University of
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Design for Plastic Hand Pump and Well

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DESIGN FOR PLASTIC HAND PUMP AND WELL

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SUMMARY

This project was intended for the design and preliminary testing of simple, maintenance-free hand pumps for rural water supplies. A design was engineered to used modern plastics materials and manufacturing methods which are within the capabilities of most less developed countries.

The basic parts of the unit involve a PVC well casing which also functions as the pump cylinder for a plastic piston. The plastic foot valve is constructed of components which are common with the piston. The flow of water in the piston and foot valve is regulated by simple rubber plate valves.

Polyethylene piston rings provide adequate hydraulic seals on the piston with much less frictional resistance than leather cups or rings. Wear is concentrated on the rings, which are easily replaced, rather than on the well casing. The foot valve can be removed readily for inspection or repair.

Most of the unit is made of plastic parts which are standard size extrusions. The remainder are easily injection molded or machined from stock items. Repairs should be relatively rare and easily made in the field.

RECOMMENDATIONS

1) A plate valve arrangement should be used as a final design for the piston and recoverable foot valve. While giving maximum efficiency this setup also maintains a high degree of simplicity. Rubber should be used as the plate. One or two polyethylene piston rings can be used with very little change in efficiency.

2) Leather cups while displaying excellent sealing properties, should not be used in wells deeper than 30 m.

3) The total possible flow area past the valve should be at least 1/10 the total cross sectional area of the piston. This would amount to eight holes 0.6 cm in diameter if the piston is 5 cm in diameter. This helps reduce flow resistance and reduce work input on the downward stroke.

4) A 1.9 cm PVC pipe may be used as the pump rod down to depths of 30 m in wells of 7.6 cm diameter. This limit is determined by the fatigue strength. When PVC pipe is used it should be joined using adhesives and a load limiting device attached to the top of the pump rod so that any failures present no serious problems.

CONCLUSIONS

1) There is very little difference between the hydraulic efficiencies of pistons with one or two rings. Various combinations of seals between the piston and well casing or foot valve and casing give good pumping efficiencies. A dramatic loss of efficiency occurs when no rings are used.

2) Polyethylene rings will wear preferentially on a PVC casing resulting in a desirable conbination since the rings may be easily replaced.

3) Leather rings or cups offer very high resistance to piston travel at depths greater than 30 m.

4) The ball valve is too unpredictable at depths above 24 m.

5) Plate valves exhibited the simplicity and high efficiency required. Leather and rubber plate valves displayed desirable properties for use as a plate valve.

6) A piston and foot valve of similar design has been successfully tested.

7) It is possible to use a 1.9 cm PVC pipe as the pump rod. However the fatigue strength of this material limits the well depth to 30 m.

1. GENERAL DESCRIPTION

This report is a summary extracted from two earlier reports in which separate consideration was given to the use of plastic well casings for rural water supplies (1) and to design of a hand-operated pump to operate in such casings (2). Only those matters which bear directly on the well and pump design which we recommend have been included in the present summary. Readers are referred to the original documents for material which deals more generally with pumps for rural water.

Figure 1 (in the flap on the cover of this report) is an assembly and detail print of the recommended pump and well. A general overview of the concepts of this design is reported first and this is followed by details of the various components.

Many different pump designs have been considered over the course of human history. The rate at which a human being can lift water from a given depth is limited entirely by this depth and the power of the operator. (See Appendix A). No pump can exceed this limit so long as a human operator supplies the motive power but various pumps may vary in efficiency within this bound. The piston pump reported here appears to provide a very good balance of low initial cost, reliability, ease of repair, efficiency and ease of operation.

The well and pump have been engineered to take advantage of the performance and cost advantages of modern materials and production methods. The pump recommended here is simple in concept. Studies under simulated use conditions have shown that it is reliable and easy to operate. Any repairs which may be necessary are easily made. The entire assembly is readily removed and replaced in the well. There are no important corrodible components and wear is localized to inexpensive, simple components. This appears also to be a relatively inexpensive pump design if advantage is taken of the availability of stock plastic parts.

Almost all the components are made of plastic materials. These have been selected for ease of manufacture and low cost, as well as for their efficiency in this application. Many of these parts are standard size, extruded items which are provided by many plastics suppliers. The relatively few special shapes which are required can all be injection molded quite easily. None of the moldings are complicated. All the recommended plastic parts are based on rigid poly(vinyl chloride) (PVC) or polyethylene. Both are low-cost commodity polymers. Exotic materials have been avoided.

It would be impossible to provide a universal design which uses strictly indigenous materials, since such products vary from country to country. The authors believe that local craftsmen should have little difficulty in understanding the operation of the pump and effecting repairs, when these are necessary, with alternative materials which may be at hand.

The pump design is particularly suitable for depths up to about 30 m. The lever system is intended to limit the pumping force to about 15 kilograms. Deeper wells should use smaller diameter casings so that the weight of water on the piston will not be excessive. The modifications for deeper well designs will be readily apparent and are not discussed in this report.

The pump employs a submerged piston with piston ring hydraulic seals. All these components are made of plastic and most are fabricated from stock shapes which are available wherever a plastics fabricating industry exists.

The piston rings function as dynamic seals. If the piston is lifted at the normal rates used in pumping water the ring provides a good hydraulic seal. Water can drain past the ring, however, if the piston is lifted very slowly. Thus, the piston and attached pump rod can be raised slowly by hand even if they support a high column of water. No special equipment or strength are needed to withdraw the piston for inspection or repair.

Plastic pump rods are used in this recommended design. This construction is less expensive than alternative metal or wooden rods. The plastic rod can be made neutrally bouyant and the suggested construction eliminates all problems with uncoupling or corrosion of the alternative pump rods. The plastic rod is sufficiently flexible that continuous lengths of 30 or more metres can be pulled out and reinstalled in a well by simply allowing the rod to flop over onto the ground. No rig or stand is needed to support long rods above the well.

The recommended plastic pump rod has been tested under short term loads corresponding to water loads in 7.6 cm pipes at well depths as great as 60 metres. This is probably as deep a water well as can be pumped manually. We have not had time to determine the fatigue resistance of the material under prolonged cyclic loading, however. Conservative calculations indicate that 30 metres in a 7.6 cm casing is probably a limit until more extensive usage experience has been acquired.

A simple modification of the standard piston serves as the foot valve in this design. The foot valve may be glued into the recommended PVC well casing. A preferable modification employs a removable foot valve, however. This is accomplished by seating the piston in a polyethylene cup seal. The friction of the polyethylene against the PVC casing is such that the foot valve provides an excellent hydraulic seal but is not so high that the valve assembly cannot be lifted out of the well without problems. A leather seal cup would provide a hydraulic seal which is at least as good as that provided by the polyethylene cup but the foot valve with the leather seal could not be pulled out of the well without the exercise of a great deal of force. The provision of PVC well casing and a polyethylene cup seal around the foot valve gives just the right balance between good hydraulic efficiency and ease of removal for inspection or repair. The polyethylene cup seal would have to be injection molded or cut from the bottoms of polyethylene bottles whose diameters match that of the well casing.

The above-ground assembly is also largely based on plastic and wooden components. There is probably some possibility for adaption of this part of the well to take advantage of local materials and skills. The below-ground components should not be altered from those recommended without serious consideration of all the possible consequences of such departures from the tested balance of costs and function.

The pump is based primarily on items which are "off-the-shelf", at least in countries with moderately developed plastics industries. Replacement parts are readily available in international markets and specialty items like metal castings are not used. Special plastic shapes are preferably injection molded. In emergencies, however, these can be machined or cut from stock shapes of plastics.

Although this report considers the pump operating in a new well, it is obvious that it can be adapted in a straightforward fashion to replace all or some parts of pumps which are in disuse on existing wells.

2. PLAN OF THIS REPORT

Details of the various components in the recommended final design given in Figure 1 are described first. Later sections of the report give experimental results which led to and support this design choice. Where appropriate, descriptions are given of alternative components which may be equally satisfactory under some circumstances or which have been found to be deficient compared to the preferred design.

3. PLASTIC WELL CASINGS (1)

A pump consisting of a submerged piston in a well casing which functions also as the pump cylinder provides the advantages of low initial cost, durability and ease of maintenance and repair. General advantages of plastic over metal pipe include cost savings, ease of transportation and corrosion resistance. Plastic pipe can be made in less developed countries to reasonable quality standards with less capital investment than would be needed for iron or steel pipe. It is also easier to ensure consistent quality of plastic pipe than concrete pipe in such regions of the world.

The portion of the casing which functions as the pump cylinder must have a smooth, internal surface to minimize wear of the hydraulic seals on the piston. Normal good commercial practice produces pipe without internal roughness. Visual inspection of the inside bore is adequate to ensure smoothness. The inside surface should have a shiny appearance and any competent extruder operator should be able to produce such material.

The pipe must also be round to ensure a good hydraulic seal against the submerged piston. Lack of ovality is not so easily guaranteed or maintained. The plastic pipe in which the piston operates is normally at the bottom of the well and we recommend that a reasonable length (one or two metres) be selected for roundness and matched to the particular piston which is to be used. This assembly can be shipped and handled as a unit. It is not so critical that the rest of the well casing be round.

The most widely used thermoplastics for pipe production are rigid poly(vinyl chloride) (PVC) and polyethylene. Both types of pipe are reviewed in detail elsewhere (1).

We prefer to use PVC pipe because this casing is easily joined in the field without special tooling or skills, and because the current state of commercial practice is such that PVC pipe is generally freer of ovality. Polyethylene pipe is easier to extrude, on the whole, but PVC pipe is very competitively priced, at least at the time of writing in North America.

Pipe costs may vary greatly with location. The following is a reasonable current cost estimate.

Series 100, 7.6 cm pipe is generally useful for the present application. This pipe has an outside diameter of 8.9 cm, a wall thickness of 0.22 cm and contains 588 cubic cm of plastic metre of pipe.

A suitable formulation is:

PVC 100 parts
tin stabilizer 0.6 (approved for food contact)
calcium stearate 0.6

paraffin wax 1.0

low density polyethylene 0.15

titanium dioxide 1.0

calcium carbonate 3.0

acrylic processing aid 1.0

density of compound 1.4 grams/cm^3.

Raw material costs (US 1976) are 56 cents per kg. Blending costs are estimated at 4.4 cents per kg. while extrusion costs should be less than 15.4 cents a kg. Total direct costs of pipe is then 75.8 cents per kg. There is 0.91 kg per metre of pipe and the raw material and processing costs are thus 68.9 cents per metre of pipe. Current list prices are \$3.15 a metre with 50 percent discount readily available (Canada, 1977). Larger discounts are obviously obtainable with volume purchases.

II. Poly(Vinyl Chloride) (PVC)

(a) PVC Material Specifications

PVC pipe is available in various sizes, wall thicknesses and compound types. The material of interest for rural water supplies is rigid (unplasticized) PVC compound. The plastic compound is classified into various types and grades according to ASTM standard D1784-75 which covers the polymer and compounding ingredients, such as stabilizers, pigments and fillers. The specification does not refer specifically to the pipe. However, PVC pipe should be extruded from compound which meets cell classification 12454-B according to D1784-75 or its equivalent in the country in which the PVC compound is made.

The requirements of cell classifications 12454-B refer to various physical properties of compression-molded flat specimens made from the compound which would be used for pipe extrusion. It ensures the polymeric material meets certain minimum requirements for strength and chemical resistance.

Many PVC compound types are available. Cell classification 12454-B provides the least expensive and most generally suitable material for manufacture of pipe for potable water uses, and should be specified by the extruder. The purchaser of the final pipe should also specify that the material has been extruded from compound which meets this specification.

It should not be necessary for the extruder or the pipe purchaser to enter into a testing program to ensure that the PVC meets specification. Reputable manufacturers of PVC polymer or compound can ensure that their products meet this specification or its equivalent in standards of other countries.

A concordance between ASTM specification numbers and those of other standard organizations has not been included here. Such an attempt would inflate this report with information which would be useful only in special circumstances. In any event, such information can be provided by particular PVC manufacturers.

Table I Appendix B lists the requirements for Class 12454-B poly(vinyl chlorides). Those skilled in the field will recognize that these data describe conventional general purpose PVC and that the pipe manufacturer would also need to specify other properties, such as those related to extrudability, which are of no concern to the ultimate user of the pipe.

It is important that pipe which is to be used for the supply of potable water should not contain any materials which are potentially injurious to health. In particular, lead stabilizers which are widely used in PVC compounds, are entirely unacceptable in this application. Absence of toxic ingredients can be specified in any purchase agreement but this will be very difficult to monitor and enforce on a world-wide basis. PVC pipe is particularly susceptible to this problem because the polymer must be compounded with other ingredients before extrusion and this is usually done in the local extrusion shop. (Polyethylene, by contrast, can be formed directly into pipe without addition of any material to that supplied by the prime plastics manufacturer.)

All plastics intended for potable water applications should conform to the World Health Organization permissible levels for extractable toxic substances as illustrated, for example, in Canadian Standards Association Standard B137. 0-1973 (2). These values, which are given in Table 1 (d) Appendix B, refer to concentrations in water which have been standing in contact with the pipe for 3 days. Details of the testing and conditioning procedures are given in the cited specifications and in "Standard Methods for the Examination of Water and Wastewater" (4). Pipe manufactured for sale in the United States must have the certification of the National Sanitation Foundation (Ann Arbor, Michigan). This requires the testing of one lot of pipe for 10,000 hours and two lots of pipe of the same compound for 2000 hours. Other countries may have their own variation of these regulations.

(b) PVC Pipe Specification

PVC pipe is dimensioned according to either standard iron pipe sizes (IPS) or the standard dimension ratio (SDR). The SDR is obtained by dividing the average outside pipe diameter by the minimum wall thickness of the pipe. Pipes made from the same raw material and having the same SDR value have the same pressure rating for all sizes. Thus SDR pipe is rated according to pressure resistance for water at 23°C, while IPS pipe pressure ratings vary with pipe size.

The common IPS sizes in North America are Schedules 40 and 80. The former, which has the thinner wall, can withstand 1.79 MPa water pressure in 7.6 cm diameter size. The maximum pressure in a hand pumped well will be 600 KPa at a depth of 61 m, so that the IPS schedule pipes are obviously oversized for the present purpose. Series 100 pressure rated PVC is the most generally suitable and readily available product in North America. At 7.6 cm diameter, the series 100 pipe costs less than half the price of an equal length of schedule 40 pipe.

Table II Appendix B, compares some properties of schedule and SDR PVC pipes with various nominal sizes. It will be seen that SDR 41 corresponds to a minimum working pressure of 690 KPa regardless of pipe size. This is the lowest working pressure rating generally available in North America. Most rural water wells can operate with casings with lower ratings if these were available. Less expensive pipe with thinner walls than those in series 100 could be made to special order if the volume justified the special extrusion set-up.

PVC pipe is generally supplied in North America in lengths of 6 metres, but other lengths can be made available.

PVC drain vent waste (DVW) system pipe is normally made from high impact PVC. The wall thickness of DVW pipe is greater than that of series 100 at the same nominal pipe size.

The extra expense for DVW pipe cannot be justified for water wells.

Note that the series-sized PVC pipe is made to a standard outside diameter. The tolerance is on the inside diameter. The nominal pipe size does not match either the outside or the inside diameter. For example, series 100 nominal 7.6 cm pipe has an OD of 8.89 cm, a nominal ID of 8.46 cm and a minimum wall thickness of 0.22 cm according to specification.

SDR sized PVC pipe is described in ASTM specifications D2241 and in Canadian Standards Association Standard B137.3-1972. The tolerances on dimensions listed in Table III, Appendix B are taken from the latter specification, which seems to be somewhat easier to read. These tolerances can be specified when PVC pipe is purchased.

The important specifications for PVC pipe include dimensions, as mentioned, as well as the quality of extrusion as determined by ASTM D1252. The quality of PVC pipe is often assessed in an acetone immersion test in which the pipe must not flake or disintegrate under specified conditions. A flattening test (ASTM D1785) is also very useful. In this case, the pipe is placed in a vise and the jaws are closed at a steady rate to 40 per cent of the pipe diameter. The sample must not show signs of splitting, cracking or breaking after the load has been removed.

Other properties which are often specified are burst strength and impact strength, but these are not likely to be of great importance in this application. Toxicity is of great importance, as has been mentioned.

As far as is known, rigid PVC is not affected by fungi, algae or bacterial growth. Rodents and termites are not particularly attracted to the material. Rodents may gnaw through PVC (or any plastic pipe) to get to the water inside. There is no current means to prevent such occasional damage.

(c) Handling and Storage of PVC Pipe

Unplasticized PVC is about one fifth as dense as cast iron. Because of light weight, PVC pipes are often handled with less care than iron pipe. This practice should be discouraged.

Pipe sections should not be stacked in large piles since the bottom pipes may distort under this load, especially at warmer temperatures.

Long term storage of rigid PVC pipe is preferably undertaken using pipe racks on which the whole length of the pipe is supported. Failing this, supports should be at spacings not greater than 1 metre centres beneath the pipes and at twice this spacing along the sides, if the stack is regular. The bearing surface of each support should be at least 7 cm..

Pipe should not be piled more than seven layers high. If different pipe types are piled together the material with the thickest walls should be at the bottom.

Conditions for temporary field storage racks are more demanding. The ground should be level and free of sharp objects, loose stones, tramp metal, etc. In this case, pipes would not be stored more than three high. Stack heights should be reduced, even to a single layer, if pipes of different diameters are nested inside each other. Whenever possible, PVC pipe must be stored in the shade.

When pipes are being transported care should be taken to avoid contact with sharp corners or projections. The pipes should be secured tightly and supported over their entire lengths and during transit they should not be allowed to project beyond the end of the trailer, leaving long lengths of unsupported pipe. Pipes may be off-loaded by rolling them gently down ramps or timbers. They should not be thrown one onto each other or onto hard surfaces.

(d) Joining PVC Pipe Sections

Rigid PVC is quite notch sensitive and threaded joints may tend to bind. The use of threaded joints is not recommended, particularly for the relatively thin walls which are the most ecconomical for rural water supply usage.

The most generally useful method for joining rigid PVC pipe sections is by solvent or cement welding. This process first requires that one end of the pipe be belled to receive the other end (which is called a spigot). The solvent compound is brushed onto the pipes which are then pushed together. The solvent softens the PVC surfaces so that they bond after the solvent has evaporated. Recommended bell dimensions are given in ASTM specification D2672 from which Table IV is reproduced.

Pipe can be purchased belled or it can be belled in the field by warming the pipe end in hot oil (a minimum of 120°C is needed) and then forcing the softened casing over a properly sized wooden or metal mandrel. This procedure can also be used to correct imperfections in factory-made bell ends.

An alternative joining procedure to belling involves the use of injection molded couplings. Schedule 40 or schedule 80 couplings may be used since the SDR pipe is sized on its outside diameter. A socket-socket coupling should be used and the pipe should be solvent cement welded onto the coupling. If socket-socket couplings are indeed used, it should be noted that these fittings have internal lips which are sized to the wall thickness of the corresponding IPS schedule pipe. Thus a schedule 40 or schedule 80 coupling will have an internal flange which protrudes more than the wall thickness or a series 100 pipe.

This protrusion would hinder passage of a tight-fitting piston through the casing and the internal lip would have to be turned down to match the wall thickness of the pipe to be used. A better and alternative procedure is, of course, to mold the couplings to fit the particular pipe thickness.

Detailed instructions for solvent cement welding are given in Appendix C, which is reproduced from a brochure of Building Products of Canada, Limited. These instructions should be followed as closely as possible, except that the use of a pipe primer (which is usually methyl ethyl ketone) can often be omitted.

Solvent cements are specified in ASTM D2564-73a. Safe handling of solvent cement is covered in ASTM F402-74 and a recommended practice for making solvent-cemented joints is given in ASTM D2855-73.

Solvent welding compounds begin to set quickly but optimum strength is not reached until about 24 hours after the joining operation. Cements contain 10 percent or more PVC resin in a suitable solvent. A number of solvent systems are available. A popular mixture includes tetrahydrofuran (boiling point 67°C) and cyclohexanone (boiling point 156°C). Both liquids are good solvents for PVC. The "high boiling" cyclohexanone prevents the adhesive from setting very quickly on exposure to air.

(e) Recipes for Solvent Cements

The following gives detailed instructions and recipes for solvent cement formulations. The commercial mark-up of such materials is very high, in our experience, and it may be worthwhile for aid agencies and local authorities to know how to mix these simple formulations. The PVC resins mentioned below (Geons) are B. F. Goodrich products, since some of the following information was supplied by that company. Users can obtain equivalent materials from their local PVC suppliers. It is not critical that an exact match be made to these polymers.

It should be noted that solvent cements cannot be mixed in the field. The formulations given here should be prepared in a shop with adequate fire safety and vapor removal facilities. Almost all the organic solvents are injurious to health if inhaled or swallowed and all such products should be mixed and handled with caution.

As mentioned in Appendix C, surfaces to be cemented must be clean and dry. If necessary, a small amount of methyl ethyl ketone or carbon tetrachloride can be used to clean the joint surfaces before the cement is applied. The former, which is less toxic, is the usual primer. Under extreme humidity conditions the solvent should be allowed to dry and then excess moisture from condensation should be removed before the cement is applied.

Preparation of solvent cement is not difficult, bur care must be exercised. It is recommended that solvent cements be mixed with an air driven mixer rather than an electric mixer due to the fire hazard from solvents. When mixing, the resin should be added slowly to the solvent to get a good dispersion of the resin. After all the resin has been added, the maximum mixing rate should be used. Most resins will dissolve in about 30 minutes; however, some will require a longer mixing period. Generally, five to thirty parts of resin are added to the solvent to give the cement the consistency of thick soup. However, a cement with about 10% resin content is the easiest to apply.

The following formulations provide satisfactory cements. The viscosities range from about 100 to 1000 centipoise. (Water at room temperature has a viscosity of 1 centipoise.) The viscosity will influence the ease of application. Cements which are too thin or of low viscosity will suffer excess run-off and those which are too thick or highly viscous will not flow sufficiently. The formulator should try a few experiments with his own PVC and solvents to determine the best formulation.

The following gives some useful formulations. The solvents are coded as follows:

THF - tetrahydrofuran

CX - cyclohexanone

Parts are by weight.

Cement Formulation	Approx. Viscosity (CP)
80% THF, 10% CX, 10% Geon 103EPF7	142
90% THF, 10% Geon 103EPF7	122
85% THF, 15% Geon 103EPF7	706
75% THF, 10% CX, 15% Geon 103EPF7	904

Geon 603X560 can be substituted for Geon 103EPF7.

The drying times of the cements will be longer with higher cyclohexanone contents. However the latter cements will bond to the pipe better.

Alternative mixtures to those cited include cyclohexanone-methyl ethyl ketone (MEK) and tetrahydrofuran-dimethyl formamide. An excellent cement for pipe joints is based on 35 parts dimethyl formamide, 65 parts tetrahydrofuran and 15 parts Geon 103EPF7 PVC resin.

(f) Casing for Recommended Well

The casing for this particular pump well be a 7.6 cm series 100 PVC pipe.

The bottom pipe will be fitted with a retainer ring. This ring serves to support the foot valve. The bottom strainer pipe should be chosen such that it can be solvent welded into the ring.

This casing of 7.6 cm pipe will be suitable for a well up to a 30 metre depth. Deeper wells will require a smaller size casing as the leverage ratio becomes too great if 7.6 cm casing is used.

When this casing is installed there should be approximately 7.6 cm protruding from the base to allow the connection of the reducer coupling for the top end.

4. LEVERAGE SYSTEM

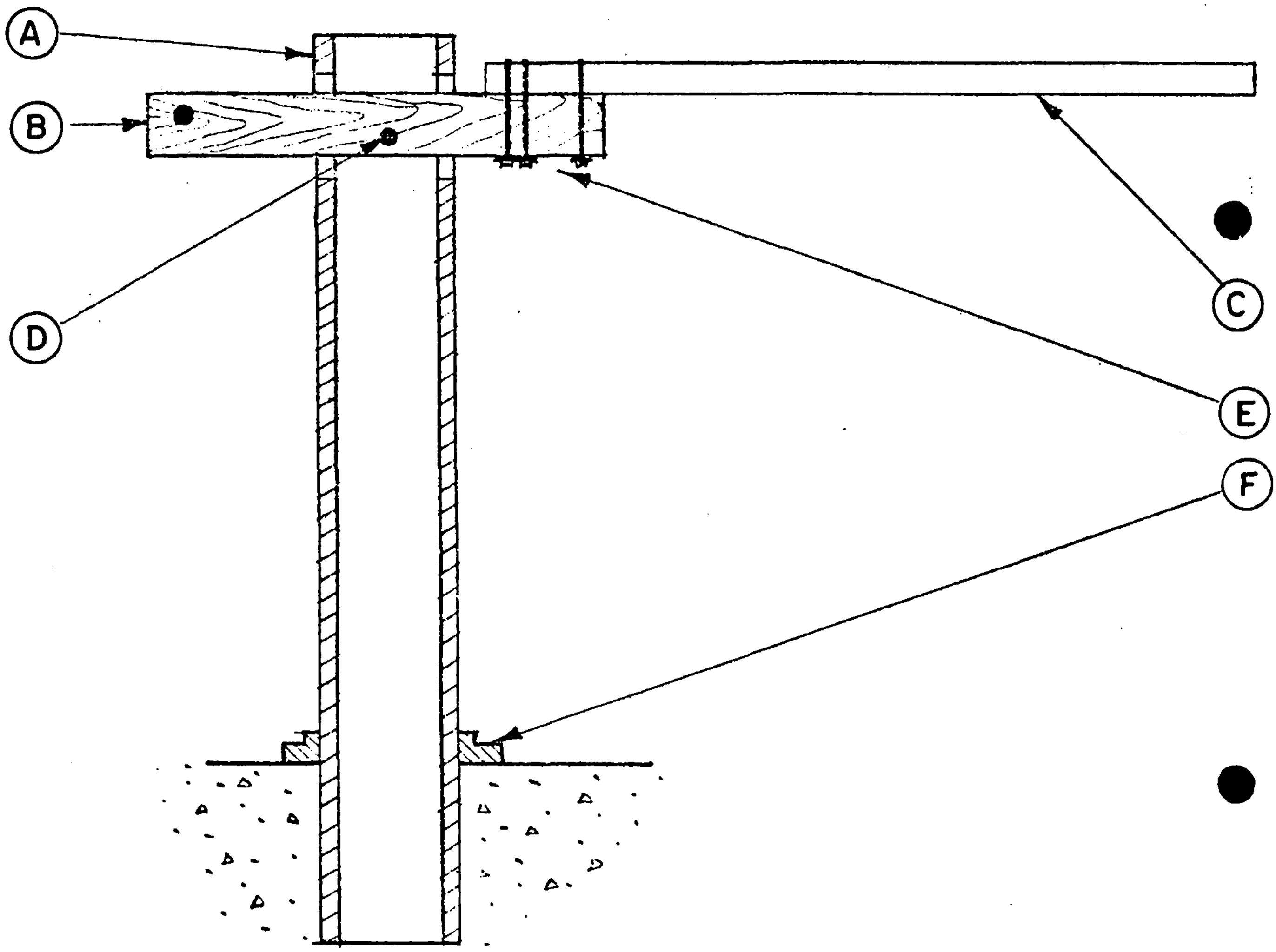
The recommended leverage system consists of a very simple pedestal and lever arm. The pedestal shown in Figure 2 is a 15.2 cm series 160 high density polyethylene pipe. (See Reference (1) for details of polyethylene pipe specifications and nomenclature.) This particular casing has a wall thickness of 1.9 cm. High density polyethylene is preferable in this application but any good pipe grade polymer will be suitable. The wall thickness and characteristics of the plastic mean that this plastic pipe pedestal should be literally unbreakable.

It is possible to design for a particular use but not for abuse, since the stress levels under abusive conditions cannot be forecast. We have therefore selected this particular polyethylene pipe as the toughest pedestal material whose properties can be guaranteed by the designers.

The pedestal specified here is far more rugged than is actually needed for the actual pumping stresses. The plastic size is able to withstand prolonged and intensive abuse as well as normal use. A thinner wall, smaller diameter plastic pipe may well be suitable for this purpose in many applications. PVC and ABS (1) could also be substituted for the polyethylene. These are more rigid than polyethylene but are generally not as tough.

FIGURE 2

LEVERAGE SYSTEM



A POLYETHYLENE PIPE 15.2 cm DIA.

B HARDWOOD 5 cm THK. x 10 cm x 66 cm LONG

C STEEL PIPE 4.5 cm

D GALVANIZED PIPE 2.5 cm

E U-BOLTS

F OPTIONAL FLANGE

In any event, the plastic pipe should be stabilized against ultra-violet light degradation. If this is not done the pedestal may become embrittled in locations where the sunlight is very intense. Adequate, inexpensive stabilization is provided by using about 3 per cent by weight of a small particle size carbon black which is well dispersed in the polymer. Raw material suppliers can provide suitable compounds. The stabilization technique is well known.

Concrete pedestals are alternatives and it is also possible to encase the plastic pedestal and the top end of the well casing in concrete. If concrete is used, the recommended volume mix proportions for general use in regions where weigh patching is neither feasible nor desirable are ONE part (bucket or shovel) cement: TWO parts fine aggregate-sand: FOUR parts course aggregate-gravel. Enough water should be added to produce a workable mixture. It is not necessary to use any reinforcing. (We have not recommended concrete as a general rule because there are regions in which inferior mixes are routinely used.)

