Cl %) |
|---|---|---|---|
| NACS | 15.00 | 0.51 | 14.05 |
| NCDC | 6.85 | 2.53 | 06.29 |
| DRUMLAB | 6.30 | 2.60 | 05.33 |
| NAW | 5.92 | 1.73 | 05.33 |
| SBUSKLAB | 1.57 | 0.32 | 01.50 |

It was concluded that although all the samples had decayed to different levels, all had about same excess $OH^-$. Therefore decomposition did not appear to have generated or absorbed any acidity. It therefore seemed that $OH^-$ ions did not affect the decomposition rate.

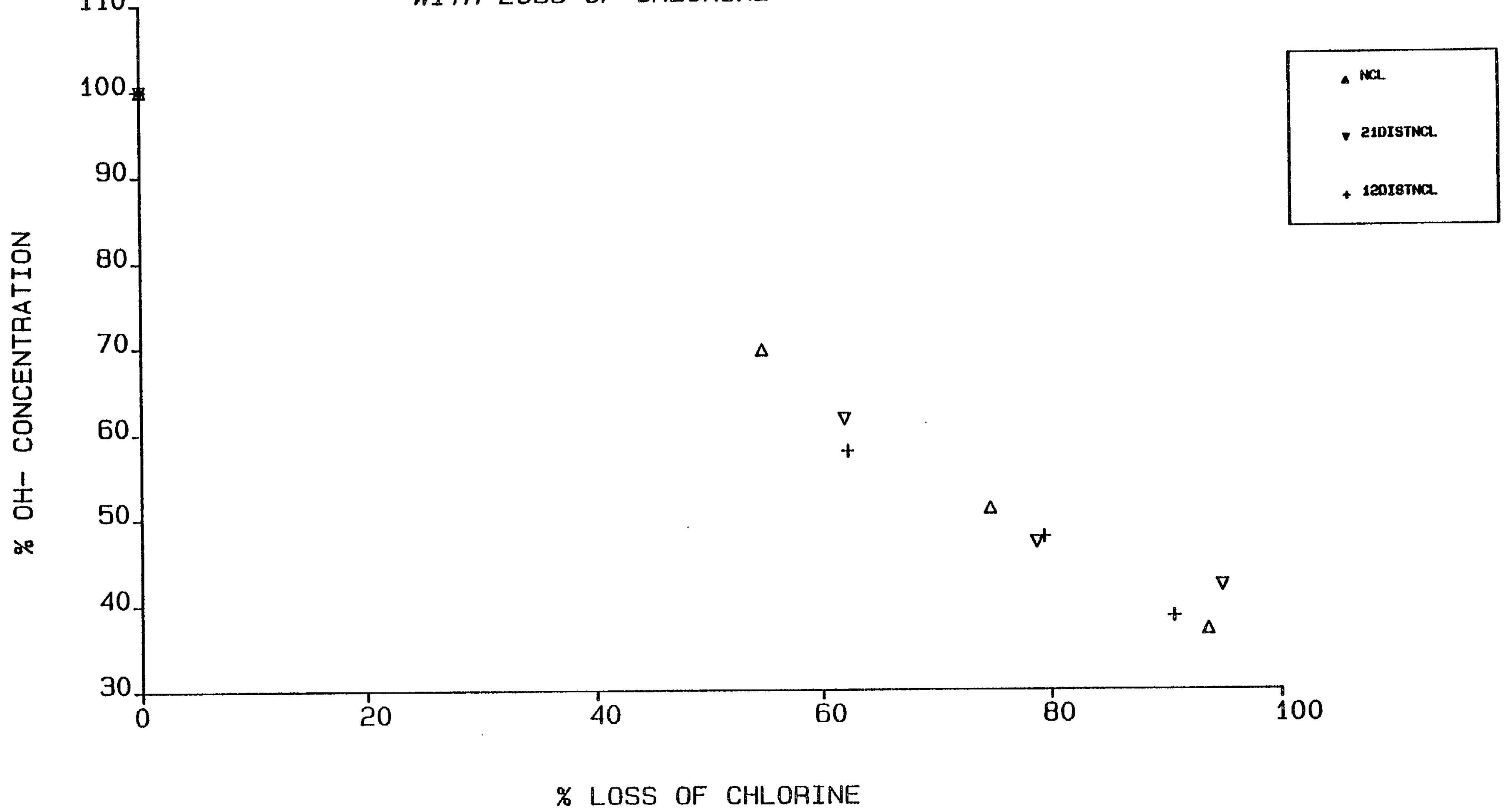
However, since all samples were 9 months old, there was no way of knowing whether the excess $OH^-$ concentration might have been affected by other influences. To eliminate this possibility, fresh samples were made up and were decomposed rapidly so that $OH^-$ ion concentration could be measured before and after the decomposition. They were made up of sodium hypochlorite from the drum in the cool store. Altogther, nine samples were prepared of three different concentrations: 15%.10% and 5%. Samples of each concentration were placed in:-

