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MMPHIL 10

COMPUTER AIDED ENQUIRY SYSTEM FOR PUMP SELECTION

JON ARTHUR TOOTHILL

A thesis submitted in partial fulfillment of the requirements of
the Council for National Academic Awards for the degree of
Master of Philosophy

September 1992

Nottingham Polytechnic in collaboration with
Dresser Pump Division (UK)

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Section 1 Acknowledgements

I would like to thank Mr B.Reeve & Dr K.Henthorn for thier help and advice throughout the duration of this project. In addition I would like to thank the many people at both Nottingham Polytechnic and Dresser Pump Division who have offered technical assistance.

COMPUTER AIDED ENQUIRY SYSTEM FOR PUMP SELECTION

MPhil SUMMARY - J.A.TOOTHILL

This thesis considers the application of advanced software techniques to the product selection of hydraulic pumps. The project aim was to develop a computer aided enquiry system enabling the production of timely, professional tenders in response to customer enquiries. The work was undertaken as part of a Teaching Company association between Dresser Pump Division (U.K.) and Nottingham Polytechnic.

The original Polytechnic feasibility study highlighted the use of expert system shells as a suitable vehicle for the solution of this problem. Initial work proceeded from this with the development of a prototype using Leonardo. This performed basic selection for a limited number of pumps allowing a variety of data models to be examined.

On further consideration of the amount of data being accessed, a need for enhanced facilities was identified. A change of development shell was needed, with Egeria being the chosen product. A second prototype was developed with increased capability covering a complete pump range. However, it soon became apparent that the adoption of Object Oriented Programming would be the key to a clearer representation of the problem.

The selection of a pump by computer is mathematically intensive. Since a rule based system is not ideally suited to calculation, a hybrid approach (combining rule based and conventional techniques) seemed appropriate.

Upon reappraisal of the project requirements it became apparent that Object Oriented Programming would form the major part. A decision to abandon the rule based approach in favour of development in C++ was taken. The groundwork already covered allowed rapid redevelopment of the system. This showed significant gains over the shell based systems. Execution time, implementation cost and hardware dependency were all reduced. In addition the control over the resulting code was held within the company. A live system began user trials in September 1991 throughout all UK sales offices, with worldwide distribution scheduled for November 1991.

The application of new techniques to this problem has proved successful. The foundations for a powerful and versatile engineers tool have been laid. Further developments for product training and market research use are now possible.

SECTION 3

INTRODUCTION

The downturn in British Manufacturing Industry has been blamed on many outside influences. Common through the reasons is the failure to respond to change, poor customer service and an inability to respond with sufficient speed. This document outlines the initial stages in one company's attempt to counter these problems by introducing a computer system to aid engineers to respond faster and in greater quality to a customer's enquiries.

The project's aims were to increase the company's tendering output, and the conversion ratio from tender to order by providing the means for producing timely, quality quotations in response to a customer's enquiry. To do this requires that the system select an appropriate product from the company's range of hydraulic pumps, enable this to be priced and produce a quotation consisting of technical data sheet, performance curve and general arrangement drawing, in various styles and degrees of detail.

The project was carried out under the funding of a Teaching Company scheme between Nottingham Polytechnic and Dresser Pump Division (U.K.). Section 3 introduces the parties concerned in development and outlines the project aims. An overview of pump selection is given in Section 4, covering the use of Expert Systems for pump selection. Approaches to the problem are given in Section 5, examining concepts for solutions. The development of the programme using various software is covered in Sections 6,7,8 and 11, with 9 and 10 detailing the reasons for a change in approach from expert system shells to a high level object oriented language. Conclusions and suggestions for further development are presented in Sections 12 and 13.

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3.1 TEACHING COMPANY SCHEME

The Teaching Company scheme was based on that of Teaching hospitals, both seeking to develop the skills of young graduates in real life situations. The scheme's mission is to change traditional attitudes and help form lasting partnerships between higher education and industry. Through this it seeks to improve UK industrial performance, profitability and management.

Each scheme is a partnership between three groups, a company with a suitable project, a higher education institution with relevant research interests and a number of graduates who form the link between the two. The project tackled should be central to the company's future, but beyond its current resources.

The scheme aims to benefit all involved. Industrial performance and methods by using academic resources and implementing advanced technology effectively. Academic staff's exposure to industry both benefits research and enhances the relevance of teaching. Graduates benefit from the training opportunities available under the scheme, and from the exposure to real-world research projects.

Funding for the project is met jointly by the company and the SERC or DTI. The scheme has recently celebrated the start of its 1000th programme.

This particular scheme involves two graduates over a three year period. I was the first, with this thesis detailing the work done in the first two years. The arrival of the second graduate coincided with the receivership of Expertech, work from this point was done collaboratively.

3.2 Dresser Pump Division (U.K.), Worthington Simpson Operations

The company has a long association with the pumping industry, stretching back to 1778. During the early days of the steam age, Thomas Simpson's workshops were responsible for the maintenance of the steam pumping plants at various London Waterworks. His grandson, James Simpson, began the family's involvement with pump manufacture in 1886, with the formation of James Simpson & Co. Ltd. The company entered into an agreement with Henry R. Worthington of New York to manufacture his pumps, in the U.K. He relocated from London to Newark in 1901 to a site which is still the company's location. The link between Worthington and Simpson was strengthened in 1917 with their amalgamation to form Worthington Simpson. The growth of the joint company, and its expansion into international markets led to it becoming part of the Worthington group in 1969. Worthington was acquired by Dresser in 1985 to form one of the three biggest pump companies worldwide, increasing the Newark site's scope for overseas sales.

Dresser Pump Division is part of the worldwide Dresser Industries Group. The pump division is approximately 10% of the parent group, with the U.K. operations being a tenth of the pump division. The division has 29 sites in 13 countries, making it one of the major forces in the pump industry. The Newark site is the main U.K. manufacturing site. Among the locations it is unusual in having its own foundry on site, bringing the complete manufacturing process together. The products made at Newark are standard, pre-engineered centrifugal pumps. Currently the site is one of the lead sites within Dresser for the design and manufacture of new product ranges for worldwide sales. Two new ranges are scheduled for introduction in 1992.

3.3 Nottingham Polytechnic

Nottingham Polytechnic was founded in 1970 as Trent Polytechnic, changing the name in 1990. It is one of the largest of the U.K.'s thirty polytechnics, and among the most popular with prospective students. The polytechnic is made up of 22 departments in 8 faculties, spread over 3 sites. The majority are located on the main City site located in the centre of Nottingham.

The department of Mechanical Engineering is one of five within the Faculty of Engineering. It has over 60 staff, and offers a range of full-time, sandwich and part-time courses. The department is participating in four teaching company schemes with various local businesses. Research interests cover heat transfer and fluid flow, expert systems, CAE and control systems.

3.4 The Project

The project arose from a feasibility study [1] conducted in 1988 by Dr. A. R. Uzel and Dr. K. S. Henthorn, into the possible use of expert system techniques for pump selection. It concluded that the company's range of pumps,

> "... is a suitable application domain for expert system developments".

The initial aim, as perceived in the feasibility study was to develop an

> "expert customer enquiry system for the computer assisted selection of Worthington Simpson's range of pumps".

This would question the user about the pump's application, then use stored knowledge on the company's pumps to select an appropriate unit. The system would display the correct specification with a performance curve and general arrangement drawing. Using the system would result in improved speed, and better selection and greater consistency, as the system would employ all the available knowledge.

After the project start, discussions with the engineers suggested that a system focusing purely on selection would not result in significant gains in speed or productivity. The project was widened to

> "Increase company market share by the provision of a means to produce high quality, timely tenders in response to customers' enquiries."

By including the final output stage of tendering much of the engineer's time in filling in data sheets could be saved, and the quality of the resulting output be improved. In addition to speeding the response to the customer, by presenting more information in a better quality format, it would improve the chance of converting the tender to an order. This obviously being the major aim of the programme, i.e. to increase the company turnover and profit.

SECTION 4

EXPERT SYSTEMS AND PUMP SELECTION

The decision to use an expert system for this project was made in the early stages of the feasibility study. The first part of this section considers the features of an expert system, this is presented as an overview, more depth being widely available in the texts listed in the Bibliography. The second part applies this to the subject of pump selection.

4.1 What Is An Expert System

The definition of just what is an expert system is very difficult with almost every text having its own slightly differing definition. In his book on Management Support Systems[2], Professor Efraim Turban defines:

"Expert systems are computerised advisory programmes that attempt to imitate or substitute the reasoning processes or knowledge of experts in solving specific types of problems".

A more cynical view is offered by Professor Roger Penrose in 'The Emperor's New Mind'[3]. He asks:

"... is it merely that long lists of factual information, together with comprehensive cross-referencing, are all that can be expected to be achieved ?"

Expert systems rose not from conventional computing, but as an applied form of Artificial intelligence. They seek to address problems of human knowledge or experience. Developers are offered various ways to represent the experts' rules and heuristics, in a Knowledge Base. To apply these to a problem, an expert system contains an Inference Engine. This maintains the status of a problem and selectively applies the knowledge to move toward a solution. Together with interfaces for the developer and the user, these make up the main parts of an expert system.

An implemented expert system should exhibit similar qualities to a human expert. Its knowledge should be restricted to a relatively limited, and tightly defined area of expertise, it should solve problems both quickly and accurately, know its limitations, and on request, be able to explain or justify an answer.

One of the most striking differences between conventional and expert systems is the type of data they deal with, where a conventional system will be based on simulations or mathematical models, an expert system, akin to the human, manipulates symbolic, qualitative data and may operate in situations with unknown or incomplete data.

These differences are crucial to the development of expert systems. Professor Turban cites this as the key insight learned in the mid. 1970's as expert systems began to develop from AI, saying,

"... the power of an ES is derived from the specific knowledge it possesses, not from the particular formalisms and inference schemes it employs".

4.2 How It Can Aid Pump Selection

The area of pump selection requiring knowledge may most neatly be summarised as the time the engineer spends before and after consulting the price book. While reading a customer's enquiry the application engineer is building up an idea of the requirement beyond those stated. This reduces the solution space to a small number of possibilities to be examined in detail, from which the engineer selects the best for the customer's situation.

This rapid reduction is essential in finding the appropriate pump. Within the company's D-Line product line, there are thought to be in excess of 4 million combinations of the standard parts. On being presented with an enquiry the engineer will reduce this range of possibilities to less than 10, in seconds. This ability is the primary area where the engineer's knowledge is vital to allow a solution to be found in an acceptable time.

After performance analysis has been performed there may be several suitable selections. Determining the best of these requires the engineer, or expert system, to evaluate which parameter the customer will most value and how this may be traded off against others.

All of these rely on the engineer knowing the products and their applications, and equating these with what he knows about a customer and the application the pump is for. Perhaps more important than the requirements stated in an enquiry are those that an engineer knows from past experience must also be satisfied.

SECTION 5

APPROACHES TO THE PROBLEM

This section considers some of the ways in which pump selection by computer may be approached.

5.1 SEARCH METHODS

5.1.1 Brute Force Search

This refers to the use of raw computing power to locate the possible solutions with little finesse. It is perhaps the most obvious route, and as such is that taken by many early systems which attempt to assist in pump selection. While the basic algorithm is simple, success relies on large amounts of computing power to obtain timely results when more than trivial numbers of pumps are analysed.

Under the Brute Force method every pump and every option is evaluated to determine its suitability for the application. This continues regardless of how 'obvious' it may be that a group of sizes, or even a complete range, will yield no solutions. The order in which elements of a pump are checked is arbitrary, a full analysis being performed in every case. While the method may appear flawed in its aggressive approach to the problem, it has many advantages. As every possibility is examined, the user may be sure the system is thorough, and has not overlooked a possibility. The simplicity of the algorithm leads to small executable programmes with short cycle times, the long execution time is caused by the number of cycles being performed. While for large numbers of pumps, this approach may be inappropriate, it offers a way of dealing with small groups, quickly and simply.

5.1.2 Intelligent Search

The use of an intelligent search refers to methods more akin to those an experienced applications engineer would use to find a selection. The capacity of the human mind does not allow large numbers of pumps to be evaluated in the time available, usually 2-3 would be the limit.

Instead of beginning with the detailed hydraulics, the engineer will progress to this level of detail. The search considers large groups of pumps at a time. The initial stage would be to consider what types of pump are appropriate, then sub-types until the product lines are reached. The diagram, Figure 5.1, shows the tree for a situation where a pump from the D-Line range is the best choice. The search considers the widest groupings, gradually narrowing the focus of attention as it becomes increasingly specialised. At each level there may be several possibilities, these may be evaluated in parallel as alternatives, or the 'better' choice may be pursued, returning to an other option if a satisfactory solution is not found.

Intelligent search methods seek to reduce the need for long, complex analysis to a minimum by reducing the population of the solution space in large chunks.

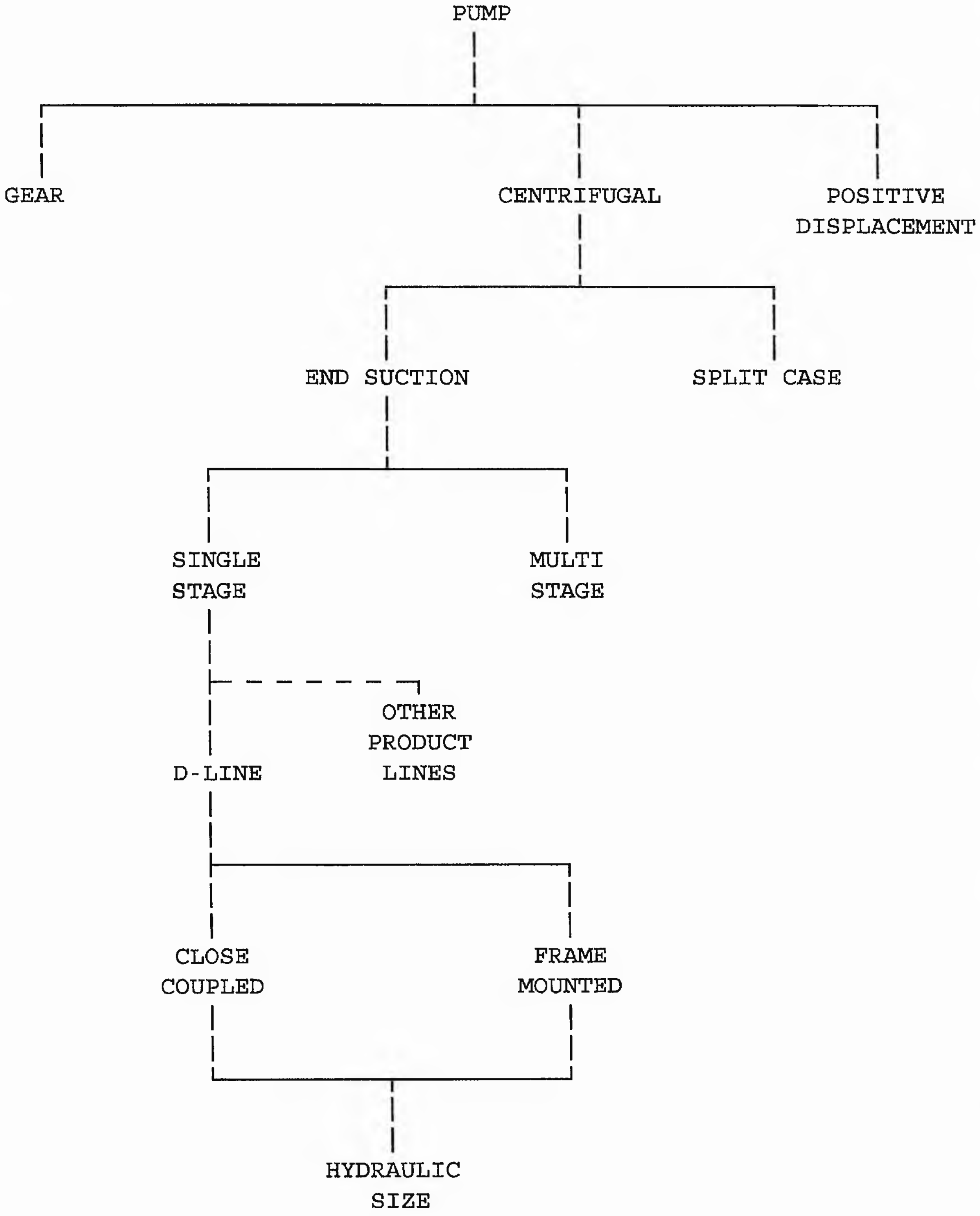


FIGURE 5.1 INCREASINGLY SPECIALISED SEARCH

5.1.3 Data Accumulation

This third approach to pump selection works by building a profile of the solution as the programme progresses. A series of stages each assesses a part of the problem and add their results to a central data store.

The diagram, Figure 5.2, shows the four stages in pump selection. Each phase has a distinct start and end point and its own focus.

Level 1 is the communication with the user. This must extract relevant data from the user and combine this with the system's knowledge to build a complete specification for the pump. This level should be capable of making assumptions when data is missing, but should also prompt the user for more input when it is vital to the selection, or when an assumption would be dangerous or unreliable. This level is where the system is most required to be intelligent, basing decisions on knowledge elicited from experienced engineers.

The second level takes the specification and finds the appropriate pump. In addition to the evaluation of performance, the programme will use company policy rules on deciding between possible selections, and may need to generate a request for a quotation for bought-out parts. The selection algorithm may be based on either of the two methods above.

Pricing of the selection is performed in Level 3. This is a series of rules, acting on figures extracted from a database. The final price is based on the pump selected, the quality control and testing requirements, the associated documentation, any special finish or paints and the customer's status and location. Information on each of these is passed down through the system from the user-interface.

The final stage, Level 4, is the production of the final printed tender for the customer. This is comprised of a printed data sheet, performance curve and general arrangement drawing. These may be required in a variety of styles, varying in detail depending on the customer.

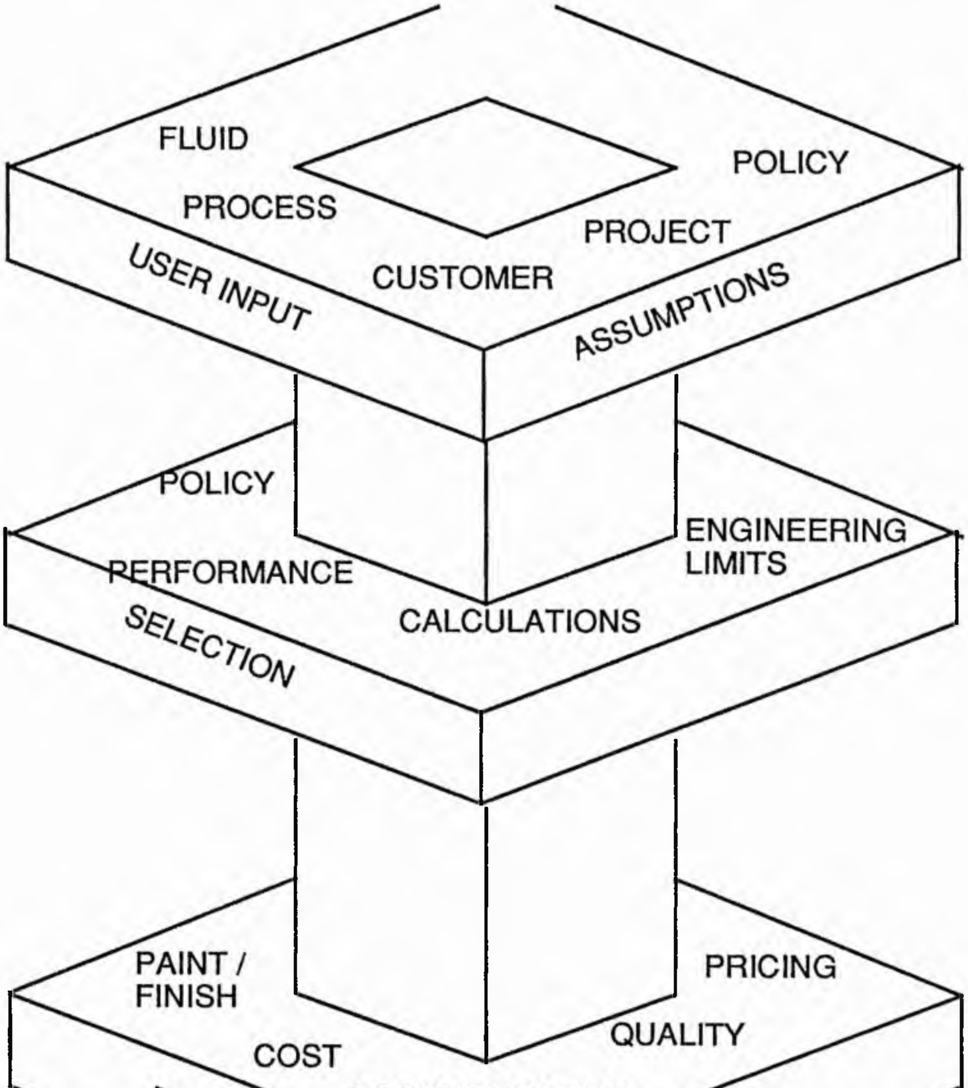


FIG 5.2 Data Accumulation

5.2 Performance Curves

5.2.1 Performance Curve Model

While the performance characteristics of a pump follow a curve, much of the early work was carried out with straight lines. Though these do not approximate the curve to great accuracy they allow calculations to be checked by hand, ensuring results are as expected.

The initial calculation is to find the impeller diameter to meet a given duty. This is done using the affinity laws, as detailed in Appendix C. While the answers were close to those of an engineer, they would vary in the area midway between the curves, sometimes making significant changes in diameter for a small duty point change as the algorithm switched the nearest curve, used in the calculation, from that above to one below the duty point.

Conversations with the Engineering department on the more accurate methods used on larger pumps being tested suggested the DFDP graphs for correcting diameter, detailed in Appendix C. These give a correction factor between theoretical and actual diameter, generalised across several pump sizes. The use of this technique improved the diameter calculation, with varying results. In the area close to the pump's best Efficiency Point the calculated diameter corresponded to those expected. Away from BEP the calculation gradually diverged from expectations, obviously the approximation to the affinity laws changes across the operating capacity range. As the DFDP graph is a generalisation of several pumps it did not allow for this variation.

A second method used by Engineering primarily during the design phase of a pump relies on indices calculated between diameters to replace 2 in the affinity law relating head and diameter. Diameters consistently matching those selected by an engineer were achieved by calculating the indices for a duty point between the nearest two diameters along a parabola through the duty point, detailed in Appendix C. By selecting duty points across the envelope of a pump the variation of the figure can be shown, this is typically from 1.3 toward closed valve to 3.5 at End of Curve. In addition to varying across the capacity range, the figure also changes between different pairs of impellers.

5.2.2 Representation As A Curve

Once a dependable calculation algorithm had been found for simple performance curve models, a more accurate equation could be substituted to achieve the required diameters. Two basic methods could be used, as detailed in Appendix C, with the use of a fourth order polynomial being preferred. A system within the Engineering department already uses this form for the plotting of Estimated Performance Curves, so data for a number of pump ranges, including D-Line already existed.

The initial, and most major problem, was the hardware. While the shell was on a standard IBM compatible machine, the curve drawing system and data resided on a Rair Black Box. This offers a degree of compatibility, with the option to write to floppy discs in PC format, though all initial attempts to export the data failed.

A second problem was the format of the data. The original estimated curve data was available in an ASCII file in Engineering notation, however, dBase III+ does not hold data in this format. Although dBase had sufficient decimal places to hold the coefficients (15 places), the significant figures were more than the 7 which Leonardo could cope with. While the effect of the lost digits is small in calculating a point on a pump performance curve, whether this is so during calculations, or if the errors accumulated is not known.

The mathematical precision required for the complete system is difficult to determine. While the programme undergoes a long series of calculations to determine an exact figure for the diameter, the final figure required is an integer. For many D-Line units the final 'accuracy' is less than this, as the impellers are only available in a series of predetermined size in steps of 2 to 5 millimetres. Hence, once an exact value is found, it is compared to the sizes which are manufactured, and an appropriate diameter chosen.

5.3 Stock Pumps

While there is no charge to the customer for the trimming of an impeller, they will often take an alternative size stock pump for the increased availability. As it is preferable to Worthington Simpson to sell a stock unit, the system should recommend these whenever possible.

The stock list consists of twenty-nine combinations of pump and motors, covering the smaller D-Line units.

The system determines whether a stock pump is appropriate using a simplified set of rules. These check that the fluid is water, that the fluid is clean. In addition the requirements must be for a 2 pole (2900 RPM) unit in Cast Iron, with no performance testing.

While stock pumps may be appropriate in other situations, these would require more work by the engineer. The current rule covers the majority of cases, and will "failsafe" i.e., will not recommend a stock pump for a situation in which it could be inappropriate.

As no impeller diameter need be calculated for a stock unit, its selection is performed in a different way. The diameters for stock units correspond to the stored diameters for the relevant pumps. The hydraulic size to be tried is checked against the stock list to find the diameters and motors available. The generated head on the curve is calculated at the duty flow rate, and compared to the duty head. The smallest diameter to exceed the required duty is selected as the stock offer, if none is found then a larger pump is tried.

The selection of a stock unit presents the user with less information than a trimmed impeller selection. The system displays the pump size, impeller diameter,motor power and the stock code number.

5.3 Fluid Parameters

The fluid to be pumped can have a great effect on both the type of pump which is suitable, and on the hydraulic performance of the chosen unit.

Ideally, the system should be able to provide details about the fluid to the user, or to check the information entered by the user against a database of fluid data. To allow the demonstration of such a database, a small example file containing the data for five common fluids was compiled.

Determining the appropriate materials of construction for given duty conditions is significantly more complex. While the fluid's corrosive nature is usually the dominant parameter, the material required may be influenced by the process taking place, the industry or the specific customer. It would be useful to hold in the fluid database which materials are appropriate, to allow the user to be informed of this when considering the other fluid parameters.

As with the other fluid parameters, the material compatibility changes with concentration and temperature, making it difficult to represent the data so as to cover all situations. This is further complicated by the effect of the 'context' of the application. The process being undertaken can dictate the use or preclusion of particular materials, e.g. for applications on cold water, a cast iron pump is usually the most appropriate, however, if the application is in the textile industry, and the water is used to wash the cloth after dying, then stainless steel must be used, any traces of iron in the water would give a yellow mark on the cloth. For wash water prior to dyeing, the cast iron unit would be appropriate.

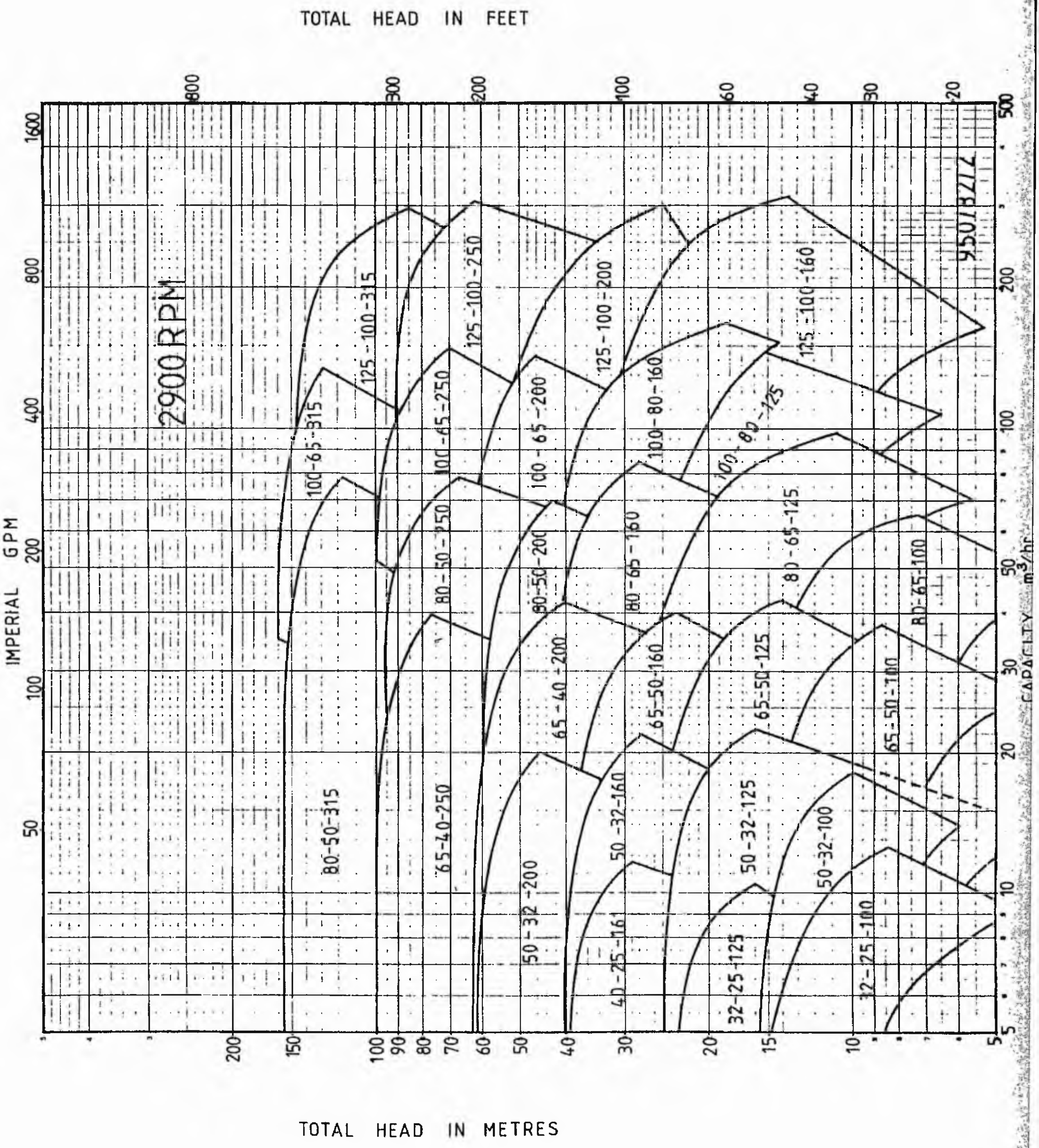
Similarly, the industry, rather than the process, may override what appears an appropriate material, i.e. Foodstuffs industries use stainless steel pumps rather than cast iron to reduce the risk of contamination.
The area of material compatibility is at present left to the engineer, until the completion of hydraulic selection allows more time to be devoted to this area.

5.5 Choosing the appropriate pump size

Before any analysis of the hydraulic performance can take place, the size of pump to be evaluated must be determined. The engineer uses a coverage chart in the price book to indicate the most suitable pump for a duty. If the duty point is near to the edge of a unit's performance envelope then several pumps may be evaluated to find the most suitable.

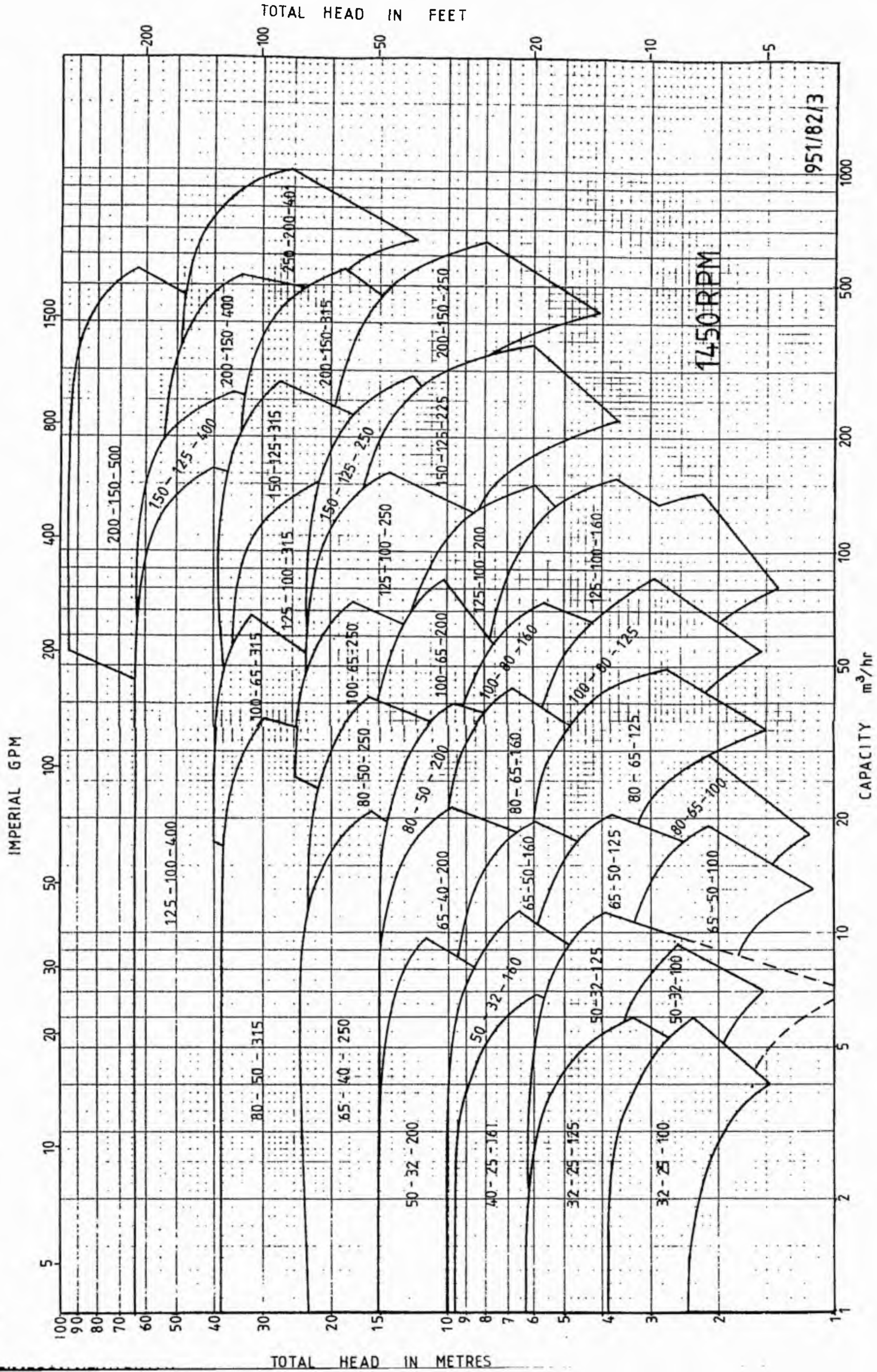
WATER RATING CHART 50 HZ

2900 R.P.M.



WATER RATING CHART 50 HZ

1450 R.P.M.



SECTION 6

IMPLEMENTATION IN LEONARDO

6.1 LEONARDO

6.1.1 WHAT IS LEONARDO

Leonardo is a software package providing a complete environment for the development, testing and execution of an expert system. It provides the frame work or shell for the development of systems intended for a wide range of problems. It was developed by Creative Logic Ltd. in the mid 1980's. The package is available at 3 levels, with additional tool kits.

6.1.2 WHY LEONARDO?

Nottingham Polytechnic have used Level 3 Leonardo as their teaching system for many years, building up experience in its application. Their feasibility study considered several options with Leonardo being the recommended tool.

6.2 Fluids Database

Rather than define and populate a fluid database in-house, a decision was made to obtain this commercially, then to add the material compatibility data. A wide range of databases are available, both on disc, and on-line, giving information on the nature and behaviour of a range of liquids. However, all of these covered specialist topics. While the data could have been taken from the Lab. to provide a database of all the fluids previously handled, it was difficult to see how this could be applied to concentrations or temperatures not previously handled. While the small example file remained part of the system, it was not expanded to more fluids, and forms a major area to be tackled later, outside the scope of this thesis.

When a fluid is entered, the system searches the database for a match. If it is not found, the fluid parameters are blank for the user to fill in. For fluids in the database, the values are retrieved and presented as defaults for the user to accept, or overtype. While the system does not check the input values, by displaying a default it gives the engineer an indication if the information on an enquiry is likely to be incorrect.

Viscosity and SG correction are performed according to the Worthington Simpson methods rather than those of the Hydraulics Institutes.

6.3.1 Selection Of Pump Range

The hydraulic analysis assumes we have already decided upon the type and range of pump to use, hence the system must decide which pump range to pursue.

Initially the programme to do this was separate from the main hydraulics. The system takes the user responses for the pump features required along with the duty conditions, to arrive at a list of possible pump ranges. If several are present in the list, then a ranking system based on price determines which to pursue.

Four parameters were used initially to indicate the area of application, with others being added later. The operating duty of the unit is the most important. For each range a general coverage is held to which the required duty is compared. If the required duty is outside the rectangle then no pumps in this range are suitable so the entire range may be rejected. However, if the point is within the coverage this does not imply that a pump is definitely available, the limitations stored for a pump range are chosen to cover all possibilities, rejecting items definitely not appropriate, leaving possibilities to be investigated further.

The description field allows the user to indicate the type of pump required, options are:-

End Suction
Split Case
Multistage
Gear
Positive Displacement.

Often the user will know the required type as each has its own area of application, if not the system considers all options. If the user doesn't give a description to limit the search, units of inappropriate types of pump are usually excluded by the other parameters. Similarly, the choice of configuration between close coupled and frame mounted limits the search.

The final parameter is whether the unit is required to be self priming. This can greatly reduce the ranges available, or require the use of additional items to prime the pump ready for operation.

Other parameters added later allow the user to indicate which manufacturing site within Dresser would be preferred and the casing material. Later versions also calculate the specific speed and use this, in addition to the duty, to give an indication as to whether the performance required will lie within the range being considered.

6.3.2 Finding the Size of Pump

Rather than model the complex shapes of the flag chart, Section 5.5 the system represents this as a rectangular grid. This is based on the original chart and seeks to suggest the smallest, and hence cheapest pump which may be suitable. If on evaluation the pump is not suitable for the duty then another is tried.

On diagram FIG 6.1, point A indicates a duty point which lies within the performance envelope, hence shows a suitable pump. Point Blies beyond the capacity range of the pump suggesting a pump with larger suction and discharge piping to be considered. Conversely, point D is prior to the minimum flow requirements, indicating a pump with smaller suction & discharge may be appropriate. Point C shows the required head exceeding that generated by the pump, A pump with larger nominal diameter impeller would be neccesary.Point E indicates the opposite with a smaller nominal impeller being required to reduce the generated head.

The rectangles are not an accurate representation of the pumps performance envelope. The first size is suitable 60% of the time and more than one move is rarely needed giving a selection time of approximately 20 seconds for duties on water. Fluids requiring viscous correction alter the performance curve and make moves more likely. This with the extra calculations increases selection time to approximately 60 seconds.

While the search should lead to the smallest pump this is not always the 'best' selection. Other pumps may have higher efficiency, or availability from stock or shorter deliveries. Without examining numerous pumps it is not possible to find these 'better' selections as doing this would increase the selection time.

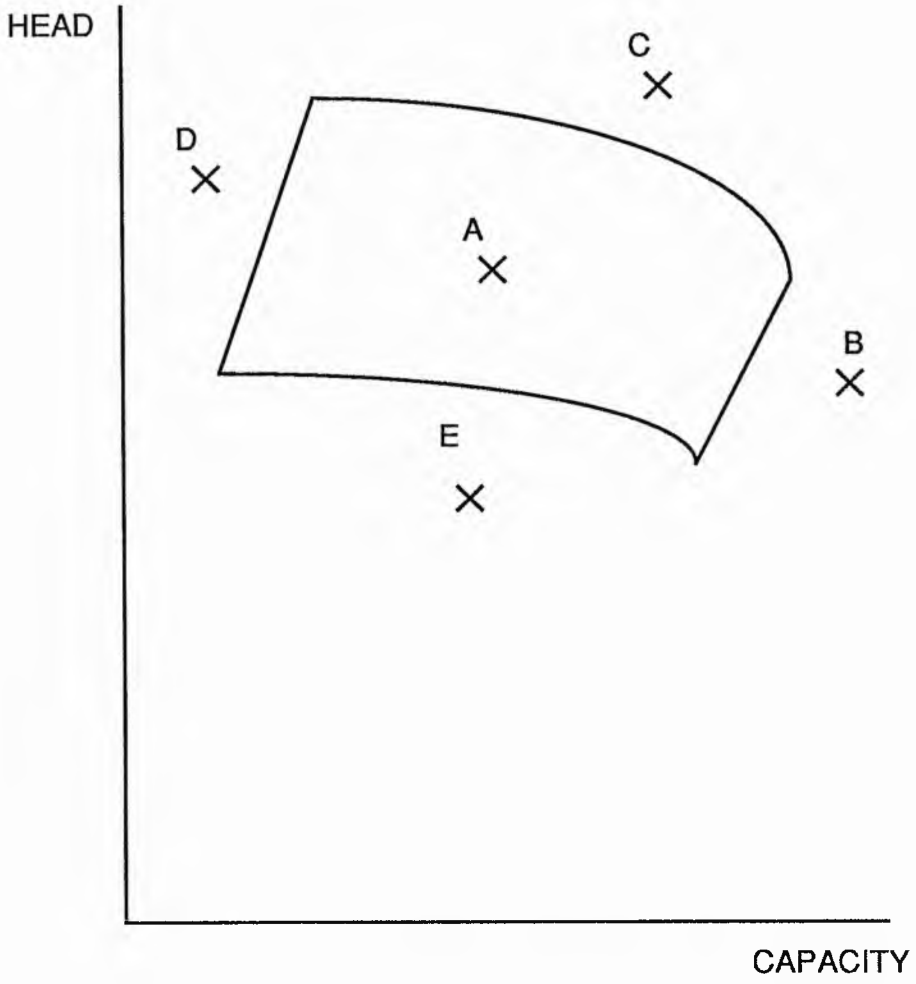


FIG 6.1 DUTY POINTS AROUND A PERFORMANCE ENVELOPE

6.4 Accuracy Of Efficiency Figures

In many cases the pumps efficiency is the deciding factor in the decision as to the best selection. However, particularly in the Water Supply Industry, an economic assessment is made including both purchase price and the running cost over 10 to 15 years. A small increase in efficiency can yield tremendous cost savings in these situations. The accuracy of the quoted efficiency is hence very important.

The figures displayed by the system are derived from the flow rate, generated head, and absorbed power taken from the digitised price book. While these would be expected to match the ISO efficiency lines, this was not the case with discrepancies of between 2 and 5 percentage points occurring in an inconsistent manner. With the efficiency equation verified as correct, the problem must lie with the polynomial representation, although these appear to model head and power correctly.

The discrepancies were traced to a combination of several areas related to the difference between the human engineers interpretation of the performance curve and the computers manipulation of the equivalent equations. While the capacity, head and power figures are determined from performance tests, the efficiency is always a derived quantity. In the drawing of a curve the results of many tests are used to give a series of points through which a hydraulics engineer can fit, by eye, the best curve. This produces the head and power curves for a number of diameters. From these a series of calculations give the efficiency at various points on each diameter. These are again joined by eye to give the iso-efficiency lines for the price book page. Although care has been taken to determine the points there is no guarantee that the efficiency is exactly as stated along the complete line, the thickness of the printed line smoothing small discrepancies.

This line thickness is the root of the second source of error. An engineer reading head and power from a performance curve can return a range of values depending whether they use the top, middle or bottom of the curve. Particularly with larger pumps the scale on the graph can give large difference in the value 'seen' by the engineer. By contrast the system reads the curve to 7 digit precision. There is no interpretation, and the value is calculated and compared to this precision in all calculations. This occurs twice for each curve, firstly during digitising, as the operator takes points from the plotted curves and secondly in the checking of the results of the algorithms.

This twin difference allows large scope for discrepancies to occur and these are hidden by the users interpretation of the curve.

The effect of the line thickness was shown by a series of calculations deriving power from the capacity, head and efficiency. The resulting power, while differing from a value read from the curve, still lies within the thickness of the line and would be acceptable as a value from the curve. By taking values of head and power corresponding to the limits of the line thickness, the variation of efficiency can be shown. While the change in capacity, head and power appear small, they combine to have an effect on the efficiency of up to 3% points from the expected figure.

The only effective way to reduce this is to generate the power curves from the iso-efficiency values.

While this greatly improves the efficiency figures displayed for the stored impellers, intermediate diameters still give values which vary from those expected. Although the variation was reduced to around 2% points, no reason was apparent at this stage in development.

6.5 PROBLEMS AND SOLUTIONS

Although the Leonardo language is flexible in its representation of knowledge and its ability to allow procedural code, there are areas where the developer is limited. Three areas of particular importance to the pump selection system are detailed below.

6.5.1 Data Access

While Leonardo's interfaces allow access to files in Dbase III+ format, this is only in the form of sequential access not supporting the use of index files. The user can move to the first or last record in the file or move in sequence through the database, however, if the programmer wishes to find a record matching particular criteria, each record must be read in turn until the required is found.

With small files this is not significant making little difference to the initial prototype containing 4 sets of hydraulics. However, with the full set of 2 pole machines, the effect when selecting a size toward the end of the file was sufficient to require an alternative method.

Instead of using a database file to hold all the records for a complete range, each pump is stored in its own file. This evens the access time, so each takes the same. However, file organisation is poor as we have a file for each pump, instead of each group of pumps, making file management difficult.

6.5.2 Mathematical Abilities

Most Expert Systems give facilities to do calculations as part of the processing, however, the workings of the inference engine means that such systems are more suited to symbolic manipulation than complex mathematics. In this light it is perhaps unfair to criticise Leonardo's mathematical ability. In the total pump selection process the hydraulic analysis may be a small part, but the system must have the ability to perform these calculations at a speed acceptable to the user.

Leonardo restricts this in two areas. The precision to which numbers are stored is 7 significant figures. The polynomials representing the curves have coefficients with up to 9 figures. While the effect of the lost significant is far less than the final accuracy required, the repeated rounding errors during calculation can accumulate to produce a difference. Even with the extra facilities of the mathematical toolkit, the calculation speed is unacceptable for the system under development.

6.6 Conclusions on Leonardo

While all of these can be overcome, however this leads to a compromise in the design which is unnecessary if a different development system is used. Whilst poor mathematical features may be considered a general feature of expert system shells, the other two are not. Ultimately, the database access prompted the change to an alternative environment.

SECTION 7

EGERIA - RULE BASED USE

7.1 OVERVIEW OF EGERIA

Egeria, like Leonardo, provides an environment for the development, debugging and execution of an Expert System. It has a much simpler framework than Leonardo, concentrating on the individual parts, more than the integration. It is based around the Egeria language, a relational object oriented knowledge representation language. It allows the development of interactive and real time applications for use as stand alone systems, front ends, or embedded systems.

Egeria was written by Expertech in the mid to late 1980's, in order to supplement the successful rule based shell Xi+. It was developed from the earlier Savoir shell to give users the choice between the pure rule based approach offered by Xi+, and the more sophisticated package offering knowledge representation in a variety of forms. The use of Egeria rather than Xi+ was suggested by Expertech, who felt our application would benefit from the more sophisticated facilities.

7.2 COMPARISON WITH LEONARDO

Leonardo and Egeria are intended to perform the same purpose, i.e. allow development of an expert system, but in many areas they take very different approaches.

Both packages offer support for external databases, but the addition of index files to Egeria can dramatically speed up the process of finding a specific record.

The support for mathematical manipulation shows significant differences. Leonardo's seven digit precision and its limited, basic functions (even with the optional mathematics package) suggests a system aimed at symbolic use. By contrast Egeria offers full fifteen bit precision, and a comprehensive maths function set. The additional feature of holding and manipulating all numerical values as a high and low range, gives the impression of a system far more able to handle complex mathematical analysis of data.

Support for Object Oriented concepts differs between the shells. Leonardo's frames and single level inheritance give only the very basic facilities. In comparison Egeria allows multiple level inheritance, and allows objects to be defined within other objects. Additionally, relationships allow objects to be grouped and manipulated collectively, or to be related to each other in ways analogous to the real world.

Both shells allow their capabilities to be extended through external functions. Leonardo allows any executable (.EXE only) file to be run, with data being passed through an ASCII file. Egeria calls routines in 'C' or PASCAL (Microsoft versions) and can pass data on the stack, or through a User I/O device manager giving external programmes access to the Egeria internals.

The truth maintenance mechanisms used by the two shells are very different and have a significant impact on the ease with which either package can be learnt. In Leonardo, the rules are represented in familiar IF ... THEN ... type structures. Truth maintenance ensures that when a variable changes, rules based on this are triggered and applied. This is relatively easy to learn coming from a high level language, the inference engine will fire rules according to how variables change. Egeria 'reverses' the structure, defining a variable in terms of the rules which influence its value. When a variable changes, all variables are re-evaluated from their definition giving a "net" of inter-related variables. This coupled with daemons firing on particular combinations of states, make the likely execution paths more difficult to follow. This deviation from typical high level languages means the developer has to think in a different way, and extends the learning time.

7.3 DEVELOPMENT OF SELECTION SYSTEM

The first phase of the Egeria development follows the approach taken with Leonardo, using rules and procedures to model the hydraulic selection algorithm, and classes to model the types of pumps available. The multi-level inheritance allows this to be extended and linked to form a complete system. Initial work in Egeria was very slow with the major differences in knowledge representation and application, however, once this was mastered the environment allowed rapid prototyping of extensions.

7.3.1 Type And Range Of Pump

The initial choice of type of pump to use is based on the Leonardo system, using capacity, head and the derived specific speed to determine types which may be appropriate. In addition, the fluid viscosity and specific gravity are compared to an operating range for each type. The suction pressure at the pump is used in preference to the self-priming question, as it allows both an upper and lower boundary to be set, the self-priming requirement equating to a negative suction pressure. The final parameter is the casing material required. This only becomes significant if a special material is required. The system defaults to selecting close coupled in preference to frame mounted, however this may be reversed by the user as one of a number of default parameters.

On selecting the type of pump, the system specialises within the suitable types to find the appropriate product range. These are evaluated in the same way as the pump types, with the same parameters having more restrictive ranges. Initially only the End Suction leg was extended to the D-Line product line. Later developments added the Magline to End Suction and the French 'F' range to the Multistage branch.

7.3.2 Hydraulic Selection

The Egeria hydraulic selection implements the same rules as Leonardo, with the addition of an index to the dBase III access.

Egeria's enhanced mathematical abilities allow the programme to execute faster, a viscous selection typically taking 40 seconds against 60 seconds in Leonardo. While implementing the Egeria viscosity correction routine it was noticed that a significant portion of the time is spent finding the BEP. As this is fixed it could be calculated once then stored with the performance curves to be read when that pump is evaluated. This further decreases the selection time for viscous duties by 25% to typically 30 seconds. Non-viscous selections are unaffected as they do not require any calculations using the value of BEP.

While the impeller diameter required to meet the duty is calculated to the full 15 figure precision, this accuracy is not sensible to the user. The Leonardo system rounded up this figure to give an integer diameter. For D-Line a set of predefined impeller cuts are specified. The size of step between cuts depends on the nominal diameter, ranging from 2mm for the smallest units to 5mm for the largest. Once the exact diameter is known, the figure is compared to the list of available diameter cuts with a margin of 0.25 mm applied to allow the rounding of the diameter to take account of manufacturing and testing tolerances.

The treatment of stock pumps in Egeria differs to Leonardo. Initially the trimmed selection is made and presented to the user. Following this the stock list is read to determine if a pump of the selected size is stocked, if so the stock diameters are checked until one is found which exceeds the selected diameter, this is then offered to the user as an alternative stock selection. If a stock offer in the selected size cannot be found the next size up is checked against the stock list, and this size offered.

7.3.3 D-Line Build Configurations

Within the D-Line product range there are 9 different styles of assembly. These cover the two main casing materials, cast iron or stainless steel, the choice of mounting, close coupled or frame mounted, the sealing arrangements, packed gland, standard seals or provision for special seals, and the option of a heavy duty driving frame. The selection of the appropriate build is dependent on many factors, the size of the pump, the motor power required, the fluid being pumped and the customer's preferences. For a particular size all 9 will not be available, e.g. close coupled builds can have a maximum of a 37kw motor.

The evaluation of the builds should ideally take place in parallel to the hydraulic selection, as the two can affect each other. As DOS does not permit this, the Inference Engine controls the tasks, switching between hydraulics and builds when information is required from the other. For a build to be suitable it must be of the appropriate material, have temperature and pressure limits sufficient to cover the duty, be available for the selected casing size and motor.

While this limits the list there are still usually several options. These are ranked according to cost, with the cheapest option being offered. The user may influence this by changing the preferred casing material, or indicating that frame mounted be considered in preference to the cheaper close coupled arrangement.

7.3.4 Net Positive Suction Head (NPSH)

The final aspect of a pump's performance is to consider the NPSH characteristics. This involves the comparison of two figures, the NPSH available, explained in Section 2.4, and the NPSH required. While the programme can always calculate the NPSHR, the engineer will often not know that available.