The plastic pipe pedestal shown in Figure 2 is secured by bolting it to the concrete pad (same volume mix proportions) through an attached plastic flange. Such plastic flanges are normally stock items for use with rigid plastic pipe. An alternative anchoring method would, of course, dispense with the flange by casting the pipe into the concrete when the pad itself is being formed. Concrete can also be poured into the base of the pedestal to improve its anchoring. The polyethylene pedestal is provided with support holes for the galvanized iron pipe which functions as fulcrum pivot. The specified wall thickness of the pipe provides adequate support for the pivot.

The pedestal pipe is slotted to limit the piston stroke. The slot is also sized to restrict side play of the handle. This is important since the conventional pumps can be damaged by side stresses for which there is inadequate design. Children tend to move the handle with more side play than is experienced when adults operate the pump. The pipe specified has more than enough strength and toughness to resist erratic stressing modes.

The handle shown consists of an oil-impregnated hardwood bearing section, bolted to a length of iron pipe to obtain the required leverage ratio. The fulcrum pivot and yoke pivot will turn in the wood section and will be stationary in the pedestal and yoke.

Galvanized steel in oil-impregnated hardwood provide a very long-lasting, low friction bearing (5). The wooden handle and bearing holes are sized to provide a large bearing surface and avoid overstressing of the wooden handle. This component requires no lubrication and should last for a long time. The wood type and oil are not specified since products of the locality will very likely be satisfactory.

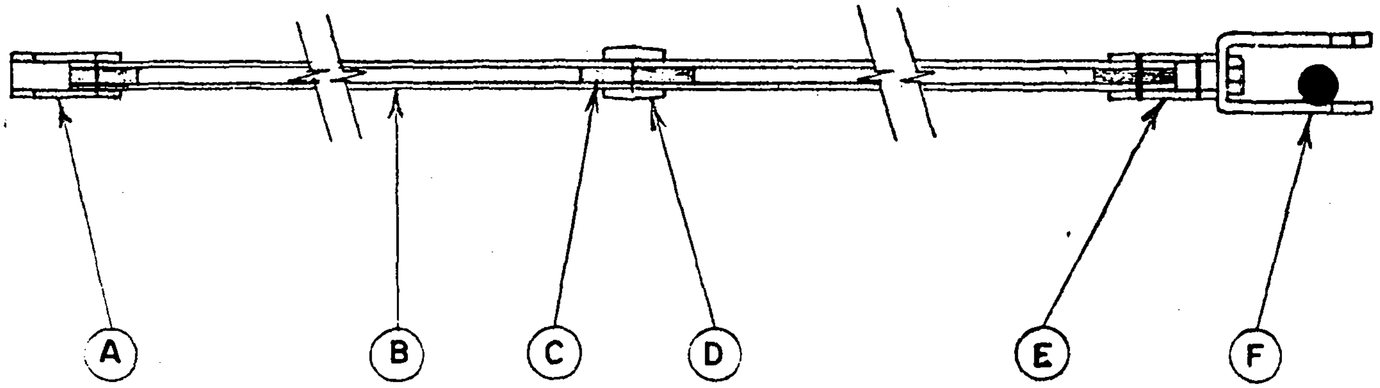
Oil impregnation is a simple procedure. The two holes shown should be bored undersize and the handle then immersed in oil Both the handle and the oil should be heated until the gassing process due to release of air and water subsides. (Of course, care should be taken not to char the wood.) Finally, the holes should be rebored to size.

As mentioned, wear is restricted here to the oiled wood/galvanized iron interface and the bearings need not be sealed or lubricated.

The pipe strapped to the wooden handle limits the pumping force to a maximum of 18 kg. In series 100 nominal 7.6 cm PVC pipe there is 5.62 kg of water per metre of depth. Thus, a 9:1 lever ratio is needed for a 30.5 m hydrostatic head and lower lever arm values may be used for shallower wells.

FIGURE 3

PUMP ROD



A. Galvanized Pipe 2.5 cm x 7.6 cm LG
B. PVC Pipe 1.9 cm Schd. 80 x 6 m lengths
C. PVC plug x 7.6 cm LG.
D. PVC coupling schd. 80 socket - socket
E. Same as A
F. Yoke 6.4 cm wide x 5 mm thick flat bar

5. PUMP ROD

The pump rod should be adequately strong, reasonably flexible, light and securely coupled. It is also an advantage if the rods float, so that sections which may be inadvertently dropped into the well can be retrieved easily. These properties can be combined with reliable performance and relatively low cost by using small diameter PVC pipe as the pump rod.

The pump rod as shown in Figure 3 is made up of 6 m lengths of 1.91 cm schedule 80 PVC pipe solvent welded together using PVC double socket couplings. These are standard items in the trade. Each pipe section has both ends plugged with a PVC plug, solvent welded into place. These will make the rod buoyant as well as strengthen the bolted connections at the top and bottom.

This pump rod has many advantages over alternative metal or wooden rods. It is light and easy to transport, is not corrodible and does not swell or rot. Coupling failure will not occur because the entire rod is solvent-welded together. The novel pump rod suggested here is the least expensive alternative in the market for which we could get price estimates. The pump rod is flexible enough that it can simply be withdrawn from the well when required and allowed to bend onto the ground under its own weight. The plastic pump rod is strong enough for use with hand-operated wells. It is probably not suitable for

FIGURE 3 (a)

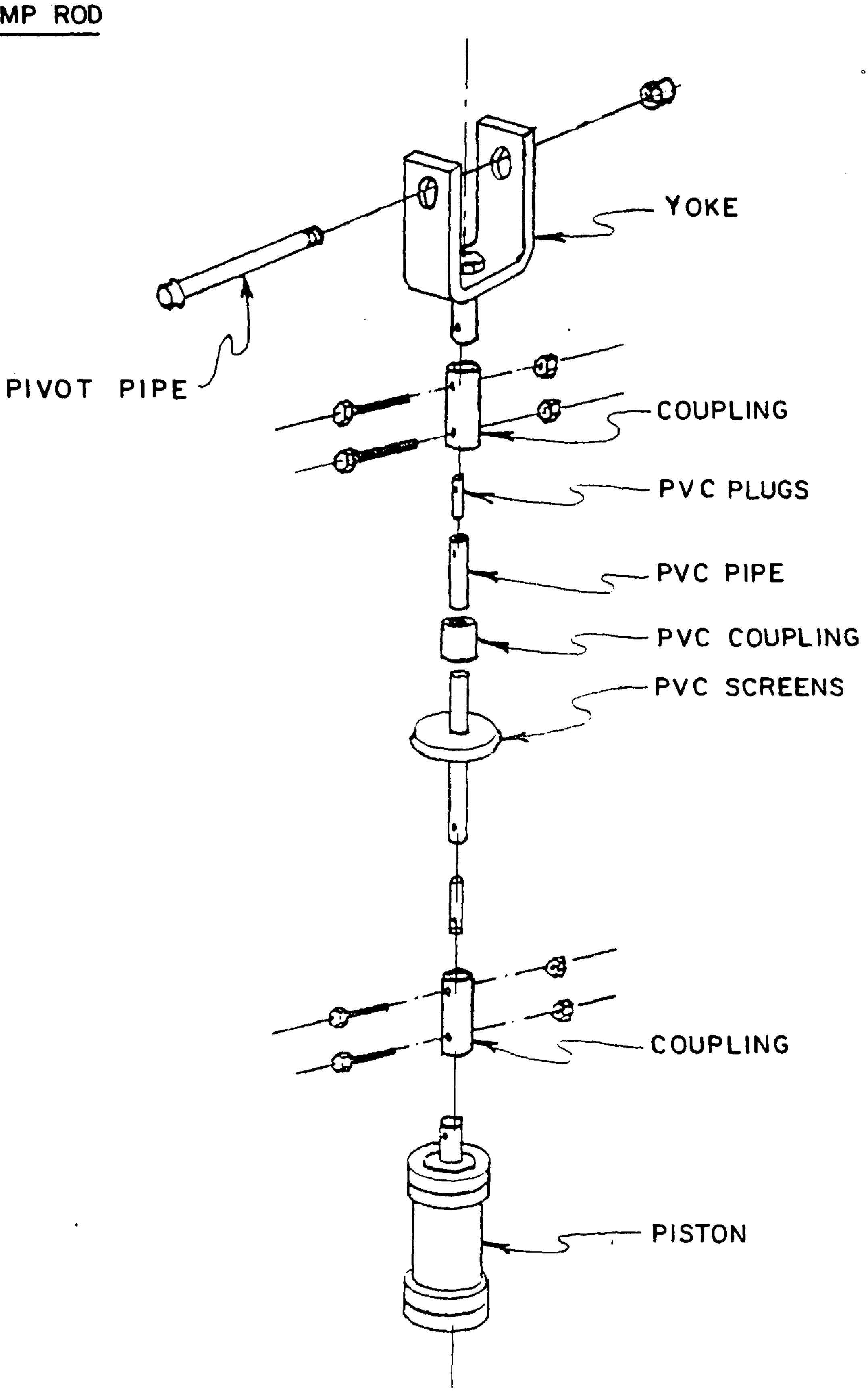
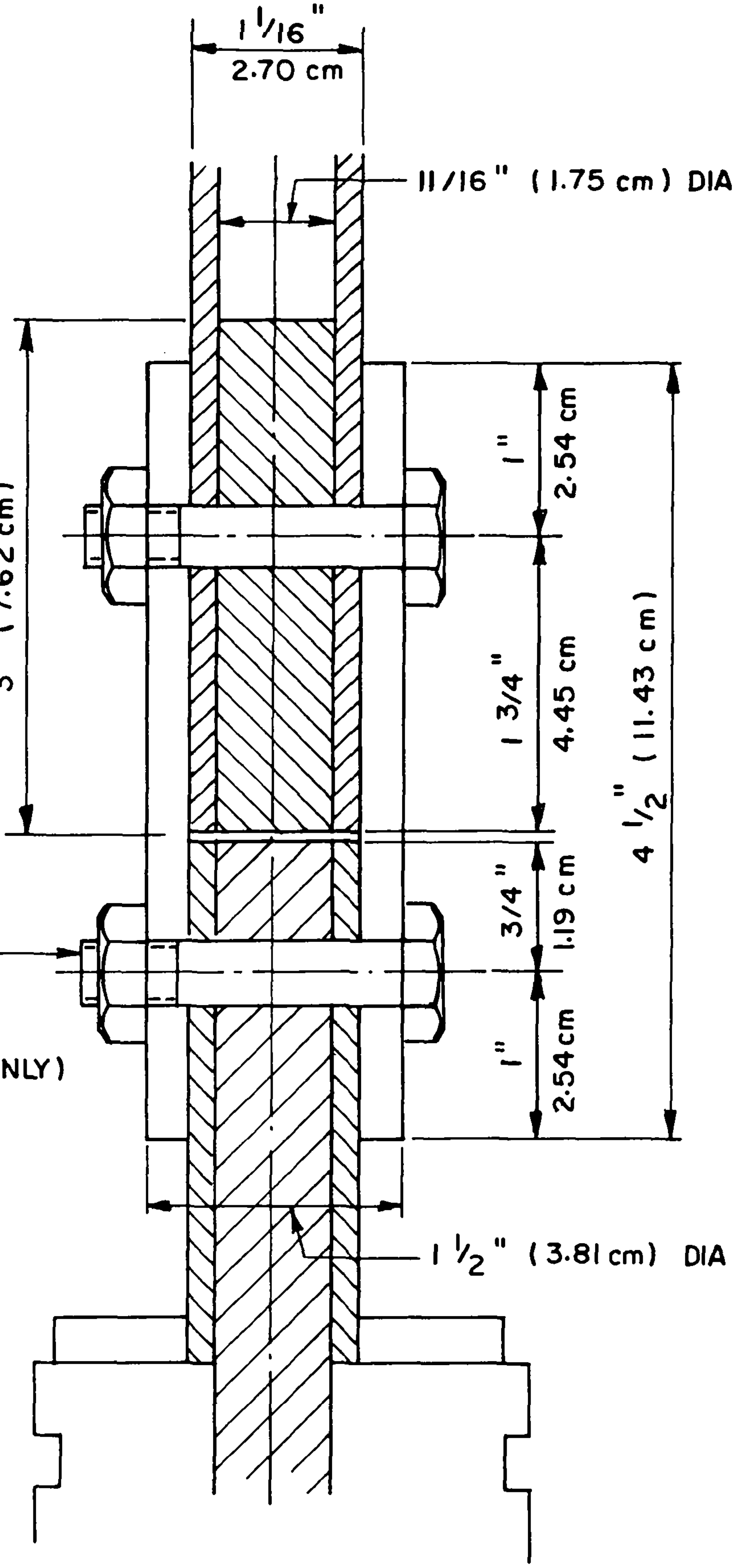

PUMP ROD
YOKE
PIVOT PIPE
COUPLING
PVC PLUGS
PVC PIPE
PVC COUPLING
PVC SCREENS
COUPLING
PISTON

Figure 4

IDRC PUMP ROD COUPLING



mechanically pumped units where metal or wooden pump rods are used.

The end connections make use of two short lengths of galvanized steel pipe bolted to the pipe and piston at the bottom, and to the yoke and pipe at the top. The bolted connections are necessary to allow the piston to be removed and dismantled. The rod need not be dismantled as the pipe's flexibility allows it to be pulled from the well intact. It is recommended that slotted plastic or wooden spacers (See Figure 3(a) be placed on top of each coupling to prevent excessive lateral motion and to prevent wear of the coupling on the well casing.

The pump rod has bolted connections at each end. The design of end connections in Figure 1 has been reconsidered and it is recommended that the version shown in Figure 4 be used. This design employs 0.95 bolts threaded at the ends only (these are called "carriage bolts" in North America) and a longer length of galvanized iron pipe. Both modifications improve the shear strength of the connections.

The tensile properties of this pump rod were tested. The solvent welded coupling proved to be the weakest, but even then the strength averaged 916 kg. Therefore the rod has a static factor of safety of 2/1 in a 61 m well.

Strength under fatigue conditions is not easily determined, however. Calculations based on methods suitable for metal parts indicate a possible limiting shear force of about 453 kg under repeated loadings. The published experimental data on PVC fatigue life are inadequate for design purposes. It is suggested that use of the 1.91 cm schedule 80 PVC pump rod be limited to loads around 227 kg. This corresponds to the weight of water in 30 m of 7.6 cm well casing.

6. TOP END AND SPOUT

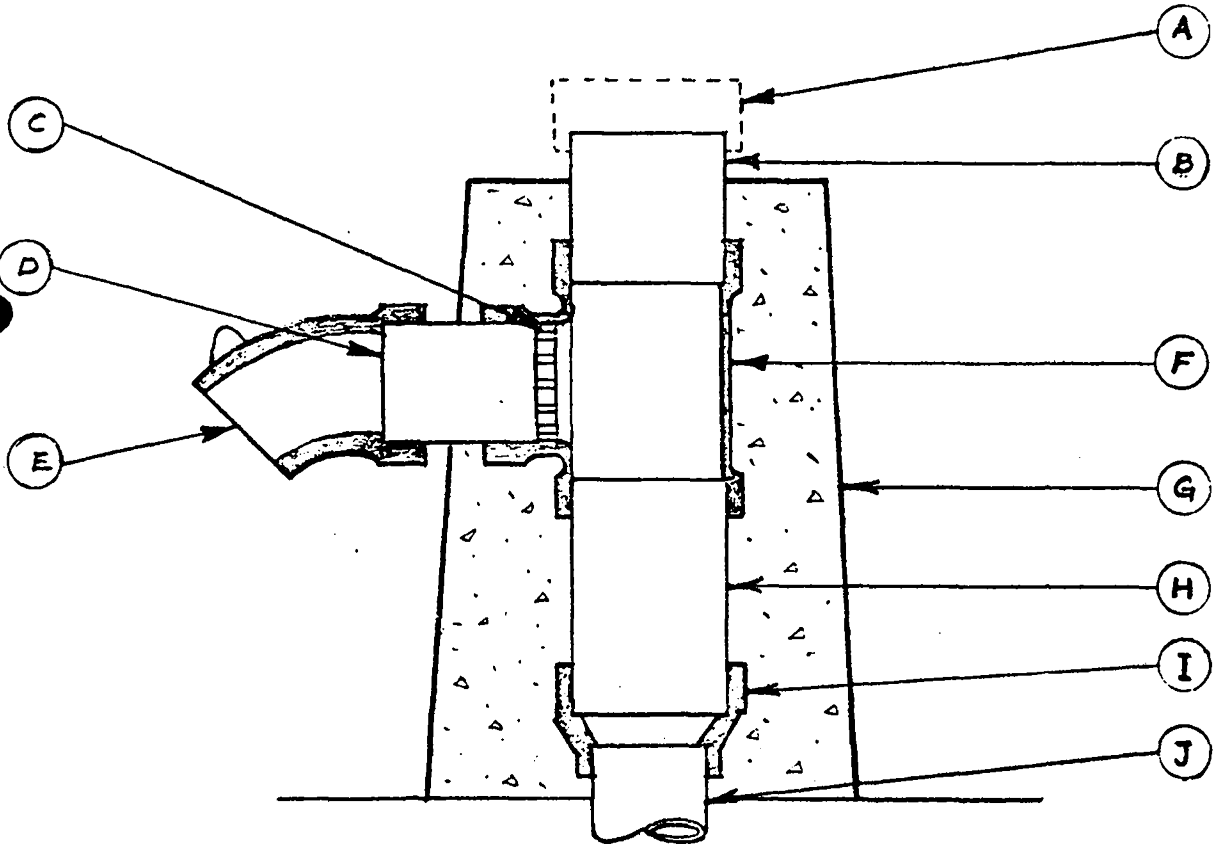
The top end and spout as shown in Figure 5 is one for a typical 7.6 cm well. Details of the casing are given in Figure 6. The entire structure is made from 10.2 cm schedule 80 PVC pipe and connections, solvent welded together. The heavy duty components shown should be rugged enough but the whole top end may be encased in a concrete pillar as a precautionary measure.

A reducer coupling is used to connect 7.6 cm well casing to the top end which is made up entirely of 10.2 cm components to allow the piston and foot valve to pass when dismantling the pump. The 10.2 pipe from the reducer is connected to the bottom of the tee joint. This tee joint acts as the outlet to the spout which is a 45° elbow. A small protrusion may be solvent welded on top of the elbow to hold a pail handle.

The joining pipe between the tee joint and elbow has a PVC or other plastic screen or grating solvent-welded ahead of it in the tee joint to hold back debris. Another short section of pipe extends from the top of the tee joint allowing it to be connected to the casing cover.

FIGURE 5

TOP END & SPOUT



A. Casing cover

B. PVC pipe 10 cm schd. 80 x 9 cm lg.

C. PVC grating

D. PVC pipe 10 cm schd. 80 x 9 cm lg

E. PVC elbow 45° schd. 80

F. PVC 10 cm tee joint schd. 80

G. Optional concrete pillar

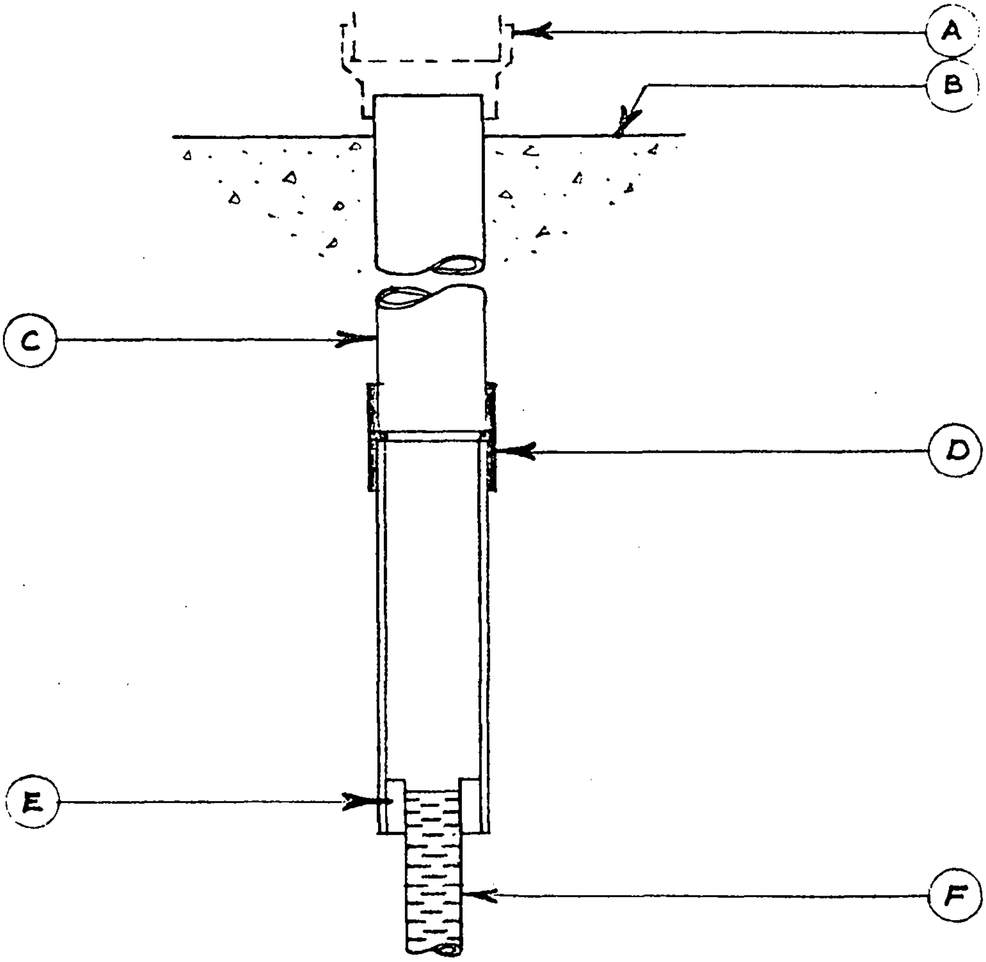
H. PVC pipe 10 cm schd. 80 x 45.7 cm lg

I. PVC reducer coupling 7.6 cm x 10 cm

J. Casing

FIGURE 6

CASING



A. Top end

B. Concrete base

C. PVC pipe 7.6 cm series 100 x 6 m lengths

D. PVC 7.6 cm coupling socket - socket

E. PVC retainer ring 6.4 cm lg.

F. PVC pipe slotted

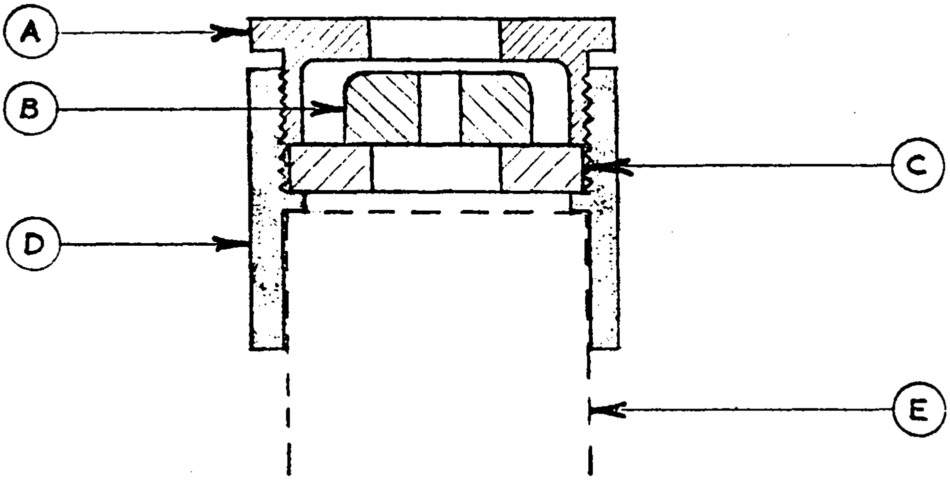
7. CASING COVER

The casing cover as shown in Figure 7 will allow the pump rod freedom of movement in two directions while keeping the top end closed off. This cover consists of one PVC coupling, one PVC threaded plug and two PVC washers. The coupling is a threaded-socket type with the socket end solvent welded to the pipe while the plug is threaded in the other. The plug has an oval slot allowing the rod to move back and forth from the pumping action. The bottom washer with an identical oval slot acts as a stop for the smaller washer. This small washer has a close clearance fit hole allowing the rod to slide through it but moves laterally with the rod thus covering the exposed opening of the slot.

The debris that slips through the slot in the plug can be removed by removing the threaded plug. The removal of the plug is also necessary when the piston or foot valve are to be removed. An additional plate similar to the sliding PVC disc may be placed on top of the whole assembly to act as a cover plate and eliminate debris which might accumulate in the oval slot which is cut in the top PVC plug.

FIGURE 7

CASING COVER



A. PVC 10 cm plug 5 cm lg. oval slot in top
B. PVC disc - clearance hole for pipe
C. PVC collar - slotted same as A
D. PVC 10 cm coupling socket - threaded
E. PVC 10 cm pipe - top end

8. PISTON

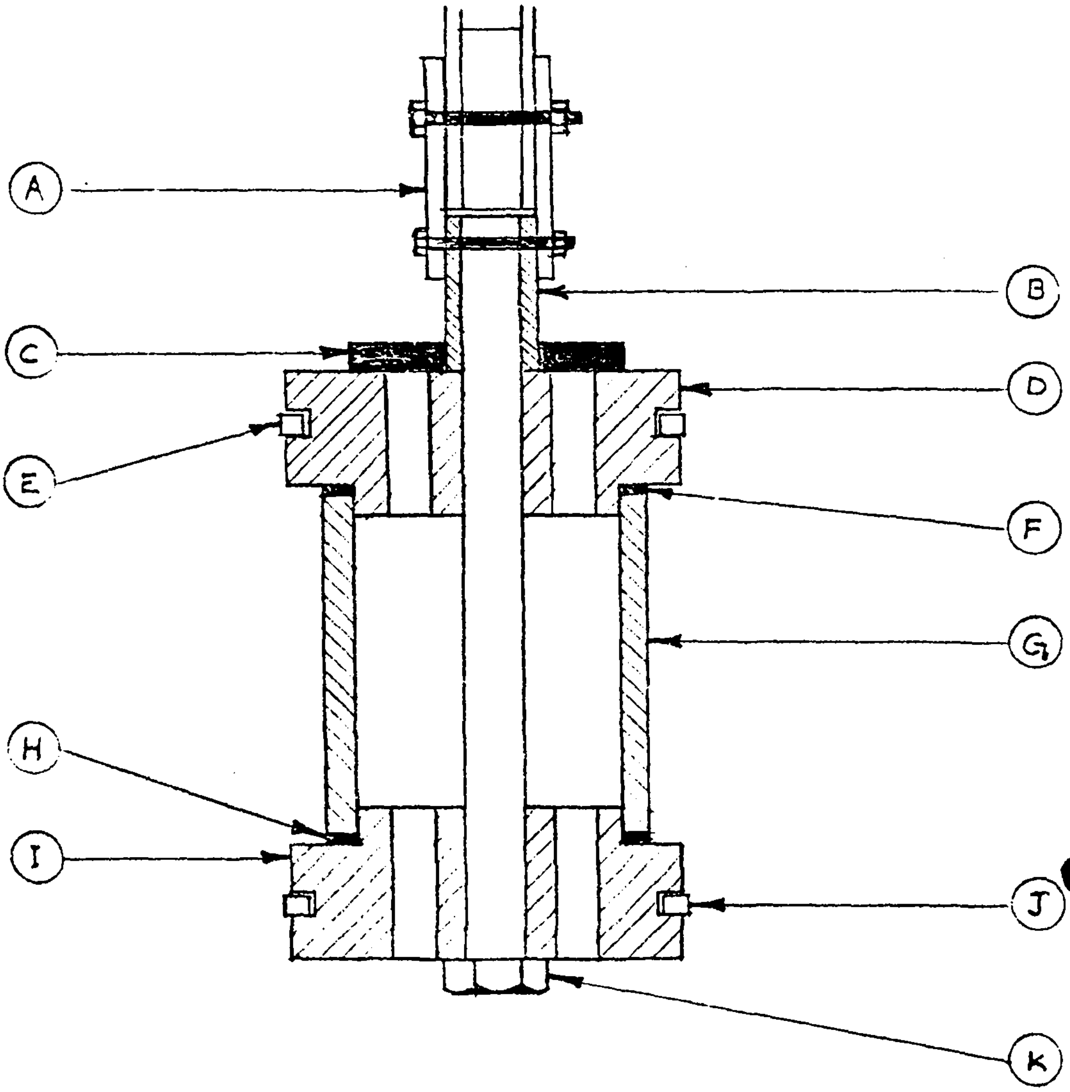
The piston, which is shown in Figure 8 has many components in common with the foot valve which is discussed in the following section.

The majority of components in the piston are stock items. A large standard bolt holds the entire assmebly together. A short length of 6.4 cm PVC pipe acts as a spacer between the top and bottom sections of the piston. The length of the spacer should be greater than the inside diameter of the casing to prevent cocking of the piston. The plate valve is preferably a 0.5 cm thick rubber sheet with 60 Shore A hardness. Leather and rigid PVC could also be used here but rubber is preferable as it provides the best seal and also lifts off the top end of the piston most easily when the movement of the pump rod is reversed. The sealing gaskets (F and H in Figure 8) are optional and need not be included.