a) Direct Sunlight
b) Back of the laboratory
c) Cool store

After twenty four hours, a sample from each location was titrated with 0.02N hydrochloric acid. There had been little change in this time, and so further titrations were carried out after six, nine and twenty six days.

A graph was plotted of % $OH^-$ concentration against % loss of chlorine for the three samples placed in the sunlight (Fig 8). It can be observed from the graph that as the % loss of chlorine increases, there is a corresponding loss of hydroxyl ions from the solution. The three samples follow almost the same decomposition pattern.

*FIG 8 VARIATION OF HYDROXYL ION CONCENTRATION WITH LOSS OF CHLORINE*




17.14

It was thought that the decrease of hydroxyl ions is possibly the result of the hypochlorous acid in the solution decomposing to form hydrochloric acid and nascent oxygen. The hydrochloric acid formed combines with some of the hydroxyl ions in the neutralisation process.

It was felt that the high initial $OH^-$ concentration might mask small changes. To compensate for this effect, two more samples were made from the drum in the cool store. One of the samples was diluted to 1% of available chlorine while the other was left neat. The pH of both samples was brought down to approximately 8. Samples of exactly pH 8 were found to be difficult to make. Both samples were placed at the back of the lab and the % available chlorine with pH was measured after every ~~one~~ hour. The results are tabulated in Table 6.

TABLE 6 EFFECT OF DILUTION ON LOSS OF AVAILABLE CHLORINE

| | DILUTE SAMPLE | | NEAT SAMPLE | |
|---|---|---|---|---|
| TIME (HOUR) | % AVAILABLE CHLORINE | pH | % AVAILABLE CHLORINE | pH |
| 1 | 0.72 | 7.93 | 11.27 | 9.00 |
| 2 | 0.67 | 7.86 | 07.34 | 8.62 |
| 3 | 0.64 | 7.74 | 03.08 | 7.94 |

It can be observed from the above table that the pH and the % available chlorine both decrease with time. In the neat sample, the % available chlorine decreases by about 70% in three hours whereas in dilute samples the decrease is about 11%. The rapid loss of chlorine from the solution may have been due to the fact that at low pH, the concentration of chlorine in solution approaches saturation. At this point chlorine starts to come out of the solution. It can be observed from the above table that the amount of chlorine retained by the acidic solution of sodium hypochlorite is quite small. This test was inconclusive.

## Conclusions

This work has shown that if sodium hypochlorite solution, as delivered, is kept in a cool dark place, it will keep its strength for a period to be measured in months rather than days.

Even diluted solutions will keep well. Dilution with a natural water with some chlorine demand should have little effect on solution life.

It is exposure to light which is the main cause of loss of chlorine.

Although the decay was expected to be first-order, this was not so, and the deviation from first order over several months was significant. The tests showed that solutions of different strengths kept in different conditions decayed at different rates. It was not possible to identify the factors at work or in any other way to develop a model of decay which could be related to the conditions of storage. Thus, while it had been hoped to propose a system of "use-by" dating we do not yet have the scientific basis.

SODIUM HYPOCHLORITE SHELF LIFE TESTS RES1.DAT JULY 86

SAMPLE 1
NCW

| DAYS | % Cl |
|---|---|
| 0 | 16.200 |
| 0 | 15.700 |
| 1 | 14.500 |
| 1 | 14.900 |
| 1 | 15.400 |
| 4 | 12.000 |
| 4 | 12.000 |
| 8 | 10.700 |
| 13 | 8.200 |
| 13 | 8.000 |
| 36 | 1.600 |
| 53 | 0.550 |
| 74 | 0.275 |
| 74 | 0.249 |
| 98 | 0.231 |
| 98 | 0.240 |
| 132 | 0.288 |
| 132 | 0.235 |
| 201 | 0.133 |