An appropriate value is derived from the suction pressure and vapour pressure While this differs with the fluid pumped the system currently uses a value for water corrected for temperature. If a NPSHA is input, this is checked against the approximation to ensure the consistency of the figures, forcing the user to alter the input until the figures match. However, if no figure is given then the approximation is used for NPSHA, as the best figure in the absence of other information.

For a pump to work the NPSHA must exceed the required. Usually a margin is required dependent on the situation. The programme compares the two figures directly, with no margin. If insufficient NPSH is available, the system ascertains if an inducer may be fitted to reduce the NPSH required figure, if so the same evaluation is performed with the new figure and the user advised if this gives an acceptable result. Should the pump still not meet the NPSH requirements, then an alternative pump must be tried. The shape of the NPSHR curve means that lower figures tend to be required toward the mid-flows of the range. To move the flow toward area, a pump with a larger suction diameter is assessed.

Should this continue to fail to find a suitable selection, after 3 attempts the system will abort the search, and advise the user that a solution cannot be found due to the NPSH requirement and suggest that half duty units be considered. Using multiple pumps at lower duties reduces the size of the units required, with the smaller pumps tending to require less NPSH.

7.3.5 Extensions To Scope Of The System

While the D-Line product range comprises of 37 different casing sizes, over 100 different hydraulic curves provide the range's coverage. In addition to some sizes having optional impeller designs to give continuously falling curves, the majority may be driven by 2 or 4 pole motors. The pump end of the unit is identical, with different couplings and motor frames allowing the fitting of alternative motors. Performance between the speeds is different, with a separate set of curves, and associated coverage chart at each speed. Typically the 1450 RPM units generate a lower head, though additional larger sizes give them a greater range of flow rates.

Though the 9 D-Line builds are available in both speeds, the speed affects the limitations, with 4 pole units having lower pressure limits. The hydraulic evaluation of the 4 pole pumps is identical to 2 pole, allowing the same routines to be used for calculation of either speed.

The coverage charts for 2 and 4 pole D-Line show considerable overlap, hence, a decision on speed must be made. For a given duty a 4 pole unit is typically larger and less efficient, however, they often have lower NPSH requirements than 2 pole units, and are the preferred choice for some industries.

If the customer states a preference for a particular speed, this is what they will be offered, however if the engineer has a free choice, the 2 pole option is the likely offer due to its better price and efficiency. In order to simulate this preference another item was added to the initial assumptions screen. Similar to the coupling choice in Section 7.3.3., if the system uses its standard assumptions then a 2 pole unit will be selected if possible, if not, 4 pole selections are considered, however, the user may change the assumption to state a preference for 4 pole units, these are then considered first, reverting to 2 pole if no suitable units are found.

The limitations given in the D-Line builds for pressure and temperature are the upper maximum. To allow use towards the limits may require an alteration to the standard build. The Egeria system advises the user when the standard limit has been exceeded, and informs the user of the options which must be used to achieve the requirements, this may involve checking bearing life, fitting standard or special mechanical seals, special materials or cooling systems. The system lists the suggested options for both temperature and pressure if applicable, however, it does not reconcile the two lists, or advise which of several choices to use, leaving this to the engineer's knowledge of the customer and the situation.

7.3.6 Accuracy Of Efficiency And Power Values

With the addition of the 4 pole performance curves, and a correction for motor running speed, Appendix C the focus returned to the accuracy of the power, and efficiency figures . For the diameters stored the values were within the accuracy required, however, where the duty lay between stored curves the values wandered from the expected, being worse the further the duty was from a stored curve. The calculation of diameter uses an index NH, to represent the variation from the affinity laws of the head-diameter relationship. However, the capacity-head and capacity-power relations are assumed to follow the square and cube affinity law. This has the effect of preserving the value of efficiency at the point on the nearest stored curve from which the values are calculated. Hence, the efficiency figure is not affected by the change in diameter. To model the actual changing value of efficiency with diameter the equation relating capacity or diameter to the power must vary from the cube.

Re-examining the Engineering Standard from which the NH index was taken reveals a second index, NE - the index of efficiency. This parameter had previously only been considered important during the design phase of a pump or impeller. Its effect was exactly that of varying power relationship from cubic, hence, it appeared to be our missing term to give accurate efficiency figures, giving it a significance during computational selection as well as design, Appendix C.

7.4 OTHER RANGES

To improve the range of duties catered for by the system, two further product ranges were added. The two products chosen gave the opportunity to explore the expansion of the system in different ways. The first range, Magline, is a derivative of the D-Line, allowing exploration of how it is possible to cover specialised products. Secondly, the 'F' pump range is a Multistage product. This adds a parallel range with different hydraulics, and adds more options at the higher levels of the selection hierarchy.

7.4.1 Magline

In response to requests from users, the first extension to the system was to cover the Magline product group. This is a development of the existing D-Line product to offer a unit with a contactless drive for use in hazardous environments. The pump part of the unit is identical to D-Line, though limited to the smaller units. The coupling between pump and motor is where the units differ, Magline having a Magnetic Coupling to drive the unit.

This has no effect on the generated head curves, hence the diameter selection is as D-Line, however, extra power losses are incurred which must be added to the powers, hence, the motor size efficiency and motor running speed are affected.

The selection of a Magline unit is a two stage process. Initially a hydraulic selection is made as for a D-Line pump, then this is altered for Magnetic Drive. The initial absorbed power, and corresponding torque define an initial choice of drive size. From this power losses due to Eddy currents are determined, these vary with the drive size and the capacity. If the fluid is viscous a second loss is determined dependent on the drive size and the viscosity. This represents the extra slip through the magnetic coupling when the viscosity increases.

Adding these to the initial powers gives the absorbed and maximum power through the selected drive. When a motor is selected, the power rating is compared to the maximum rating of the drive, if it exceeds the drive's rating a larger magnetic drive is required. This changes the losses, hence, the powers must be recalculated and the motor reselected.

7.4.2 Multistage Pumps - 'F' Range

The second range of pumps to be added were the 'F' pumps. These are multistage units, having between 2 and 7 impellers designed for water applications, particularly irrigation. They are manufactured by Pompe Jeumont Schneider in France.

The upper levels of the hierarchy now contain expansion within two of the types of pump. This allows intelligent filtering to be added at this level to decide between types of pump and to reflect company policy where multiple product ranges offer suitable selections. The effect of these for a range of conditions could now be explored and altered to develop an appropriate set of rules.

The hydraulic selection of single and multistage units differs in many ways, though the same basic components of selection are used. The versatility of the procedures could be assessed and where possible enhanced to allow a routine to be applied to both types of pumps when possible.

The treatment of the 'F' pumps was at a simplified level to give a 'Demonstrator' for a meeting of a Dresser Working Party on tools for marketing. While the selection was simplified it illustrates the addition of a further range and the extension to multistage selections. The selections made do not allow for the trimming of the impeller, and do not correctly consider the calculation of power and efficiency. In these areas the hydraulic analysis differs most from single stage pumps.

The decision on which range of pumps to offer is made at a higher level in the hierarchy. There is little overlap between the two ranges, with the 'F' pumps tendering to cover low flow rates, generating heads in excess available with D-Line. In situations where either may possibly contain a selection, a policy rule dictates that the D-Line range takes preference. If on investigating the D-Line no suitable selection is found, the system reverts to its second option and pursues the 'F' pump selection.

7.4.3 Ease Of Adding Ranges

While both ranges show how the system may be extended they do so in different ways. The Magline extension was as a separate programme to the D-Line, hence, no additions were made at the upper levels . While this may seem to be avoiding the intelligent part of the system, the reason for tackling Magline was the addition of extra code, to extend the existing parts to a specialised situation. An engineer would know before starting the programme that a unit with magnetic drive is required.

The addition of Magline was in two stages, the first being in response to a specific customer enquiry for a large number of Magline units. As the details of the enquiry were known a number of simplifications were made, primarily that none of the pumps were to be used on a viscous liquid, so the viscous losses were not implemented. This speeded the addition to the point where the three days to add the code, test it, then make the selections was less than the engineer required to make the same selections manually. The Magline section was later returned to and extra sections added to allow the system to be used for general magnetic drive situations.

In contrast the 'F' range was specifically chosen to show how the system would cope with two product ranges, for different types of pump having differing hydraulics. It was prompted by the formation of a Working Party within Dresser to view systems for Marketing and recommend which system the entire organisation should pursue. As the group contained representations from many of the Dresser sites, it was felt the versatility of our approach should be shown by the addition of a different type of pump, manufactured at a different site. The availability of a system which could cater for both types of pump, intelligently choose between them, then back track if the choice seemed inappropriate impressed the Working Party and the Newark developments were chosen as the lead site for selection aids for pre-engineered pumps.

7.5 PROBLEMS AND SOLUTIONS

The improved accuracy of efficiency and power figures, and the expanded treatment of ranges means the system is approaching the point where it would be useful for an engineers everyday use. However, many of the potential users expressed concern over the speed of response, particularly in situations where the customer is on the phone and wants a simple answer i.e., the pump, and its price and availability. Though the Egeria programme is faster than the previous Leonardo version, the new added features slow it to an unacceptable speed. As noted with Leonardo mathematical processing is usually a poor feature of expert system shells, as they are designed primarily for symbolic, not numeric, manipulation. An option to improve the overall speed would be to use an external language for the numerical procedures which could be activated by the Egeria rules.

A problem of more significance in development was the increasingly untidy nature of the code. As the ordering of rules and classes is of little consequence to the inference engine, the tendency during rapid prototyping had been to add a rule anywhere. This unstructured approach is common during the early stages of expert systems development when many strategies are tried and tested. However, with the expansion of the system we were nearing the point where it would be advantageous to re-examine the rules and tasks to allow an overall design to be formulated. This would ease the difficulties in following a rule sequence, impart order to allow further expansion and perhaps result in a more efficient system.

With the expansion we appeared to be getting situations where a rule sequence was triggered, or a task activated at an inappropriate time. This was partly due to poor definition of the situation under which a rule should be evaluated. When one rule triggers unexpectedly this in turn causes the evaluation of others and can result in interactions between rules which were never intended.

One of the major causes of this was the representation of the procedural parts of selection in rules or tasks. In many cases this was inappropriate. The user of an external procedural language would reduce this significantly with a single rule being used to activate a block of calculations.

The task firing mechanism also contributed to this situation. When a tasks triggering conditions become true the task does not execute immediately but is added to the task stack. While the truth maintenance ensures all variables are in a consistent state, the task stack is not included, there being no way to remove a task from the stack should conditions change. During the search to find a hydraulic size many variables change and cause this to happen, with tasks coming off the stack and changing the variables in an undesired way. More complicated was the situation where a variables state triggers a task which is added to the stack, the situation changes and the trigger expression is reset, then a further change triggers the task again. Although the task has not been executed from the first time, this causes a second copy to be put on the stack, hence the task will at some time later be executed twice. Again these problems arise mainly due to the large amount of procedural mathematical manipulation being carried out in what is an inappropriate system. An overall design which splits the current system into a controlling rulebase with external language routines would overcome the majority of the difficulties.

The need for a redesign was obvious though advice on methods to use was scarce. Many of the documented larger system were using the object oriented approach. Egeria supported the facilities to do this, and the problem domain appeared to fit this approach, hence this was selected as the approach. Adding the use of an external language to this appeared to address the main problems with the current Egeria system.

SECTION 8

EGERIA - OBJECT BASED

8.1 EGERIA FACILITIES FOR OBJECT ORIENTED DEVELOPMENT

Egeria has a number of features which support programming under the object oriented paradigm. They are more extensive than Leonardo's frame system allowing the developer to model a problem as a system of objects manipulated by rules. An Egeria Class represents the properties of an entity by allowing any Egeria item to be declared within a class, i.e. data, rules and tasks may all be specific to a class. This extends to supporting nested classes, useful when modelling entities which exist as part of an assembly. The nesting is limited to forty levels, the first of which is taken up by the system class Common. The creation of a parent class automatically triggers the creation of new instances of any nested classes. This feature presents part of Egeria's support for encapsulation. Items may refer to other items within the same class, or to items in classes enclosing them. However, direct access may not be made to items within the classes they enclose. Further support for encapsulation is given by the PRIVATE directive. This limits access to the defining class, no access may be made from items outside the current class.

8.2 A STRUCTURE FOR OBJECT-ORIENTED PUMP SELECTION

One of the major benefits of object-oriented software is the natural correspondence of the software objects to entities in the problem The objects required in the system are based on the physical and abstract items the engineer would use when thinking about the problem. The most significant area is in the modelling of the hydraulic performance and selection through a specialised search,see section 5.2. This is appropriate for the first design of an object-oriented approach. Each level contains knowledge on the suitability of it's objects, allowing progression towards suitable product ranges from which a selection may be made.

In addition to the hydraulics, other areas of the selection may be represented as objects. Within D-Line there are a number of possible builds. Rather than represent them as sub-ranges each with its own limited set of hydraulics they are modelled separately as a build, with each having its own data and rules on suitability. As all builds are not available for all hydraulic sizes, a further abstract object is necessary to represent the combination.This gives the point onto which other objects, such as motors, may be added later.

One reason for adopting an object based approach was that it would easily allow multiple pumps to be considered during selection. A suitable method is based on the existing search method for the smallest suitable pump. In addition to the four pumps to consider if it is found unsuitable, each pump will hold a list of the sizes surrounding the current selection. When the original algorithm finds a suitable selection, each pump in the surrounding list is evaluated, giving the user a selection of possible pumps.

8.3 OBJECT ORIENTED DEVELOPMENT - TRIALS AND PROBLEMS

Rather than move the complete system to a new design approach, it was decided to tackle small sections. These were those which would most immediately benefit from the use of objects and had caused difficulties in the current system. The first area was the representation of a full D-Line selection, i.e., an allowed combination of hydraulic size and build design. This situation is modelled by three objects, size, build and combination. Initially these objects did not hold the complete selection rules, instead a shell with a simple rule is assessed. Each allowed combination is represented by a combination object associated by relationships to the appropriate size and build. The combinations' rules combine the suitability of the parts to decide which permitted pairings are applicable to the situation.

The initial programme to do this uses statically created objects defined within the source code to represent the D-Line range. To create the complete set of objects prior to the validity rules being invoked takes 15 seconds. A completed system would hence have an appreciable delay on start-up before interaction with user begins. Hard coding the pump objects within the rule base restricts the ease with which changes can be made. To alleviate this restriction and examine an alternative approach, the same code was implemented with dynamically created objects. On start-up a task reads the size, build and combination data from three databases, creating appropriate objects as necessary. The file read and dynamic object creation is a lengthy process extending the time to the execution of validity rules to 28 seconds, almost double the equivalent static object example.

To increase the size and scope of the system, a fourth object to model the impeller was added. Again this was an empty shell with a single rule to give an indication of suitability. This adds an extra part to each size. Its addition showed the limitation of Egeria's object store, with the system running out of memory while creating an impeller for each combination.

Addition of a counter to the object creation task shows this occurs at 130 object present in the system.

To reduce the number of objects current in the system a 'Garbage Collection' task was added. Its purpose is to keep track of objects no longer needed in the system, and remove them to free memory. In Egeria a secondary relationship allows such a routine to be implemented. When a size or build object has been evaluated and found unsuitable, it and the associated combinations are no longer necessary.

While this technique can reduce the number of objects, this is only so when the analysis is taking place. In the initial stage where objects are being created, no suitability tests are being carried out hence no objects require deleting. To prevent memory overflow requires a change to the way in which the objects are set-up.

Instead of creating the complete set of objects in one go, why not construct it in stages? The system may create and evaluate the units, using garbage collection to reduce the number of objects as analysis proceeds. Once suitable pumps are found, impeller objects are created for each and evaluated. While this now executes without filling the memory it achieves little as the shell objects contain no realistic code to evaluate suitability. Adding the code to the classes would dramatically increase the size of each created object and the programme would again be too big to execute. A more radically different approach is required if an object oriented approach is to be used.

8.4 OBJECT ORIENTED DEVELOPMENT - OPTIONS

It had been hoped that a move to an object oriented system would give the overall structure needed to allow the programme to develop further. However, the initial stages of showed that while Egeria has the facilities to support such an approach, the operating environment does not allow this on the scale we require.

As the system cannot support object orientation on the required scale the obvious route is to use an alternative design methodology, however, to do this would miss the point. It is not the method which is inappropriate, the limitation on its use is a feature of the operating environment. As the use of objects brings significant benefits, it would be sensible to select the areas that gain the most from this usage and implement these with objects and use less memory hungry approaches elsewhere.

As the limitation is the operating environment perhaps this could be change. Egeria's developers suggest that by moving to an OS/2 based system our design could be implemented. The OS/2 version is not subject to the same 640K memory limit as DOS and can use the hard disk to provide virtual memory. While OS/2 runs on PC type hardware its requirements for processor, memory and hard disk exceed those for MSDOS. One of the requirements of the system is that it be capable of running on standard PC hardware hence a DOS based solution is required.

If the memory available to the system cannot be expanded then more effective use must be made of it. Egeria allows knowledge bases to be started from within each other. However, the two are entirely separate with no facility to pass variables between them. While this would allow the system to be divided into smaller units, the only way data could be transferred between them would be through a datafile. This would be sufficient for data, but the status of variables and tasks could not be transferred, hence this is not a practical solution.

Egeria allows routines written in C or Pascal to be called within a knowledge base. Variables may be passed to and from external routines, though the internal data structures cannot be accessed. This would allow a series of small routines to be called to carry out specialised calculations. This may allow the size of a programme to be increased.

Returning to the more obvious, if Egeria under DOS could not support our application, then should we consider using something else? While this was an option we were happy with the facilities provided in Egeria, and would prefer to use this if possible.

8.5 EXPERTECH RECEIVERSHIP

While considering the above options for further development, Expertech announced they were going into receivership. Expertech were purchased by an American company, Inference, who were well established in the upper end of the expert system market with the ART system for workstations. Their interest in Expertech was the rulebased shell Xi, rather than Egeria. Inference had recently announced ART-IM, a version of ART for PC based development, bringing it into direct competition with Egeria. Their plans were to sell on the Egeria system, though the possibility of doing this was thought to be small by many within the Expert System community, and the discontinuation of Egeria more likely.

At the time of the announcement, we were negotiating the purchase of the Egeria shell, hence we were not yet financially tied to Egeria. Our options were to disregard the doubt over Egeria and continue with its purchase, or change to a different shell. To continue with Egeria would allow us to continue development, though we would risk being left with a product that was no longer supported, and not being further developed. Changing shell would set back development while a new system was found and learnt.

While a projected 3-6 month delay was a major blow to development, the risk of being left with no technical support was too great. An alternative shell would have to be found.

SECTION 9

ALTERNATIVE SHELLS

With the receivership of Expertech and subsequent replacement of Egeria by ART-IM. An opportunity arose to consider the various shells available. Over the 16 months of the project a number of new shells had been introduced. This section examines our requirements of a shell, and the facilities of the four considered, ART-IM, NEXPERT OBJECT, KAPPA PC and LEVEL 5 OBJECT.

9.1 Ideal Shell And the Four Viewed

Arrangements were made for demonstrations to be made of the capabilities of all four. To allow an objective comparison to be made between them, a specification was drawn-up. This covered seven major areas:-

i) Access to external databases.
ii) The ability the load rule sets at runtime.
iii) Object oriented features.
iv) inferencing control.
v) Use of external language routines.
vi) Runtime hardware and software requirements.
vii) The development environment.

More detail on each section is given in the document "Selection of an Expert System Shell", in Appendix E. This document then relates the features of each shell to the seven requirement to allow a decision to be made. Though there was little to choose between the four, two shells ART-IM and NEXPERT were eliminated. To allow the remaining two to be compared in greater detail, evaluation copies were requested.

9.2 Evaluation Of KAPPA PC And LEVEL 5

While the demonstrations of both packages showed the features they contained, it is only through hands on use in building a small prototype that a shells ease of use and suitability may be properly assessed. A small example application was devised to represent the upper level of the selection system. This was to make a decision between two pump types, based on their specific speed range. To do this, flow rate, generated head and motor speed were to be entered by the user, then a calculation performed to determine the specific speed. This tests many of the features we require using objects, inheritance, calculation and user input and output. Ideally the calculation was to be done in C and called through the external language interface, though a need for additional software prevented this.

The graphical environment of KAPPA took a while to become familiar with, but proved very effective. The KAPPA Application Language (KAL), may be used in an interpreted mode as well as programmes. This allows the developer to create objects, send messages to them from KAL to trigger methods then view the behaviour. This extends rapid prototyping to allow an application to be incrementally built. The object oriented bias of KAPPA seemed appropriate both for the prototype and the full application. Unfortunately both the provided example programmes and our prototype were slow in operation, suggesting the required speed for the full application would not be attained under this package. Kappa was rejected as too slow to be suitable.

Level 5, being rule and object based, proved slightly easy to become familiar with, being closer to Leonardo and Egeria. The prototype was quicker than KAPPA, but exhibited strange behaviour. In runtime mode the example only assessed one of the two objects. However, using the debugging tools to try to find why caused both objects to be assessed. Talking to the company revealed this to be a problem of which they were aware. Although it could be worked around, this sort of manipulation was central to the application. This unexpected and changing behaviour being so easily forced to occur led to doubt over Level 5's ability to work consistently and as expected. It was rejected, leaving no suitable shells.

SECTION 10

RE-EVALUATION OF REQUIREMENTS

With the failure of the expert system shells to meet our requirements, A re-evaluation of the pump selection system's aim and the facilities necessary was required.

10.1 Where Must The System Be Intelligent

The preparation of a tender in reply to a customer enquiry may be considered in 5 stages. Figure 10.1 shows the levels and where intelligence may be used to guide the system toward a completed quotation, in this section the pricing of the pump is not considered.

The first Section, User Interface, is where a large part of any intelligence is required. It is here that the system must try to extract all relevant information from the user, making deductions and assumptions to reduce the amount requested. By using backward chaining the system could request only the necessary data, however the system's users disliked this form of questioning, preferring a traditional input form for the main data, with more detail being requested when necessary. A sequence of questions is defined so intelligence is used only to dictate how defaults are arrived at. This could equally be implemented in a convention sequential language. A second area of intelligence within the user interface is the modelling of an engineers knowledge of customers and processes and how to apply this to particular situations. This area has not been tackled in the current programme, but would involve large amounts of knowledge. To completely select a unit in the way an experienced engineer would requires that the programme 'knows' the customer and the situation the pump is to be used in.

The system must recognise a customer, process or project and recognise that a particular standard is relevant, and perhaps that certain types of pump are either not suitable or are to be preferred. Extending this, it should realise that certain preferences apply to more than individual customers, perhaps covering an industry or a particular market. For new customers the system should recognise which of these generic groups are fitted and use guiding preferences. Most difficult of all perhaps the system must reconcile the differing preferences for the customer, industry, project, process and fluid to arrive at a single overall guide to the best pump ranges to select from.

While this is an ideal at which the system is aimed, this represents an unbounded domain using significant amounts of 'common sense' knowledge, neither of which lend themselves to a PC based expert system shell. It represents a large task in A.I. which influences the operation of the main part of the pump selection but is not essential to it, an experienced engineer using the system could provide the guiding hand. Such an intelligent assistant could be built onto a pump selection system at a later stage to increase its usability. This area has been deferred, with a consequent shift in the intelligence expected to be exhibited by the programme.

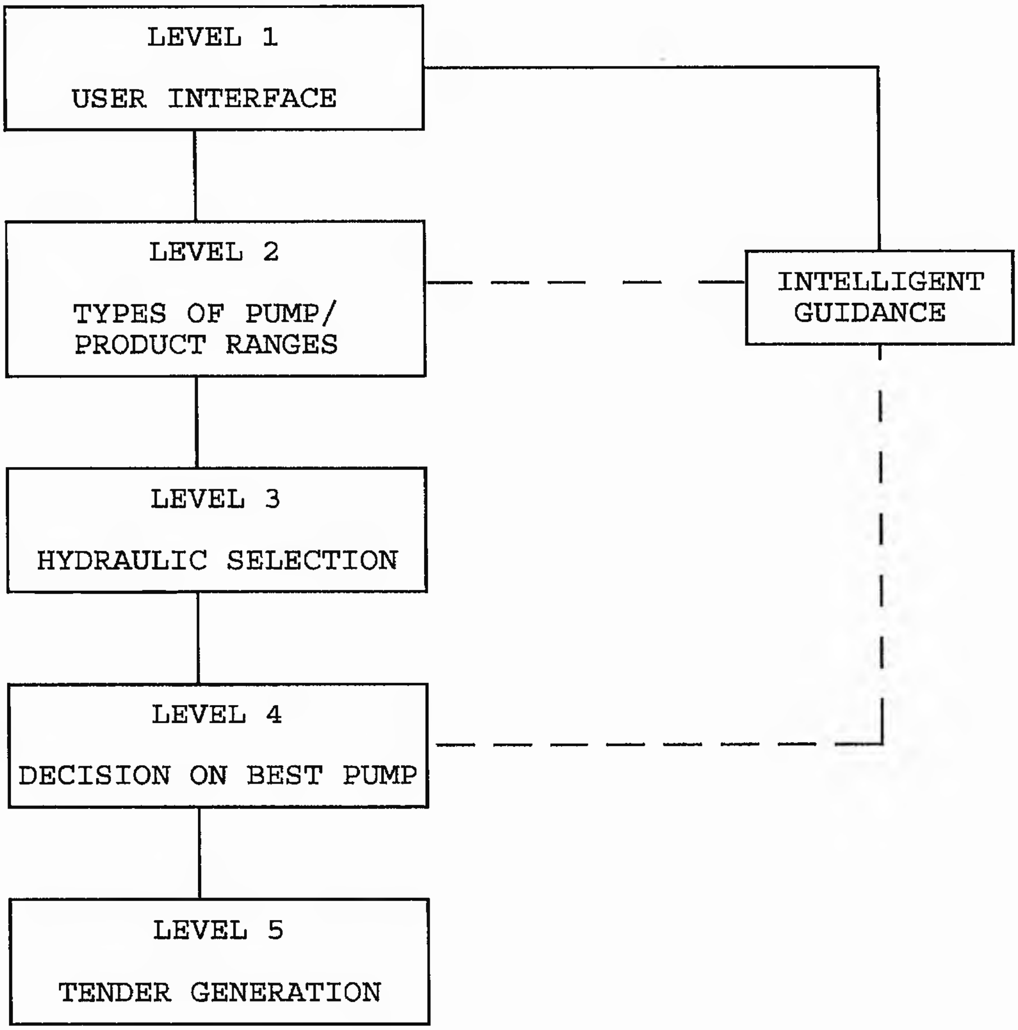


FIGURE 10.1 LEVELS IN PUMP SELECTION

The influence of the customer and process extends to the second layer of deciding the types of pump, and the product ranges to consider in depth. A basic decision can be made based on whether the duty point lies within a product range's coverage and other parameters, lie within the overall operating range of the product line. Typically this yields several product ranges which may contain a suitable selection. While a system could examine each product range in turn, the use of intelligence to order the ranges according to a preference would reduce the search space. While intelligent guidance at this level is not essential, there is a trade off between the time taken to reach a solution and the intelligence the system has. The level at which this is balanced is dictated by how long the user is prepared to wait both for an answer from a programme and for the arrival of such a programme.

The third, middle layer, represents the hydraulic analysis. Here a predetermined sequence of calculations are performed on the pumps indicated by the layer above. No experience based decisions are taken, with all pumps being suitable or not by virtue of their hydraulic performance and the individual engineering limits. This area is not suited to implementation in a rule base, its primary purpose being numerical analysis. The use of a conventional, high level language would lead to faster, smaller code in this area.

When several pumps are evaluated, a decision between them must be made. How the choice should be made will depend on individual circumstances, and may be greatly influenced by the upper user interface level. Again, for a system to work independent of an engineers influence would require a large degree of intelligence to allow the various options to be assessed in the light of the individual situation. If an engineer makes the final decision, it is sufficient to present the necessary information.

After a unit has been selected, the final task is to output the information in a form which may be given to the customer. The majority of this level is simply pulling together data and printing a datasheet for the customer, basically a word processing task. While the production of a company standard datasheet requires no intelligent guidance the quotation required by a farmer for an irrigation pump differs greatly from that required for a chemical plant or oil refinery. Hence, the level of intelligence depends on the variety of output we wish to give. If all tenders are treated the same, then none is required. However, the system must assess the customers information needs, if each is to be given an individual custom quotation.

10.2 MUST THE SYSTEM BE INTELLIGENT FROM THE START

While the original proposal centred around the use of an expert system shell, it is now considered that the core functions in the hydraulic selection are best performed by conventional high-level languages. While other selection systems have been developed without any AI influence, their failing has been the speed of execution. A system for use by an experienced engineer does not need to embody large amounts of knowledge, but to respond quickly to guidance to arrive at technically detailed alternatives. A system would be of immediate use to the company's sales engineers. While large knowledge bases are not necessary, the use of search algorithms developed from the previous shell based systems reduce the number of pumps evaluated and the overall time. To an acceptable level the system may not require the shells facilities to develop large rule bases, however, the approach taken to finding a solution is still knowledge based, modelling the engineers methods of limiting the search space.

10.3 WHAT DO WE GAIN FROM A SHELL

In the shells that were used, and the four viewed in seeking an alternative, there are two common features, the user friendly, interactive, environment and the variety of structures which may be used to model an experts knowledge.

The development environment benefits of a shell are basically in allowing easy and versatile access to the multitude of ways in which knowledge can be represented. Typically, the shell will allow three basic forms of knowledge, rules, tasks and objects. The provision of rules and the associated inference engine was the first area of expert systems. The addition of tasks, or daemons, allows conditions to activate the execution of procedural code, and forms the second stage of shell development. A third stage, the addition of objects has transformed the ease with which a problem may be modelled. While the newest addition to the features of shells, it is perhaps the most important in our application.

10.4 DOES PUMP SELECTION REQUIRE A SHELL

With the inability of any of the shells to satisfy our requirements, and the suggestion that other development environments be considered, it is appropriate to consider the features of a shell in the light of our problem.

In Sections 10.1 and 10.2, the need for a numerical core based on traditional high level languages was established. This section of the system is inappropriate for implementation in an expert system as the experience and resulting execution time with Leonardo and Egeria has shown.

The re-design of the Egeria system was based on the use of objects to provide the framework within which the system could be developed. While all the shells later considered support the use of the object oriented approach they are not the only development environments to do so. Implementations of purely object based systems, e.g., Small talk and Eiffel, are available on PC's, however, like the shells these are not particularly fast when applied to complex numerical situations. With the rise in the popularity of the object oriented approach, implementations of high-level languages with extensions to support this are now available. They include C++ and objective C as extensions to C, the Turbo Pascal extension to Pascal, and Modula 3 based on Modula 2.

The use of inferencing with the Egeria system is relatively small. While much of the programme is implemented in rules, the connections between them are well defined. With the users preference for a preset sequence of input screens, backward chaining is not used to ask questions. After data has been entered, forward chaining derives defaults from the entered data, and checks the information for consistency, advising the user if this fails. The biggest use of inferencing is in the task switching during the joint evaluation of an hydraulic size, and a build to give a completed pump description. Even here another approach could be used if inferencing were not available.

In Section 10.3, much was said of the benefits of the extensive user interfacing in shells and the consequent ease with which rapid prototyping may be achieved. While this is useful in the early stages allowing different approaches to be tried, the benefit decreases as the system develops and expands. The Egeria system required re-implementing due to its unstructured code. When the system reaches the stage where an overall strategy is apparent and a framework can be designed for the code, there should be little needed for rapid prototyping. Hence in large systems while a shell may be invaluable in the early stages of capturing and structuring the knowledge, benefits are less when this has been accomplished, and an overall design and implementation are begun.

SECTION 11

C++

If the initial phase of the system is to be developed in something other than an expert system shell, then the requirements are still similar. Any language used should support object oriented programming and have an easy to use development environment with good debugging facilities. The language chosen was C++, in particular the Borland C++ implementation.

11.1 Why C++

C++ is a relatively new language, developed by Bjarne Stroustoup as a superset extension to C. C itself is a widely used language, particularly in engineering situations and on workstations where it forms the heart of the UNIX operating system. The extensions in C++ provide easier memory allocation, stronger type checking and most importantly, facilities for the support of classes and object oriented programming. With the rise in popularity of this approach in the 90's, and the ease with which it allows 'Windows' programmes to be written, C++ is rapidly growing in use, heading to overtake C as the language of choice.

11.2 Design Approach

As C++ supports class hierarchies, the approach to the design is similar to that conceived for Egeria in Section 8.2. Egeria's relationships have no direct equivalent in C++, though a similar effect could be achieved through the use of pointers. The support for multiple inheritance is less restricted in C++, allowing inheritance from any parents, even if they have a base class in common. While this is permitted, some object oriented experts feel this is an unwise technique and great care must be taken.

Following the Egeria approach, the completed pump selection is built-up from a number of segments. The hydraulic size, build and motor are all represented by separate objects. These are then pulled together by a further object representing the completed selection. It is this which forms the basic level at which differing types of pumps may be manipulated and compared. In addition, it provides the body around which the model may be expanded. If at a later stage the depth of analysis requires expansion by the evaluation of bearings and seals, then objects representing these may be added to the main link. By separating the pump into major assemblies in this way, each may be developed separately, with later additions to the implementation having little effect on the overall system. This loose coupling of sections is another feature of object oriented software, and one which the pump selection system should exploit.

In addition to the individual objects for the main assemblies, many others will be defined to allow these to be built up through inheritance trees. Though the detail of different products differs, many features and methods are common. By using inheritance these common sections are brought together into abstract objects from which the objects representing real world entities are derived.

By doing this in this way, duplication within the system is minimised, leading to smaller programmes which are easier to understand and maintain. The complexity of the hydraulic model means many levels of inheritance are required, Fig. 11.1 shows the initial design for D-Line units, with scope for other ranges. This contains four levels of inheritance, including one involving multiple inheritance. The design allows the tree to be extended to other types of pump, to multi-stage units and to pumps where the impeller diameter may not be varied. While the hydraulics is the largest of the sections, it is not the only one which may benefit from inheritance. Different types of motors may have different features, but all could be derived from a base class, additionally other types of drive, e.g. diesel engines could be derived from the same base. The main link object will require inheritance to allow it to represent different pump ranges while bring a consistent class interface to them. Polymorphism through the use of C++ virtual functions allows this to be achieved.

To take this independence of parts further, the system will be formed of three major parts. The pump model described above, the user interface and an overall programme manager to provide the selection algorithm and control the data exchanged between the other two modules. By making these independent, they may more easily be changed, e.g. swapping the user interface, or changing the programme manager to use a different search technique, or integrating the use of more intelligence.

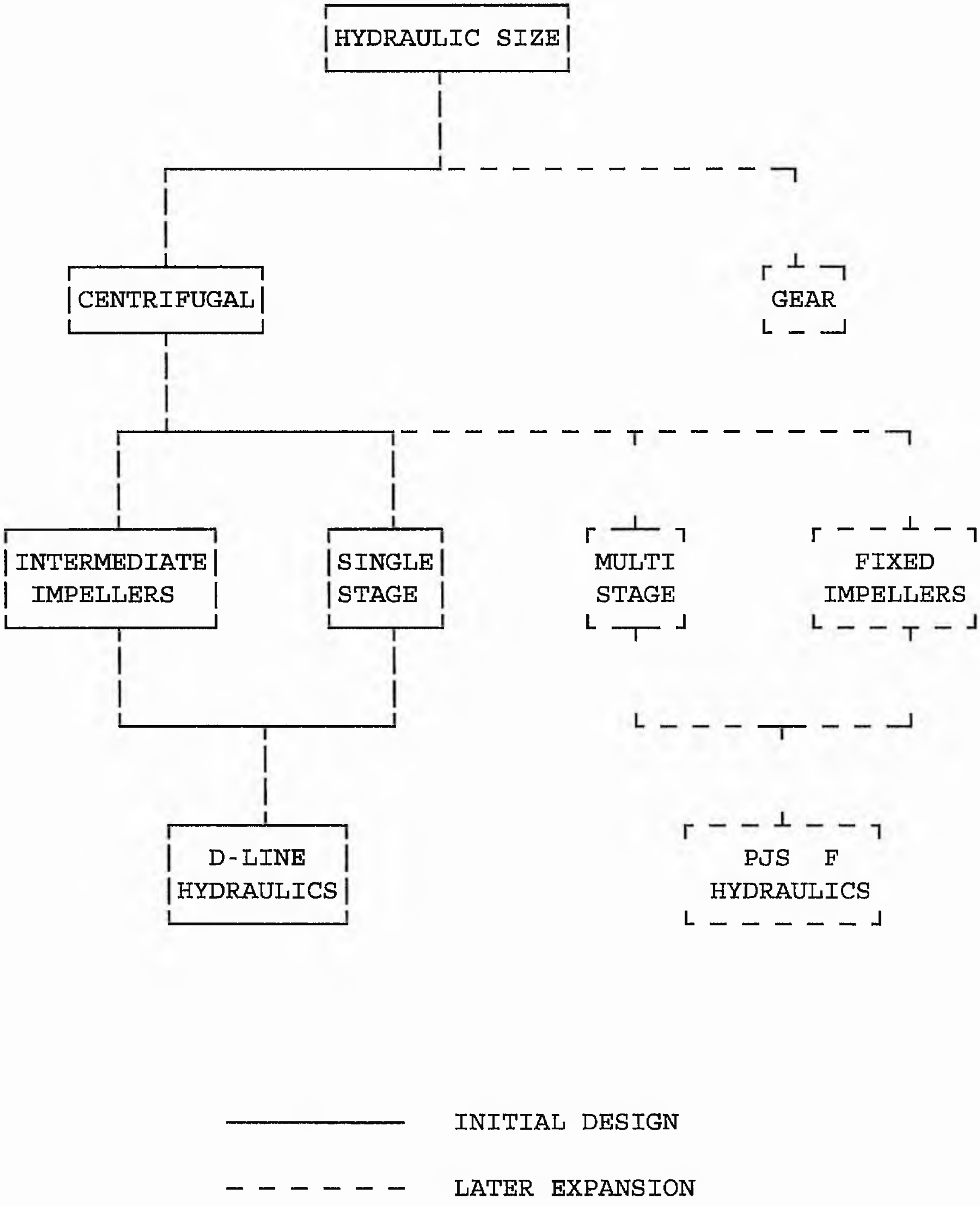


FIGURE 11.1 **ABSTRACT OBJECTS FOR PUMP SELECTION**

11.3 Pump Selection In C++

As with the conceptual design in Section 11.2, the initial development follows the approach begun in the change to objects in Egeria. While both shell based systems considered only single selections, the plan was to extend this to allow multiple pumps to be considered. The experience with generating large numbers of objects in Egeria suggested that this took up large amounts of memory and could introduce a significant start-up time.

As each selection is an instance of the same class with different hydraulic data, it is necessary only to define and test code for a single pump size initially. The functions used to perform the hydraulic analysis are derived directly from those developed in Egeria. Selection is made using the indices detailed in Appendix C and takes into consideration the effect of the fluid viscosity and SG. Motor size is selected according to the company standard, based on a margin over maximum power. The builds are assessed differently, with all the compatible builds being evaluated. The cheapest suitable option is used as the default, with a list of the others maintained to allow this to be altered.

It had been anticipated that re-coding the hydraulic selection in a more appropriate language would increase its speed, however the change was more dramatic than expected. A single selection in Egeria took from 40 seconds for a water duty to 60 seconds for viscous fluids.

The comparable selections in C++ gave an answer in under 1 second for water, with no measurable increase for viscously corrected selections. This was a huge difference, particularly as there may be room to optimise sections of the code to decrease this time further.

A change of execution speed of this order alters what may be considered an appropriate way to tackle the problem. Previously the aim had been to reduce the number of units being assessed to keep the total execution time to an acceptable level. However, the C++ implementation could completely evaluate all 100 pumps in the D-Line range in less than 2 minutes. As 90% of these could be dismissed early in the analysis, a target of 30 seconds to consider every D-Line pump is not unreasonable. A change of approach was thus made, rejecting the need for a fast, intelligent search in favour of 'Brute Force' as outlined in Section 5.1. While this seeks to consider every option, wherever knowledge could be used to speed the evaluation, this was done. Although the time for a single range may be below 1 minute, the system ultimately will consider many ranges by reducing the time taken, wherever possible a more detailed analysis may be performed giving the user more information on which to base a decision, still within what is considered an acceptable execution time.

Extending the system to create multiple objects allows several possible selections to be displayed to the user. As efficiency is usually the most important factor, the pumps are listed by decreasing efficiency. Currently the system gives no indication of price. When this is added the user will be able to switch the ordering between efficiency and price. The main screen displays the basic information about the pump for the most straight forward selections; pump size, impeller diameter and type, absorbed, maximum and motor power and the available NPSH. From here the user may seek more detailed information, example screen shots are shown in the PSI user manual in Appendix F.

A second performance screen shows more whether the impeller is the maximum or minimum, the head rise to a maximum diameter and the duty's proximity to the best efficiency and end of curve points. Similar information can be reviewed graphically on screen. The head and power performance curves are shown for maximum, minimum and selected diameter with the duty point marked. Curves showing the efficiency along the selected diameter and the NPSH required are also shown.

While the system will select both motor and build, other options are available for the users choice. A motor screen displays a range of motor sizes which may be fitted to a specific pump. The system displays the motor KW rating and size, with information on the margins the motor provides over duty and maximum power, and if relevant the flow rate at which the motor will overload. This permits the user to compare the margins to any required in the pump specification and to assess the safety of reducing the size of the motor. This allows the user to change the selection to a more competitive offer if the system conditions allow, while being confident that the systems default suggestion is a safe offer.

Similarly, the user has control over the build of the pump. the system defaults to an order of preference based on the cost. The build screen displays the builds available, the programme having assessed compatibility with the size, and whether the duty conditions are suitable for this option. Each available build is displayed with the configuration, i.e. close-coupled or frame mounted, the material, and the limits for temperature and suction and working pressure. These are the maximum values for a build and may require the use of optional features. When this is so the programme indicates this to the user.

Further screens allow the user to view a list of possible stock pump options, to see the pumps rejected by the system, which almost meet the requirements and to pull all the data on a single selection together onto one screen. It is this screen which will be the point at which the user makes a selection. The chosen pumps data may then be saved to file, to allow a quotation and performance curve to be produced. Although work has begun on these areas, they are not currently available.

Above this hydraulic evaluation level is a layer where the choice of product ranges is made. While the speed allows a large number of pumps to be assessed quickly, it is not appropriate to examine every range for each selection. An upper level performs a similar search to Egeria to determine which ranges may contain suitable pumps. The resulting list is presented to the user who may select number to be investigated further. If several ranges are chosen the suitable pumps are all contained in a single list ordered by efficiency. This allows the user to easily compare the options from a number of product ranges.

As at this time the system was approaching a level where it could be released to the sales engineers for use, it was decided to name the system. The company had previously issued guides to selection under the name Pump Selection for Industry and PSI is both an abbreviation for a pressure unit and a term used when referring to the source of intelligence. As we wished to emphasise the fact that the system was based on the human approach to selection, i.e. knowledge based, unlike existing system the name PSI - Pump Selection with Intelligence was chosen.

11.4 Evaluation Of C++ Based System, PSI

While the Egeria based system was evaluated by potential users, and was used for some enquiries, the C++ version is the first to have had significant exposure to the users. Throughout the development a number of meetings took place between the sales force, marketing engineers and PSI's development team to establish what should be targeted as major requirements and how selections should be presented to the user. Its trial use by the application engineers allows its performance to be considered in three areas: the usefulness to the engineer, the level of detail provided, and the use of C++.

The majority of feedback from engineers suggests that the increased speed of the programme is of great benefit. The user is able to consider more options than would be possible by hand, though it is restricted to one range, D-Line. For many enquiries the default information on the main screen is sufficient to allow the engineer to respond to a customer, with more detail being readily available when needed. Negative response seem to relate to the system's limits, i.e., it would be better if it could price the pump, produce printed quotations and performance curves and do this for several pump ranges.

By observing new engineers introduced to the system, the user's influence on the interface design is apparent. Engineers are presented with the information they expect, and quickly learn how more detail can be requested. The data entry endeavours to keep typing to a minimum, with options selected from menus whenever possible. The overall effect is to keep familiarisation time to 5-10 minutes for an engineer familiar with pumps. The benefits of the system are best illustrated by two jobs from the marketing area. The first concerned a customer's enquiry for 100 pumps for use on a variety of liquids in several sizes. PSI allowed fully detailed selections to be made within a working day. An engineer would typically have taken a week or more to perform the same selections, and would have considered fewer options probably in less detail. The second was an enquiry for 16 units on assorted duties. Here the engineer spent approximately the same time as would have been needed by hand. However, using PSI to consider all the options allowed the engineer to reduce the number of different pump sizes required for the duties. This reduces the number of standby units and spare parts required, and hence, the overall cost of the tender. While no time was save, PSI allowed a better offer to be put together than would have been achieved manually.

The level of detail used in the selection process by PSI exceeds that which would be generated manually. Because the user receives more detail on request the extras do not obscure the major information required for simpler selections. For a typical enquiry for a water pump, the sales engineer would not calculate the impeller diameter, its size not affecting the overall price, as the customer would tend to be on the telephone awaiting a price. Using PSI this information is always calculated. While not explicitly necessary it may remind the engineer of situations where maximum or minimum diameters should not be used. Having the diameter and the relevant performance curve allows the engineer to consider reducing the size of the motor, hence cutting the price to the customer. Often such telephone customers will require a stock pump. PSI quickly presents the user with all the stock options which may be used for the duty.

If a large price saving can be made by using a smaller stock unit which fails to make the duty, this can be discussed with the customer, with all the relevant data available. Often this will be acceptable, stock units often being used to transfer fluid between tanks. If the customer has estimated his duty conditions, or the requirement is for a daily top-up of a tank then a unit which does the job over a longer time at lower cost may be suitable.

The change to implementing the system in C++ has greatly affected its usefulness to the engineers. The shell based system, while being faster than manual selection, appeared very slow because of the time taken between questions. The tremendous boost in speed allows the engineers to use the system in many situations where it may not have been used before. Additionally, the speed and the lower memory usage gives scope to expand the system into other areas, in addition to adding more product groups. The flexibility of the language, and the wide range of toolkits available, expand the possible scope of the system beyond what could have been achieved in a shell. This wider scope may allow the system to eventually encompass the original ideas, with C libraries being used to enable rule based processing to be added within objects.

SECTION 12

FUTURE DEVELOPMENT

Future PSI development will be concentrated in two directions, to expand its produce coverage and to integrate it with other business systems.

12.1 Additional Ranges

This is the area which could have the greatest impact on the engineer's use of the system. At present the systems use is limited, both by the product ranges covered, and by the availability of machines to the user. With PSI covering the major product ranges, the users need and desire to use the programme will allow the company to justify the purchase of more PC's allowing each engineer access at their desk.

The first expansion should be the Magline extension to the standard D-Line product group. This was tackled previously in the Egeria system hence, difficulties in representing this range have been assessed. As the Magline is derived from a D-Line pump, the hydraulic performance is identical, hence the object oriented design should allow these sections to be reused, with other objects modelling the different build.

The company plan to develop two new product ranges over the next two years, to be sold by all the worldwide Dresser sites. To aid in the marketing of these, it would be advantageous if they could be added to PSI as the products were being developed. This would enable the distribution of a selection at the product launch, easing the engineers task in becoming familiar with the new products capabilities.

In addition to the U.K. use, interest has been shown by other sites in having their product lines added to PSI, particularly by the French site Pompes Jeumont Schnieder. This would require the system to be widened to cater for multistage units. The design of the class hierarchy in PSI allows for this to be done. While the F pumps were demonstrated in Egeria they were in a very simplified version. More work would be required to correctly perform the hydraulic analysis. Having products from several sites in one system would benefit the sales force. The system would be of great use in situations where units from other sites are required, or when products from more than one site need comparing.

The depth of the selection could also be expanded further to allow wider use. The motor selection allows the user to switch between several sizes though all are the standard motor. This could be extended to allow the user to change the type of motor, e.g. flameproof or to specify the manufacturer. This would require motor data for all the options, as the running speed of the motor affects the hydraulic performance. Support could be added for the selection of couplings, baseplates and seals. Coupling and baseplates are comparatively simple, however the seal depends on the fluid and application. Full seal selection would be difficult to add, though the system could suggest the options open to the user.

Beyond viewing the performance curve, no further information is available on pumps which just fail to be suitable. This could be expanded to indicate the performance which could be attained by the unit.

12.2 Output

While PSI speeds up the selection part of answering an enquiry, the engineer is still left to turn this into a quotation to be sent to the customer. A greater impact could be made if the system were able to produce a printed data sheet, which ideally would also cover pricing of the unit. Unfortunately all customers do not require the same type of response. Any facility for output must be able to handle the variations and be capable of dealing with both single and multi-term enquiries.

Currently PSI's only outputting feature is to use the DOS Print Screen on the quotation screen. While this contains all the information on the chosen unit, the resulting sheet is not suitable for sending to the customers. Often this will be used by the engineers to fill in either the standard company datasheet, or the customers datasheet.

To aid the output of large multi-item jobs a programme was written in dBase III+ to produce an output similar to the company's multi-item datasheet. This generates a summary table giving information on six pumps from the data stored by PSI. While this is suitable for sending to a customer, its use requires the user to be familiar with dBase, hence, it is not in general use.

A possible source of output is a programme developed and used by the U.K. sales force MAJIK. This is a system written in Clipper to perform office management, pricing and tendering. Discussions with its author have begun to identify ways it may be connected to PSI and work is underway to allow this.

The production of a written or printed quote is only part of the complete tender process. Many customers also require a performance curve for the pump, and a General Arrangement Drawing. While the engineer may view the performance curve on screen, this may not currently be passed to the printer.

Overall the usefulness of PSI would be greatly improved by the addition of output facilities. The gains to the engineer will be increased, and the possibility for transcribing errors will be eliminated.

12.3 User Interface

The current user interface was designed in conjunction with representatives of the U.K. sales office. While it displays all the necessary data, and permits the user to seek more detail, it relies on remembering the key presses to do this (these may be displayed on a help screen should the user forget). With the current single range the number of options from each screen is relatively small, however, as more ranges are added and the scope of the system widened, the number of key press options will increase. To ease the user's use of the system it may be beneficial to alter the interface to incorporate the use of pull-down menus. This would ease a user's introduction to the system when the options are greater, once familiar with these the user would be able to bypass the menus with single key strokes.

As the number of ranges available increases the possible entries on the main screen will grow. How many are shown will depend on the ranges the user chooses to assess, however, if several are selected the user may be presented with multiple screens of suitable pumps from which to make a choice. To aid the user it may be beneficial to increase the control over what is shown in the list and the order of display. Currently all suitable pumps are shown sorted by the efficiency. A menu driven interface should allow the user to alter this by changing the sort order and by defining filters on the information. While the user is presented with detailed data from which to determine if a unit meets a customers specification, it may be better if the system could eliminate some pumps when there is a large list, e.g. many customers specify the duty point should not be to the right of best efficiency point. While PSI displays the duty as a % of BEP, it may be inconvenient for a user to scan several pages of selections deleting those where this exceeds 100%. A filter to eliminate these pumps from the display would greatly ease this task.

The current users of PSI are the U.K. Sales Force, and the Newark application engineers. This allows familiarity with the product, and the data shown and terminology to be assumed. In later versions aimed at distributors and customers this would not be the case. The system would have to provide a greater degree of help to the user, and to perform more checking on the input data, to ensure it was consistent. Coupled to the above is the addition of an intelligent interface to aid the inexperienced. This would be sensitive to the customer to allow the system defaults to be adopted to previous experience in similar situations. This would be a return to the original aims of the project in widening the availability of the experienced engineers' knowledge of pump selection. The system would aim to use stored knowledge on customers, industrial processes and fluids to give the most appropriate selection for an enquiry. Perhaps the most difficult part of this would be in determining when the system should not offer a selection, instead advising the user to consult the sales office. To do this would require the system to know the limit of its expertise or to be able to assess the risks of an inappropriate choice of pump, deferring to a human expert where this was too great.

12.4 Integration With Other Functions

As PSI is extended to other ranges, covering the majority of enquiries, opportunities will arise which allow the stored information on quotations to be used in other business areas. This may enable a more accurate transfer of data between areas, or provide more information for business functions. Three possible areas where this may occur are outlined below

Perhaps the most obvious area of expansion is to allow the system to communicate with the order processing systems. Currently when the customer responds to a quotation and places an order, the details on the customer and the pump are entered onto the mainframe computer. If the pump is of completely standard configuration then a code is used to describe the details to the mainframe. This entry passes the information both to Finance for invoicing of the customer and to Production to allow manufacture to begin. Both the coding and the entry onto the mainframe are areas where errors could occur, and are bottlenecks where the lead time on a unit depends on the personnel being available to perform the task. The majority of the data required is available in PSI, which could perform the coding, the extra areas being related to the customer's status and location, information which is available in other files held on the mainframe. The potential for errors and the time for this operation could be greatly reduced by passing the data between systems.