The polyethylene piston rings may be cut from a standard polyethylene pipe. Polyethylene was chosen as the ring material because of its relatively low coefficient of friction on PVC. This reduces the pumping force required. Simulated wear tests in our laboratory show that wear is limited to the rings which are easily replaced. The PVC

FIGURE 8

PISTON



A. Galvanized pipe as coupling

B. PVC pipe 1.9 cm schd 80 x 5 cm lg.

C. Plate valve - rubber, leather, PVC 6.4 cm O.D.

D. & I. Molded PVC

E. & J. Polyethylene ring - cut from 9 cm pipe

F. & H. Sealing gasket - leather, rubber (Optional)

G. Spacer PVC pipe 6.4 cm schd 80 x 10 cm lg.

K. Stainless or galvanized bolt 1.8 cm dia. x 23 cm lg.

casing should not suffer any significant damage even if the water contains abrasive materials.

These rings seal only under dynamic conditions. The piston can therefore be removed by hand if it is withdrawn slowly, even when the casing has a full head of water. Once the piston is withdrawn, it can be completely dismantled by removing the bolt which connects it to the pump rod.

The top and bottom sections of the piston are identical and are the only components which are not stock shapes. These parts must be machined from sheet stock or injection molded.

9. FOOT VALVE

The foot valve as shown in Figure 9 is very similar to the piston. The foot valve uses an eyebolt to hold the unit together and a polyethylene cup which provides a static seal. Also, the top coupling is a PVC double socket coupling which limits the travel of the plate valve.

The eyebolt will permit removal by hooking onto the end of the pump rod. The polyethylene cup offers little friction resistance when being removed but provides an excellent static seal.

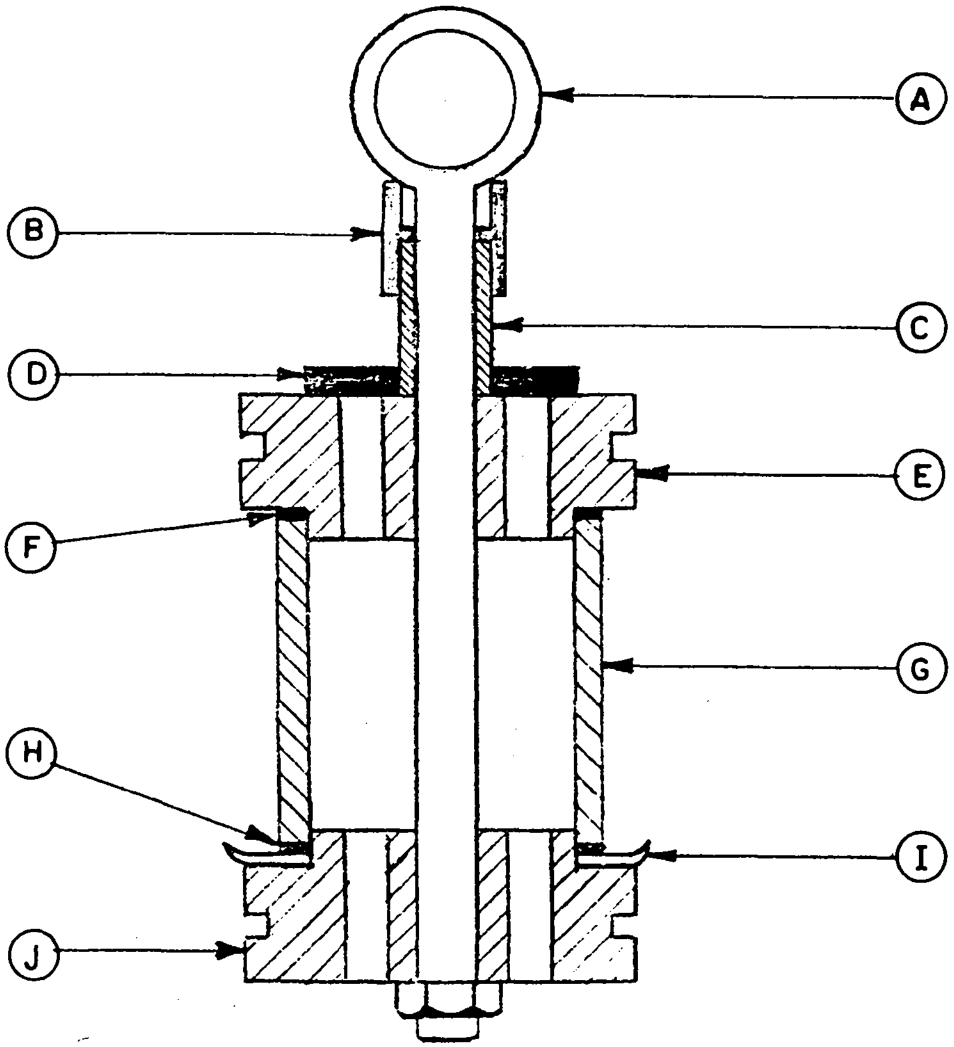
While in service the foot valve will rest on the retainer ring thus supporting the column of water. As the water rushes up through the valve during the pumping action the resistance of the polyethylene cup will be sufficient to hold it down in position.

It is essential that a polyethylene cup be used here. A leather cup will also provide a very good static seal but it offers too much frictional resistance to being drawn up from the surface.

If suitably-sized polyethylene bottles are available the polyethylene cup can be cut from their bottom sections. A more reliable source of supply is provided if the cup is injection molded.

FIGURE 9

FOOT VALVE



A. Eye bolt 1.8 cm x 28 cm lg
Stainless or galvanized

B. PVC coupling 1.9 cm schd. 80 socket - socket

C. PVC pipe 1.9 cm schd. 80 x 5.0 cm lg.

D. Plate valve - rubber, leather, PVC

E. & J. Molded PVC same as piston

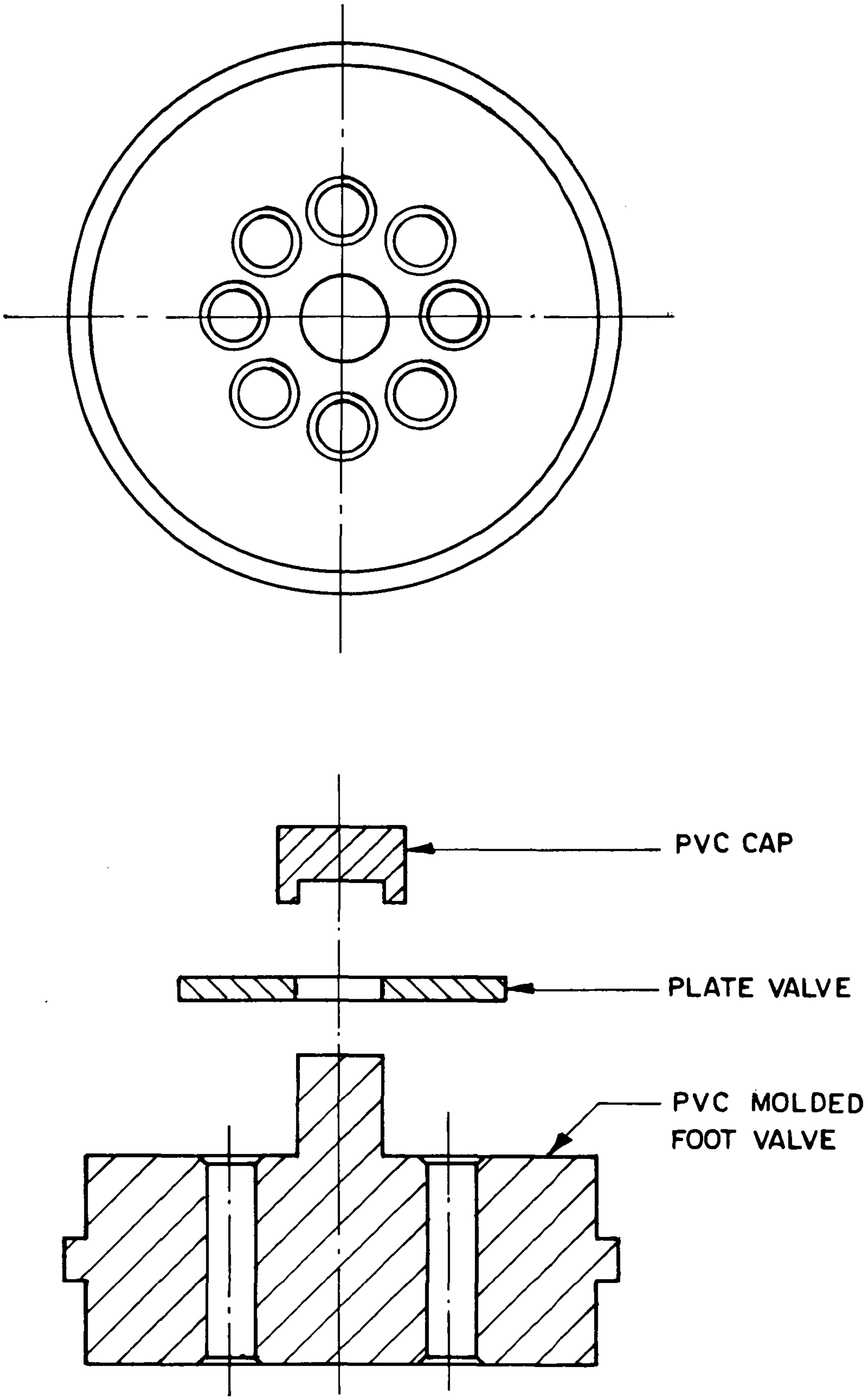
F. & H. Gasket - rubber leather

G. PVC pipe 6.4cm schd. 80 x 10 cm lg.

I. Polyethylene cup

Figure 10 depicts an even simpler, non-recoverable foot valve which can be glued into position on the retaining ring at the bottom of the 7.6 cm casing. This valve cannot be removed for inspection or repair, however.

Figure 10



NON RECOVERABLE FOOT VALVE

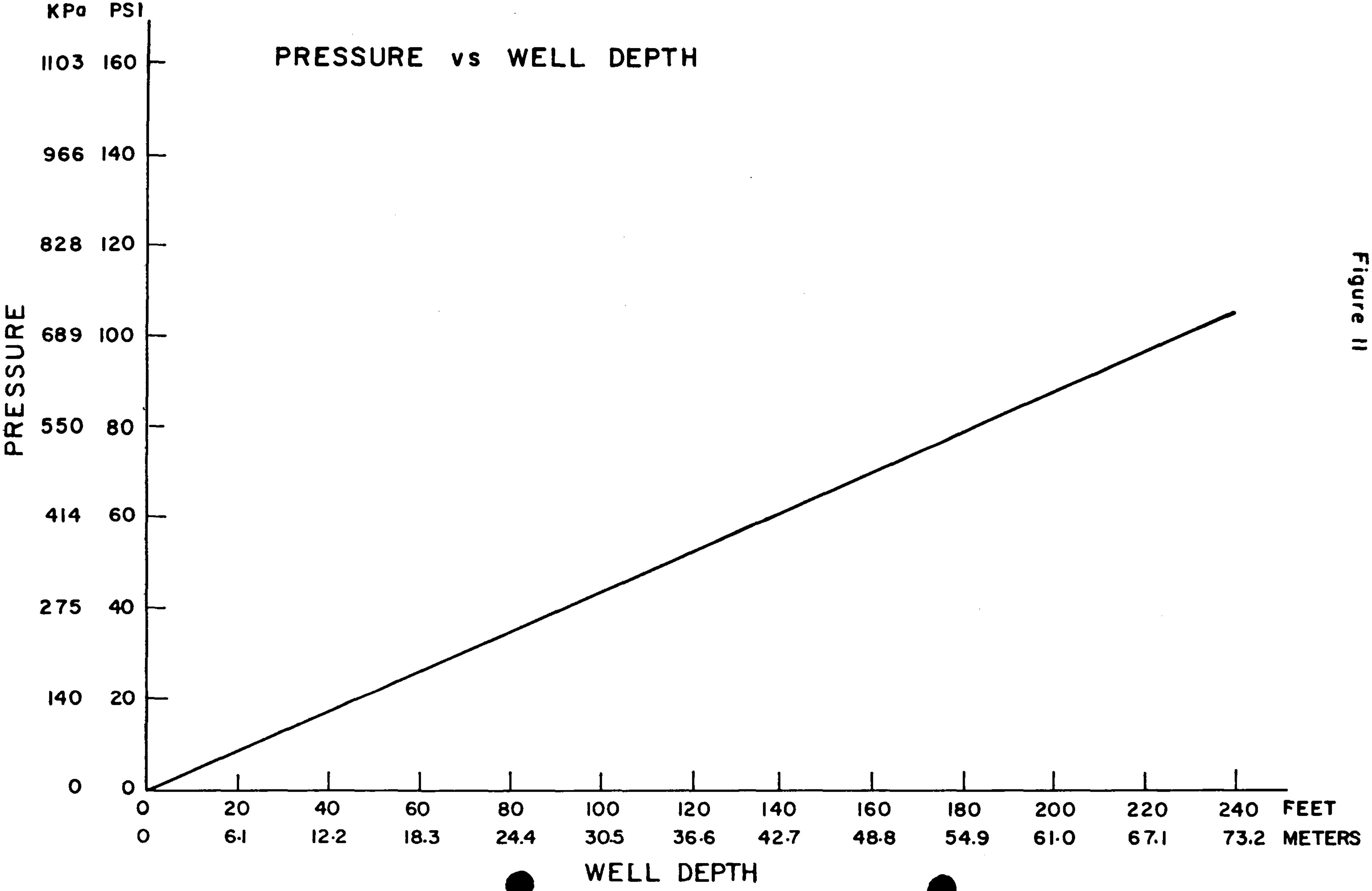
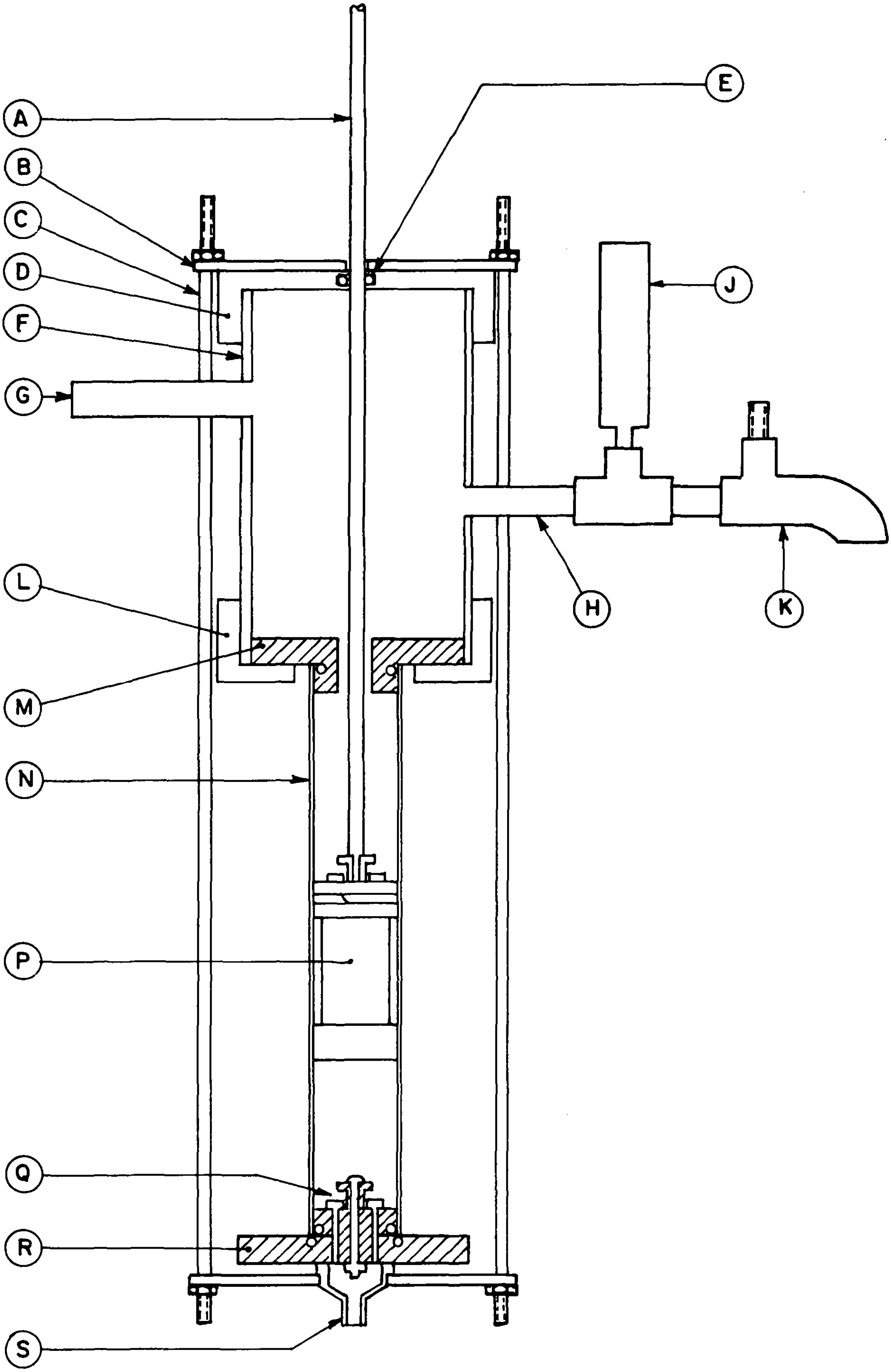
PRESSURE vs WELL DEPTH
KPa PSI
1103 160
966 140
828 120
689 100
550 80
414 60
275 40
140 20
0 0
PRESSURE
0 20 40 60 80 100 120 140 160 180 200 220 240 FEET
0 6.1 12.2 18.3 24.4 30.5 36.6 42.7 48.8 54.9 61.0 67.1 73.2 METERS
WELL DEPTH

Figure 11

Figure 12



SIMULATED HEAD PUMP

10. PUMP TEST RESULTS

I 5 cm Pump Tests

The main objective was to design a pump which would be virtually maintenance free and would have a maximum projected well depth of 61 m. Simplicity has been the keynote in designing the pump.

Obviously, materials that might fail should be easily replaced. Plastics such as PVC and polypropylene, were investigated and on the basis of performance figures, the design has been recommended for field testing. Testing for shallow wells was performed on an actual head model while deeper well testing was performed on a simulated head pump.

(i) Simulated Head Pump

The simulated head apparatus was designed and constructed to perform the equivalent of deep well testing as well as providing an alternate means of testing shallow wells. Pressurized water (0-689.5 KPa) acted on top of the piston to simulate a column of water up to 70 m deep (Figure 11).

A pressure chamber was mounted above a PVC casing and piston assembly (Figure 12). Upward movement of the piston drew water through a non recoverable foot valve (Figure 10) from a water reservoir which was monitored to establish the total weight and hence the total volume of water displaced.

SIMULATED HEAD PUMPS PARTS LIST

A - 0.95 cm Cold Rolled Steel Pump Rod

B - Restrictor Plates (2) - 22.86 cm dia. x 0.64 cm thick

C - Tierods (3) - 0.95 cm dia.

D - Aluminum Cap - 19.05 cm O.D.

E - O-Ring Seal - 0.95 cm I.D.

F - Pressurized Water Chamber - 16.51 cm O.D. x 0.64 cm wall thickness

G - Pressure Chamber Inlet Port - 2.5 cm dia. pipe

H - Pressure Chamber Outlet Port - 1.9 cm dia. pipe

J - Pressure Gauge - 0 - 689 KPa

K - Pressure Relief Valve - 68 - 862 KPa

L - Aluminum Cap - 19.05 cm O.D.

M - Upper End P.V.C. Plate - 2.22 cm I.D.

N - P.V.C. Casing - 5.0 cm SDR 26 x 40.6 cm long

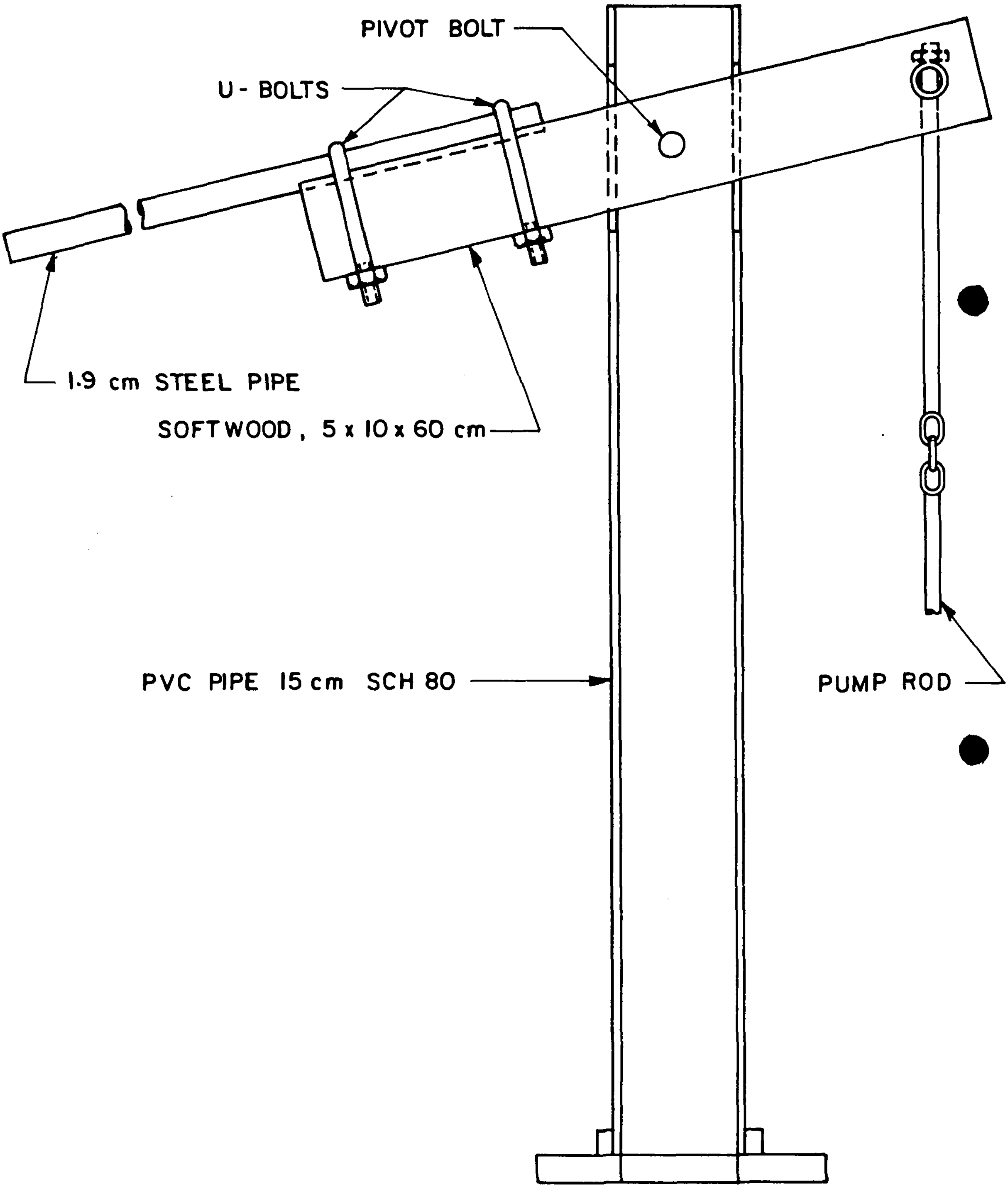
P - Piston and Valve Combination

Q - Foot Valve - Plate Valve Assembly

R - Lower End P.V.C. Plate - 0.5 cm holes x 8

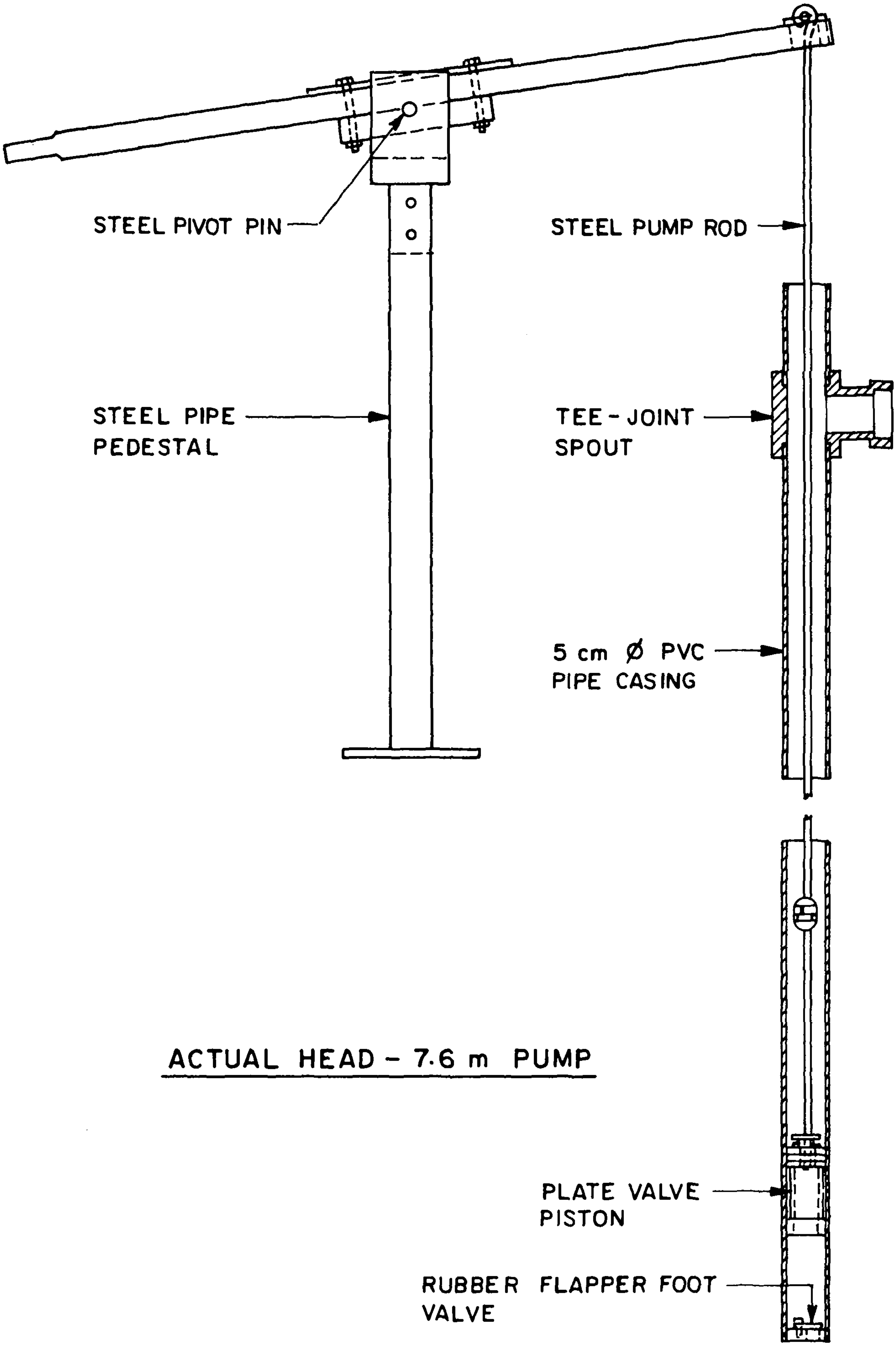
S - Water Inlet

Figure 13



SIMULATED HEAD SUPERSTRUCTURE

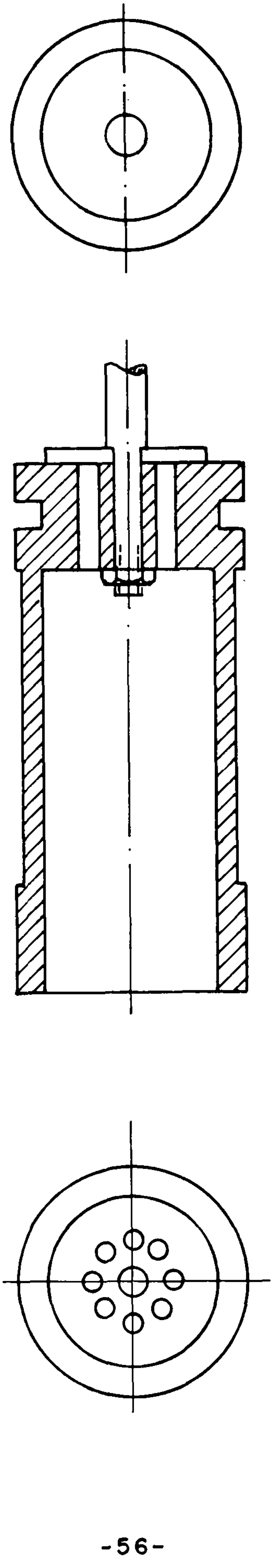
Figure 14



ACTUAL HEAD – 7.6 m PUMP

Figure 15

RUBBER FLAPPER PINNED IN THE CENTER



During the upward stroke, the pressure increased on top of the piston opening a pressure relief valve allowing water to flow through the outlet. By measuring the flow back through the foot valve a direct means of establishing leakage rates was possible.

The above ground section of the pump was constructed from a 19 cm schedule 40 PVC pipe. The handle consisted of a 5 cm by 10 cm spruce block with a 1.9 cm pipe attached with U-bolts. A 6:1 mechanical advantage was used for all tests conducted on the simulated head apparatus. A short section of chain inserted in the pump rod insured a vertical path (Figure 13).

ii) Actual Head - 7.6 m Pump (Figure 14)

The superstructure was similar to that of the simulated head pump with a few minor changes. A 5 cm steel pipe was used as the post with a steel pivot point. The handle was one continuous piece of wood 152 cm long with a 1:1 advantage.