SAMPLE 2
10DEIONCW

| DAYS | % Cl |
|---|---|
| 0 | 1.640 |
| 1 | 1.600 |
| 4 | 1.070 |
| 4 | 1.150 |
| 8 | 0.620 |
| 8 | 0.670 |
| 13 | 0.580 |
| 13 | 0.540 |
| 36 | 0.140 |
| 53 | 0.040 |
| 74 | 0.020 |
| 98 | 0.023 |
| 132 | 0.023 |

SAMPLE 3
100DEIONCW

| DAYS | % Cl |
|---|---|
| 0 | 0.1580 |
| 1 | 0.1380 |
| 4 | 0.0900 |
| 13 | 0.0070 |
| 36 | 0.0050 |
| 53 | 0.0030 |
| 74 | 0.0030 |
| 98 | 0.0039 |
| 132 | 0.0044 |

SAMPLE 4
21DIONCW

| DAYS | % Cl |
|---|---|
| 0 | 10.800 |
| 0 | 10.300 |
| 1 | 9.300 |
| 1 | 10.800 |
| 1 | 10.400 |
| 4 | 8.650 |
| 4 | 8.390 |
| 8 | 7.900 |
| 8 | 8.000 |
| 13 | 6.100 |
| 13 | 5.900 |
| 36 | 2.000 |
| 53 | 0.830 |
| 53 | 0.810 |
| 74 | 0.440 |
| 74 | 0.400 |
| 98 | 0.230 |
| 98 | 0.210 |
| 132 | 0.180 |
| 132 | 0.190 |
| 201 | 0.110 |

SAMPLE 5
10DISTCW

| DAYS | % Cl |
|---|---|
| 0 | 1.780 |
| 0 | 1.640 |
| 1 | 1.460 |
| 4 | 1.200 |
| 4 | 1.290 |
| 8 | 0.620 |
| 13 | 0.570 |
| 53 | 0.050 |
| 74 | 0.047 |
| 98 | 0.020 |
| 132 | 0.023 |
| 201 | 0.018 |

SAMPLE 6
NAW

| DAYS | % Cl |
|---|---|
| 0 | 15.700 |
| 0 | 16.200 |
| 1 | 13.900 |
| 1 | 15.800 |
| 1 | 16.300 |
| 4 | 15.700 |
| 8 | 14.700 |
| 8 | 15.000 |
| 36 | 11.800 |
| 53 | 10.700 |
| 53 | 10.800 |
| 74 | 10.000 |
| 74 | 9.200 |
| 98 | 9.300 |
| 98 | 9.500 |
| 132 | 8.800 |
| 132 | 8.700 |
| 151 | 7.700 |
| 201 | 6.800 |
| 260 | 5.900 |
| 260 | 5.900 |

SAMPLE 7
10DEIONAW

| DAYS | % Cl |
|---|---|
| 0 | 1.640 |
| 0 | 1.730 |
| 1 | 1.380 |
| 1 | 1.550 |
| 4 | 1.730 |
| 8 | 1.730 |
| 8 | 1.780 |
| 36 | 1.570 |
| 53 | 1.580 |
| 53 | 1.550 |
| 74 | 1.620 |
| 74 | 1.440 |
| 98 | 1.570 |
| 98 | 1.550 |
| 132 | 1.570 |
| 132 | 1.580 |
| 201 | 1.420 |
| 201 | 1.590 |
| 266 | 1.520 |
| 266 | 1.550 |

SAMPLE 8
100DEIONAW

| DAYS | % Cl |
|---|---|
| 0 | 0.156 |
| 1 | 0.140 |
| 4 | 0.150 |
| 8 | 0.158 |
| 36 | 0.155 |
| 53 | 0.160 |
| 74 | 0.159 |
| 98 | 0.173 |
| 132 | 0.169 |
| 201 | 0.155 |
| 266 | 0.162 |

SAMPLE 9
21DEIONAW

| DAYS | % Cl |
|---|---|
| 0 | 9.800 |
| 0 | 10.900 |
| 1 | 10.250 |
| 1 | 10.100 |
| 4 | 10.500 |
| 8 | 10.400 |
| 8 | 10.500 |
| 36 | 9.600 |
| 53 | 9.400 |
| 53 | 9.300 |
| 74 | 9.140 |
| 74 | 9.050 |
| 98 | 8.250 |
| 98 | 8.920 |
| 201 | 7.280 |
| 201 | 7.320 |
| 261 | 7.100 |
| 261 | 6.660 |