Information on the numbers of quotes made, and the type and size of units concerned would be useful marketing information for both analysis and planning. Current market analysis is based on orders sold, as no complete source of enquiries and tenders was previously available. The extra data increases what may be achieved. It will be possible to compare data on tenders and orders to identify areas where the company gains or loses business.

This in turn should aid in identifying gaps in the company's coverage of the market, and opportunities for new products or options. Additionally, more accurate data on conversion rates from tender to order for individual ranges or sizes may be used to influence the pricing policy for existing and future ranges.

In a similar way to the above, information on pumps quoted for may aid in improving production planning. This is based on patterns of historical usage of parts to dictate what batches, in what sizes should be produced. By providing data on the units which have been quoted, with sales engineers' estimates of the chance of the order and the timescale, perhaps this could be used to allow for the likely orders.

12.5 Training Aid

As the scope of the system widens, PSI may be expanded for use as a training aid. There are two separate areas where this would be appropriate. Where a new product range is introduced the engineer is tasked with becoming familiar with the use and limitations of the new pumps. By performing the hydraulic analysis PSI frees the salesman to identify benefits to the customer, allowing him to give a better service and ultimately sell more units.

A second use is in the training of new application engineers, this would require expansion of the programme's help facilities and the reasons why options were rejected. At each stage of the selection process the system could explain the effect of the various parameters. The reasons for rejecting pumps on the near miss list would require more detail allowing them to explain why a pump is not suitable, pointing out features which the new engineer should be aware of. When more detail is requested by calling up the motor or build lists, the system could advise the user of the situations where it may be appropriate to use an option other than the default.

Adding the necessary extra facilities would increase the size of the system, and slow down the overall execution speed. A training version would hence be separate from the main programme allowing some features to be removed.

CONCLUSIONS

The conclusions from this study can be drawn in four areas:-

The use of expert system shells on PC's.
Knowledge based approach to programming.
The rise of Object Oriented programming.
PSI - Pump Selection with Intelligence.

Each of the four areas is covered below.

13.1 Expert System Shells

The dramatic speed increase between shell based and C++ implementations illustrate that expert system shells are ill-suited to numerically intensive applications. If an application requires both numerical and symbolic processing, then a hybrid approach combining an expert system with routines in an external language should be used.

The size of the problem which may be modelled on a DOS based PC is severely limited. While it may be possible to split the problem into several knowledge bases, passing information between these can be difficult.

While a Windows based shell may not be the ideal delivery tool, it forms an ideal prototyping and development environment.

As a tool for aiding in structuring knowledge, shells are ideal. Prototypes may be quickly built and rapidly altered, then the final system design re-implemented in an appropriate language with gains in efficiency.

13.2 Knowledge Based Systems (KBS)

At the beginning of the project, 1989 knowledge based systems was a term used synonymously with expert systems. Over the intervening period the technology has matured so this is no longer true. Knowledge Based Systems may combine techniques from many sources with different tools being appropriate at different stages in a projects life.

Knowledge based systems may now be considered to be the approach to the problem, rather than the technology on which it is based. KBS implies systems which base their solution on how the human would seek to solve the problem.

13.3 Object Oriented Programming

Object oriented programming has developed from use in specialist languages and expert system shells to acceptance in mainstream programming languages. Its influence on software design has been dramatic, with this approach becoming dominant in programme development for PC's, particularly applications for Microsoft Windows.

Object Oriented Development is well suited to many engineering computing problems. It allows the developer to model and solve a problem in terms of real world entities.

The selection of pumps with the need to consider several related components and sub-assemblies is an application which may successfully be tackled in this way.

13.4 PSI - Pump Selection With Intelligence

The C++ implementation of the system demonstrates that object oriented and knowledge based techniques may successfully be applied to pump selection. The rapid development of these areas has lead to a system which combines them to give a tool for application engineers.

Development has been through a number of stages and involved the use of three software tools to lead to a successful system. The D-Line version of PSI is in use with the Dresser U.K. sales force and international interest suggests that after expansion it will be adopted through Dresser for standard pump use.

The programme provides a base which may be expanded upon, both to cover more products and to add additional features. As the D-Line system suggests, PSI will then be a useful aid for application engineers allowing a better response to customer enquiries.

References

[1] Feasibility Study into the possible use of expert system techniques for pump selection for Worthington Simpson.
Dr A.R.Uzel & Dr K.S.Henthorn. April 1988 Trent Polytechnic, Department of Mechanical Engineering.

[2] Decision Support & Expert systems : Management Information Systems. 2nd Edition.
E.Turban. 1990 Macmillan Publishing.

[3] The Emperor's New Mind.
R.Penrose. 1990 Vintage UK Publishing.

APPENDICES

APPENDIX A BASIC COMPONENTS OF PUMP SELECTION

This section considers the basic features involved in pump selection by manual methods. Many fluids books, see bibliography, cover the selection process in mathematical detail dealing with the principles of fluid hydraulics. However, in general the application engineer relies on faster graphical methods, working on performance curves drawn in accordance with test results. It is these methods which shall be covered in this section, and which provide the foundation, and test cases, for the selection system.

A.1 TYPES OF PUMP

At its most basic, a pump is a device supplying energy to a flowing liquid. This may be to overcome frictional losses, or to raise the fluid to a higher level. There are basically three categories into which the various units may be divided. Perhaps the largest group are centrifugal pumps where the energy, or head, is given to the liquid by centrifugal action. The most common design is the volute pump. Here, liquid enters along the axis of a high speed impeller. The rotation of which throws the liquid radially outward into a progressively widening casing.

A different principle, positive displacement, is behind the operation of the other two main types. Rotary pumps transfer liquid forcibly through the action of rotating parts within a rigid casing. The rotating parts may be gears, lobes, vanes or screws. The performance of these pumps may be varied by changing the rotational speed. The third type transfers liquid by varying the internal volume. The most common example of this is the piston pump. Pumping rates are varied by changing either the frequency, or the length of the stroke.

Of the three types, centrifugal pumps form the major part of the pump market, and the focus of Worthington Simpson's business. It is this area on which the system will focus. Within centrifugal pumps there are many variations of design, the most significant being pumps may consist of more than one impeller stage. The Dresser product line covers both single and multiple stage units, in a variety of sizes and materials.

A.2 PERFORMANCE CURVES AND DUTY CONDITIONS

The majority of the hydraulic information is described by four variables. The capacity, Q, is the amount of liquid the pump is required to deliver in a given time period. It may be expressed as either a mass or volumetric flow rate. The head is a measure of the energy which must be given to the fluid. The pump's generated head is usually given in height of water, through head may also be expressed as a pressure. The power requirement of a pump is a function of the capacity, the head and the efficiency which is dictated by the design. The final parameter is the Net Positive Suction Head, NPSH this is the differential between the pump suction pressure and the liquid vapour pressure. Two values of NPSH are used during the selection, the available NPSH, is a feature of the piping system, indicating the actual conditions at the pump's suction. NPSH required is a feature of the pump, it dictates the condition which must be exceeded for pumping to take place. The Head, Power and NPSHr values are the characteristics of a pump. Each varies with capacity to give a curve. An example curve, and the company definitions of how these values may be calculated is given in Appendix B.

Each pump size has its own performance curve for a particular speed. These are general curves derived from hydraulic design and testing of units. The curve typically shows sets of curves for several diameters, these being chosen to correspond to a motor size. At it's simplest selection involves plotting the capacity and head on the graph, finding the first curve to cover this, i.e. give sufficient head at the capacity, and reading off the diameter and motor size. If necessary the efficiency may also be read from the iso-efficiency lines and the absorbed power at the duty read from the power curve, or calculated from capacity, head and efficiency. For duty points on or close to the plotted curves, this is sufficient, however when the duty lies between curves, this will lead to a unit which exceeds the requirements.

The diameters shown on the curve are the maximum, minimum and a number of intermediates. Often many other diameters are also available, the step size between them depending on the product range, and the size of pump. Where a duty lies between two drawn impellers, the engineer interpolates to find the appropriate diameter for the requirements.

This is usually done by eye, with a curve being drawn between the two existing curves, following their shape. From the intersections with the iso-efficiency lines, power figures may be calculated and a curve drawn for this. For most small units the NPSH does not vary with the diameter significantly and may be considered unchanged. In situations where the attaining of the exact duty is essential, the engineer may refer the selection to the Engineering department who will consider the pump in more depth, using test results to evaluate whether the cut diameter will perform as expected.

The power requirements of the pump may be considered at either the duty point, or at the point of maximum absorbed power along the curve for the selected diameter. The standard method for motor sizing applies a margin to the motor power, which gives a maximum power figure up to which a motor may be used. Customers may specify their own margins applied to either to the maximum or the duty power to give a figure the motor power must exceed.

In situations where the capacity required is toward the pump's minimum flow, the motor power may greatly exceed that absorbed at the duty. If the engineer knows sufficient about the application it may be appropriate to size the motor on the duty rather than the maximum power absorbed. The engineer can use the power curve to determine the flow rate which would cause the motor to overload. If the system curve, section A.4, prevents this point being reached then the motor may be used safely. It is this area where the engineer's knowledge of the customer's application is used to determine whether a smaller, and hence cheaper motor may be offered.

A.3 FLUID EFFECTS

The standard pump performance curves are drawn based on cold, clean water as the pumped liquid. Where the liquid is other than this it may be necessary to alter the expected performance curve for the pumped fluid. The most significant effects are made by Specific Gravity (S.G.) and the Viscosity.

The specific gravity of a fluid affects the power requirements for a duty due to the change in mass flow rate for the same volumetric flow rate. The change is directly proportional to the S.G. i.e. the power for a given fluid is the equivalent power for a water duty multiplied by the S.G. As the conversion between pressure and column height of fluid, for the head, is also proportional to S.G., the efficiency value at a given flow and head is unaffected.

The fluid viscosity has a potentially greater impact on performance as it affects both power and head. The head generated at a given flow is reduced by the viscosity due to the increased frictional losses within the pump. The drop is proportional to the square of the capacity, hence the variation from the water curve is increased as the flow increases. The power requirements increase due to the rise in the disc friction of the impeller. The increase is determined as a reduction in the pump's efficiency at the Best Efficiency Point. The resulting increase in power this causes is then applied to all points along the pump curve. The overall effect is to raise the power curve, parallel to the original curve for water.

Appendix B shows how these corrections are calculated and gives an example on a fluid requiring both corrections. In this situation the S.G. power multiplier should be applied before the power gain due to the viscosity. Both the above parameters are dependent on the fluid's temperature. Additionally, the vapour pressure and hence the NPSH available is influenced by the pumping temperature. When fluids are at elevated temperature more care must be taken.

The effect of the fluid on pump selection goes beyond the performance. Both temperature and the nature of the fluid, i.e. the corrosion and toxicity, can indicate the materials which must be used in construction. Some fluids may require the use of special sealing to ensure there is no leakage from the pump. If this is so, the fluid influences the product ranges and the build constructions available.

While the S.G. and Viscosity corrections may be defined and applied mathematically, the material and construction influences are more difficult. Results in these areas are dictated by the engineer's experience and knowledge of the exact situation under consideration.

A.4 SYSTEM CHARACTERISTICS

The value of head within a pumping system may be measured at various points. The most important, for pump selection is the total head,i.e. the difference between the discharge and suction heads. This dictates what head the pump is required to generate at a given flow rate. The total head is made up of two components. The static head represents the overall height through which the fluid is lifted in the system, this is fixed by the design of the piping. The dynamic head is the frictional losses within the piping, it is related to flow rate, increasing with increasing capacity.

The point where the pump's generated head curve and the system head curve intersect is the normal operating point. In installations where the pump's performance may be controlled, by throttling or varying the speed, any change in output follows the system curve.

The available NPSH is also dictated by the pumping system, being the difference between the pressure at the pump suction flange and the vapour pressure of the liquid at the pumping temperature. The calculation of the NPSH uses the pressure on the liquid, the vapour pressure, the suction head or lift and the friction loss in the suction line. It's formulae is given in Appendix B, with an example.

A.5 THE BEST SELECTION

What constitutes the best selection for a customer's requirements is where the majority of experience within pump selection is focussed. The engineer from his knowledge of the customer and application must determine what is likely to be the criteria on which a decision between rival tenders will be made. The most likely parameters are:

(i) Efficiency - the pumps overall operating efficiency at the duty point.

(ii) Price - the initial cost to the customer of the pump.

(iii) Availability - the delivery period for the required pump.

(iv) Economic Evaluation - total running cost of the pump over its anticipated life.

In many cases the engineer will trade-off these against each other to decide upon the most suitable unit.

An extra level of complication is added when the customer has a preference or dislike for a particular feature. This may be a material, running speed, type of pump or build style. In these situations the engineer must consider the effect of the customer's preference on what will make the best offer.

Worthington - Simpson Ltd

GENERAL PUMPING DATA

DEFINITIONS

CAPACITY is the amount of liquid a pump is required to deliver during a certain period of time, and may be expressed in a variety of ways, such as: gallons perminute, gallons per hour, tons per hour,. cubic feet per second, litres per second, etc.

In this book the capacity ratings are almost invariably given in gallons per minute—G.P.M., and factors are provided in a later page to facilitate conversion from other units. In all cases when gallons are indicated Imperial, not U.S. gallons, are understood.

SPECIFIC GRAVITY—S.G.—is the ratio of the weight of a given volume of liquid to that of an equal volume of pure cold water. A column of water 2.31 feet high exerts a pressure at its base of 1 pound per square inch. Therefore for any liquid—Head in feet =

$$\frac{\text{Pressure in p.s.i.} \times 2.31}{\text{S.G.}}$$

VISCOSITY is the measure of the degree of fluidity of a liquid, and is generally recorded as the number of seconds taken by a given quantity to flow through an orifice of given dimensions, e.g. cold water has a viscosity of 29 seconds Redwood No. 1.

PIPE FRICTION is the resistance offered by pipes and fittings to flow of a liquid and is a function of the rate of flow, viscosity of the liquid, and the pipe diameter. It is usually calculated in feet loss per 100 feet of pipe.

VELOCITY HEAD of a liquid moving at a given velocity is the equivalent height through which it must fall to attain the same velocity, i.e. Head in feet = $\frac{v^2}{64.4}$ where v is the velocity in feet per second.

ATMOSPHERIC PRESSURE at sea level exerts an absolute pressure of 14.7 p.s.i. which is equivalent to 34 feet of water or 30 inches of Mercury (Hg).

The atmospheric pressure decreases with an increase in altitude, the decrease being approximately 1 p.s.i. for every 2000 feet above sea level.

VACUUM correctly defined, is a complete absence of pressure, but the term is generally used to indicate when the pressure in an enclosed space is below that of the surrounding atmosphere. The extent of a vacuum is measured from atmospheric pressure as the datum, that is to say a vacuum of 20 inches Hg. means that a pressure exists equivalent to 20 inches of mercury less than atmospheric. The absolute pressure, with a barometer of 30 inches Hg., would then be 30-20, i.e. 10 inches Hg. It is generally important to give consideration to the barometric pressure when dealing with cases involving vacuum, since it can have considerable effect on the absolute pressure. For instance, if the barometer is 27 inches Hg., as it can be at certain altitudes, then a vacuum of 20 inches Hg. would give an absolute pressure of 7 inches as compared with 10 inches for a 30 inch barometer.

Vacuum is expressed generally in inches of mercury but may be easily converted into equivalent feet of water by the relation:—

1 inch Hg. = $\frac{34}{30}$ feet water since 30 inches Hg. = 34 feet water.

VAPOUR PRESSURE may be defined as that pressure necessary to just keep a liquid at a given temperature from boiling. For example:—

Water at 150°F. has a vapour pressure of 3.72 p.s.i. absolute.

Water at 250°F. has a vapour pressure of 29.82 p.s.i. absolute or 15.12 p.s.i. gauge.

SUCTION CONDITIONS have so important a bearing on the proper performance of a pump that, at the risk of being elementary, certain essential points are emphasised here.

Let us assume a suction line full of liquid with the source of supply under pressure, which may be atmospheric. When the pump commences to operate, a reduction in pressure is caused at the suction through the transfer of liquid, and as a result of this pressure difference liquid continues to flow into the pump.

GENERAL PUMPING DATA

It will be clear that the minimum pressure within a pump cannot be less than the vapour pressure corresponding to the temperature of the liquid, otherwise the pump will become vapour bound.

In any one pump there is, for a specified capacity, a definite friction and velocity head loss which must be overcome before the liquid receives energy from the impeller or piston, consequently, the pressure at the pump suction must exceed the vapour pressure of the liquid by not less than this loss. It should be emphasised that the pump entrance loss is not a constant figure but varies widely with the style and design of the pump, and with the capacity and speed at which it is operated.

NETT POSITIVE SUCTION HEAD.—N.P.S.H.—is the term now generally applied to the differential pressure between that at the pump suction and the vapour pressure of the liquid, and, as stated above, must always be not less than the pump entrance loss. N.P.S.H. (determined in absolute figures) is the pressure in feet at the pump suction minus the vapour pressure in feet corresponding to the temperature. An explanation of how to calculate the available N.P.S.H. is given on page 13.

MEASUREMENT OF HEAD: The following definitions are taken from the British Standard BS.599, the datum being the centre line of a centrifugal pump, or the discharge valve deck of a reciprocating pump.

> "**The 'Static Suction Head'** at the datum level shall be that which would be recorded by the suction gauge with the whole system filled with the liquid being pumped but with the pump not working and with the pump delivery valve closed, subject to a correction for any difference in the level of the water in the gauge and the datum level.
>
> **The 'Static Delivery Head'** at the datum level shall be that which would be recorded by the delivery gauge with the whole system filled with the liquid being pumped but with the pump not working and with the pump suction valve closed, subject to a correction for any difference in the level of the liquid in the gauge and the datum level.
>
> **The 'Suction Head'** at the datum level shall be that which would be recorded by the suction gauge with the pump operating under the specified conditions subject to the correction for any difference in the level of the liquid in the gauge and the datum level.
>
> **The 'Delivery Head'** at the datum level shall be that which would be recorded by the delivery gauge with the pump operating under the specified conditions subject to a correction for any difference in the level of the liquid in the gauge and the datum level."

The Total Head is made up of the sum of the readings of the suction and delivery gauge, i.e. Suction Head plus Delivery Head.

Alternatively Total Head is the sum of :—

1.—The difference in the pressures existing on the intake and delivery liquid surfaces. This is an important factor in such cases as boiler feed and condenser extraction pumps.

2.—The total lift i.e. the net vertical height through which the liquid has to be raised.

3.—The friction loss in the whole system external to the pump between the intake and the delivery outlet.

PRIMING.—It will be apparent that when the level at the source is lower than at the pump, and the source pressure is atmosphere or below, then some means must be provided for evacuating the air in the suction piping before the pump will operate.

Reciprocating pumps, in themselves, are capable of evacuating the air, but centrifugal pumps, unless they are of the self-priming type, are unable to do this, and separate priming arrangements are then required. There are several methods of priming the suction piping, the most common being the provision of a footvalve at the source and a filling connection at the top of the suction pipe. The suction pipe should rise steadily throughout its length from the source level to the pump suction, and upward loops, which would cause air pockets, should be avoided.

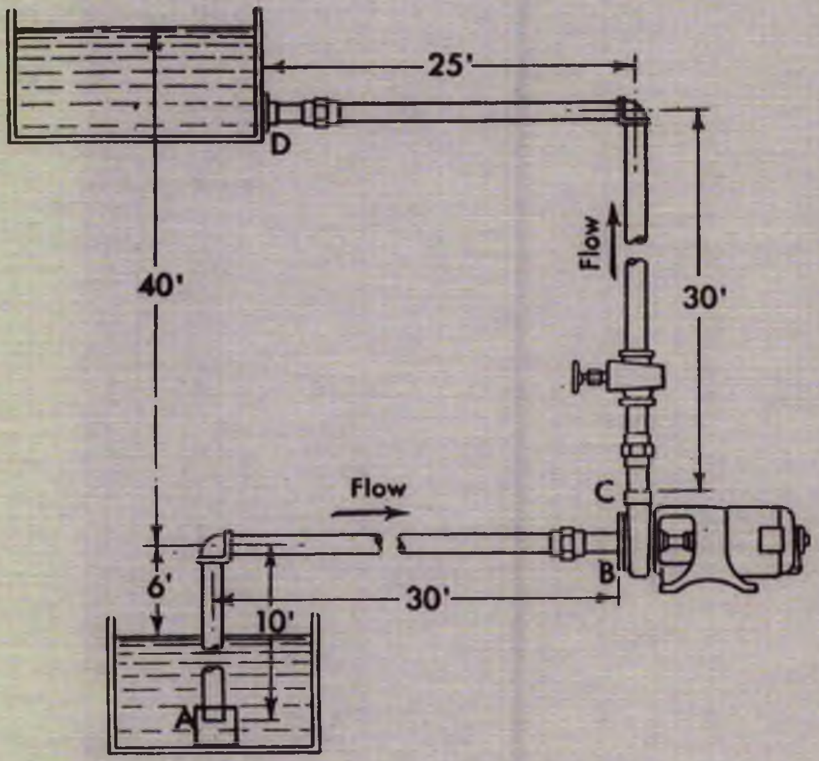
HOT WATER or volatile liquids can only be pumped under suitable suction conditions. To locate the pump above the level at the source of supply is generally impractical, as the liquid in the pump being at reduced pressure would vaporise, consequently a static suction head is usually necessary to provide the required N.P.S.H.

All pump selections must be based on TOTAL HEAD.

TYPICAL INSTALLATIONS are shown in the following pages with examples to show the calculation of the heads involved. These examples are for cold water working, and further examples will be later introduced to show temperature effects, and the calculation of N.P.S.H.

GENERAL PUMPING DATA

TYPICAL INSTALLATIONS



PUMP CAPACITY 150 GPM.

SIZE OF ALL PIPE AND FITTINGS 3"

Pipe Friction

Delivery piping C to D (55 feet of pipe with 1 std. bend and 1 sluice valve) = 8 feet

Suction piping A to B (40 feet of pipe with 1 std. bend and 1 Foot valve) = 9 feet

Static delivery head = 40 feet

Delivery pipe friction =10 feet

Delivery head = 48 feet

Static suction lift = 6 feet

Suction pipe friction = 9 feet

Total suction lift = 15 feet

TOTAL HEAD = 63 feet

PUMP CAPACITY 300 GPM.

SIZE SUCTION PIPE 5".

SIZE DISCHARGE PIPE AND FITTINGS 4".

Pipe Friction

Delivery piping C to D (165 feet of 4" pipe with 2 std. bends and 1 sluice valve) = 18 feet

Suction piping A to B (32 feet of 5" pipe) = 1 foot

Static delivery head =150 feet

Delivery pipe friction = 18 feet

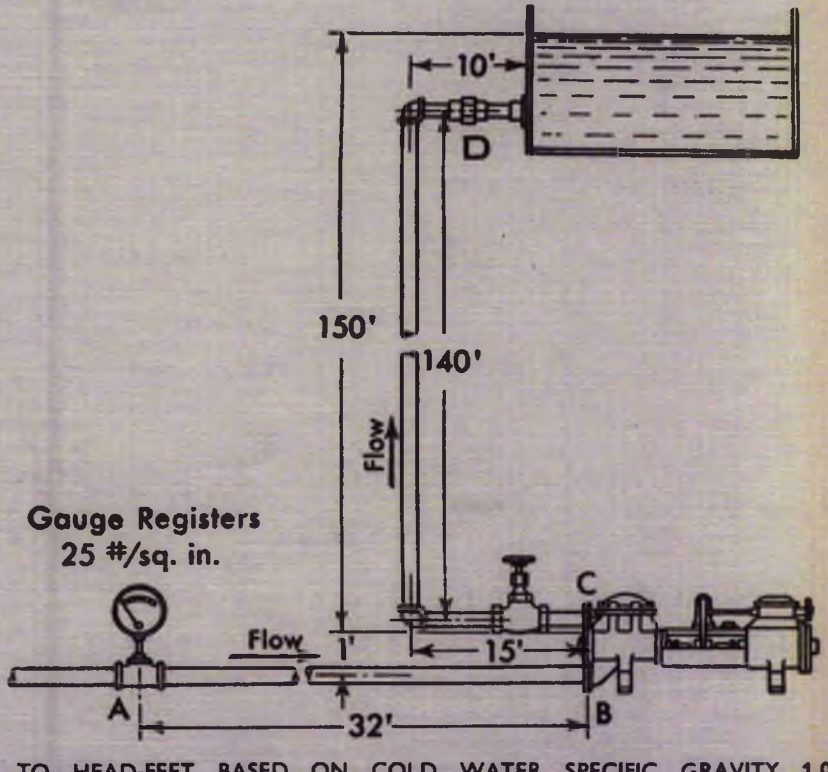
Delivery head = 168 feet

(Gauge pressure 25 lb. × 2.31) minus 1 foot = 57 feet

Suction pipe friction = 1 foot

Positive suction head = 56 feet

TOTAL HEAD = 112 feet



CONVERSION FROM POUNDS-GAUGE TO HEAD-FEET BASED ON COLD WATER SPECIFIC GRAVITY 1.0

GENERAL PUMPING DATA

TYPICAL INSTALLATIONS

PUMP CAPACITY 50 GPM.

SIZE OF ALL PIPE AND FITTINGS 2"

Pipe Friction

Delivery piping C to D (70 feet of pipe with 1 std. elbow and 1 globe valve) = 11 feet

Suction piping A to B (35 feet of pipe with 1 std. elbow and 1 globe valve) = 8 feet

Static delivery head = 60 feet

Delivery pipe friction = 11 feet

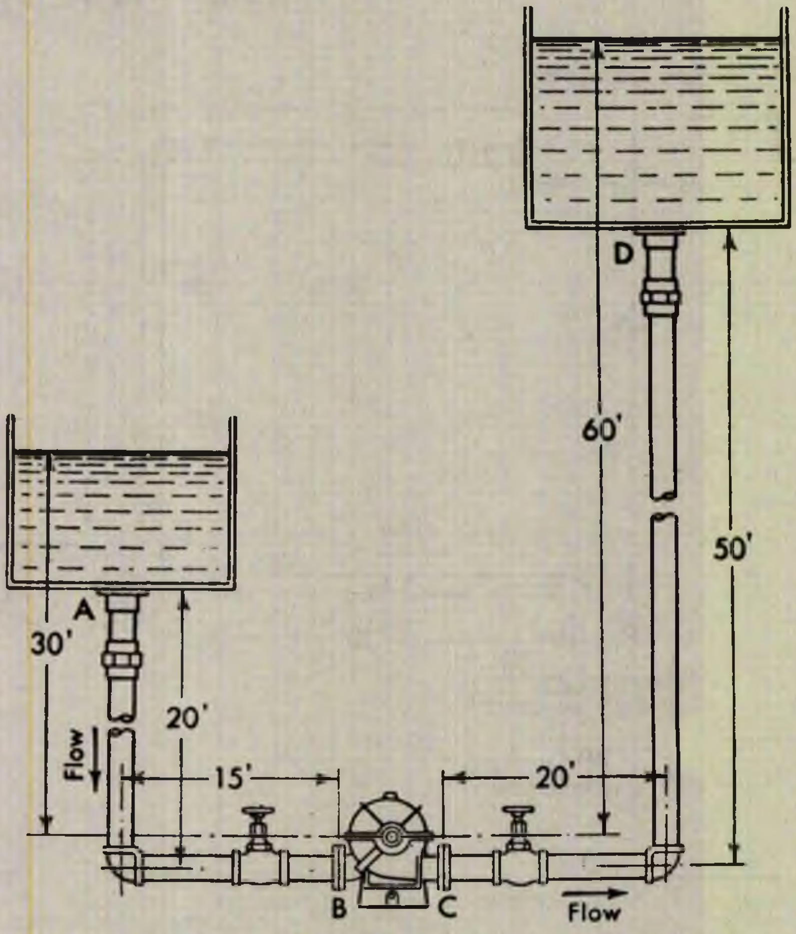
Delivery head = 71 feet

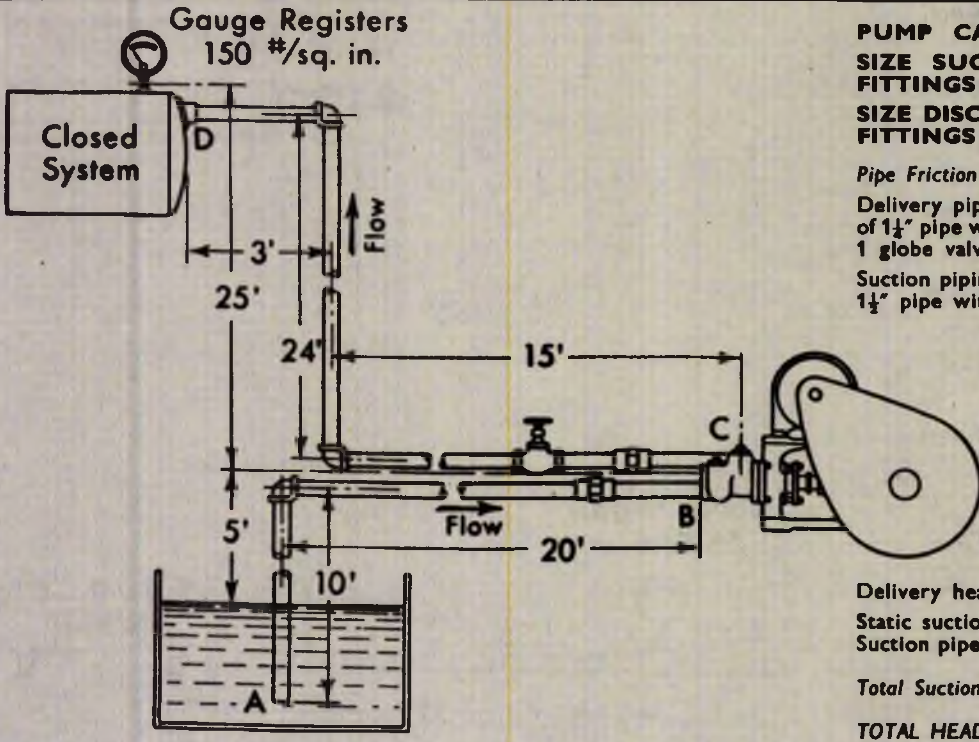
Static suction head = 30 feet

Suction pipe friction = 8 feet

Positive suction head = 22 feet

TOTAL HEAD = 49 feet





PUMP CAPACITY 15 GPM.

SIZE SUCTION PIPE AND FITTINGS 1¼".

SIZE DISCHARGE PIPE AND FITTINGS 1¼".

Pipe Friction

Delivery piping C to D (42 feet of 1¼" pipe with 2 std. elbows and 1 globe valve) = 8 feet

Suction piping A to B (30 feet of 1¼" pipe with 1 std. elbow) = 2 feet

(Gauge pressure 150 lb. ×2.31) plus 25 = 372 feet

Delivery pipe friction = 8 feet

Delivery head = 380 feet

Static suction lift = 5 feet

Suction pipe friction = 2 feet

Total Suction Lift = 7 feet

TOTAL HEAD = 387 feet

CONVERSION FROM POUNDS-GAUGE TO HEAD-FEET BASED ON COLD WATER SPECIFIC GRAVITY 1.0

GENERAL PUMPING DATA

USEFUL FORMULAE

$$\text{Power Kw} = \frac{\text{m}^3\text{/hr} \times \text{Tot. Head in m} \times \text{S.G.}}{367 \times \text{Pump Efficiency}}$$

$$\text{Brake Horse Power (B.H.P.)} = \frac{\text{Imp. G.P.M.} \times \text{Total Head in ft.} \times \text{S.G.} \times 10}{33{,}000 \times \text{Pump Efficiency.}}$$

$$\text{Electrical Horse Power (E.H.P.)} = \frac{\text{B.H.P.}}{\text{Motor Eff.}} \qquad \frac{\text{E.H.P.}}{1{\cdot}341} = \text{Kilowatts.}$$

$$\text{Synchronous Speed of A.C. Motor} = \frac{\text{Frequency} \times 60}{\text{No. of pairs of Poles.}}$$

USEFUL EQUIVALENTS

One British Barrel = 36 Imperial Gallons.
One U.S. Barrel = 42 U.S. Gallons,
One French Tonne = 2200 lbs.
One U.S. Ton = 2000 lbs.

One Imp. Gallon of Fresh Water weighs 10 lbs. at 62°F.
One Cubic Foot of Fresh Water weighs 62·28 lbs. at 62°F.

CONVERSION FACTORS

PUMP CAPACITIES as stated in various units can be converted to Imperial Gallons per Minute by multiplying by the following factors :—

U.S. G.P.M.	0·833
Million gallons per 24 hours	695
Cubic feet per second (cu. secs.) ...	374
Cubic feet per minute	6·23
Cubic feet per hour	0·1038
Metric tonnes per hour	$\frac{3{\cdot}666}{\text{S.G.}}$
Cubic metres per hour	3·666
Cubic metres per minute	220
Cubic metres per sec.	13200
Kilogrammes per hour	$\frac{0{\cdot}00366}{\text{S.G.}}$
Pounds per hour	$\frac{1}{600 \times \text{S.G.}}$
British tons per hour	$\frac{3{\cdot}733}{\text{S.G.}}$
Litres per second	13·2
Litres per minute	0·2204

PUMPING HEADS as stated in various units can be converted to feet by multiplying by the following factors :—

Pounds per sq. inch	$\frac{2{\cdot}31}{\text{S.G.}}$
Inches Mercury (Hg.)	$\frac{1{\cdot}133}{\text{S.G.}}$
Cms. Mercury (Hg.)	$\frac{0{\cdot}447}{\text{S.G.}}$
Metres	3·28
Atmospheres	$\frac{33{\cdot}95}{\text{S.G.}}$
Kilogrammes per square centimetres ...	$\frac{32{\cdot}8}{\text{S.G.}}$

GENERAL PUMPING DATA

CONVERSION FACTORS

Given Unit	Required Unit	Factor	Given Unit	Required Unit	Factor
B.t.u.	Kg.-calories	0.252	Gallons (Imp.)	Cu. cm.	4545.
B.t.u.	Ft.-lb.	778.	Gallons (Imp.)	Cu. ft.	0.1603
B.t.u.	Hp.-hr.	0.0003927	Gallons (Imp.)	Cu. in.	277.
B.t.u.	Joules	1054.	Horsepower	B.t.u. per min.	42.44
B.t.u.	Kw.-hr.	0.000293	Horsepower	Ft.-lb. per min.	33,000.
B.t.u. per min	Watts	17.57	Horsepower	Kilowatts	0.746
Centimetres	Inches	0.3937	Inches	Cm.	2.54
Cm. per sec.	Ft. per min.	1.97	In. of mercury	Ft. of water	1.133
Cm. per sec.	Miles per hour	0.0224	In. of mercury	Lb. per sq. ft.	70.73
Cu. cm.	Cu. in.	0.061	In. of mercury	Lb. per sq. in.	0.4912
Cu. cm.	Gallons (Imp.)	0.00022	In. of water	In. of mercury	0.0736
Cu. ft.	Cu. metres	0.0283	In. of water	Lb. per sq. in.	0.0361
Cu. ft.	Gallons (Imp.)	6.23	Joules	B.t.u.	0.000949
Cu. ft.	Litres	28.32	Joules	Watt-hours	0.000278
Cu. in.	Gallons (Imp.)	0.00361	Kilograms	Pounds	2.205
Cu. in.	Cu. cm.	16.39	Kg.-calories	B.t.u.	3.968
Dynes	Grams	0.00102	Kg.-calories	Ft.-lb.	3086.
Dynes	Pounds	2.248x10^{-6}	Kg.-calories	Kw.-hr.	0.001162
Degrees (angular)	Radians	0.01745	Kilowatts	B.t.u. per min.	56.92
Feet	Metres	0.305	Kilowatts	Horsepower	1.341
Feet of water	In. mercury	0.883	Kilowatts	Kg.-calories per min.	14.34
Feet of water	Lb. per sq. ft.	62.4			
Feet of water	Lb. per sq. in.	0.434	Kw.-hr.	B.t.u.	3415.
Ft. per min.	Cm. per sec.	0.508	Kw.-hr.	Joules	3.6x10^{6}
Ft. per min.	Miles per hour	0.01136	Kw.-hr.	Kg.-calories	860.5
Ft. per sec.	Cm. per sec.	30.48	Metres	Feet	3.281
Ft. per sec.	Miles per hour	0.682	Metres	Inches	39.37
Ft.-lb.	B.t.u.	0.001286	Mm. of mercury	Ft. of water	0.0446
Ft.-lb.	Ergs	1.356x10^{7}	Mm. of mercury	Lb. per sq. in.	0.01934
Ft.-lb.	Hp.-hr.	0.505x10^{-6}	Pounds	Dynes	4,444,823.
Ft.-lb.	Joules	1.356	Pounds	Grains	7000.
Ft.-lb.	Kg.-calories	0.0003241	Pounds	Grams	453.6
Ft.-lb.	Kw.-hr.	0.3766x10^{-6}	Pounds per cu. in.	Gr. per cu. cm.	27.68
Ft.-lb. per min.	Horsepower	0.303x10^{-4}	Radians	Degrees	57.3
Ft.-lb. per min.	Kilowatts	2.26x10^{-5}			

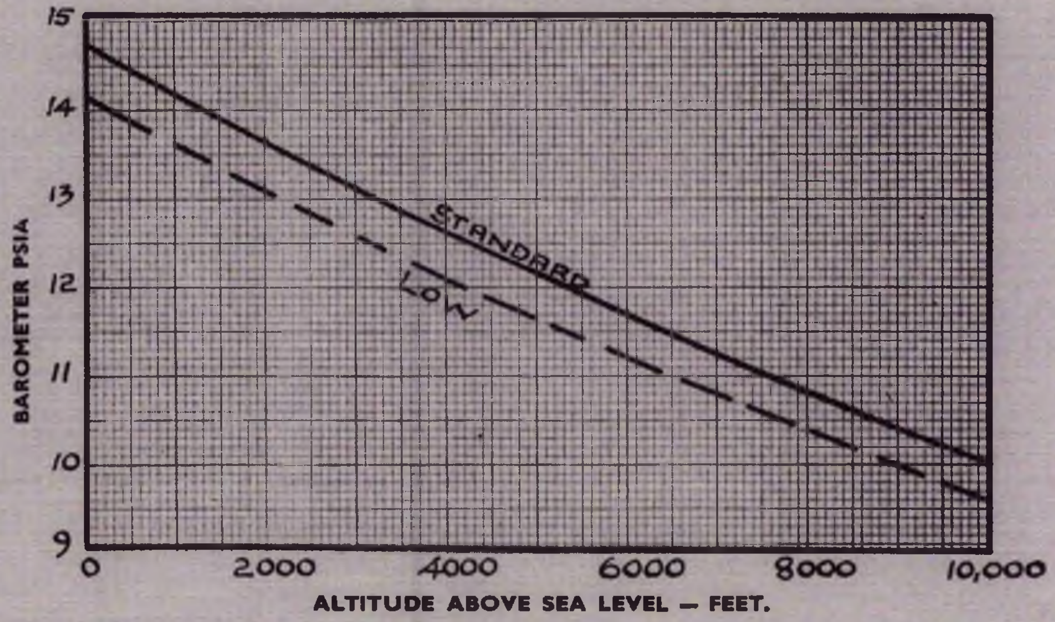
The Factors on this page represent the number of "Required Units" to equal one "Given Unit."

SPECIFIC GRAVITY & VAPOUR PRESSURE OF WATER

Temp. deg. F.	Temp. deg. C.	Specific gravity	Vapour pressure lb. per sq. in. absolute	Temp. deg. F.	Temp. deg. C.	Specific gravity	Vapour pressure lb. per sq. in. absolute	Temp. deg. F.	Temp. deg. C.	Specific gravity	Vapour pressure lb. per sq. in. absolute
39.1	4.0	1.0000	.1176	180	82.2	.9709	7.510	360	182.2	.8851	153.01
50	10.0	.9998	.1780	200	93.3	.9633	11.525	380	193.3	.8725	195.70
60	15.6	.9994	.2561	212	100.0	.9593	14.696	400	204.4	.8590	247.25
70	21.1	.9981	.3628	220	104.4	.9558	17.188	420	215.6	.8549	308.82
80	26.7	.9969	.5067	240	115.6	.9479	24.97	440	226.7	.8419	381.59
90	32.2	.9950	.6980	260	126.7	.9390	35.43	460	237.8	.8173	466.94
100	37.8	.9932	.9487	280	137.8	.9288	49.20	480	248.9	.8010	566.26
120	48.9	.9889	1.692	300	148.9	.9196	67.01	500	260.0	.7815	681.09
140	60.0	.9834	2.887	320	160.0	.9092	89.65	520	271.1	.7628	812.72
160	71.1	.9774	4.739	340	171.1	.8975	117.99	540	282.2	.7417	962.73

GENERAL PUMPING DATA

VARIATION OF BAROMETER WITH ALTITUDE



SPECIFIC GRAVITY CONVERSION TABLES

FOR LIQUIDS HEAVIER THAN WATER

$S.G. = \frac{145}{145 - {}^\circ\text{Baumé}}$ $S.G. = \frac{200 + {}^\circ\text{Twaddell}}{200}$

Brix	S.G.	T	Be	Brix	S.G.	T	Be	Brix	S.G.	T	Be	Brix	S.G.	T	Be	Brix	S.G.	T	Be
0	1·00	0	0	24	1·101	20·2	13·35	48	1·220	44	26·30	64	1·314	62·8	34·64	79	1·410	82	32·10
2	1·01	2	1·13	26	1·110	22	14·45	50	1·230	46	27·38	66	1·326	65·2	35·66	80	1·420	84	42·60
4	1·017	3·4	2·24	28	1·120	24	15·54	51	1·238	47·6	27·91	68	1·340	68	36·67	82	1·430	86	43·50
6	1·022	4·4	3·37	30	1·130	26	16·63	52	1·244	48·8	28·43	70	1·351	70·2	37·66	84	1·440	88	44·50
8	1·03	6	4·49	32	1·140	28	17·73	53	1·249	49·8	28·96	71	1·357	71·4	38·17	86	1·460	92	45·44
10	1·04	8	5·60	34	1·150	30	18·81	54	1·255	51	29·48	72	1·364	72·8	38·66	88	1·470	94	46·60
12	1·066	9·2	6·71	36	1·160	32	19·90	55	1·261	52·2	30·00	73	1·370	74	39·16	90	1·480	96	47·30
14	1·057	11·4	7·81	38	1·170	34	20·98	56	1·267	53·4	30·53	74	1·376	75·2	39·65	92	1·500	100	48·20
16	1·066	13·2	8·94	40	1·180	36	22·10	57	1·272	54·4	31·05	75	1·383	76·6	40·15	94	1·510	102	49·10
18	1·074	14·8	10·04	42	1·190	38	23·13	58	1·278	55·6	31·56	76	1·389	77·8	40·64	96	1·530	106	50
20	1·083	16·6	11·15	44	1·200	40	24·20	60	1·290	58	32·60	77	1·396	79·2	41·12	98	1·540	108	51
22	1·092	18·4	12·30	46	1·210	42	25·26	62	1·302	60·4	33·60	78	1·403	80·6	41·61	100	1·560	112	52

FOR LIQUIDS LIGHTER THAN WATER

Specific Gravity $= \frac{141{\cdot}5}{131{\cdot}5^\circ \text{ A.P.I.}}$

Degrees A.P.I.	Specific Gravity	Degrees A.P.I.	Specific Gravity	Degrees A.P.I.	Specific Gravity	Degrees A.P.I.	Specific Gravity
10	1·0000	30	·8762	50	·7796	70	·7022
15	·9659	35	·8498	55	·7587	75	·6852
20	·9340	40	·8251	60	·7389	80	·6690
25	·9042	45	·8017	65	·7201	85	·6536

GENERAL PUMPING DATA

VISCOMETER CONVERSION TABLE

Redwood No. 1 Seconds	Kinematic Viscosity Stokes (C.G.S. units)	Redwood No. 2 Seconds	Saybolt Universal Seconds	Saybolt Furol Seconds	Engler Degrees
29	0·010	—	31	—	1·0
40	0·0581	—	45	—	1·47
50	0·0940	—	57	—	1·78
60	0·1267	—	69	—	2·09
70	0·1577	—	80	—	2·41
80	0·1875	—	92	—	2·73
90	0·2151	—	104	—	3·04
100	0·2405	—	115	—	3·34
120	0·2910	—	137	—	3·96
140	0·3411	—	159	—	4·58
160	0·3911	—	181	—	5·22
180	0·4410	—	204	—	5·86
200	0·4908	—	226	25	6·51
250	0·6149	—	282	30	8·09
300	0·7388	—	338	35	9·72
350	0·8626	—	394	40	11·35
400	0·9654	—	450	46	12·97
450	1·1101	—	506	51	14·61
500	1·2337	—	562	57	16·23
600	1·4809	—	674	69	19·49
700	1·7281	—	786	80	22·74
800	1·9752	—	899	91	25·99
900	2·2223	—	1010	103	29·24
1000	2·470	100	1120	114	32·49
1200	2·964	120	1350	137	38·99
1400	3·458	140	1570	160	45·49
1600	3·952	160	1800	183	51·99
1800	4·446	180	2020	206	58·49
2000	4·940	200	2250	229	65·00
2200	5·434	220	2470	252	71·50
2400	5·928	240	2690	274	78·00
2600	6·422	260	2920	297	84·50
2800	6·916	280	3140	320	91·00
3000	7·410	300	3370	343	97·50

$$\text{Kinematic Viscosity (in Stokes)} = \frac{\text{Absolute Viscosity (in Poises)}}{\text{Specific Gravity.}}$$

Poises = 100 Centipoises.

VISCOMETER CONVERSION FORMULAE

Viscometer	Range over which Formula holds good	Kinematic Viscosity, Stokes (C.G.S. Units)
Redwood No. 1	T = 40–85 secs.	$v = 0{\cdot}00264T - \frac{1{\cdot}90}{T}$
	T = 85–2000 secs.	$v = 0{\cdot}00247T - \frac{0{\cdot}65}{T}$
Redwood No. 2	T = above 100 secs.	$v = 0{\cdot}0247T$
Engler	E = up to 7°E	$v = 0{\cdot}01E \times 7{\cdot}6^{(1-E^{-3})}$
	E = above 7°E	$v = 0{\cdot}076E$
Saybolt Universal	T = up to 100 secs.	$v = 0{\cdot}00226T - \frac{1{\cdot}95}{T}$
	T = above 100 secs.	$v = 0{\cdot}00220T - \frac{1{\cdot}35}{T}$
Saybolt Furol	T = 25–40 secs.	$v = 0{\cdot}0224T - \frac{1{\cdot}90}{T}$
	T = above 40 secs.	$v = 0{\cdot}0216T$

The Redwood No. 2 and Saybolt Furol are specially designed for measuring the more viscous oils and give a reading in seconds approximately one tenth of that given for the same oil by the Redwood No. 1 and Saybolt Universal respectively.

If viscosity is given at any two temperatures, the viscosity at any other temperature may be estimated by plotting the viscosity against temperature in degrees on logarithmic graph paper. The points for a given oil lie approximately in a straight line.

GENERAL PUMPING DATA

FRICTION LOSSES IN PIPING AND FITTINGS

The following charts show the frictional losses for water, in feet per 100 feet of straight wrought iron, or cast iron piping of average age. The charts also show the approximate water velocities in feet per second.

For other classes and conditions of piping, the losses given by the charts are to be multiplied by the following factors—

Clean, new piping	0.7
Old piping	1.51
Clean, new smooth piping (solid drawn brass, copper, aluminium, lead, glass, plastics)	0.59
Smooth piping, approx. 10 years old.	0.73
New steel pipes	0.62
Riveted steel piping	1.2
Fire hose (rubber lined)	0.77
Fire hose (unlined linen canvas)	1.22

For friction losses with viscous liquids in steel pipes, see instructions on page 19 and associated charts.

The above factors cannot be used in conjunction with the friction loss charts for viscous liquids in steel pipes.

For small differences in diameter such as actual manufactured diameter to nominal diameter the friction loss can be taken as inversely proportional to the fifth power of the diameters.

The charts for water and viscous liquids are all based on up-to-date information at the time of publishing.

When calculating pipe losses, allowances must be included for tees, bends, valves, strainers, and other fittings in the pipe line and this is done by adding an allowance of straight pipe equivalent to each fitting, so that the losses can be taken from the friction charts.

Each type of fitting is taken to be equivalent to a straight pipe with a length equal to a certain number of times the bore of the fitting. The equivalent straight length in feet

$$= \frac{\text{Bore in inches x number of diameters}}{12}$$

For each of the usual standard fittings, the number of diameters is as follows:-

Square elbow	60	dias.
Square tee	60	,,
Rounded elbow	40	,,
Short right angle bend, Rad.=1 dia.	25	,,
Long right angle bend, Rad. = 3-5 dias.	20	,,
45° Bend	15	,,
Sluice Valve, full open	10	,,
Reflux or Foot Valve, hinged flap	40	,,
Straight through Mushroom Valve or Foot Valve	100	,,
Right angle Globe Valve	150	,,
Straight through Globe Valve	200	,,
Sharp edged entrance or orifice	20	,,
Sudden enlargement	20	,,
Basket or perforated strainer, twice pipe area	15	,,
Basket or perforated strainer, three times pipe area	9	,,

Fittings for fire fighting apparatus are usually very poor hydraulically and ample allowances should be made for these.

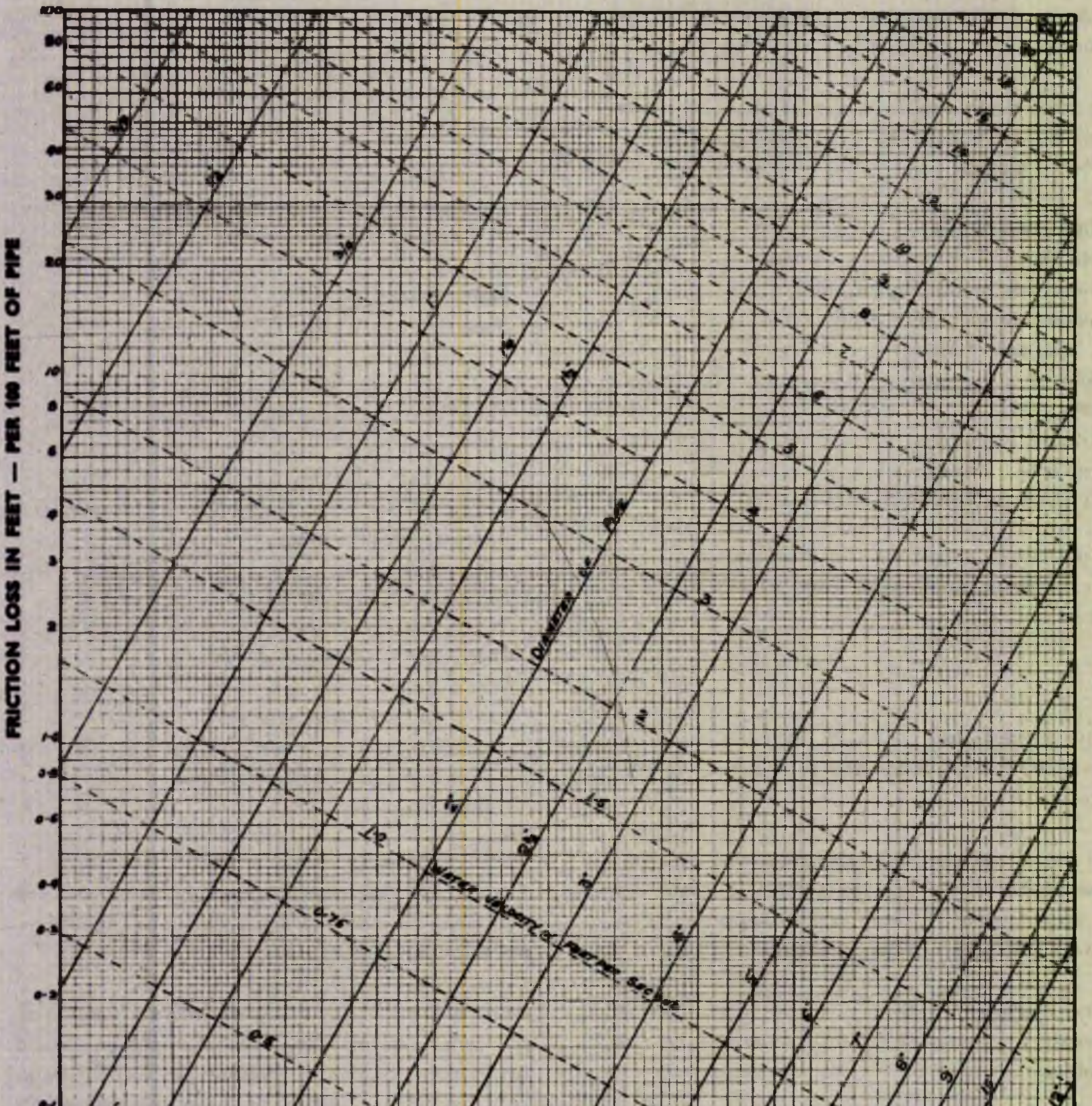
When estimating total heads, all items and features of the installation must be taken into account— static lift, vacuum or positive pressure on suction, static head, positive pressure or other resistances on discharge side, syphonic assistance, etc., and losses in all piping and fittings.

