MINISTRY OF LOCAL GOVERNMENT, HOUSING AND CONSTRUCTION

NATIONAL WATER SUPPLY AND DRAINAGE BOARD

SRI LANKA

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DESIGN MANUAL D5

MECHANICAL, ELECTRICAL AND
INSTRUMENTATION ASPECTS OF
WATER SUPPLY DESIGN

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MARCH 1989

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1. INTRODUCTION AND OBJECTIVES

This Manual provides design notes and information on mechanical, electrical and instrumentation aspects of water supply design, particularly for water or sewage pumping stations. It is intended to assist Design Engineers having a civil engineering background.

In the design of pumping stations, the Design Engineer does not need to have a detailed mechanical knowledge of pump design, but he must have sufficient information on the various types of pump, motor, starter etc., to be able to choose the most suitable plant and to be able to install it to best advantage. As equipment guarantee requirements have become severe in recent times and highest efficiencies are demanded, it is essential to work in accordance with definite and generally accepted standards if misunderstandings are to be avoided. Hence, in the planning of any pumping plant, due regard should be given to the type and efficiency of the pump because these two factors could influence the economy of a whole plant.

Information is presented about practical design aspects of pumps and pump installations, motors, starters, auxiliary equipment and instrumentation for monitoring, control and protection of equipment. It is not intended here to cover in-depth theory of pump, motor or instrument design, and for further information on these subjects, a list of references is given.

The manual has been compiled by Mr. G.A. Bridger of the USAID Project from material provided by Mr. Ananda Silva and Mr. Cornelius of NWSDB and Mr. S. de Saram and Mr. P. Mead of the USAID project, and other sources.

2. MECHANICAL ASPECTS

2.1 Types of Pumps

Pumps can be divided into two main categories:

- o positive displacement (reciprocating or rotary); and
- o rotodynamic, including centrifugal, mixed flow and axial flow types.

The characteristic feature of a positive displacement pump is that it delivers a definite volume of liquid at every stroke or revolution, regardless of the head against which it is required to work.

There are two common types of reciprocating pump, the double acting piston pump and the single-acting plunger pump. The diaphragm pump, mainly used for chemical dosage, would also come under this category. There are a large number of different designs of rotary positive displacement pumps, the most common in the water field being the "MONO" type screw pump and the Archimedian screw type pump.

Generally, positive displacement pumps of one type or another are employed where it is required to deliver a relatively small volume of water against a relatively high head. The Archimedian screw pump is an exception where large quantities can be delivered against a low head.

In positive displacement pumps the volume of flow is determined by the geometry of the pump and is given by the swept volume per stroke or revolution less the leakage rate; the head developed is fixed by the system or reservoir into which the pump is delivering and not by the pump itself.

Rotodynamic pumps function on an entirely different principle. The maximum head that can be developed is a definite characteristic of the particular design of pump, while the volume of flow can vary from zero to a certain maximum value corresponding to zero delivery head. The operating point of a rotodynamic pump is determined by the intersection of the pump characteristics curve with the system curve (see Section 2.2).

These pumps are often referred to simply as centrifugal pumps since the head is developed by centrifugal force. These are the most common type of pumps used in water and sewage pumping systems. They may be of various type, such as vertical turbine, radial, submersible, or multi-stage.

Centrifugal pumps, by the action of an impeller, create a difference in pressure between the inlet (suction) side and outlet (discharge) side of the pump, thus causing the fluid to flow through the pump. The discharge head or pressure must be great enough to overcome the static head on the discharge pipe or there will be no flow. The difference between the available head and the static head together with the characteristics of the pipeline (diameter, length, material and minor losses) determines the rate of flow through the discharge pipe. The characteristics of the pump determine the relationship between the flow through the pump and the discharge head, after considering the suction conditions, particularly any suction lift. From this, a particular pump in a particular pipe system will have a discharge and head than can be determined.

More information on different pump types and their application is given in Table 1.

2.2 Determination of Head

In selecting the most suitable centrifugal pump for a given application, the "duty" must be determined, i.e. the desired capacity and head against which the pump will be required to operate. This total system head is made up of the following (see Fig. 1):

1. Static head ($H\ s_t$)

2. Difference in pressures existing on the liquid ($P_d - P_s$)

3. Friction head (H_f)

4. Entrance and exit losses (H_i and H_e)

5. Velocity head (H_v)

The friction head loss in a system of pipes, valves and fittings varies as a function (roughly as the square) of the flow through the system. For the solution of pumping problems, this is best shown graphically as the system curve (see Fig 2).

The system friction head, together with the other parts of the total system head, listed above, combine to form the system head curve (See Fig. 3).

The total head (H_T) of a centrifugal pump is the energy imparted to the liquid by the pump ($H_d - H_s$) (See Fig. 1)

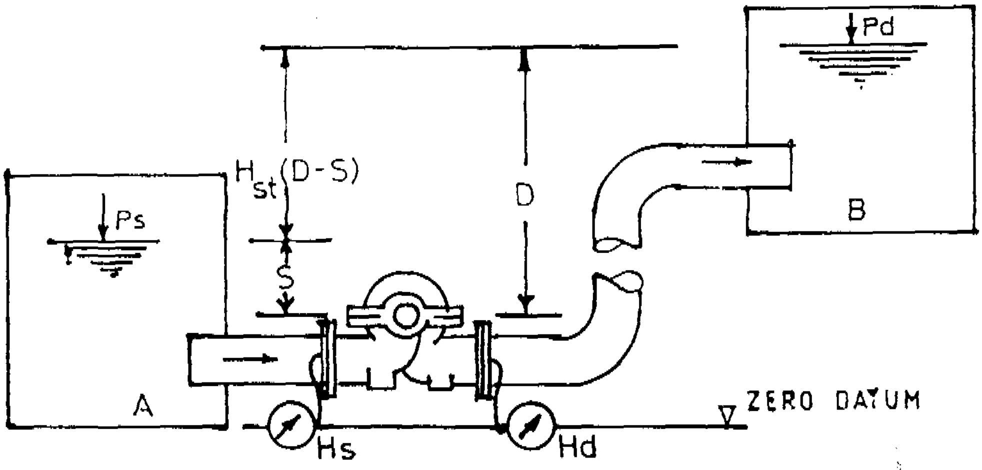
The total head of a vertical well-pit pump is determined as follows: discharge head measured at the centre-line of the discharge nozzle, with velocity head included, plus the static distance to the suction water level.

Table - 1 INFORMATION ON PUMPS

Type of Pump	Practical Suction Lift *	Usual Well-Pumping Depth	Usual Pressure Heads	Advantages	Disadvantages	Remarks
Reciprocating 1. Shallow well 2. Deep well	7-8 m 7-8 m	7-8 m 180 m	30-60 m Up to 180 m above cylinder	Positive action. Discharge against variable heads. Pumps water containing sand & silt. Especially adapted to low capacity and high lifts.	Pulsating discharge. Subject to vibration and noise. Maintenance cost may be high. May cause destructive pressure if operated against closed valve.	Best suited for capacities of 20-100 L/Min. against moderate to high heads. Adaptable to hand operation. Can be installed in very small diameter wells(50 mm casing) Pump must be set directly over well (deep well only).
Centrifugal 1. Shallow well a) Straight centrifugal (single stage)	6 m max.	3-6 m	30-46 m	Smooth, even flow. Pumps water containing sand and silt. Pressure on system is even and free from shock. Low starting torque. Usually reliable and good service life.	Loses prime easily. Efficiency depends on operating under design heads and speed.	Very efficient pump for capacities above 230L/Min. and heads up to about 46 m.
b) Regenerative vane turbine type (single impeller)	8.5 m "	8.5 m	30-60 m	Same as straight centrifugal except not suitable for pumping water containing sand or silt. Self priming.	Same as centrifugal except maintains priming easily.	Reduction in pressure with increased capacity not as severe as straight centrifugal.
2. Deep well a) Vertical line shaft turbine (multi stage)	Impeller submerged	15-90 m	30-240 m	Same as shallow well turbine. All electrical components are accessible, above ground.	Efficiency depends on operating under design head. and speed. Requires straight well large enough for turbine bowls & housing. Lubrication and alignment of shaft critical. Abrasion from sand.	
b) Submersible turbine (multi-stage)	Pump & motor submerged	15-120 m	15-120 m	Same as shallow well turbine. Easy to frost-proof installation. Short pump shaft to motor. Quiet operation. Well straightness not critical.	Repair to motor or pump requires pulling from well. Sealing of electrical equipment from water vapour critical. Abrasion from sand	3500 RPM models, while popular because of smaller diameters or greater capacities, are more vulnerable to wear and failure from sand and other causes.
Jet: 1. Shallow well	5-6 m below ejector	Up to 5-6 m below ejector	24-46 m	High capacity at low heads. Simple in operation. Does not have to be installed over the well. No moving parts in the well.	Capacity reduces as lift increases. Air in suction or return line will stop pumping.	
2. Deep well	5-6 m below ejector	8-37 m (60 m max.)	24-46 m	Same as shallow well jet. Well straightness not critical.	Same as shallow well jet. Lower efficiency, especially at greater lifts.	The amount of water returned to ejector increases with increased lift - 50% of total water pumped at 15 m lift and 75% at 30 m lift.
Rotary: 1. Shallow well (gear type)	7 m	7 m	15-76 m	Positive action. Discharge constant under variable heads. Efficient operation.	Subject to rapid wear if water contains sand or silt. Wear of gears reduces efficiency.	
2. Deep well (helical rotary type)	Usually submerged	15-150 m	30-150 m	Same as shallow well rotary. Only one moving pump device in well.	Same as shallow well rotary except no gear wear.	A cutless rubber stator increases life of pump. Flexible drive coupling has been weak point in pump. Best adapted for low capacity and high heads.

* Practical suction lift at sea level. Reduce lift 0.3 m for each 300 m above sea level.

Table adapted from "Small System Design and Construction"



$H_T = H_d - H_s$

$= H_{st} + H_f + H_i + H_e + H_v + (P_d - P_s)$, where

H_T = Total head
H_d = Delivery head
H_s = Suction head
H_{st} = Static head
H_f = Friction head
H_i = Entrance losses.
H_e = Exit losses.
H_v = Velocity head

Fig. 1. DETERMINATION OF TOTAL HEAD

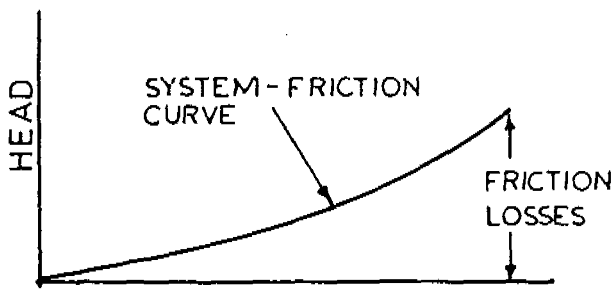


Fig. 2. SYSTEM - FRICTION CURVE

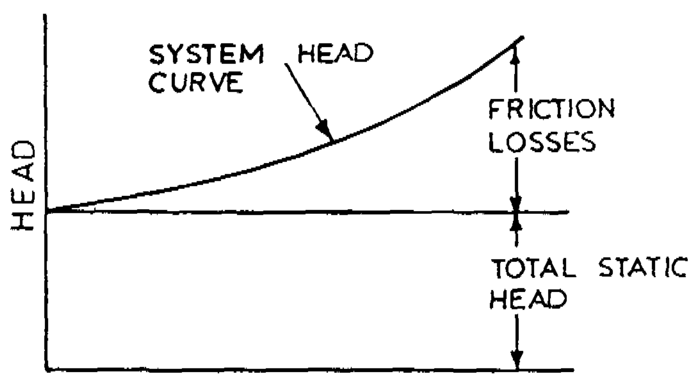


Fig. 3. SYSTEM - HEAD CURVE

2.3 Suction Conditions

It should be noted that it is atmospheric pressure alone which forces water into a pump with a free suction, and all pump impellers require a minimum of net positive head to perform satisfactorily. Rather than talk in terms of suction lift, it is proper to think in terms of net positive suction head (NPSH.).

NPSH is the total suction head (in metres of liquid absolute) determined at the suction nozzle and referred to datum, less the vapour pressure of the liquid (in metres absolute).

NPSH is expressed as follows:

$NPSH_{avail} = H_{abs} - H_{vap} + H_s - H_F$

H_{abs} = Atmospheric pressure (in metres absolute) on surface of liquid in suction well.

H_{vap} = Vapour pressure of liquid (in metres absolute) at pumping temperature.

H_s = Total static head (+ ve) or lift (− ve) in metres between centre line of pump and liquid surface.

H_F = Friction head and entrance losses in suction piping.