SAMPLE 10
10DISTAW

| DAYS | % Cl |
|---|---|
| 0 | 1.640 |
| 1 | 1.640 |
| 8 | 1.780 |
| 8 | 1.690 |
| 36 | 1.510 |
| 36 | 1.530 |
| 53 | 1.580 |
| 53 | 1.540 |
| 74 | 1.520 |
| 74 | 1.570 |
| 98 | 1.600 |
| 132 | 1.570 |
| 132 | 1.580 |
| 201 | 1.590 |
| 201 | 1.600 |
| 260 | 1.580 |

SAMPLE 11
NCDC

| DAYS | % Cl |
|---|---|
| 0 | 15.100 |
| 1 | 15.400 |
| 1 | 15.100 |
| 4 | 15.600 |
| 4 | 15.000 |
| 8 | 15.400 |
| 13 | 14.300 |
| 13 | 14.400 |
| 36 | 12.000 |
| 36 | 12.100 |
| 55 | 11.600 |
| 75 | 10.600 |
| 75 | 10.500 |
| 99 | 10.000 |
| 99 | 9.900 |
| 133 | 9.700 |
| 133 | 9.600 |
| 153 | 8.700 |
| 209 | 7.700 |
| 209 | 7.600 |
| 269 | 6.600 |
| 269 | 7.100 |

SAMPLE 12
10DEIONCDC

| DAYS | % Cl |
|---|---|
| 0 | 1.730 |
| 1 | 1.640 |
| 4 | 1.690 |
| 8 | 1.630 |
| 13 | 1.580 |
| 13 | 1.560 |
| 36 | 1.550 |
| 36 | 1.530 |
| 56 | 1.590 |
| 56 | 1.600 |
| 79 | 1.630 |
| 79 | 1.530 |
| 99 | 1.650 |
| 99 | 1.620 |
| 133 | 1.590 |
| 133 | 1.550 |
| 209 | 1.580 |
| 209 | 1.560 |
| 270 | 1.600 |
| 270 | 1.580 |

SAMPLE 13
100DEIONCDC

| DAYS | % Cl |
|---|---|
| 0 | 0.161 |
| 1 | 0.155 |
| 4 | 0.149 |
| 8 | 0.156 |
| 13 | 0.156 |
| 36 | 0.155 |
| 55 | 0.161 |
| 75 | 0.161 |
| 99 | 0.161 |
| 99 | 0.160 |
| 133 | 0.150 |
| 210 | 0.126 |
| 269 | 0.115 |

SAMPLE 14
21DEIONCDC

| DAYS | % Cl |
|---|---|
| 0 | 10.700 |
| 1 | 10.700 |
| 4 | 10.600 |
| 18 | 10.600 |
| 24 | 10.120 |
| 36 | 9.700 |
| 56 | 9.500 |
| 76 | 9.400 |
| 98 | 8.750 |
| 136 | 8.700 |
| 152 | 8.220 |
| 208 | 7.600 |
| 270 | 7.000 |

SAMPLE 15
21DEIONCDC

| DAYS | % Cl |
|---|---|

SAMPLE 16
NACS

| DAYS | % Cl |
|---|---|
| 0 | 16.300 |
| 1 | 14.700 |
| 4 | 15.750 |
| 4 | 15.500 |
| 8 | 16.400 |
| 36 | 15.100 |
| 55 | 15.600 |
| 55 | 15.700 |
| 75 | 15.980 |
| 75 | 15.540 |
| 104 | 15.270 |
| 104 | 14.910 |
| 133 | 15.220 |
| 203 | 14.470 |
| 203 | 14.560 |
| 263 | 15.440 |
| 263 | 14.470 |

SAMPLE 17
10DEIONACS

| DAYS | % Cl |
|---|---|
| 0 | 1.690 |
| 1 | 1.640 |
| 4 | 1.600 |
| 4 | 1.550 |
| 8 | 1.580 |
| 36 | 1.540 |
| 55 | 1.600 |
| 79 | 1.580 |
| 104 | 1.580 |
| 104 | 1.570 |
| 131 | 1.570 |
| 131 | 1.560 |
| 151 | 1.690 |
| 151 | 1.710 |
| 213 | 1.620 |
| 273 | 1.570 |
| 273 | 1.600 |