When the total head is low, 25 feet and under, an allowance should be included for entering and exit velocity head loss.

GENERAL PUMPING DATA

FRICTION LOSS IN FT. — PER 100 FT. OF PIPE

Quantities 1 to 500 G.P.M.

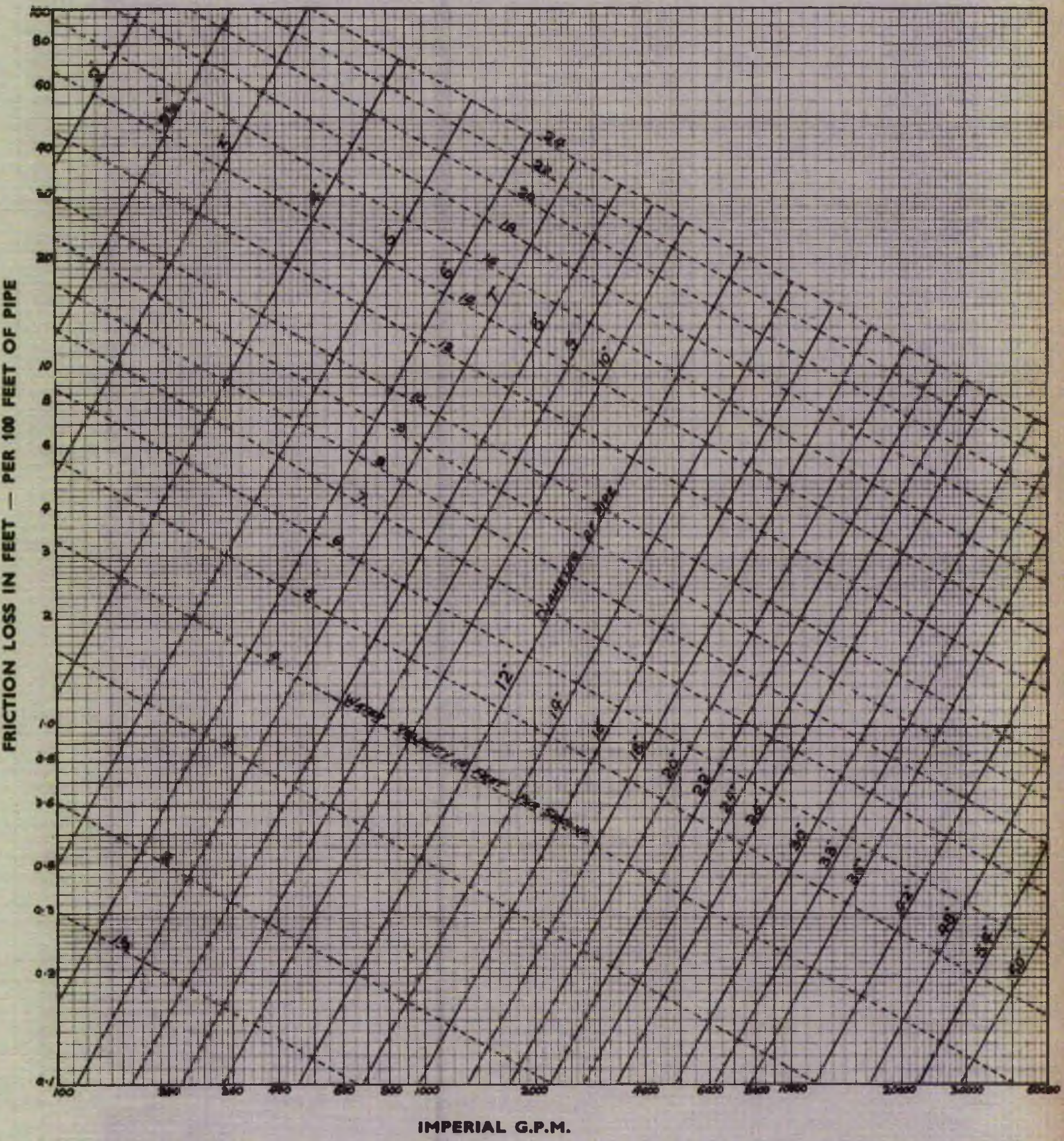


Curve No. $\frac{1783}{1969}$

GENERAL PUMPING DATA

FRICTION LOSS IN FT. — PER 100 FT. OF PIPE

Quantities 100 to 50,000 G.P.M.



Curve No. $\frac{1782}{1969}$

GENERAL PUMPING DATA

DISCHARGE OF JETS WITH DIFFERENT HEADS

These values are for well shaped fire fighting nozzles. For sharp edged holes multiply G.P.M. values by 0·6.

Head on Jet ft.	Dia. of Jet in Inches.																
	1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1	1¼	1½	1¾	2	2¼	2½
	Imperial Gallons per Min. Discharged.																
5	.537	1.21	2.15	3.36	4.83	6.58	8.59	13.4	19.3	26.3	34.4	53.7	77	105	137	174	215
10	.758	1.71	3.03	4.74	6.82	9.3	12.1	18.9	27.3	37.1	48.5	75.8	109	148	194	244	303
15	.929	2.09	3.72	5.81	8.36	11.4	14.8	23.2	33.4	45.5	59.4	92.9	134	182	238	301	372
20	1.07	2.41	4.29	6.7	9.66	13	17.2	26.8	38.6	52.6	68.6	107	154	210	274	347	429
25	1.2	2.7	4.8	7.5	10.8	14.7	19.2	30	43.2	58.8	76.8	120	173	235	307	389	480
30	1.31	2.95	5.25	8.21	11.8	16.1	21	32.8	47.3	64.4	84.1	131	189	258	336	426	525
35	1.42	3.19	5.68	8.87	12.8	17.4	22.7	35.5	51.1	69.6	90.9	142	204	278	364	460	568
40	1.52	3.41	6.07	9.48	13.6	18.6	24.7	37.9	54.6	74.3	97.1	152	218	297	388	491	609
45	1.61	3.62	6.44	10.1	14.5	20.2	25.8	40.3	58	80.7	103	161	232	323	412	522	644
50	1.7	3.82	6.79	10.6	15.2	21.3	27.1	42.4	61.1	84.9	109	170	244	340	434	550	680
60	1.86	4.18	7.44	11.6	16.7	22.8	29.7	46.4	66.9	91.9	119	186	267	364	476	602	744
70	2.06	4.52	8.03	12.5	18.1	24.5	32.6	50.6	72.3	98.4	129	206	289	393	514	650	803
80	2.14	4.83	8.58	13.4	19.3	26.3	34.3	53.6	77.2	105	137	215	309	421	549	695	858
90	2.27	5.12	9.1	14.2	20.5	27.9	36.4	56.9	82	111	145	227	328	446	593	738	910
100	2.4	5.4	9.6	15	21.6	29.4	38.4	60	86.4	117	153	240	346	471	615	778	960
110	2.52	5.66	10.1	15.7	22.6	30.9	40.3	62.9	90.6	123	161	252	362	493	644	815	1010
120	2.63	5.91	10.5	16.4	23.6	32.6	42	65.7	94.6	130	168	263	378	522	673	852	1052
130	2.72	6.15	10.9	17.1	24.6	33.5	43.7	68.4	98.5	134	175	273	394	536	700	886	1094
140	2.84	6.39	11.2	17.7	25.5	34.8	45.4	71	102	139	181	284	409	557	727	920	1136
150	2.94	6.61	11.7	18.4	26.4	36	47	73.5	106	144	183	294	423	576	752	952	1176
175	3.17	7.14	12.7	19.8	28.5	39	50.8	79.4	114	156	203	317	457	624	813	1029	1270
200	3.39	7.63	13.5	21.2	30.5	41.5	54.3	84.8	122	166	217	339	490	665	869	1099	1358
250	3.79	8.53	15.1	23.7	34.1	46.5	60.7	94.8	136	186	243	379	546	744	971	1230	1518
300	4.15	9.35	16.6	25.9	37.4	50.1	66.5	104	149	204	266	415	598	816	1064	1346	1663

HEIGHT OF JETS WITH DIFFERENT HEADS

Head on Jet ft.	Diameter of Jet in Inches.																
	1/8	3/16	1/4	5/16	3/8	7/16	1/2	5/8	3/4	7/8	1	1¼	1½	1¾	2	2¼	2½
	Height of Jet in Feet																
5	4.7	4.8	4.85	4.88	4.9	4.9	4.92	4.94	4.95	4.96	4.97	4.97	4.98	4.98	4.98	5	5
10	8.75	9.15	9.37	9.5	9.6	9.65	9.7	9.75	9.8	9.82	9.84	9.87	9.9	9.91	9.92	9.93	9.94
15	12.18	13.1	13.6	13.9	14	14.2	14.3	14.45	14.5	14.6	14.65	14.7	14.77	14.8	14.83	14.85	14.86
20	15	16.7	17.5	18	18.33	18.6	18.75	19	19.2	19.3	19.4	19.5	19.6	19.6	19.7	19.73	19.75
25	17.2	19.8	21.1	21.9	22.4	22.8	23	23.5	23.7	23.9	24	24.2	24.3	24.4	24.5	24.57	24.6
30	19	22.5	24.4	25.5	26.25	26.8	27.2	27.75	28.3	28.4	28.6	29	29.1	29.2	29.3	29.38	29.44
35	19.7	24.8	27.4	28.9	29.9	30.4	31.2	32	32.5	32.8	33.1	33.5	33.7	33.9	34	34.1	34.2
40	20	27	30	32	33.3	34.3	35	36	37	37.1	37.5	38	38.3	38.6	38.7	38.9	39
45	19.6	28	32.4	34.9	36.6	37.8	38.7	40	40.8	41.4	41.8	42.5	42.9	43.2	43.4	43.6	43.7
50		29	34.4	37.5	39.6	41	42.2	44	45	45.5	46.1	47	47.4	47.8	48	48.3	48.4
60		30	37.5	42	45	47	48.7	51	52	53.5	54.4	55	56.2	56.6	57	57.5	57.7
70			39	45	50	52	55	58	60	61	62.4	64	65	65.6	66	66.6	66.9
80			40	48	53	57	60	64	67	68	70	72	73.3	74.2	75	75.5	76
90				49	56	61	65	70	73	75	77	80	81.6	83	84	84	85
100				50	58	64	69	75	79	82	84	87	90	91	92	93	93.7
110					60	67	72	80	85	88	91	95	97	99	100	101	102
120						68	75	84	90	94	97	102	105	107	109	110	111
130						70	77	88	95	100	104	109	112	115	117	118	119
140							79	91	99	105	109	116	120	123	125	126	128
150							80	94	103	110	115	122	126	130	132	134	136
160								96	106	114	120	128	133	137	140	142	144
175								98	111	120	127	137	143	148	151	154	156
180								99	112	122	129	139	146	151	155	157	160
200								100	116	129	137	150	158	166	169	172	175
220									119	133	145	159	165	177	182	186	190
240									120	137	150	168	180	189	195	200	204
250										138	152	172	185	194	201	206	211
260											155	175	190	200	203	213	218
280											158	182	198	210	219	225	231
300											160	187	206	220	230	237	244
350												198	222	241	255	265	279
400												200	233	257	275	289	300

D = Dia. of Nozzle in 1/8 inches.
G = G.P.M. Imperial.
H = Actual Pressure at Nozzle in Feet of Water.
40 Ft. Max. Press. for each 1/8" of Jet.
h = Maximum Height of Jet in Feet.

$$D = \sqrt{\frac{G}{\cdot 24\sqrt{H}}}$$

$$G = \cdot 24D^2\sqrt{H}$$

$$H = \left(\frac{G}{\cdot 24\ D^2}\right)^2$$

$$h = H - \frac{\cdot 0125H^2}{D}$$

GENERAL PUMPING DATA

CALCULATION OF AVAILABLE N.P.S.H.

As described on page 2, the N.P.S.H. requirement of a pump depends only on the pump itself, and can (in most cases) be read off the curve when making the selection. For the selected pump to operate satisfactorily, the system to which it is applied must provide at least as much N.P.S.H. as that required by the pump, and preferably a margin to cover unknown factors.

As already mentioned, the N.P.S.H. available is the difference in feet between the pressure available at the pump suction flange and the vapour pressure of the liquid at the pumping temperature. The most convenient method of calculating the N.P.S.H. available is to determine the Temperature Advantage, add or subtract the suction head or suction lift, and finally subtract the friction loss in the suction line.

Temperature Advantage is the difference between the pressure acting on the liquid surface, and the vapour pressure of the liquid at the pumping temperature, converted to feet head of liquid.

$$\text{N.P.S.H. Available} = \left\{\begin{matrix}\text{Temperature}\\ \text{Advantage}\end{matrix}\right\} \begin{matrix} + \text{(Suction Head)} \\ - \text{(Suction Lift).}\end{matrix} - \text{Friction loss.}$$

$$\text{N.P.S.H. Available} = (P - Vp)\frac{2.31}{SG} \pm Hs - Hf$$

Where P = Pressure acting on the liquid surface in P.S.I.A.
Vp = Vapour pressure of liquid at pumping temperature in P.S.I.A.
Hs = Suction Head or Suction Lift in feet.
Hf = Friction loss in suction line in feet.

The pressure acting on the liquid surface may be atmospheric as in the case of an open tank, or vacuum as in the case of a condenser, or above atmospheric as in the case of a de-aerator.

To allow for normal variations in the barometer it is a good practice to use 14·1 P.S.I.A. (28·7" Hg) rather than the standard atmospheric pressure of 14·7 P.S.I.A. With export enquiries in particular, attention should be given to the height above sea level of the installation, and a correction applied to the barometer according to the curve on page 7.

The following typical examples will illustrate the procedure.

1. To find the N.P.S.H. available with a static suction lift of 10 ft., 3 ft. friction loss, and a water temperature of 70°F.

$$Vp = 0.363 \quad SG = 0.998 \text{ at } 70°\text{F.}$$

$$\begin{aligned}\text{N.P.S.H. available} &= (14.1 - 0.363)\frac{2.31}{0.998} - 10 - 3\\ &= 31.8 - 10 - 3\\ &= \mathbf{18.8\ feet}\end{aligned}$$

2. Find the maximum permissible total suction lift when pumping water at 60°F. with a pump requiring 15 ft. N.P.S.H.

$$Vp = 0.256 \quad SG = 0.999 \text{ at } 60°\text{F.}$$

$$\text{N.P.S.H.} = 15 = (14.1 - 0.256)\frac{2.31}{0.999} - Hs - Hf$$

$$\begin{aligned}Hs + Hf = \text{total suction lift} &= (14.1 - 0.256)\frac{2.31}{0{\cdot}999} - 15\\ &= 32.0 - 15\\ &= \mathbf{17\ feet}\end{aligned}$$

GENERAL PUMPING DATA

3. An extraction pump is to draw from a condenser containing water at 91·6°F. and a vacuum of 28·5" Hg. Find the necessary positive suction head required for a pump requiring 5 ft. N.P.S.H. if there is a suction line loss of 0·5 ft.

Reference to steam tables shows that these are equivalent conditions, i.e. the water is boiling. In this case the Temperature Advantage is zero.

$$\text{N.P.S.H.} = 0 + \text{Hs} - 0{\cdot}5 \text{ ft.} = 5$$
$$\therefore \text{Hs} = 5 + 0{\cdot}5 = 5{\cdot}5 \text{ ft.}$$

4. A boiler feed pump drawing feed water heated to 180°F. from an open tank. The pump requires 18 ft. N.P.S.H. Find the necessary positive suction head if the suction line losses amount to 1 ft.

$$\text{Vp} = 7.51 \text{ P.S.I.A.} \quad \text{S.G.} = 0.9708 \text{ at } 180°\text{F.}$$
$$18 = (14.1 - 7.51)\,\frac{2.31}{0.9709} + \text{Hs} - 1.0$$
$$18 = 15.66 + \text{Hs} - 1.0$$
$$\text{Hs} = 18.0 - 15.66 + 1.0 = 3.34 \text{ ft.}$$

SELECTING PUMPS FOR HOT WATER

When hot water is to be pumped against a pressure in lbs. per square inch, and when the capacity is stated in weight measurements, allowance must be made for the specific gravity of the water.

A table of temperatures and specific gravities is given on page 6.

If the capacity is given in bulk measurements, and the head in feet or equivalent, adjustment for specific gravity is not required, except in the calculation for W.H.P. and B.H.P.

EXAMPLES :

(1) 100,000 lbs. water per hour, 210°F. at 500 lbs. per sq. in., S.G. = .96

$$\text{G.P.M.} = \frac{100{,}000}{60 \times 10 \times .96} = 174$$

$$\text{Head in feet} = \frac{500 \times 2.31}{.96} = 1205$$

Pump must be selected for 174 G.P.M. at 1205 feet, using efficiency shown on curve for this duty.

$$\text{W.H.P.} = \frac{174 \times 10 \times .96 \times 1205}{33{,}000} = 61.0$$

(2) 10000 galls. per hour, 210°F., 500 lbs. per sq. in.

$$\text{G.P.M.} = \frac{10{,}000}{60} = 167$$

$$\text{Head} = \frac{500 \times 2.31}{.96} = 1205$$

Select for 167 G.P.M. 1205 feet and use efficiency at this duty.

$$\text{W.H.P.} = \frac{167 \times 10 \times .96 \times 1205}{33{,}000} = 58.5$$

(3) 100,000 lbs. water per hour, 210°F., 1155 ft. total head, S.G. = .96

$$\text{G.P.M.} = \frac{100{,}000}{10 \times 60 \times .96} = 174$$

Select for 174 G.P.M. 1155 ft. and use efficiency at this duty.

$$\text{W.H.P.} = \frac{174 \times 10 \times .96 \times 1155}{33{,}000} = 58.5$$

(4) 10,000 gallons per hour, 210°F., 1155 ft. total head, S.G. = .96

$$\text{G.P.M.} = \frac{10{,}000}{60} = 167$$

Select for 167 G.P.M. 1155 ft. and use efficiency at this duty.

$$\text{W.H.P.} = \frac{167 \times 10 \times .96 \times 1155}{33{,}000} = 56$$

The differences in W.H.P., which result in correspondingly different B.H.P., according to the units in which the duties are specified, should be noted.

Bear in mind that above certain temperatures, special features such as materials, water cooling, etc., are required.

GENERAL PUMPING DATA

DIAMETERS, AREAS AND DISPLACEMENTS

Diameter	Area	Displacement in Imperial Gallons per foot of Travel	Diameter	Area	Displacement in Imperial Gallons per foot of Travel	Diameter	Area	Displacement in Imperial Gallons per foot of Travel
in.			in.			in.		
⅛	.0122	.0005	6	28.27	1.221	15¾	194.8	8.415
¼	.0490	.0021	6¼	30.67	1.325	16	201.0	8.683
⅜	.1104	.0047	6½	33.18	1.433	16¼	207.3	8.955
½	.1963	.0084	6¾	35.78	1.545	16½	213.8	9.236
⅝	.3068	.0132	7	38.48	1.662	16¾	220.3	9.516
¾	.4417	.0190	7¼	41.28	1.783	17	226.9	9.802
⅞	.6013	.0259	7½	44.17	1.908	17¼	233.7	10.095
1	.7854	.0339	7¾	47.17	2.037	17½	240.5	10.389
1⅛	.9940	.0429	8	50.26	2.171	17¾	247.4	10.687
1¼	1.227	.0530	8¼	53.45	2.309	18	254.4	10.990
1⅜	1.384	.0641	8½	56.74	2.451	18¼	261.5	11.297
1½	1.767	.0763	8¾	60.13	2.597	18½	268.8	11.612
1⅝	2.073	.0895	9	63.61	2.747	18¾	276.1	11.927
1¾	2.405	.1038	9¼	67.20	2.903	19	283.5	12.247
1⅞	2.761	.1192	9½	70.88	3.062	19¼	291.0	12.571
2	3.141	.1356	9¾	74.66	3.225	19½	298.6	12.900
2⅛	3.546	.1531	10	78.54	3.393	19¾	306.3	13.232
2¼	3.976	.1717	10¼	82.51	3.564	20	314.1	13.569
2⅜	4.430	.1913	10½	86.59	3.740	20½	330.0	14.256
2½	4.908	.2120	10¾	90.76	3.920	21	346.3	14.960
2⅝	5.411	.2337	11	95.03	4.105	21½	363.0	15.681
2¾	5.939	.2565	11¼	99.40	4.294	22	380.1	16.420
2⅞	6.491	.2804	11½	103.8	4.484	22½	397.6	17.176
3	7.068	.3053	11¾	108.4	4.682	23	415.4	17.945
3⅛	7.669	.3313	12	113.0	4.881	23½	433.7	18.735
3¼	8.295	.3583	12¼	117.8	5.088	24	452.3	19.539
3⅜	8.946	.3864	12½	122.7	5.300	24½	471.4	20.364
3½	9.621	.4156	12¾	127.6	5.512	25	490.8	21.202
3⅝	10.32	.4458	13	132.7	5.732	25½	510.7	22.062
3¾	11.04	.4769	13¼	137.8	5.952	26	530.9	22.935
3⅞	11.79	.5193	13½	143.1	6.182	26½	551.5	23.824
4	12.56	.5426	13¾	148.4	6.410	27	572.5	24.732
4¼	14.18	.6125	14	153.9	6.649	27½	593.9	25.656
4½	15.90	.6868	14¼	159.4	6.886	28	615.7	26.598
4¾	17.72	.7655	14½	165.1	7.132	28½	637.9	27.567
5	19.63	.8480	14¾	170.8	7.388	29	660.5	28.533
5¼	21.54	.9348	15	176.7	7.633	29½	683.4	29.522
5½	23.75	1.026	15¼	182.6	7.888	30	706.8	30.533
5¾	25.96	1.121	15½	188.6	8.147			

BYPASS LINE FOR CLOSED VALVE OPERATION

It is often necessary to run a centrifugal pump against closed delivery valve for a short time, for instance during starting up, and this does no harm. However there are certain applications, boiler feeding with modulating flow control for example, where longer periods are involved, and this may lead to overheating of the water.

To prevent overheating it is necessary to arrange for a small permanent bypass flow back from the delivery side of the pump to the suction supply tank. Note that it is not sufficient to take the bypass back to the suction line.

The permissible temperature rise will depend upon several factors, but mainly upon the suction conditions and the feed water temperature. Too high a temperature rise may lead to flashing in the pump when the delivery valve is suddenly opened, with resultant drop in suction pressure. Where pumps are on suction lift the bypass flow should not be less than about 5% of the best efficiency capacity for the pump, or air may accumulate in the pump casing leading to depriming.

Since this bypass line will be permanently open, the pump should be able to meet the duty capacity plus the bypass flow rate at the duty head.

To simplify calculations, particularly where the length of the bypass line is unknown, it is usual to make it of ample size, and then fit an orifice plate to restrict the flow to the required value.

USE OF CHART :

The chart overleaf provides a ready means of sizing the orifice plate.

For the given pump there will be a closed valve B.H.P. absorbed. Entering the chart from the B.H.P. scale on the right hand side, and coming across to intersect the 10° temperature rise line will give the quantity of leak off required.

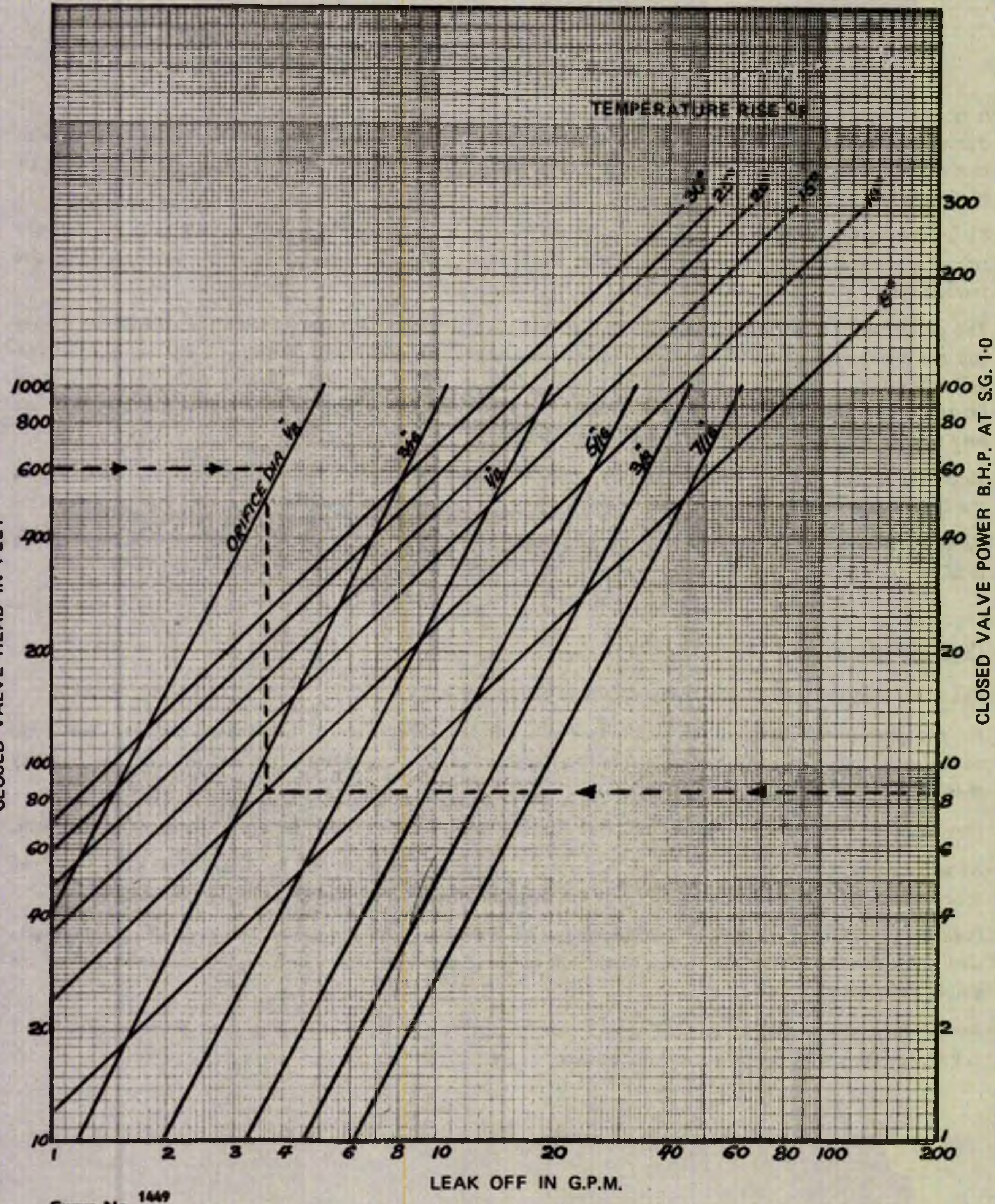
Moving up or down the line of leak off to the closed valve head indicates the appropriate orifice diameter.

As an example, consider a 2″—5 stage 'NT' for a duty of 68 G.P.M. × 500 ft. From the rating curve the approximate closed valve head and power are 600 ft. and 8.5 B.H.P.

Entering the chart at 8.5 B.H.P. indicates about 3.6 G.P.M. leak off required. This leak off rate intersects with a line coming in from 600 ft. just to the left of the ⅛″ diameter orifice line. In this case then a ⅛″ orifice would be selected.

At the duty head of 500 ft. this orifice will pass 3.5 G.P.M. therefore the pump must be selected for 71.5 G.P.M. × 500 ft. and the power calculated accordingly.

GENERAL PUMPING DATA



Curve No. $\frac{1449}{65}$

CHARTS FOR PIPES FRICTION WITH VISCOUS LIQUIDS

EXPLANATION OF CHARTS:

These pipe friction charts show the friction loss for the incompressible flow of viscous liquids including water in steel pipes of average age. Each chart covers the losses for a single size of pipe based on the kinematic viscosity in c/stokes.

The upper left-hand portion of each chart is a region of laminar flow and the lower right-hand portion is a region of turbulent flow. The laminar and tubulent regions are divided by a narrow zone which is chain dotted. This zone is a transition zone where the flow becomes unstable and changes to either laminar or turbulent.

INSTRUCTION FOR USE OF CHART:

Obtain the kinematic viscosity of the liquid in c/stokes from the viscometer conversion chart on W.S. 130, page 20.

Select the chart for the required pipe size and enter the chart at the capacity scale and follow vertically to the inter-section with the viscosity line then read off the friction loss per 100 ft. of pipe in the vertical scale.

If the intersection of capacity and viscosity lines indicate turbulent flow, but the viscosity is above the figures indicated, then a friction loss should be determined from the intersection of capacity with the upper limit of the transition zone.

EXAMPLE:

A flow of 10 g.p.m. through a 1" diameter pipe with a liquid viscosity of 5 c/stokes has a friction loss of 20 ft. per 100 ft. of pipe and the flow is turbulent. If the viscosity is increased to 10 c/stokes, the flow will be turbulent and the friction loss will be 24.5 ft. per 100 ft. of pipe as indicated by the intersection of the capacity line and the upper limit of the transition zone. With a further increase in viscosity to 35 c/stokes, the friction loss will be increased to 26 ft. per 100 ft. of pipe but the flow will be laminar.

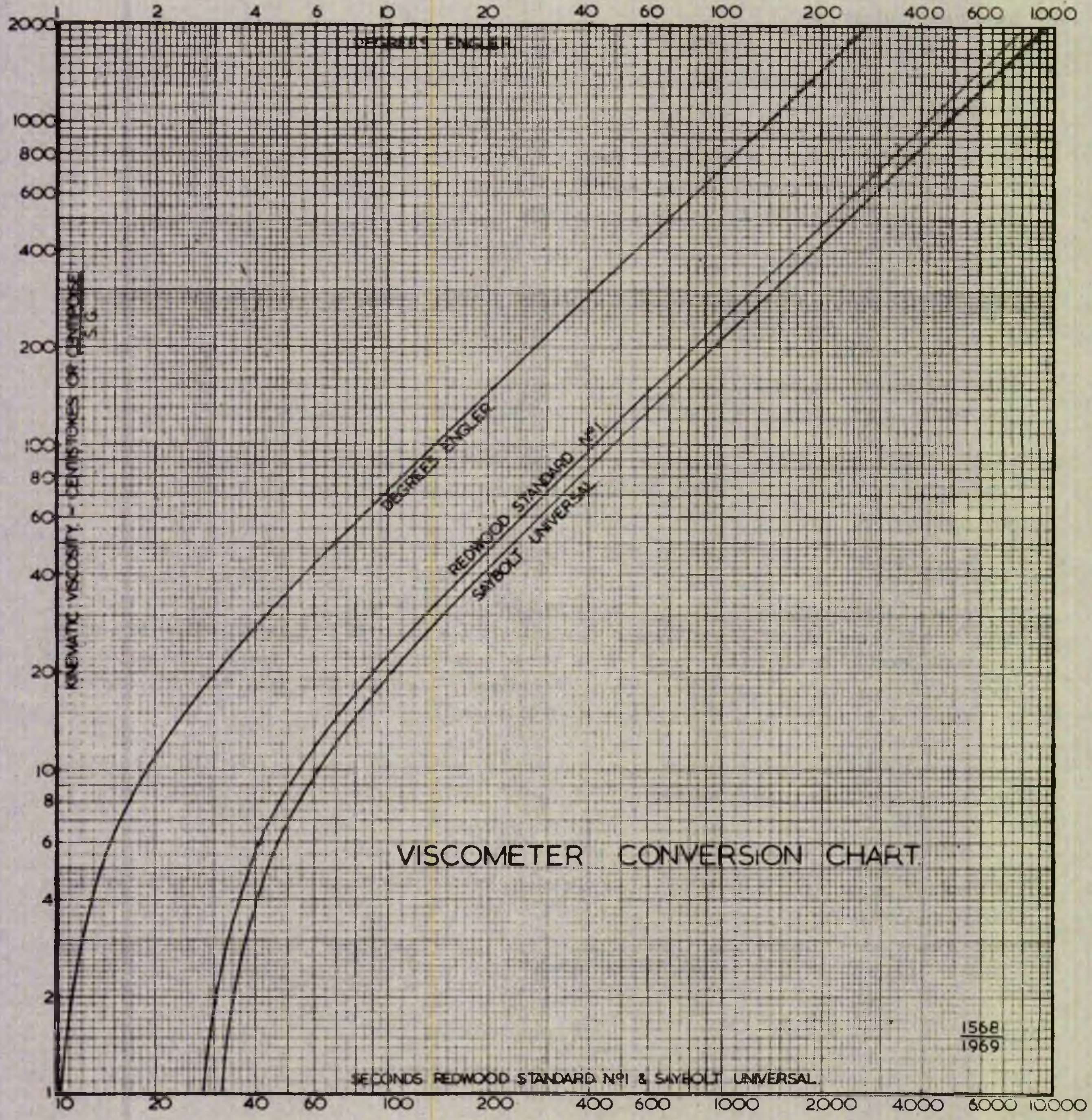
When calculating pipe losses, allowances must be included for tees, bends, valves, strainers and other fittings in the pipe line as explained in W.S. 130 page 9.

CAUTION:

It should be noted that the charts are only applicable to steel pipes and cannot be factored to give values for varying pipe materials.

Refer to Newark for losses in pipes of different materials.

GENERAL PUMPING DATA



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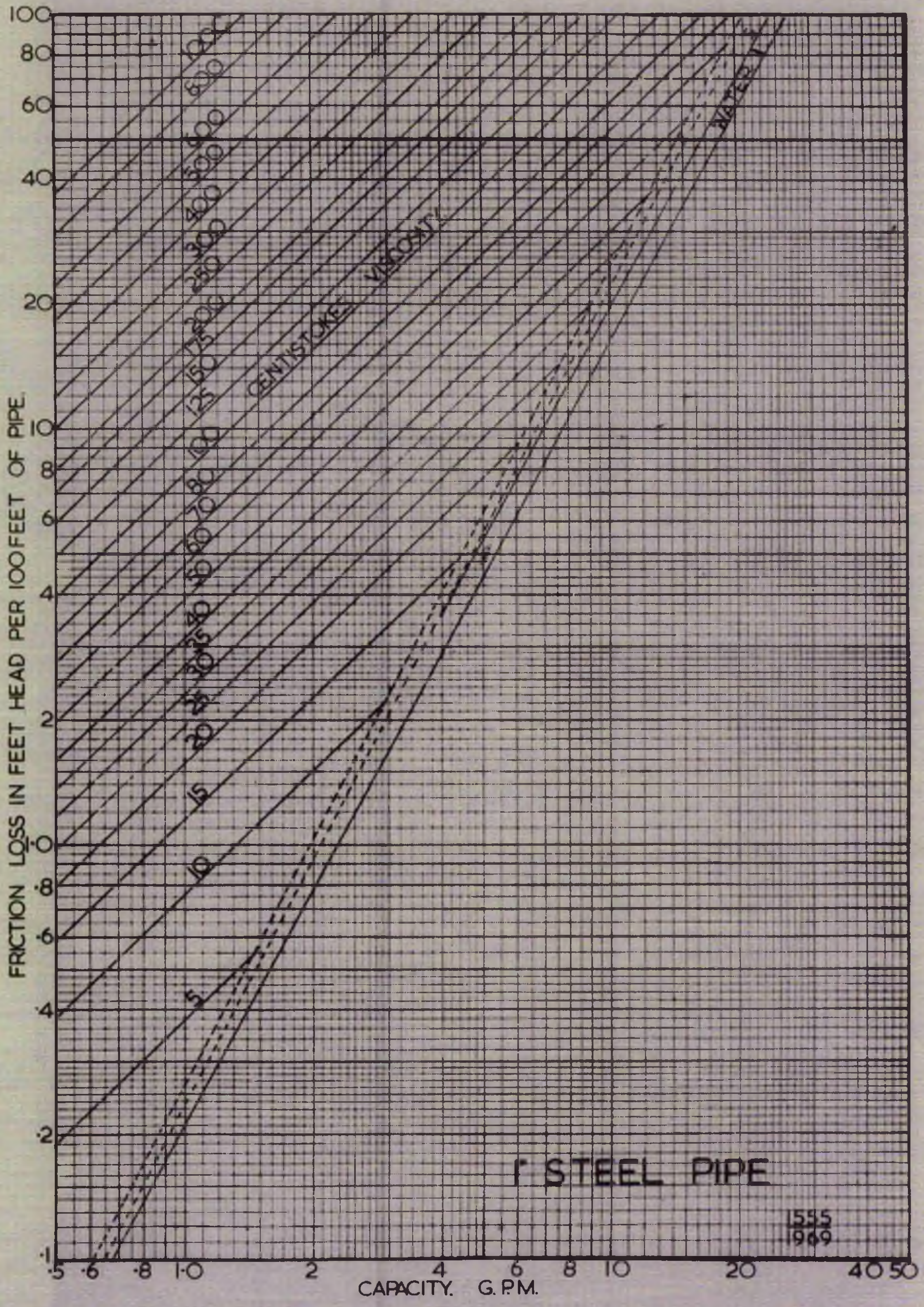

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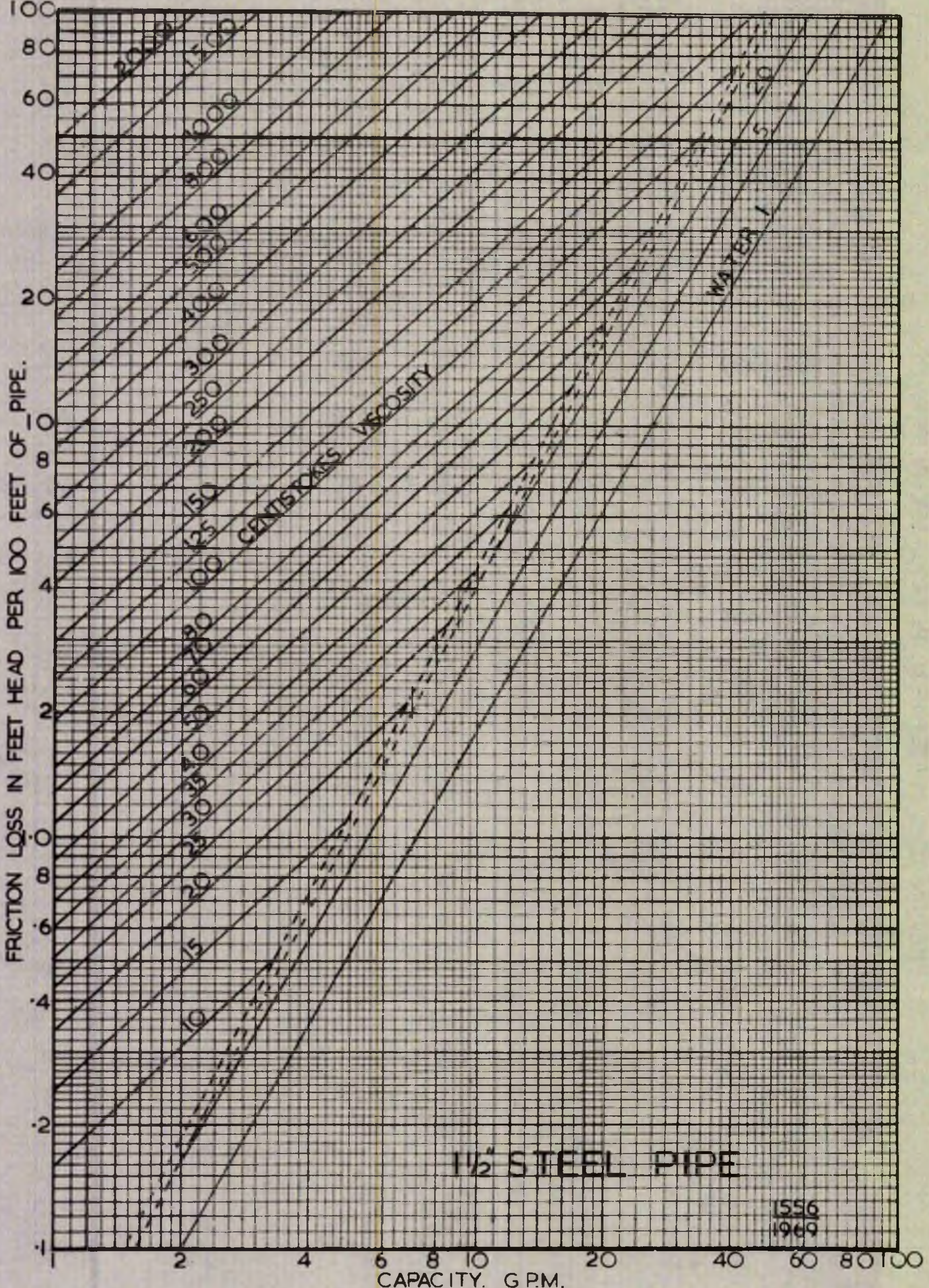
GENERAL PUMPING DATA



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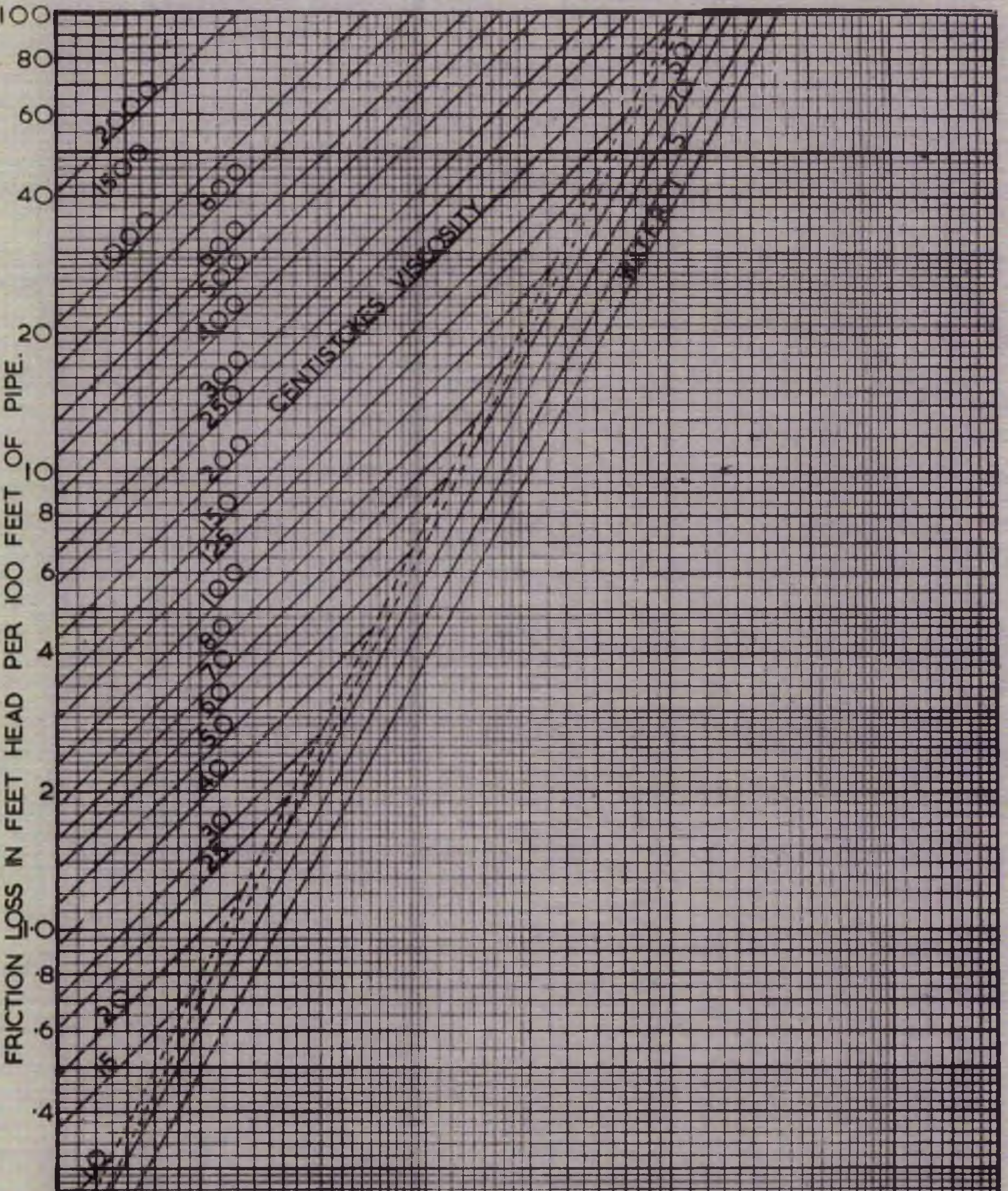

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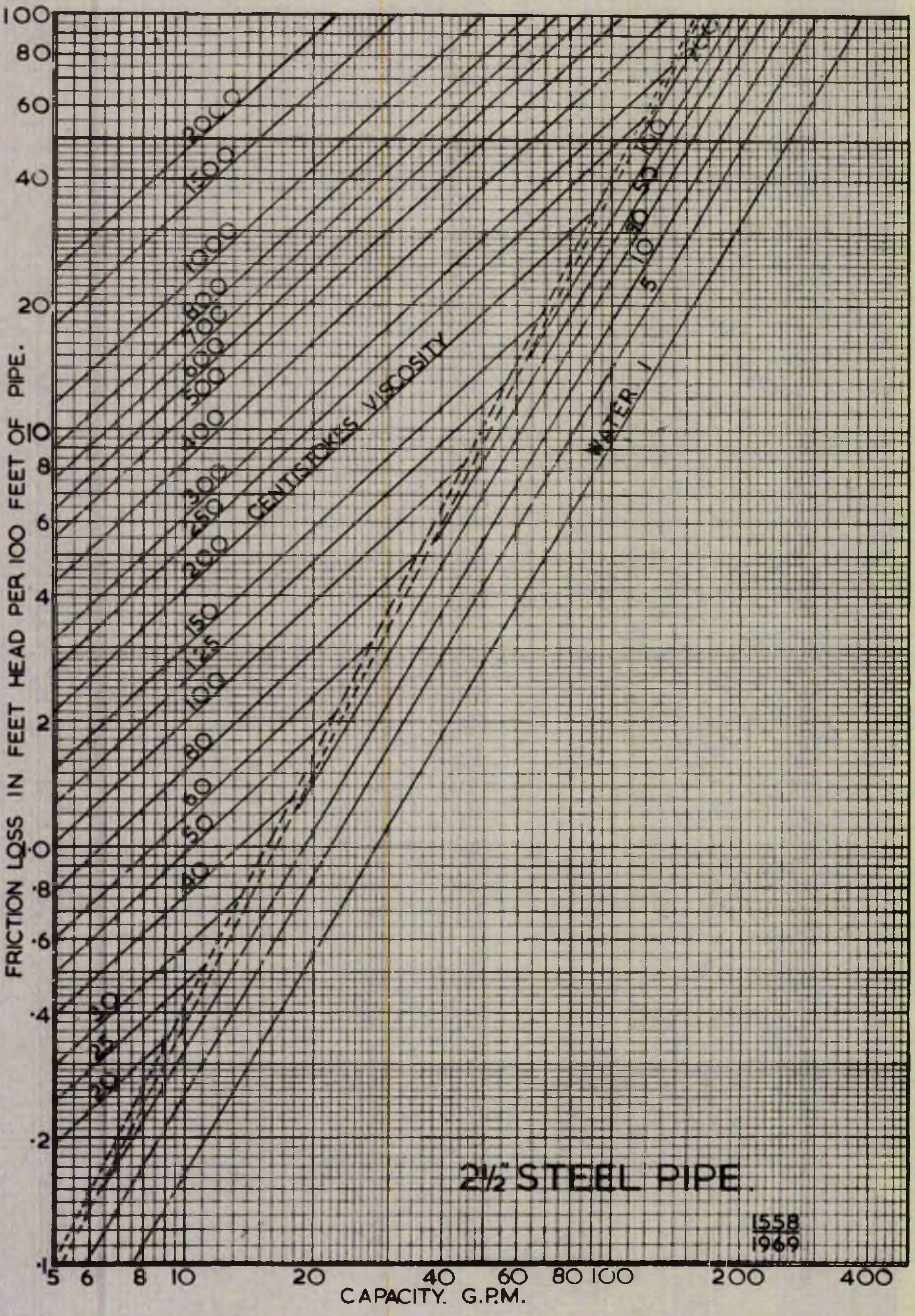

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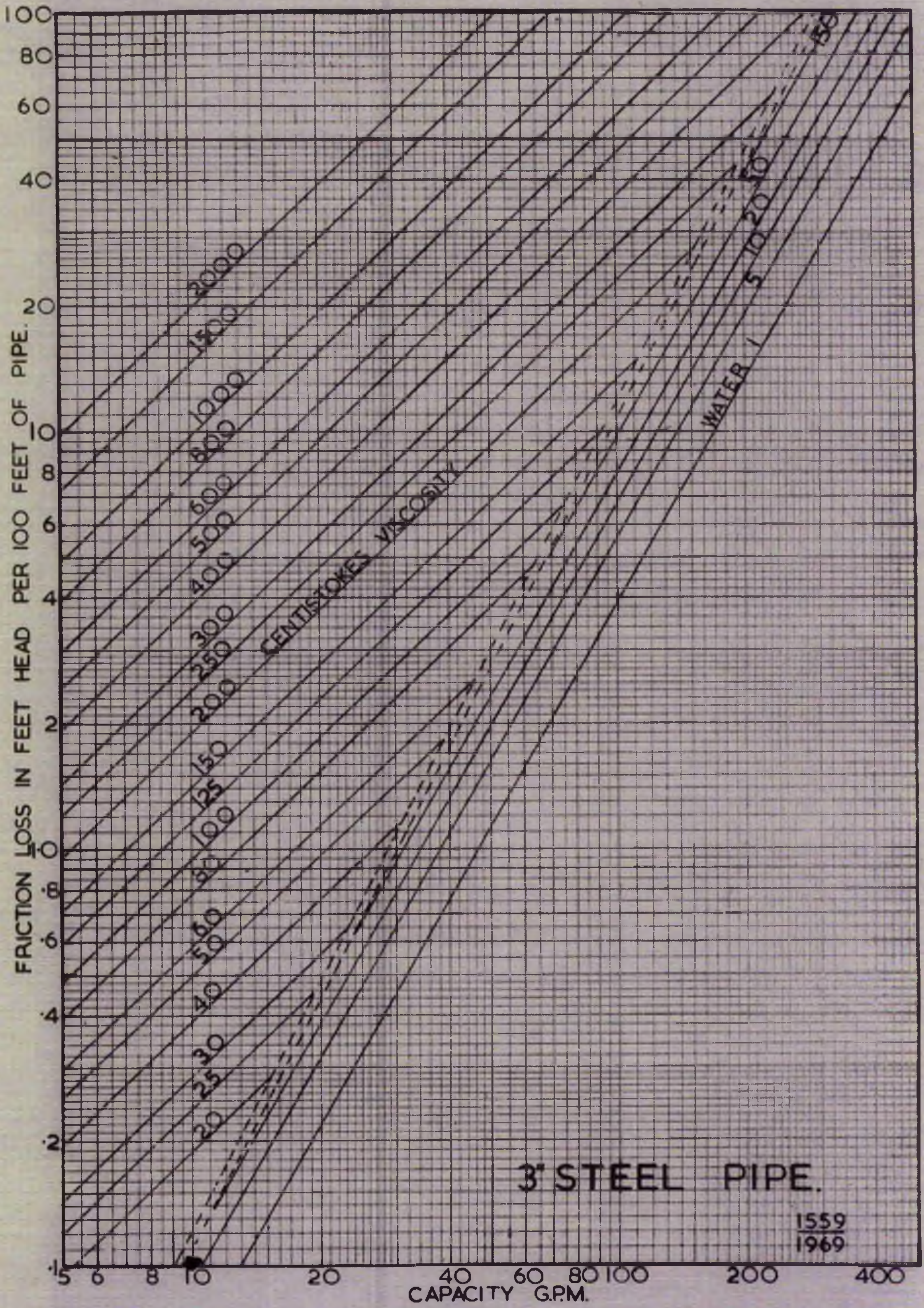