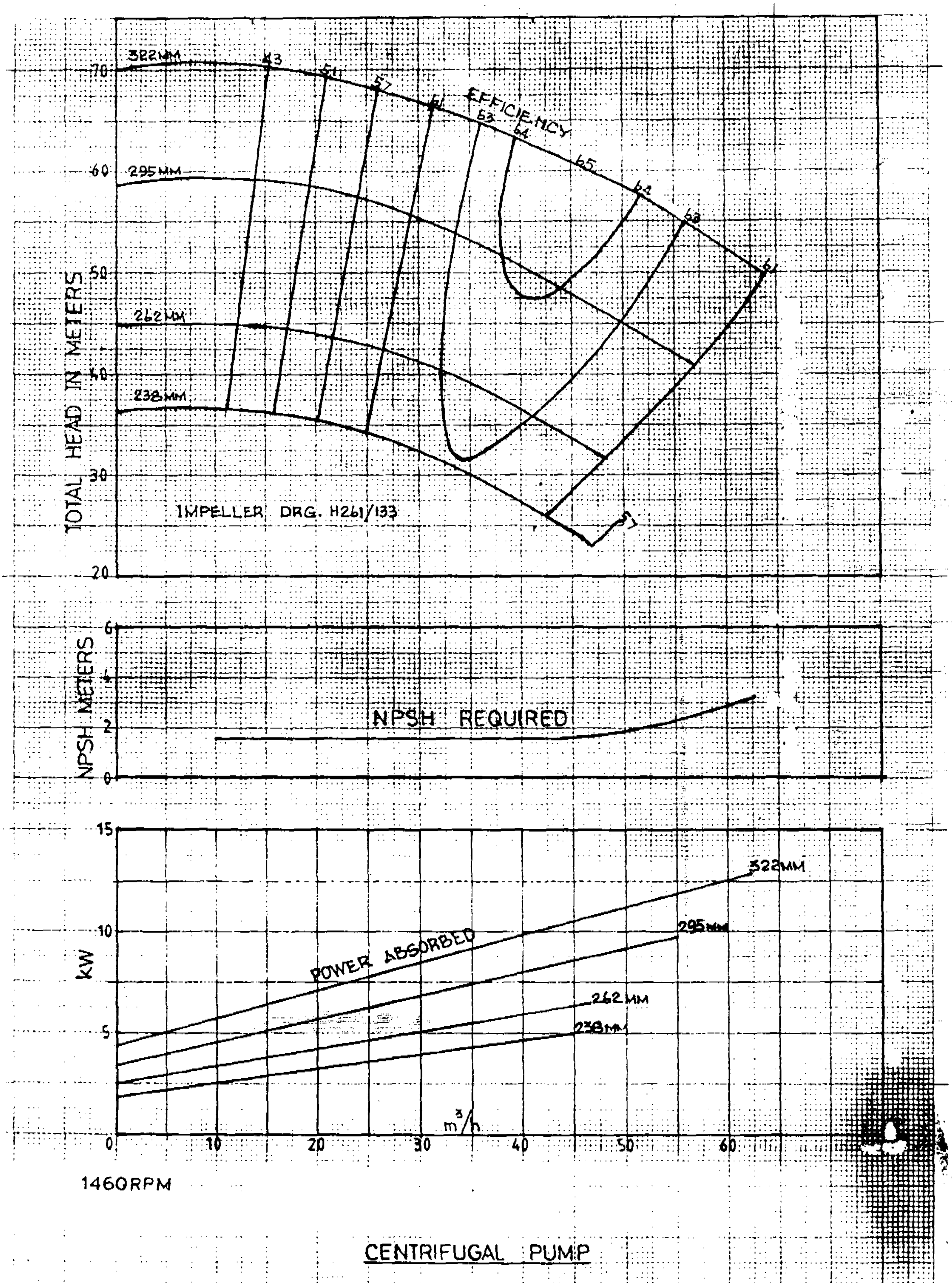
When designing an installation, the NPSH to be made available should be borne in mind as the NPSH required by the pump will be fixed by virtue of its design characteristics.

2.4 Pump Characteristics

There are various relationships, usually expressed in terms of pump discharge, which are collectively known as the characteristics of a pump. These relationships are discharge/efficiency, discharge/power, and discharge/required net positive suction head (NPSH). Because of the relationship between discharge and head, each of the other characteristics could be expressed in terns of head rather than discharge, e.g. head/power, but discharge is the customary common factor.

These characteristics are usually shown on a graph, called the performance curve of the pump. As will be explained later, the characteristics depend upon the pump speed (rpm) and this must be specified on the curve. As will also be explained later, typical electric motors that are used for pumps have speeds that are dependent upon the cycles in different countries, either 50 Hz or 60 Hz. Pump manaufacturers who serve countries with both cycles usually have performance curves for 50 Hz and for 60 Hz.

A performance curve showing all four characteristics for a typical centrifugal pump is shown in Figure 4. Because the common factor is the discharge, it may be thought that this is what controls the head. By partially closing the discharge valve it easily can be shown that changing the head controls the discharge.



PERFORMANCE CURVES FOR TYPICAL PUMPS

FIG. 4

It is important to understand the relationship between head and discharge. Typically, as the head is decreased, the discharge increases at an increasing rate, producing a curve that is concave downward. The shapes of the curves for efficiency, power and NPSH are also typical, but there are exceptions. The left end of the discharge/head curve shows the shut off head; there is zero flow at that head. The right end of the curve shows the maximum discharge of the pump; further decrease in head will produce no increase in flow but, instead, will usually result in cavitation and excessive vibration and should be avoided.

Cavitation is a phenomenon that occurs when the pressure at some point inside the pump is reduced to the vapour pressure of the pumped fluid (water). For a detailed explanation the reader is referred to the literature on pumps.* Cavitation is the collapse of the vapourised fluid back to the liquid state, which results in an implosion causing intense impact on the impeller. It can usually be heard as a rattle, much like the rattle of a diesel engine, the rattle being the repeated implosions of collapsing bubbles of vapour. Cavitation can occur when the suction lift is excessive (hence the specified NPSH) or when the discharge is at the limit of the pump. Cavitation is not (usually) the result of high water temperature but rather of lowered pressure because of increased velocity through the pump. (Refer to Bernouilli Theorem.)

There are peculiarities of pumps which should be considered. Figure 5 shows the discharge-head curve for each of three pumps. Each pump will meet the duty point of 110 L/s at 37 m, but there are differences. The upper curve is what is called a flat curve in which the discharge is greatly affected by a small change in head. Unless the head is to be very steady, a pump of this type may not be a good choice. The middle curve shows a peculiarity that can cause trouble. At a head of 42.5m there are three different discharges! This is no problem when the pump is starting because the transient conditions will carry it on through the trap, and there is no problem on shut down. But if the head is increased while the pump is running, the flow will decrease steadily until the trap is reached. Then the flow may reduce suddenly to the far side of the trap and with minor changes in pressure, may surge back and forth from one point to another of the three discharges corresponding to the one head. Pumps with this pattern of discharge/head curve should be avoided unless it is sure that the pump will always run at a point well beyond the trap. The bottom curve is for a pump with characteristics that are usually preferred. The pump will operate over a wide range of head with no problem of low discharge or erratic flow.

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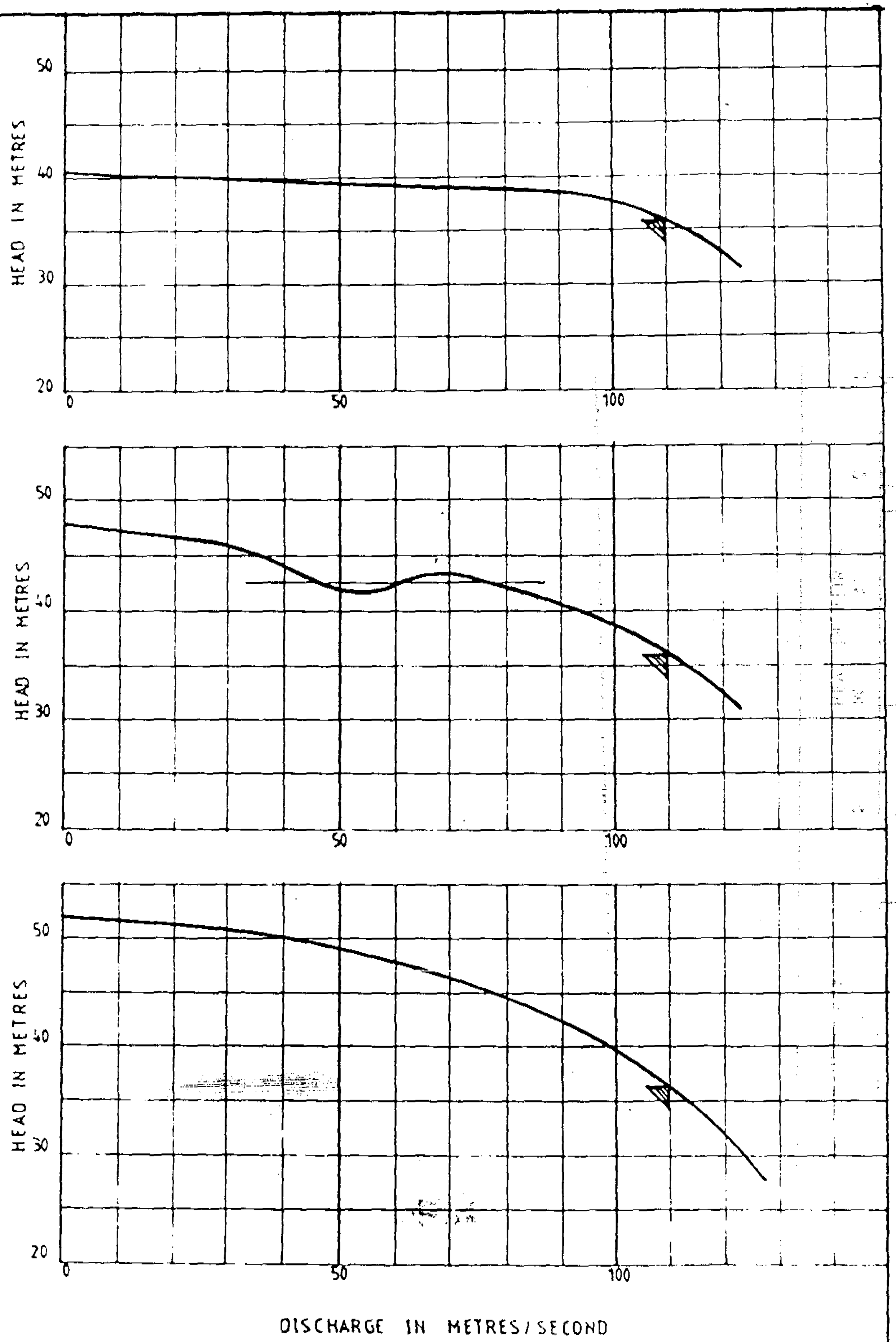
* Pump Handbook, Reference 1.



VARIOUS DISCHARGE/HEAD CURVES

FIG. 5

Another typical characteristic that most pumps have is an increasing power requirement with increasing discharge. This factor should be considered by the designer in specifying a pump. If the motor is sized for the power required at a particular duty point on the pump curve, the motor may not have enough power for a point near the right end of the curve where the pump may actually run if the head is reduced for whatever reason. This is particularly important for booster pumps in distribution systems where peak demand may greatly reduce the discharge head. Therefore, it is common practice to require the motor to have enough power to handle all points on the discharge/head curve.

Therefore, having established the duty or duties the pumps are required to perform, there are usually a variety of designs available. It is as well to review the whole range of types. All pumps can be classified by their specific speed which is defined as:

$$Ns = \frac{3.65\ N.Q^{0.5}}{H.^{0.75}}$$

Where N_s = Specific speed (rpm)

Q = Discharge in m^3/s

H = Head in metres

(Specific speed is defined as the impeller speed (rpm) necessary to produce 1 gal/min at 1 ft of head, in the foot-pound system).

The main use of N_s is in identifying pump type Pump performances can be related to specific speed in the manner that Reynold's No. is a criterion for pipe flow. For any impeller the specific speed will vary from 0 to ∞ on the H-Q curve, so when we refer to N_s it normally implies that it relates to the best efficiency point. (For a double-entry impeller the Q value is halved, and for multi-stage pumps the head for each stage is used).

The above expression for N_s tells us that a pump built for a large quantity and small head will tend to have a high specific speed and vice versa. Radial flow impellers are found in centrifugal pumps up to an N_s value of 2000. Mixed flow impellers are in the N_s range 3000-7000m and for axial flow impellers, N_s is 7000 and upwards.

A pump can be available with two forms of casings, one with volute surrounding the impeller, the other one with some kind of diffuser ring with fixed guide vanes. The choice is dictated by geometrical considerations.

2.5 Types of Installation

2.5.1 General Rules for Pump Locations

Pumps installed indoors, in poorly lighted and cramped locations or where dirt and moisture accumulate, are improperly placed for dismantling and repair, they will be neglected and both pump and driver may become damaged. Pumps should be placed in light, dry and clean locations whenever possible.

If a motor driven unit will be operated in a damp, moist or dusty location, the proper motor must be selected. Pumps and motors designed for outdoor installation are especially constructed to withstand exposure to weather. However, whilst the civil works costs are saved on such an installation, the drawbacks due to vandalism and improper maintenance due to bad weather should not be underestimated. Sufficient room must always be provided for dismantling the pump and removing the motor.

When pumping equipment must be used at levels where flooding is possible, two courses of action may be followed:

1. A vertical wet-pit pump may be used: or

2. An auxiliary wet-pit sludge pump must be provided as an insurance against damage to the main equipment.

If possible, pumps should be located as close as possible to the source of liquid supply. When convenient, the pump centre-line should be placed below the level of the liquid in the suction reservoir.

2.5.2 Boreholes

Submersible pumps, usually of multistage centrifugal type, due to their low capital cost and ease of installation/withdrawal have virtually replaced the shaft-driven type of vertical pump. Jet type centrifugal pumps, which use compressed air or water to force the water to ground level, are used in shallow wells where small quantities of water are required.

Wet-well Pumps - the pump is suspended from the motor-room floor or intermediate floor level so that the pump is submerged. The discharge bend can be arranged above or below support floor level.

Dry-well Pumps - the pump is arranged vertically at the bottom of the dry-well, the motor being situated at floor level above ground and the drive effected by intermediate shafting.

2.5.3 Booster Pumps

Booster pumps are used to increase flows or pressures and in some instances to lift water from one area or service to another. Installations of these types vary depending on local requirements. They can be single or multistage centrifugal, horizontally or vertically mounted, or they may be the in-line, submersible, multistage centrifugal type. Booster pumps are also used in large water supply transmission mains that are carrying water over long distances, generally from a surface-water supply source to either a distribution system or treatment plant.

2.5.4. High Service Pumps

High-Service pumps are used where water taken from a storage tank, reservoir, or clear well is pumped directly into a water distribution system. For this type of installation, single-stage horizontal centrifugal pumps are usually used.

2.5.5. Factors to be Considered

- Civil engineering costs
- Initial plant costs
- Running costs.
- Reliability
- Maintenance

The development of fully submersible electric motors has opened up new areas in pumping station design for water supply projects. Submersible water pumps are now quite normal, particularly for the smaller installations. For water supply, submersible motors are used both with well and borehole pumps and for boosting. It should be noted that there are some reputed submersible pumps which are proving quite reliable and the arrangement offers a major saving in civil engineering cost.

2.6 Special Types of Pumps

2.6.1 Self Priming Pumps

A true self priming pump is one that will clear its passage of air if it becomes air bound and resume delivery of the pumped liquid without outside attention. A self-priming pump requires an air-separator, which is a large stilling chamber provided on its discharge side to effect this separation.

Several ways exist of making a centrifugal pump self-priming, the most important being the following:

- o Re-circulation from discharge back into suction.
- o Re-circulation within the discharge and impeller itself.

These two basic methods have many variations. Self-priming pumps are very expensive compared to the cost of normal centrifugal pumps with foot-valves, but have two important applications:

- o Larger pumps where it is difficult to get foot valves for large diameter suction ends; and
- o Unmanned pumping installations.