The piston and PVC casing were identical in material and dimensions to that of the simulated head pump. The casing was 7.6 m from foot valve to exit nozzle. Three sections of 0.95 cm steel rod coupled with brass fittings were used as the pump rod. However, due to the corrosive nature of the steel, rust appeared in the water after extended use.

The piston was placed about 46 cm below the water level. This insured that the pump would remain a positive displacement pump at all times and not rely on suction. Since the foot valve was submerged it was difficult to measure leakage rates directly.

iii) Pistons

Pistons of similar material and dimensions but with different valve arrangements (Figures 15 - 19) were used for both the 7.6 m and simulated head pumps. A PVC pipe 5.4 cm outside diameter and 12.7 cm in length was used as the basic shell.

A. Centrally Pinned Rubber Flapper (Figure 15)

This piston consisted of an inverted PVC cup with one piston ring on the upper section. The ring served as a hydraulic seal as well as a guide guidance for the piston within the casing. The valve ports consisted of eight 0.48 cm holes slightly countersunk to reduce turbulence and insure proper seating of the rubber flapper on top of the piston.

B. Rubber Flapper Pinned at One Side (Figure 16)

This piston consisted of a PVC cup with a pin in the top section for connection of the piston to the pump rod, giving greater freedom of movement. In this case, one piston ring was situated on the lower section of the piston. The valve port consisted of one 2.2 cm diameter hole and a rubber flapper supported by a flat washer stiffener served as the check valve.

c. Ball Valve (Figure 17)

The shell was similar in nature to that of the piston with the rubber flapper pinned at the side. The valve port was a 1.9 cm diameter hole with a 0.48 cm deep countersunk shoulder. A standard 2.54 cm diameter steel ball bearing completed the valve by sealing on the chambered shoulder.

d. Plate Valve (Figures 18 - 19) (Preferred Design)

The shell was similar in layout to that of the centrally pinned rubber flapper. Pistons with both one and two rings were tested, but the basic operating principles of the two valves were the same. A central PVC sleeve acted as a guide for a washer shaped disc made of various materials. The washer had the freedom to travel 0.95 cm during opening and closing. Eight ports of 0.48 cm diameter holes completed the valve arrangement. These holes were slightly countersunk to relieve turbulence. With the two ring layout, the inside diameter of the section was slightly smaller to accomodate the second ring.

Figure 16

RUBBER FLAPPER PINNED AT ONE SIDE

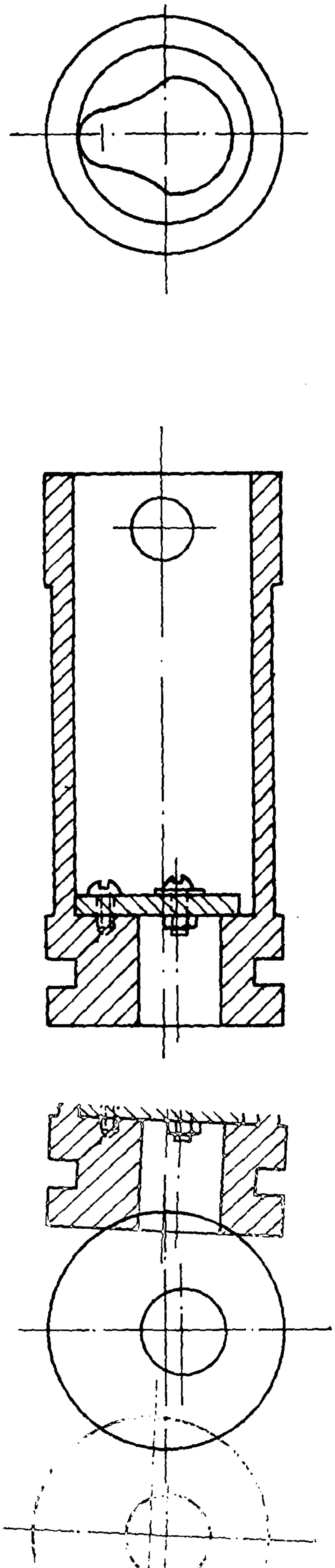


Figure 17

BALL VALVE

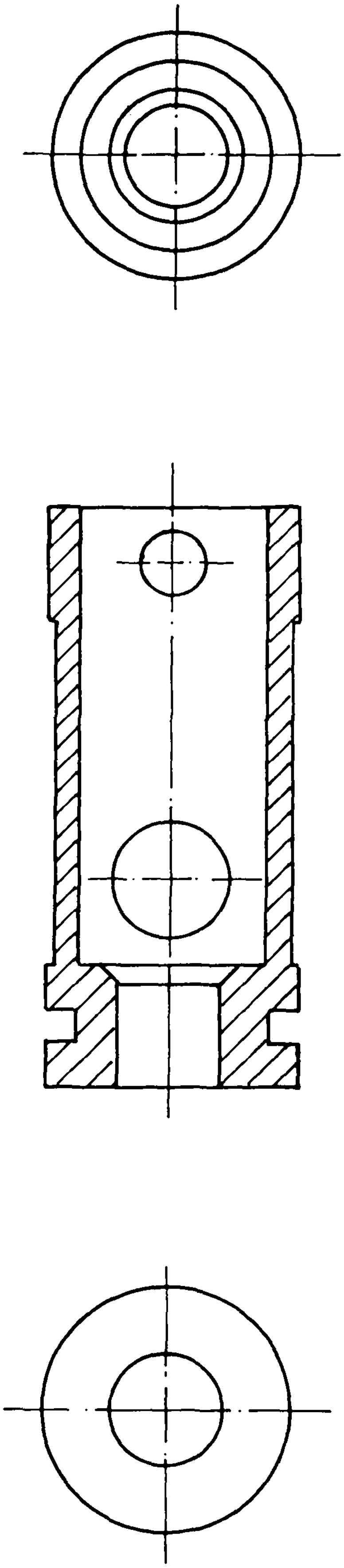


Figure 18

PLATE VALVE
ONE RING

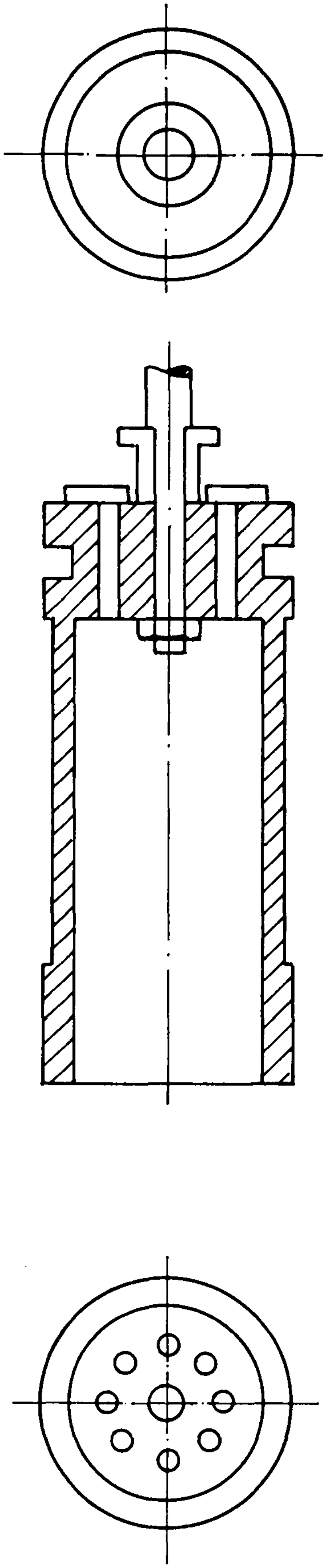
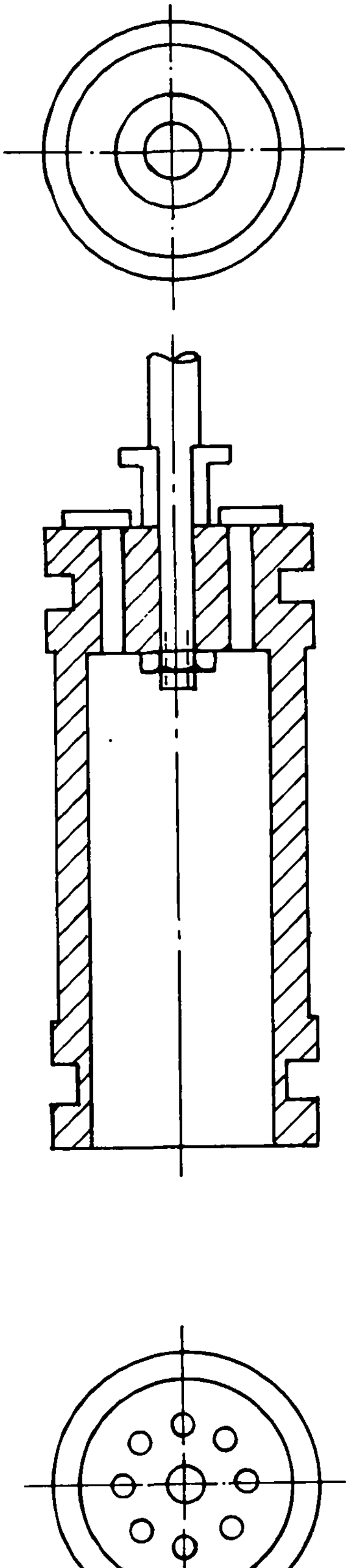


Figure 19

PLATE VALVE

TWO RINGS



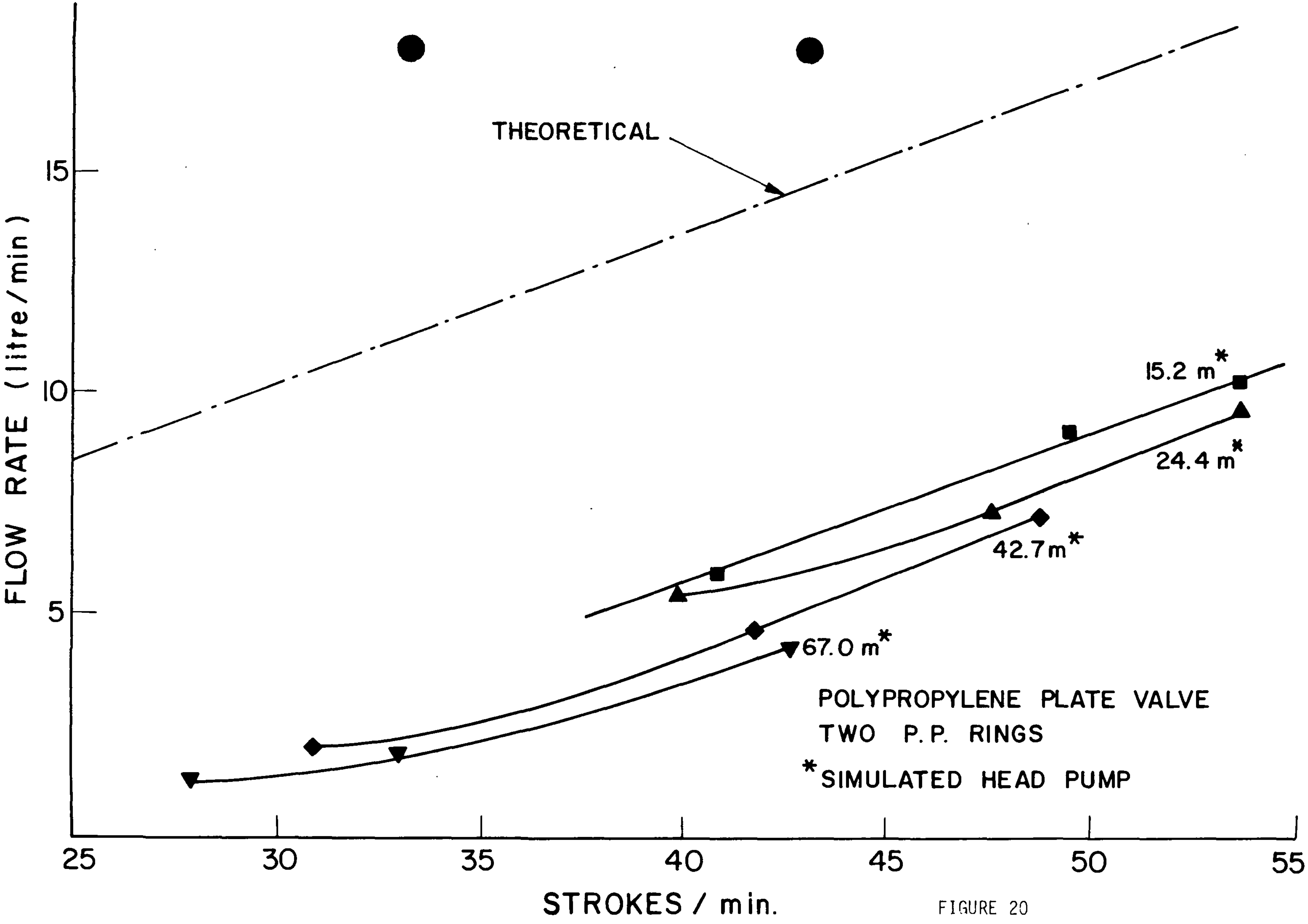

THEORETICAL
15.2 m*
24.4 m*
42.7 m*
67.0 m*
POLYPROPYLENE PLATE VALVE
TWO P.P. RINGS
*SIMULATED HEAD PUMP
FLOW RATE (litre/min)
15
10
5
25
30
35
40
45
50
55
STROKES / min.

FIGURE 20

iv) Testing Procedures

Tests for flow rate were conducted at various pressures on the simulated hand pump, corresponding to various well depths. The flow rates were recorded and plotted against stroke rate (Figures 20 - 27).

Similar tests were carried out on the 7.6 head pump with a 15 cm stroke. Generally the flow rates were measured at the discharge end, however some tests were conducted using a Kent water meter installed below the foot valve of the 7.6 m head pump. Such tests were carried out to determine whether these meters so located could be used in field trials. Generally, the volume of water pumped was the same as that recorded on the Kent meter, but since this meter registered flow in both directions any leakage was naturally subtracted from the flow monitored at the discharge. As expected, the Kent meter recorded lower volumes of water pumped when compared to those measured at the discharge end.

1) Polypropylene Plate Valve with Two Polypropylene Rings (Figure 20)

Polypropylene was ductile enough that the piston rings could be installed very easily. The rings were springy, a quality needed for efficient sealing. Although it was extremely ductile its machinability proved to be a problem since a perfectly smooth surface, free of ridges and burrs, was impossible to attain.

Hence the sealing properties of polypropylene was erratic as seen in the irregularity of the flow rate curves in Figure 20. They hydraulic efficiency for various well depths is given in Table 1.

TABLE 1 Polypropylene Valve - 2 Rings

Well Depth (m)	Flow/ Stroke litre/stoke	Efficiency (%)
15.2*	0.168	51.0
24.4*	0.155	46.0
42.7*	0.109	32.0
67.0*	0.064	19.0

* Simulated Head Pump

The polypropylene rings showed considerable wear after use. The outer surface of the rings were scored because of wearing on the PVC casing.

2 (a) Rubber Flapper Valve Pinned at a Corner - One PVC Ring (Figure 21)

The rubber flapper was 0.48 cm thick and was given additional stiffness by a washer bolted to the centres of the flapper. Even with this added stiffness, at 41.4 MPa or 42.7 m head of water, the flapper was forced through the port because of the high pressure differential. This problem may be resolved by one of two methods:

1) By attaching a large washer to the back of the rubber flapper. The washer should be larger than the valve port hole.
2) By having numerous smaller holes of about 0.32 to 0.64 cm diameter rather than one large hole. At the equivalent of shallow depths, the valve worked efficiently and offered very little resistance to flow. The results are given in Figure 21 and Table 2.

TABLE 2

Rubber Flapper Valve Pinned at Corner - One PVC Ring

Well Depth (m)	Flow/ Stroke (litre/stroke)	Efficiency (%)
7.6	0.296	88.6
7.6*	0.278	82.5
24.4*	0.232	69.0

* Simulated head pump

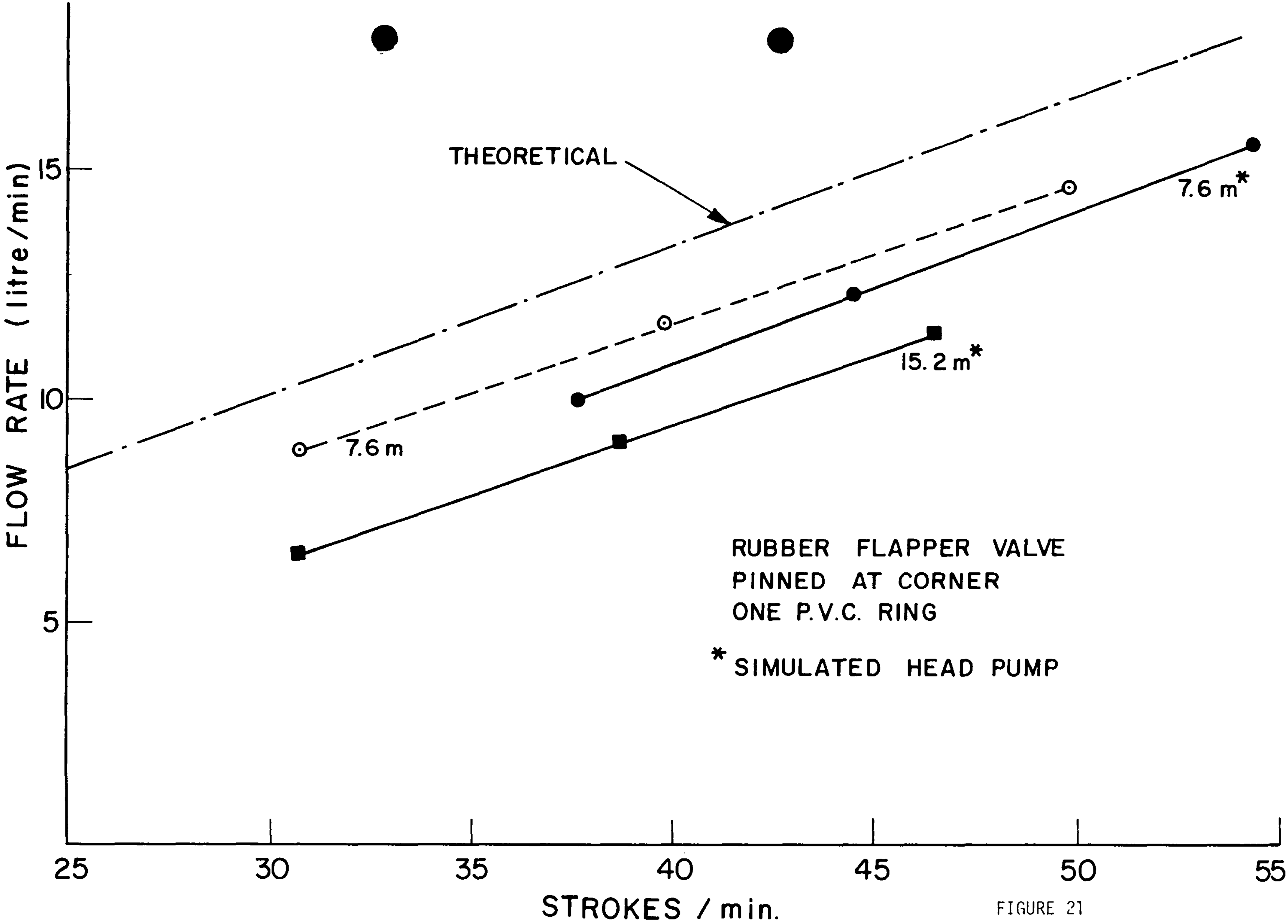
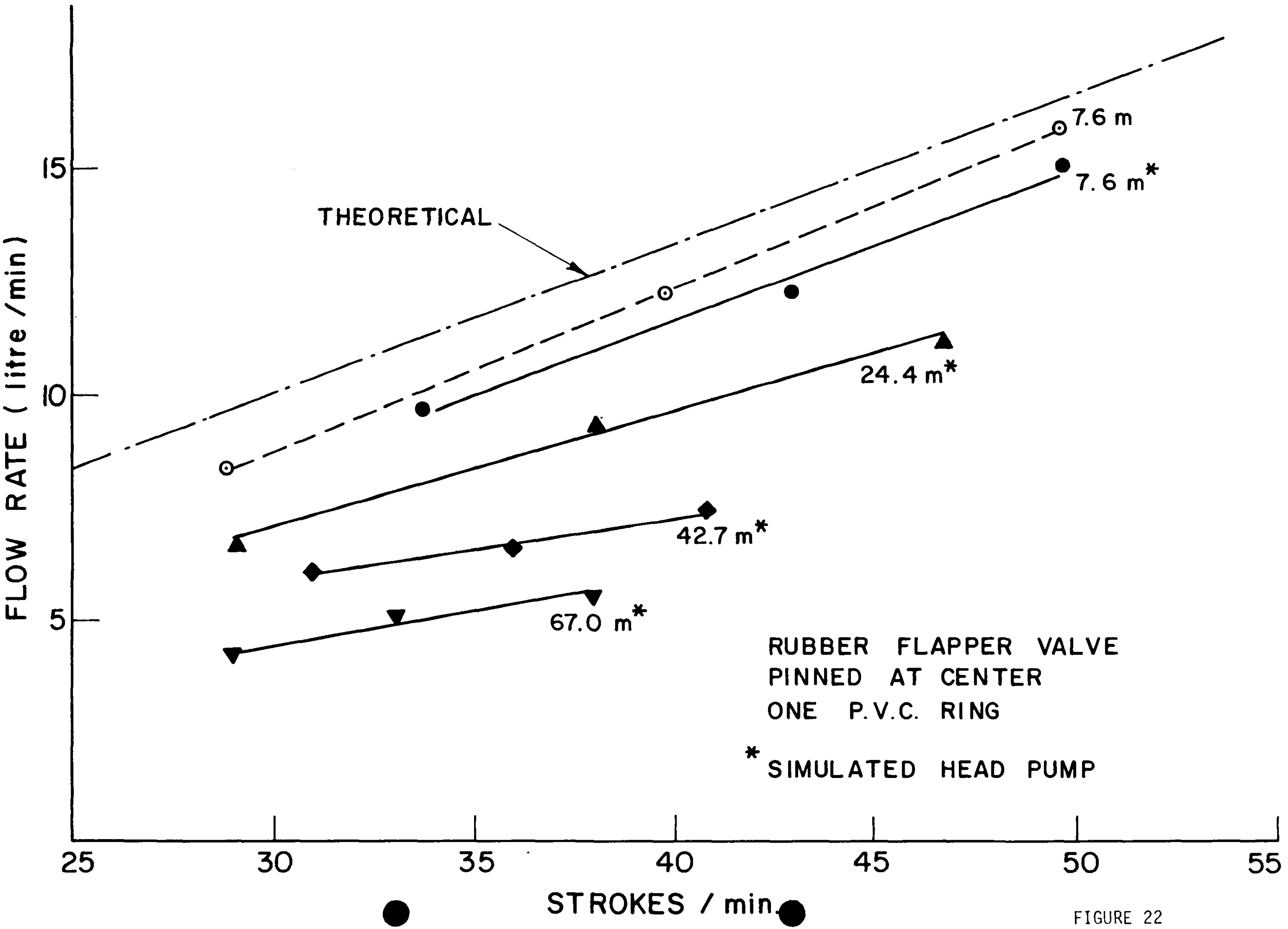

THEORETICAL
7.6 m*
7.6 m
15.2 m*
RUBBER FLAPPER VALVE
PINNED AT CORNER
ONE P.V.C. RING
* SIMULATED HEAD PUMP
FLOW RATE (litre/min)
15
10
5
25
30
35
40
45
50
55
STROKES / min.

FIGURE 21



FLOW RATE (litre / min)
5
10
15
STROKES / min.
25
30
35
40
45
50
55
THEORETICAL
7.6 m
7.6 m*
24.4 m*
42.7 m*
67.0 m*
RUBBER FLAPPER VALVE
PINNED AT CENTER
ONE P.V.C. RING
* SIMULATED HEAD PUMP

FIGURE 22

2(b) Rubber Flapper Valve Pinned in the Centre - One PVC Ring (Figure 22)

Although this arrangement had particularly good sealing properties it also offered an increased resistance to flow. While no work should be done on the downward stroke, this valve arrangement would not permit the water to flow through the valve fast enough at 60 strokes per minute without exerting some work.

The hardness and the thickness of the rubber are important in this type of valve and a rubber which is harder than 60 Shore A or thicker than 0.32 cm would present too much flow resistance. Another problem with such an arrangement is the degree to which the rubber is compressed on assembling the flapper. If too much force is applied the rubber curls up at the edges increasing the amount of water leakage. The flow rates are given in the accompanying Table 3 and Figure 22.

3) Ball Valve - 2.54 cm Steel Ball Bearing (Figure 23)

The results obtained with this arrangement were quite inconsistent since a stroke rate of 35 strokes per minute could not be attained for well depths beyond 24.4 m. At high pressures (high equivalent depths), a cushion of water caused the ball to float on the seat rather than sealing imediately. After

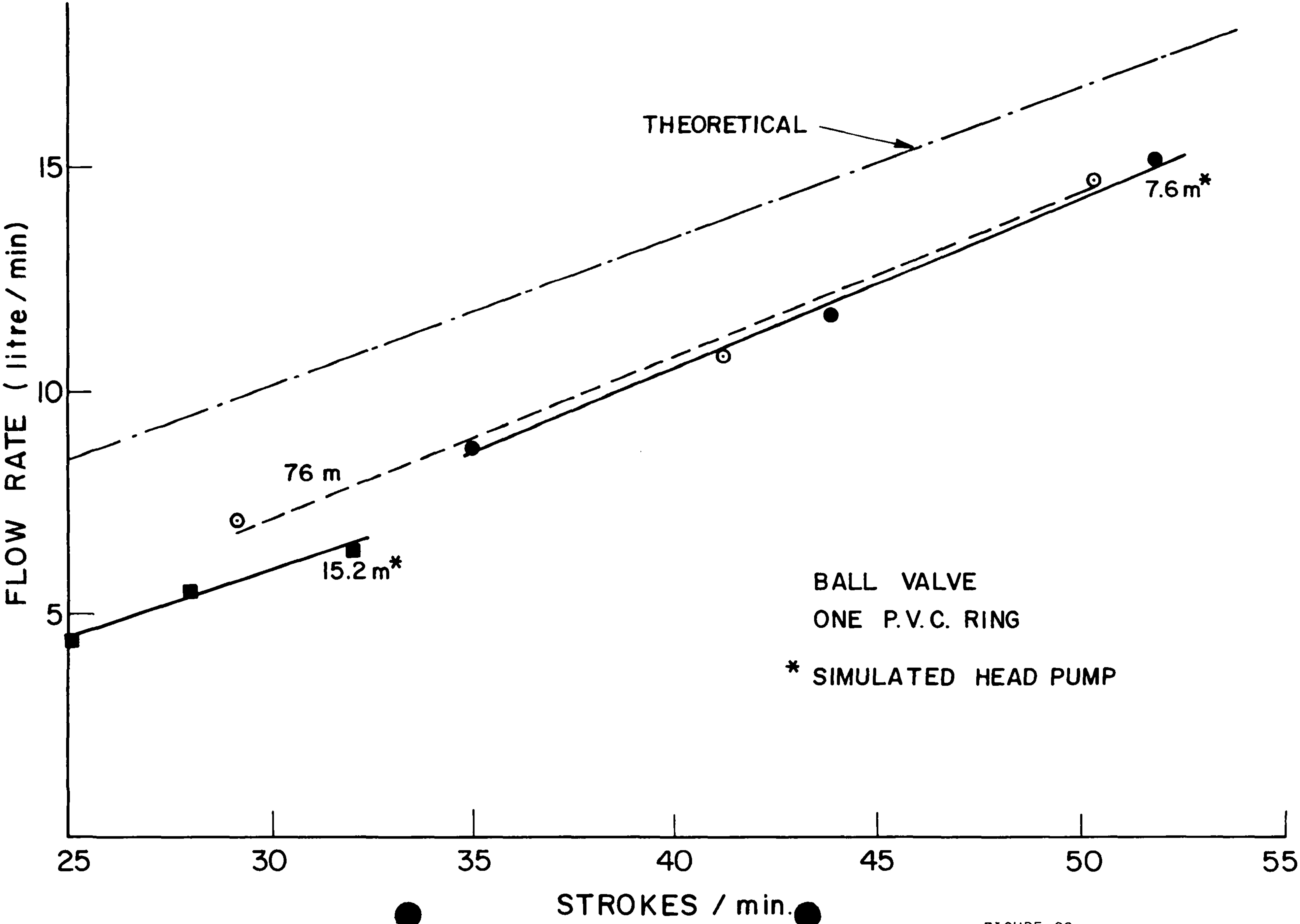

THEORETICAL
76 m
7.6 m*
15.2 m*
BALL VALVE
ONE P.V.C. RING
* SIMULATED HEAD PUMP
FLOW RATE (litre / min)
15
10
5
25
30
35
40
45
50
55
STROKES / min.