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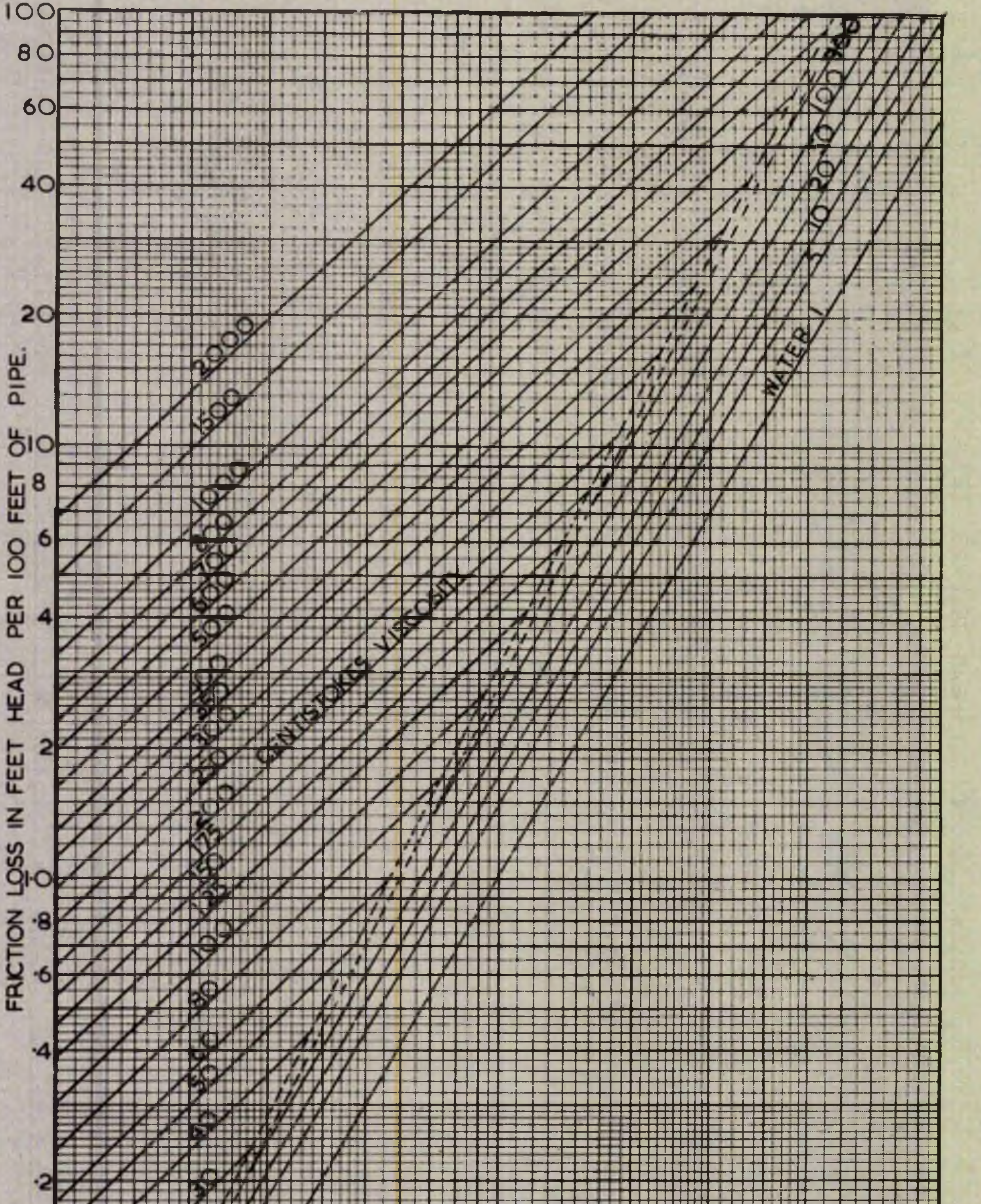

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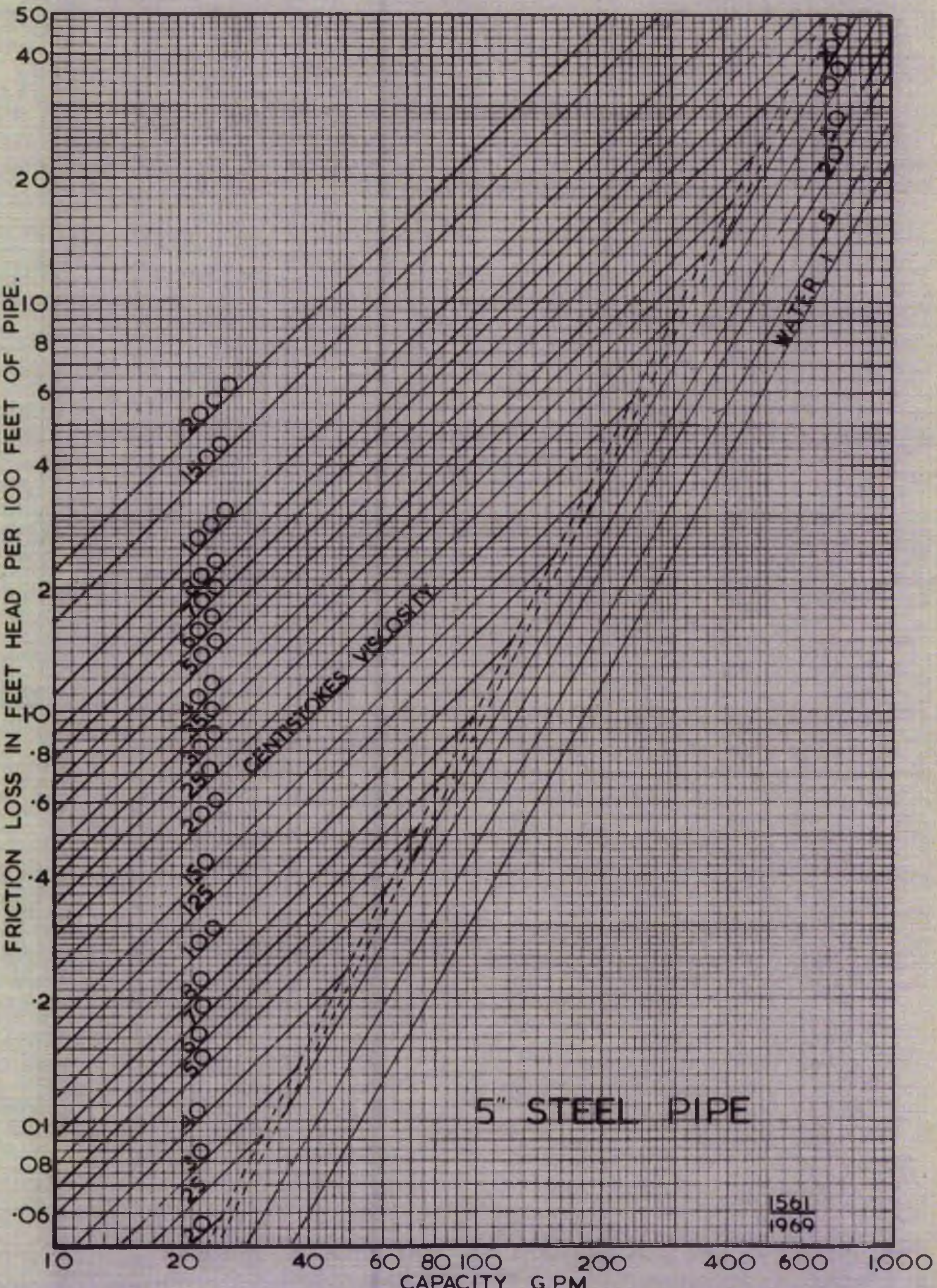

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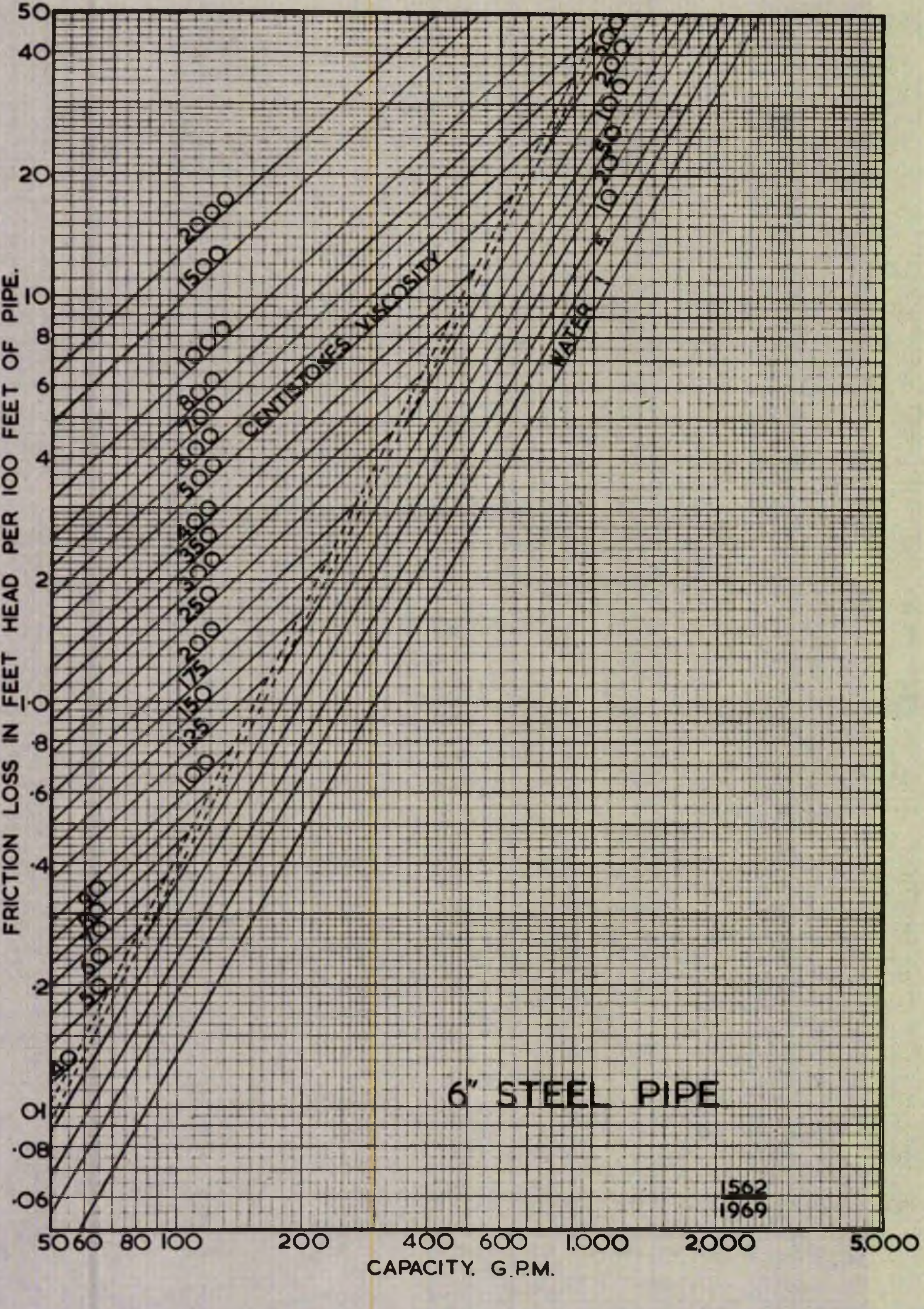

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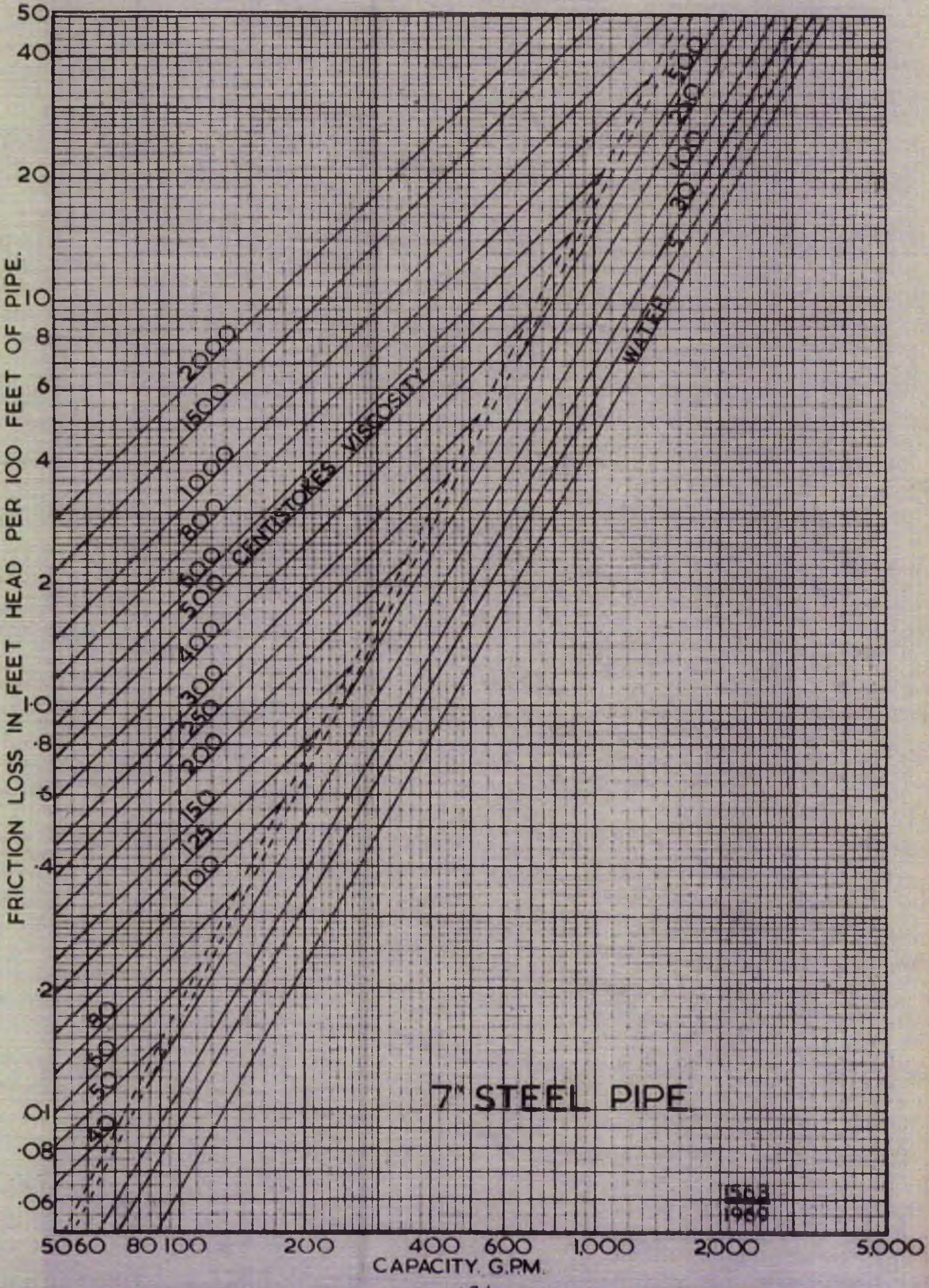
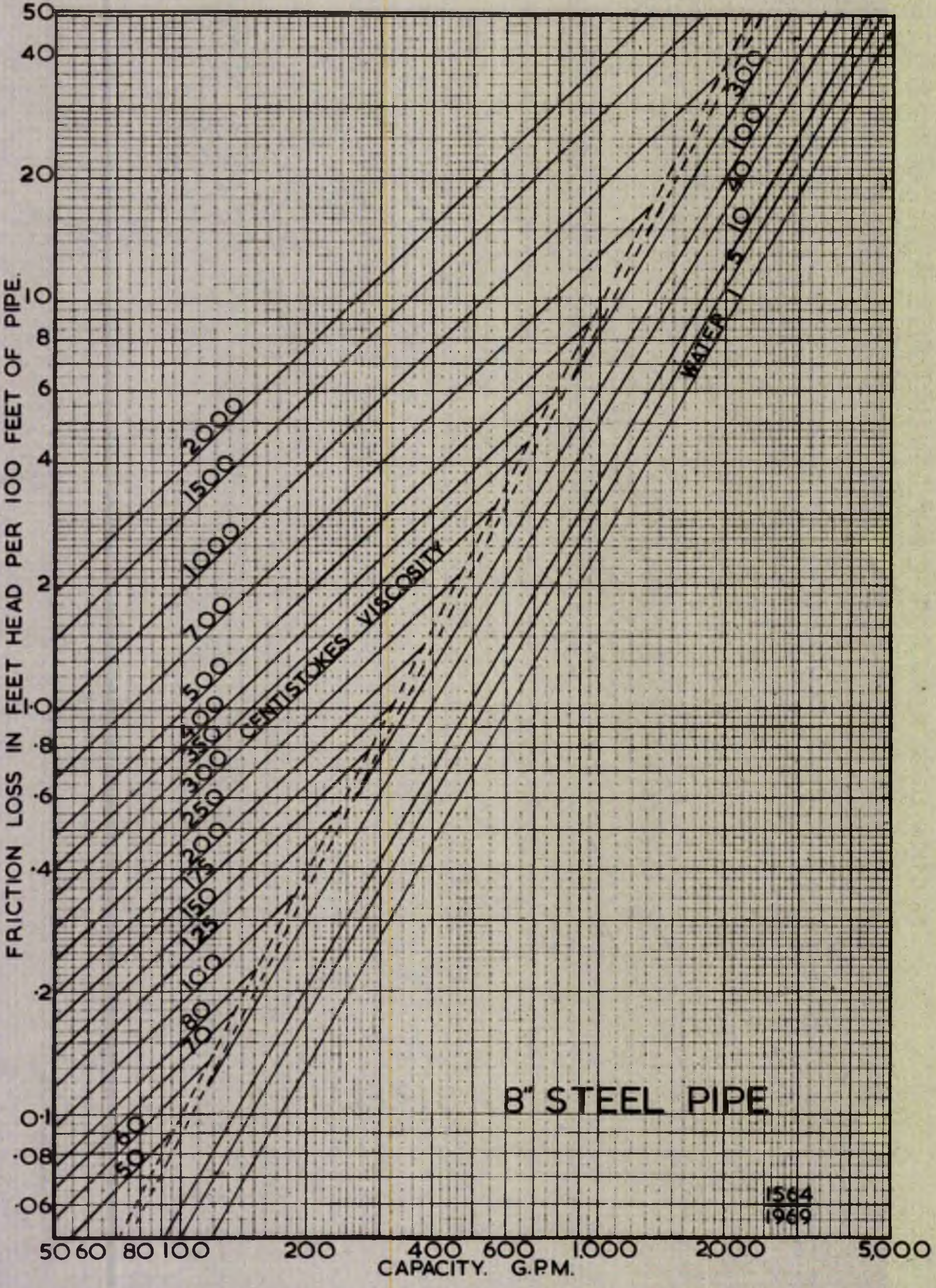
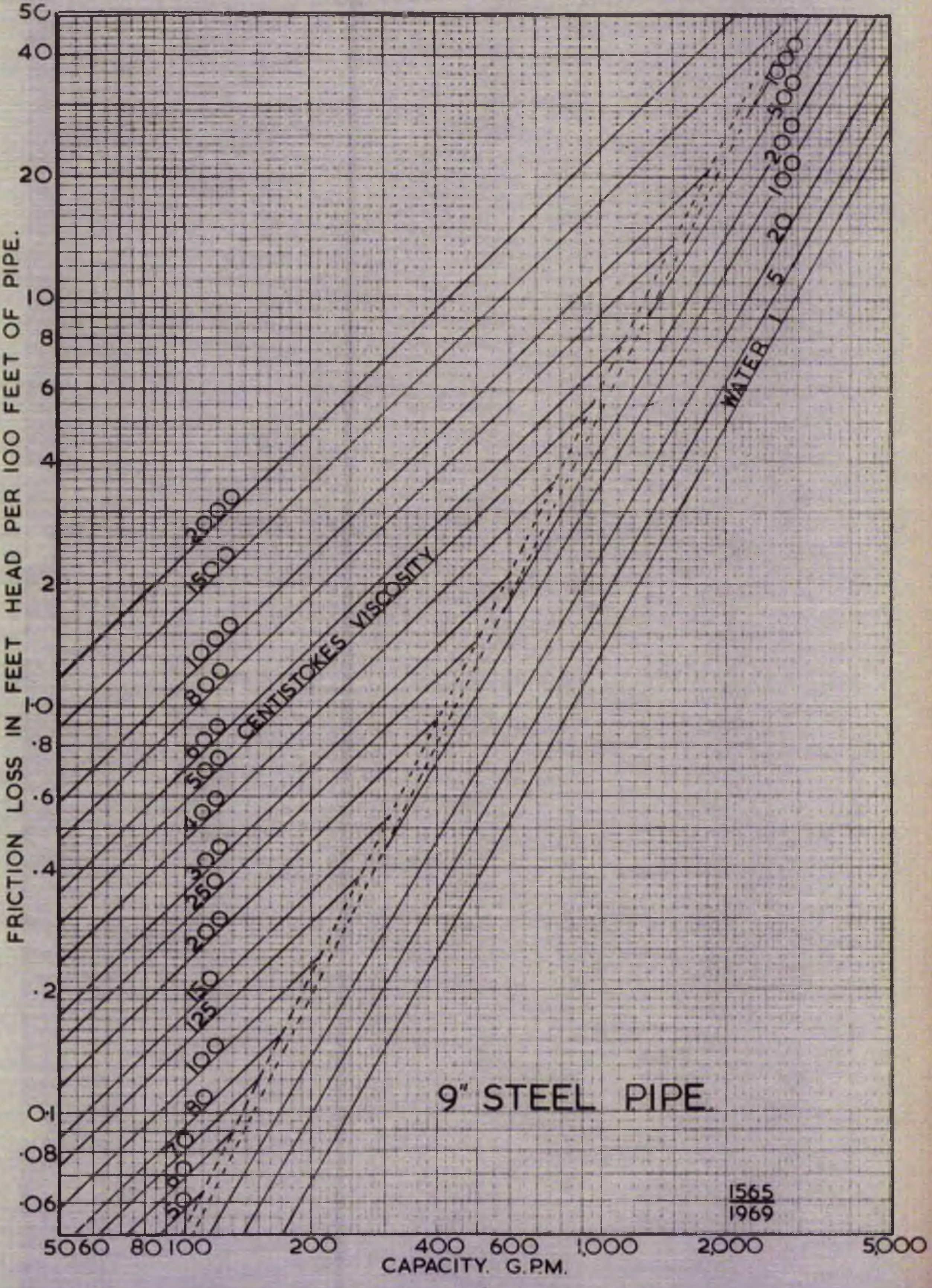


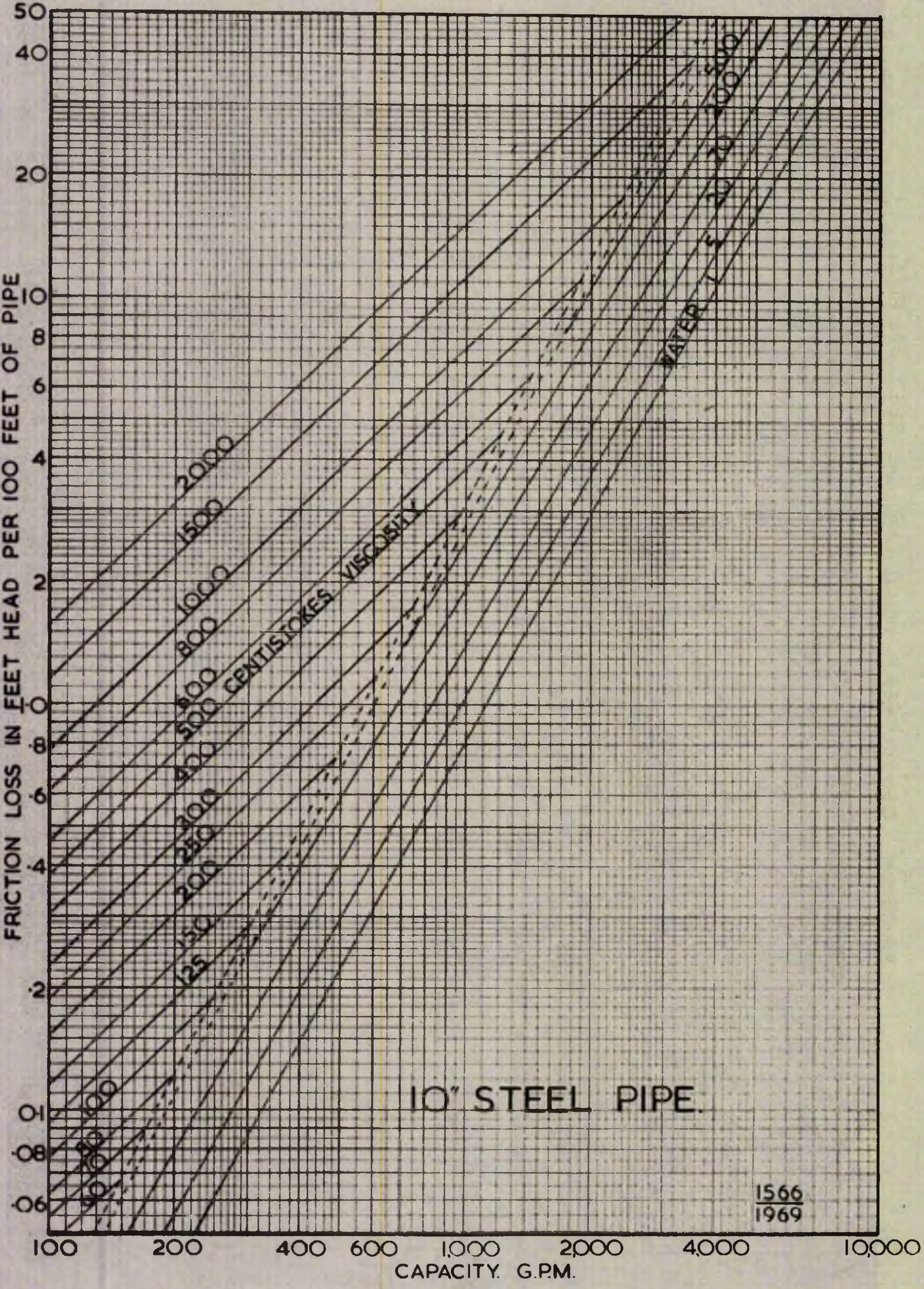

FRICTION LOSS IN FEET HEAD PER 100 FEET OF PIPE.
50
40
20
10
8
6
4
2
1·0
·8
·6
·4
·2
0·1
·08
·06
2000
1500
1000
700
500
400
350
300
250
200
175
150
125
100
80
70
60
50
CENTISTOKES VISCOSITY
300
100
40
10
5
1
WATER
8" STEEL PIPE
1564
1969
50
60
80
100
200
400
600
1,000
2000
5,000
CAPACITY. G.P.M.

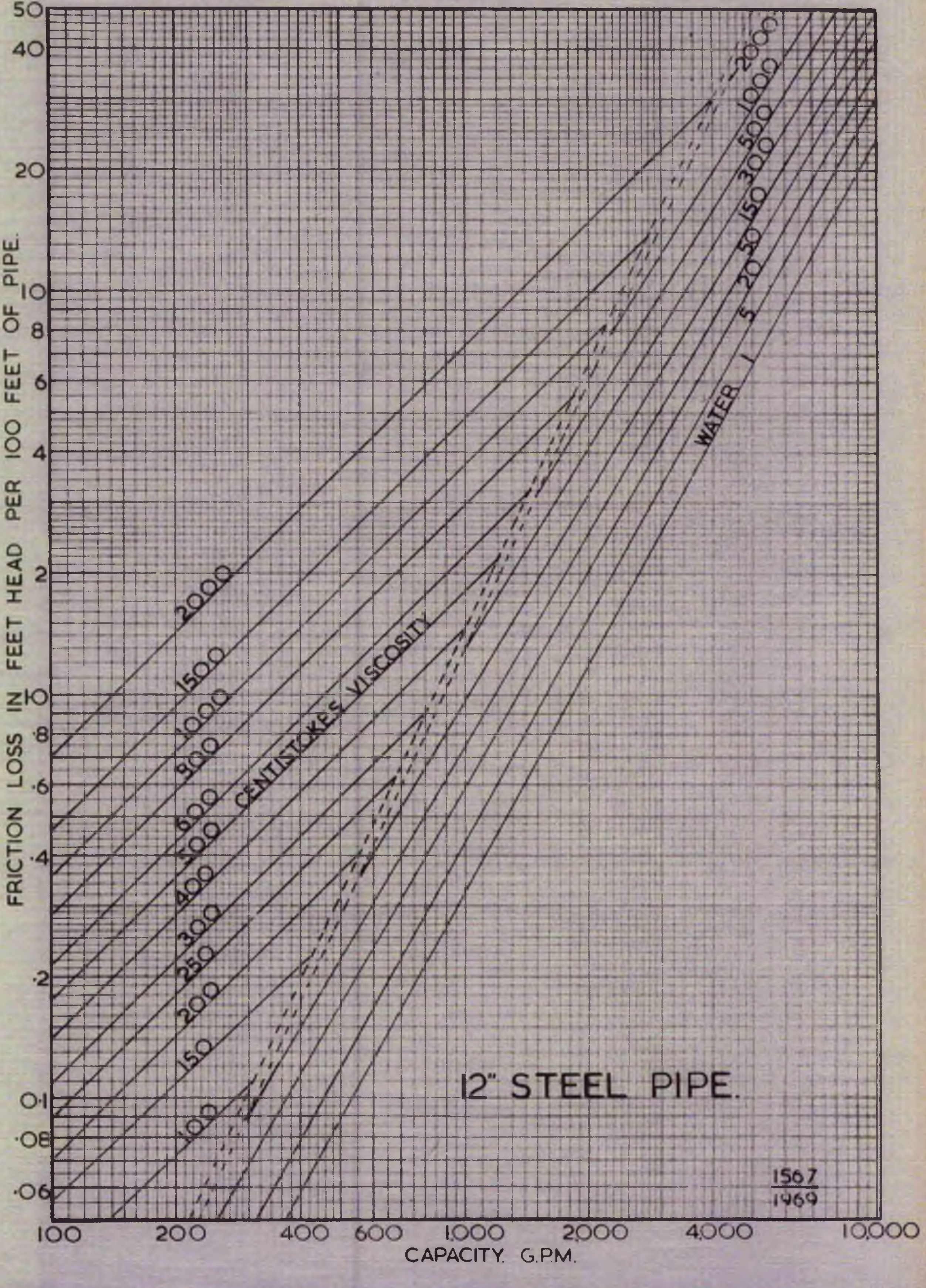
GENERAL PUMPING DATA



9" STEEL PIPE

GENERAL PUMPING DATA




50
40
20
10
8
6
4
2
1·0
·8
·6
·4
·2
0·1
·08
·06
FRICTION LOSS IN FEET HEAD PER 100 FEET OF PIPE.
100
200
400
600
1,000
2,000
4,000
10,000
CAPACITY. G.P.M.
2000
1500
1000
900
600
500
400
300
250
200
150
100
CENTISTOKES VISCOSITY
2000
1000
500
300
150
50
20
5
1
WATER
12" STEEL PIPE.
1567
1969

CENTRIFUGAL PUMP DATA

DEFINITIONS

The description, centrifugal pump, is frequently employed to cover three main classes of pumps, namely, centrifugal, mixed flow, and axial flow or propeller.

CENTRIFUGAL PUMP, properly defined, is one in which the pressure is developed principally by the action of centrifugal force and the flow through the impeller is radially outwards. A particular feature of centrifugal pumps is that the power absorbed is a minimum at zero flow, and for this reason they can be started up against closed valve.

AXIAL FLOW OR PROPELLER PUMP is one in which the pressure is developed by the propelling action of the impeller vanes or blades and the flow is axially through the impeller. As distinct from the centrifugal, the axial flow pump absorbs the maximum power at zero flow.

MIXED FLOW PUMP is one in which the pressure is developed partly by centrifugal action and partly by propulsion by the vanes and, as the name implies, the flow is both axial and radial through the impeller.

DOMESTIC AND VORTEX PUMPS — although included in this section, do not belong to the general centrifugal classification. They are of the vaned wheel type, self-priming, and obtain their high head characteristics by the circulatory or vortex pattern of flow in the vanes and peripheral channel; these pumps absorb maximum power at zero flow.

SPECIFIC SPEED of a centrifugal pump is the revolutions per minute at which a geometrically similar pump would run in order to deliver one gallon per minute against one foot head. It is derived by the following formula :—

Specific speed $N_S = \frac{\sqrt{Q} \times RPM}{H^{3/4}}$ where

H = Head in Feet per stage.
Q = Cub. ft. per sec.

The specific speed, generally taken at the point of maximum efficiency, is an indication of the class of pump. Centrifugal Pumps cover the lower ranges of specific speeds, axial flow the higher, and mixed flow the intermediate values.

Where the performance of a pump at a certain speed is known, the performance at other speeds may be predicted with reasonable accuracy as follows :—

If Q_1, H_1, N_1 and P_1 are the known capacity, head, speed and power respectively, then at the new speed N_2

$$\frac{Q_2}{Q_1} = \frac{N_2}{N_1} \quad : \quad \frac{H_2}{H_1} = \left(\frac{N_2}{N_1}\right)^2 \quad : \quad \frac{P_2}{P_1} = \left(\frac{N_2}{N_1}\right)^3$$

In other words the capacity varies as the speed, head as the speed squared, and power as the speed cubed.

SELECTION AND INSTALLATION NOTES

PUMP SELECTION. For each type of pump composite selection charts showing the ratings of the respective pumps, together with full selection instructions, are provided. In addition, sets of individual curves for each pump, giving more detailed information as to performance, are also included.

It may be observed that two or more different types of pumps can fulfil a particular duty and the question of the most suitable type to offer arises. No hard and fast rule can be given, as type of installation, clients' preferences, competition, etc., all have their effect in varying degrees.

It may be said, however, that where electric drive is required, every effort should be made to put forward our combined pump and motor units, viz., the Monobloc types.

TENDERING. It will be noted that the specification for each type of pump appears on one page together with a typical illustration and list of parts, and that overleaf, overall dimensions of the various pumps are given. Additional copies of these sheets will be available to accompany quotations in lieu of the Bulletin to those Firms who are being regularly quoted. Furthermore these Sheets may be used in certain instances, such as the Monobloc Units, to certify dimensions in acknowledgement of orders.

CENTRIFUGAL PUMP DATA

PUMP DUTY. The ratings given in this section of capacity, head, and power for the various centrifugal pumps are on a cold water basis, i.e. on a S.G. of 1.0 and at a temperature not exceeding 70 °F. For liquids other than water, but of similar viscosity, the power absorbed will be the rating value multiplied by the S.G. For liquids of appreciably greater viscosity than water, reference must be made to viscosity correction data provided. Refer to Newark above 1.000 S.R.I.

A viscous fluid has a considerable effect on the characteristics of a centrifugal pump in relation to water ; capacity, head, and efficiency all being reduced. For this reason centrifugal pumps are unsuited for dealing with the more viscous liquors. No precise limitation in viscosity can be given, as this depends on conditions and the design of the pump.

SUCTION CONDITIONS. On the various individual performance curves provided, lines are shown indicating the N.P.S.H. required. The allowable suction lift or head must be calculated as already shown under General Pumping Data.

Where low head pumps are required the total head should always be greater than the suction lift by a margin, approximately 10 feet: the purpose in this being the provision of slight delivery pressure for gland sealing, and also to ensure stable operation of the pump.

GLAND SEALING CONNECTIONS. The standard sealing connection from the pump casing to the stuffing box is for the purpose of preventing entry of air where there is a suction lift or vacuum, and also to provide some lubrication to prevent overheating and wear.

They are provided on standard stocked pumps on the assumption that the pump will be used under circumstances where the standard sealing arrangements will be beneficial.

There are cases, however, where the layout, or the liquid pumped, is such that the standard sealing arrangement would be detrimental and an alteration must be made. Some of the more common examples are as follows :—

1. Liquids harmful to the stuffing box such as :—

    Those containing sand, grit, or other abrasive materials.

    Those which deposit hard scale.

    Those containing material likely to choke the sealing connections.

    Those containing starch, grain husks, and other food products.

    WITH SUCTION LIFT.—Remove the sealing pipe, plug the hole in the pump casing, and connect an external clean water supply at 5 to 10 lbs. gauge pressure, or fit a lubricator to the stuffing box.

    WITH POSITIVE SUCTION PRESSURE.—Remove the sealing pipe, plug the hole in the pump casing, and fit a lubricator to the stuffing box, or fit an external clean water supply which must be at a pressure 5 to 10 lbs. higher than the pump suction pressure.

2. Pumps dealing with liquids having no lubricating qualities such as petrol, paraffin, etc., are normally provided with metallic or semi-metallic packing and a soap or non-soluble grease lubricator on the stuffing box, depending on the recommendations of the packing maker. The sealing pipe is removed and the hole in the casing plugged, irrespective of suction lift or positive suction pressure.

3. Reasonably clean liquid, unharmful to the stuffing box, with positive suction pressure. Remove the sealing pipe, plug the holes in the pump casing and stuffing box. If desired, the lantern ring can be removed and more packing inserted in its place.

When the circumstances are known the requirements should be stated on the Sales Order.

There are also other cases such as pumps for Ammonia and those fitted with mechanical seals, but as these involve arrangements special to the particular conditions, no general action can be stipulated.

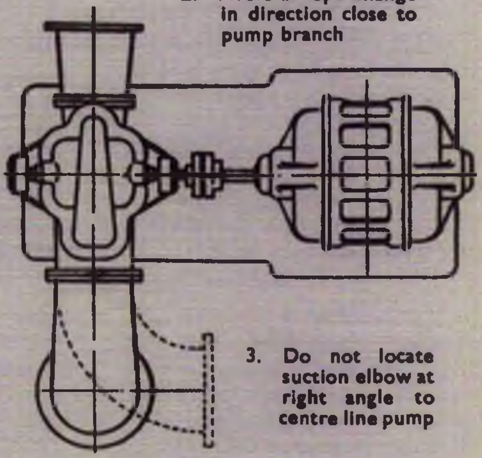
PIPE CONNECTIONS. The pump suction and delivery branch sizes are not necessarily the same as the associated piping, and, at the larger capacities of any pump, increased pipe connections, involving the fitting of taper pieces, are generally required. The size of the associated piping is, of course, determined by the allowable friction loss in the system.

The performance of a centrifugal pump can be impaired by an ill-considered arrangement of its associated piping, and the following points with explanatory sketches are worth noting.

CENTRIFUGAL PUMP DATA

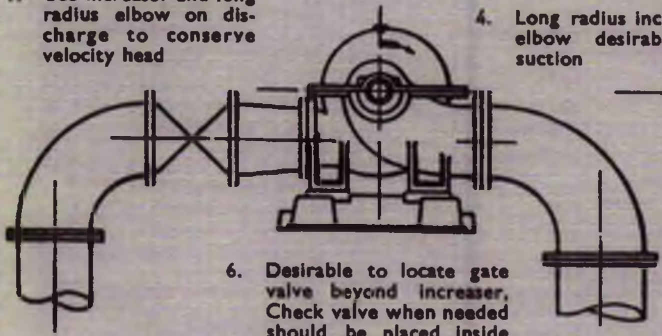
External losses resulting from excessive velocity in pipe lines and short radius bends close to pump nozzles materially affect the overall plant efficiency. Elbows located close to suction branch and turned at right angle to centre line of pump will cause an unequal flow to each side of impeller. This tends to reduce capacity and excessive thrust frequently results.

Increasers should have a gradual taper. When located on suction side of pump, an offset increaser is preferable, to prevent high spot in suction for accumulation of air.



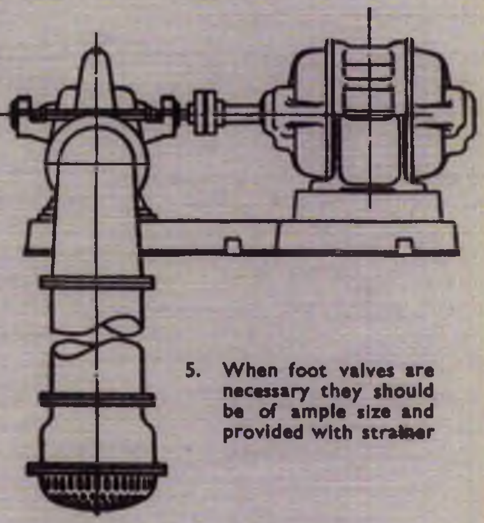
2. Avoid abrupt change in direction close to pump branch

3. Do not locate suction elbow at right angle to centre line pump



1. Use increaser and long radius elbow on discharge to conserve velocity head

6. Desirable to locate gate valve beyond increaser. Check valve when needed should be placed inside gate valve



4. Long radius increasing elbow desirable on suction

5. When foot valves are necessary they should be of ample size and provided with strainer

MECHANICAL ROTARY SEALS

The provision of rotary shaft seals in lieu of the usual stuffing box and gland where conditions are suitable the rotary seal possesses many advantages over stuffing box and gland. The power absorbed is lower and is constant, whereas a gland excessively tightened causes a considerable increase in power absorbed—in small pumps it may result in overloading the motor. In addition maintenance costs are reduced, the rotary seal operating for long periods without wear or attention.

The Worthington-Simpson standard seal consists of a stationary carbon ring insert in the casing, or seal cover where such is provided, and against this a metal ring of easy clearance on the shaft sleeve rotates, contact between the faces being ensured by a lightly loaded coil spring. The rubbing faces of both carbon and metal rings are independently lapped to give a dead flat surface.

A synthetic rubber ring, of circular cross-section, contained between shaft sleeve and metal ring, in a groove in the latter, effectively prevents leakage between them.

The diameter of the groove is such that a squeeze is exerted on the rubber ring, thus a sufficient frictional force is provided to rotate the metal ring, with certain exceptions which will be mentioned later. The width of the groove is, however, made considerably greater so that the metal ring is capable of free axial float with accompanying rolling action of the rubber ring.

Materials used for the various seal parts are generally as under :—

Carbon stationary ring in all cases.

Synthetic rubber ring in all cases.

Bronze rotating ring with bronze spring for Standard and All Gunmetal Pumps.

Stainless Steel rotating ring for All Iron Pumps.

For non-lubricating liquids, such as ammonia, glycol, petrol, paraffin, transformer and quenching oil, etc., the rotating ring is made of stainless steel to give a harder surface.

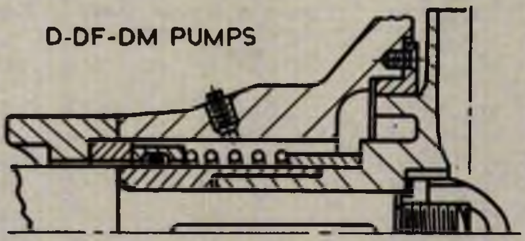
The following is a list of liquids at moderate temperatures and pressures for which Worthington-Simpson seals are suitable.

Alcohol
Ammonia
Beer
Cider
Glycol
Lubricating Oils
Paraffin
Petrol
Quenching Oil
Transformer Oil
Vegetable Oils
Water, Fresh or Sea
Wort

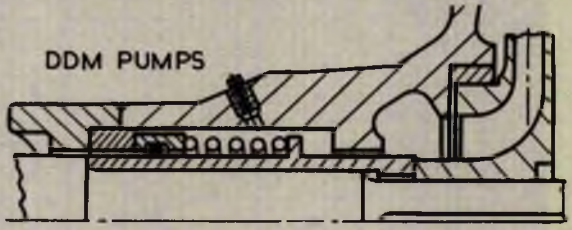
Seals with positive drive are provided for all except the smallest size $1\frac{1}{16}$" for the TPS and DS, i.e., the spigot-mounted pumps.

Domestic, Vortex and Cevac pumps are provided with Rotary Seals as a standard fitting and cannot be supplied with soft packing stuffing boxes.

Worthington-Simpson seals are specially designed to suit the dimensions of the standard shaft sleeves and stuffing boxes, and they can, therefore, be provided in any D, DF, DM or DDM pump when such is particularly desired. The modification necessary is not one which can be carried out readily at site, since the lip at the bottom of the stuffing box must be bored out on all but the DDM pump, as can be seen from the accompanying illustrations showing the provision of the seal on "D" class pumps.



D-DF-DM PUMPS



DDM PUMPS

TEMPERATURE AND PRESSURE LIMITATIONS FOR MECHANICAL SEALS AND STUFFING BOXES OF STANDARD CENTRIFUGAL PUMPS

The following will summarize the pressure and temperature limitations for mechanical seals and stuffing Boxes of standard centrifugal pumps.

The figures given are absolute limitations in each case and apply to clean water only. All liquids other than clean water must receive special consideration by Newark.

Temperatures and pressures in excess of those mentioned below require Water Jacketed Stuffing Boxes or cold liquid circulation to the Shaft Seal. We have no standard pumps which provide the former, and our standard Shaft Seals are not designed for the latter.

1. All Rotary Seals, No. 1, or E.B. using standard materials are suitable for the present Price Book limitations of temperature and pressure.

2. No. 1 and E.B. Seals using Stellited F.M.B. Rotating Rings and standard carbons are suitable for water up to 300 degs. F. and suction pressures up to 60 p.s.i.g.

3. Packed stuffing boxes using standard packing and materials are suitable for present Price Book limitations of temperature and pressure.

4. Packed stuffing boxes using special packing and special coated sleeves are suitable for water up to 350 degs. F. and corresponding pressure of 150 p.s.i.g. Some leakage and steaming will be experienced and this is essential to keep the packing lubricated.

5. All pumps for water above 250 degs. F. must have increased clearances at rings and bushes, and consequently the efficiency will drop a point or two.

FLEXIBOX AND CRANE MECHANICAL SEALS FOR TYPES 'L', 'R' AND 'U' CENTRIFUGAL PUMPS

When the customer requires us to fit a Crane or Flexibox Seal, a quotation should be obtained from Crane or Flexibox giving full details of the application. It is most important that the makers should select the most suitable seal for the job, and to arrive at the total extra price for fitting the bought out seal, the following procedure should be carried out.

A quotation should be obtained from Crane Packing Ltd., Slough, Bucks., or Flexibox Ltd., Nash Road, Trafford Park, Manchester 17, or the respective local office, giving with the enquiry full details of the liquid, temperature, pressure, R.P.M., and other details required. Flexibox supply forms for this purpose. A handling charge of 10% should be added to the quoted price for the seal parts, noting that two seals are required per pump and together with the fitting charge given in the tables shown on the appropriate price pages the total nett extra will be obtained.

Flexibox should be asked to quote for the seal plates in addition to the seal parts, Crane will quote for seal parts only, leaving us to provide the seal plate and cover, and the prices take these factors into account. These seal plates will be provided without circulation connections as the standard water seal tube on the pump will be retained to provide liquid circulation in the seal box as specified by the seal suppliers.

When the pumped liquid is such that it will attack the rubber in the Crane 1A seal, the makers may recommend a 109 seal. This type can be accommodated in these pumps, but price details have not been listed as selection of the 109 seal is likely to be infrequent for these standard pump applications. Please refer to Newark in these cases.

The equivalent W.S. seal to the 109 is the EBM seal, and reference should also be made to Newark in such cases giving full details of the liquid, etc.. for a selection and prices.

The foregoing procedure applies to Worthington-Simpson personnel only. Overseas agents and Worthington Corporation price book holders should refer to export department in London whilst Worthington-Simpson distributors in the United Kingdom should refer to our branch office nearest to them for such information.

PROCEDURE FOR ISSUE OF SPEED TORQUE CURVES

A. LIMITATIONS OF USE

1. Use only for centrifugal single and multi-stage pumps.
2. The curve represents starting under the worst conditions which will nearly always be under open discharge valve conditions in a system which is entirely friction head. Certain pumps, e.g. 12LA1, have maximum power absorbed at closed valve, and this value of power should then be used (see below).

B. COMPLETING THE CURVE

1. For the specified conditions of:-

   Pump size
   Speed
   Impeller diameter
   Capacity

   read off from the Price Book curve absorbed in kW

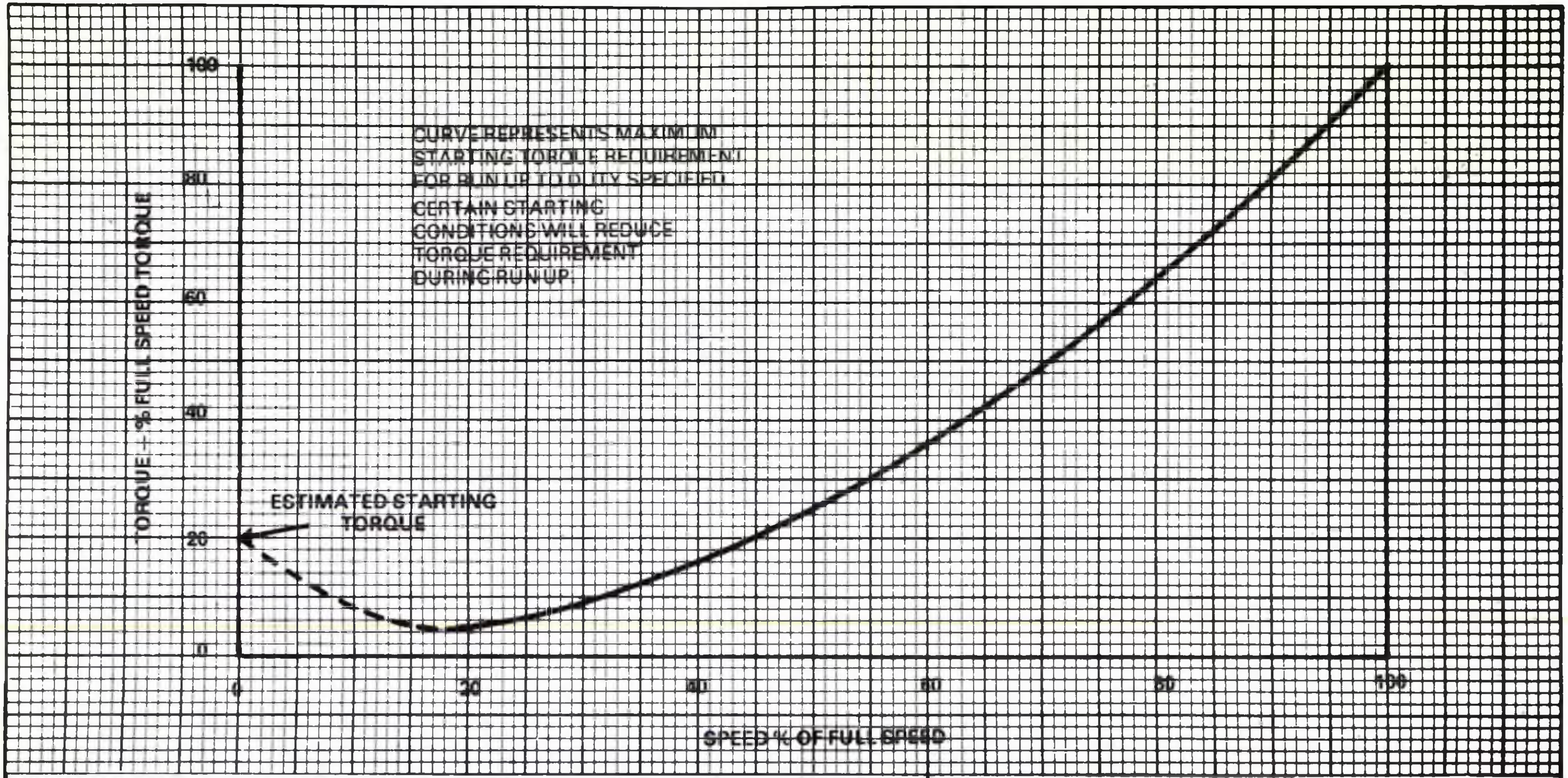
   Note: a) Convert to kW if curve is in BHP.
   b) For pumps with highest power absorbed at closed valve use closed valve power.
   c) For duty points to the right of peak power absorbed, use the peak value.
2. Adjust power absorbed for S.G. and viscosity of liquid handled.
3. Calculate maximum torque (100% torque) from:—

$$\text{Torque in Nm} = \frac{9550 \times \text{kW}}{\text{RPM}}$$

4. Obtain WR^2 value if required.
5. Fill in appropriate boxes on curve. (overleaf)

C. ADMINISTRATION

1. Send photo-copy of curve to customer.
2. Retain original curve on file.



CUSTOMER:	PUMP SIZE: DUTY:
CUSTOMER REF:	S.G. : VISCOSITY:
PUMP SERVICE:	SPEED 100% = RPM
W-S ORDER/REFERENCE NUMBER.	TORQUE 100% = Nm
DATE:	WR² : kg.m²

Worthington-Simpson Limited
Lowfield Works, Newark

SPEED TORQUE CURVE

VISCOSITY CORRECTION

NOTE: METRIC UNITS USED THROUGHOUT

The performance of a centrifugal pump is adversely affected by the handling of any liquid having a viscosity greater than that of water.