2.6.2 Jet Pumps

This is a centrifugal pump and ejector combination to lift water over 9.5 m from the suction side. A portion of the pumped water is re-circulated through the ejector to lift water to the requisite height for the centrifugal pump impeller to take over. The unit is inefficient, but worth considering for small sizes say up to 5 hp for boreholes or wells with the water level about 20 m below ground level. The pump is situated at ground-level and the ejector is in the well. The arrangement is economical compared to the alternative of a small submersible pump in terms of initial cost and maintenance. The running cost would be comparable.

2.6.3 Vertical Turbine Pumps

The term turbine pump is usually given to the type of multi-stage centrifugal pump often used in water supply engineering. They form the basis of some of the centrifugal borehole and submersible pumps. In the turbine pump, the velocity head induced by the moving impellers is transformed into a pressure head by means of diffuser chambers before the water is passed to the impeller of the next stage. The diffuser chambers are fitted with tapering guide passages discharging into spiral passages. In this manner, comparatively small quantities of water can be lifted through quite high heads. Engine-driven, vertical turbine pumps could be used for boreholes and wells, where electrical power is not available.

2.7 Auxiliary Equipment and Control

The satisfactory operation of a pumping unit depends not only on the design of a pump, but also to a large measure on how the pump is made to perform. Performance under running conditions is a major design criterion, but this normal performance is not particularly important in the selection of the drive and its controls. How the unit is to function under transient or abnormal conditions generally establishes the design criteria for its controls.

Pump controls consist of the starter, the valve controller, and other devices that act together to govern the operation of the pump under all conditions, with limits imposed by both the hydraulic and electrical systems.

Many pumping facilities are provided with auxiliary equipment that either affords protection or makes for some efficient or effective operation. Although these items may be important they often are not absolutely essential to the operation; there may be a loss of efficiency or some danger to the system, but the pumps will still run, even though not very well. For this reason and because the functioning and the importance of the auxiliary equipmnent may not be understood or appreciated, maintenance is often lacking. Once an item of such auxiliary equipment stops working, it might never be put back in running order. Examples, are surge protection, priming systems, seal water systems, and such miscellaneous items as air and vacuum valves, pressure relief valves, pressure regulating valves, and check valves.

2.7.1 Pump Starting

The starting of high-service pumps must be controlled to avoid line surges or water hammer. Usually it is necessary to have some mechanism on the pump discharge to prevent backflow both prior to and during starting, until the pump develops sufficient pressure to overcome the system's pressure. In its simpler form, this mechanism may be some type of mechanical check valve. Line surges are prevented by regulating the speed at which the discharge valve opens so that the fluid is eased into the system.

Pump discharge valves may offer other advantages. Pumps with centrifugal characteristics require less starting torque with a closed discharge than with an open discharge. The drive motor, therefore, can employ a normal-torque, low starting-current design. Care should be exercised whenever a centrifugal pump is started against an open discharge because it may overload the driver. Other types of pump may require different starting procedures and special controls.

Starting control requirements also depend on site and location. Pump priming is an element of pump control that must be taken into account. Whether or not priming is required depends on hydraulic conditions. Priming is an artificial means of forcing fluid into the pump. It is usual to evacuate the casing using a vacuum system, so that atmospheric pressure forces fluid into the casing through the suction connection. The priming operation, or the interlock to prevent starting unless prime exists, is an element of the start sequence. Other aspects of starting controls and protection devices are discussed in Chapter 3.

2.7.2 Surge Protection

Where pumps discharge into long pipelines or closed pipe networks, there is danger of damage to the system because of surge (water hammer*) which occurs when the pumping rate is changed rapidly. This danger can be lessened by opening and closing valves slowly but this will not take care of the problem of a power failure or other unplanned stoppage of pumps. The problem can sometimes be avoided by pumping a short distance to a higher elevation, either to a hilltop reservoir or to an elevated tank, and providing gravity flow from that point onward. Where this is not possible, surge protection should be provided.

The most simple surge control is a bottom-connected tank or standpipe. The tank must be high enough to avoid overflow during upsurge and must have enough volume at the normal operating level to provide the water required to fill the pipe during downsurge. There are no moving parts and the device requires no special maintenance. Surge tanks are typically used on systems where the diameter of the pipeline is large.

For pipelines less than about 1000 mm diameter, a more commonly used protection is a surge vessel. A surge tank is usually unsightly because of the necessary height and, for smaller systems, the surge vessel becomes economically feasible. The equipment comprises a pressure vessel with a connection from the bottom of the vessel to the pipe system and a source of compressed air connected near the top of the vessel. It is a type of hydropneumatic tank in that it contains both water and air. As with other hydropneumatic systems it is necessary to maintain the proper ratio of water and air, taking into consideration the pressure corresponding to the volume of air. This is accomplished by adding air from the compressed air

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* Refer to Pump Handbook and to other publications by John Pariamakian.

source or bleeding off air as needed. The vessel should also be equipped with a sight tube for determining the water/air interface, with shut off valve to allow for maintenance, and two try cocks or test valves, one each at the upper and lower limits of the water/air interface for normal operation. The try cocks are a back-up for the sight tube in case it is broken or otherwise defective.

The surge vessel is designed so that there is sufficient air volume to allow the upsurge to be absorbed by flowing into the vessel and further compressing the air. There must also be sufficient water volume to provide the water for the downsurge without emptying the vessel and losing air. Other protective devices such as check valves, air and vacuum valves and pressure relief valves are often used in conjunction with surge vessels or may comprise the surge protection without a surge vessel, where the severity of the surge is not great. These items are described in Section 2.7.5.

The operation of a surge vessel is automatic, except for the water/air ratio and even this can be automatic. However, maintenance is required. The sight tube can become dirty or break and will need cleaning or replacement. Pressure gauges on the vessel as well as on the air compressor will need to be kept in working order, and so will the compressor itself. The shut off valves (there are usually several of them) and the two try-cocks may become stuck in position (frozen) and should be manipulated periodically or serviced or replaced if defective. Some surge vessels are designed with the water connection entering the side of the vessel with an internal syphon that terminates near the bottom of the vessel. This forms a sediment trap at the bottom of the vessel which should be purged occasionally by opening the bottom drain. The vessel is provided with an access hatch to permit entry for cleaning and painting or relining the inside surface and this is part of the required maintenance.

It is common to see, in Sri Lanka and elsewhere, surge vessels that ceased to operate long ago. Sight tubes are missing, valves are stuck, either open or shut, and corrosion is consuming the equipment. The valve on the pipe connecting to the mains has been closed, and there is no longer surge protection. How does the system survive. Perhaps it was overdesigned and surge protection was not really needed. More probably, the protection is needed and the unsuppressed surge is damaging pipes, fittings, valves, causing leakage and loss of water. The part of the system that is buried cannot be seen and its true condition is not known and can only be suspected.

A special form of surge protection that can be provided in pipe systems consists of nothing more than air cushions. A short vertical riser near each valve in the plumbing of a building, for example, will automatically trap air within the full length of the riser. When the valve is closed suddenly, this pocket of air allows space for the upsurge to dissipate, thus avoiding localised water hammer. This type of problem may not be noticed where pressures are very low; but when the system is upgraded and pressures increase, localised water hammer becomes an irritating disturbance that can be avoided very easily with proper construction.

2.7.3 Priming Systems

Pumps that are submerged, such as vertical turbine well pumps, and those that are in dry wells with the pump below the water level of the wet well, require no special priming. There are many installations where the level of the pump is above the level of the water and, for centrifugal pumps, some method of priming is required. The two methods most commonly used are vacuum priming and foot valves.

Vacuum Priming:

A vacuum priming system consists of some means of isolating the pump from the downstream piping and a means of evacuating the air from the pump. The isolation is usually accomplished with a check valve. In some cases, especially when the check valve has not been maintained and will not seal shut, the valve on the discharge side of the pump is closed and later opened. The check valve does this automatically. The evacuation is by means of a vacuum pump which may operate manually or automatically. The details of design and of the equipment will not be discussed, the purpose here being to explain the need for the system and to emphasise the need for maintenance.

When the pump is to be started, it is first necessary to evacuate the air from the bowl of the pump. This reduces the pressure inside the pump and the water from the wet well or intake is forced into the pump by the higher pressure of the atmosphere. When the pump bowl is full, as evidenced by water being discharged from the vacuum pump or as otherwise sensed by automatic equipment, the vacuum is shut off and, at the same time, the pump is started.

In most water supply installations with vacuum priming, the water level of the intake is always below the level of the pump (except during a flood). Because the pump will not run without priming and can only be primed by the vacuum priming system, there is usually enough attention to maintenance to keep the priming equipment in some sort of running condition. The automatic controls may be abandoned in favour of manual operation, and instrumentation may be long gone, but the pump can be primed - or it will not run. In sewage pumping systems the circumstances are different. The level in the collection well varies and, unless the pump is above the surface of the ground, will eventually rise high enough to fill the pump. This may be considered a method of priming but it is not a good one because the sewers may be flooded while the level is rising.

Vacuum priming systems require maintenance. Ideally, there should be duplicated vacuum pumps, especially with automatic systems. Manually operated systems might have a spare vacuum pump available and ready to be installed, on-site, and with all the tools and skills required on-site, also.

<u>Footvalves</u>: A foot valve is a check valve placed at the bottom, or foot, of the suction pipe of the pump. Initially, it may be necessary to prime the pump by introducing water. This might be done by opening the discharge valve if there is pressure on the downstream pipeline. Otherwise, an opening in the system can be provided and water can be poured in from a bucket. Once the pump is primed, the foot valve should hold the prime.

Foot valves are simple but they can become clogged and fail to seat. When this happens, maintenance is difficult. If the pump is of the vertical configuration with the suction pipe hanging down from the pump, it may be necessary to remove the pump to get at the suction pipe and the foot valve.

A better solution may be to use a horizontal pump with an elbow at the top of the suction pipe.

Special Considerations: Even though the pump is in a dry well below the normal level of the water (or sewage), it is possible for the pump to become air locked and thereby not be primed. This can occur with intermittent pumping from a collection well, particularly with sewage lift stations. If the level in the wet well is drawn too low, air may be sucked into the pump just when it is stopping. The check valve closes and the bowl of the pump remains full of air. On the next cycle, the pump will not pump; it runs, but there is no discharge. This problem can be avoided quite easily by installing an air release valve on the pump.

In an emergency, it should be possible to prime a pump by back flow. If there is pressure on the downstream pipe (otherwise why would a pump be necessary) the check valve can be partially opened (if it has an external lever, and it should) to allow water (or sewage) to flow back into the pump. This will cause the pump and the motor to run in reverse unless the backflow is very small, in which case the pump may not prime in any event. The back spin can be prevented or retarded by using a piece of wood held against the shaft or the couplings as a brake. This method should be used only as an expedient in an emergency and not as a regular means of priming. There are safety hazards and care should be exercised.

2.7.4 Seal Water Systems

The bearings of the pump must be lubricated and water is often used for this, especially on large pumps. Water is readily available from the pump itself and will try to leak into the bearing area in any event. Therefore, a small amount of water is deliberately permitted to leak through to lubricate and to cool the bearings. In the case of large pumps handling sewage or the silt laden water of a river intake, there is a need to lubricate the bearings and, also, a need to prevent the pumped liquid from entering the bearing area. Stuffing boxes or mechanical seals might accomplish this, but a more secure method often used is water sealing.

In this method, water is injected into the bearing area at a pressure that is higher than the pressure on the pump side of the bearing box. The packing or other sealing on both sides of the bearing is loose enough to allow a small amount of water to leak through. This ensures that the abrasive material in the liquid that is being pumped is swept away from the seal on the pump side and gives assurance that the system is working by the evidence of the water emerging from the seal at the end of the shaft.

Seal water pumps, small capacity, high head pumps, are used to provide the pressure required for sealing. A duplex installation is usually provided so there will be back-up in case of a pump failure. A source of clear water is required, usually from the potable water system. This water should pass into an intake tank with an air gap to prevent a cross-connection. The seal water system is usually electrically interconnected with the main pumps so that the main pumps will not operate (at least not automatically) if there is not sufficient seal water pressure. The system requires careful attention to maintenance.

2.7.5 Miscellaneous Equipment

In addition to discharge valves and, possibly, suction valves, various other mechanical devices are used in pumping facilities. These include check valves, air and vacuum valves, and pressure relief valves.

A check valve (non-return valve or reflux valve) closes automatically when the flow in the normal direction stops or when it starts to reverse. This provides for one-way flow in a pipeline and prevents backflow. The alternative is to use a shut-off valve of some type, but a check valve works automatically and, if properly maintained, very effectively. There are various designs that go by various names but what is usually wanted is one that will slam shut on reverse flow. An external lever may be desirable because it allows manipulation by the pump operator. Check valves can become clogged, particularly by grease in the case of sewage or by carbonate deposits in the case of water, and they do require maintenance if they are to function properly. When used with a pump, the check valve should be placed between the pump and the shut-off valve, not downstream from the valve, to facilitate maintenance.

Air and vacuum valves are used to release air from a pipeline that is being filled with water and to allow air to enter a pipeline to prevent negative pressure. There should also be provision for the release of accumulated air because, in typical design, once the air release seats it remains held in position by the pressure in the pipeline whether that pressure is from the water or from accumulated air (which will be at the same pressure). Air and vacuum valves should be placed at the high points or summits of pipelines where they will prevent air locking. They are also used in conjunction with surge protection. The details of design and installation are well covered by the catalogues of manufacturers. Air and vacuum valves require little attention but should be inspected and serviced periodically to ensure that the sealing device is seating properly. Deposits of carbonates or of algae are the most common problems.

Pressure relief valves, as the name implies, relieve pressure when it reaches a pre-set maximum amount by discharging water. They close again when the pressure has been relieved. Pressure relief valves are used in conjunction with surge protection and also with pressure regulating stations. They require periodic inspection and possible cleaning for the removal of carbonate deposits and algae.

2.8 Miscellaneous Design Considerations

2.8.1 Basic Design Objectives

- Identification of pump station duty, and required pump characteristics.
- Selection of type of pump of required efficiency.
- Selection of type of motor, starting equipment and auxiliary equipment for required duty.
- Consideration of requirement for standby pumping sets (50% or 100% depending on importance of station).
- Necessity for standby generator where power failures are frequent.
- Standardization of equipment, instruments and their units of measurement.
- Specifications should be sufficiently tight to ensure quality equipment - commissioning and testing requirements should be included in specification, along with spare parts requirements, and operation and maintenance manuals.