FIGURE 23

TABLE 3

Rubber Valve Centre - One PVC Ring

Well Depth (m)	Flow/ Stroke (litre/stroke)	Efficiency (%)
7.6	0.300	90.0
7.6*	0.300	89.5
24.4*	0.246	73.5
42.7*	0.196	58.5
67.0*	0.155	46.0

* Simulated head pump

a second or two, however, normal pumping action could be carried out for another couple of strokes until floating occurred again. This problem may be remedied by controlling the port hole size to be between 5/8 and 2/3 of the size of the ball. Restricting the vertical travel of the ball would also help return the ball faster but may not correct the problem. The contact area between the ball and the PVC should be kept to a minimum for maximum sealing properties. Line contact is an ideal situation.

The flow resistance was very low. At shallow depths pumping at the rate of 60 strokes per minute or more was easily achieved. The results are shown in Figure 23 and Table 4.

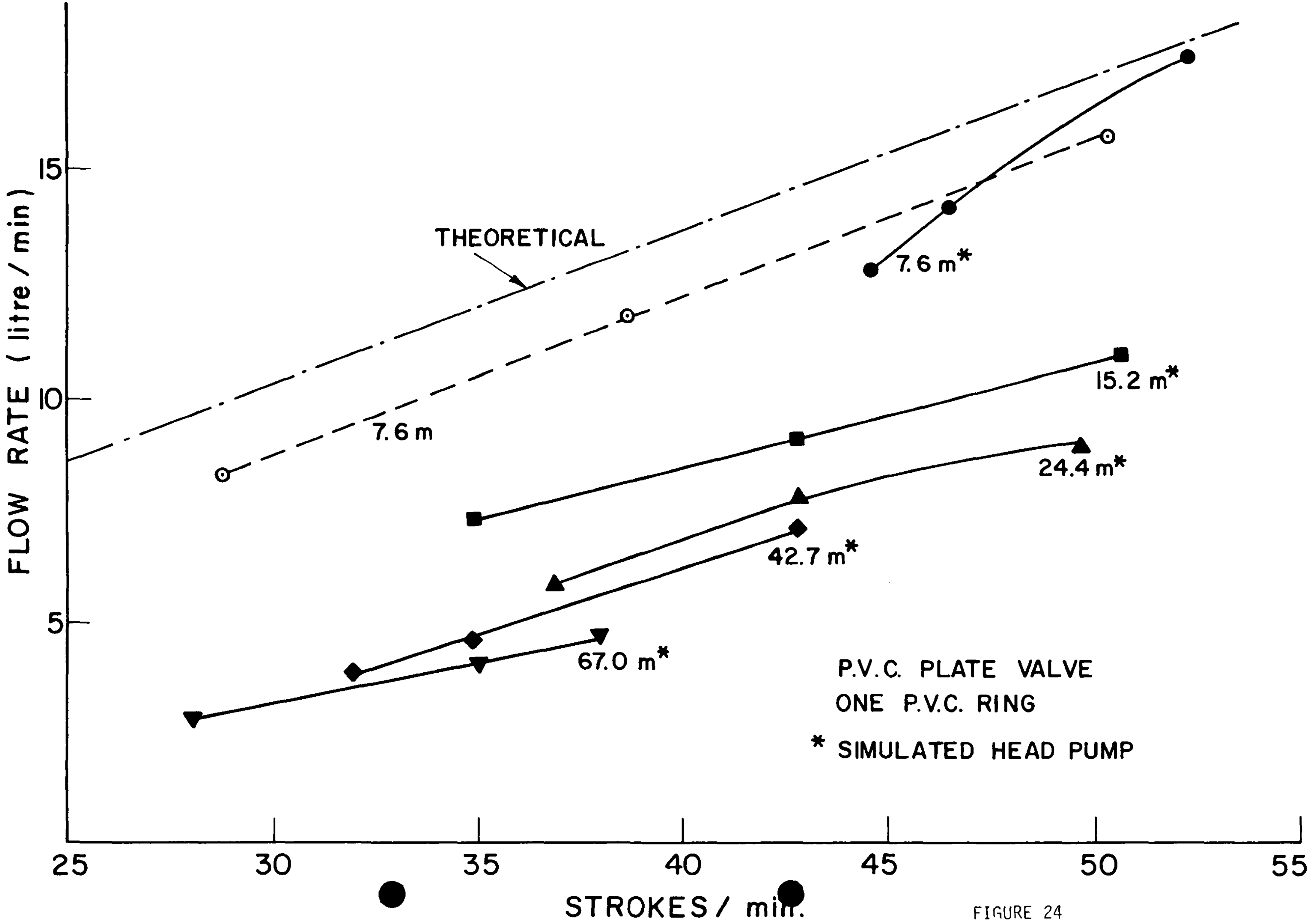

FLOW RATE (litre / min)
STROKES / min.
5
10
15
25
30
35
40
45
50
55
THEORETICAL
7.6 m
7.6 m*
15.2 m*
24.4 m*
42.7 m*
67.0 m*
P.V.C. PLATE VALVE
ONE P.V.C. RING
* SIMULATED HEAD PUMP

FIGURE 24

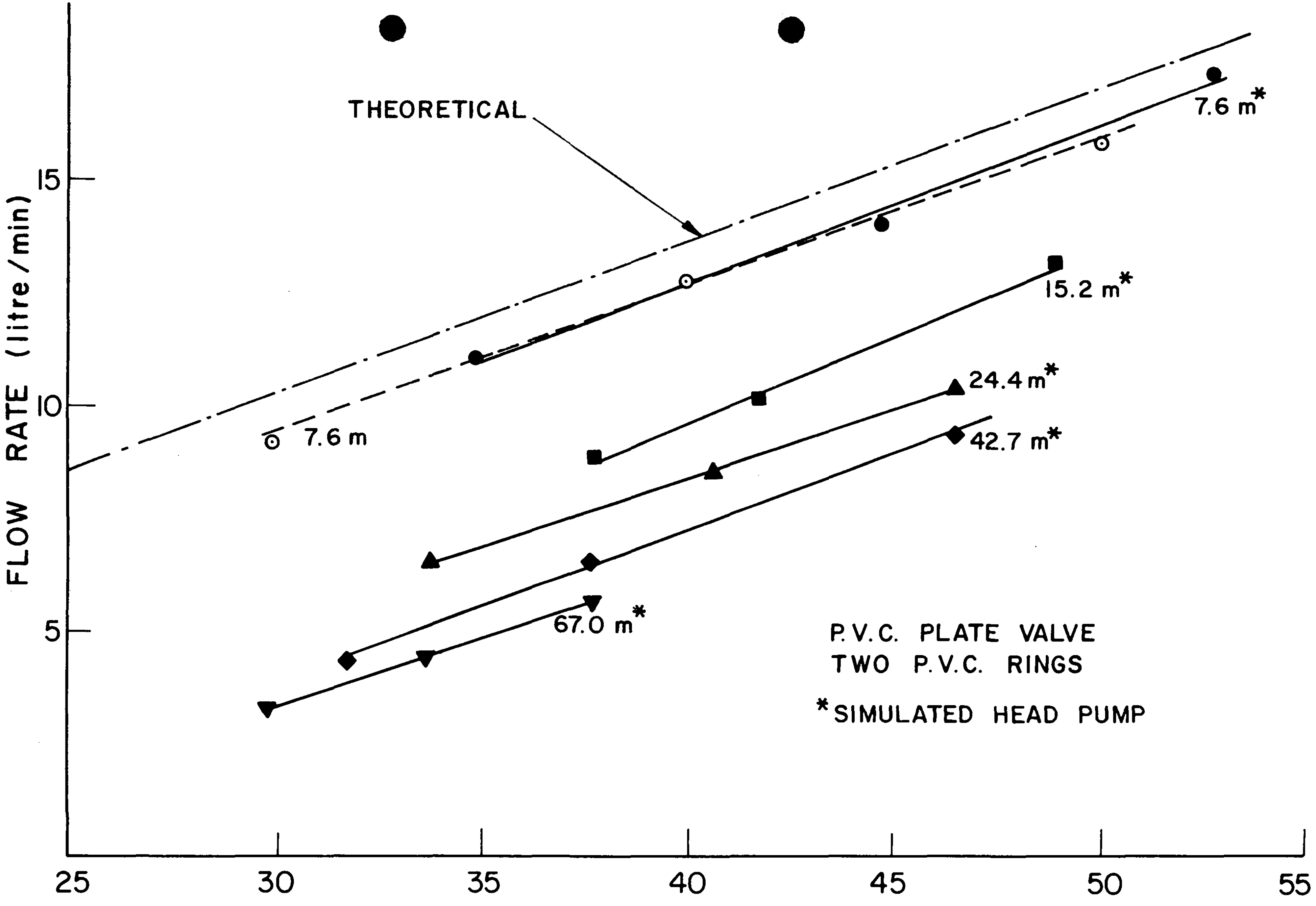

THEORETICAL
7.6 m*
15.2 m*
24.4 m*
42.7 m*
67.0 m*
7.6 m
P.V.C. PLATE VALVE
TWO P.V.C. RINGS
*SIMULATED HEAD PUMP
FLOW RATE (litre/min)
5
10
15
25
30
35
40
45
50
55
STROKES / min.

FIGURE 25

TABLE 4

Ball Valve

Well Depth (m)	Flow/ Stroke (litre/stroke)	Efficiency (%)
7.6	0.273	80.5
7.6*	0.273	80.5
24.4*	0.196	58.0

* Simulated Head Tests

Since a steel bearing will corrode in time, a non-corrosive material would be required for the ball valve.

4(a) PVC Plate Valve (Figures 24 and 25)

On installing the piston rings, they had to be either softened in hot water or small longitudinal grooves cut on the internal diameter of the ring in order to give a little more compliance. However, it is felt that with piston rings greater than 7.6 cm in diameter, these measures need not be taken. Considering the plate valve, the clearance between the plate and the guide post should be at least 0.16 cm to prevent any cocking. Also the plate must rise 0.48 cm to 1.27 cm off the seat to reduce flow resistance and allow free passage of water through the valve.

The flow rate results are given in Figures 24 and 25 and Table 5.

TABLE 5

PVC Plate Valve - Different No. of Rings

Number of Rings	Well Depth (m)	Flow/ Stroke (litre/stroke)	Efficiency (%)
2 PVC Rings	7.6	0.30	90.0
	7.6*	0.31	92.5
	15.2*	0.237	70.0
	24.4*	0.196	59.0
	42.7*	0.164	49.0
	67.0*	0.123	37.0
1 PVC Ring	7.6	0.296	89.0
	7.6*	0.30	90.0
	24.4*	0.168	50.0
	42.7*	0.141	43.0
	67.0*	0.114	34.0
No Rings	7.6*	0.164	49.0

* Simulated Head Test

The efficiency of those pistons with one and two rings is virtually the same. But with no rings, the efficiency drops drastically. The port holes were the same size as those with the centrally pinned flapper but the flow resistance was reduced substantially with the plate valve.

The optimum design for the piston was determined on the basis of the above tests. However, on careful inspection of the piston it was found to have a poorly fitting plate valve which allowed considerable leakage. As a result, the PVC plate valve could be incorrectly judged as being inferior to the rubber and leather (see later). It was decided to construct a new piston using a better fitting PVC plate valve and retest its feasibility.

A new piston with two PVC piston rings was constructed and the test was conducted in the 7.6 m actual head pump with the optimum spool foot valve (see separate section). To measure the volume pumped, two water meters were coupled in series at the outlet of the pump and to insure that the spool was functioning properly a slow upstroke was used. These results showed an efficiency of 97.3% compared to the previously recorded 90.0%. Hence, rejection of the PVC plate valve is questionable and it was decided to carry out subsequent tests on the 7.5 cm diameter pump using a PVC plate valve.

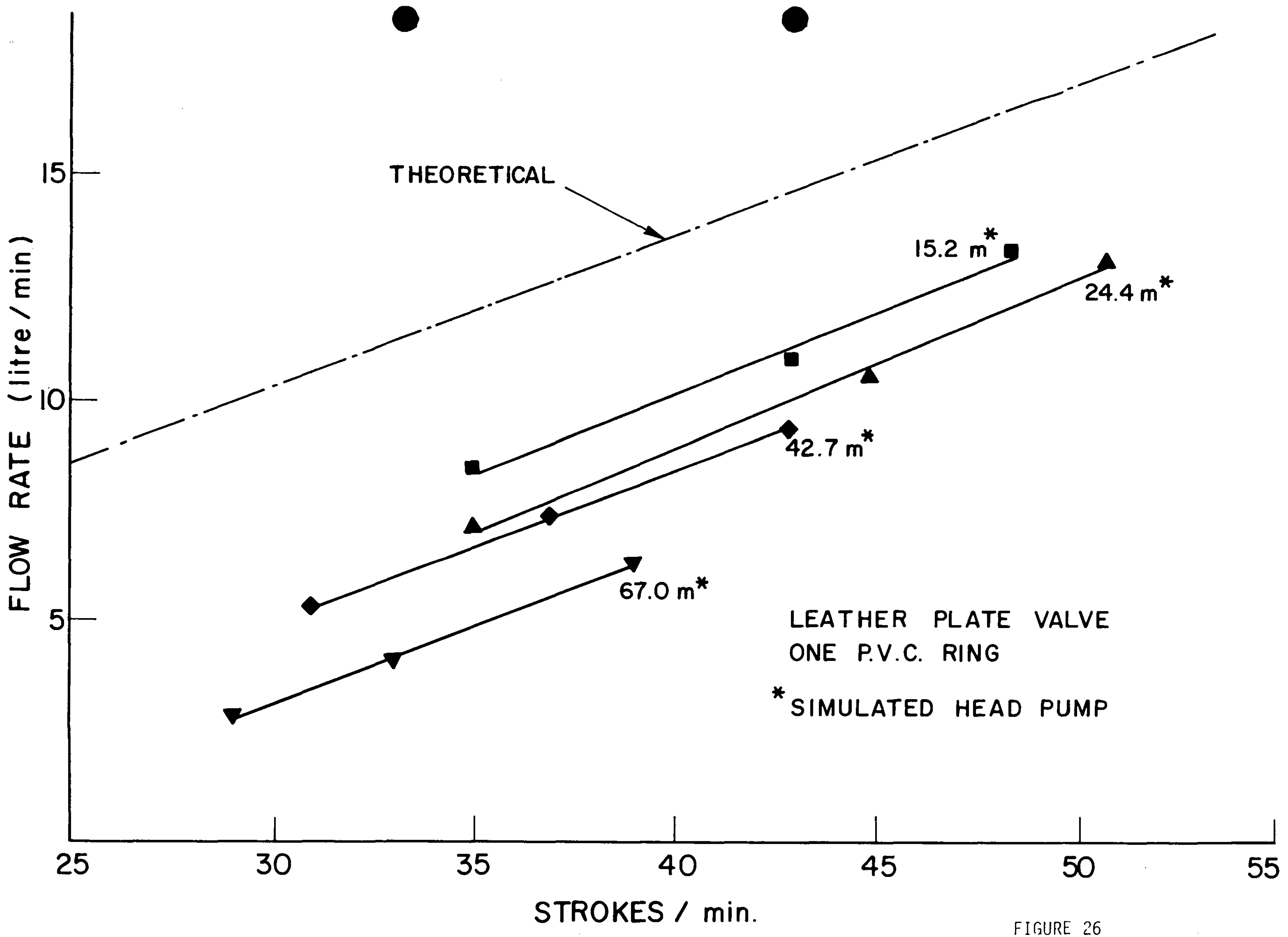

FLOW RATE (litre / min)
STROKES / min.
15
10
5
25
30
35
40
45
50
55
THEORETICAL
15.2 m*
24.4 m*
42.7 m*
67.0 m*
LEATHER PLATE VALVE
ONE P.V.C. RING
*SIMULATED HEAD PUMP

FIGURE 26

4(b) Leather Plate Valve (Figure 2.6)

Leather of 0.56 cm thickness was cut in the shape of a washer and used as the plate valve. The central hole required a clearance of 0.16 cm to prevent the leather from dragging on the central guide. Although the leather formed an excellent seal, flow resistance was very high and pumping on the downward stroke required added work. The flexibility of the leather allowed it to conform to any waviness in the top of the foot valve and piston. The flow results are given in Figure 26 and Table 6.

TABLE 6

Leather Plate Valve

Well Depth (m)	Flow/ Stroke (litre/stroke)	Efficiency (%)
15.2*	0.246	74.0
24.4*	0.228	67.0
42.7*	0.191	57.0
67.0*	0.114	34.0

* Simulated Head Test

4(c) Rubber Plate Valve (Figure 27)

The valve consisted of disc of 0.48 cm thick rubber with a hardness of 60 Shore A. The clearance between the rubber and the central post should be at least 0.24 cm, or more if possible. The rubber dragged on the post and remained open if the clearance was any less. Flow resistance was minimal compared to that of the centrally pinned flapper. The results are shown in Figure 27 and Table 7.

TABLE 7

Rubber Plate Valve

Well Depth (m)	Flow/ Stroke (litre/stroke)	Efficiency (%)
15.2*	0.24	72.0
24.4*	0.223	66.0
42.7*	0.177	53.0
67.0*	0.146	44.0

* Simulated Head Test

The problem of the plate securing itself to the top surface of the piston did not occur, as with the leather plate.

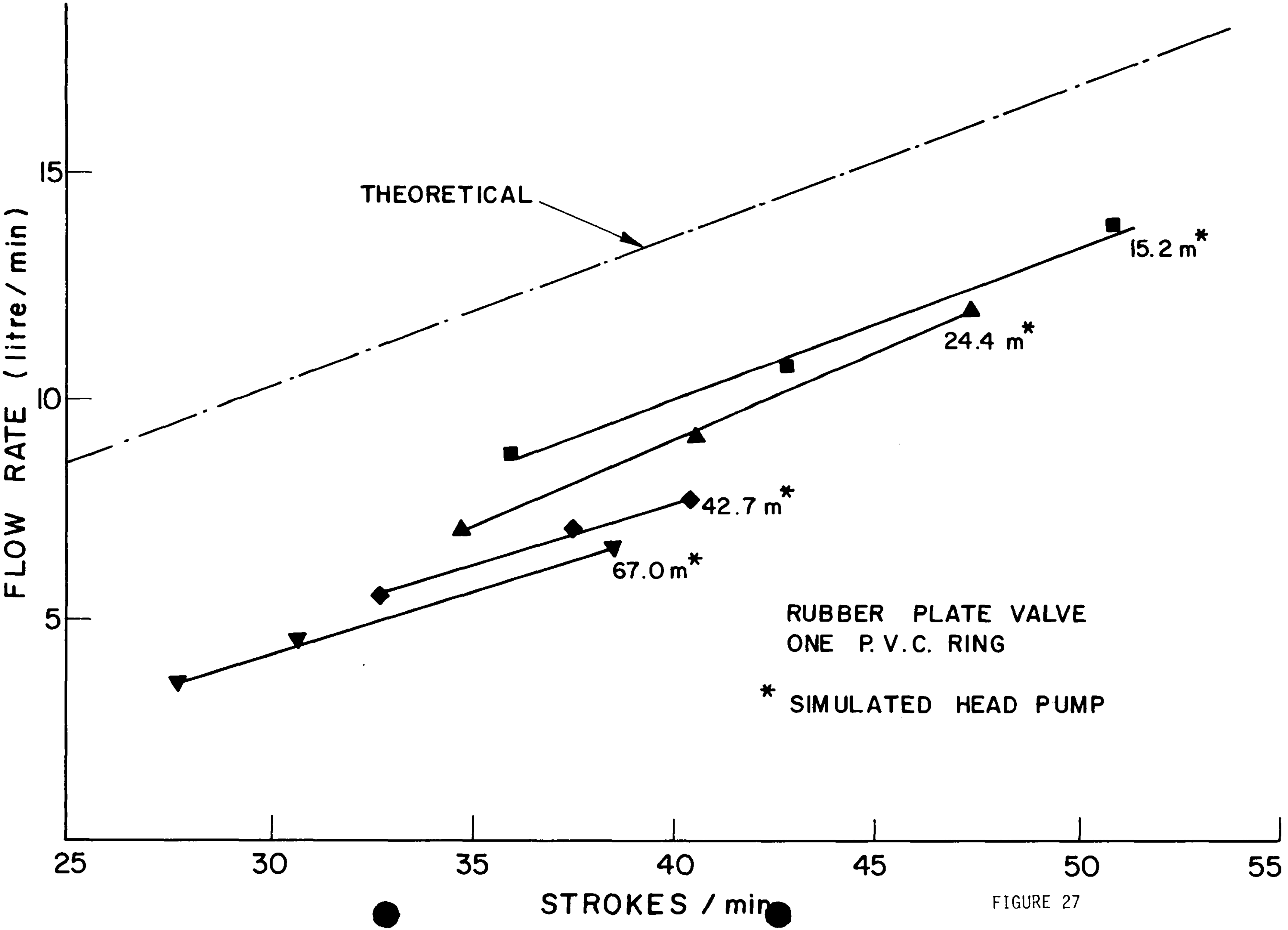

THEORETICAL
15.2 m*
24.4 m*
42.7 m*
67.0 m*
RUBBER PLATE VALVE
ONE P.V.C. RING
* SIMULATED HEAD PUMP
FLOW RATE (litre / min)
5
10
15
STROKES / min
25
30
35
40
45
50
55

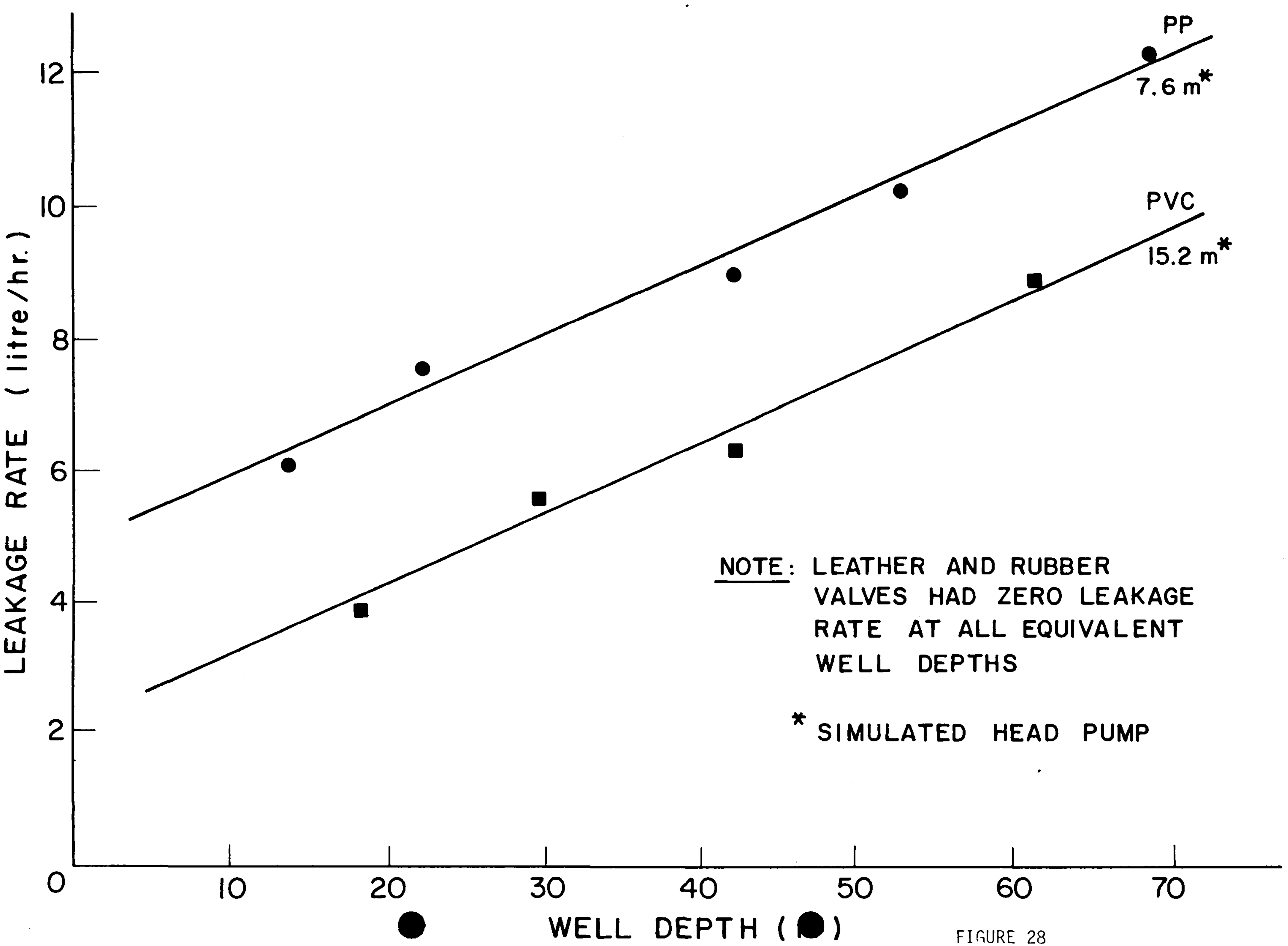
FIGURE 27

The results obtained in this section (iv) lead to the following conclusions:

1) The pumping results obtained using the simulated and actual head pumps were very similar.
2) There appeared to be very little difference between the hydraulic efficiency of pistons with one or two rings. However, as expected a dramatic loss of efficiency occurred when no rings were used.
3) Leather rings or cups offerred a high resistance to piston travel at depths greater than 30 m.
4) The ball valve gave unpredicatable results at depths above 24m.
5) Plate valves exhibited a high hydraulic efficiency. The plate valve setup was very simple although it did not give the same freedom of movement of the pump rod as the inverted piston configuration.
6) Leather and rubber plate valves displayed highly desirable properties for use as plate valves.

(v) Leakage Rates

From the flow rate figures, just discussed, it was possible to determine the leakage rates. From the theoretical flow rate and the actual flow rate, the leakage rate may be deducted as follows:



NOTE: LEATHER AND RUBBER VALVES HAD ZERO LEAKAGE RATE AT ALL EQUIVALENT WELL DEPTHS

* SIMULATED HEAD PUMP

FIGURE 28

leakage past piston + leakage past foot valve =
theoretical flow - actual flow

Since all the tests which will be described were conducted using the same PVC plate foot valve, the following results can be used to assess the relative order of leakage past the pis[illegible]n, and these are given in Figure 28.

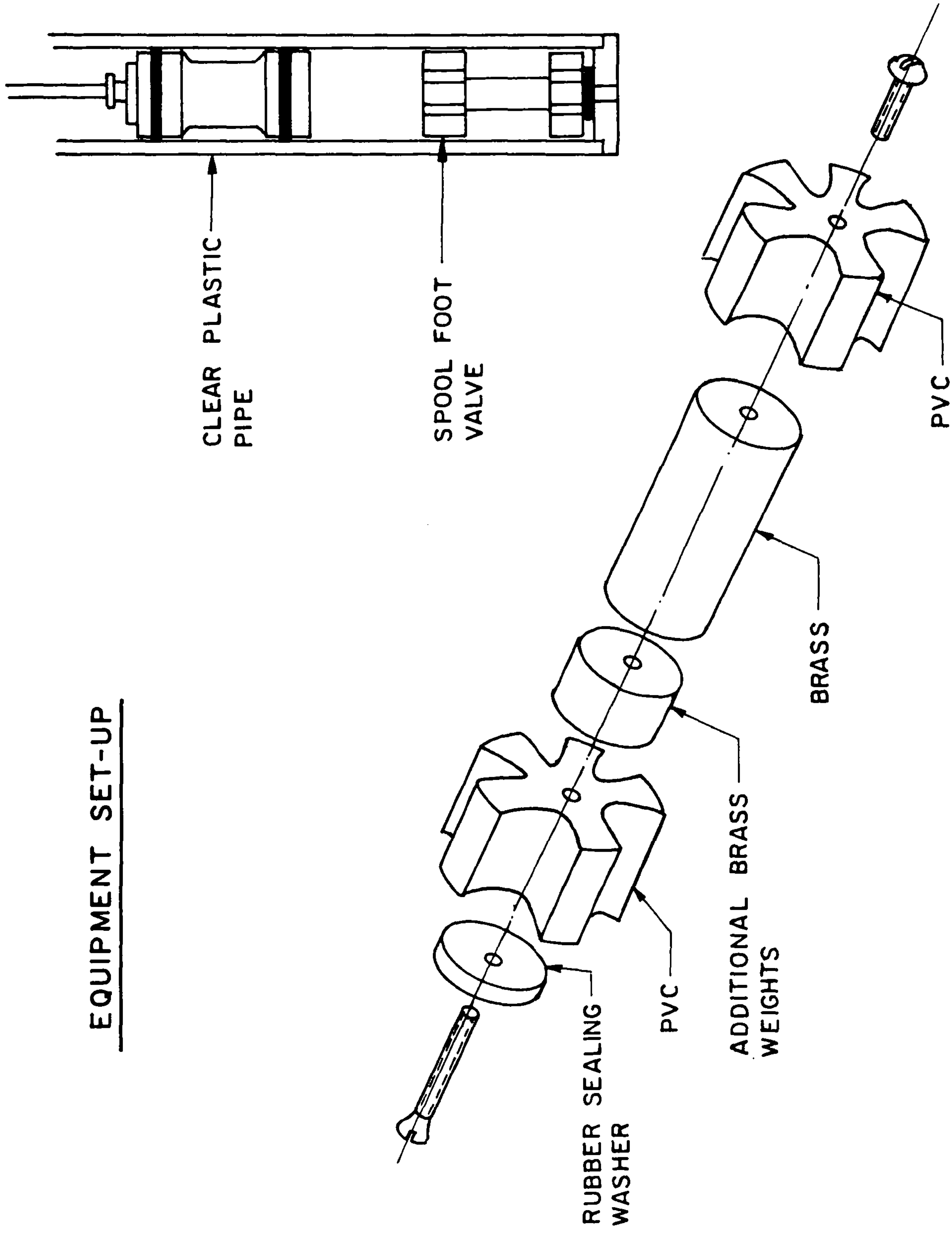
Considering the leather plate valve, leakage past the foot valve was reduced to nil at all well depths. The leather became soft and gummy when exposed to water. This allowed the plate to secure itself to the top of the foot valve and piston, forming an excellent seal. Likewise, the rubber possessed the ability to conform to its mating surface and leakage past the foot valve was also nil at all the depths tested. In these cases, any leakage past the piston would, in fact, be by the rings and not through the valve on the piston.