Firstly, the increased friction losses through the pump cause a reduction in generated head, and secondly the power requirement is increased by virtue of the increased disc friction.

Suitable allowance must be made for these two factors when making a pump selection.

It is the purpose of the performance correction chart to provide a means of determining the performance of a conventional design of centrifugal pump handling a viscous liquid, when its performance on water is known. It is also intended to be used as an approximate method in selecting a pump for a given application.

A. LIMITATIONS FOR USE

1. Use only within the scales shown. Do not extrapolate.
2. Use only for pumps of conventional hydraulic design in the normal operating range with open or closed impellers. Do not use for axial or mixed flow pumps.
3. Use only where adequate NPSH is available in order to avoid the effect of cavitation.
4. Use only on Newtonian liquids. Gels, slurries, paper stock and other non-newtonian liquids may produce widely varying pump performance, depending on particular characteristics of the liquids.
5. The performance correction chart 355/84 is intended to be entered with capacity and head performance of the pump on water and to provide the corrections for the viscous performance. The use of the chart to make the initial selection of impeller (as described in Section B) is therefore approximate only. Its inaccuracy will be greatest for large corrections and pump selections away from B.E.P.

B. INSTRUCTIONS FOR PRELIMINARY SELECTION OF A PUMP IMPELLER DIAMETER FOR A GIVEN HEAD — CAPACITY — VISCOSITY DUTY

1. At the specified duty point on viscous liquid, determine the required total head in metres, the capacity in m^3/hr and the liquid viscosity in centistokes. Viscosity conversion information is given in WS-130, Page 8.
2. Enter chart 355/84 at the bottom with the desired viscous capacity and proceed upward to the sloping line which corresponds to the desired viscous head. For multistage pumps use head per stage. Then move horizontally left or right to the sloping line which corresponds to the viscosity then go vertically upwards to read off the correction coefficients for capacity (CQ) and head (CH).
3. Divide the viscous capacity by CQ to get the approximate equivalent water capacity and divide the viscous head by CH to get the approximate equivalent water head.
4. Now choose a pump and select the impeller diameter.
5. In a similar way efficiency correction coefficient CE and hence approximate KWs absorbed can be derived if desired.
6. Now proceed to establish the accurate selection as described on page 2.

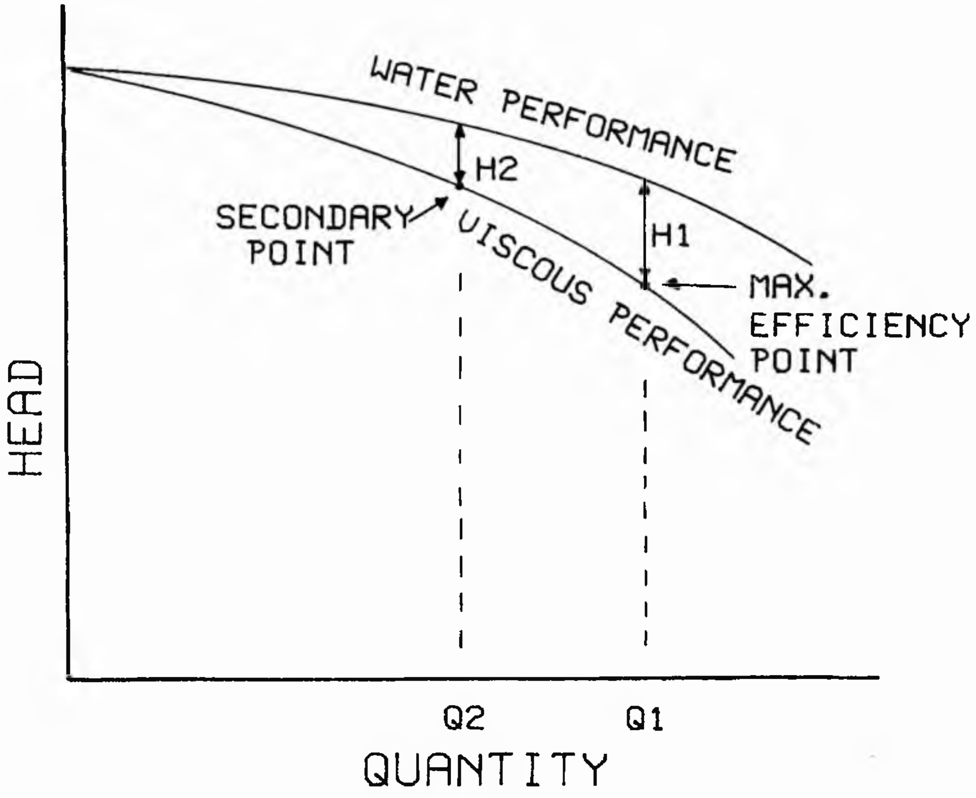
VISCOSITY CORRECTION

C. INSTRUCTIONS FOR DETERMINING PUMP PERFORMANCE ON A VISCOUS LIQUID FOR A KNOWN PERFORMANCE ON WATER

1. Having made the preliminary selection of impeller diameter find the maximum efficiency point and record the head, capacity and efficiency for this maximum efficiency point.
2. With these maximum efficiency point figures use the viscosity correction chart 355/84. Starting with the maximum efficiency capacity which is the horizontal co-ordinate on the chart, move vertically upwards until you reach the maximum efficiency head. Then move left or right until you reach the viscosity in centistokes. From this second intersection, move vertically upwards and read the various correction factors for the efficiency, capacity and total head respectively.
3. Multiply each of these correction factors by the equivalent value at the maximum efficiency point, i.e. multiply CE by the efficiency at maximum efficiency point, CQ by the capacity at maximum efficiency point and CH by the head at maximum efficiency point.
4. These values obtained in step 3, are the co-ordinates of a new point which is actually the maximum efficiency point for that impeller when operating on a viscous fluid. This point can then be plotted on the pump performance curve.
5. A new viscous performance curve can now be plotted through the new maximum efficiency point by using the following relationship between head and capacity:—

$$\left(\frac{Q1}{Q2}\right)^2 = \frac{H1}{H2}$$

H1 = head loss at maximum efficiency point.
H2 = head loss at secondary point.
Q1 = quantity at maximum efficiency point.
Q2 = quantity at secondary point.



Closed valve head on water will equal closed valve head on viscous liquid. It is suggested that the secondary 'point' be the duty capacity. The 3 points C.V., B.E.P. and duty point will allow the viscous performance curve to be drawn. This should be of sufficient accuracy for most purposes but additional points can be added if necessary.

VISCOSITY CORRECTION

6. After sketching this new viscous performance curve determine whether the required viscous performance can be met. If the required viscous point is above the curve then a new larger impeller or larger pump must be selected. If the viscous performance point is below the curve, then it may be necessary to select a smaller impeller.
7. After having selected an impeller which will give the viscous performance required, it is now necessary to determine the power characteristics of the impeller when pumping viscous fluids.

   The first step is to plot the power curve for the impeller selected, when pumping a non viscous liquid having the same specific gravity as the viscous liquid being checked, i.e. plot the power curve for the original impeller selected taking into consideration the specific gravity of the liquid being handled. For small end suction pumps this will probably be a straight line.
8. On the pump price book curve, plot the power at maximum efficiency point when handling the viscous fluid. This power is determined by the following:—

   $$\frac{H \times Q \times S.G.}{Effy. \times 367}$$

   where:— H, Q & Effy are for the viscous liquid.
9. We now have a curve representing the power on a liquid of negligible viscosity and also a point representing a power on the viscous liquid. Now draw a line through the viscous power point, parallel to the original, negligible viscosity power line. With the new viscous power line drawn, values can be read off for any capacity.

This method, therefore, gives a new viscous head — capacity performance curve and a new viscous power capacity performance curve. In most cases these curves will be sufficient.

D. MULTISTAGE PUMPS

As stated in paragraph B.2 the correct procedure for multistage pumps is to take the head per stage.

E. MULTILINE PUMPS

Treat generally as multistage pumps but add 15% margin to power absorbed before selecting motor.

VISCOUS CORRECTION EXAMPLE

A pump is required to deliver 45 m^3/h of a viscous liquid at a total head of 70m. The viscosity at pumping temperature is 150 centistokes, at an SG of 0.90.

The preliminary selection is made as described in Section B, using the viscous duty conditions. Following the lines drawn on the chart:—

CE = 0.73
CQ = 0.94
CH = 0.96

Equivalent water performance is then:—

Q = 45/0.94 = 47.8m^3/h; H = 70/0.96 = 72.9m

Approximate impeller diameter is 235mm on 50—250, see curve No. 595/76 opposite. If required at this stage, the approximate power absorbed is calculated from the efficiency of 58% at duty on the curve as follows:—

$$\frac{45 \times 70 \times 0.9}{0.73 \times 0.58 \times 367} = 18.2\text{kW}$$

Proceed then using Section C to establish the exact performance and selection.

From the curve for 235mm impeller diameter determine the capacity, head and efficiency on water at the maximum efficiency point, i.e., 58m^3/h X 68m — 59% respectively.

Obtain the correction factors (lines not drawn this time on chart 355/84 page 6).

i.e., CE = 0.74, CQ = 0.95, CH = 0.975

Hence the corrected capacity, head, and efficiency on a viscous liquid are:—

0.95 X 58 = 55.1m^3/h
0.975 X 68 = 66.3m
0.74 X 59 = 43.7%

This then gives the corrected maximum efficiency point.

To obtain the head loss H2 at the required duty capacity (selected as the secondary point) of 45m^3/h:—

$$\left(\frac{Q1}{Q2}\right)^2 = \left(\frac{H1}{H2}\right) \text{ ie., } H2 = \left(\frac{Q2}{Q1}\right)^2 \times H1$$

where Q1 = Capacity at maximum efficiency = 55.1m^3/h
Q2 = Capacity at secondary duty point = 45m^3/h
H1 = Head at corrected BEP capacity Q1 on water — Head at Q1 on viscous liquid
= 69.5—66.3 = 3.2

$$H2 = \left(\frac{45}{55.1}\right)^2 \times 3.2 = 2.1\text{m}$$

Therefore, at the duty capacity of 45m^3/h, the head on viscous liquid from the curve is 74.9—2.1 = 72.8m, which is a little too high. Revising the impeller diameter to 233mm and repeating the calculation leads to a revised corrected BEP capacity, head and efficiency on a viscous liquid of:—

0.95 X 57.0 = 54.2m^3/h
0.975 X 66.5 = 64.8m
0.74 X 59.0 = 43.7%

H1 = 3.2 therefore H2 = 2.2

This then gives the final corrected maximum efficiency point and hence a final water duty of 45m^3/h X 72.2m. This is the duty to be specified on the Sales Order Sheet, and is the duty point against which a pump performance test, on water, will be accepted.

A curve can now be drawn in through these two points.

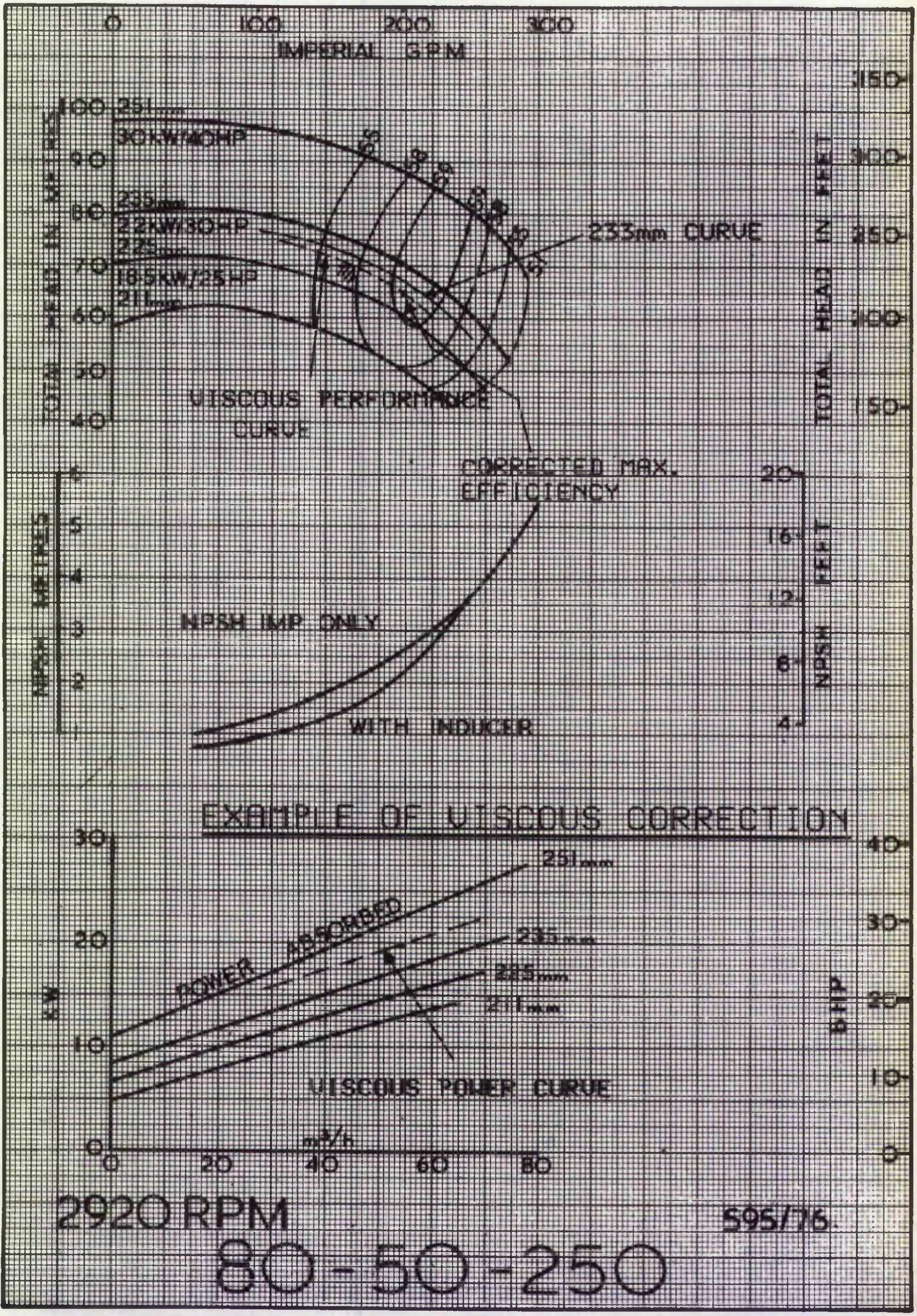
The next step is to plot the power curve for the impeller selected, when pumping a non viscous liquid having the same specific gravity as the viscous liquid being checked, i.e. plot the power curve for the original impeller selected taking into consideration the specific gravity of the liquid being handled.

On the same co-ordinate system plot the power at maximum efficiency point when handling the viscous fluid. This power is given by:—

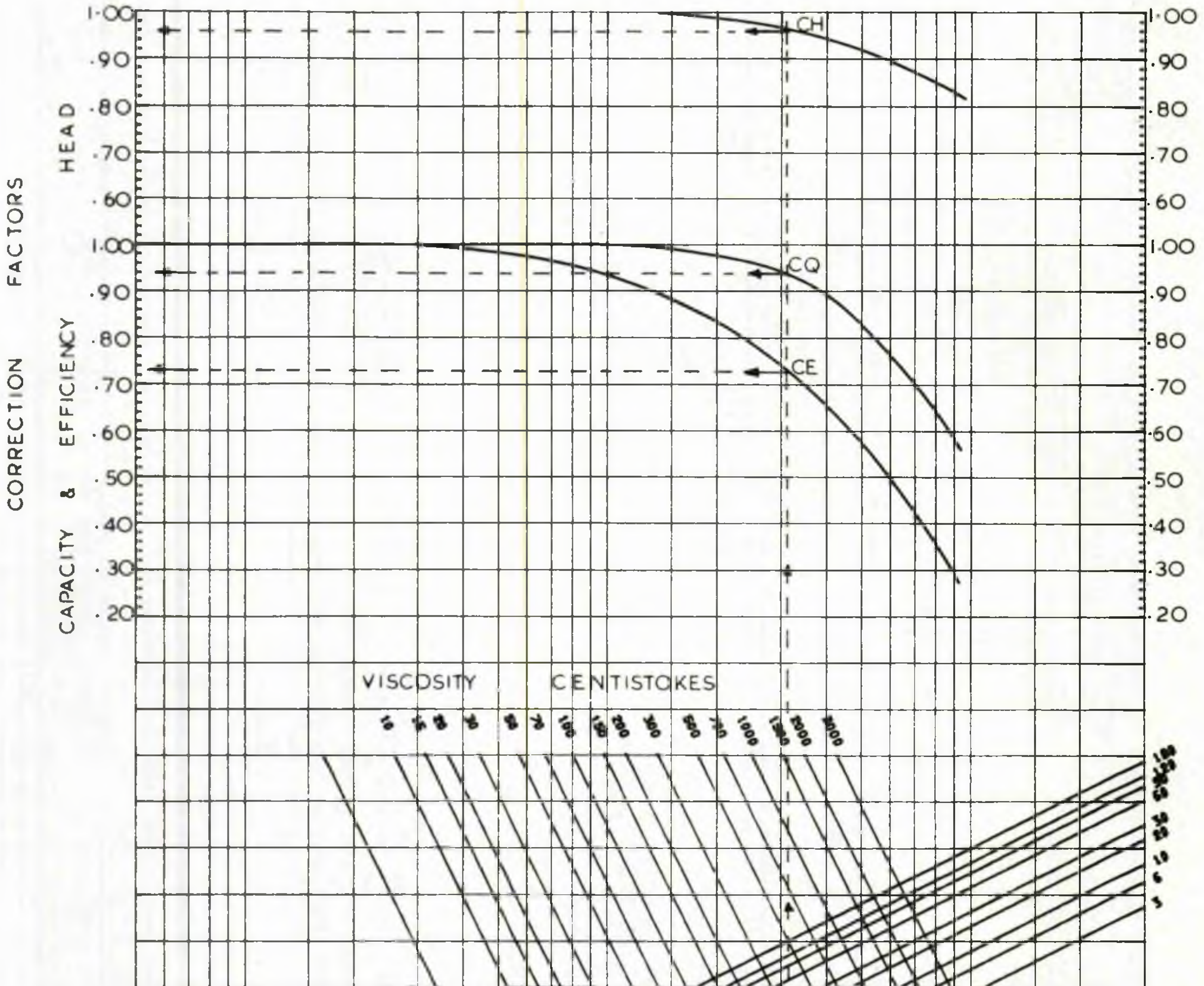
$$\frac{54.2 \times 64.8 \times 0.9}{0.437 \times 367} = 19.7\text{kW}$$

We now have a curve representing the power on a liquid of negligible viscosity and also a point representing a power on the viscous liquid. If a line is now drawn through the viscous power point, parallel to the original negligible viscosity power line, the power absorbed at the duty capacity can be read off as 18.2kW.

EXAMPLE OF VISCOUS CORRECTION



PERFORMANCE CORRECTION CHART



355/84

Consultation with the author of Selpump, and Dr. Cliff Voisey of Nottingham Polytechnic's Mathematics department suggest that a polynomial is the most appropriate representation for our purpose. The calculations will be significantly easier to implement using polynomials, as only a single equation is being dealt with. In view of the previous work done by engineering on the subject and the ready source of data, it was decided to continue to use the fourth order polynomial representation currently in use.

C.2 CALCULATION OF IMPELLER DIAMETER

The selection of the impeller diameter is a matter of interpolating between the existing curves to derive an intermediate. The problem is in finding how the curves for different diameters are connected, i.e. what relationship should be used for the interpolation. The development of a suitable relationship has progressed through a number of stages, detailed below with the reasons for change between them being explained throughout the text.

C.2.1 THE AFFINITY LAWS

The affinity laws are the basic relationships governing ideal pumps. They give performance values based on those at other values. Their main applications are scaling of prototype tests, small changes in impeller speed and diameter. Under these circumstances the variation from the two being geometrically similar is small, hence the errors may be ignored. The relationships are those developed in many hydraulic texts, however these do not continue on to detail how the variation from these rules may be determined for real pumps. The affinity laws relate to either the diameter, D, or the rotational speed, N, as follows:

i) Capacity, Q, is directly proportional

$$\frac{Q1}{Q2} = \frac{N1}{N2} \qquad \frac{Q1}{Q2} = \frac{D1}{D2}$$

ii) Head, H, is proportional to the square

$$\frac{H1}{H2} = \left(\frac{N1}{N2}\right)^2 \qquad \frac{H1}{H2} = \left(\frac{D1}{D2}\right)^2$$

iii) Power, P, is proportional to the cube

$$\frac{P1}{P2} = \left(\frac{N1}{N2}\right)^3 \qquad \frac{P1}{P2} = \left(\frac{D1}{D2}\right)^3$$

This results in the efficiency being independent of a change in diameter or speed. For the variations required for pump selection this is not the case hence a method which alters the effect of the affinity laws is required.

C.2.2 DFDP MODIFICATION GRAPHS

A graphical method to correct for the deviation from the affinity laws was the DFDP graph, the meaning of the initials now being unknown. It is used when the impeller diameter for a D-Line pump is required to be calculated precisely. A series of graphs are used to cover the D-Line range.

Each graph plots the head ratio against the square of the diameter ratio for pairs of figures. Performance tests on units at maximum diameter and a cut diameter provide the initial data for the graphs with each being plotted at its best efficiency point. Several geometrically similar pumps are grouped for each graph, giving a series of points at different ratios allowing a best fit straight line to be drawn. The deviation from the affinity law can be seen in the closeness of this line to a line at $y = x$, i.e. passing through equal values on each ratio axis, which represents the theoretical relationship.

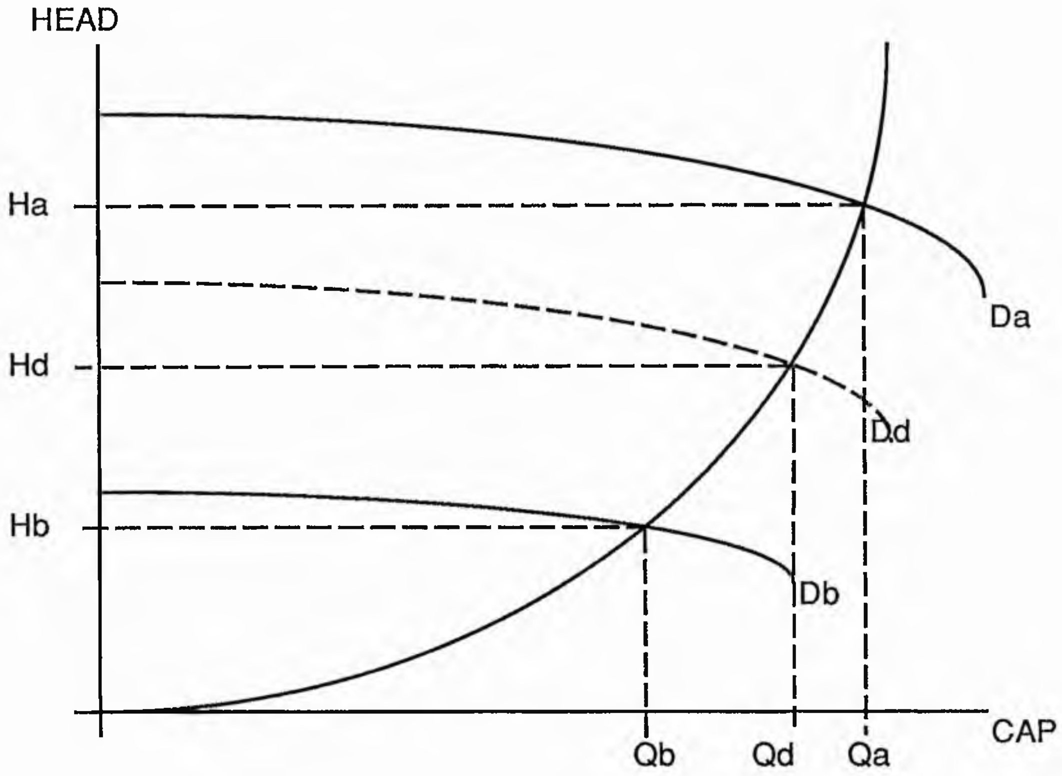
To use the graph, the engineer plots a square law curve, i.e. $y = x^2$, through the origin and the duty point. The intersection of this with a performance curve gives a head value on a known diameter. The head value and the duty head give the head ratio to be looked up on the DFDP graph. The resulting diameter ratio can be used to calculate the required diameter from that of the known performance curve.

C.2.3 HEAD INDEX MODIFICATION

A more general method for use across the whole of a pumps application range is the head index, NH. This is based on the method used in the drawing of performance curves for prototype pumps. It improves on the DFDP graph by being calculated for a single pump size, locally to the duty point.

As with the DFDP graph, a square law curve is drawn through the origin and duty point. Intersections are found with two performance curves, Fig. C.1 . The ratios of head and diameter at the two points are used to determine the index relating them, rather than the theoretical 2.

The resulting index, with the intersection on one of curves, is used with the duty head to find the required diameter. The variation from the affinity law is shown by the value of the index. This varies with different pairs of diameters and across the range of capacities. Typical values range from 1.5 close to closed valve to 3 at end of curve.



$$NH = \frac{LN\ (Hb / Ha)}{LN\ (Db\ /Da)}$$

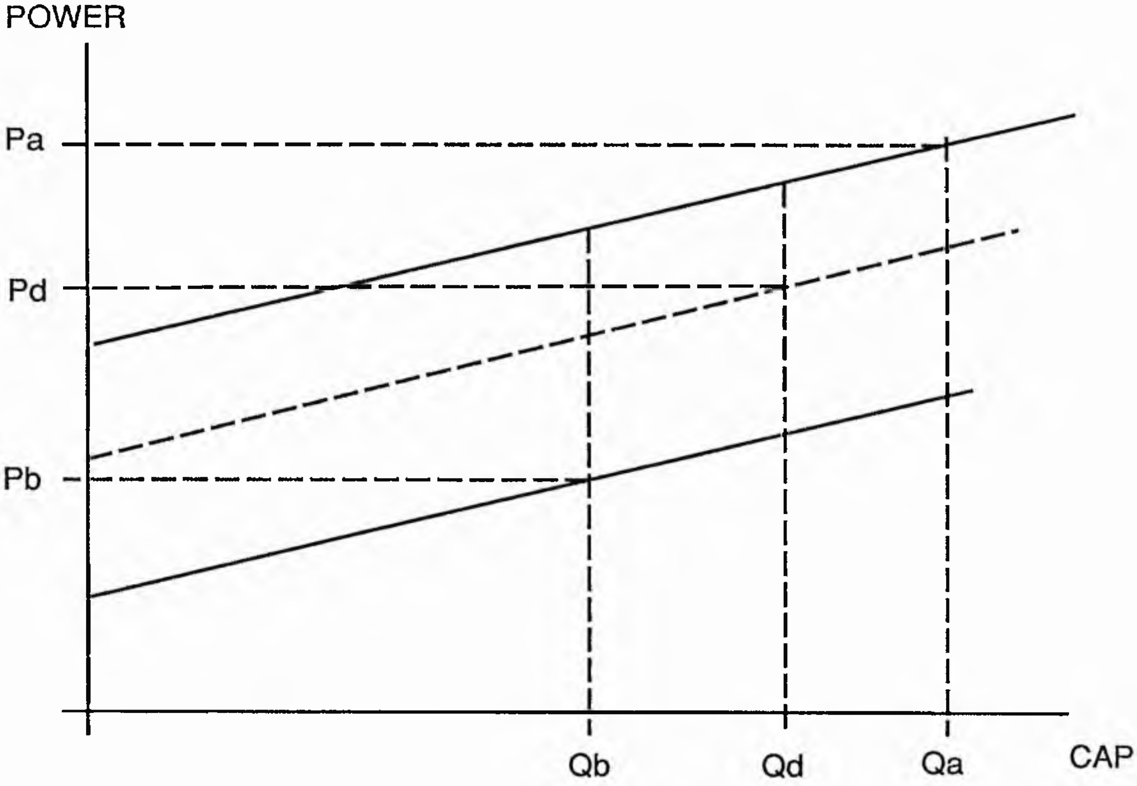
$$Qd = Qa\ (\ Dd / Da)^{NH / 2}$$

$$Hd = Ha\ (\ Dd / Da)^{NH}$$

FIG C.1 DIAMETER CALCULATION

C.2.4 POWER INDEX MODIFICATION

The power index modification, NE, is based on the same principle as the calculation of the head index. To improve the accuracy for real pumps an index figure is found to replace the standard 3 in the affinity laws. When the intersects on two diameters for the head index is found, the corresponding power figures are also determined. These are then used with the known diameters to calculate the power ratio local to the duty point. This is defined as a combination of the head ratio, NH, and an index, NE, which represents the index of efficiency change, Figure C.2.



$$3/2 * NH - NE = \frac{LN\ (Pb / Pa)}{LN\ (DB / Da)}$$

$$Pd = Pa\ (Dd / Da)^{3/2 * NH - NE}$$

FIG C.2 POWER CALCULATION

C.2.5 VARIATION OF NPSHR WITH DIAMETER

Some pump ranges give NPSHR curves for more than one diameter. In these cases maximum and minimum diameter curves are usually given, with values for other diameters being interpolated between these.

Calculation of an appropriate figure for a duty begins with the intersections found for the head ratio. These are extended to give intersection capacities corresponding to the diameters for which NPSH curves are given, usually maximum and minimum. A linear relationship between diameter and NPSH is found from these figures, which is used to find an NPSH for the selected diameter,

C.3 SELECTING THE MOTOR

The selection of a motor size for a given duty is performed, as by the engineer, in accordance with margins in the Engineering Standard. The margins are applied to each motor size to find the maximum power each may take. After selecting for a duty, the maximum power absorbed on the calculated impeller is found. This is then compared to the list of maximum powers for the motors to find the appropriate size. Above 150kW the motor will be non-standard and quotations may be sought from several motor manufacturers.

While in some cases it may be possible to safely fit a smaller motor, the programme makes no attempt to do this. The final PSI implementation calculates the margins and overload conditions for several sizes of motor, though the decision to move to an alternative size is made by the user.

C.4 FLUID EFFECTS

Of the various effects the fluid may have on the selection, only those relating to performance, viscosity and SG are applied in the programme. The choice of an appropriate material is made by the user.

C.4.1 VISCOUS CORRECTION

The routines for calculation of the viscosity correction factors are translated from the Engineering department's curve drawing system, written in BASIC. The derivation of the equations is undocumented, but they are based on the graph used by the engineers.

The method of application however differs from the manual approach. Instead of correcting a curve, trying it then iteratively finding the best diameter, the programme corrects the complete performance curve. This gives a set of impeller performance curves for the liquid viscosity. The diameter calculation methods may then be applied as for water to find the diameter in a single step.

C.4.2 SG CORRECTION

The SG correction is a simple multiplier to the power curve calculation. It is applied as an overall scaling factor wherever the power is calculated. It is not integrated into the curve coefficients like the viscosity correction. It is important to also apply the SG as a scaling factor to the efficiency to ensure this is calculated independent of SG.

C.5 MOTOR RUNNING SPEED

All the performance curves are drawn to a nominal speed, however the actual pump running speed will be determined by the motor size and the absorbed power at the duty point. For each motor size the manufacturer provides details of the full load power and speed. A linear relationship through this point, and a point at synchronous speed and zero power gives a slip in rpm per kW of absorbed power.

For a duty point the absorbed power may be used to find the slip on the motor. Deducting this from the synchronous speed gives the motor running speed at this point. As the speed difference between this and the nominal curve speed is small we may assume that the affinity laws apply.

The theoretical procedure would be to correct points on the performance curve for the speed then iteratily change the impeller diameter and correct for speed until the required duty is attained. However, both the speed correction and the impeller diameter calculation move points along square law curves, hence the overall effect is simply to change the impeller diameter. The speed correction routine uses this and leaves the originally calculated curve unchanged, but alters the diameter figure by the speed ratio.

APPENDIX D OBJECT ORIENTED DEVELOPMENT

This Section deals with a change to the basic ideas behind the software development. The use of object oriented techniques is an area which is growing rapidly both within expert systems and conventional programming. It promises gains in pace of development and ease of maintenance by modelling the problem and solution in a way familiar to the developer. Its use is considered ideal for the further development of this application.

D.1 WHAT IS OBJECT ORIENTED PROGRAMMING

Object oriented techniques are a change from the previous software methodologies. They seek to ease the development of systems by making parts of a system reusable in many situations. The developer is aided by shifting the emphasis onto items more familiar in the problem, and allowing these to be modelled and manipulated.

The focus in an object oriented solution are entities in the problem space. These, and their behaviour are modelled by objects in the software which interact by passing messages. This is in contrast to the traditional approach to software design which breaks a system down into a sequence of processes. Each entity in a problem is represented by a software object, this contains definitions of both its state, i.e. variables and its behaviour, i.e. the routines which act on those variables. In contrast to traditional programming these are held together with the behaviours or methods defining what operations may be performed on data in a class. This feature of isolating the internals of classes from each other is encapsulation, it allows each class in a system to be considered separate from the others, allowing its reuse in other areas.

Not all objects within a system model physical entities. To improve the ease with which a design may be understood, or to promote reuse, extra abstract entities may be introduced. This is particularly useful where an object is large and complex, built-up from many parts. To aid in assembling complex or specialised versions of objects, the approach allows inheritance. This denotes situations where an object derives part of its make-up, both state and behaviour, from another object. The new inherited object may then add further states and behaviours, or override the existing ones. Inheritance may take place through many levels, and from multiple sources to allow complex class systems to be built, however some implementations place limitations on this.

The main benefit of inheritance is again to promote reuse of existing code. By inheriting from a base class, the common feature of several different objects need only be defined once. Where several specialised objects are derived from a base, each may re-define a behaviour to work in a way particular to it. This ability to respond differently to the same message is known as polymorphism. It allows one class to send a message to another to cause the appropriate behaviour without explicitly needing to know which specialised version the receiving class is. Instead it simply knows the second object will understand the message and act accordingly.

While object oriented programming is a powerful way to view problems, it is based on these three basic principles:-

Encapsulation of states and behaviours.
Inheritance from other classes.
Polymorphic response to messages.

These together form the basis for software reuse

D.2 APPLICABILITY TO PUMP SELECTION

The modelling and selection of hydraulic pumps appears to be a natural candidate for the use of object oriented techniques. The way the application engineer approaches the task is analogous to this method, considering the hydraulic size, build, motor, seal etc. as separate entities before assembling a solution.

By allowing the problem to be modelled in the same way, object oriented techniques should ease the expression of the engineers knowledge and its translation into the system.

Each of the major components may be considered a separate entity together building into the complete pump, the solution for the programme. By treating each as an individual object they may be isolated from the others and developed separately. This aids the development process allowing the system functionality to gradually add components which then interact with the existing system.

The modelling of the hydraulic performance is both the most important, and the most complex. It will involve several layers of inheritance through abstract objects. These would represent the generalised properties of centrifugal pumps, then single stage pumps before arriving at the layer to represent the particular features of the D-Line range. It is unlikely that initially each size would require its own class, but as knowledge is added this could be done.

By introducing a structure to the representation of the pumps, the object hierarchy eases the addition of knowledge. By ascertaining how general the rule is its position in the tree of abstract entities is easily found. Each needs to be placed in only one class, the reuse in the hierarchy ensure it is available wherever relevant, hence, reducing the systems duplication.

SELECTION OF AN EXPERT SYSTEM SHELL

D.Franklin
J.Toothill

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INTRODUCTION

SPECIFICATION

COMPARISON OF THE EXPERT SYSTEM SHELLS

ALTERNATIVES TO EXPERT SYSTEM SHELLS

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Introduction

The following document is designed as an aid to the decision of which Expert System Shell to choose for future development work. It outlines the various criteria for a selection and compares the performance of four alternative shells, it then recommends a choice for the implementation of the selection system.

Specification

The specification can be divided into 7 main areas :-

(1) Access to Databases
(2) Handling of Rules
(3) Object Oriented Facilities
(4) Knowledge Inference Facilities
(5) External Language Facilities
(6) Hardware and Software requirements
(7) Development Environment

There follows a brief description of each area.

(1) Access to Databases

The shell has to have the facility to access dBase III+ databases, additional database types would be welcomed. The manner of preferred access would be using indexed files, these being the speediest way of accessing a database record. The facility should also be able to handle multiple indexes and multiple files opened at a particular time.

(2) Handling of Rules

It is considered advantageous if the shell allows rules to be stored external to the main programme, this would allow a smaller programme to be used in run-time. This facility should be available if and when called for by the main programme.

(3) Object Oriented Facilities

The Expert System shell should have the facility to use objects to represent entities, this should be allowed dynamically for creation and deletion during run-time. All other facilities associated with ′objects′ should be catered for.

(4) Knowledge Inference Facilities

Ideally the shell should be able to give information to the user about what the Inference Engine is doing at a particular time, possibly with diagrams, etc. Standard facilities associated with Inferencing should be catered for, i.e. Forward and Backward chaining, default reasoning, etc.

(5) External Language Facilities

External language routines should be callable from within the Expert System shell with ease with variables passing between the routine at run-time. The time taken for the switching should not be unfavourably long.

(6) Hardware and Software Requirements

Ideally the shell should be usable on any available personal computer using any central processor, i.e. from a '8088' to a '80486'. Use whatever screen driver is available, and be free from restrictive software requirements. It should be able to utilise extra facilities such as, extended memory and co-processors, etc. Should be network compatible, and portable to other platforms, i.e. UNIX, etc.

(7) Development Environment

Flexible rule and object editing, rule network illustrations would be an advantage. An extensive and user friendly de-bugger would be necessary.

There are other areas of interest which relate to the acceptability of a shell:-

(i) The extent of software support and the availability of training courses.

(ii) Its foreseeable longevity, i.e. whether it will still be useful in a number of years time, and whether it will be obsolete.

(iii) Whether it is possible to transport the programme across different platforms, i.e. UNIX, Mainframes, etc.

(iv) The shell should have reasonable facilities for the output of information to the user, in a variety of forms.

Comparison of the Expert System Shells

Four alternative shells were examined with regard to the above criteria, these were: *ART-IM*; *KAPPA PC*; *NEXPERT Object* and *LEVEL 5 Object*. A summary of the results of the examination are shown in the table APPENDIX A.

From the criteria it is clear that the software available will fulfil all the basic requirements. One of the most important areas of interest is the executability of the software on basic '8088' processors. The survey has shown that the choice of software shell will affect the machines it will be executable on. Only ART-IM has the capability of running on a '8088' processor machine, whilst the other three can only run on a minimum of a '286' machine. However, is this a reasonable requirement ? The aim of the programme is to produce a fast, good quality response to enquiries, is it therefore reasonable to run an advanced software programme on a slow and arguably outdated computer when Dresser UK is currently purchasing '286' machines as a minimum.

Other criteria such as access to Dbase indexed files are not so critical, since 'C' library routines are available that deal with dBase III+ accessing, allowing the calculations to be performed and answers passed back to the shell.

If then a decision has to be made on the four choices of software shell then it must be based largely around cost, with regard to development price and run-time costs. Appendix A summarises the comparative costs of the software, added to this are the costs of additional software, such as 'Windows 3', where required. Also the use of Windows 3 in three of the shells requires that there be 2 MegaBytes of Ram on the machine, this is necessary for both development and run time. This, however is not as important as run-time costs, i.e. how much it would cost to distribute to the sales offices of Dresser Pump (UK). For each programme a run time licence has to be used, the cost ranging from £250-£800. If ,for instance, 5 licences were required for the Newark site and 8 for the Sales Offices, then a total cost of £3250-£10400 is reached depending upon which shell is used. If the distribution is on a larger scale special rates can be applied, these are still however expensive, typically £400,000 for a world wide licence, and in the region of £25,000 for a UK licence. The need for a run-time licence for each distributed copy hence makes the application of the programme as a supplement to brochures, etc, uneconomical.

Alternatives to Expert System Shells

In addition to using an expert system shell for development work there are a number of alternative options:-

(a) Writing a Expert System in a conventional high level programming language such as 'C'.

(b) Using a shell as a knowledge acquisition tool and then transferring the knowledge held by the shell into a language such as 'C'.

(c) A toolkit library built on an A.I. programming language e.g. 'PROLOG', could be used to write a custom Expert System, that would mean the programme only offers the facilities that are required for the application.

The alternatives listed above offer certain advantages to using a shell for the total system. All of the possibilities above would mean that there would be no run-time licence, hence the only cost of distribution is the price of the floppy disks. Writing an Expert System in a programming language or using a Toolkit would require a longer lead time, since it would require expertise that is not available at present within the project team, although 'C' programming language is being learnt. Although arguably all of the three above alternatives have equal difficulty involved in them.

If these options were considered viable then a step away from the projects original path is made, since the scheme produces a Knowledge Based System and not an Expert System in the final form of use.

Discussion

The key areas of interest above, relate to the acceptability of a shell. A decision process has now to be quantified. During discussions between Mr Reeve, Mr Toothill and Mr Franklin, it became clear that a systematic approach needed to be applied to help decide the choice of a shell. Hence, a chart comparing Egeria, all 4 shells, writing the programme in 'C', and using a Toolkit in a programming language, was compiled. Appendix B

It has become clear that there are two alternative ways of writing a pump selection system, these are :

(i) writing the system in a shell and then distributing run-time versions, or

(ii) writing the system in a language such as 'C', and distributing without run times, since it would not require one.

Writing the system in a shell gives the advantage of rapid and easy prototyping, thus giving the programmer an opportunity to assemble ideas and implement into code quickly, prior to testing. In a complex system such as the selection programme a quick means of prototyping is vital. As has been said earlier a run time licence is required for distribution of the software, the cost of which is prohibitive, when considering a wide distribution area. Whilst a system written using a language such as 'C' or 'PROLOG', does not require a run time version.

It was therefore decided to utilise the best points of both alternatives, by using a shell to implement a prototype system, and then transfer the code to a language suited to knowledge based systems. If the correct choice of shell was made, then the transfer of code could be implemented in stages by the use of external routines. If problems are encountered during the transfer then either sections of code could be passed for external coding by consultant programmers, or run times can be used, the suitability depending upon the shell being used. Since a run time version would be available then a limited number of versions could be distributed for evaluation, perhaps to the sales offices and Newark site users, without the cost being prohibitive. This would mean that a user network is then available for testing the updated versions during the code transfer, i.e. for BETA testing. Also if someone wanted the software for selections then they could buy the run time version and additional software, and a copy of the programme could be supplied.

One problem that may well occur is the time taken for the implementation of the various stages, these being :

(i) Learning the language of the 'Shell'.

(ii) Learning a language for code transfer, ideally 'C'.

(iii) The possible learning of toolkits for use in the language.

The time taken for the implementation of the method advocated in this document for the production of a pump selection system, should not be underestimated. What may well occur is the programme will run beyond the length of the Teaching Company Scheme if a version is required for world wide distribution. It does however have a distinct advantage, at all times a version of the programme is available in the shell for use.

What is left is a decision between the four shells (*ART-IM, KAPPA-PC, LEVEL 5 object* and *NEXPERT object*) based upon their individual merits with regard to the user interface and the debugging environment. Since there is now no requirement to distribute the programme world wide using run times, the costs are not really important to a choice of a shell, and hence drop from the criteria.

Since all four software shells offer comparative facilities it is not readily possible to choose on their merits, it is easier to eliminate shells based upon inadequacies. Using Appendix B certain shells can be eliminated form the list.

ART-IM can be dismissed due to the lack of adequate technical support, because the applications engineers are at this time learning the package for themselves, and hence their knowledge will be not to a great depth.

NEXPERT object is approximately twice the price of either LEVEL 5 or KAPPA-PC, for the same facilities, hence the justification of this shell is difficult.

LEVEL 5 and KAPPA-PC approach the task of software development in two different directions, KAPPA-PC is biased towards objects, whilst LEVEL 5 is biased towards rules. To help decide which is the most appropriate shell for use as a development tool, evaluation copies of the two have been obtained.

RECOMMENDATIONS

The associates make the following recommendations :-

(i) An Expert System shell is to be used for prototype work and during all development work. Once a selection programme is finalised the system is to be transferred to ´C´.

(ii) The development shell will either be LEVEL 5 or KAPPA-PC depending upon the evaluation results.

APPENDIX A : Comparison Chart

POINTS	ART-IM	KAPPA PC	NEXPERT Object	LEVEL 5 OBJECT
DATABASE ACCESS	NOT USING INDEX FILES	YES FULLY	YES ?	NOT INDEX FILES TO BE ADDED...
EXTERNAL RULES	NO : ALL ONE PROGRAMME	YES	YES FULLY	YES
OBJECT ORIENTED	YES	YES AND BIASED	YES	YES
KNOWLEDGE BASE FACILITIES	YES FULL STANDARDS	YES FULL STANDARDS	YES FULL STANDARDS	YES FULL STANDARDS
EXTERNAL LANGUAGE	YES, BECOMES PART OF KB	YES, BECOMES PART OF KB	YES	YES
HARDWARE/ SOFTWARE (DEVELOPMENT)	2-4 MB Ram ANYTHING: 8088 AND UPWARDS MICROSOFT 'C' 8 MB HARD DISC FREE	'286' OR '386' CPU REQUIRED WINDOWS 3 MICROSOFT 'C' HERC, EGA OR VGA DRIVERS 2MB Ram/HARD D	'286' OR '386' CPU 2-4 MB Ram MICROSOFT 'C' WINDOWS 3 EGA/VGA OPT' WINDOWS SDK	'286' OR '386' 2 MB Ram WINDOWS 3 MICROSOFT 'C' EGA/VGA
(RUN-TIME)	ANYTHING: 8088 AND UPWARDS RUN TIME £400 APPROX'	ABOVE LIST RUN TIME £300	'286' OR '386' CPU 2 MB Ram DIFFERENT FORMS OF DRIVERS FOR AVAILABLE SCREENS RUN TIME £800	'286' OR '386' WINDOWS 3 2 MB Ram RUN TIME £250
DEVELOPMENT ENVIRONMENT	SINGLE STEP/ BREAKS, ETC	SAME	SAME	SAME
OTHER PLATFORMS	MAINFRAME,UNIX SUN,DEC, ETC	NONE	MAINFRAME,UNIX,DEC SUN, ETC	SOME : BEING ADDED TO.....
SUPPORT/ TRAINING	FEB' '91	NO OFFICIAL UK ON SITE PREFFD	1 PER MONTH INTRO & ADVANCED	1 PER MONTH
PRICE (DEVELOPMENT VERSION)	£5000	£2500	£4500	£2160

APPENDIX B : Decision Chart

	EGERIA	ART-IM	KAPPA-PC	NEXPERT	LEVEL 5	'C'or PROLOG	SHELL -> 'C'
START	RECODE IN C RESTRUCTURED						
CODE	LEARNING 'C'	LEARNING SHELL (LS)	LS	LS	LS	LEARNING LANG'AGE & TOOLKITS	LEARNING SHELL & 'C'
DEVELOPMENT EQUIPMENT	286/386 CPU 'C' LANGUAGE	286/386 CPU 2-4 MB Ram MICROSOFT 'C'	286/386 CPU 2 MB Ram EGA/VGA MICROSOFT 'C' WINDOWS 3	286/386 CPU 2-4 MB Ram WINDOWS 3/SDK & OTHERS EGA/VGA MICROSOFT 'C'	286/386 CPU 2 MB Ram MICROSOFT 'C' WINDOWS 3 EGA/VGA	ANY	AS SHELL 'C' DEVELOP ON ANY
RUN TIME EQUIPMENT	ANY	ANY	286/386 CPU WINDOWS 3 2 MB Ram	286/386 CPU WINDOWS 3 2 MB Ram	286/386 CPU WINDOWS 3 2 MB Ram	ANY	AS SHELL ---- FINAL ON ANY
SOFTWARE PRICE (£)	4000	5000	2500	4500	2160	?	AS SHELL + 'C' AND LIBR'S
RUN TIME PRICE (£)	300	400	300	800	250	N/A	AS SHELL + N/A
FUTURE	UNCERTAIN !!	PORTED FROM WORKSTATION	PORTED FROM WORKSTATION	40 % WORLD WIDE MARKET	19 th LARGEST SOFTWARE HOUSE IN WORLD	AS LANGUAGE DEPENDENT UPON COMPANY	SELF WRITTEN UNDER OUR CONTROL
BENEFITS	ICL MAINFRAME LINK	OTHER PLATFORMS	SUN USING 'KEE'	OTHER PLATFORMS	OTHER PLATFORMS	NO RUN TIME	DEVELOP' ENV'ENT LESS R-T COST
TRAINING	?	?	GERMANY/USA ON SITE PREFD	1 PER MONTH	1 PER MONTH	AVAILABLE	AS SHELL + 'C' AVAILABLE
TRAINING COST (£):2	?	1800	3/4000	2000	1300	?	SHELL + OTHERS
DEBUGGING ENVIRONMENT	TEXT	STEPS,BREAKS, RULES,OBJECTS-	SAME PLUS GRAPHICS	SAME PLUS GRAPHICS	SAME PLUS GRAPHICS	TEXT, SINGLE STEP ,ETC	AS SHELL + 'C' DEBUGGING
OTHER	CONTACT WITH COMPANY	CONTACT WITH COMPANY	MAINLY OBJECT BASED				MORE CONTROL

USER INSTRUCTIONS FOR P.S.I.

PUMP SELECTION WITH INTELLIGENCE

VERSION 2.1

DRESSER PUMP DIVISION (UK)
MARKETING SYSTEMS

B. Reeve Ext 316
J. Toothill Ext 386
D. Franklin Ext 386

CONTENTS

1.0 Introduction

The attached disc contains version 2.1 of a selection system written in C++. It was written through a Teaching Company Scheme in connection with Nottingham Polytechnic, and in consequence all the techniques and expertise lies in house and not in an external company.

The philosophy behind this software has been to cater for the majority of cases where pump selections are carried out. The key to the programming has been to keep the quick selections quick i.e. a customer gives a HEAD and CAPACITY only ! but give sufficient flexibility to allow it's use for the more complicated selections.

Development was carried out with the assistance of the UK sales force, who advised on the layout and content of the screens. As the system is constantly being improved, further feedback is welcomed.

2.0 Installation

The disc contains three files:

(i)	INSTALL.BAT	: Installation Programme.
(ii)	ARCHIVE.EXE	: Archive containing programme & data.
(iii)	READ.ME	: Read me file.

The installation programme will create a subdirectory ***'PSI21'*** on the hard disc, copy the archive into this, then extract the programme and data ready to run.

To install PSI move to the drive containing the installation disk, then type *INSTALL* followed by the drive letter on which to copy the programme.
E.g. If installing from floppy drive A: to hard disc C: type:-

```
A:
INSTALL C:
```

Note

(i) The software must be installed before it can be run.
(ii) The installation procedure always creates a subdirectory *'PSI21'* in the root of the chosen drive. If this would cause a problem, the programme may alternatively be installed by copying ARCHIVE.EXE to the required directory, then unarchived by typing ***ARCHIVE***.
(ii) To remove this installation move to the installed directory i.e. ***psi21***, enter ***attrib -r *.****, then enter ***del *.****. This should remove the programme from the computers hard disk.

3.0 How to use the programme

To start the programme type in *PSI* from the PSI21 directory.The entry screen Figure 1.0 requires values for HEAD and CAPACITY, all other values are defaulted. If values are known use the editing facilities to overwrite, or replace those shown. If after pressing PAGE DOWN or F10, the screen returns, the computer requires a value to be entered within one of the fields, i.e. a 0 : ZERO has been entered as a value, where a non-zero is required.

The units for entry of the duty conditions are defaulted to metric units. If other units are required, pressing 'U' will pull up a list of alternative units available for this field. Each field is independent, i.e changing head to feet does not change the units for npsh. Figure 2.0.

After completion of the duty conditions, a menu of available casing materials is displayed. Select a material using the arrows and return key. Only a single material may be chosen, if a number are required for viewing, select 'ALL'. Figure 3.0.
The system preselects the suitable ranges of pumps for the entered conditions, and presents these to the user. Pressing 'RETURN' toggles acceptance of each range (indicated by 'RANGE ACCEPTED'). When the user has decided which ranges to investigate further, pressing 'F10' starts the selection. Figure 4.0.

A status box is displayed to give the user an indication of the progress with the selection. A percentage completed plus the number of pumps found is displayed. Figure 5.0.

Once the selection process is completed the MAIN SCREEN is displayed FIGURE 6.0, giving a basic hydraulic information about a number of pumps, ordered by efficiency.