- o Consideration of civil, mechanical and electrical capital costs.

- o Consideration of operating costs.

2.8.2 Cyclone Separators

When pumping turbid river water, raw water pump should incorporate cyclone separators on gland packing lubrication lines. This will minimize abrasive wear on shafts, sleeves and packing.

2.8.3 Higher Speed Pumps/Motors

Where new pumps are to be installed, consider the use of higher speeds (2900 rpm instead of 1450 rpm)

Advantages:
- o Greatly reduced capital cost;
- o Reduced size and weight;
- o Increased efficiency;
- o Lower cost spares;

Disadvantages
- o Increased raise (not relevant);
- o Inceased abrasive wear when pumping raw water with high suspended particles;
- o More sensitive - alignment and balancing;
- o Balancing of rotating parts after repair, more critical;
- o More noisy;
- o Less reliability.

2.8.4 Chemical Feed Pumps

Motorized pumping units (for alum, lime, $FeCl_3$ calcium hypochlorite) should be replaced whenever possible by gravity feeders. Such devices could be fabricated locally. See Reference (4).

2.8.5 Replacement of Old Pumps

Care should be taken to ensure that replacement pumps and pump impellers are of the correct characteristics for the required duty.

2.8.6 Parallel Pumps

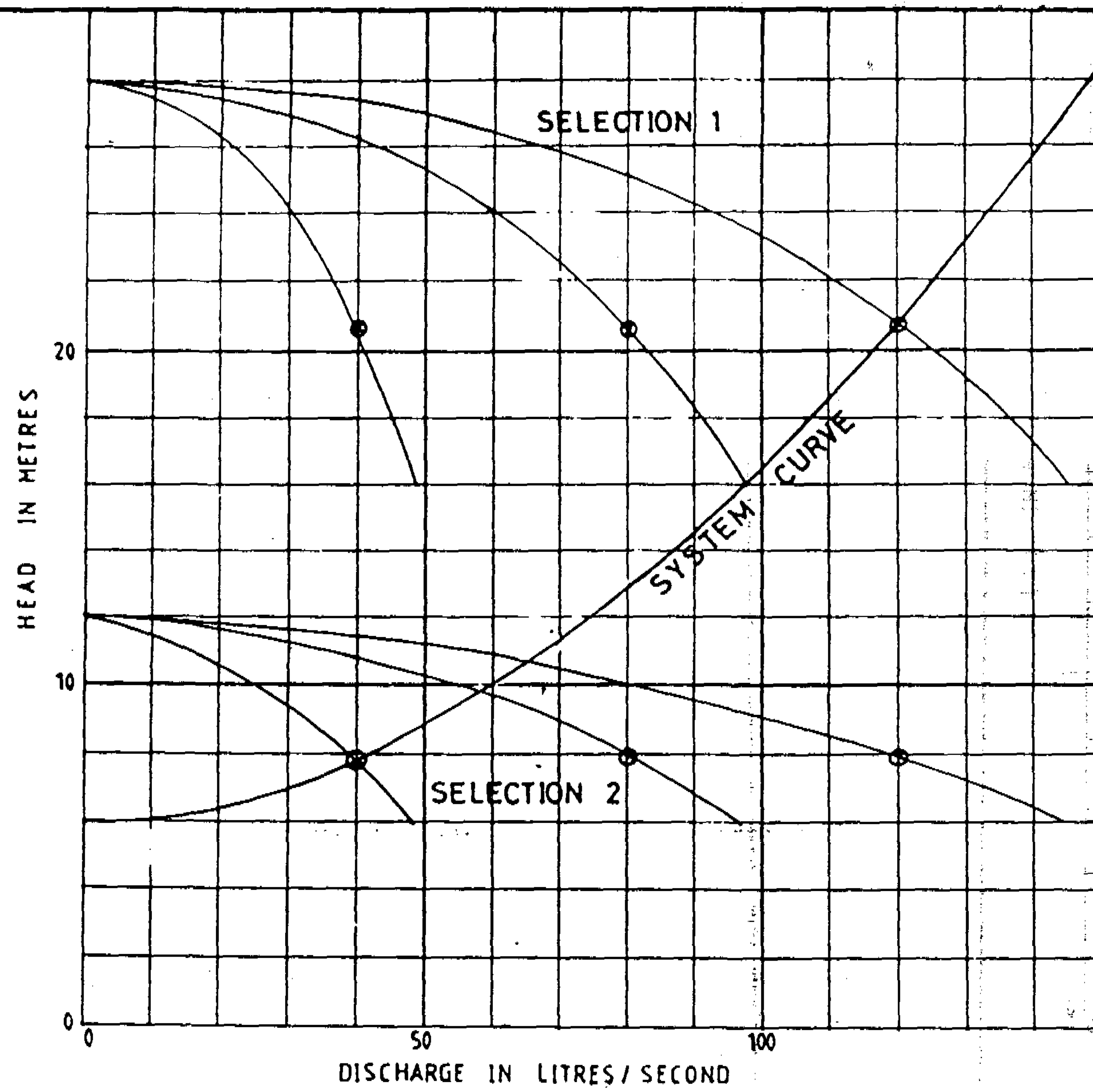
Facilities with parallel pumps are occasionally incorrectly designed, but the pumps can still be operated, although inefficiently, if the operator or his supervisor understands the problem. The typical error that arises in design is due to a lack of understanding of pumps and involves varying flow in a system where the head loss due to friction is large compared to the static head (lift).

Parallel pumps that lift the discharge through a short pipe or through a separate discharge pipe for each pump, such as from one level of a canal sytem to a higher level or directly into an elevated reservoir, cause no problems because the head does not change appreciably as the number of duty pumps changes. Similarly, where more than one pump operating in parallel discharge into the same pipe system, there is no problem (even if the pipeline is long and produces a high head loss) as long as the total discharge remains constant. This is because the head also remains constant and the pump can be selected to meet this head.

When the pipe friction loss is high (long pipeline) and the discharge is varied by varying the number of pumps, the pumps will not perform efficiently at both the high head and the low head that will result from high and low pipeline flow. This may seem obvious but it apparently is not always recognised and appreciated by design engineers, nor by O&M personnel. The problem should be made clear by Figure 6 which shows the system and performance curves for a three-pump facility.

The system curve is constructed by plotting the discharge/head curve of the pipeline, offset vertically by the amount of total lift. The discharge/head curve of the selected pump is drawn in the same way as it is shown on the manufacturer's performance curve. The curve for two pumps is drawn by doubling the discharge of one pump for each of a series of heads. The curve for three pumps is drawn in the same way, only tripling the discharge. It should be readily apparent that a pump chosen to run alone will be very inefficient when three identical pumps are running.

In the example, based upon realistic data and pumps, the pumps of Selection 1 will perform when all 3 are running, but are at the end of the curve. When only 2 run, they should be throttled back by adding 8m of head. One pump alone cannot reach the system curve and needs an additional 13m of head. The extra head can be supplied by partially closing the discharge valve, but this is extremely inefficient. With Selection 2 which has been chosen to satisfy the requirement for one pump, the second and third pumps will run without problem, but will not produce the required flow. Adding the second pump will increase flow to 1.4Q instead of 2Q and adding the third pump increases it to only 1.6Q instead of 3Q. Nothing can be done with these pumps to produce the required maximum flow.



System Data : Pipe diameter 0.6 m
Pipe length - 1000 m
C_1 (Hazen-Williams) 100
Static lift 6m

Pump requirement : Q_1 = 40 L/s , Q_2 = 80 L/s , Q_3 = 120 L/s .

Pump Selection 1:

Q_3 = 120 L/s , Q_2 = 100 L/s , Q_3 misses the curve
Q_2 = 80 L/s is possible by adding 8m head.
Q_1 = 40 L/s . is possible by adding 13 m head.

Pump Selection 2:

Q_1 = 40 L/s , Q_2 = 58 L/s , Q_3 = 64 L/s .
discharge for Q_2 & Q_3 cannot be improved.

WRONG APPLICATION OF PARALLEL PUMPS

FIG. 6

Once a pumping facility with this type of problem has been constructed, not much can be done to correct the problem, aside from changing the pumps. What can be done, however, is for the operating personnel to be aware of the dangers of insufficient pump head, if that is the direction in which the error lies, and use valves to create enough discharge head to protect the pumps and motors. The proper way to design a facility with multiple pumps, variable flow, and a long forcemain is to use different sizes of pumps, each designed to fit the system curve at the particular discharge.

2.8.7 Hot Motors and Tired Pumps

These are common fallacies which arise from a lack of basic understanding of pumps, motors and hydraulics.

In an inspection of a pumping facility it may be found that a pump that should be running, is not. A reason (or excuse) often given by the operator is that the motor was overheating; he knew that it was overheating because it felt hot to the touch. An ambient temperature of 30o C is about average in a tropical climate and 35° C is common in drier and hotter climates. A mass of cast iron will feel distinctly warm at a temperature exceeding the normal body temperature of 37°C. Motors are expected to run 10°C or more above ambient, depending upon the effectiveness of ventilation, and therefore will normally in Sri Lanka run at about 40 - 45°C.

The proper way to evaluate temperature is with a thermometer. If the ambient temperature is normal, the ventilation adequate, and the amperage within the allowable range, the motor should not overheat. One thing that can cause a motor to get hot is rapid cycling - being turned on and off too frequently. The excessive current required for starting the motor accumulates heat faster than it can be dissipated by the normal cooling system of the motor. For this reason, large motors are usually limited to about six cycles per hour or even less.

It may also be found during an inspection that the wrong pump is running for the prevailing conditions; the large pump may be running at low demand or vice versa. The explanation usually is, "that pump just ran for two hours and needs a rest." Pumps used in water and sewage pumping facilities are designed for continuous operation and do not need to rest. They do not get tired. Identical pumps should be alternated if not on each pumping cycle at least weekly; but this is not for purposes of rest, rather to equalise the wear and to be sure each pump is kept in running order. Where different sizes of pumps are involved, the proper size should be used to fit the pumping needs, regardless of whether "it has just been running." Wet well size and pumping cycles should be selected to avoid any problem of too frequent starts and stops.

2.8.8. High_Wet_Well_Level

The operators may be maintaining too high a level in the wet well. This is usually restricted to sewage or storm drain pumping for two reasons. In the first place, the wet well level of a water intake pump is usually relatively constant or at least is not affected by the pumping. In the second place, personnel in the water business understand the need to supply water whereas the sewerage system personnel may not recognise the problems caused by flooding a sewer.

The reasons given for not pumping down to the proper level are many. One is that it requires less power per unit of volume pumped and this is usually true. As the level rises, the lift decreases. The discharge will increase because of lower head, balanced somewhat by the increase in friction head from the increased discharge. The required power will increase but the rate of discharge will increase even more.

Another reason is that it requires fewer changes of the duty pump (from small capacity to larger capacity). This is also true. If the smaller pump is used, the discharge will be inadequate to maintain the proper low level, but the discharge will increase as the level rises and equilbrium will be reached before overflow - perhaps, but not always. With enough allowed variation in wet well depth, one pump could be selected that would handle all variations in flow.

The ultimate reason is that the personnel do not consider the level important. This is not necessarily because they do not care but perhaps because they quite honestly do not understand the consequences. The wet well almost never overflows because there is some point in the system that is lower. If there was not initially, there may very well be after the first overflow. The street in front of the facility is usually lower than the rim elevation of the wet well, and any manholes or catch basins will discharge into the street before overflowing the wet well. In the case of a sewer, there may be a connection to a storm drain or canal or river to ensure no overflow at the pumps. It is only where the pumps are truly at the low spot, more often in drainage systems than in sewers, that the personnel truly recognise the need to "pump or get wet."

Failure to maintain the proper level in the wet well, especially during low flow, causes a great reduction in pipeline velocity and this results in deposition of sediment or other suspended solids. In the case of sewers, there is also the resulting septicity to be considered . Despite all of the arguments of operating personnel, the wet well must be kept at the proper level to avoid a variety of health, sanitation, and maintenance problems upstream.

3. ELECTRICAL ASPECTS

3.1 Electric Motors

Electric motors transform electric energy into rotary mechanical energy. The simplest configuration of any electric motor is the arrangement of an electrical circuit and magnetic fields in such a way that a rotating magnetic field is established. The rotating magnetic field drags or pulls the iron of the rotor (the rotating member of the motor) around with it.

All motors must perform the following tasks:

- o Start a load from rest
- o Accelerate the load to full speed without damage to the motor or the driven machine
- o Continue to operate under normal load conditions
- o Withstand load conditions and abnormal power-system conditions that might develop.

To comply with these various conditions, motors are designed and classified for various operating characteristics.

More current is needed to start most motors than to keep them running. The current taken by the motor the instant the motor is connected to the power system, while the motor rotor is yet at rest, is called the locked-rotor current, which is often from 5 to 10 times the normal full-load current of the motor. Both the full load current and the locked-rotor current at the rated voltage of the motor are given on the motor nameplate. The time required for a motor to start from rest and reach full speed varies from 1 to 8s. During this time, the excessive current drawn by the motor causes an abnormal voltage drop in the power system, as evidenced by the dimming of lights. Excessive voltage drops during starting can cause inconveniences such as the drop-out of relays, solenoids, or other motor starters. Drops that are not excessive, but cause a noticeable light flicker, can be a nuisance when they occur frequently as a result of repetitive motor starting. The size of the motor has a considerable influence on the motor-starting problem and its effects.

There are two broad classifications of AC Motors - the single-phase induction motor and the three-phase induction or synchronous motor.

Single-phase motors: single-phase motors are motors designed to operate on single-phase alternating current. A motor with only a straight single-phase winding has no starting torque, but if it is started in either direction and brought up to speed mechanically by spinning its shaft or by some similar outside means, it will run and continue to carry its load. Thus some means must be provided to cause the motor to start. These means are simply variations in designs of starting winding to make the motor appear to be something other than straight single-phase. It is not uncommon to find a single-phase motor that will not start, but if given a spin externally, will continue to run.

Single-phase motors generally have fractional horsepower but may be used up to approximately 10 hp (7.46 kW). These motors are usually rated 120 or 240 V. Single-phase motors may be divided into six general classes; split-phase,repulsion-induction, capacitor-start, shaded-pole, synchronous, and series-universal.