The same argument holds for the pistons with rubber flappers. However, with the flapper pinned at one corner there was not an even force distribution over the entire flapper resulting in higher leakage rates than those pistons with the flapper pinned in the centre.

For the polypropylene plate valve with two polypropylene rings, the leakage rate was the highest for all the equivalent well depths. The polypropylene was not flexible enough

Figure 29

SPOOL VALVE



EQUIPMENT SET-UP

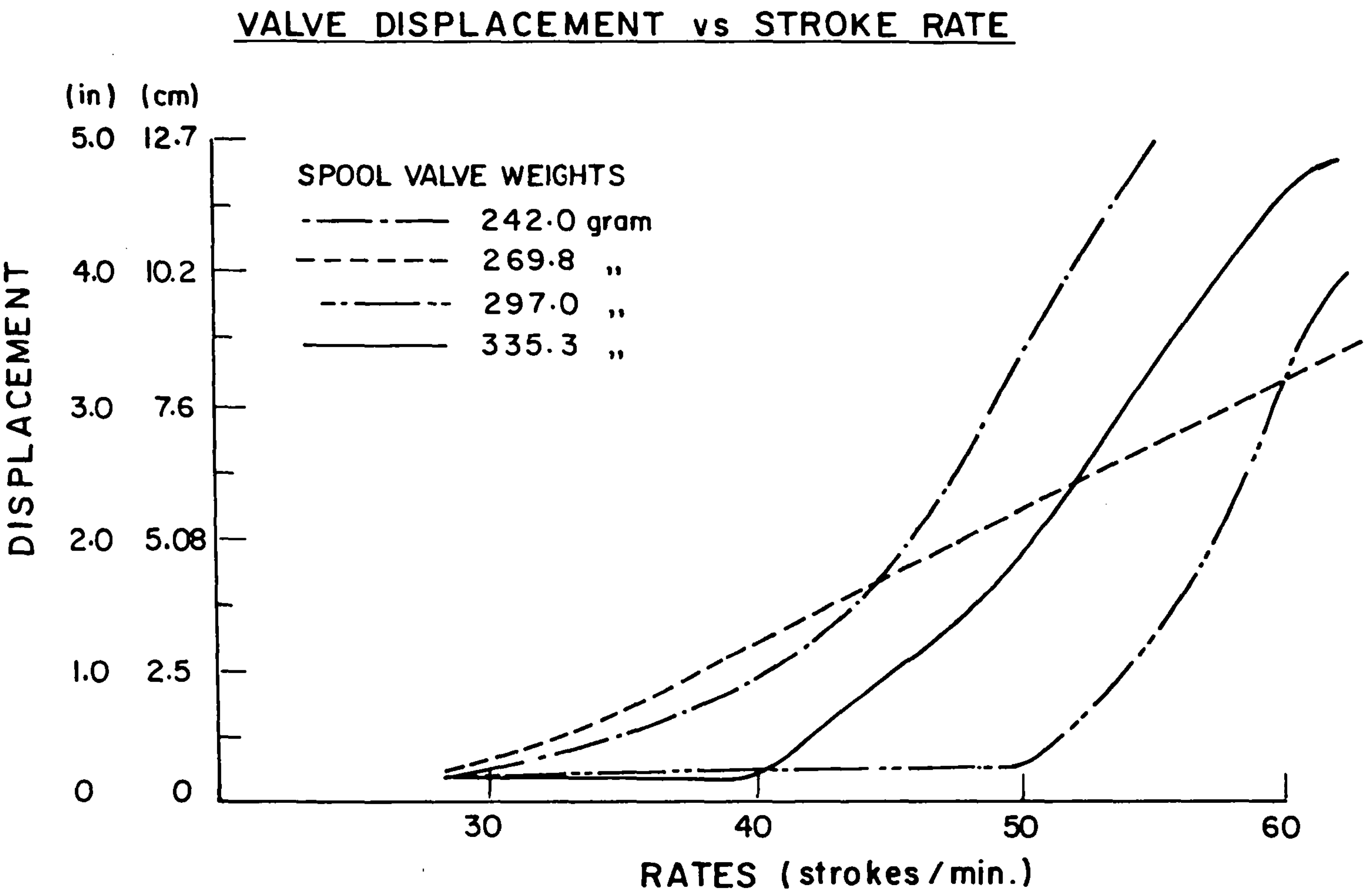
to conform to irregularities (i.e., waviness) in the mating surface. This lack of conformity resulted in a considerable static leakage rate past the foot valve and this was accelerated by the large amount of wear on the rings during testing.

PVC is much easier to machine and the smoother finish resulted in lower leakage rates, as seen in Figure 28. Also, it must be borne in mind that these rates were determined with the badly fitting plate valve.

(vi) Recoverable Foot Valve - Spool Type

Experiments were conducted using a spool type foot valve in the hope of developing a foot valve that could be easily removed for maintenance after the well had been installed.

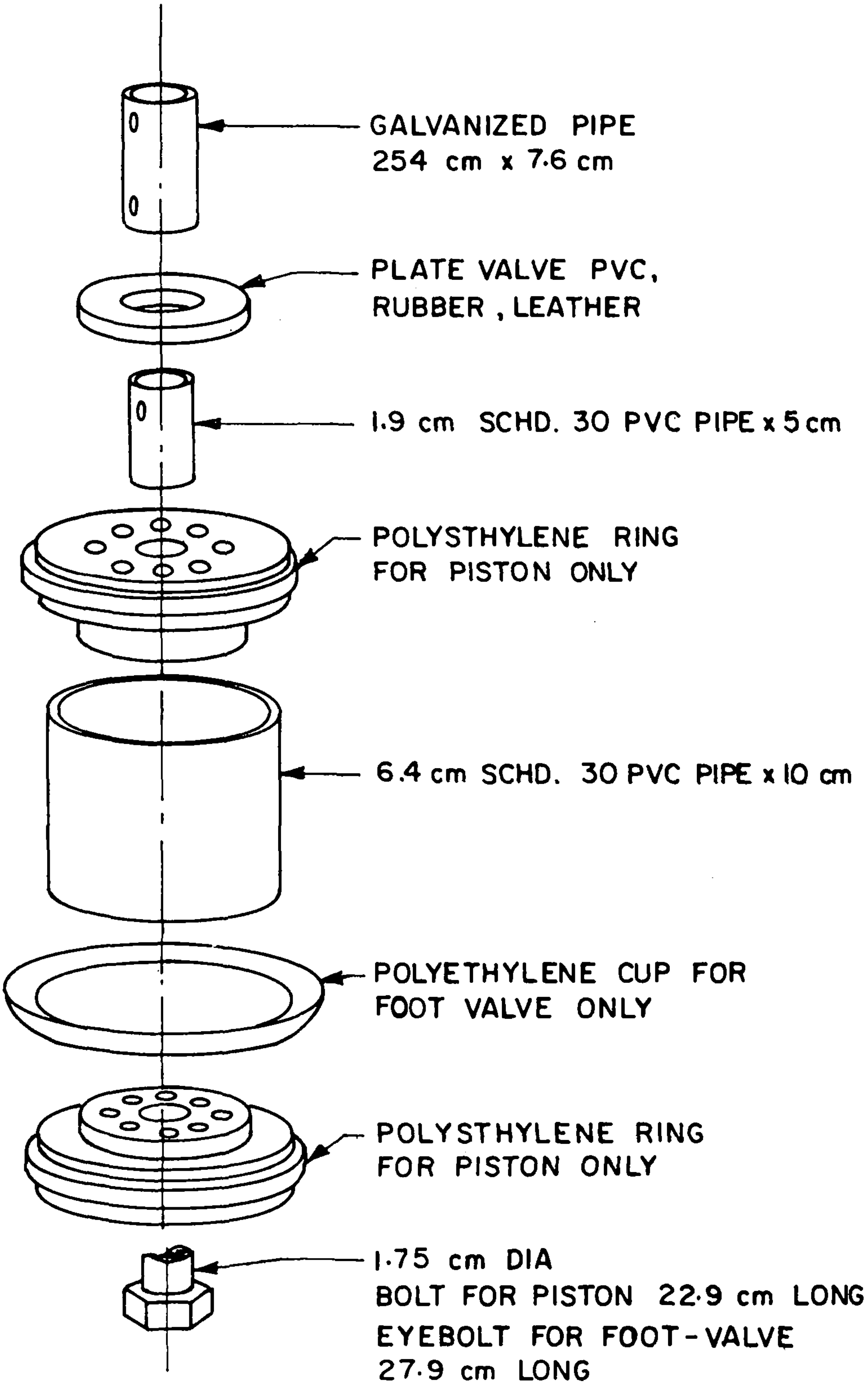
To check this feasibility, a spool valve of solid PVC was installed on the 7.6 m 5 cm diameter pump. Unfortunately, this caused an excessive thumping during the pumping action. To determine the cause, it was decided to install a clear plastic casing (PMMA) at the bottom end of the well. This arrangement is shown in Figure 29 on the following page. It became obvious that the spool was too light. Therefore, a solid brass spool was constructed and installed. This proved to be too heavy and again caused excessive vibrations. Therefore a spool valve with interchangeable weights was constructed as shown at the bottom of Figure 29. For the final test, the weights and pumping rates



VALVE DISPLACEMENT vs STROKE RATE

Figure 30

Figure 31


GALVANIZED PIPE
254 cm x 7.6 cm
PLATE VALVE PVC,
RUBBER , LEATHER
1.9 cm SCHD. 30 PVC PIPE x 5 cm
POLYSTHYLENE RING
FOR PISTON ONLY
6.4 cm SCHD. 30 PVC PIPE x 10 cm
POLYETHYLENE CUP FOR
FOOT VALVE ONLY
POLYSTHYLENE RING
FOR PISTON ONLY
1.75 cm DIA
BOLT FOR PISTON 22.9 cm LONG
EYEBOLT FOR FOOT-VALVE
27.9 cm LONG

were varied and the spool's upward displacement was recorded. The results are shown in the following Table 8 and Figure 30.

TABLE 8

Spool Valve Displacement

Strokes min	Spool 242 gm	Spool+1 Weight 269.8 gm	Spool+2 Weights 297 gm	Spool+3 Weights 335.3 gm
30	32 cm	64 cm -slight clatter	0.32 cm -tips to one side	0.32 cm -tips to one side
40	2.5 cm	3.81 cm	0.64 cm	0.32 cm -tips -slight chatter
50	8.9 cm -varying, long then short	5.0 cm	0.64 cm	1/4" - 3 1/2" -varies 0.64 - 8.4 cm
60		7.6 - 8.9 cm	8.9 cm	10. - 11.4 cm -consistent

Figure 30 clearly shows that the displacement was not dependent upon the stroke rate but upon the upward velocity of the piston. An optimum spool weight would have to be determined by comparing the range of piston velocities to spool displacements, although in this test, the spool with an additional weight seems to be the optimum. Selection of a suitable spool weight is obviously a difficult matter.

It is also likely that a spool valve which had the correct weight to respond quickly to piston movements would destroy its restraining ring. Hence, a spool valve is not recommended. It will work if made properly but its set-up and maintenance costs are likely to be excessive.

II 7.6 cm Pump Tests

A 7.6 cm diameter pump was constructed to test the feasibility of having the piston identical to the foot valve. This enables the foot valve to be removed after the well has been installed. Also, the piston and foot valve may be easily repaired since the majority of parts are the same, the only difference being the sealing devices and the center bolts holding them together, see Figure 31.

Testing was performed on a 7.6 cm deep well and pump arrangement identical to the 5 cm pump and was conducted in order to determine the optimum sealing components for both the piston and foot valve. For each test both components had a PVC plate valve. Various seals on the piston and foot valve were investigated and the corresponding hydraulic efficiencies are given in Table 9.

TABLE 9

HYDRAULIC EFFICIENCIES FOR VARIOUS SEALS

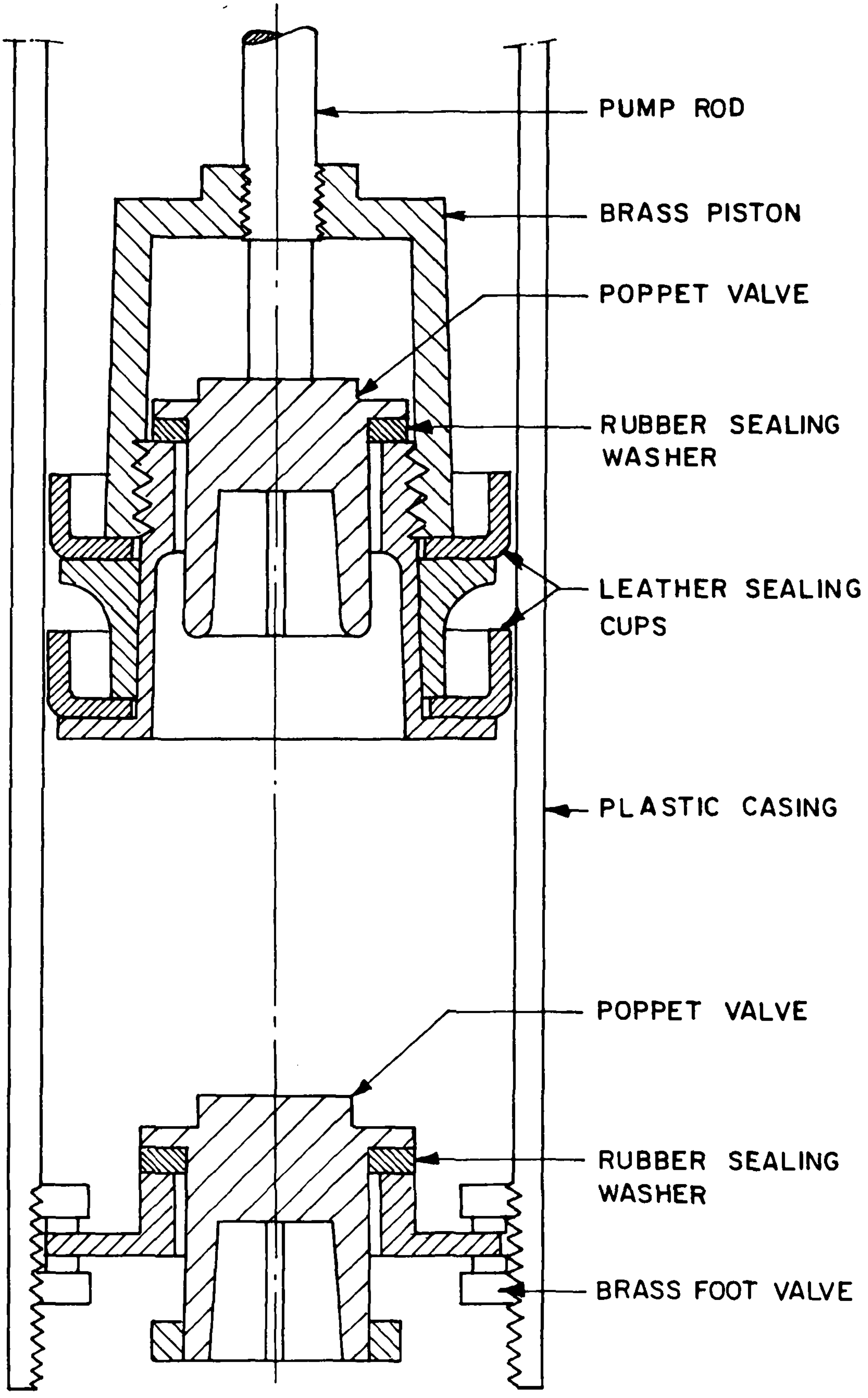
Trial No.	Arrangement of Seals		Volume of Water litre/stroke	Efficiency %	Remarks
	Piston	Foot Valve			
[illegible]-4	2 PVC rings	2 layer leather cup	av. 0.64	av. 74.5	About 0.22 litre of water leaked past piston/stroke
5-7	2 PVC rings with 2 layer leather added cup	2 layer leather cup	0.83-Trial 5 1.1-Trials 6,7	av. 96.5	High frictional resistance during pumping
8,9	2 PVC rings with polyethylene cup	2 layer leather cup	av. 1.04	av. 89.5	Lower pumping resistance
10,11	2 PVC rings with polyethylene cup	Polyethylene cup	av. 1.145	av. 99.0	
12	Polyethylene cup only	Polyethelene cup	1.01	88.0	No rings on piston
13,14	2 PVC rings	Polyethylene cup	1.09-Trial 13 1.16-Trial 14	91.5 97.0	Trial 14 had higher stroke rate
15,16	2 high density polyethylene rings	Polyethelene cup	1.10-Trial 15 1.16-Trial 16	95.0 98.0	Trial 16 had higher stroke rate

It is apparent that it is possible to achieve a good pumping efficiency using various combinations of seals between the piston and pump wall or foot valve and pump wall. As described in a later section on wear, it is desirable to have the soft wear components on the piston so that they may be more easily replaced. For this reason the combination of two high density polyethylene rings on the piston and a polyethylene cup on the foot valve was chosen. It was noticed that when raising this piston very slowly, there was very little sealing on the rings. This should be regarded as being attractive since the piston may be serviced easily if raised slowly. Also, the leakage rate (which of course is also a function of the efficiency of the foot valve) was found to be only 0.22 litre/hours, ie. overnight, the level in 7.6 cm diameter well would drop 51 cm.

ii) Dempster Pump (Two Leather Cups) (Figure 32)

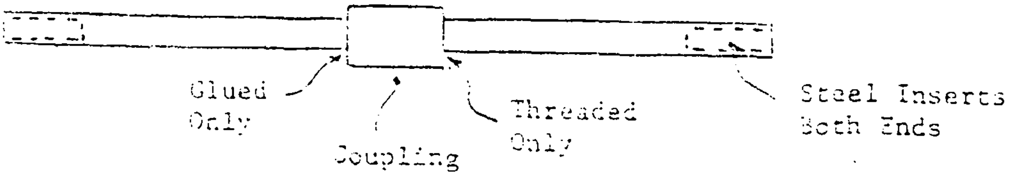
The Dempster Pump has a 7.6 cm diameter PVC casing with brass leather piston arrangement shown in Figure 32. For comparison with the present work this pump was attached to the simulated head equipment. The foot valve had a zero leakage rate at all equivalent well depths down to 60 m.

Figure 32



DEMPSTER PUMP

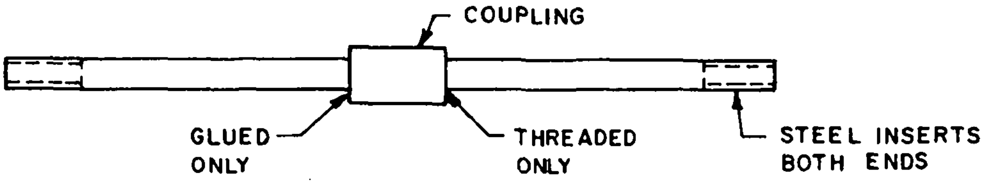
At well depths greater than 38 m the piston required too much force to move with a 6:1 mechanical advantage in the lever arm. At 24.4 m, the leather cups offered three times the drag as that of the PVC ring piston (Appendix D). Hence, although the sealing properties of such a pump are extremely good, it is limited by the depth at which they can be effectively used.



11. PUMP ROD TESTS

a) PVC Pipe Coupling Test

This test was carried out in order to determine the strength of 1.9 cm and 1.27 cm diameter PVC pipe and coupling. A socket-threaded coupling was chosen to determine whether a glued joint was stronger than a threaded one. The sample pipes were assembled as shown below.



The steel inserts prevented the pipe from collapsing in the jaws of the Tatnall testing machine. Since this machine had a dial readout, only the ultimate strength was recorded. The results obtained are as follows:

TABLE 10

Failing Loads of Glued/Threaded Pump Rod Couplings

Pipe Size cm	Thread Engagement #Turns	Max. Load kg	Comments
1.90	5	916	Glue Joint Failed
1.27	4 1/2	649	Glue Joint Failed

From these results, it is apparent that either glued or threaded sections will be strong enough to maintain the weight of water in a 61 m 7.6 cm diameter well (approximately 295 kg). The threaded joints, may however, be susceptible to fatigue failure and for future reference, the shear stress of the glued joints will be considered in the following manner:

TABLE 11

Failing Stresses of Glued/Threaded Pump Rod Coupling

Pipe cm	X-Sect. Area cm^2	Shear Area cm^2	Tensile Stress M pa	Shear Stress M pa
1.90	3.3	10.5	27.0	8.6
1.27	2.3	8.6	27.9	7.4

The observed shear stress on failure should have been equal to the maximum of PVC shear stress (24.1 M Pa) because the joints were solvent welded. The only possible explanation for this descrepancy is that there was not 100% glue coverage in the joint.

b) Bolted PVC Pipe Couplings

Other couplings were bolted to the pipe in order to test the tensile properties. With this arrangement there were many possible modes of failure which include the following:

1. Bearing on pipe
2. Bearing on coupling

3. Shear of bolt
4. Shear tearout of pipe
5. Shear tearout of coupling
6. Tension failure of pipe
7. Tension failure of coupling

To match the tensile strength of the pipe with the shear strength of the bolt, originally a 0.48 cm dia. stainless steel bolt was used. To attain the maximum strength, the shear area of the pipe and the coupling were made equal and to further increase the strength of the pipe, a PVC plug was solvent welded into the end. This had the added advantage of making the pump rod bouyant. Since there was a limited supply of coupling, only one test on each pipe size was carried out and the results are shown below.

TABLE 12

Failing Loads of Bolted PVC Pipe Couplings

Pipe cm	Max. Load kg
1.90	649
1.27	377

The mode of failure was by shear tearout of the coupling in both cases. To increase the strength of a bolted connection a piece of galvanized pipe should be used as a coupling thus allowing the shear area in the PVC pipe to be made as large as possible and this will be considered later.

c) PVC Rod - Piston and Pump Rod Connection

Tensile tests were performed on a threaded PVC rod to determine its feasibility as a means of connection to the piston. The first specimen had a National coarse thread machined at one end and a National fine thread at the other. This was simply to determine which thread was the stronger. The coarse thread proved to be the weaker as it failed in tension at a load of 408 kg. The second specimen tested was a 1.27 cm PVC rod threaded at both ends with a 20 National fine thread. Each end was engaged 1.27 cm in the holders. The tensile failing load was 544 kg.

The static strength of the threaded PVC was sufficent to support the weight of the water but its fatigue strength may be greatly reduced because of the stress concentration at the root of the threads. For this reason, it would be advisable to use galvanized or stainless steel connecting bolts and the fatigue properties of these materials are considered. These tests have shown that the glued coupling provided the strongest joint, however, by using design procedures a bolted connection of the same strength may be provided.

Using standard analytical techniques (6), the fatigue and static failure loads in both shear and tension were calculated for various sizes of connecting bolts and galvanized steel pipe sheaths. This allowed the optimum sizes to be determined and the final design is shown in Figure 4. It should be noted that this design was tested in the 7.6 m pump. The static and fatigue failure loads of all the components are given in Table 13 and a typical calculation is given in Appendix E.

TABLE 13

Static and Fatigue Failure Loads of Coupling Components

Component	Ultimate Stress (Tension) MPa	Failing Load kg			
		Static		Fatigue	
		Shear	Tension	Shear	Tension
Stainless Bolt 9.5 mm Ø	469.0	1406		438	
Galvanized Steel Sheath	324.1	3969	4672	347	792
Stainless Centre Bolt	469.0	9356	2591	1923	532
PVC Pump Rod (1.90 cm)	48.3	2818	5906	1082	257

When these values are considered in light of the fact that the dynamic load of water in a 7.6 cm diameter well 61 m deep is 439 kg (for the same diameter well 30.5 m deep, the load is 220 kg) then it is apparent that the tensile fatigue strength of the PVC pump rod (1.9 cm) will limit this design to a depth of 30.5 m.

d) Pump Rod - Load Limit Device

In order to pre-empt the pump rod couplings from failing due to fatigue in the well a short length of the pump rod should be directly attached to the handle. This short length should contain one hole of 1.27 cm diameter in the horizontal plane. The failing load in fatigue will then be limited to 255 kg using the same type of analysis as used above.

12. ALTERNATIVE COUPLING METHODS

PVC casing sections can also be joined by using factory-made gasketted seals or by using heat-shrink tubing. The latter method is the better of the two, but neither can be recommended at present.

The trend in North American industry appears to be towards use of gasketted bells which are essentially bells with an internal sealing ring. These are push-fit joints and consist of a socket designed to give clearance fit on the outside diameter of the corresponding pipe spigot end. A groove is formed inside the bell and an elastomeric ring is seated in this groove. Various designs are available. They generally provide a tighter seal the higher the pressure, because of the manner in which the ring is constituted.

There are several advantages to this system when used in industrialized countries. Large pipe is generally somewhat difficult to solvent seal because there may be a problem in the field supplying enough solvent and then in joining the softened pipe ends quickly enough to secure a good weld. This is not likely to be a problem in wells designed for hand operated pumps, since the casing size is not likely to be more than 4 inches in diameter. However solvent sealing could be troublesome where mechanized pumping is contemplated and larger well bores accomodated. The advantage of a mechanical push-fit seal in this case is obvious and the major attraction of these joints is in their simplicity since laying such pipe requires less training, is quicker and less prone to error. Also the gasketted pipe can be installed under almost any weather conditions and even under water.

A major disadvantage to this system is the cost. The tooling required to produce such gasketted bells in the factory is expensive and sophisticated and current prices for such joints are in the range of five dollars. It is very unlikely that the available markets would justify the costs of installing such equipment in factories in under-developed countries.

These seals are suitable for horizontal irrigation casings but may not be adequate for vertical use in wells. Most seals will not stand an end load. One seal (Plas-Tyton trademark) was tested and it was found that the seal came apart at loads much lower than would be exerted by a column of water in a medium depth well (Table 14). Gasketted bells are not recommended for water well casings at the present time.

An alternative method for joining PVC sections involves the use of heat-shrink pipe sleeves. This procedure has much promise, but it also cannot be recommended at present since there are still some problems to overcome with the procedure.

The shrink tubing used in our study was Canusa Heat Shrink Pipe Sleeve distributed by Shaw Flexible Tubes Limited, of Rexdale, Ontario. This is a cross-linked polyethylene tube coated inside with a heat-sensitive adhesive.

The sleeve is slid into place over the joint and is heated with a propane torch until the color of the polyethylene changes from yellow to orange. The sleeve shrinks to form a tight fit on the pipe. The pipe sections must be held aligned which the retaining sleeve is shrunk onto them. This can be easily accomplished in a number of ways, such as by using wooden cradles to support the horizontal sections. A long interior retaining plug mounted on a pole long enough to reach the joint from the end of a section may be used to facilitate alignment.

A test was carried out on 10.7 cm sleeve which was designed to shrink down to 8.9 cm. On a nominal 7.6 cm PVC pipe (8.9 cm OD) the sleeve produced a joint which ruptured under a tensile load of only 395 kg. A double sleeve, applied in two successive heat applications, failed at 885 kg load, which is almost triple the dead weight load to be expected in a 60 metre well. Data are given in Table 14.

TABLE 14

Failing Loads of Casing Couplings

Pipe Used	Coupling	Ultimate Strength
PVC	Heat Shrink	395 kg
PVC	2 Layers Heat Shrink	885 kg
PVC	Plas-Tyton	23 kg
Polyethylene	Heat Shrink	288 kg

It was found, however, that inadvertently heating the PVC pipe while the sleeve was being shrunk on caused ripple-like distortions in the inside wall of the pipe. These perturbations were sufficiently great to impede the passage of a moderately tight-fitting piston.

This problem can possibly be alleviated by using a lower shrinkage temperature and correspondingly longer shrinkage time. However, it is clear that more care is needed than can normally be expected in field installations. Solvent cement welding with standard socket-socket couplings is more dependable and not much more expensive. Therefore it is recommended as the preferred procedure, although the use of shrink sleeves could be developed further.

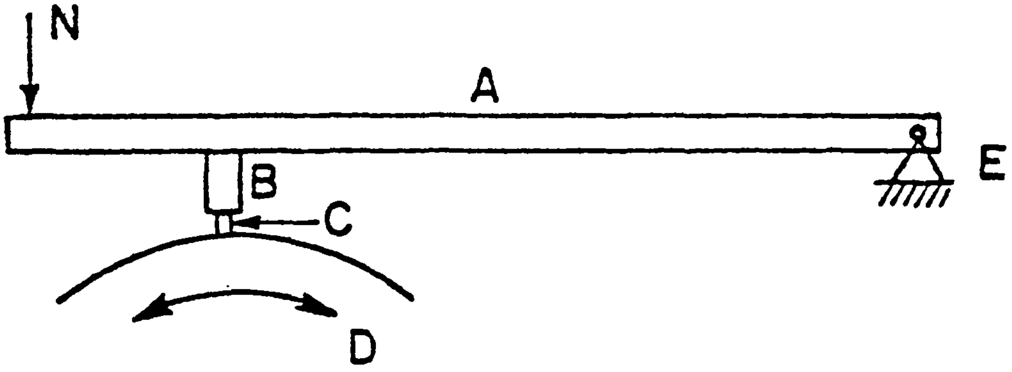
The shrink sleeve seal was not tested for pressure since it was eliminated from further consideration for the reason given. It is highly likely that a single sleeve will suffice for shallow and medium (up to 30 m) wells, although a double sleeve may be needed for greater hydrostatic heads.