SAMPLE 18
100DEIONACS

| DAYS | % Cl |
|---|---|
| 0 | 0.162 |
| 1 | 0.154 |
| 4 | 0.138 |
| 8 | 0.155 |
| 36 | 0.154 |
| 55 | 0.161 |
| 75 | 0.159 |
| 104 | 0.159 |
| 131 | 0.158 |
| 203 | 0.157 |
| 263 | 0.162 |

SAMPLE 19
21DEIONACS

| DAYS | % Cl |
|---|---|
| 0 | 11.000 |
| 1 | 9.000 |
| 8 | 10.700 |
| 36 | 10.400 |
| 55 | 10.700 |
| 55 | 10.800 |
| 79 | 10.600 |
| 104 | 10.400 |
| 104 | 10.300 |
| 131 | 10.500 |
| 131 | 10.500 |
| 203 | 10.200 |
| 203 | 10.100 |
| 263 | 9.800 |
| 263 | 10.200 |

SAMPLE 20
10DISTACS

| DAYS | % Cl |
|---|---|
| 0 | 2.000 |
| 1 | 1.600 |
| 4 | 1.640 |
| 4 | 1.600 |
| 8 | 1.590 |
| 36 | 1.500 |
| 55 | 1.600 |
| 55 | 1.610 |
| 79 | 1.650 |
| 104 | 1.600 |
| 131 | 1.590 |
| 131 | 1.630 |
| 203 | 1.680 |
| 203 | 1.660 |
| 263 | 1.590 |
| 263 | 1.580 |

SAMPLE 21
DRUMLAB

| DAYS | % Cl |
|---|---|
| 0 | 15.800 |
| 0 | 15.700 |
| 1 | 15.800 |
| 4 | 15.400 |
| 4 | 15.500 |
| 41 | 12.400 |
| 41 | 11.700 |
| 41 | 11.900 |
| 55 | 11.500 |
| 55 | 11.600 |
| 79 | 10.780 |
| 79 | 10.870 |
| 104 | 9.540 |
| 104 | 9.360 |
| 131 | 8.960 |
| 153 | 8.390 |
| 153 | 8.340 |
| 209 | 5.410 |
| 209 | 6.350 |
| 269 | 6.210 |
| 269 | 6.390 |

SAMPLE 22
DRUMCOOL

| DAYS | % Cl |
|---|---|
| 0 | 16.800 |
| 1 | 16.200 |
| 4 | 16.200 |
| 4 | 16.200 |
| 41 | 15.900 |
| 41 | 15.800 |
| 55 | 16.300 |
| 55 | 16.200 |
| 79 | 16.000 |
| 79 | 16.000 |
| 104 | 15.500 |
| 104 | 15.600 |
| 121 | 15.600 |
| 121 | 15.600 |
| 153 | 15.700 |
| 153 | 15.700 |
| 209 | 14.600 |
| 209 | 14.800 |
| 269 | 14.200 |
| 269 | 14.300 |

SAMPLE 23
SBUSKDC

| DAYS | % Cl |
|---|---|

SAMPLE 24
SBUSKLA

| DAYS | % Cl |
|---|---|
| 0 | 1.620 |
| 0 | 1.590 |
| 32 | 1.480 |
| 59 | 1.420 |
| 59 | 1.420 |
| 79 | 1.390 |
| 79 | 1.420 |
| 132 | 1.320 |
| 132 | 1.330 |
| 194 | 1.350 |
| 194 | 1.330 |
| 197 | 1.110 |
| 197 | 1.180 |

pH TITRATIONS RES2.DAT JULY 86

SAMPLE

| 10DEIONCDC VOL 0.02N HCl (ml) | pH |
|---|---|
| 0 | 10.15 |
| 4 | 9.48 |
| 8 | 8.97 |
| 9 | 8.86 |
| 10 | 8.80 |
| 12 | 8.67 |
| 15 | 8.54 |
| 20 | 8.36 |
| 25 | 8.20 |
| 30 | 8.08 |
| 40 | 7.88 |
| 50 | 7.70 |
| 60 | 7.54 |
| 70 | 7.37 |
| 80 | 7.20 |
| 90 | 6.99 |
| 100 | 6.69 |
| 110 | 6.19 |
| 115 | 5.54 |
| 120 | 3.82 |
| 130 | 3.21 |
| 140 | 2.97 |