For Dline and Magline selections, the following apply : -

(i) an 'o' next to the impeller diameter indicates that this selection uses an optional impeller

(ii) a '*' before the npshr indicates insufficient npsh is available

(iii) an 'i' after the npshr indicates this figure is achieved by fitting an inducer.

All ranges of pumps can have the following for NPSHr : -

'REFER' in place of an npshr figure indicates the capacity is before the start of the npsh curve, hence the computer cannot give a value. The user should refer to Newark.

Pressing 'F1' on all the screens, except the performance curve graphic, displays information about the available key presses, for that particular screen, Figure 6.1.

The options from this screen are

- (i) Key 'n' :- NEAR MISS SCREEN.
- (ii) Key 'b' :- BUILD SCREEN.
- (iii) Key 's' :- STOCK SCREEN.
- (iv) Key 'm' :- MOTOR SCREEN.
- (v) Key 'p' :- Toggles PERFORMANCE data display.
- (vi) Key 'q' :- QUOTE SCREEN.
- (vii) Key 'd' :- DELETE cursor item from list.
- (viii) Key 'g' :- GRAPH of cursor item.

Pressing 'p' displays additional performance data for the selections displayed on the MAIN SCREEN, Figure 7.0. The options from here are identical to those available from the MAIN SCREEN.

Pressing 'n' will display the NEAR MISS SCREEN, Figure 8.0, this contains all the pumps evaluated but rejected by PSI, with an appropriate reason for the failure. From this screen there are three options

- (i) Key 'g' :- Display a graph of the cursor item
- (ii) Key 'd' :- DELETE cursor item from list.
- (iii) Key 's' :- Display STOCK SCREEN.

Pressing 'm' displays the MOTOR SCREEN, Figure 9.0, giving a list of motors that can be fitted to the pump highlighted on the MAIN SCREEN, if that selected by the system is deemed inappropriate. To alter the motor to be fitted first highlight the appropriate size by using the cursor keys, then hit the RETURN key, this automatically returns to the Main Screen, changing the motor size and correcting the performance for the new motor's running speed. Replacing the motor reevaluates the build options, and hence should be performed before an alternative build option is selected. The item marked "<< ESS" is the motor size according to Newark Engineering Standard Specifications. Hitting ***'Esc'*** on this screen has the effect of doing nothing, i.e. the motor already fitted will be unchanged. The system at present only caters for motors capable of up to 150kW. Above this the maximum power absorbed is rounded up to give an indication of the motor power required. Non-standard motors are often required at these sizes, hence the motor data will be added later.

Pressing 'b' will display the BUILD SCREEN, this shows the alternative configurations available giving different Engineering limits e.g. pressure. The format and content differs between ranges, though the currently selected build is always shown at the top of the list. As with motors, RETURN changes the build to that highlighted and returns to the main screen, ***'Esc'*** returns without making changes.

Dline and Magline build screens, Figure 10, show which of the standard builds are available, with the appropriate pressure and temperature limits. Where an option is required to achieve the conditions, this is noted.

LNN builds, FIGURE 11.0, show those available of the four standard builds (material combinations). Using differing materials for the Casing, Rotor and Impeller gives a number of limits for pressure, torque and circumferential speed. Each may be altered individually where an alternative exists. Materials marked '*' are optional materials for that standard combination. For some LNN sizes, data is not available on the rotor. These have the rotor material and pride shown as ***REFER***. Selections on these units should be referred to the SBU.

A guide is given to the relative price of the builds, and the optional materials. This is **NOT** the selling price.

(i) Key 'k' : Displays the material abbreviation table. Figure 12.0.
(ii) Key 'c' : Displays the Casing options. Figure 13.0
(iii) Key 'r' : Displays the Rotor options. Figure 14.0
(iv) Key 'i' : Displays the Impeller options. Figure 15.0

On the option screens, keys RETURN and ESC work as on the build screen.

Pressing 's' will display the STOCK SCREEN, Figure 16.0, this searches for stock options for the units on the Main Screen list and Near Miss list (**NOTE:** this only finds dline stock selections), the stock list being ordered by nearness to the required duty conditions (the nearest above the required head in descending order, and then those below the required head in descending order). The options from that screen are :

(i) Key 'q' :- Display QUOTE SCREEN.
(ii) Key 'd' :- DELETE cursor item from list.
(iii) Key 'g' :- Graph of cursor item.

If an value of greater than 1 is entered for s.g., or a viscosity > 4 is entered then the STOCK SCREEN will display the maximum power absorbed by the pump at the duty. Occasionally it may be found that the motor supplied with that stock combination will not cover the power required, due to the nature of the fluid. It is therefore necessary to change the diameter for that stock size, and check the seal compatibility, etc, to ensure the correct operation of that stock option. This will have to done manually, the computer will display when this is necessary, by a message on the QUOTE SCREEN. The price displayed on the STOCK SCREEN is only relevant to UK Sales at present, also the '*In Stock*' number is for later use, and should be ignored.

Pressing 'q' displays the QUOTE SCREEN, Figure 17.0, which displays all the information related to the highlighted item on the MAIN SCREEN. Hitting any key will display a message asking whether to save this to a file, Figure 18.0. If a printed performance curve is required, the data should be saved **at this point**. Answering this question returns to the previous screen.

Pressing 'd' deletes the highlighted item completely from the list, there is no going back and retrieving the deleted item, the only alternative is to run the system again with the same duty conditions, from the final option screen.

Pressing 'g' displays the performance curve on screen, Figure 19.0. This option is available for the highlighted item from the following screens: MAIN SCREEN, NEAR MISS SCREEN, and STOCK SCREEN. After an on-screen graph 'Esc' returns the user to the previous screen. For hard copies of curves see below.

At all times it is possible to hit the 'Escape' key, this always exits from the screen you are currently on. In the case of the STOCK, MOTOR and BUILD SCREENS the effect is to do nothing, i.e. no alterations are made to the item on the MAIN SCREEN. The F1 key is also available from all screens except the graph screens.

'Escape' from the MAIN SCREEN displays a menu, Figure 20.0, enabling the programme to be exited or rerun in a variety of options. If the option to quit is chosen you will be asked if you wish to print performance curves Figure 21.0. The printing routine will drive either a laser printer (HP Laserjet or compatible) or a dot matrix printer (Epson or IBM Proprinter formats). The printer must be connected to LPT1:, it cannot be directed anywhere else from within PSI, at present.

Note:
The printing routine creates a temporary file of up to 1Mb. Sufficient disc space must be available to allow this. If hard copies are required, answer yes to the question at the end of the selection system, Figure 21.0. A list of the saved pumps will then be displayed, Figure 22.0, allowing the user to '*TAG* (indicated by a '✓' next to the item selected), those that need printing, (this is achieved by hitting the '*Enter* key on the highlighted item, see Figure 23.0, it can be untagged by hitting '*Enter*' again). Once those requiring printing have been tagged hitting the *F10* key will display the choice of output devices and quality, Figure 24.0 (higher quality takes more time to complete), hitting the *Enter* key will select the highlighted device and quality of print. The system will then produce the performance curves. If there is more than one tagged item a further question asks whether the device and quality is for ALL the tagged items, answer appropriately.

Currently the programme writes to a text file which is used for curve drawing. With extensive use this file becomes too large for practical use. Further modules will overcome this problem but for this version the text file should be periodically deleted. (Before running PSI type *DEL P_QUOTES.TXT*)

At present the only quotation output available is by hitting the 'print screen key' from either of the QUOTE SCREENS (i.e. MAIN SCREEN and STOCK SCREEN). Additional facilities will be added in further versions of the software.

4.0 Known Problems

There are a number of problems that have been found during programming and testing. These are as follows :-

(i) DOS 4.01 : When using the DOS Shell - If the user exits from this shell i.e. QUITS, and then runs PSI, the programme may crash. If however a 'command prompt' is run from the shell, then the programme works correctly. This appears to be a problem associated with this version of DOS, rather than PSI.

(ii) The DLine 32-125 & 32-200 show no NPSHr curves. Characteristics for these units are under investigation at Newark

(iii) The system is suitable for standalone PC's only.

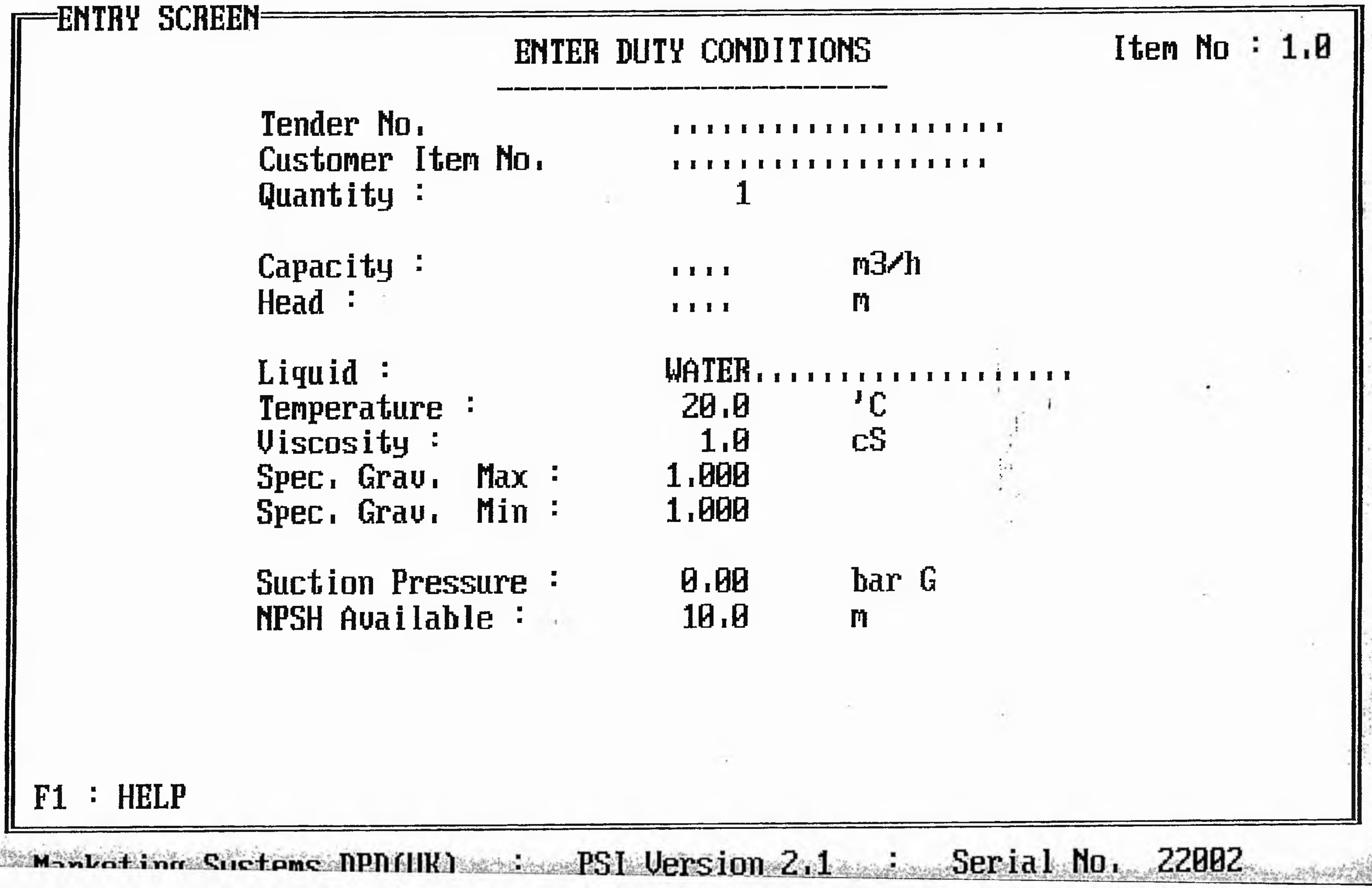
5.0 What to do if it Appears not to Work, or Crashes

All of the following information is required by us before an investigation of a problem may begin :

(i) What were the duty conditions entered into the programme.
(ii) What if anything was displayed by the computer when the system crashed.
(iii) What equipment was the programme being run upon, i.e. machine, display adapter and printer.
(iv) What version of the software was being used.

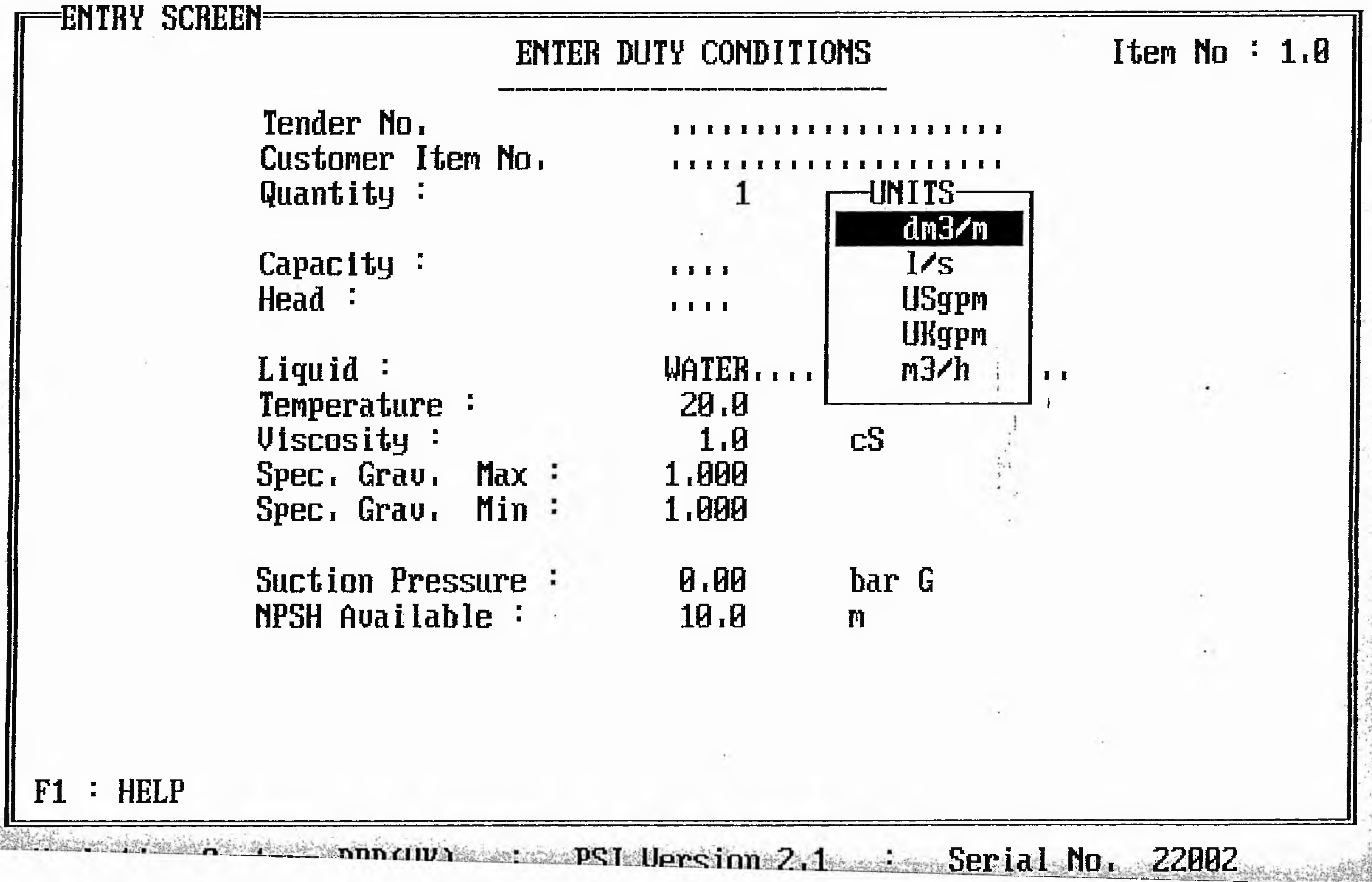
If the programme does crash, try rebooting the machine and running again, preferably with no TSR programmes resident in memory. If all else fails try reinstalling PSI, and try again.

FIGURE 1.0



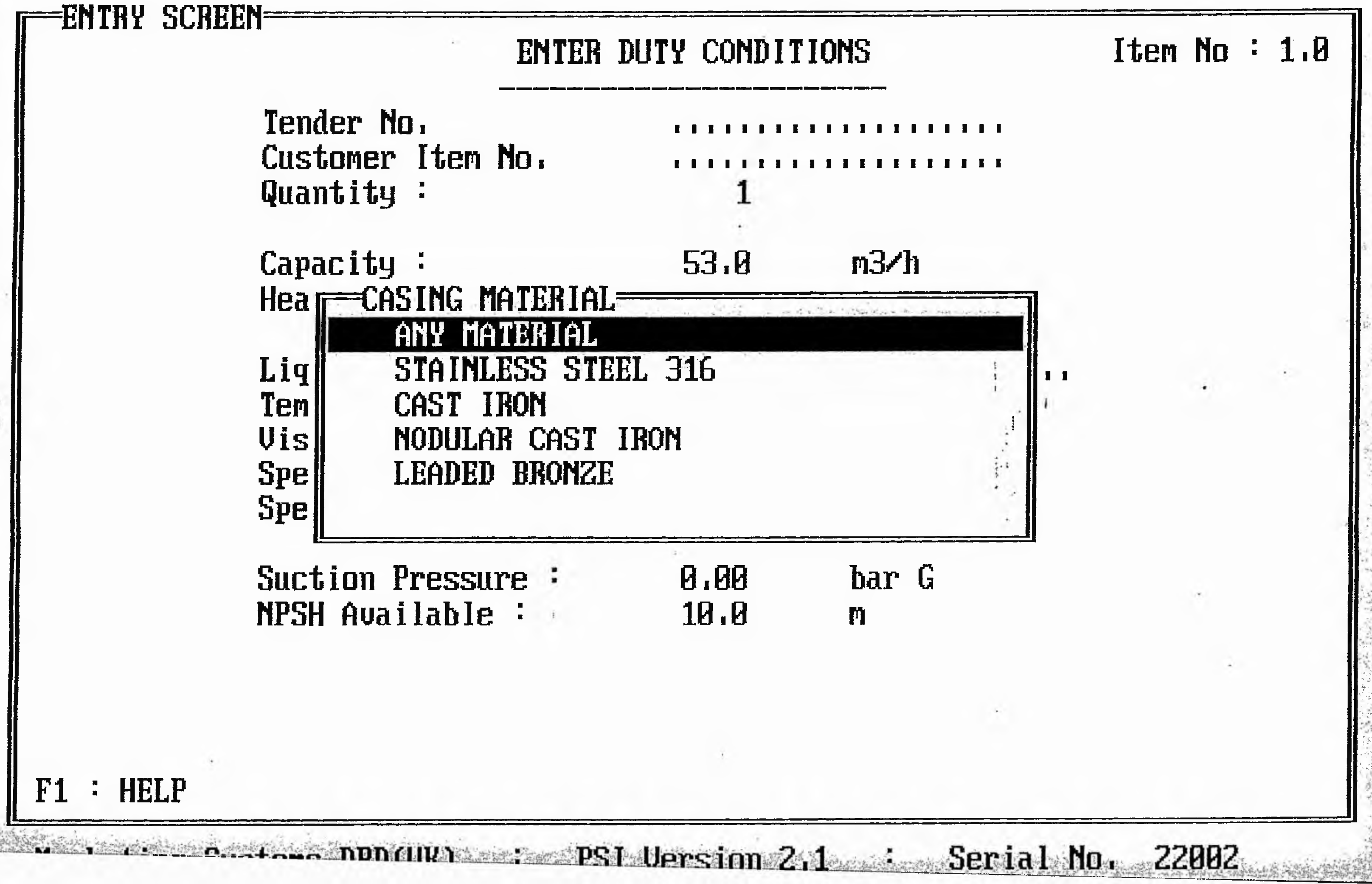
```
ENTRY SCREEN
                        ENTER DUTY CONDITIONS                    Item No : 1.0
                        ---------------------

           Tender No.                  ....................
           Customer Item No.           ....................
           Quantity :                    1

           Capacity :                  ....      m3/h
           Head :                      ....      m

           Liquid :                    WATER.................
           Temperature :                20.0     'C
           Viscosity :                   1.0     cS
           Spec. Grav.   Max :         1.000
           Spec. Grav.   Min :         1.000

           Suction Pressure :           0.00     bar G
           NPSH Available :             10.0     m



F1 : HELP

Marketing Systems DPD(UK)   :   PSI Version 2.1   :   Serial No. 22002
```

FIGURE 2.0



```
ENTRY SCREEN
                    ENTER DUTY CONDITIONS                  Item No : 1.0
                    ---------------------
       Tender No.                ......................
       Customer Item No.         ......................
       Quantity :                    1     UNITS
                                           dm3/m
       Capacity :                ....       l/s
       Head :                    ....       USgpm
                                            UKgpm
       Liquid :                  WATER....  m3/h    ..
       Temperature :              20.0
       Viscosity :                 1.0     cS
       Spec. Grav.  Max :        1.000
       Spec. Grav.  Min :        1.000

       Suction Pressure :         0.00     bar G
       NPSH Available :           10.0     m

F1 : HELP
                          :    PSI Version 2.1    :    Serial No.  22002
```

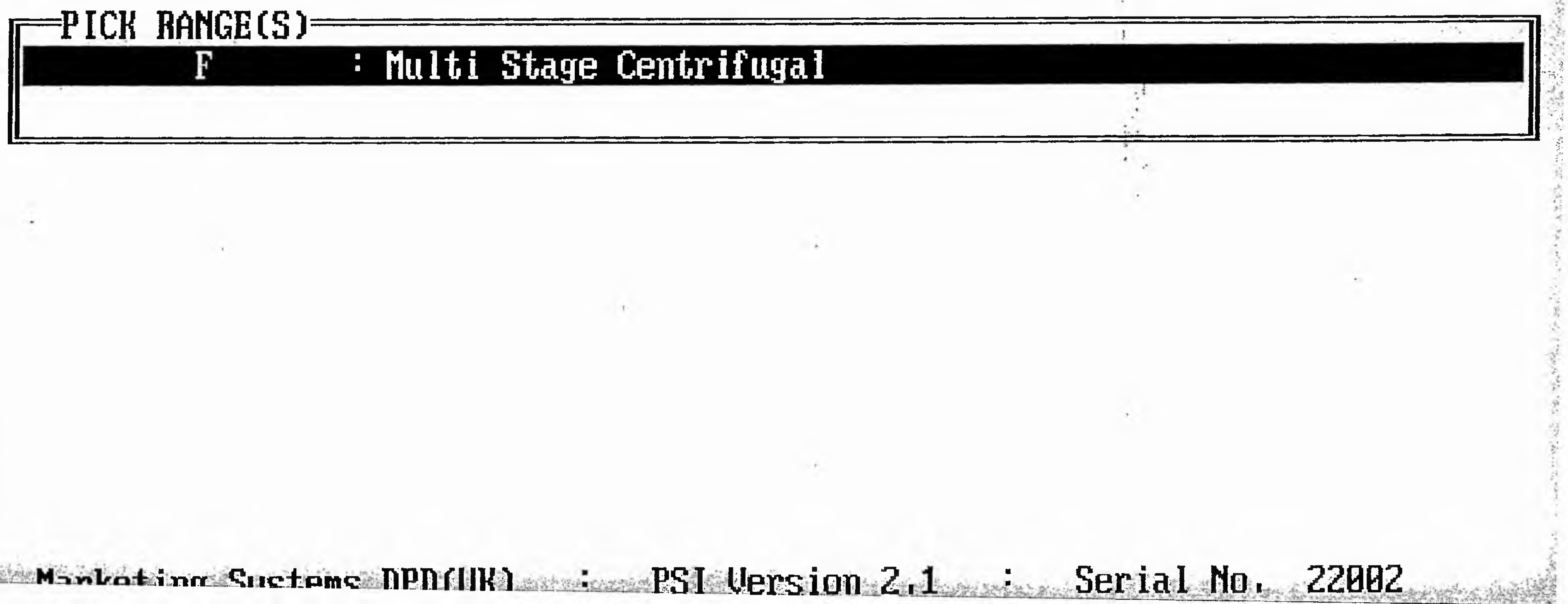
FIGURE 3.0



```
ENTRY SCREEN
                         ENTER DUTY CONDITIONS                Item No : 1.0
                         ------------------------
               Tender No.                 ....................
               Customer Item No.          ....................
               Quantity :                      1

               Capacity :                 53.0      m3/h
               Hea ╔CASING MATERIAL═════════════════════════╗
                   ║   ANY MATERIAL                          ║
               Liq ║   STAINLESS STEEL 316                   ║ ..
               Tem ║   CAST IRON                             ║
               Vis ║   NODULAR CAST IRON                     ║
               Spe ║   LEADED BRONZE                         ║
               Spe ║                                         ║
                   ╚═════════════════════════════════════════╝
               Suction Pressure :         0.00      bar G
               NPSH Available :           10.0      m

F1 : HELP
```

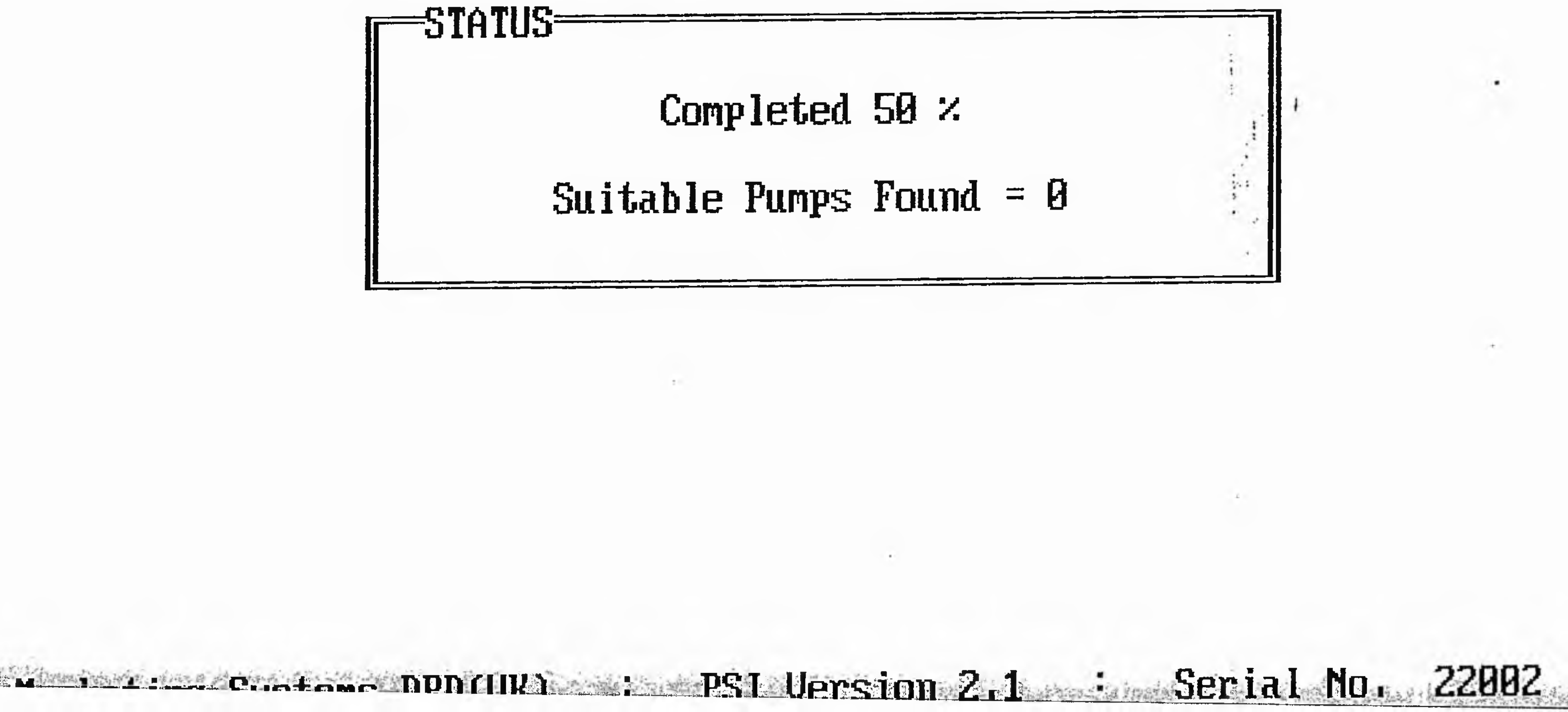
: PSI Version 2.1 : Serial No. 22002

FIGURE 4.0



```
PICK RANGE(S)
      F        : Multi Stage Centrifugal

Marketing Systems DPD(UK)   :   PSI Version 2.1   :   Serial No.  22002
```

FIGURE 5.0



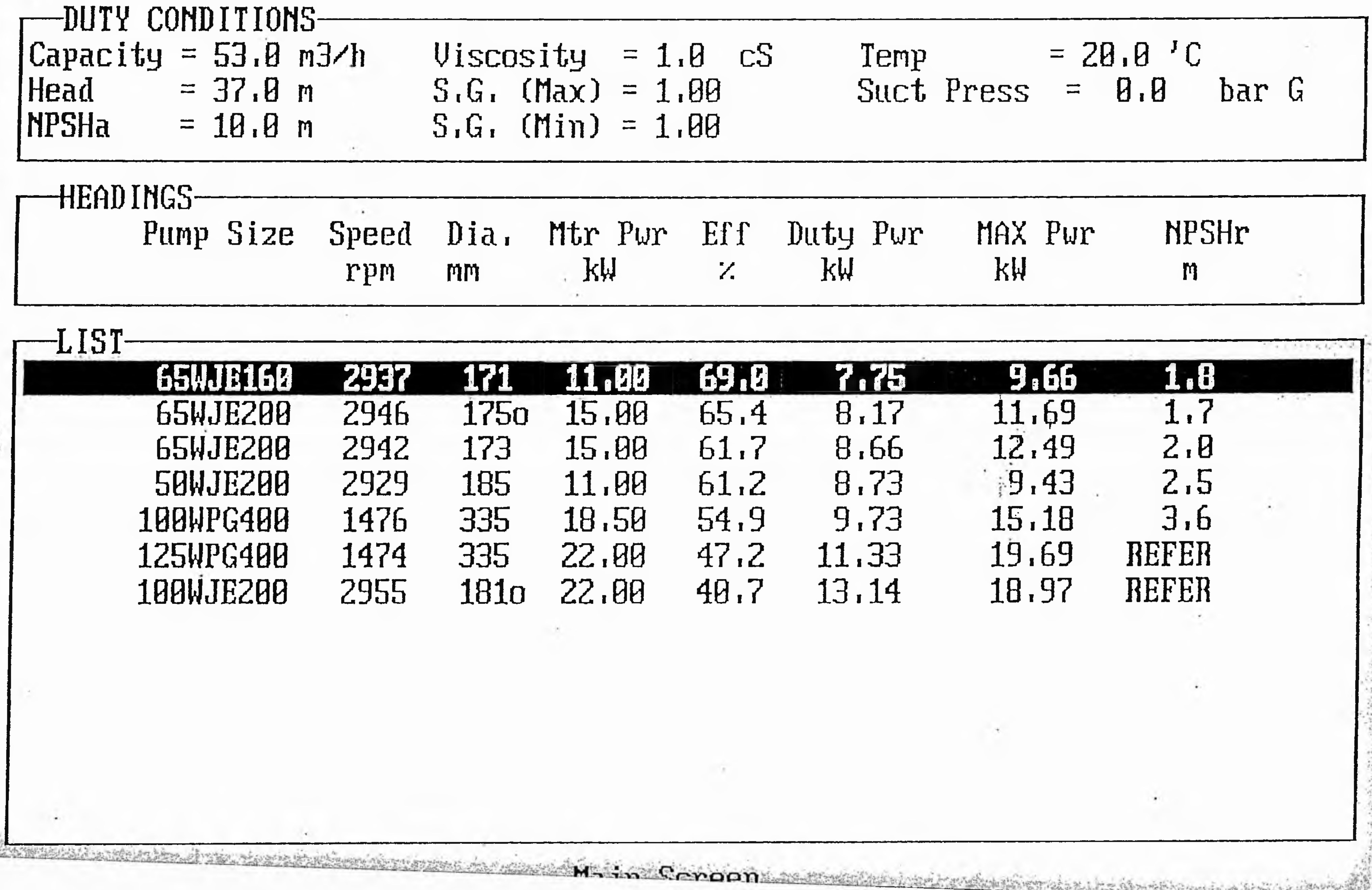
STATUS

Completed 50 %

Suitable Pumps Found = 0

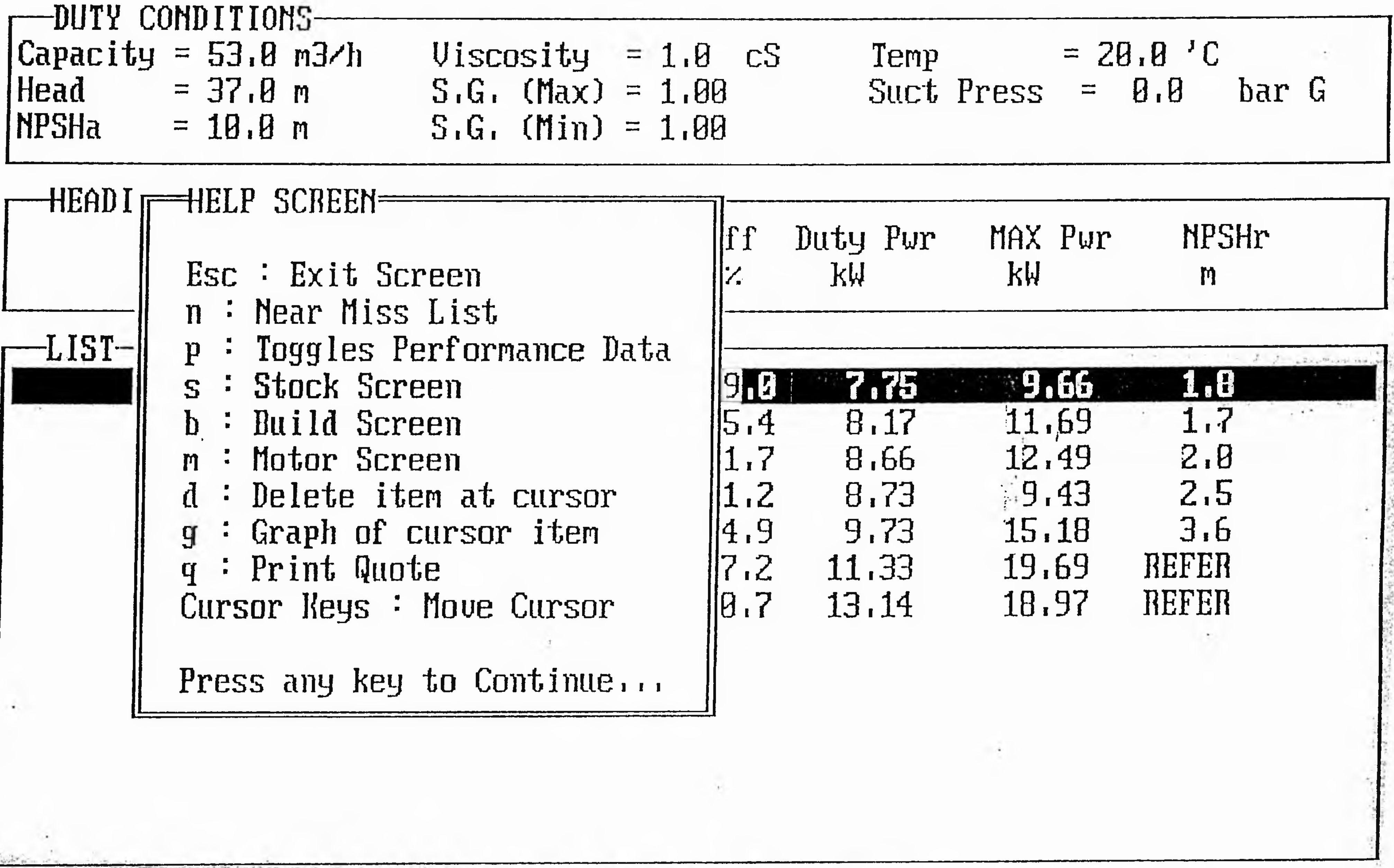
Systems DPD(UK) : PSI Version 2.1 : Serial No. 22002

FIGURE 6.0



```
DUTY CONDITIONS
Capacity = 53.0 m3/h     Viscosity   = 1.0  cS       Temp          = 20.0 'C
Head     = 37.0 m        S.G. (Max) = 1.00          Suct Press   =  0.0   bar G
NPSHa    = 10.0 m        S.G. (Min) = 1.00

HEADINGS
        Pump Size  Speed  Dia.  Mtr Pwr  Eff  Duty Pwr  MAX Pwr   NPSHr
                    rpm    mm     kW      %     kW        kW        m

LIST
        65WJE160   2937   171   11.00   69.0   7.75      9.66      1.8
        65WJE200   2946   175o  15.00   65.4   8.17     11.69      1.7
        65WJE200   2942   173   15.00   61.7   8.66     12.49      2.0
        50WJE200   2929   185   11.00   61.2   8.73      9.43      2.5
       100WPG400   1476   335   18.50   54.9   9.73     15.18      3.6
       125WPG400   1474   335   22.00   47.2  11.33     19.69    REFER
       100WJE200   2955   181o  22.00   40.7  13.14     18.97    REFER

                              Main Screen
```

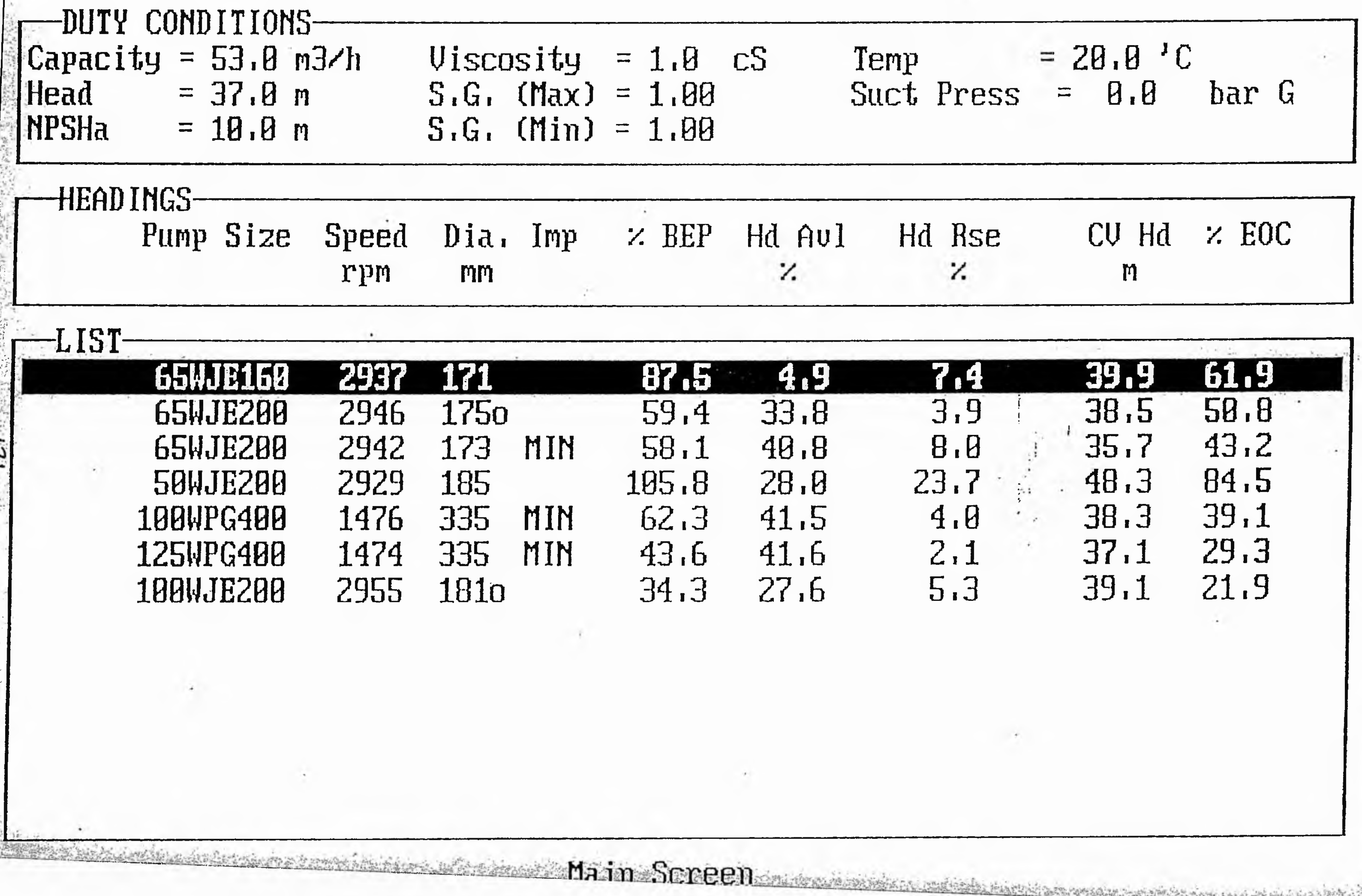
FIGURE 6.1



```
DUTY CONDITIONS
Capacity = 53.0 m3/h     Viscosity  = 1.0  cS      Temp        = 20.0 'C
Head     = 37.0 m        S.G. (Max) = 1.00         Suct Press  =  0.0   bar G
NPSHa    = 10.0 m        S.G. (Min) = 1.00

HEADI  HELP SCREEN
                                          ff   Duty Pwr    MAX Pwr     NPSHr
         Esc : Exit Screen                %       kW         kW          m
         n : Near Miss List
LIST-    p : Toggles Performance Data
         s : Stock Screen                 9.0    7.75       9.66        1.0
         b : Build Screen                 5.4    8.17      11.69        1.7
         m : Motor Screen                 1.7    8.66      12.49        2.0
         d : Delete item at cursor        1.2    8.73       9.43        2.5
         g : Graph of cursor item         4.9    9.73      15.18        3.6
         q : Print Quote                  7.2   11.33      19.69      REFER
         Cursor Keys : Move Cursor        0.7   13.14      18.97      REFER

         Press any key to Continue...
```

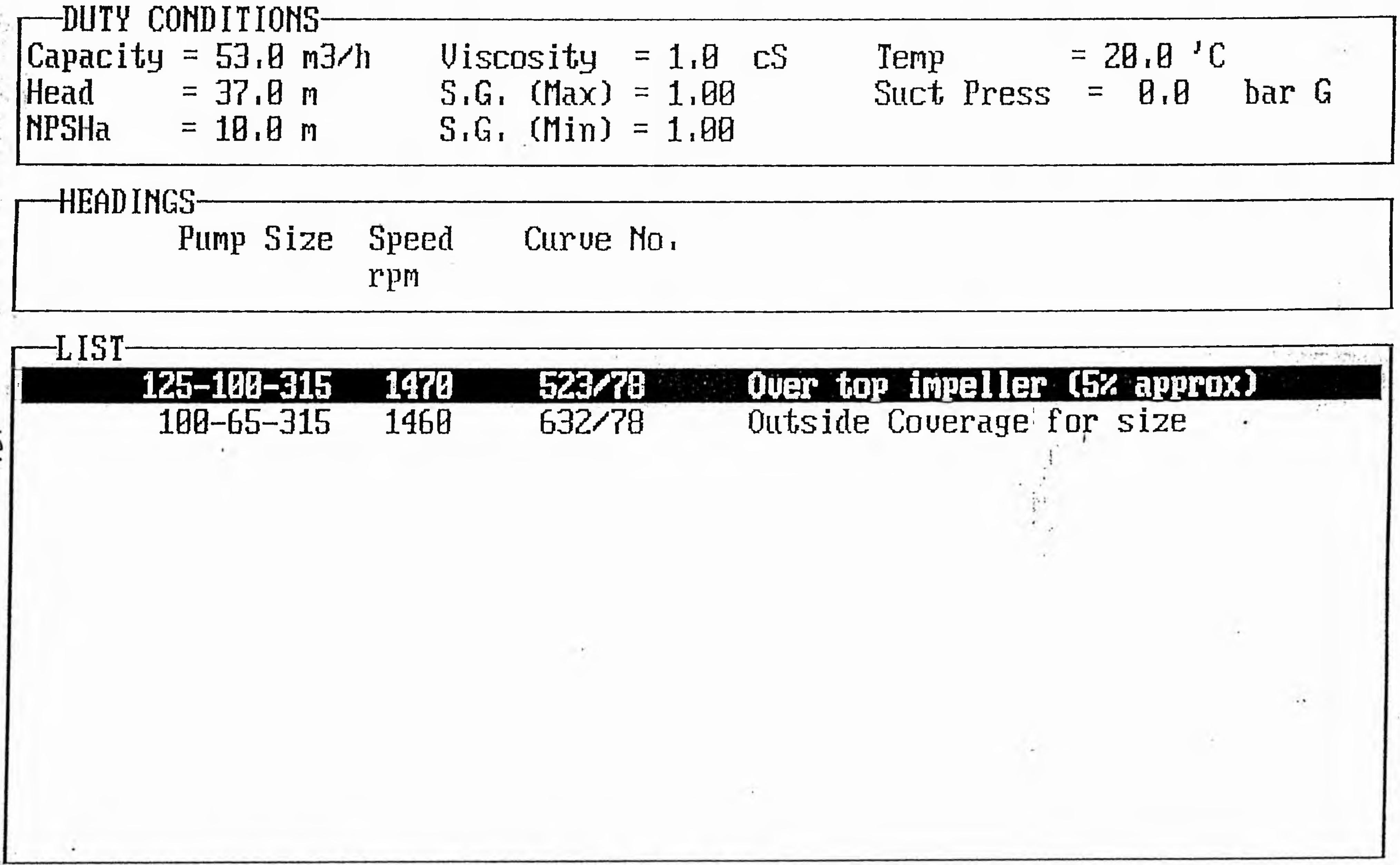
Main Screen

FIGURE 7.0



```
DUTY CONDITIONS
Capacity = 53.0 m3/h     Viscosity   = 1.0   cS      Temp          = 20.0 'C
Head     = 37.0 m        S.G. (Max)  = 1.00          Suct Press    =  0.0    bar G
NPSHa    = 10.0 m        S.G. (Min)  = 1.00

HEADINGS
       Pump Size  Speed  Dia. Imp     % BEP  Hd Avl     Hd Rse       CV Hd   % EOC
                   rpm    mm                   %          %            m

LIST
        65WJE160   2937   171          87.5     4.9        7.4        39.9    61.9
        65WJE200   2946   175o         59.4    33.8        3.9        38.5    50.8
        65WJE200   2942   173   MIN    58.1    40.8        8.0        35.7    43.2
        50WJE200   2929   185         105.8    28.0       23.7        48.3    84.5
       100WPG400   1476   335   MIN    62.3    41.5        4.0        38.3    39.1
       125WPG400   1474   335   MIN    43.6    41.6        2.1        37.1    29.3
       100WJE200   2955   181o         34.3    27.6        5.3        39.1    21.9

Main Screen
```

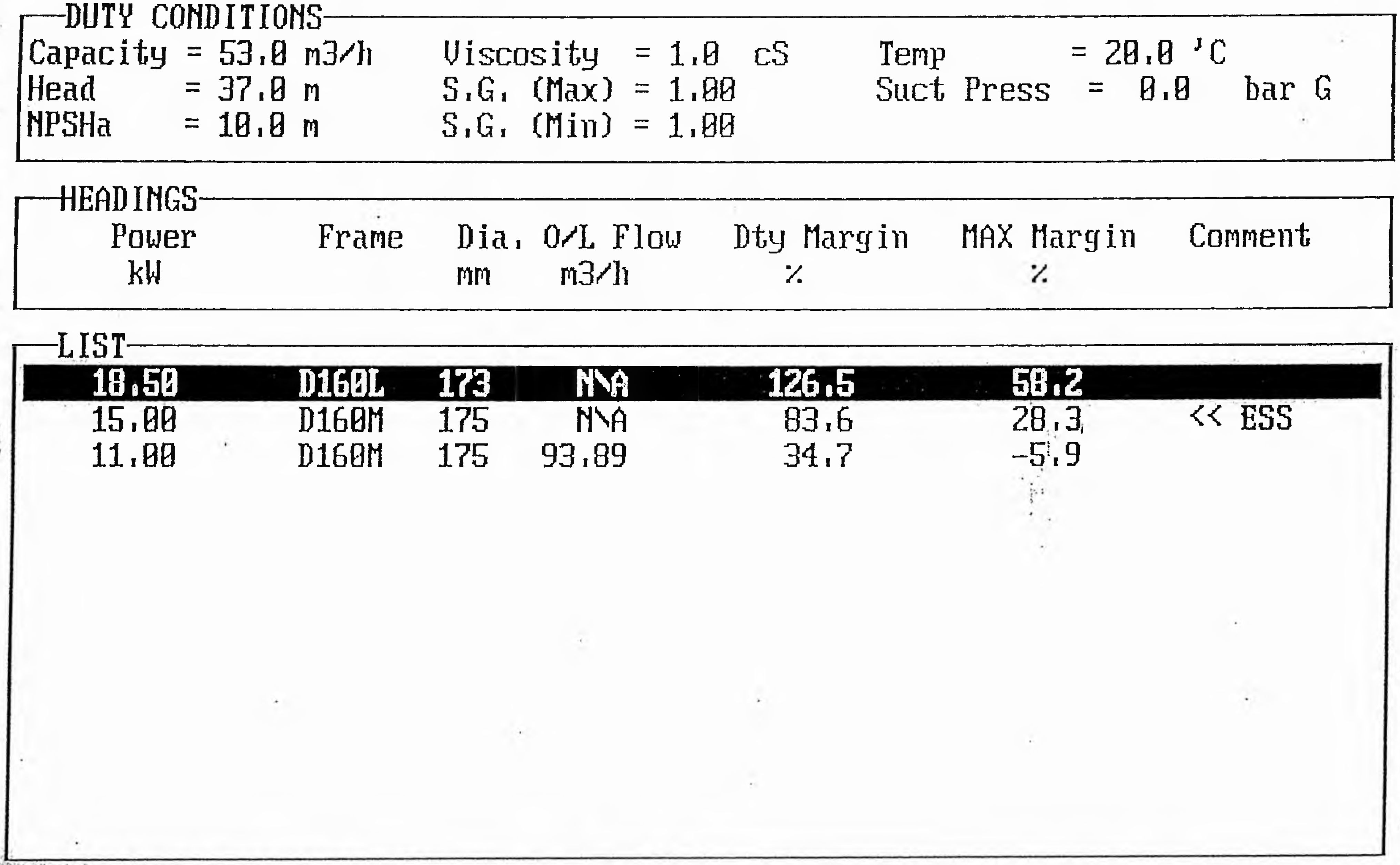
FIGURE 8.0



```
DUTY CONDITIONS
Capacity = 53.0 m3/h    Viscosity   = 1.0  cS      Temp          = 20.0 'C
Head     = 37.0 m       S.G. (Max) = 1.00          Suct Press   =  0.0   bar G
NPSHa    = 10.0 m       S.G. (Min) = 1.00

HEADINGS
         Pump Size  Speed     Curve No.
                    rpm

LIST
       125-100-315   1470     523/78      Over top impeller (5% approx)
        100-65-315   1460     632/78      Outside Coverage for size
```