13. POLYMER ON POLYMER WEAR TESTS

The object of these tests was to determine the component wear rates in a hydraulic pump made from various plastic components and the conditions of testing were so chosen that there was as close simulation of the normal stresses, sliding velocities, sand contamination, and stroke length as those observed by the pump elements.

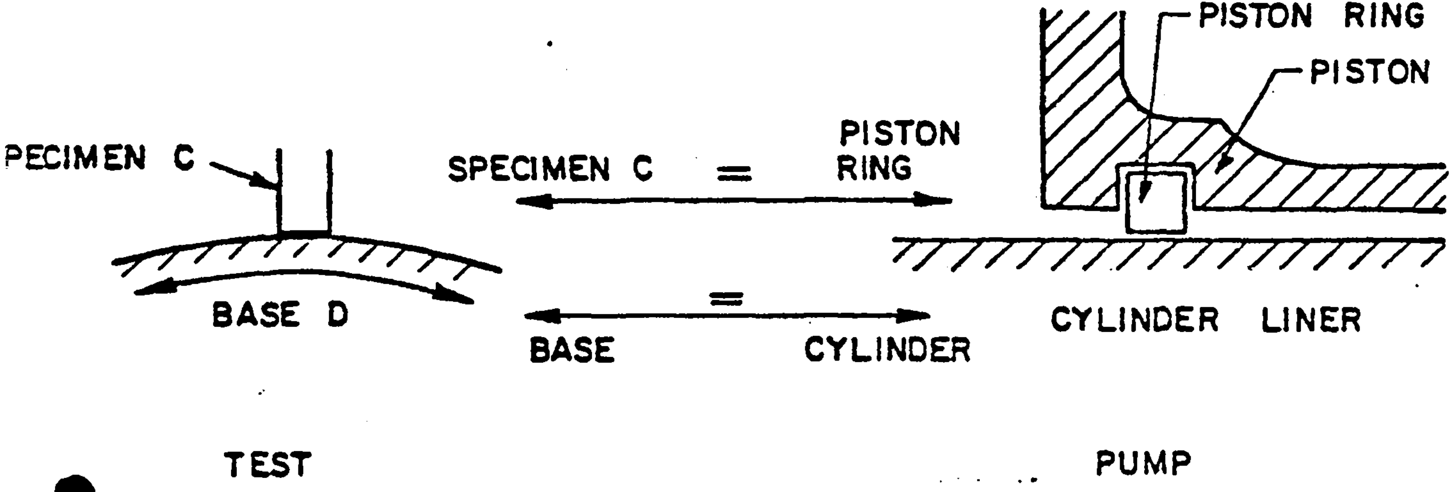
In order to simulate the pump motion and loads for different combinations of polymers and yet maintain identical contamination conditions, a nine stage reciprocal wear test apparatus was constructed. The features of this wear test apparatus are shown in Figure 33.

FIGURE 33



The arm A is pivoted at E and supports the speciman holder B. The specimen C, is referred to as the rider. At the end of the arm A a normal load N is applied to simulate the various pump pressures. The speciman C is stationary and the frictional drag occurs on the same contact at all times. This simulates the wear of the piston rings as they are employed in the actual pumps. The complementary component to the rider is the semi circular block D (called the base). This base undergoes an oscillatory rotation of approximately 1.3 radians about its centre. In this fashion it simulates the wear on the cylinder wall of the pumps. The equivalence between these tests and the pump is sketched in Figure 34.

FIGURE 34


PISTON RING
PISTON
PECIMEN C
SPECIMEN C
=
PISTON
RING
BASE D
=
BASE
CYLINDER
CYLINDER LINER
TEST
PUMP

The major dimensions of the rider and base are given in Table 15.

TABLE 15

Dimensions of Rider and Base - Wear Specimens

	Rider	Base
length	23 mm	75 mm ϕ
width	6 mm ϕ	13 mm
thickness	6 mm ϕ	25 mm

The rocking motion of base D was provided by a crank mechanism, operating at a fixed speed of 90 cycles per minute. This provided for two wear passes per cycle. The normal loads N were calculated to give pressures equivalent to those experienced by the piston ring for the following depths of water above the piston; N_1 for 20 m, N_2 for 40 m and N_3 for 60 m. All of the 9 test stages were completely submerged in water to which 10% "Ottawa River" grade sand was added. A special stirring vane on a rocking shaft prevented the sand from settling. The system thus simulated pumping in sandy water.

To measure the wear of each specimen the dimensions from the bottom of the rider to the top of arm A were measured with a micrometer. This provided for a linear wear measurement on the rider only. To determine the wear on the base it was necessary to remove it to measure the depth of the wear track. The wear on the base was only measured after each test was completed in order not to disturb the set-up.

An appropriate measure of wear is given by the following expression:

$$w = \frac{\text{thickness of material removed per pass}}{\text{length of pass}}$$

The units of the measured wear are m/m or inch/inch. This measure is very suitable for the particular application of the pump because dimensional changes are more important than the net amount of material removed.

As a wear rate the following measure was used:

$$w = \frac{\text{total linear wear on rider and base}}{\text{number of passes}} \quad [\text{m/pass}] .$$

Table 16 contains values for the measured total linear wear w_T, and values for the total linear wear rate W_T of both the rider and base for the various material combinations tested. Also indicated is the percentage distribution of the individual component linear wear, $\%w_{rider}$ and $\%w_{base}$ and the method of determining these quantities is given in Appendix F.

The results show the following:

(1) Polyethylene piston rings on a PVC casing yield a situation in which all the wear is on the piston ring. This is desirable because the ring is a replaceable item.

(2) The wear on the polyethylene piston ring increases in the order ultrahigh molecular weight > high density > low density polyethylene. The first material is obviously the best, but it is not generally available and either of the latter two is preferable from cost/benefit point of view. The ring can be sliced from a polyethylene pipe with appropriate diameter and should cost pennies.

TABLE 16

Rider Material *	Base Material	Depth Simulator (m)	$\%w_{rider}$ (%)	$\%w_{base}$ (%)	w_T (m/m) $\times 10^{10}$	$\dot{w}_T$ (m/pass) $\times 10^{11}$
UHMWPE	PVC	20	≈100	≈0	5	2.5
UHMWPE	PVC	40	≈100	≈0	52	26
UHMWPE	PVC	60	≈100	≈0	23.5	11.8
PVC	LDPE	20	≈0	≈100	13.7	6.86
PVC	LDPE	40	≈0	≈100	9.94	4.97
PVC	LDPE	60	≈0	≈100	22.9	11.4
HDPE	PVC	20	≈100	≈0	42.5	21.2
HDPE	PVC	40	≈100	≈0	65.7	32.8
HDPE	PVC	60	≈100	≈0	115	57.5
LDPE	LDPE	20	86	14	545	273
LDPE	LDPE	40	58	42	1980	986
PVC	PVC	20	96	4	106	53
PVC	PVC	40	94	6	231	115
PVC	PVC	60	94	6	254	127
LDPE	PVC	20	≈100	≈0	62	31
LDPE	PVC	40	≈100	≈0	52	26
LDPE	PVC	60	≈100	≈0	158	79

*UHMWPE = ultrahigh molecular weight polyethylene. This is an extremely high molecular weight high density polyethylene.

HDPE = high density polyethylene.

LDPE = low density polyethylene.

14. REFERENCES

(1) A. Plumtree and A. Rudin, "Plastic Well Casings for Use with Hand Operated Water Pumps", Waterloo Research Institute Project 609-01-02, International Developement Research Centre, August 1977.

(2) A. Plumtree, A. Rudin and J. Tevaarwerk, Waterloo Research Institute Project 609-01, International Development Research Centre, September, 1977.

(3) Canadian Standards Association, 178 Rexdale Blvd., Rexdale, Ontario, M9W 1R3, Canada.

(4) "Standard Methods for the Examination of Water and Wastewater", 13th ed., 1971. American Public Health Association, 1970 Broadway, New York, N.Y.

(5) Professor Y. Sternberg, University of Maryland, Private Communication.

(6) J. E. Shigley, "Mechanical Engineering Design", second edition. McGraw Hill, N.Y., 1972.

APPENDIX A

A human adult can work steadily at a rate equal to about 50 watts (0.067 horsepower). No device can improve this value so long as all the power is supplied by the human operator. Dimensionlly, power is equal to the product of pressure times volume in flow rate (in suitable units). Knowing the pressure of water as a function of well depth, it is therefore straightforward to calculate the maximum flow rate of water from a well as a function of depth, with the stated human power source.

The results of this calculation are shown in Figure A1 . It will be seen there, for example, that the maximum flow rate from a 20 metre well is about 2.5×10^{-5} in 3/sec. This is an absolute limit, given the stated 50 watt power source. Various pumps will produce less than this amount, depending on their efficiencies. None can produce more.

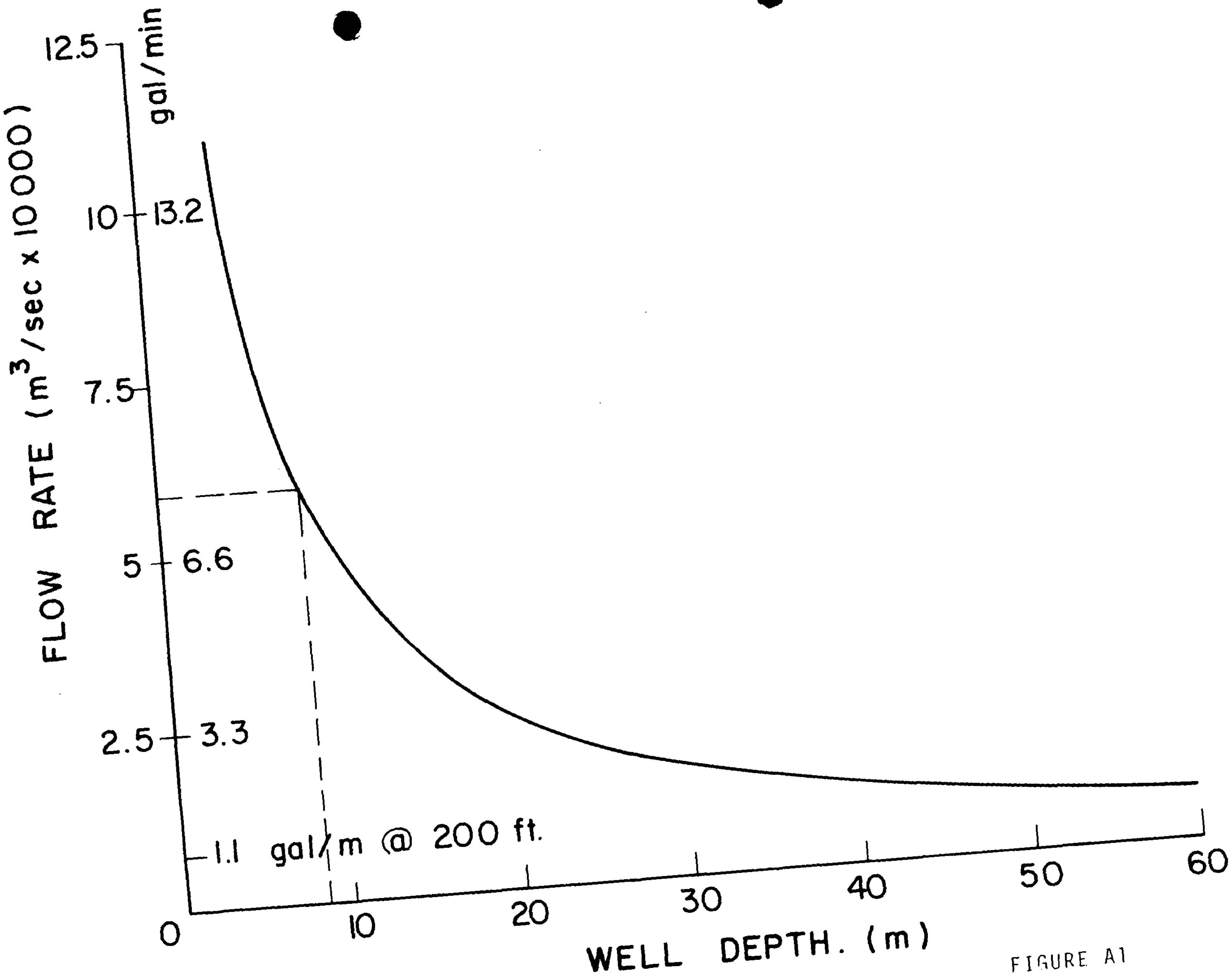

FLOW RATE (m^3/sec x 10000)
gal/min
12.5
10
13.2
7.5
5
6.6
2.5
3.3
1.1 gal/m @ 200 ft.
0
10
20
30
40
50
60
WELL DEPTH. (m)

FIGURE A1

APPENDIX B

TABLE I

ASTM D 1784 - 75 Specification for Rigid PVC Compound

a) Class 12454-B rigid PVC (recommended):

Class 1 2 4 5 4

Identification

Poly(vinyl chloride) homopolymer

Property and Minimum Value:

Impact strength (Izod) (34.7 J/m (0.65 ft.lbf/in.)

Tensile strength (48.3 MPa (7000 psi)

Modulus of elasticity in tension (2758 MPa (400 000 psi)

Deflection temperature under load (70 C (158 F))

Chemical resistance (meets the requirements of Suffix b):

TABLE I (cont'd)

ASTM D 1784 - 75 Specification
for Rigid PVC Compound

(b) Suffix Designation for Chemical Resistance

Solution	A	B	C	D
H_2SO_4(93 percent) - 14 days immersion at 55 ± 2C:				
Change in weight:				
Increase, max, percent	1.0*	5.0*	25.0	NA**
Decrease, max, percent	0.1*	0.1*	0.1	NA
Change in flexural yield strength:				
Increase, max, percent	5.0*	5.0*	5.0	NA
Decrease, max, percent	5.0*	25.0*	50.0	NA
H_2SO_4(80 percent) - 30 days immersion at 60 ± 2C:				
Change in weight:				
Increase, max, percent	NA	NA	5.0	15.0
Decrease, max, percent	NA	NA	5.0	0.1
Change in flexural yield strength:				
Increase, max,percent	NA	NA	15.0	25.0
Decrease, max, percent	NA	NA	15.0	25.0
ASTM oil No. 3 - 30 days immersion at 23C:				
Change in weight:				
Increase, max, percent	0.5	1.0	1.0	10.0
Decrease, max, percent	0.5	1.0	1.0	0.1

*Specimens washed in running water and dried by an air blast or other mechanical means shall show no sweating within 2h after removal from the acid bath.

**NA - not applicable.

TABLE 1 (cont'd)

(c) PHYSICAL PROPERTIES FOR PVC TYPE 1 GRADE 1
(Class 12454-B)

PROPERTY	VALUE	UNITS	A.S.T.M. No.
Specific gravity	1.38		D792-66
Tensile strength (73F)	7,000	p.s.i.	D638-71a
Modulus of elasticity in tension	415,000	p.s.i.	
Flexural strength	14,500	p.s.i.	D790-71
Izod impact (notched at 73F)	0.8	ft.lb/in.	S256-47T
(unnotched at 73F)	45	ft.lb/in.	D256-72a
Hardness (shore "D")	78/82		D785-65
Coefficient of linear expansion	.0000278	in./in./^{O}F	D696-70
Heat distortion (^{O}F at 264psi)	165	degrees F	D648-72
Coefficient of thermal conductivity	1.0	BTU/hr./ sq.ft./in.	C-177-71
Specific heat	0.25	BTU/lb./F	
Water absorption(24 hrs. at 25C)	.07	per cent	D570-63
Flammability		self extinguishing	
Poisson's Ratio (74^{O}F)	.34		
Rockwell hardness	110	"R" scale(min.)	D785-65

TABLE 1 (cont'd)

d) CONCENTRATION OF TOXIC SUBSTANCES IN WATER

Substance	Concentration (mg/1)
Antimony (Ab)	0.05
Arsenic (Ag)	0.05
Cadmium (Cd)	0.01
Chromium (Cr^{6+})	0.05
Cyanide (CN)	0.2
Fluoride (F)	2.4
Lead (Pb)	0005
Phenols	any detectable odor

TABLE II

PROPERTIES OF PVC PIPE

The following formulas were used in the computation of the values shown in the table:

Area of outside surface (sq.ft./linear foot) = $0.2618D$
Weight of pipe (lbs./foot) = $1.868t(D-t)$
Weight of water (lbs./foot) = $0.3405\ d^2$

Where: t = mean pipe wall thickness (inches)
D = outside diameter (inches)
d = inside diameter (inches)

(Data from Practiplast Ltd., Toronto, Ontario)

Nominal Pipe Size Outside Diameter Inches	Schedule	SDR	Maximum Working Pressure PSI at 23°C	Wall Thick-ness Inches	Inside Diameter Inches	Area of Outside Surface per Linear ft.	Weight of Pipe per Foot Lbs.	Weight of Water per Foot Lbs.
1/4"	40		780	.088	.364	.141	.09	.045
.540	80		1130	.119	.302		.10	.031
3/8"	40		620	.091	.493	.177	.11	.083
.675	80		920	.126	.423		.14	.061
1/2"	40		600	.109	.622	.220	.16	.132
.840	80		850	.147	.546		.21	.102
		21	200	.080	.680		.13	.157
3/4"	40		480	.113	.824	.275	.23	.231
1.050	80		690	.154	.742		.28	.187
		21	200	.080	.890		.17	.270
1"	40		450	.133	1.049	.344	.32	.374
1.315	80		630	.179	.957		.41	.312
		21	200	.080	1.155		.20	.454
1¼"	40		370	.140	1.380	.434	.43	.648
1.660	80		520	.191	1.278		.56	.556
		21	200	.080	1.500		.27	.766
	40		330	.145	1.610	.497	.51	.882
1½"	80		470	.200	1.500		.68	.766
1.900		21	[illegible]	.090	1.720		.34	1.006
		26	[illegible]	.080	1.740		.31	1.030

Nominal Pipe Size Outside Diameter Inches	Schedule	SDR	Maximum Working Pressure PSI at 23°C	Wall Thick-ness Inches	Inside Diameter Inches	Area of Outside Surface per Linear ft.	Weight of Pipe per Foot Lbs.	Weight of Water per Foot Lbs.
2" 2.375	40		280	.154	2.067	.622	.68	1.455
	80		400	.218	1.939		.93	1.280
		21	200	.113	2.149		.52	1.572
		26	160	.091	2.193		.43	1.636
2½" 2.875	40		300	.203	2.469	.753	1.07	2.075
	80		420	.276	2.323		1.41	1.837
		21	200	.137	2.601		.75	2.303
		26	160	.110	2.655		.62	2.400
3" 3.500	40		260	.216	3.068	.916	1.41	3.204
	80		370	.300	2.900		1.91	2.864
		21	200	.167	3.116		1.10	3.306
		26	160	.135	3.230		.91	3.552
		32.5	125	.108	3.284		.73	3.672
		41	100	.085	3.330		.61	3.775
3½" 4.000	40		240	.226	3.548	1.047	1.68	4.285
	80		350	.318	3.364		2.32	3.852
		21	200	.190	3.620		1.44	4.462
		26	160	.154	3.692		1.18	4.640
		32.5	125	.123	3.754		.96	4.798
		41	100	.098	3.804		.77	4.926
4" 4.500	40		220	.237	4.026	1.178	2.00	5.518
	80		320	.337	3.826		2.77	4.983
		21	200	.214	4.072		1.81	5.644
		26	160	.173	4.154		1.49	5.874
		32.5	125	.138	4.224		1.21	6.074
		41	100	.110	4.280		.99	6.236
5" 5.563	40		190	.258	5.047	1.456	2.70	8.671
	80		290	.375	4.813		3.90	7.886
		21	200	.265	5.033		2.78	8.624
		26	160	.214	5.135		2.28	8.977
		32.5	125	.171	5.221		1.82	9.280
		41	100	.136	5.291		1.48	9.530
6" 6.625	80		280	.432	5.761	1.734	5.28	11.299
		21	200	.315	5.885		3.95	12.236
		26	160	.255	6.115		3.22	12.729
		32.5	125	.204	6.217		2.59	13.161
		41	100	.161	6.301		2.08	13.516

TABLE II CONT'D

TABLE III

MAXIMUM AND MINIMUM AVERAGE OUTSIDE DIAMETERS AND CIRCUMFERENCES - PVC

Nominal Pipe Size	Minimum Outside Diameter	Maximum Outside Diameter	Minimum Circumference	Maximum Circumference
1/8	0.401	0.409	1.260	1.285
1/4	0.536	0.544	1.684	1.709
3/8	0.671	0.679	2.108	2.133
1/2	0.836	0.844	2.626	2.651
3/4	1.046	1.054	3.286	3.311
1	1.310	1.320	4.115	4.147
1¼	1.655	1.665	5.199	5.231
1½	1.894	1.906	5.950	5.988
2	2.369	2.381	7.442	7.480
2½	2.868	2.882	9.010	9.054
3	3.492	3.508	10.970	11.021
3½	3.992	4.008	12.541	12.591
4	4.491	4.509	14.109	14.165
5	5.553	5.573	17.442	17.511
6	6.614	6.636	20.778	20.847
8	8.610	8.640	27.049	27.143
10	10.735	10.765	33.725	33.819
12	12.735	12.765	40.008	40.102

NOTE: All dimensions are given in inches.

(b)

TABLE III (cont'd)
OUT-OF-ROUNDNESS
MINIMUM AND MAXIMUM OUTSIDE DIAMETER
SERIES PIPE

Nominal Pipe Size	SDR 41	
	Minimum	Maximum
1/8	0.390	0.420
1/4	0.525	0.555
3/8	0.660	0.690
1/2	0.825	0.855
3/4	1.035	1.065
1	1.300	1.330
1¼	1.645	1.675
1½	1.870	1.930
2	2.344	2.405
2½	2.845	2.905
3.	3.3470	3.530
3½	3.950	4.050
4	4.450	4.450
5	5.513	5.613
6	6.575	6.675
8	8.550	8.700
10	10.675	10.825
12	12.675	12.825

NOTE: All dimensions are given in inches.

(c)

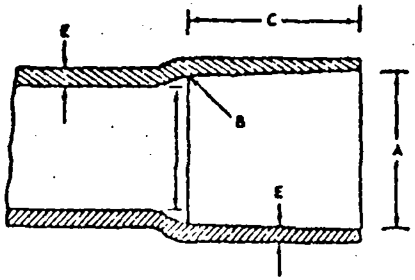
TABLE III (cont'd)
MINIMUM AND MAXIMUM WALL THICKNESS
SERIES PIPE

Nominal Pipe Size	SDR 41	
	Minimum	Maximum
1/8		
1/4		
3/8		
1/2		
3/4		
1		
1¼		
1½		
2		
2½	0.080	0.100
3	0.085	0.105
3½	0.098	0.118
4	0.110	0.130
5	0.136	0.156
6	0.162	0.182
8	0.210	0.235
10	0.262	0.293
12	0.311	0.348

NOTES:
1. All dimensions are given in inches.
2. For pipe 2 inches and smaller nominal size, wall thichnesses not specified are 0.080 minimum and 0.100 maximum.

TABLE IV

Tapered Sockets for Bell-End Pipe, in.



Pipe Size	A Socket Entrance Diameter			B Socket Bottom Diameter			C Socket Length, min*
	Nominal Diameter	Tolerance on Nominal Diameter	Maximum Out-of-Round	Nominal Diameter	Tolerance on Nominal Diameter	Maximum Out-of-Round	
⅛	0.417	±0.004	±0.008	0.401	±0.004	±0.008	0.500
¼	0.552	±0.004	±0.008	0.536	±0.004	±0.008	0.500
⅜	0.687	±0.004	±0.008	0.671	±0.004	±0.008	0.750
½	0.848	±0.004	±0.008	0.836	±0.004	±0.008	1.000
¾	1.058	±0.004	±0.010	1.046	±0.004	±0.010	1.250
1	1.325	±0.005	±0.010	1.310	±0.005	±0.010	1.500
1¼	1.670	±0.005	±0.012	1.655	±0.005	±0.012	1.750
1½	1.912	±0.006	±0.012	1.894	±0.006	±0.012	2.000
2	2.387	±0.006	±0.012	2.369	±0.006	±0.012	2.250
2½	2.889	±0.007	±0.015	2.868	±0.007	±0.015	2.500
3	3.516	±0.008	±0.015	3.492	±0.008	±0.015	3.250
3½	4.016	±0.008	±0.015	3.992	±0.008	±0.015	3.500
4	4.518	±0.009	±0.015	4.491	±0.009	±0.015	4.000
5	5.583	±0.010	±0.030	5.553	±0.010	±0.030	4.000
6	6.647	±0.011	±0.030	6.614	±0.011	±0.030	6.000
8	8.655	±0.015	±0.045	8.610	±0.015	±0.045	6.000

* All tolerances on minimum dimensions shall be on the plus side.

APPENDIX C

APPENDIX A

SOLVENT WELD JOINING

THERE ARE NO SHORT CUTS TO MAKING SUCCESSFUL HIGH STRENGTH SOLVENT WELDED JOINTS. FOLLOW THESE PROCEDURES CAREFULLY AND THOROUGHLY.

The following instructions are based on the use of PVC pipe primer, pipe cleaner, and PVC solvent welding compound recommended by Building Products. Other primers, cleaners and solvent welding compounds may vary in formulation and in performance and should be selected with caution. Such materials should be checked for their compatibility with ESFLO Pipe and with the fittings selected, and for their suitability to the particular application. In such cases the manufacturer's recommendations must be consulted.

Install the pipe with proper alignment and grade. Do not bend it into position in such a way as to cause misalignment at fittings.

Bring pipes and fittings to the same temperature before installation.

For light service applications and with smaller diameter pipes and fittings, solvent welding procedures described in ASTM D2855, which essentially dispense with the use of a pipe primer, may prove adequate.

figure 23

EXAMINING PIPE END AND SOCKET OF FITTING FOR DAMAGE

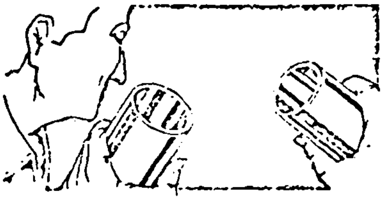


figure 24

CUTTING PIPE SQUARE

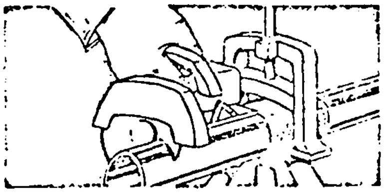


figure 25a

REMOVING BURRS AND RAISED EDGES

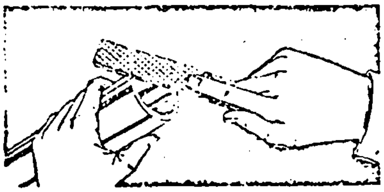


figure 25b

BEVELLING OF PIPE

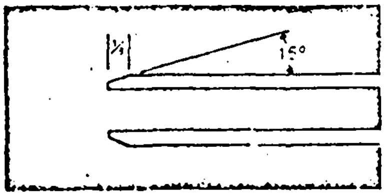
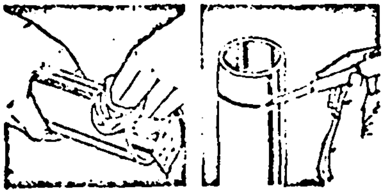


figure 26

CLEANING DUST, DIRT, GREASE AND MOISTURE FROM MATING SURFACES AND MARKING FITTING SOCKET DEPTH ON PIPE END



1. Remove dust, dirt and foreign material from the ends of pipes and sockets of fittings to facilitate inspection and examine them for damage such as hairline cracks, deep scratches and gouges resulting from transportation and handling.

If necessary, cut back pipe and discard damaged ends, or choose new fittings.

2. Cut pipe square using a fine-toothed power saw or a hand saw and a mitre box. Pipe cutters are also available with a cutting wheel designed especially to facilitate the cutting of plastic pipe. Square cuts are essential for the pipe to bottom properly in the fitting socket and to prevent reducing the bonding area.

3. Remove all saw burrs or the raised edges caused by the pipe cutter from both the inside and outside of the end of the pipe, using a coarse file, sharp knife or sand paper. At the same time, bevel the pipe end as shown in Figure 25b, using the coarse file, knife or a bevelling tool. Burrs may cause channelling of walls softened by pipe primer and solvent welding compound and create uneven tolerances between pipes and fitting sockets.

Bevelling aids in socketing the pipe and prevents scraping of solvent welding compound from the walls of fitting sockets.

4. If necessary, wipe the mating surfaces with a clean rag to remove any accumulated dust, dirt or moisture. Remove grease by using a clean rag moistened with pipe cleaner (or primer).

On pipes 6 inches or larger, light abrasion of the mating surfaces with emery cloth will improve the penetration of the primer and solvent welding compound into the walls and provide for improved joining of the components.

Solvent welding will be successful only if the mating surfaces are free of moisture.