Three-phase motors: Most of the 1/2-hp (0.37 kW) and larger motors on water distribution systems will be 3 phase, rated at 230, 460, 2300, or 4000 V. The three general classes of 3-phase motors are squirrel-cage induction, synchronous, and wound-rotor induction motors. Of these, only the synchronous motor runs at synchronous speed. The induction motors run at slightly less than synchronous speed but are referred to by their synchronous speeds. For example, reference may be made to a 3600-rpm induction motor, although it is understood that such a motor will operate only at an approximate full-load speed of 3450 rpm.

The squirrel-cage induction motor is the simplest of any of the motors and requires the simplest controls. The power-supply leads connect to windings in the stator (the stationary part of the motor), which are arranged in such a way that a rotating magnetic field is established. The rotor (the rotating part of the motor) is made up of bars arranged cylindrically and joined at the ends by continuous end-rings. The rotor then looks like a squirrel cage, hence the name.

Two basic concepts of motors should be understood by those who design or use pumps:

(i) RPM: the rpm (revolutions per minute) of the type of fixed speed motor used for pumping is determined by the cycles per second of the electric current (Hz) and by the number of poles in the winding (P) as follows:

$$rpm = s \cdot \frac{Hz \times 60^*}{P/2}$$

where s is the slippage factor that varies from 1.0 for synchronous motors to about 0.97 for the more usual squirrel-cage induction motors. This is why pumps are listed as 3500 rpm, 1760 rpm, etc. for 60 Hz and 2900 rpm, 1460 rpm, etc. for 50 Hz. A synchronous two-pole motor runs at 3000 rpm on 50 Hz.

The rpm of a wound-rotor motor can be varied by controlling the current in the rotor. This is usually done in steps during starting by advancing from one resistance to a lower one on the starter mechanism. The current flowing through the resistor creates heat. The starter is used only briefly and the heat is quickly dissipated. If the running speed is to be varied by the same means, the resistor must be designed to dissipate the continuous heat that develops. Such speed control mechanisms are usually as large as the motor and pump combined. This is an effective but inefficient way of varying the rpm and, thereby, the discharge of the pump. It is, however, more efficient than throttling the discharge valve.

Various speed controls are available for the more efficient squirrel-cage induction motors. They are very efficient in terms of power consumption but are also expensive and usually complex. A reasonable compromise may be had by using two sets of poles in a squirrel-cage motor and shifting from one set to the other to change rpm. Thus with a 6 pole/8 pole motor, the rpm can be selected as either 960 or 720. This will produce a moderate change in pump discharge. In designing two-speed pumps it is important to select the proper rpm ratio.

(ii) Volts, Amperes and Power: engineers know that power (kW) is the product of volts and amperes but they may not recognise that it is usually the amperes that varies. The power requirement is determined by the rpm. At full design voltage a motor will strive to run at full rpm by increasing the amperes to go with the available volts. This is the basic cause of most motor failures. The excess amperage causes overheating, which results in premature deterioration of the insulation. This is what keeps electric shops busy rewinding motors.

A change in voltage will affect the rpm to some degree, running several rpm faster with a 10% increase in voltage and similarly slower with a decrease.

* The factor 60 converts cycles per second to cycles per minute.

However, the voltage also affects the amperage in the opposite sense to maintain the relationship between kW and the product V x A. Motors are designed to handle an increase or decrease of 10%, but beyond this the pump and motor may not operate satisfactorily. It is common practice to stop operation if the voltage drops by as much as 15%.

3.2 Motor Starters

There are various types of starters for electric motors. The most simple type is a switch for direct-on-line (DOL) starting. The pump operator pushes a button or throws a switch and the motor starts. There is a surge of power as the motor goes from stop to full speed and, in poorly wired facilities, the lights may go dim. However, the surge is brief and the wiring can handle the excess current. This type of starter is used for small motors where any over-sizing of the wire that is required is less costly than providing a more complicated starter. Switches are cheap.

For a wound-rotor motor the starter is a variable resistor, usually in discrete steps rather than continuous, that allows the current of the starter to be increased gradually as the motor speed increases from stop to full speed. This type of starter generates a large amount of heat, so it must be advanced through the steps quickly. The maximum starting time, typically about 30 seconds, is usually stamped on the case of the starter.

Another starter is the star-delta, which is a two position starter*. Approximately 58% of full-line voltage is applied to each winding and the motor develops 33% of full-voltage starting torque. This results in a current of 33% of normal locked rotor current from the line. When the motor has accelerated, the starter is switched to the second position which restores the normal delta operation of the motor.

When a motor is installed there should be no problem about the starter because the designer and the installer have, or should have, sufficient knowledge about motors and starters to use the proper equipment. It is when a starter fails, perhaps because it is simply worn out, that the trouble starts. The people who make the replacement may not understand the subject as well as did the designer and installer. To them it may be that "a starter is a starter;" and the wrong one may be ordered or, worse yet, substituted from what is excess and available. Only competent people trained in

*Refer to Pump Handbook (Ref. 1)

electricity should make decisions regarding the substitution of electrical equipment. A pump mechanic might be trusted to make a replacement of an identical starter, but only electricians should try to "make something else work." Even then, it is safer to use the correct equipment.

Starting methods for various applications are as follows:

(a) Direct on-line starting of squirrel cage motors

Direct on-line starters are mainly recommended for low to medium power motors of up to 2.2 kW (3 hp), and is the simplest method of starting motors. However, reference must be made to CEB regulations regarding the maximum power to be connected to CEB mains.

(b) Star-delta starting of squirrel-cage motors

This type as described above, is suitable for starting no load and low-load radial flow, centrifugal pumping sets. However, it is not recommended beyond a power rating of more than 55 kW due to the high transient current developed during the change-over from star to delta.

Note also that this method is not recommended for shaft-driven turbine pumps due to high transient reverse currents during the change over from star to delta.

(c) Auto-transformer starting of squirrel-cage motors

The motor is supplied with reduced voltage by means of an auto transformer which is switched out of the circuit when starting is completed. The motor starts under reduced voltage on two stages smoothly and thirdly connects the motor into the final stage, connecting the motor to the full main supply voltage thereby causing the two starting contactors to open.

In this device the motor is not separated from the main supply and as the current is not interrupted, transients are eliminated. This method of starting is recommended for high power motors.

Note that this method is ideally suited for shaft driven turbine pumps as the shaft is not subjected to high stresses because the transients are eliminated.

(d) Slipring motors and starters

Slipring motors are used normally where machines have to be started with full load. A slipring motor cannot be started in one stop because of un-acceptable torque and current peaks: while the stator is supplied with the full main voltage it is necessary to insert in the rotor circuit a bank of resistances which are then shorted out progressively. Full speed is attained when the resistance is entirely shorted out.

Normally these motors are not manufactured over 1500 rpm because of quick wearing-out of brushes and sliprings. The maintenance cost is therefore higher than squirrel-cage motors.

(e) High tension squirrel-cage motors

High tension squirrel-cage motors over 500hp/3.3kV are always recommended to use auto-transformer starting.

3.3 Motor and Starter Protection

Many motor designs are available, each providing varying degrees of protection to the windings from falling, airborne, or wind-driven particles, and from various atmospheric and surrounding conditions. An open motor is one having ventilation openings that permit passage of external cooling air over and around the windings. A drop-proof motor is an open motor in which ventilation openings are so constructed that drops of liquid or solids falling on the machine at any angle less than 15 degrees from vertical cannot enter the motor. A splashproof motor is an open motor in which ventilation openings are so constructed that drops of liquid or solid particles falling on the motor or coming toward it in a straight line at any angle less than 100 degrees from vertical cannot enter the motor. A guarded motor is an open motor in which all ventilation openings are limited.

Motors should be protected against incorrect voltage, single phasing (if a 3-phase motor), excess current, and lightning where this is a problem. Because problems of voltage affect all of the electrical equipment of the facility, voltage protection is usually provided at the main switchboard or control panel. The protection may be nothing more than a voltmeter under the watchful eye of an operator who is ready to throw the main switch when the voltage drops too low. This type of protection is effective but it is only as dependable as the employee, who may have other things to do at the time he is needed to throw the switch. Therefore, it is much better to use, as the primary protection, the automatic voltage protection devices that are available and also use the voltmeter and an alert operator as a back-up in case of failure. The automatic equipment can be provided with a time delay to avoid tripping because of a momentary drop in voltage.

Single phasing can also be detected by personal observation but, as with voltage protection, it is more certain and more dependable to use protective equipment. This again should be at the main control because single phasing will affect all of the three phase equipment. A delay element can be provided to avoid interruption of power due to momentary single phasing.

Fuses and circuit breakers for current protection are in common use, but they may be set too high. If the device is set for the design running of the motor, it may trip during starting because of the extra current required. This should be avoided by using a by-pass during starting, perhaps further protected at above the maximum starting current, or by using a delay element that will allow for brief excess current. In any event, each motor should have its own circuit protection in addition to the protection intended for the main service and for other circuits within the facility.

Small motors of less than about 1.0 kW should be provided with overload protection built into the motor. This is usually a bi-metal strip in the circuit that will spring away from a contact upon overheating from excessive current through the strip. It is usually necessary to press a re-set button to restore the circuit. This added protection serves two purposes: it makes the operator aware that there has been an overload so that he may do something about the cause before the motor is again started, and it avoids the hazard of having the motor start again unexpectedly when the bi-metal strip cools. One reason why the built-in protection is necessary on small motors is because the circuit breaker is usually at a minimum value of 5A which is not enough to protect a 1.0 kW motor operating on 440V and drawing less than 3A, or on a much smaller motor operating on 220V.

Lightning is common in Sri Lanka and there are reports of lightning causing damage to electrical equipment. Large buildings are commonly provided with lightning arrestors which should protect the structure from a direct hit. Lightning is common in other parts of the world, also, and electric transformers are frequently struck. This does not appear to be a problem with properly designed and installed tranformers. There may be damage to the transformer itself, but not to the equipment of the consumers. If motors are actually being knocked out by a surge of voltage caused by lightning striking the electrical distribution system, the installation should be investigated by a competent electrical engineer and appropriate protection measures taken.

As a part of motor protection, all starters for any except very small motors, say less than 0.5 kW, should be so designed that the motors will not re-start automatically after being stopped by a power failure. An exception would be allowed for fully automated installations. There is a danger to men and to equipment if several motors re-start automatically. Fully automated installations usually incorporate sequencing and delay equipment to moderate this potential problem.

In summary, therefore, it is necessary that motor control centres (MCC) should be equipped with the following starting, protection and metering devices:

(a) Motor starters

- Contactors - should conform to BS 5A24 -IEC 158-1 VDE 660/02 and should be rated for minimum AC3 category.

- Overload relays should incorporate:

  - thermal protection for balanced overloads;
  - differential protection for unbalanced overloads;
  - ambient temperature compensation

- Star-delta starters should have:

  - mechanical and electrical interlocks;
  - variable timer up to 50 s with short pause time on changeover from star to delta.

- Add on auxiliary contacts for audio-visual indication of operating conditions.

- Main supply to each motor starter should be controlled by a circuit breaker of proper rating.

- All control circuits should be protected by fuses or MCB's.

(b) Motor protection

The main supply to the MCC should be controlled by a circuit breaker with minimum breaking capacity 30 kA. The following protection against supply faults should be incorporated in each MCC.

- o Phase failure protection - monitoring should be for phase angle between voltages and not for voltage levels.
- o Phase reversal.
- o Under voltage - trip levels should be adjustable to suit site supply conditions.
- o Over voltage - trip levels should be adjustable to suit site supply conditions
- o Voltage imbalance - trip levels should be adjustable to suit site supply conditions.
- o Earth faults - differential-type relay with continuously variable sensitivity adjustments to suit site conditions (1 - 10 amps). Torroidal transformer should incorporate independent test winding for simulating a fault for test tripping.
- o Automatic resetting should be provided for supply faults upstream of the main incomer and manual resetting for supply faults downstream of the main incomer. Visual indication should be provided to identify individual fault conditions.
- o Provision for low-level cut-out

(c) Metering

Each motor starter should incorporate an hours-run meter; a voltmeter with selector switch for incoming supply; an ammeter with selector switch; (and a current transformer for motors rated over 60 amps).

Direct reading ammeters for motors rated below 60 amps and MCC's rated over 60 amps should incorporate a power factor meter and wherever necessary power capacitors to bring the power factor near unity

3.4 Switchboard Design

The following factors and instrumentation should be considered:

- o Specification regarding the actual expected duties of the connected load
- o Diversity factor
- o Layout plan of the installation
- o Safety levels
- o Indicating instruments:
  - Volt meters
  - Ampere meters
  - Hour meters
  - Indicating lamps
  - Under-current relays (especially for auto-starting)
  - Lightning arrestors (necessary with submersible pumps)
  - Duty selector switches
  - Instrument fuses
  - Back-up protection fuses
  - Main circuit breakers
  - Provision for starters
  - Phase sequence relay
  - Phase imbalance relay
  - Isolator on each pump motor
  - Control circuit design
  - Circuit diagram to be fixed on the panel drawn on aluminium foil, or plastic sheet
  - Earth leakage protection relay.

3.5 Breakdown - Causes and Remedies

Some motors are directly connected to machinery which can "bog down" and overload the motor by reducing the rpm. An example is a motor on a circular saw into which the wood is being pushed too fast. This type of overload seldom occurs with centrifugal pumps because the impeller can slip through the water, unless the impeller becomes clogged with sand or other obstruction. There are also those exceptional instances where a bearing on a pump may bind and, in the process of scoring the shaft, may produce an excessive load.

Centrifugal pump overload is usually from one of two causes; improper design or improper voltage. If the motor was not properly selected to meet the maximum power requirement of the pump, it can be overloaded when the pump is operating at full discharge . This usually occurs when the head is reduced below the design value, which can be because of an error in design, an error in operation, or an unexpected occurance. These causes can all be protected against by selecting the correct size of motor. The motor can also be protected by limiting the current.

If the motor has been properly selected, it can still become overloaded in terms of current if the voltage drops. The amperage will rise to give the required power, and it is the amperage (current) that does the damage. In both cases, the rise in current above the design value is not great, usually about 10 to 15% at the most. There is not a sudden failure at the first overload. It takes time for this amount of excess current to over-heat and break down the insulation of the windings. However, the damage is cumulative and the motor will fail. Even voltage and current protection may not prevent this slow but steady type of damage because the excess current may be enough to cause premature failure of the insulation but not enough to trip the protective devices.