| NAW VOL 0.02N HCl (ml) | pH |
|---|---|
| 0 | 11.10 |
| 2 | 10.89 |
| 4 | 10.51 |
| 6 | 9.90 |
| 8 | 9.12 |
| 10 | 8.64 |
| 12 | 8.39 |
| 14 | 8.21 |
| 15 | 8.13 |
| 20 | 7.81 |
| 25 | 7.55 |
| 30 | 7.30 |
| 35 | 6.98 |
| 40 | 6.54 |
| 45 | 4.87 |
| 50 | 3.40 |
| 55 | 3.10 |
| 60 | 2.94 |
| 65 | 2.83 |

| DRUMLAB VOL 0.02N HCl (ml) | pH |
|---|---|
| 0 | 11.21 |
| 1 | 11.16 |
| 2 | 11.05 |
| 3 | 10.97 |
| 4 | 10.84 |
| 5 | 10.62 |
| 6 | 10.35 |
| 7 | 10.02 |
| 8 | 9.57 |
| 9 | 9.13 |
| 10 | 8.85 |
| 11 | 8.65 |
| 12 | 8.51 |
| 13 | 8.39 |
| 14 | 8.31 |
| 15 | 8.23 |
| 16 | 8.15 |
| 17 | 8.09 |
| 18 | 8.02 |
| 19 | 7.97 |
| 20 | 7.92 |

VARIATION OF OH CONC WITH LOSS OF Cl RES3.DAT JULY 86

| DAYS | SAMPLE | LOCATION | VOL HCl TO pH9 (ml) | VOL HCl TO pH5 (ml) |
|---|---|---|---|---|
| 1 | NEAT | Cool store | 22.75 | 108.00 |
| 1 | NEAT | Back lab | 21.60 | 108.50 |
| 1 | NEAT | Sun light | 21.75 | 104.50 |
| 1 | 21DIST | Cool store | 14.85 | 72.75 |
| 1 | 21DIST | Back lab | 15.00 | 72.00 |
| 1 | 21DIST | Sun light | 14.25 | 70.25 |
| 1 | 12DIST | Cool store | 6.85 | 34.55 |
| 1 | 12DIST | Back lab | 7.00 | 35.50 |
| 1 | 12DIST | Sun light | 6.50 | 33.20 |
| 6 | NEAT | Cool store | 22.30 | 113.00 |
| 6 | NEAT | Back lab | 22.25 | 109.00 |
| 6 | NEAT | Sun light | 15.30 | 52.75 |
| 6 | 21DIST | Back lab | 15.00 | 75.00 |
| 6 | 21DIST | Sun light | 8.75 | 30.75 |
| 6 | 12DIST | Sun light | 3.75 | 13.82 |
| 26 | NEAT | Cool store | 22.00 | 108.00 |
| 26 | NEAT | Back lab | 21.70 | 100.00 |
| 26 | NEAT | Sun light | 8.00 | 13.30 |
| 26 | 21DIST | Sun light | 6.00 | 9.00 |
| 26 | 12DIST | Sun light | 2.00 | 4.50 |

WRc ENGINEERING
PO Box 85
Frankland Road
Blagrove, Swindon
Wilts. SN5 8YR
Tel: Swindon (0793) 488301
Telex: 449541

WRc ENVIRONMENT
Medmenham Laboratory
Henley Road, Medmenham
PO Box 16 Marlow
Bucks. SL7 2HD
Tel: Henley (0491) 571531
Telex: 848632

WRc (Headquarters)
John L van der Post Building
Henley Road, Medmenham
PO Box 16 Marlow
Bucks. SL7 2HD
Tel: Henley (0491) 571531
Telex: 848632

WRc PROCESSES
Stevenage Laboratory
Elder Way
Stevenage, Herts.
SG1 1TH
Tel: Stevenage (0438) 312444
Telex: 826168

WRc SCOTTISH OFFICE
1 Snowdon Place
Stirling FK8 2NH
Tel: Stirling (0786) 71580

WRc Inc
11 Kings Oak Lane
Philadelphia
PA 19115
USA

WRc WATER BYELAWS ADVISORY SERVICE
660 Ajax Avenue
Slough, Bucks.
SL1 4BG
Tel: Slough (0753) 37277
Telex: 449541

Registered Offices:

WRc
WRc CONTRACTS
CABLETIME INSTALLATIONS LTD
Henley Road, Medmenham
PO Box 16 Marlow
Bucks. SL7 2HD
Tel: Henley (0491) 571531
Telex: 848632