As a guide for checking the interference fit and for the application of pipe primer and solvent welding compound, mark the socket depth of the fitting on the pipe end with a pencil or a fibre pen.

5. Check the dry-fit of the pipe in the tapered socket of the fitting by pushing the pipe lightly into the socket. The pipe should penetrate to at least one-quarter of the socket depth and should interfere with the socket at least at the bottom of the socket. When the fit is tight, the pipe will slide into place after the solvent welding compound is applied.

If the pipe will not penetrate to one-quarter of the socket depth, select another fitting or sand the outside of the pipe lightly to achieve a better fit, taking care not to remove excessive amounts of material from the surface of the pipe or to create flat spots.

In the case where the pipe is loose in the bottom of the socket, preferably use another pipe or fitting. If the fit is not excessively loose, the surface of the pipe can be built up with successive layers of solvent welding compound.

6. Prime the inside of the fitting socket and the corresponding area on the outside of the pipe by brushing liberally with PVC pipe primer.

The primer will cut through the glossy surfaces of the components and penetrate into and soften these surfaces, improving the fusion in the areas of interference and providing for greater strength of the welded joints.

Under normal working conditions, softening will take 5 to 15 seconds. *At lower temperatures more time will be* required for the primer to act.

Keep the mating surfaces moistened by repeated applications of the primer, if required, until the proper softening of the surfaces takes place.

Proper penetration by the primer can be shown on a piece of scrap PVC if a few thousands of an inch of softened material can be easily scratched or scraped from the primed surface with a sharp knife blade or a scraper.

Remove liquid primer which may collect in the fitting socket before applying solvent welding compound.

figure 27

DRY-FIT TO CHECK TOLERANCE

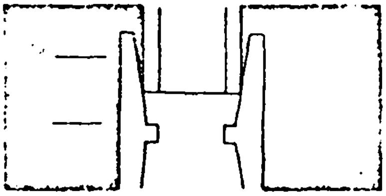


figure 28

THOROUGH PRIMING OF THE FITTING SOCKET AND THE PIPE END

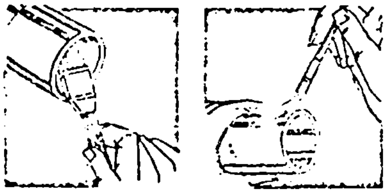


figure 29a

FLOWING SOLVENT WELDING COMPOUND LIBERALLY ON PIPE END . . .

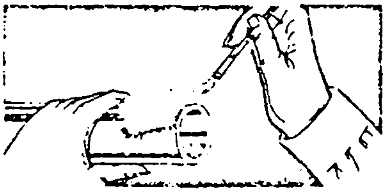


figure 29b

FLOWING SOLVENT WELDING COMPOUND INTO FITTING SOCKET . . .

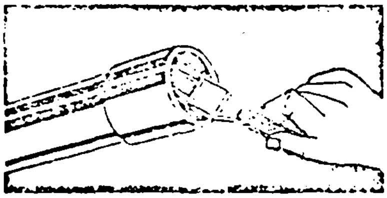
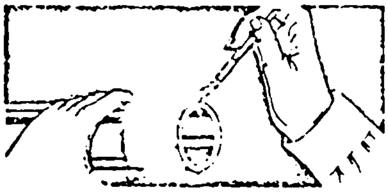


figure 29c

AND FLOWING A SECOND COATING OF SOLVENT WELDING COMPOUND FREELY ONTO PIPE END



7. While the primed and softened mating surfaces of the fitting socket and the pipe are still wet with primer, apply solvent welding compound with another natural bristle brush as follows:

A. Flow a heavy coating of solvent welding compound onto the pipe end, just past the mark made in STEP 4.

On smaller pipes, flow the welding compound around the pipe. On pipes 6 inches and larger in diameter, flow the welding compound axially, or along the length of the pipe, not around it.

These motions help to ensure that the welding compound will coat the pipe completely, without any gaps, as quickly as possible.

B. Flow a moderate coating of solvent welding compound into the fitting socket, including the shoulder at the bottom of the socket.

Make sure that the welding compound does not flow into the bore of fitting sockets where it might cause clogging or unnecessary softening of pipe walls.

C. Flow a second coating of solvent welding compound freely onto the pipe end, using the motions described in STEP 7A.

This coating will fill any gaps left from the first coating.

Practice may reveal that one coat is sufficient, particularly with smaller diameter pipes. The formation of a solid *bead around the pipe after joining* serves as a guide to indicate this.

Remember, the solvent welding compound must fill the entire gap left beyond the interference fit, between the outside diameter of the pipe and the inside diameter of the tapered socket of the fitting. Some of the welding compound will penetrate into the mating surfaces. Too much solvent welding compound can not be applied to the pipe as any excess compound will be "shaved back" by the socket of the fitting and appear as a bead around the pipe after bottoming.

Do STEPS 7A, B and C quickly as the solvent welding compound dries quickly, particularly at high ambient temperatures. Use 2 man crews to prime and solvent weld pipes and fittings up to 3 inches in diameter. Use 3 man crews to join larger pipes to prevent the solvent welding compound from drying prematurely and because larger pipes become increasingly heavy and more difficult to manoeuvre.

Good joints depend on the use of sufficient solvent welding compound. Do not use painting techniques. Apply the welding compound directly from the can to the pipe or fitting, without wiping excess compound off on the rim of the can. Be sure to cover the mating surfaces entirely.

Bring pipes with unassembled joints towards fitting sockets in existing pipe

8. *Immediately* after applying solvent welding compound, and while it is still "wet" push the pipe all the way into the fitting socket until it bottoms on the shoulder.

The wet layers of solvent welding compound on the mating surfaces will flow together, tending to form an homogeneous layer around the whole joint. Softened surfaces of the components in the vicinity of the interference between the pipe and the socket of the fitting will fuse together, providing for rapid development of strength in the joint, where it is most important, as seen in Figure 31b.

With smaller diameter pipes, turn the pipe or fitting ¼ turn while making the insertion to aid in distributing the solvent welding compound evenly. As pipe diameters increase this manoeuvre becomes extremely difficult, making the application of sufficient solvent welding compound more critical.

Insert the pipe with a steady, even motion. Do not hammer the joint together. Assembly should generally be completed within 20 seconds after the welding compound has been applied.

Excessive difficulty in bottoming the pipe in the fitting socket is often the result of applying insufficient solvent welding compound or premature evaporation of the solvent as a result of delaying assembly after applying the welding compound.

Large longitudinal forces are necessary for the assembly of interference fit joints with the larger diameter pipes. *In addition, a certain degree of out-of-roundness is normal with larger fabricated fittings.* Usually the pipe or fitting will round as the joint is assembled. However, matching should be carried out as best possible. *In such cases,* the pipe must be fully bottomed in the socket to prevent gap formation along one side or another. Mechanical forcing equipment such as "Come-alongs" or levers and braces may prove necessary.

Take care not to disturb any previously made joints during assembly.

figure 30

PUSHING PIPE AND FITTING TOGETHER UNTIL PIPE END MEETS SHOULDER FITTING

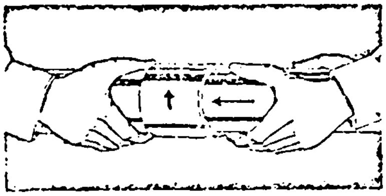


figure 31a

FULL BOTTOMING OF PIPES IN FITTING SOCKETS

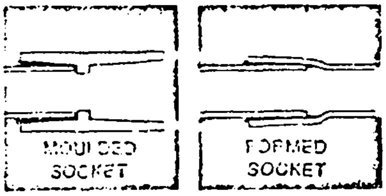


figure 31b

CLOSE-UP VIEW OF A GOOD SOLVENT WELDED JOINT

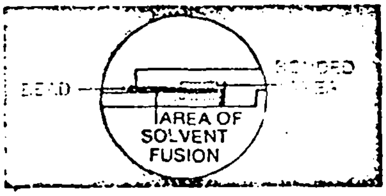


figure 32

HOLDING JOINT STILL

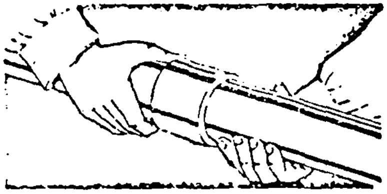
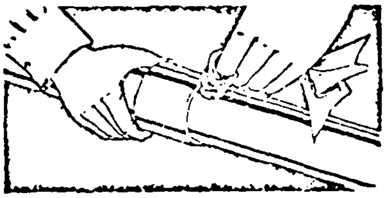


figure 33

REMOVING THE BEAD OF SOLVENT WELDING COMPOUND



9. Firmly hold the joint still until any tendency for the fitting to "back off" the pipe has been overcome, usually for 30 to 60 seconds, but possibly as long as 5 minutes or more with larger pipes under certain conditions. Support the *joined pipe and fitting after this step.* Do not let the weight of the pipe be supported by the newly formed joint.

A properly made joint will normally have a bead of solvent welding compound around its entire perimeter. Gaps in the bead may indicate a defective assembly job due to the use of insufficient solvent welding compound.

10. Remove the bead of solvent welding compound and any other excess compound with a rag. The bead of solvent welding compound does not strengthen the joint and can cause useless softening of the pipe and fitting and delay evaporation of the solvent in the joint.

11. Proceed with installation work, but for several minutes under normal conditions take care to prevent any relative motion between the newly joined pipe and fitting. Approximate set time is related to temperature as shown in TABLE 14.

Do not attempt to adjust the joint after the solvent compound has begun to set.

12. For joints to reach full strength before pressure testing, 24 hours drying is usually adequate. Smaller diameter pipes, higher ambient temperatures and tight fitting joints require shorter drying times. Larger diameter pipes, cold, humid conditions and loose fitting joints generally require extended drying periods. Approximate curing times are shown in TABLE 15.

table 14

APPROXIMATE SET TIME FOR SOLVENT WELDING COMPOUND AT DIFFERENT TEMPERATURES, HOURS

INSTALLATION TEMPERATURE, °F	PIPE SIZES, INCHES ½ to 1¼	1½ to 4	6 to 12
60 & over	¼	½	1½
30 - 60	1	2	6
10 - 30	3	6	18

table 15

APPROXIMATE CURING TIMES, HOURS, BEFORE APPLICATION OF PRESSURE TEST.

TEMPERATURE RANGE DURING CURE PERIOD °F	PIPE SIZES, INCHES ½ to 1¼	1½ to 3	4 to 12
60 & over	6	12	24
30 - 60	12	24	48
10 - 30	48	96	8 days

table 16

AVERAGE NUMBER OF JOINTS PER CONTAINER OF SOLVENT WELDING COMPOUND USING PROCEDURES RECOMMENDED IN THIS BROCHURE

One joint is 1 pipe end in 1 socket of a fitting

NOMINAL PIPE SIZE, INCHES	½	¾	1	1¼	1½	2	2½	3	4	6	8	10	12
SOLVENT WELDING COMPOUND	JOINTS PER PINT									JOINTS PER GALLON			
	180	130	75	55	35	25	15	10	7	28	16	12	8

THREADED CONNECTIONS

Only Schedule 80 ESFLO Pressure Pipe can be threaded. The walls of lighter pipes are not thick enough for threading, particularly when the notch sensitivity of PVC is taken into consideration.

Use standard steel pipe thread cutting tools and clean, sharp dies which are in good condition. Hand threading is preferable and dies should have a negative front rake of 5 to 10 degrees. External lubricants are not required, but plain water may be used.

Power threading may be accomplished using power threading dies with a 5 degree negative front rake and ground especially for PVC, provided that high speeds and heavy pressures are avoided.

Be sure not to over-thread the pipe as this will make it impossible to screw fittings on far enough to make a tight seal and because residual threads extending beyond the body of the fitting are focal points for crack propagation. TABLE 17, on page 21, is a guide to proper thread dimensions.

Do not mate metal male threaded components to PVC sockets as this may lead to joint failure due to the differential expansion rate between PVC and metal. Male PVC threaded components may be screwed into a metal socket.

APPENDIX D

1 Gal. (U.S.) = .13368 $ft.^3$

1 Gal. (Imp.) = .16710 $ft.^3$

1 Gal. (U.S.) = 8.342 lbs.

1 Gal. (Imp.) = 10.427 lbs.

1 Psi. = 2.31 ft.

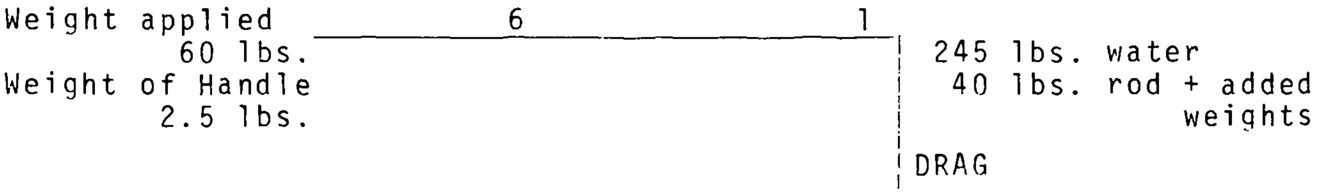
MAXIMUM POSSIBLE FLOW IN A 6" STROKE

$$= \frac{\pi d^2}{4} \text{ ft.}^2 \times .5 \text{ ft.} \times \frac{1}{.1671}$$

$$= \frac{\pi \left(\frac{2.125}{12}\right)^2}{4} \times .5 \times \frac{1}{.1671}$$

$$= .0737 \text{ Gal. (Imp.)} \equiv 0.335 \text{ litre}$$

DRAG DUE TO LEATHER CUPS



WEIGHT OF WATER @ 80 FT.

$$\frac{\pi\ d^2}{4} \times 80 = \frac{\pi(3/12)^2 \times 80}{40} = 3.93 \text{ ft.}^3$$

$$3.93 \text{ ft.}^3 \times 62.4 \text{ lb./ft.}^3 = 245 \text{ lbs.}$$

$$62.56 \text{ lbs.} \times 6{:}1 \text{ mech. adv.} = 375 \text{ lbs.}$$

$$285 \text{ lbs.} + \text{Drag} = 375 \text{ lbs.} \quad \text{(for equilibrium)}$$
$$\text{Drag} = 90 \text{ lbs.} \equiv 40.8 \text{ kg}$$

Circumference of Dempster = 9.4 inches ≡ 23.87 cm

Drag/In of Circumference = 9.6 lb./in. ≡ 8.32 kg/cm

2 RING PISTON

Weight applied 28 lbs. — 6 — 1 — 123 lbs. water

Weight of Handle 2.56 lbs. — 40 lbs. rod + added weights

DRAG

WEIGHT OF WATER

$$\frac{\pi\ d^2}{4} \times 80 = \frac{\pi \times \frac{2.125^2}{12}}{4} \text{ ft.}^2 \times 80 \text{ ft.}$$

$$= 1.97 \text{ ft.}^3$$

$1.97 \text{ ft.}^3 \times 62.4 \text{ lb./ft.}^3 = 123 \text{ lbs.}$

30.56 lbs. x 6: mech. adv. = 183 lbs.

163 lbs. + Drag = 183 lbs.

Drag = 20 lbs. ≡ 9.07 kg

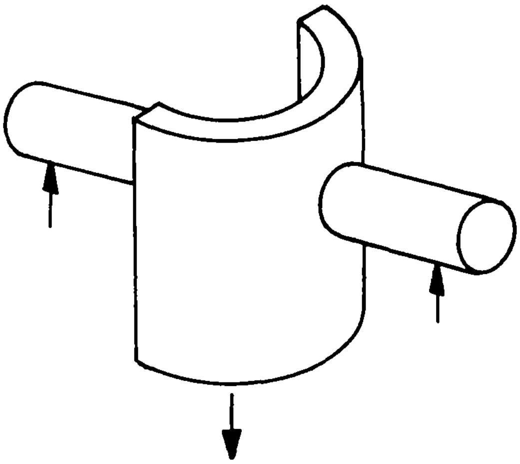
Circumference of 2" casing = 6.7 in. ≡ 17.02 cm

Drag/In of Circumference = 3.1 lb./in. ≡ 2.69 kg/cm

$$\frac{\text{Demp}}{\text{2 Ring Piston}} = \frac{9.6}{3.1} = 3.1 = \text{ratio of drag of leather cup to that of 2 ring piston}$$

APPENDIX E

GALVANIZED STEEL PIPE FATIGUE



consider half the pipe-apply the pinned plate eg.

$F = \sigma A$

$A = (w - d)\ t$

$A = [(\frac{\pi \times 1.5}{2}) - .375]\ .219$

$= (2.356 - .375)\ .219$

$= 4/34\ \text{in}^2$

$\sigma = k_a\ k_b\ k_c\ k_d\ k_e\ k_f\ \sigma^1$

$k_a = .7 \qquad k_c = .814$

$k_b = .85 \qquad k_d = 1$

$k_c = 1/k_f$

$= 1/6.68$

$= .149$

$k_t = 1$

$\sigma^1 = .5\ \sigma_{ult}$

$= .5 \times 47{,}000$

$= \underline{23300}$ psi

$k_f = 1 + q(k_t - 1)$

$= 1 + .8(k_t - 1)$

$k_t = 1.35\ k_t{}^1$

$= 1.35 \times 6$

$= 8.1$

$\frac{h}{w} = \frac{1}{2.356} = .42$

$\frac{d}{w} = \frac{.375}{2.356} = .159$

$\sigma = .0725 \times \sigma^1$

$= 1695.88$

$As = 4 \times 7/3^2 \times 1 = .875\ \text{in}^2$

58750. psi

.875 As

$\underline{.515\ At}$

10300 lb

$1/2\ F_T = \sigma A = 1695.9 \times .515 = 873.4$

$\text{TOTAL} = 2F = 1746.8$

$\text{TOTAL } F_S = 1746.8 \times .5 \times .875 = 746.2 \text{ lb} \equiv 3466 \text{ kg}$

APPENDIX F

CALCULATION OF TOTAL LINEAR WEAR

To calculate the total linear wear for any pump geometry the following formula is used:

$$w_L = \{(w_T \times \frac{\%w_{base}}{100}) \times (w_T \times \frac{\%w_{rider}}{100} \times \text{stroke length})\} \times \text{number of pumping strokes}$$

where w_L is the total linear wear for the pump. The formula is based upon the fact that the wear on the piston ring is total wear path length sensitive while the cylinder life is only pass sensitive. For example: A pump with a 60 m head and 20 cm stroke whose components are PVC throughout will have worn the following amount per one million pumping strokes. From Table 16 under PVC-PVC for a 60 m head we find;

$w_T = 127 \times 10^{-11}$ m/pass

$w_T = 254 \times 10^{-10}$ m/m

$\%w_{base} = 6$

$\%w_{rider} = 94.$

Substitution of this data into the above equation gives a total linear wear;

$$w_L = \{(127 \times 10^{-11} \times \frac{6}{100} + (254 \times 10^{-10} \times \frac{94}{100} \times .2)\} \times 10^6$$

$$= 4.85 \times 10^{-3} \text{ m.}$$

APPENDIX G

EXPECTED WEAR AFTER PUMP CYCLES x 10^6 FOR A 7.6 CM DIAMETER PUMP USING A 20 CM STROKE AT VARIOUS DEPTHS

The solution to this problem lies in evaluating the suggested linear wear equation;

$$W_L = [(W_T \times \frac{\%\ w\ base}{100} + (W_T \times \frac{\%\ W\ rider}{100} \times \text{stroke length})] \times \text{number of pumping strokes} \qquad (1A)$$

The data is recorded in Table 16 in the text. It is noticed that for LDPE and HDPE the % w base is zero. The above equation for W_L may therefore be modified as follows:

$$W_L = (W_T \times \text{stroke length}) \times \text{number of strokes} \qquad (2A)$$

or if we want to know the wear for 10^6 cycles it becomes simply

$$\frac{W_L}{10^6} = WT \times \text{stroke length}$$

For the given stroke of 0.2 m, this simply reduces to:

$$\frac{W_L}{10^6} = 0.2\ W_T \quad \text{(m/million)} \tag{3A}$$

The data from Table 16 may be used directly or it may be linearized to remove some of the scatter.

When the data for W_T is linearized the following expressions in terms of depth are found for HDPE with PVC (see Fig. 1)

$$W_T = 1.92 \times H \times 10^{16} \text{ (m/m) H in meters}$$

for LDPE with PVC

$$W_T = (2.63 \times H \times 10^{10}) \text{ (H in meters)}$$

Or for 3A we may write

$$\frac{W_L}{10^6} = .38 \times 10^{10} \times H \text{ for HDPE}$$

$$\frac{W_L}{10^6} = .52 \times 10^{10} \times H \text{ for LDPE}$$

or better yet

$$W_L = .38 \times 10^4 \times H \times M \quad (m) \text{ for HDPE}$$

$$W_L = .52 \times 10^4 \times H \times M \quad (m) \text{ for LDPE}$$

where M is in million pumping cycles

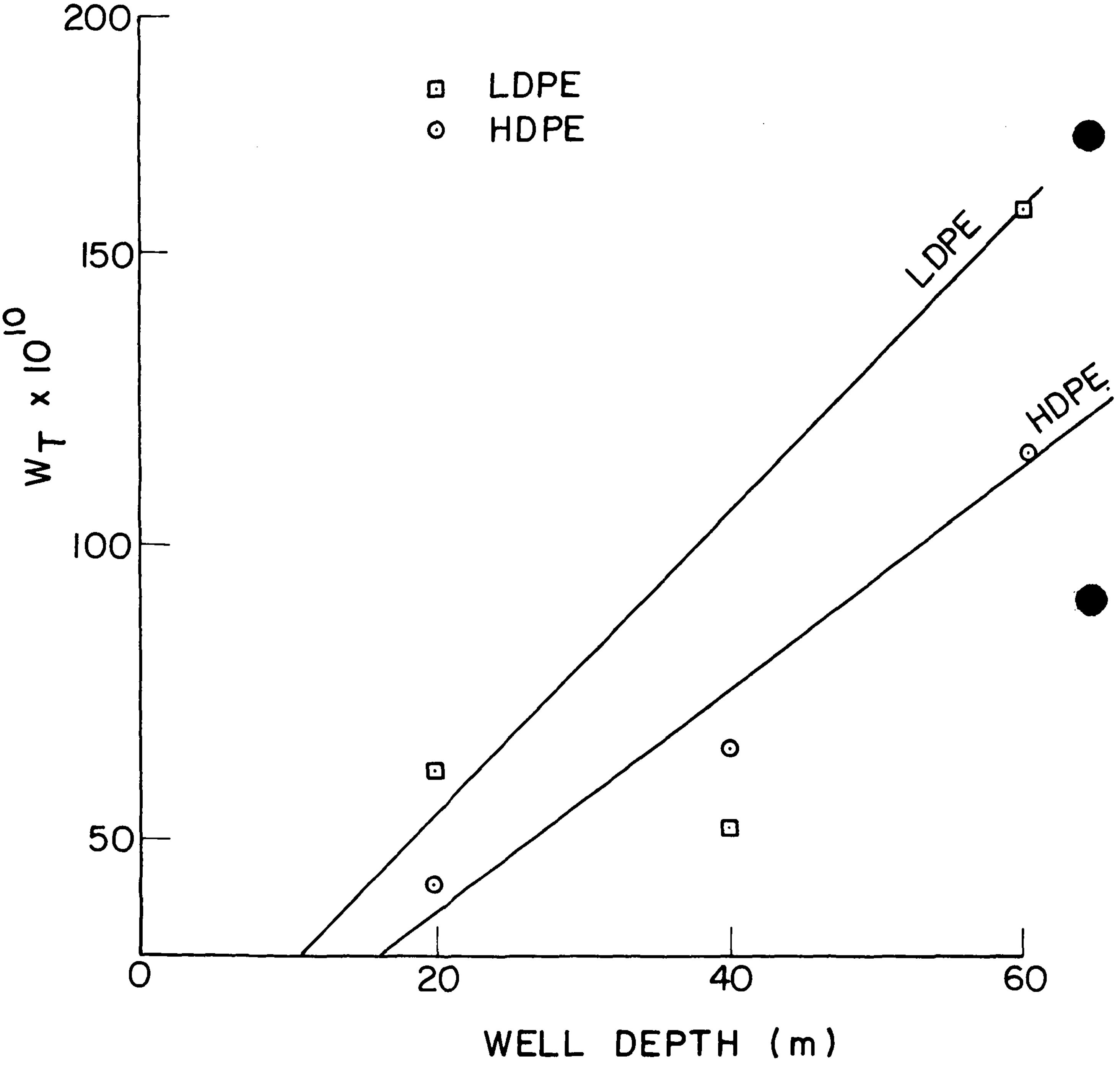
H is head in meters

The two above equations are displayed graphically in Fig. II as a function of M and H with W_L in mm.

For the suggested pump design a piston of 7.6 cm diameter is recommended. This gives a piston ring thickness of about 6mm (see Fig. III). If a maximum permissible wear of one half the ring thickness is taken as a guide to unserviceability, then lines of maximum wear may be drawn on Fig. II at the 3mm maximum. This means that the piston ring made out of HDPE used in a pump at 20 m depth has an approximate life of 4 million cycles.

The life decreases at the depth of the well increases.

FIGURE I



□ LDPE
⊙ HDPE
LDPE
HDPE
$W_T \times 10^{10}$
200
150
100
50
0
20
40
60
WELL DEPTH (m)

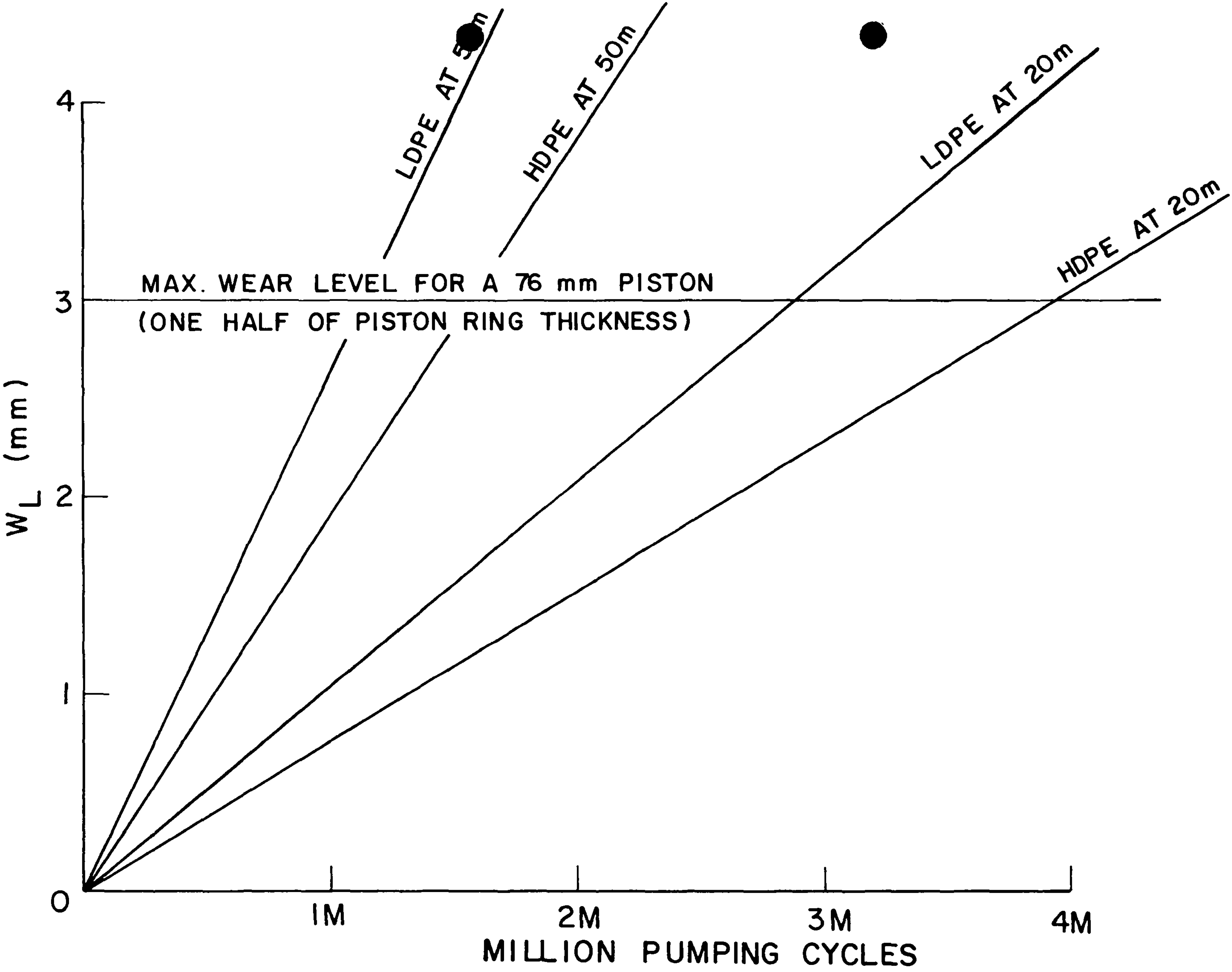

LDPE AT 50m
HDPE AT 50m
LDPE AT 20m
HDPE AT 20m
MAX. WEAR LEVEL FOR A 76 mm PISTON
(ONE HALF OF PISTON RING THICKNESS)
W_L (mm)
0
1
2
3
4
1M
2M
3M
4M
MILLION PUMPING CYCLES

FIGURE II

FIGURE III

SUGGESTED RING DIMENSIONS
BASED ON PISTON BORE