A special problem may arise with small motors. The smallest circuit breaker usually installed is 5A. For 220V and single phase, the circuit breaker will trip at 1.1 kW (5A x 220V = 1100W). If the motor is rated at 0.5 kW, it is not protected by the circuit breaker although the circuit wiring is. Such a motor could run over-loaded at well above its rated amperage of 2.27A without tripping the 5A circuit breaker. Such motors should have overload protection built into the motor.

Preventive maintenance, especially of electric motors and starters, is of vital importance. A proper record of breakdowns with a summary of causes and action taken should be maintained for future guidance. It has been noticed during the past few years in NWSDB that most of the motor failures are due to the following:

- Flashing-over due to high voltage surges (to be protected by lightning arrestors).

- Overheating due to variation of voltage of the system, (high or low).

- The 3-phase 50 cycles motors are normally wound for a 400V supply with an of allowance of ±6%. When voltages are higher or lower than ±6%, motor characteristics on full load current, speed, temperature, and power factor are affected, thus causing the weakening of the insulation of the winding mainly due to temperature rise due to excess current.

- Overloading, due to increased discharge due to pipe burst or full opening of a delivery valve

- Imbalance of the phases, generally due to a fuse blowing in the high tension system or imbalance, due to an imbalance of the distribution system.

- Single phasing, mainly due to a blown fuse in the low tension system.

- Insulation Failure: it is essential that all current carrying parts be adequately protected by high quality insulation of the motor windings, etc. The necessity for high quality insulation arises from the fact that any leakage of current is liable to create an arc which may cause fusing of the effected parts or, in the case of the winding, a complete burn-out. Furthermore it is possible with faulty insulation for the frame of the machine to be charged at a sufficiently high voltage to entail a serious risk of shock to any person touching the machine, as the best of insulation material is prone to mechanical damage. The greatest of care should be exercised when handling the windings of motors for servicing, or when rewinding.

As absolute electric strength of insulating material cannot easily be determined, periodical megger tests should be carried out to determine the condition of the motor winding such as dampness and entrapped moisture in the windings. If insulation is low, a standard method of heating should be carried out. The windings of motors are without doubt the most vulnerable part and most breakdowns caused in NWSDB pumping stations have been due to insulation failure. This type of breakdown can be prevented if periodical megger tests are taken as suggested earlier and preventive maintenance carried out in time.

Another frequent cause of winding failure is due to the presence of oil and dust. Oil is frequently referred to as the life blood of a machine and in its proper place it is exactly that, but when it is allowed to escape to the windings due to over charging, it will cause serious trouble. Dust will settle on the oil-soaked windings and dust and oil can be a destructive agent for the windings. It is further evident that this combination prevents the cooling air to enter the windings, collects metallic dust in the atmosphere and finally may block the ventilating passages thereby causing overheating. This can cause a complete burn-out of the windings.

Due to lack of maintenance yet another type of serious breakdown can occur due to a "whip" of the rotor, mostly due to bearing wastage and fouling the stator, causing heat damages of the rotor and stator. Not all insulation failures occur between the windings and the earth. It sometimes happens that a fault occurs between the turns of a winding and if such a fault remains undetected, overheating and eventual burn out will be the result.

Normal insulation resistance tests may in many cases fail to reveal such a fault espepcially if it is confined to the turns in the centre of the winding. Such faults as this can be discovered by measuring the resistance of the suspected coil and comparing it against a sister coil or from the manufacturing data. This test should be carried out with a low resistance measuring instrument.

Where motors have been installed in a humid atmosphere, or close to the sea, more frequent breakdowns have occured. Such situations may cause current seepage to earth, eventually resulting in the puncturing of the insulation.

Finally it should be noted that testing is not the complete answer to the problem of how to keep the plant running efficiently. Regular tests should be carried out as a part of a planned maintenance scheme. To reduce breakdowns, the first objective should be the elimination of dust and dirt. Regular cleaning and blowing-out of the windings is very important. More attention should be paid to slipring motors as carbon dust tends to collect on the windings.

It is essential that a maintenance service card is drawn up, so that the maintenance officer returns the card to the respective officers after filling the columns with his remarks for information and action.

3.6 CEB Supplies and Tariffs

As far as possible supply to pumping stations should be made available from the nearest 33kV or 11 kV transmission lines of the Ceylon Electricity Board. The cost of the spur line and substation from the main transmission line would have to be borne by NWSDB and therefore it is best that as far as practically feasible, pumping stations be sited in the neighbourhood of existing or proposed CEB transmission lines.

Under the Distribution Rehabilitation Plan of the CEB (Power project IX) the CEB would be constructing nearly 800 to 1200 km of 33 kV transmission lines throughout the island within the next 5 years and these lines now have been identified. If any water supply stations are planned, planners should contact the Planning Department of the CEB regarding the routing of these lines so that their exact location could be known and any alterations to proposed routes could be envisaged, so that the cost of the spur line could be reduced. At least 2 to 3 years advance knowledge should be made available to the CEB planners so that they could meet the loads required for the water supply stations.

On current estimated costs (March 1987) the CEB's cost of transmission lines and a typical substation is as given below;

11 kV HT	-	Rs.172,000/= per km
33 kV HT	-	Rs.193,000/= per km
250 kV A Substation, 33kV/LT	-	Rs.240,000/=
250 kV A Substation, 11kV/LT	-	Rs.193,000/=

Details of the IP2 and TD2 tariffs are given in the Government Gazette of 25.1.1985 publishing the latest electricity rates of the CEB.

Granting of the TD2 tariff is at the discretion of the General Manager, CEB and consumers would have to make application to the CEB (usually to the Commercial Engineer of the relevant Division). For the TD2 tariff, special meters are required costing approximately Rs.5,000/=, and this would have to be met by the consumer.

Therefore, in the case of electricity supply to water supply facilities planned for the future, it is best that regarding the question of bulk supply there be close co-ordination and advance information between water supply planners and CEB planners, for optimum use of supply and tariff.

3.7 Other Power Sources

3.7.1 Diesel Engines

Diesel engines have the important advantage that they can operate independently at remote sites. The principal requirement is a supply of diesel and lubricants and these, once obtained, can be easily transported to almost any place. Diesel engines, because of their capability to run independent of electrical power supplies, are especially suitable for driving isolated pumping units such as raw water intake pumps.

A diesel engine operates through compression of air to a high pressure, in its combustion chambers. As a result of the high compression, the temperature of the air rises to over 1,000°C. When fuel is injected through nozzles into the chambers, the compressed air-fuel mixture ignites spontaneously.

Diesel engines may be used to drive reciprocating plunger pumps as well as centrifugal pumps. Gearing or another suitable transmission connects the engine with the pump. For any diesel-driven pump installation, it is generally prudent to select an engine with 25-30% surplus power to allow for a possible heavier duty than under normal conditions.
(Note: abstracted from Ref. (3)).

3.7.2 Wind Power

The use of windpower for pumping water should be feasible if:

o Winds of at least 2.5 - 3 m/s are present 60% or more of the time.

o The water source can be pumped continuously without excessive drawdown;

o Storage is provided, typically for at least 3 days demand, to provide for calm periods without wind;

o A clear sweep of wind to the windmill is secured, i.e. the windmill is placed above surrounding obstructions, such as trees or buildings within 125 metres; preferably the windmill should be set on a tower 4.5 to 6 metres high;

- o Windmill equipment is available that can operate relatively unattended for long periods of time, for example six months or more. The driving mechanism should be covered and provided with an adequate lubrication system. Vanes, and sail assemblies should be protected against weathering.

By far the most common type of wind powered pump is the slow running wind wheel driving a piston pump. The pump is generally equipped with a pump rod that is connected to the drive axis of the windmill. Provision may be made for pumping by hand during calm periods.

The wind wheels range in diameter from about 2 to 6 metres. Even though the windmills themselves may have to be imported, strong towers can usually be constructed from local materials.

Modern windmills are designed to ensure that they automatically turn into the wind when pumping. They are also equipped with a 'pull-out' system to automatically turn the wheel out of excessive wind, stronger than 13-15 m/s which might damage the windmill. The 'sails' of fan blades can be so designed that they furl automatically to prevent the wheel from rotating too fast in high winds. The windmill will normally not begin pumping until the wind velocity is about 2.5 - 3 m/s.

(Note: abstracted from Ref. (3))

3.7.3 Solar Power

Solar energy has great potential in the application of pumping water for small scale community water supply. Much research and prototype testing is directed to the development of reliable, economical solar-powered water pumping systems (often referred to as "solar pumps"). Increasingly, this is supplemented by field trials and demonstration of promising solar pumps. A number of solar pump models are already available in the market.

Basically, in a solar powered water pumping system, solar radiation is converted into electric power, either directly (photovoltaic cells) or indirectly using a heat mechanical power-electric power conversion route. The electric power is then used to run an electromotor which drives the water pump. The overall energy conversion efficiency of solar pumps is in the order of 6-12% for a photo voltaic panel/electromotor/water pump system, and 1-15% for a heat collector/thermal power/electro-generator/electromotor/water pump system.

Solar pumps using photo-voltaic cells to generate electric power for driving the water pump, are currently more promising than thermal solar pumps with flat-plate heat collectors, due to the inherent low efficiency of energy conversion in the latter type of system.

To provide for storage in a solar pumping system, it is possible to use batteries storing electric energy. However, this is costly, and adds to the maintenance requirements of the pump system. The recommended way of providing a storage facility in a solar pumping system, is an overhead tank to receive and store the pumped water. The use of batteries can aso be avoided.

A factor of great importance for the efficiency of a solar pumping system is the choice of centrifugal water pump to be coupled to the solar power/electromotor unit. The performance of a solar-powered pumping system with a centrifugal pump can be critically impaired if centrifugal pumps are used that are too sensitive to a variation of pumping head. Thus, in the choice of pump those types and models must be selected, that are reasonably efficient even when operating away from their optimum head.

Studies and tests have shown, that for greater pumping heads, and for large volume water pumping, solar systems using a positive-displacement plunger pump are better than those with a centrifugal pump.
(Abstracted from Ref. (3)).

At a seminar in Colombo in January 1987, attended by Ananda Silva of NWSDB, it was revealed that government institutions like CGR, CEB, and Mahaweli Authority had started using solar power systems for their operational requirements as an economic alternative. The application of BP Solar's water pumping systems was also discussed and further it was revealed that tropical countries like Sudan, Egypt and Nigeria had been successfully applying these solar powered borehole pumping systems in providing drinking water requirements to their villages.

The solar powered water pumping systems are designed to start automatically as soon as there is sufficient sun light in the morning and will stop in the evening when the sun sets. These systems are designed to run completely unattended day-in and day-out, and would only require routine inspection to ensure everything is in order. The solar array provides a virtually maintenance-free power source with a life expectancy of around 20 years. Pumps and electric motors specifically designed for solar use generally need little maintenance.

Solar powered water pumping systems are capital intensive but the operation and maintenance costs are very much less, when compared to fuel-powered systems. In the long run, they can compete economically with fuel powered water pumping systems, particularly in remote dry-zone areas where electricity supply is not readily available, but where ground water is available.

Further demonstrations and pilot studies are scheduled to be carried out in Sri Lanka and design engineers are encouraged to contact Ananda Silva for the latest information on the applicability of these systems.

1. INSTRUMENTATION

1.1 Pumping Facilities

Instrumentation required at pumping facilities for efficient operation and effective control is as follows:

- o Flow measurement
- o Pressure measurement
- o Electrical current measurement
- o Voltage measurement
- o Running time measurement
- o Wet well level measurement

Details are given below;

a) Propeller type flow meters for the discharge of each pumping system, unless there is some other means of flow measurement, providing for rate of flow and totalised flow indication. No continuous recording is recommended. Units should be cubic metres per hour and cubic metres.

b) Pressure gauges of the bourdon or bellows type and of suitable size, range and units of measurement for the suction and discharge of each pump, for the discharge of manifolds of parallel pumping systems and for each surge arrestor or similar pressurised device. Preferred units are metres head of water. (1m head of water = 9.807 kN/m^2 (= 0.09807 bar = 9.807 k Pa). Use pressure snubbers/suppressors to smooth out pressure fluctuations to gauges.

c) Ammeters of suitable size and range for each pump circuit and for the main supply to the facility. The main ammeter should either be capable of indicating the current in each leg of three-phase installations or a separate meter should be placed on each leg.

d) A voltmeter of suitable size and range for the main supply to the facility.

e) An elapsed time meter (hour meter) in the circuit of each pump motor to indicate the total hours of running time.

f) A pumping level indicator, probably fabricated by NWSDB, operated by a float, wire, pully, and target on a staff board for each pumping facility where the pumping level of the intake varies sufficiently to affect pump performance. units should be in metres.

4.2 Treatment Facilities

Instrumentation required for control of the process is as follows:

- o Measurement of rate of flow and total flow of water.
- o Measurement of filter head loss.
- o Measurement of chlorine dosage.

Details are given below:

a) Parshall flume or similar device with float operated flow rate indicator and totaliser, but not a chart recorder, for measuring the inflow. Units should be cubic metres per hour, and cubic metres.

b) Propeller meters with flow rate indicators and totaliser for measuring wash water and for measuring outflow, either before or after the clear water reservoir as (a):

c) Staff gauges for measuring the water level in each filter. Units should be metres.

d) Manometer tubes tapped through the filter wall for measuring the head loss in each filter. Units should be metres.

e) Chlorinators, either Wallace & Tiernan or Fischer Porter, for post chlorination and also pre-chlorination if applicable in the process, with duplicate chlorinators in each instance for standby. Units should be kg/h.

4.3 Water Storage Facilities

The measurements required at water storage facilities are as follows:

- o Reservoir level
- o Totalised flow from the reservoir.

Details are given below;

a) locally fabricated float operated board gauges for indicating reservoir level (units should be metres)

b) Accurately calibrated pressure gauges for any remote indication of reservoir level. Units should be metres head of meter.

c) Propeller meters for indicating totalised flow from reservoirs. (Rate of flow indication not necessary). Units should be cubic metres.

4.4. Flow Measurement

In the past, most of the rate of flow meters installed at major plants have been of the Dall tube or Venturi type. In most of these meters, there is an electrical interface between the sensor (Venturi) and the recording instrument. A few meters have no electrical interface and the pressure signal is measured directly by a manometer.

In situations where raw water is pumped from a river, there is a tendency for the annulus in the Dall-tube to become clogged with pebbles. Maintenance and cleaning/removal of Dall-tubes is time consuming, particularly when the chamber is too small to permit proper access, and requires shutting down the supply, where no bypass line is provided.

In most cases, however, breakdown of flow metering devices has been caused by damaged electronics eg., burnt-out printed circuit boards. The most likely causes are voltage fluctuations and surges. In Colombo (where voltages are most stable compared to other regions) a voltage trace indicated a voltage fluctuation from 160-230 volts during a 24-hour period.

It is therefore not recommended to install Dall/Venturi tubes as flow sensors on raw water lines from rivers, and to use Parshall flumes or weirs instead. They have the advantage that they are self-cleaning, need minimal maintenance and are sufficiently accurate for board requirements. They are also ideal locations for efficient coagulant - mixing. Pre-fabricated Parshall flumes or fibre-glass could be produced locally. (See Ref. (4)).

For measuring flow of treated water or filter backwash water, the existing Dall tubes could be used. The electrical interface, however, should be eliminated and a direct pressure recording instrument installed. The instrument should also include a counter read-out of the total flow.

4.5 Other Instrumentation

For further information on control valves, telemetering, pneumatic and electronic instrumentation, and automatic control, the design engineer should consult reference (3).

REFERENCES
(Available in NWSDB Library)

1. Karassik, I.J., et al, Pump Handbook, Second Edition, McGraw Hill book Co., 1986.

2. American Water Works Association, Automation and Instrumentation, AWWA Manual M2, 1983.

3. Hofkes, E.H., and Huisman, L., Small Community Water Supplies, IRC, 1983.

4. Wagner, E.G., Upgrading of Water Treatment Plants in Sri Lanka, Assignment Report, 20 August to 30 September 1983, Project No. WHO/3RL/EHP/002, September 1983.

A N N E X A

A. SPECIFICATIONS

ANNEX A.1 NOTES ON SPECIFYING PUMPS

1. CASING

Specify quality of cast iron desired by, for example, an ASTM or BS number. Do not ask for "close grain cast iron" (close grain is too general).

2. WEAR RINGS

- Do not just specify bronze wear rings. Specify ASTM or BS number for the bronze.
- Where double wear rings are used, the impeller ring should be at least 50 brinnel greater than casing ring.
- Double wear rings are desirable in pumps 200 mm (8 in) and above.
- Double wear rings are not necessary in pumps under 150 mm (6 in).

3. BEARINGS (oil or grease ?)

Advantages of oil over grease:

- No danger of overgreasing;
- Grease may oxidize and dry out especially when not in use;
- Grease tends to be more easily contaminated in storage than oil. Operators could dip their dirty fingers into a can of grease and contaminate it;
- To clean a grease lubricated bearing is more troublesome than cleaning an oil lubed bearing.

4. CASES

If specifying axially split double suction pumps (they are easy to maintain), specify twin voluted cases in sizes 100 mm (4 in) and up. This results in less shaft deflection and less pre-rotation at eye of impeller. Radial loads on shaft are also counterbalanced.

5. PUMP SPEED (1450 or 2900 rpm ?)

Advantages of 2900 rpm

- o Higher efficiency;
- o Smaller size.
- o Lower cost.

Disadvantages of 2900 rpm

- o Maintenance becomes more critical especially balancing and alignment;
- o Higher noise level.

6. SHAFT SLEEVES

- o Shaft sleeves should be keyed to the shaft;
- o Use of chrome stainless steel rather than bronze particularly when pumping river water;
- o Use sleeve of 11-13% chrome stainless steel with Brinnel hardness of 225-300;
- o For a harder sleeve use 17% chrome stainless steel with Brinnel hardness of 550 (for water carrying abrasive material);
- o When stainless steel above 11-13% chrome is used, always use non-graphited packing. Otherwise graphite will cause sleeve to pit.

7. BASE PLATE

Steel is better than cast iron - if baseplate has to be modified because of change in motor or some other change, it is a simple matter to cut into or weld onto a steel base plate. C.I. would present a major problem. Base-plate should be provided with a drip lip to collect stuffing box drainage.

8. COUPLINGS

Use an all-metal coupling of the "Steelfex" type for pumps up to and including 50 hp (expensive but good), and gear type couplings for pumps over 50 hp.

9. EFFICIENCY

Sometimes a bidder may quote a very high pump efficiency due to a very close ring clearance. This may hold good in a factory test but after a short run in period the efficiency may drop dramatically due to slight increase in ring clearance. Bidder should therefore state ring clearance at which the quoted efficiency is guaranteed.

10 GLAND PACKING LUBRICATION

Where water with suspended matter is being pumped, do not use this water for gland lubrication. The abrasive particles will score the pump shaft. Either use a separate supply of clean water or use a cyclone separator in the gland cooling water line to separate the particles in the water.

Prepared by Skanda de Saram - O&M Consultant, USAID Project
March, 1987

ANNEX A.2 ELECTRICALLY OPERATED MOTOR CONTROL CENTRES (AUTOMATIC AND MANUAL)

1. GENERAL REQUIREMENTS

1.1 All equipment installed in a motor control centre should be operative on the standard electricity supply of 400 volts 50 Hz on polyphase and 230 volts 50 Hz on single phase systems.

1.2 Installed equipment shall comform to relevant IEC, BS, VDE, NEMA or similar international standard.

2. ENCLOSURES

2.1 Enclosures for housing motor control centres shall be so designed as to accomodate all necessary equipment on a practical layout to enable the operation and control of equipment in an efficient and safe manner.

2.2 Protection, metering and monitoring equipment and devices should be well separated from operation equipment. Adequate space shall be provided for all incoming and outgoing cables.

3. MOTOR STARTERS

3.1 Starters shall be push button operated, with provision for remote or automatic operation, when liquid level detectors or duty selectors are to be incorporated.

3.2 Motors rated for loads upto 5 hp shall be controlled by direct on line starters, and between 5 hp and 50 hp by Star Delta starters.

3.3 Electro-magnetic contactors used for switching shall be of the three-pole type unless specified otherwise.

3.4 Contacts should be quick-acting, closing above 80% rated voltage. The closed contacts shall not open or drop out above 60% of rated voltage.

3.5 Individual contactors selected for control shall be able to carry 10% more than the rated current applicable for the operation, and should be able to withstand 90% AC 3 and 10% AC 4 category making and breaking currents.

3.6 Mechanical endurance on operation of contactors shall be more than 5 million operations.

3.7 Repetitive rate of contactors shall be more than 50 operations per hour

3.8 Electrical endurance of contactors shall exceed 1 million operations on the mixed service of 90% AC3 and 10% AC1 category.

3.9 On Star Delta motor starters the change-over contactors shall be mechanically and electrically interlocked.

3.10 Overload relays on Star Delta motor starters shall be connected down-stream of the main contactor.

4. PROTECTION

4.1 Overload protection shall be provided to all motor starters.

4.2 Overload relays shall incorporate the following features;

a) Thermal protection for balanced overloads.
b) Differential protection for unbalanced over loads.
c) Automatic ambient temperature compensation.
d) Adjustable current settings.
e) Manual and automatic resetting facilities.
f) Testing facilities.
g) Trip position indicator
h) Independent NC+NO contacts or quick breaking change-over contacts.

4.3 Protection against short circuits shall be provided by 3 pole MCCB or MCB, which should also act as an isolator. The breaking capacity of the MCCB/MCB at supply voltage shall be equal to or more than the prospective short circuit current anticipated at the point of installation.

4.4 Motor control centres with more than one motor starter shall have a separate incoming MCCB to control the total current of the respective motor control centre.

4.5 All motor control centres shall incorporater earth fault protection meeting the following specifications:

a) Relay shall be of the differential monitoring type

b) Tripping sensitivity shall be adjustable in the range 200 mA and 10 amps to suit site conditions.
c) Tripping delay shall be adjustable, preferably continuously between 0 to 5 seconds.
d) Hand or auto resetting capability
e) Provision for remote control test push button.
f) Matching torrodial core balance transformer with suitable diameter for each application.
g) Core balance transformers shall incorporate a separate test winding for simulating ground faults.

4.6 The following supply fault protection devices shall be provided on every motor control centre:

a) Protection against phase reversal.
b) Protection against phase failure. Monitoring should be by phase angle between voltages and nopt by voltage levels, in order to avoid mal-function of the relay with feedback or regenerative voltages.
c) Protection against under voltage should be adjustablel to meet site conditions.
d) Protection against over voltage should be adjustable to meet site conditions.
e) Protection against voltage unbalance should be adjustable to meet site conditions.

4.7 Automatic Liquid Level Detectors

Where required, motor control centres shall be provided wwith Liquid Level Detectors for automatic switching ON and OFF of pump motors corresponding to the level of the liquid in the well and/or tank at pre-set limits.

The Liquid Level Detector shall be capable of controlling levels of all conducting liquid and be capable of performing the following operations:

a) Pump-in-Control (for storage tank) - when tank level falls below minimum preset level contacts should close to start pump motor and when maximum level is obtained contats should open to stop motor.
b) Pump-out-Control (for sump or well) contacts to close when maximum pre-set level of the well is reached to start pump motor, and contacts to open when level falls below a minimum pre-set level to stop pump motor and prevent loss of prime.

c) Simultaneous PUMP IN and PUMP OUT control contacts to close and start pump motor if and when tank requires liquid, and well has sufficient supply, and contacts to open and stop the pump motor when liquid in tank reaches maximum level or when well reaches minimum level, as the case may be.
d) The detector shall incorporate a potentiometer to adjust the sensitivity between electrodes to compensate the resistivity of different liquids.
e) The voltage between common and level electrodes should not exceed 35 volts RMS.

5. AUTO/MANUAL_SELECTOR

5.1 When specified, each motor starter shall be providedwith an auto/manual selector switch and wired to perform the following operations.

5.2 When in auto position the motor starter shall operate (ON/OFF) automatically from signals fed from a remote source.

5.3 In manual position the starter control circuit should be transferred to an ON/OFF push button station for manual operation.

6. DUTY_SELECTOR

6.1 When two or more pump motor starters are installed in a motor control centre, manual or automatic selection of duty cycles for each motor shall be.provided.

6.2 The duty cycle shall meet individual, specific requirements and period of each operating time.

6.3 When in 'Manual' position, the operator should be able to start and stop any motor starter to meet operational requirements.

6.4 'Automatic' mode shall provide the automatic run ofmotors, in a pre-set sequence for specific periods of time.

6.5 Running time of each motor shall be controlled by a timer suitable for such application.

6.6 The timer should be able to operate continuously with good precision and repeatibility performance.

6.7 Continuous operation of each motor shall be adjustable for required periods

7. ELECTRICAL MEASUREMENT

7.1 Motor Control Centres shall be provided with measuring instruments of the flush type with dials of 72 mm square for small panels and 96 mm square for larger panels.

7.2 All instruments shall meet the following specifications:

(a)	Standards:	to IEC 5, BS 89 or equivalent
(b)	Cases:	to protective standard IP 54
(c)	Accuracy:	Class 1.5
(d)	Overload:	20% continuous
(e)	Test Voltage:	2000 Volts 50 Hz for 1 minute

7.3 Voltmeters shall have a range to read 0-500 volts,with external zero adjustment screw. Connection to supply to be made via a 6-way selector switch to read phase to phase and phase to neutral potential difference.

7.4 For loads upto 60 Amps direct reading ammeters should be used. Loads above 60 Amps should be monitored using 5 Amp full scale deflection ammeters via x/5 current transformers.

7.5 Ammeters should be able to withstand and damp starting currents of connected motors.

7.6 Elapsed time meters should be provided to each pump motor to log the actual running hours of individual pumps and associated switch gear.

7.7 Where loads exceed 60 Amps Power Factor meters shall be provided to read 0.5 capacitive to 0.5 inductive. These meters should be suitable for operation on 3-phase 4-wire balanced or unbalanced loads.

7.8 Separate ammeters shall be provided for each pump motor where 2 or more motors operate simultaneously.

8. MONITORING

8.1 Visual indication shall be provided for the following indications:

(a) Three lamps of different colours, preferably RED YELLOW BLUE for 'Mains supply available' indication.

(b) A GREEN lamp for motor starter ON indication.

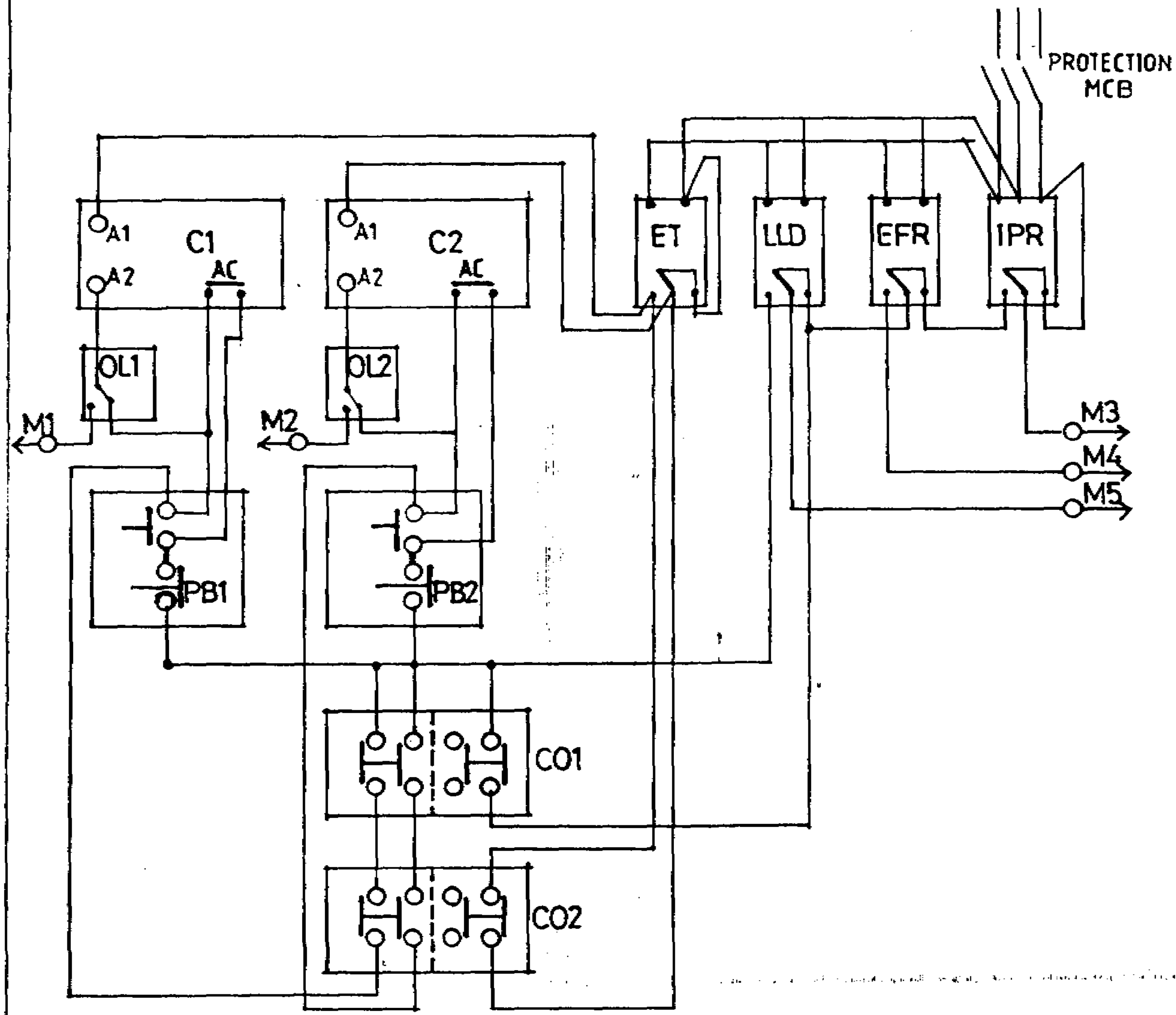
(c) A RED lamp for motor starter TRIPPED indication.

(d) An AMBER lamp for 'LOW WATER LEVEL' indication.

(e) A RED lamp for 'SUPPLY FAULT' indication.

(f) A RED lamp for 'EARTH FAULT TRIP' indication.

Prepared by Skanda de Saram - O&M Consultant, USAID Project, December 1987.



TYPICAL LAYOUT AND WIRING FOR A FULLY AUTOMATIC MOTOR CONTROL CENTRE TO DRIVE TWO MOTOR STARTERS.

CODE	ITEM
C1	MOTOR STARTER 1
C2	MOTOR STARTER 2
OL1	OVERLOAD RELAY 1
OL2	OVERLOAD RELAY 2
PB1	PUSH BUTTON STATION 1
PB2	PUSH BUTTON STATION 2
CO1	2 POLE CHANGE OVER 1
CO2	2 POLE CHANGE OVER 2
ET	ELECTRONIC TWO WAY TIMER
LLD	LIQUID LEVEL DETECTOR
EFR	EARTH FAULT RELAY
IPR	INTEGRAL PROTECTION RELAY
M1	OVERLOAD 1 TRIP INDICATOR
M2	OVERLOAD 2 TRIP INDICATOR
M3	SUPPLY FAULT TRIP INDICATOR
M4	EARTH FAULT TRIP INDICATOR
M5	LOW LEVEL TRIP INDICATOR
AC	NORMALLY OPEN AUX. CONTACTS
A1	
A2	

APPENDIX A.3

INSTRUMENTS SPECIFICATIONS

The type of specification that is usually written for the gauges, meters, and other devices used for instrumentation is in terms of size, range, units of measurement, function, shape, and working conditions. Required quality is indicated by referring to known brands or standards for comparison. Details of materials and fabrication are indicated by reference to established standard specifications of various technical societies or organizations. A typical specification for the instrumentation for sewage pumping stations is as follows:

> MATERIALS AND STANDARD SPECIFICATIONS: Provide instruments, equipment and materials suitable for service conditions and meeting standard specifications such as ANSI, ASTM, ISA, and SAMA. The intent of this specification is to secure instruments and equipment of a uniform quality and manufacture throughout the plant; ie. all instruments in the plant supplied, of the same type, shall be by the same manufacturer. This allows the stocking of the minimum number of spare parts.

In preparing specifications for direct procurement or for a supply and install contract, the generalised specification for material and standard is supplemented by a specification of description and performance for each item of instrumentation, giving as much detail as is necessary to ensure that what is needed will be supplied. In special cases a particular make and model may be required either as a replacement or for standardisation, and the specification is reduced to a statement of that make and model.

1. Pressure Gauges

Gauges shall be of the bourdon tube or bellows type with 270 degrees clockwise pointer travel. Dials shall be white with black numerals. Dial size shall be as shown on the Gauge Schedule. Accuracy shall be within one percent or less. Panel mounted gauges shall have round bezels for flush mounting and rear connection. Others shall have a stem mounting bottom connection. Connection for all gauges shall be male 15 mm with square wrench flats. Wetted parts shall be corrosion resistant to the process fluid shown in the Schedule and unless specified in the schedule shall be the manufacturer's best quality standard. Where the process fluid is likely to clog the tube or when shown in the Schedule, the meter shall be supplied with a silicone oil filled stainless steel diaphragm seal. When specified in the Schedule, gauges shall be equipped with dampeners. Cases shall be black enamelled steel. Ranges shall be as shown on the Schedule.

2. <u>Ammeters</u>

All ammeters shall have square dials with quadrant (90°) pointer travel with the pivot of the pointer in the lower left hand corner of the dial. Ranges and sizes of ammeters shall be as shown on the Ammeter Schedule. Ammeters shall be suitable for flush mounting on the inside of the control panel unless otherwise shown on the Schedule.

3. <u>Voltmeters</u>

All voltmeters shall be for 440 volt service and shall have 150mm square dials with quadrant (90°) pointer travel with the pivot of the pointer in the lower left hand corner. All voltmeters shall be suitable for flush mounting on the inside of the control panel unless otherwise specified.

4. <u>Flow Meters</u>

All flow meters shall be of either the propeller or helical vane type of the size and range shown in the Flow Meter Schedule and shall indicate rate of flow in cubic metres per hour and totalised flow in cubic metres or decimal multiples thereof. The meters shall be so constructed that the entire mechanism may be removed without disturbing the pipeline, and blank cover plates shall be furnished. Magnetic drive shall be used and the register shall be separated from the drive by a completely water tight partition or other barrier. A spare register shall be furnished for each size and range of meter. Flow meters shall be A Company, B Company, C Company or equal.

5. <u>Chlorinators</u>

The chlorinators shall be of the vacuum operated solution feed type with feed rate regulated by an accurate variable control. They shall be furnished with rotameters or other control device with a maximum capacity of 10 kg/h but so designed that the capacity can be increased in the field to 20 kg/h by replacing parts. The replacement parts for increasing the capacity shall be supplied with each chlorinator. Each unit shall be housed in a durable floor mounted fibre glass cabinet with easy access for maintenance and disassembly. Corrosion resistant materials shall be used throughout. Chlorinators shall be Wallace & Tiernan or Fischer-Porter. No other makes are acceptable for reasons of standardisation of equipment and spares.

6. <u>Additional Comments</u>

The foregoing specifications are given as examples of wording and provisions which are appropriate for different situations. If there are several sizes or capacity ranges of a particular instrument, it is usually preferable to use a schedule to show the variable details. Such schedules are usually placed at the end of the section and should be clearly identified.

The person preparing the specifications should be familiar not only with what is wanted but also with what is actually available, particularly with regard to sizes, ranges, and units of measurement. It will do no good to require a range of zero to 85 kg/h, for example, if the industry makes the instrument in the range of either zero to 50 kg/h or zero to 100 kg/h. Sometimes the problem can be resolved by specifying an approximate range or acceptable variations in the range. Similarly, it is pointless to require the scale to be in kPa if all that is available is kg/sq cm. Some of the manufacturers or stockers that will be the sources of supply for projects constructed by local contractors have not yet converted to metric nor to the international system, which is a more restricted version of metric.

Specifications should be tailored or at least modified to fit the needs of the project. There is often a temptation, perhaps through lack of experience or lack of time, to use a specification from a previous contract without fully considering whether it is appropriate. It may be that it was not appropriate even for the earlier application. Certainly, old specifications are a good starting point and a good source of wording and organisation of the provisions, but the present needs must be carefully considered.

APPENDIX A.4

INSTRUMENT PROCUREMENT

It is generally recognised that there are no local manufacturers of gauges, meters, or chlorinators suitable for use by NWSDB. All items of instrumentation except such devices as staff gauges or manometer tubes must be imported, and this has contributed to the past lack of maintenance of instrumentation. Procedures must be established for the prompt procurement of spares or replacements if the instrumentation is to be kept in service.

As part of the procurement procedure, there must be a clear understanding of exactly what is to be procured. Chlorinators and ancillary equipment should present no problem because this type of equipment has limited application and few manufacturers and, in any event, NWSDB should standardise the make and model of equipment. It is in the field of gauges and meters that there may be difficulty in identifying the correct items both as to design and as to quality.

To procure the correct type of pressure gauge, electrical meter or flow meter, there must be an adequate description in the specifications. Those persons handling the procurement must realise the importance of the specification and must not allow any deviations without approval from O&M. Certain features or details may be critical while others may be such that exceptions could be permitted, but the decision to allow a deviation should be made by the user and not by the procurer.

Quality control may be difficult. Most of the manufacturers in the industrialised countries that are potential sources of supply have been supplying to public (governmental) agencies and can be depended upon to comply with established standards and with their own specifications if proper procurement procedures including contract guarantee are used. There are manufacturers in some countries who are not reliable, and special procurement techniques may be required if there is open international tendering.

One technique is to pre-qualify the suppliers, requiring samples and specifications in advance of actual tendering. A questionnaire can be prepared, as in the pre-qualification of construction contractors, which will provide NWSDB with pertinent information about the manufacturer and about his customer. The questionnaire can include specific design or material details. Samples can be obtained, especially for small items, or the factory could be inspected. The advantage of pre-qualification is that it occurs before the price is known, thus avoiding the problem of an attractive price influencing the purchaser to accept an item that does not meet the established specification.

Aside from design details and quality, there is the problem of locating sources of supply. Much of the procurement may be by direct purchase rather than competitive tendering. This is because there may be only one source if items are standardised and because some small items must be obtained from abraod where there is not enough interest to attract supplies through the usual tendering process. Three different methods can be used in locating sources and in the actual procurement: using local agents representing overseas suppliers, contacting overseas suppliers directly and using overseas agents.

1. Local Agents

A thorough inquiry among local suppliers of a variety of equipment and among persons familiar with supply has resulted in locating only one source of supply of imported ammeters and voltmeters, and that was a small shop in Pettah that handles a variety of electric supplies, some of which might be useful. There is a local agent for Kent water meters and Wallace & Tiernan, manufacturers of chlorinators, has established an agency here, probably because of the recent construction of several treatment plants using W&T equipment. However, no sources were found for pressure gauges and hour meters and the one small shop in Pettah that stocks electrical meters is not an adequate source for the total needs of NWSDB. Other agents may exist that were not found and, in any event, it may be possible to develop interest in the supply of instrumentation equipment so that agencies will be established.

Two reasons for the apparent lack of interest in the supply of meters and gauges may be the lack of potential profit and the lack of present demand. A water utility agency the size of NWSDB is potentially a very good customer for a large quantity of water meters with a sales value of millions of rupees. Although not as many units of chlorinators are involved, the sales value is again very high. Therefore, manufacturers in these two fields will be looking for future business with NWSDB. In the field of pressure gauges and electrical meters there is not the potential volume or profit to interest the manufacturers. Such devices are usually imported as part of the pumps and motors without involving local suppliers of instrumentation. With the lack of maintenance there has been no demand for replacements and, therefore, no source of supply has developed.

This does not mean that import agents would not become interested if they had a market. If NWSDB refurbishes the older pumping and treatment facilities, a large quantity of gauges and meters will be required initially. Thereafter a steady demand should result from maintenance. If importers, like the one in Pettah that handles ammeters and voltmeters, are made aware of the potential present and future needs, perhaps they will start stocking or at least listing pressure gauges and other devices.

2. Direct Overseas Contract

If local agents are not found for the supply of instrumentation equipment, it will be necessary to go to the sources of supply in foriegn countries or even to sources of origin, the manufacturers. In the case of large items of equipment such as bulk water meters, it would not be difficult to locate appropriate manufacturers and deal with them directly. Wallace & Tiernan, the manufacturers of the chlorinator in most common use has a local agent who should be kept in regular contact for maintaining or up grading the chlorination equipment. As previously mentioned, Kent has a local agent who could be contacted regarding water meters for the uses that are appropriate.

The catalogues from Kent do not show bulk propeller meters with a dial indication of rate of flow although they do show flow rate indicators and recorders of a type which has proven to be unsuitable for Sri Lanka. There are manufacturers in the United States that make the type of flow meter that should be used. Perhaps the best known is Sparling, and there are others there as well as in other countries. NWSDB could contact such manufacturers directly and request detailed specifications and price quotations. If a mutually satisfactory business relationship develops, the manufacturer that supplies the meters may appoint an agent in Sri Lanka to promote further sales.

In the case of pressure gauges, ammeters, voltmeters and hour meters, there is not the need for standardisation that there is with water meters or chlorinators. If one of these minor instruments breaks down, it is usually best to replace it. NWSDB could seek out agents or manufacturers in foreign countries, but there are so many of them and the value of the order would be so small that this may not be the best course of action.

3. Overseas Agents

If miscellaneous supplies cannot be procured through local agents and if the size of the order of any type is not large enough to warrant dealing directly with an overseas manufacturer, the best course of action may be to use an overseas agent, a procurement service agency (PSA). NWSDB will have a need for many other imported items besides pressure gauges and electrical meters. The PSA is not restricted to a particular line of supply and can satisfy a broad range of procurement needs including packaging, shipping and insurance. The miscellaneous items of instrumentation that cannot be obtained more effectively or conveniently in some other way can be included in a request for other items being procured by NWSDB and referred to the PSA for procurement.

Specifications with a clear description of what is wanted will be required for procurement through a PSA just as with a local agent. Although the PSA and the local agent both may handle a wide variety of items, the PSA will probably have had better experience in dealing with specifications because he has a much larger volume of business and much larger staff than does the typical local agent. If NWSDB uses the same PSA over a period of time, the PSA will become familiar with the type of supplies that are needed and will, in effect, become an extension of the Supplies Department.