Near Miss List

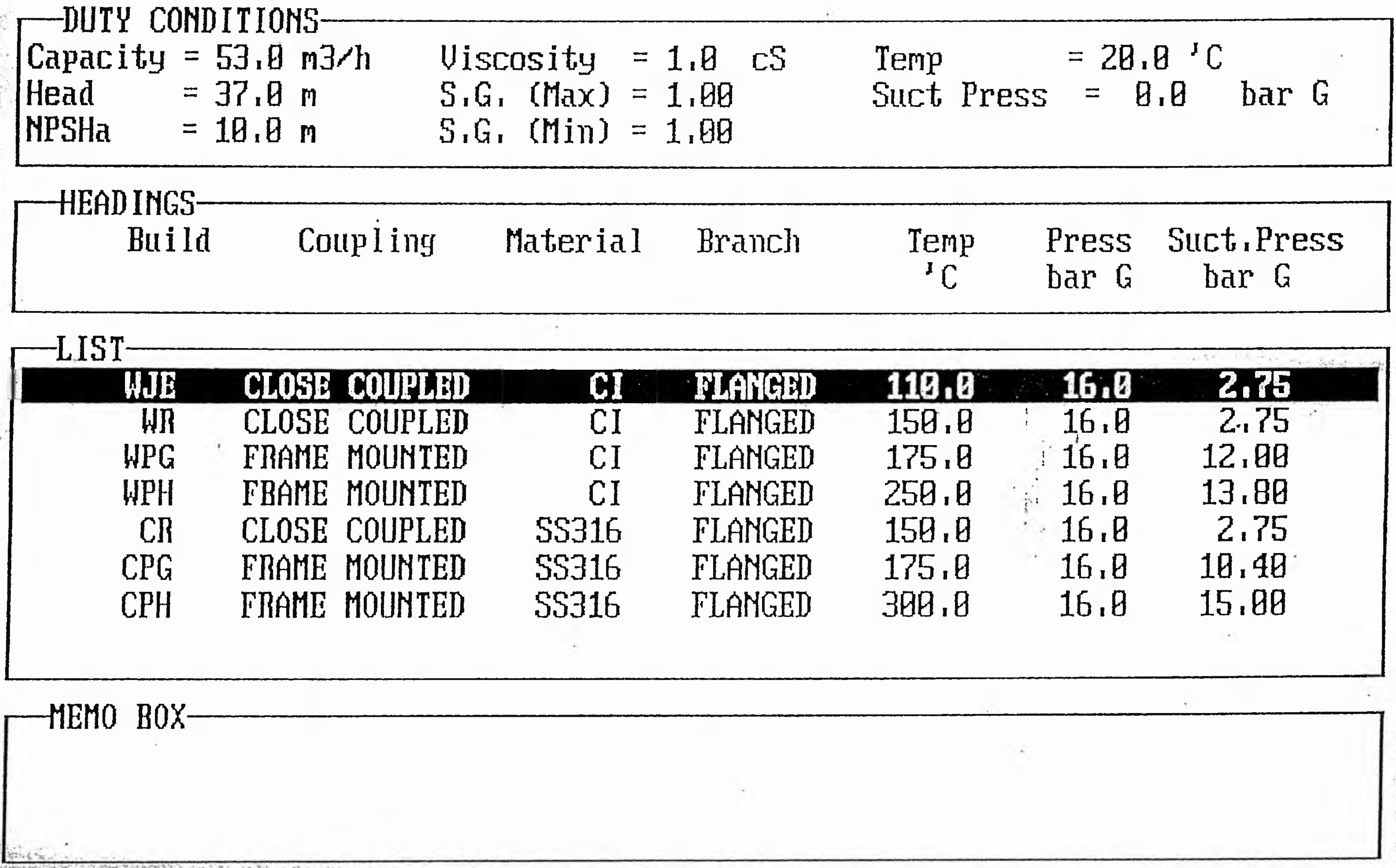
FIGURE 9.0



```
-DUTY CONDITIONS-
Capacity = 53.0 m3/h    Viscosity  = 1.0  cS     Temp        = 20.0 'C
Head     = 37.0 m       S.G. (Max) = 1.00        Suct Press  =  0.0   bar G
NPSHa    = 10.0 m       S.G. (Min) = 1.00

-HEADINGS-
  Power      Frame   Dia. O/L Flow  Dty Margin  MAX Margin  Comment
   kW                mm     m3/h        %           %

-LIST-
  18.50      D160L   173     N\A      126.5        58.2
  15.00      D160M   175     N\A       83.6        28.3       << ESS
  11.00      D160M   175   93.89       34.7        -5.9
```

Motor Screen

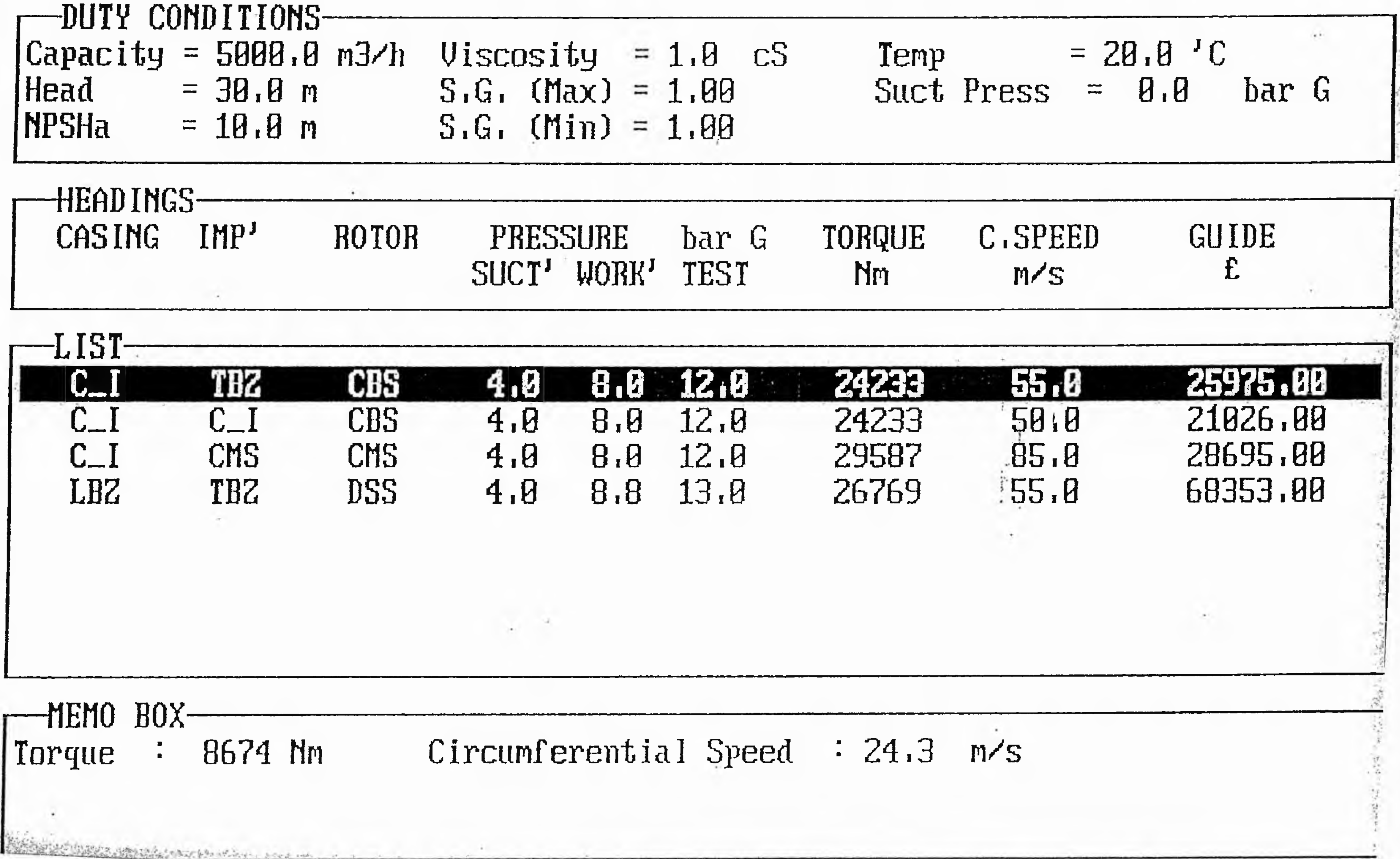
FIGURE 10.0



```
DUTY CONDITIONS
Capacity = 53.0 m3/h     Viscosity   = 1.0  cS     Temp          = 20.0 'C
Head     = 37.0 m        S.G. (Max) = 1.00         Suct Press   =  0.0   bar G
NPSHa    = 10.0 m        S.G. (Min) = 1.00

HEADINGS
    Build      Coupling       Material    Branch       Temp      Press    Suct.Press
                                                        'C       bar G      bar G

LIST
     WJE     CLOSE COUPLED        CI     FLANGED      110.0      16.0        2.75
      WR     CLOSE COUPLED        CI     FLANGED      150.0      16.0        2.75
     WPG     FRAME MOUNTED        CI     FLANGED      175.0      16.0       12.00
     WPH     FRAME MOUNTED        CI     FLANGED      250.0      16.0       13.80
      CR     CLOSE COUPLED     SS316     FLANGED      150.0      16.0        2.75
     CPG     FRAME MOUNTED     SS316     FLANGED      175.0      16.0       10.40
     CPH     FRAME MOUNTED     SS316     FLANGED      300.0      16.0       15.00

MEMO BOX
```

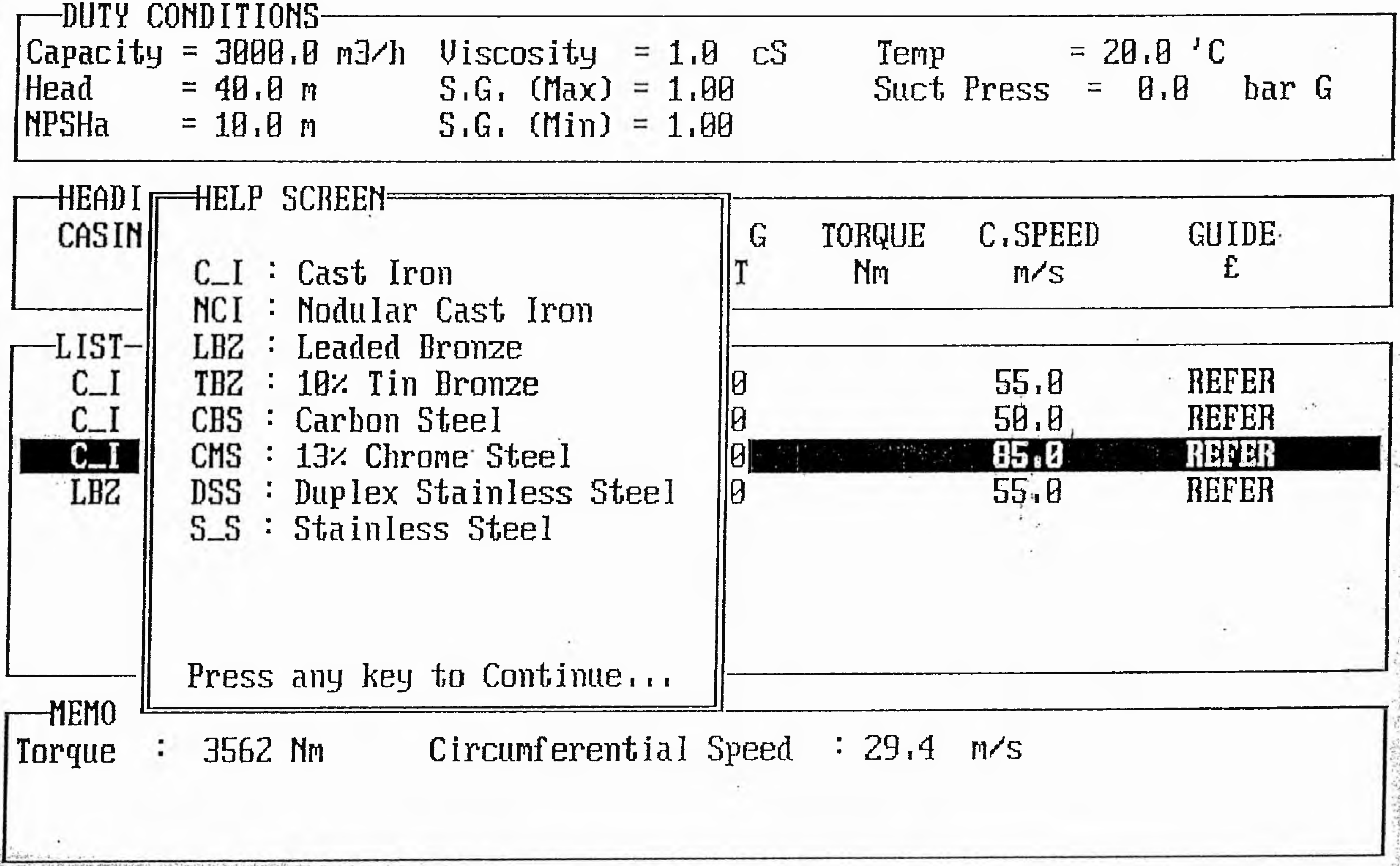
Build Screen

FIGURE 11.0



```
DUTY CONDITIONS
Capacity = 5000.0 m3/h  Viscosity    = 1.0  cS      Temp          = 20.0 'C
Head     = 30.0 m       S.G. (Max) = 1.00           Suct Press   =  0.0   bar G
NPSHa    = 10.0 m       S.G. (Min) = 1.00

HEADINGS
 CASING  IMP'    ROTOR    PRESSURE    bar G  TORQUE   C.SPEED      GUIDE
                        SUCT' WORK' TEST    Nm       m/s          £

LIST
  C_I     TBZ     CBS      4.0   8.0  12.0    24233    55.0      25975.00
  C_I     C_I     CBS      4.0   8.0  12.0    24233    50.0      21026.00
  C_I     CMS     CMS      4.0   8.0  12.0    29587    85.0      28695.00
  LBZ     TBZ     DSS      4.0   8.8  13.0    26769    55.0      68353.00

MEMO BOX
Torque  :  8674 Nm      Circumferential Speed  : 24.3  m/s
```

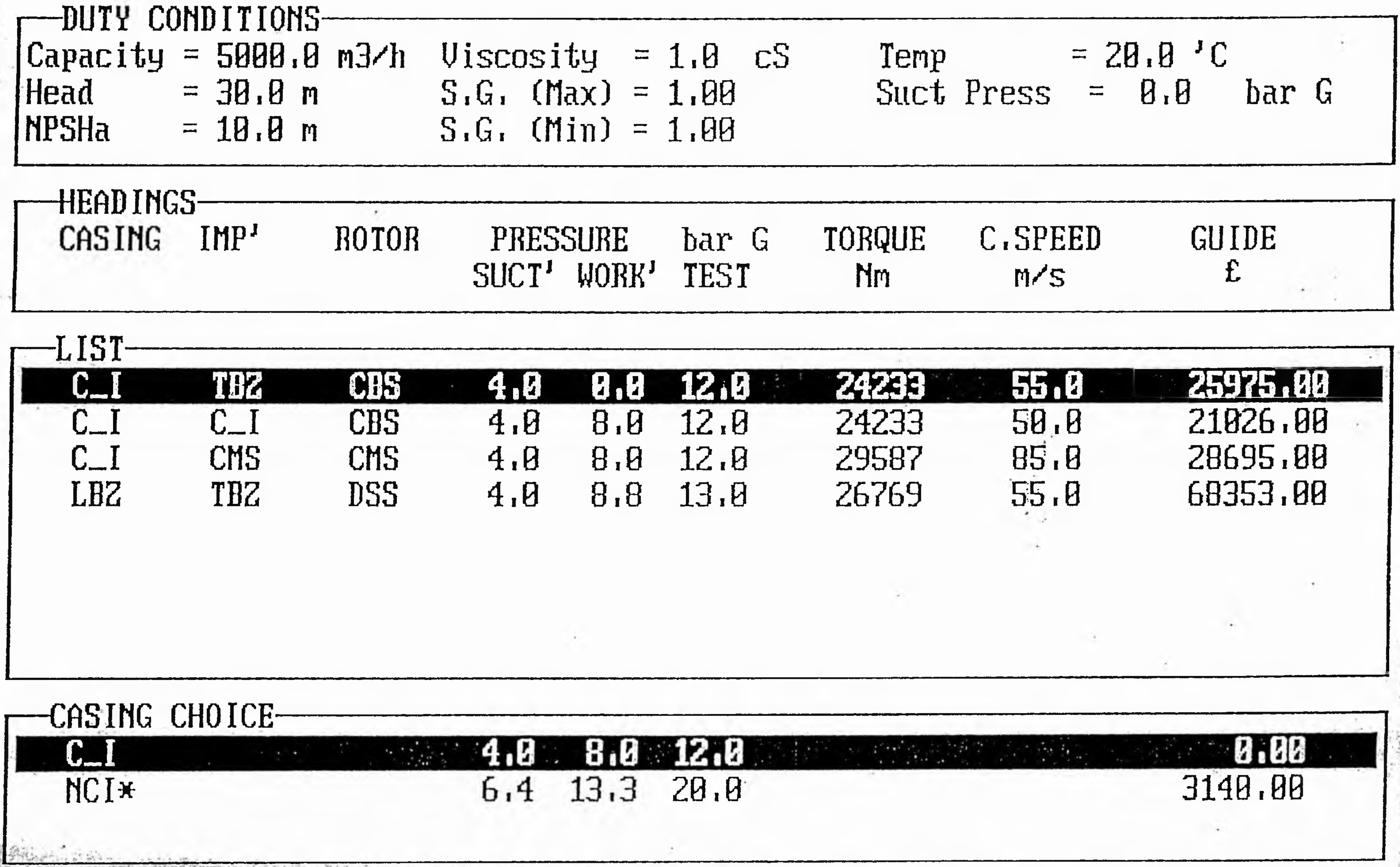
FIGURE 12.0



```
DUTY CONDITIONS
Capacity = 3000.0 m3/h  Viscosity   = 1.0  cS     Temp        = 20.0 'C
Head     = 40.0 m       S.G. (Max) = 1.00         Suct Press  =  0.0   bar G
NPSHa    = 10.0 m       S.G. (Min) = 1.00

HEADI  HELP SCREEN
CASIN                                          G   TORQUE   C.SPEED    GUIDE
        C_I : Cast Iron                        T     Nm       m/s        £
        NCI : Nodular Cast Iron
LIST-   LBZ : Leaded Bronze
 C_I    TBZ : 10% Tin Bronze                  0              55.0      REFER
 C_I    CBS : Carbon Steel                    0              50.0      REFER
 C_I    CMS : 13% Chrome Steel                0              85.0      REFER
 LBZ    DSS : Duplex Stainless Steel          0              55.0      REFER
        S_S : Stainless Steel

        Press any key to Continue...

MEMO
Torque  :  3562 Nm      Circumferential Speed  : 29.4  m/s
```

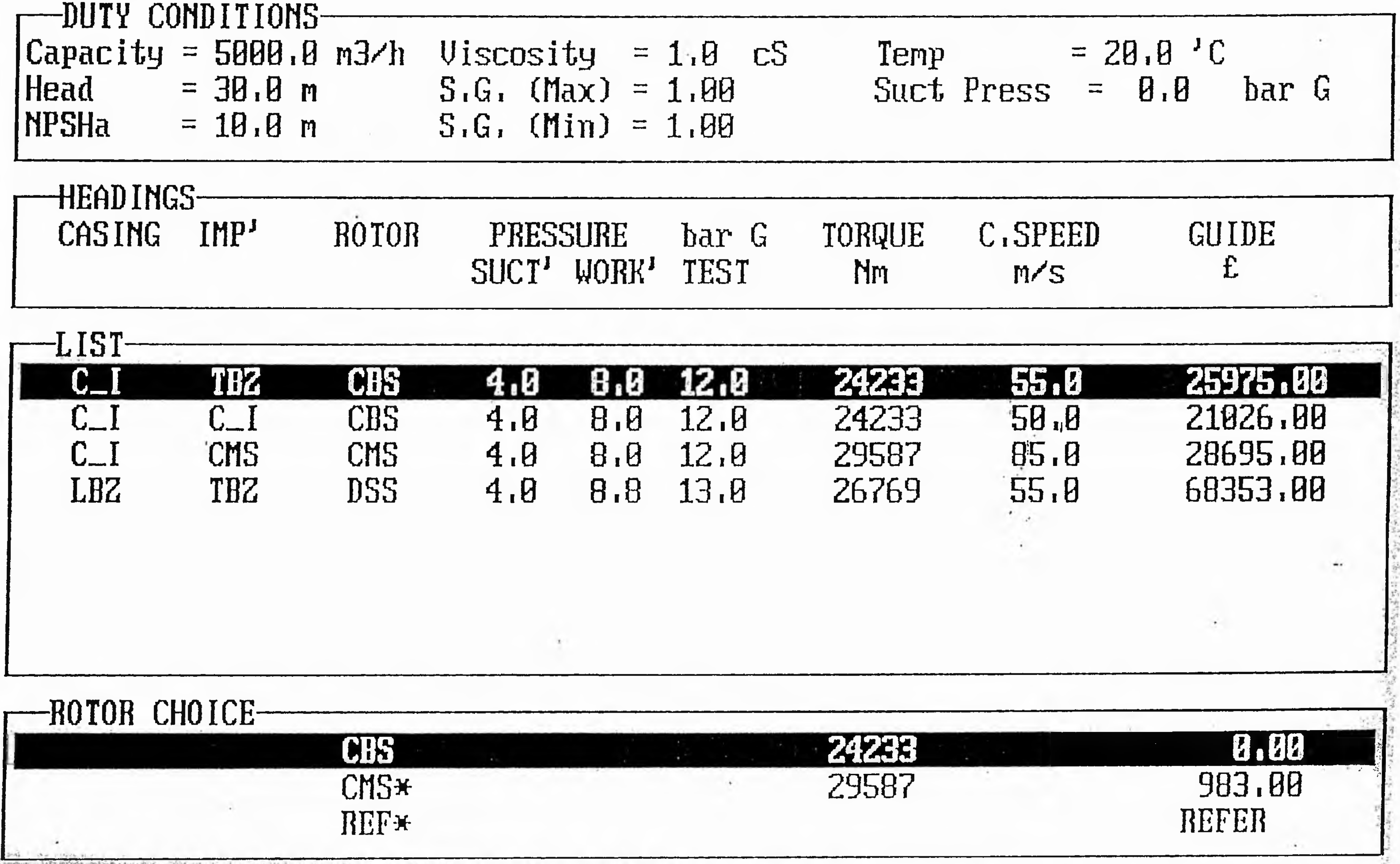
Build Screen

FIGURE 13.0



```
DUTY CONDITIONS
Capacity = 5000.0 m3/h  Viscosity  = 1.0  cS     Temp         = 20.0 'C
Head     = 30.0 m       S.G. (Max) = 1.00        Suct Press   =  0.0   bar G
NPSHa    = 10.0 m       S.G. (Min) = 1.00

HEADINGS
 CASING  IMP'    ROTOR    PRESSURE   bar G   TORQUE   C.SPEED    GUIDE
                         SUCT' WORK' TEST      Nm       m/s        £

LIST
  C_I     TBZ     CBS     4.0   8.0  12.0    24233    55.0     25975.00
  C_I     C_I     CBS     4.0   8.0  12.0    24233    50.0     21026.00
  C_I     CMS     CMS     4.0   8.0  12.0    29587    85.0     28695.00
  LBZ     TBZ     DSS     4.0   8.8  13.0    26769    55.0     68353.00

CASING CHOICE
 C_I                      4.0   8.0  12.0                           0.00
 NCI*                     6.4  13.3  20.0                        3140.00
```

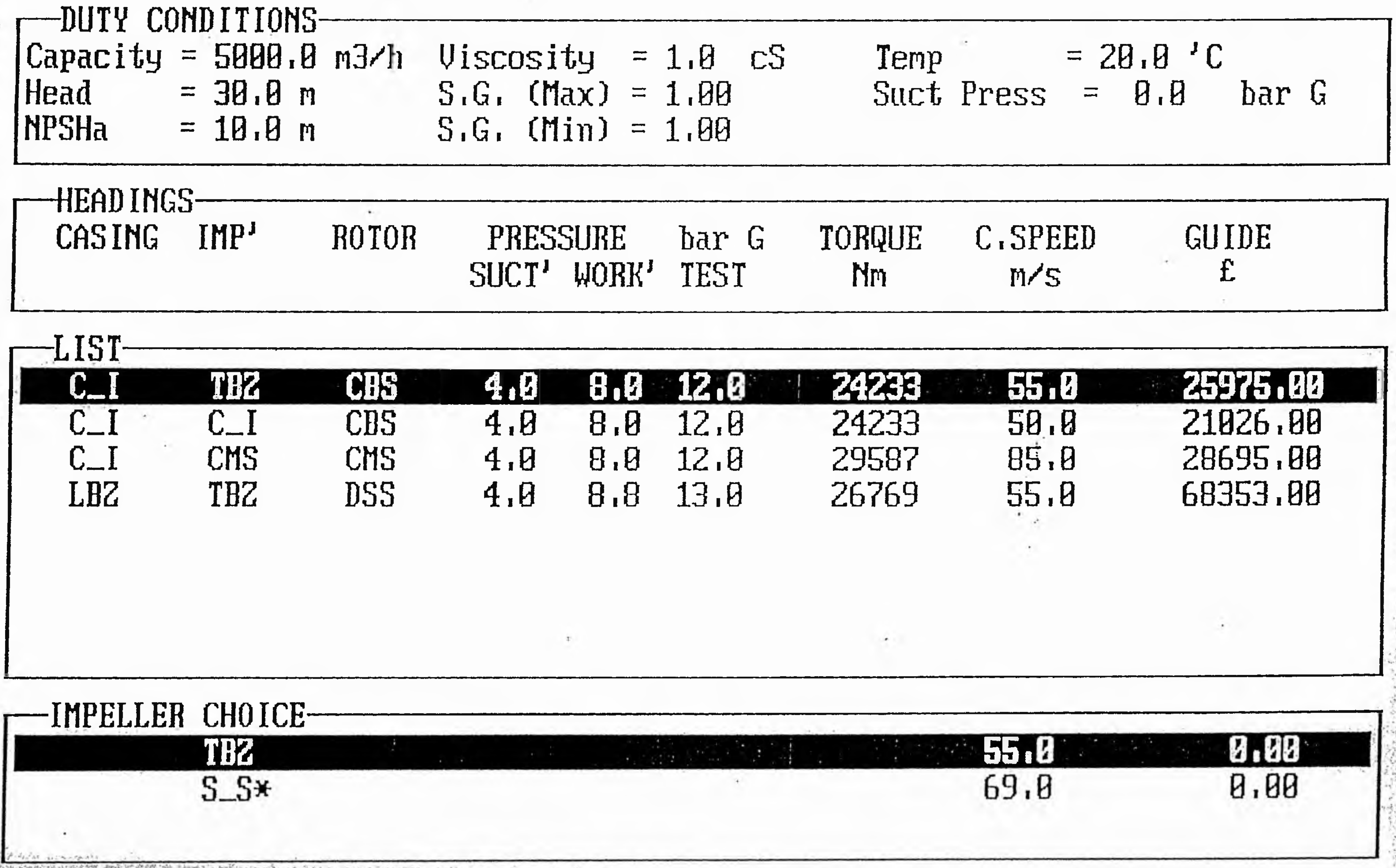
FIGURE 14.0



```
DUTY CONDITIONS
Capacity = 5000.0 m3/h  Viscosity  = 1.0  cS    Temp        = 20.0 'C
Head     = 30.0 m       S.G. (Max) = 1.00       Suct Press  =  0.0   bar G
NPSHa    = 10.0 m       S.G. (Min) = 1.00

HEADINGS
 CASING  IMP'    ROTOR    PRESSURE   bar G   TORQUE   C.SPEED     GUIDE
                        SUCT' WORK' TEST      Nm       m/s         £

LIST
  C_I     TBZ     CBS     4.0   8.0   12.0   24233    55.0      25975.00
  C_I     C_I     CBS     4.0   8.0   12.0   24233    50.0      21026.00
  C_I     CMS     CMS     4.0   8.0   12.0   29587    85.0      28695.00
  LBZ     TBZ     DSS     4.0   8.8   13.0   26769    55.0      68353.00

ROTOR CHOICE
                  CBS                        24233                  0.00
                  CMS*                       29587                983.00
                  REF*                                            REFER
```

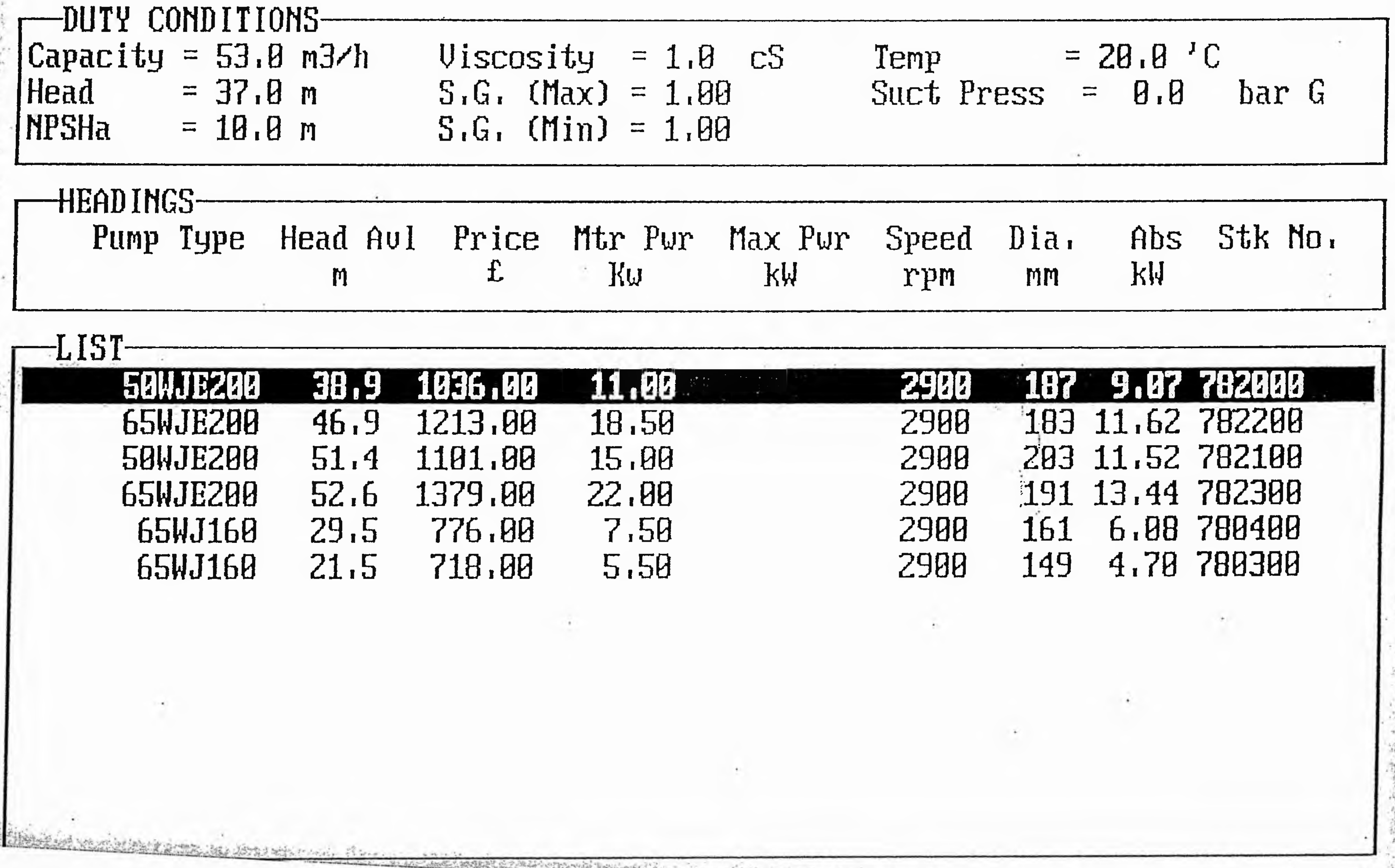
Build Screen

FIGURE 15.0



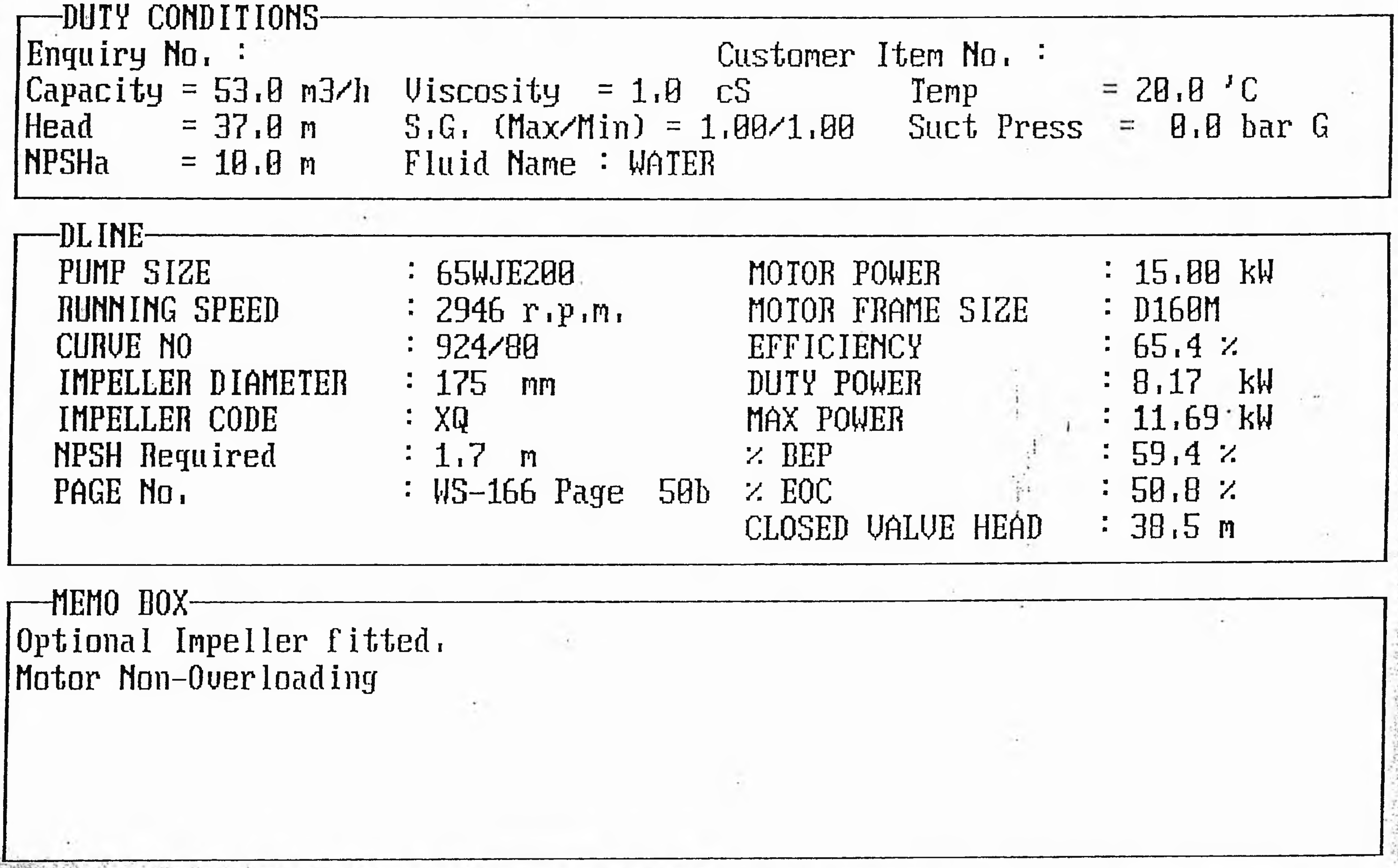
```
-DUTY CONDITIONS-
Capacity = 5000.0 m3/h  Viscosity  = 1.0  cS      Temp         = 20.0 'C
Head     = 30.0 m       S.G. (Max) = 1.00         Suct Press   =  0.0   bar G
NPSHa    = 10.0 m       S.G. (Min) = 1.00

-HEADINGS-
 CASING   IMP'     ROTOR     PRESSURE    bar G    TORQUE    C.SPEED     GUIDE
                            SUCT' WORK'  TEST       Nm        m/s         £

-LIST-
 C_I      TBZ      CBS      4.0   8.0   12.0     24233      55.0     25975.00
 C_I      C_I      CBS      4.0   8.0   12.0     24233      50.0     21026.00
 C_I      CMS      CMS      4.0   8.0   12.0     29587      85.0     28695.00
 LBZ      TBZ      DSS      4.0   8.8   13.0     26769      55.0     68353.00

-IMPELLER CHOICE-
          TBZ                                              55.0          0.00
          S_S*                                             69.0          0.00
```

FIGURE 16.0



```
DUTY CONDITIONS
Capacity = 53.0 m3/h      Viscosity   = 1.0   cS       Temp          = 20.0 'C
Head     = 37.0 m         S.G. (Max) = 1.00            Suct Press   =  0.0   bar G
NPSHa    = 10.0 m         S.G. (Min) = 1.00

HEADINGS
    Pump Type   Head Avl   Price   Mtr Pwr   Max Pwr   Speed   Dia.    Abs   Stk No.
                   m         £       Kw        kW       rpm     mm     kW

LIST
     50WJE200    38.9    1036.00    11.00               2900    187    9.07 782000
     65WJE200    46.9    1213.00    18.50               2900    183   11.62 782200
     50WJE200    51.4    1101.00    15.00               2900    203   11.52 782100
     65WJE200    52.6    1379.00    22.00               2900    191   13.44 782300
      65WJ160    29.5     776.00     7.50               2900    161    6.08 780400
      65WJ160    21.5     718.00     5.50               2900    149    4.70 780300
```

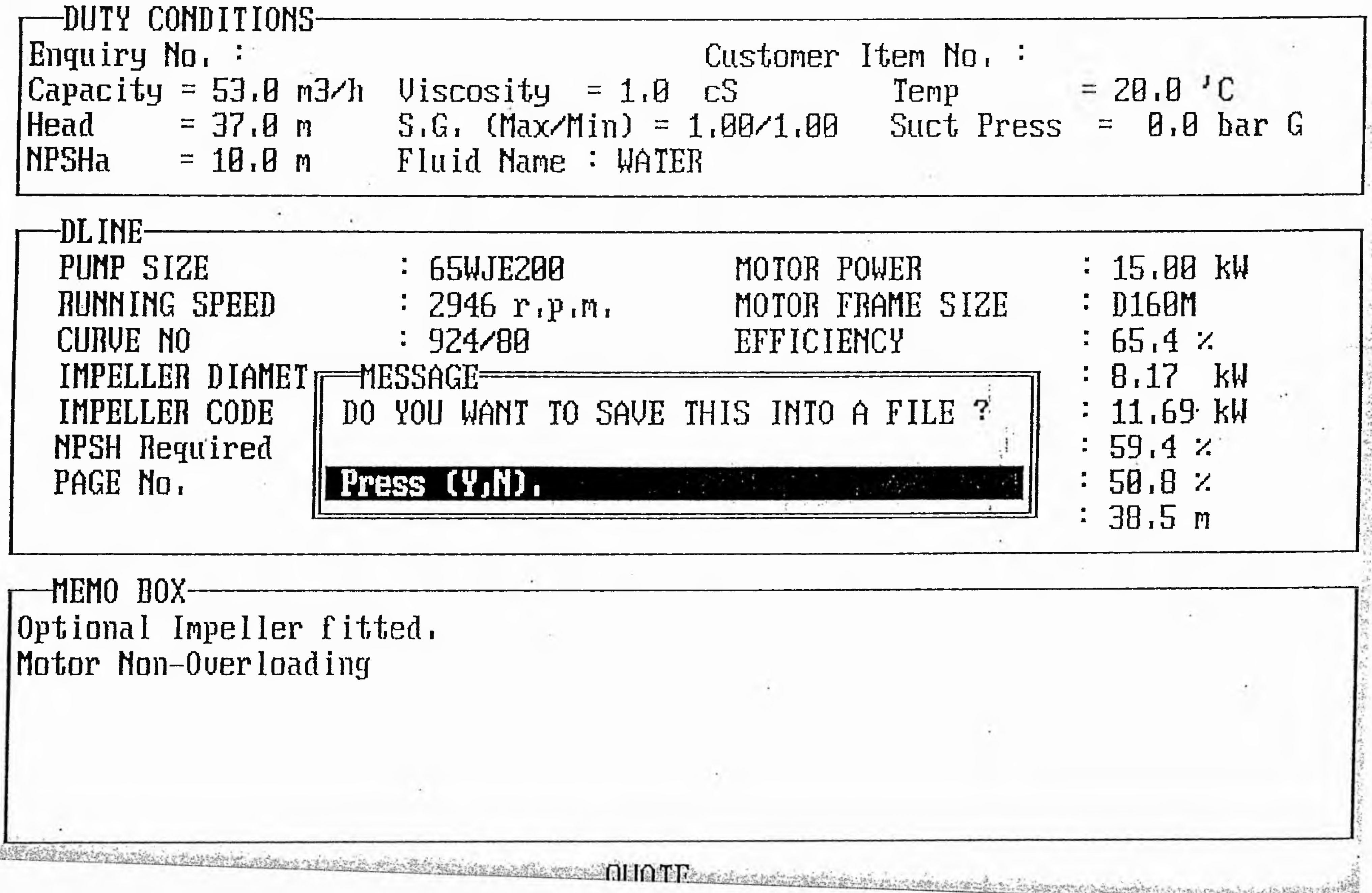
FIGURE 17.0



```
—DUTY CONDITIONS———————————————————————————————————————————————————————
Enquiry No. :                         Customer Item No. :
Capacity = 53.0 m3/h  Viscosity   = 1.0  cS         Temp        = 20.0 'C
Head     = 37.0 m     S.G. (Max/Min) = 1.00/1.00   Suct Press  =  0.0 bar G
NPSHa    = 10.0 m     Fluid Name : WATER

—DLINE—————————————————————————————————————————————————————————————————
  PUMP SIZE           : 65WJE200         MOTOR POWER          : 15.00 kW
  RUNNING SPEED       : 2946 r.p.m.      MOTOR FRAME SIZE     : D160M
  CURVE NO            : 924/80           EFFICIENCY           : 65.4 %
  IMPELLER DIAMETER   : 175  mm          DUTY POWER           : 8.17  kW
  IMPELLER CODE       : XQ               MAX POWER            : 11.69 kW
  NPSH Required       : 1.7  m           % BEP                : 59.4 %
  PAGE No.            : WS-166 Page  50b % EOC                : 50.8 %
                                         CLOSED VALUE HEAD    : 38.5 m

—MEMO BOX——————————————————————————————————————————————————————————————
Optional Impeller fitted.
Motor Non-Overloading
```

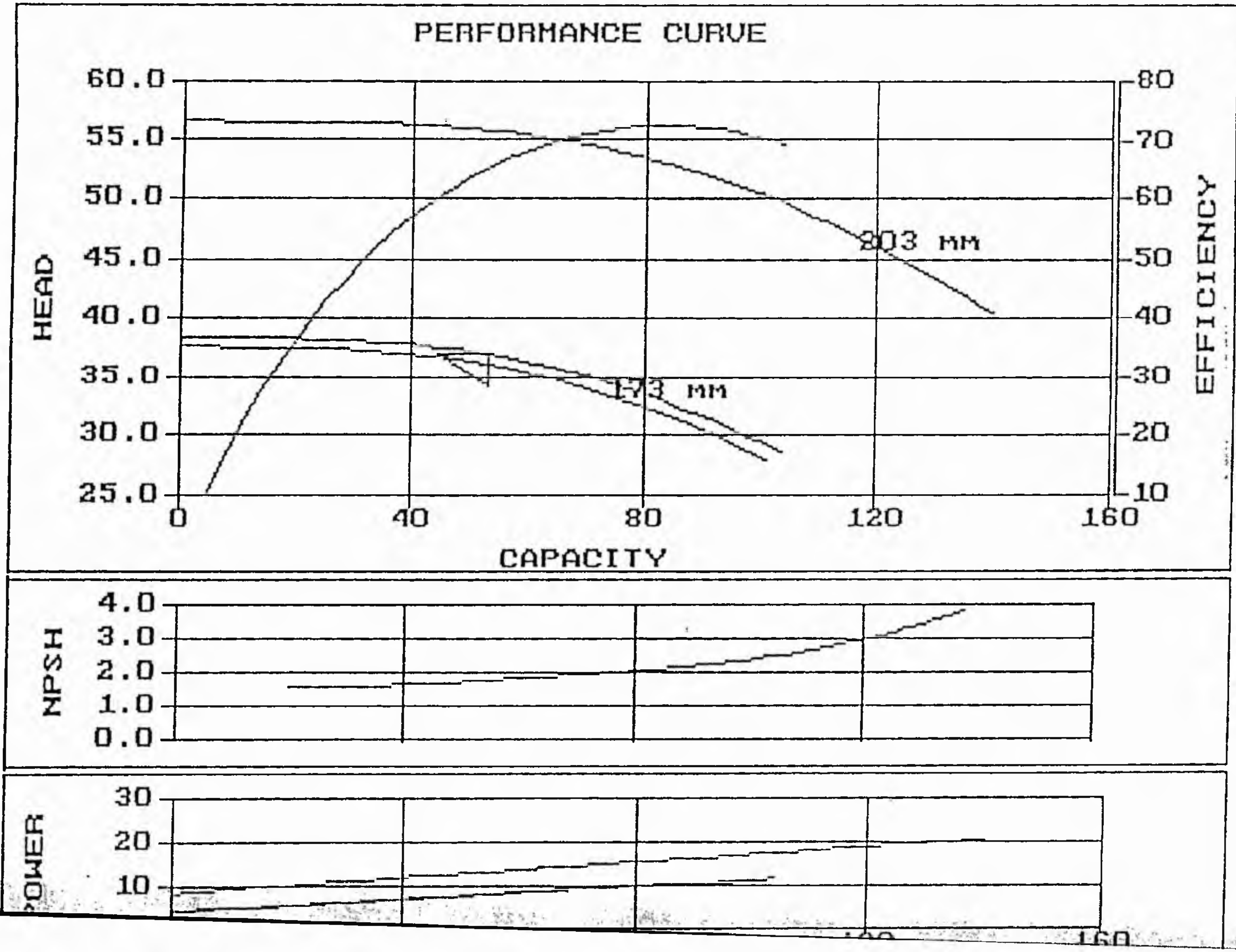
QUOTE

FIGURE 18.0



```
-DUTY CONDITIONS-
Enquiry No. :                              Customer Item No. :
Capacity = 53.0 m3/h  Viscosity    = 1.0  cS           Temp        = 20.0 'C
Head     = 37.0 m     S.G. (Max/Min) = 1.00/1.00   Suct Press   =  0.0 bar G
NPSHa    = 10.0 m     Fluid Name : WATER

-DLINE-
  PUMP SIZE            : 65WJE200        MOTOR POWER        : 15.00 kW
  RUNNING SPEED        : 2946 r.p.m.     MOTOR FRAME SIZE   : D160M
  CURVE NO             : 924/80          EFFICIENCY         : 65.4 %
  IMPELLER DIAMET -MESSAGE-                                 : 8.17  kW
  IMPELLER CODE   DO YOU WANT TO SAVE THIS INTO A FILE ?    : 11.69 kW
  NPSH Required                                             : 59.4 %
  PAGE No.        Press (Y,N).                              : 50.8 %
                                                            : 38.5 m

-MEMO BOX-
Optional Impeller fitted.
Motor Non-Overloading

                              QUOTE
```

FIGURE 19.0



Capacity 53.0 m3/h

Head 37.0 m

Viscosity 1 cS

Spec. Grav. 1.0

NPSHa 10.0 m

Pump : 65WJE200

Speed 2945 r.p.m

Dia. 175 mm

Efficiency 65.4 %

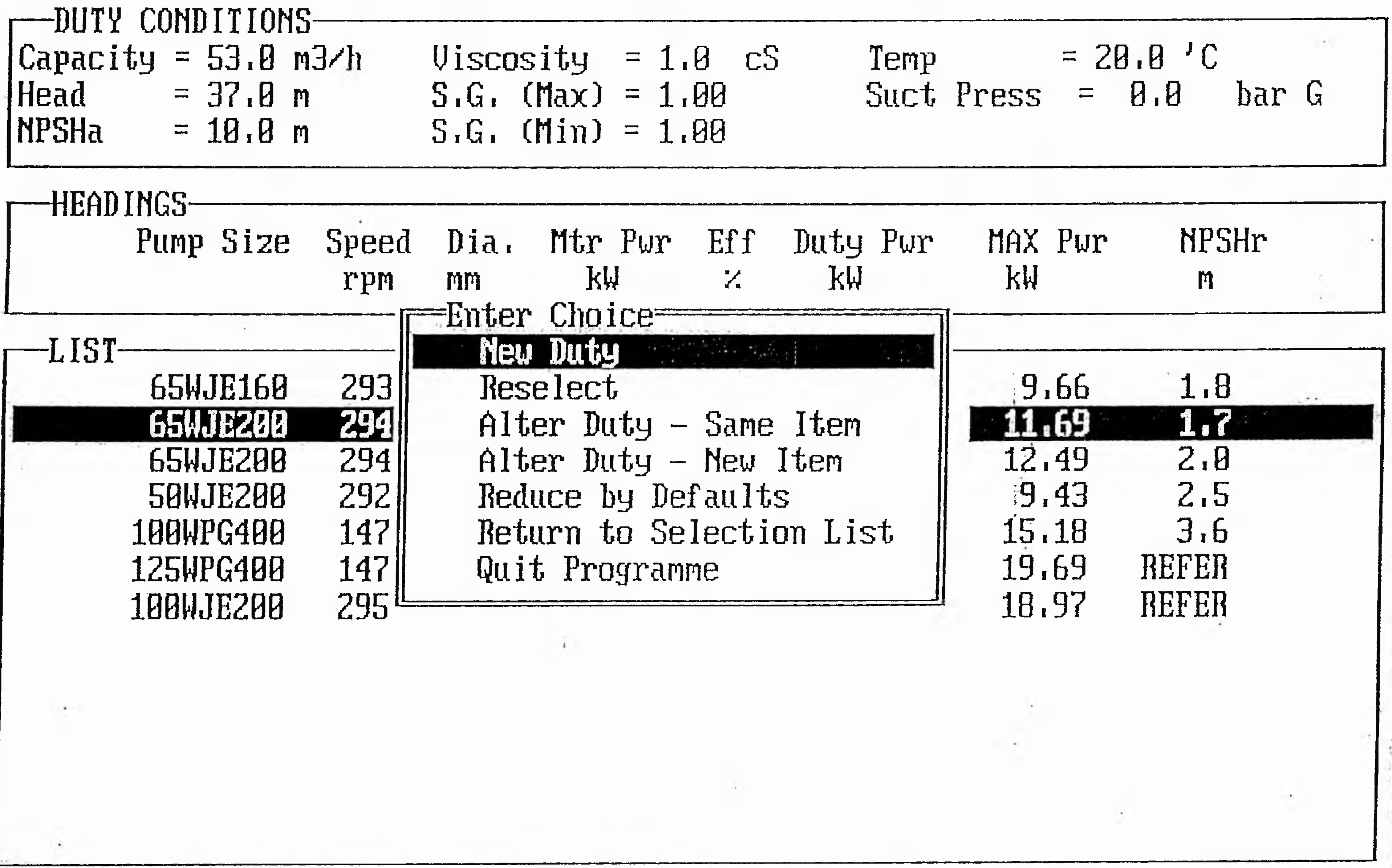
Duty Pwr 8.17 kW

Mtr Pwr 15.00 kW

MAX Pwr 11.69 kW

NPSHr 1.7 m

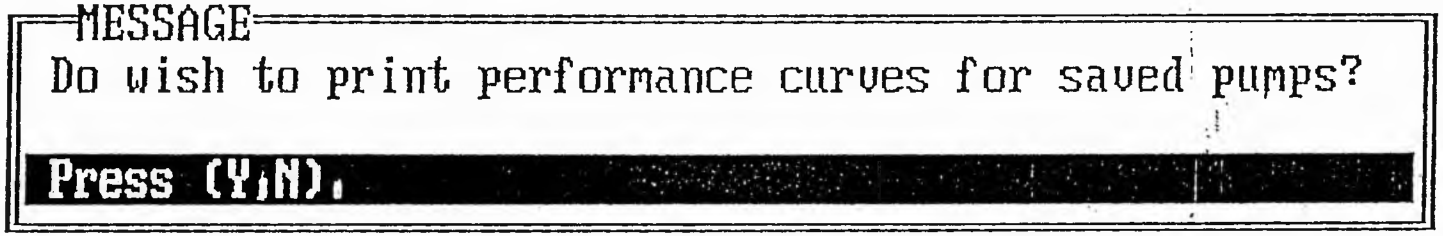
FIGURE 20.0



```
DUTY CONDITIONS
Capacity = 53.0 m3/h    Viscosity   = 1.0  cS     Temp         = 20.0 'C
Head     = 37.0 m       S.G. (Max) = 1.00         Suct Press   =  0.0   bar G
NPSHa    = 10.0 m       S.G. (Min) = 1.00

HEADINGS
       Pump Size  Speed  Dia.  Mtr Pwr  Eff  Duty Pwr  MAX Pwr  NPSHr
                   rpm    mm     kW      %      kW       kW       m

LIST                   Enter Choice
       65WJE160   293    New Duty                          9.66     1.8
       65WJE200   294    Reselect                         11.69     1.7
       65WJE200   294    Alter Duty - Same Item           12.49     2.0
       50WJE200   292    Alter Duty - New Item             9.43     2.5
      100WPG400   147    Reduce by Defaults               15.18     3.6
      125WPG400   147    Return to Selection List         19.69   REFER
      100WJE200   295    Quit Programme                   18.97   REFER
```

Main Screen

FIGURE 21.0

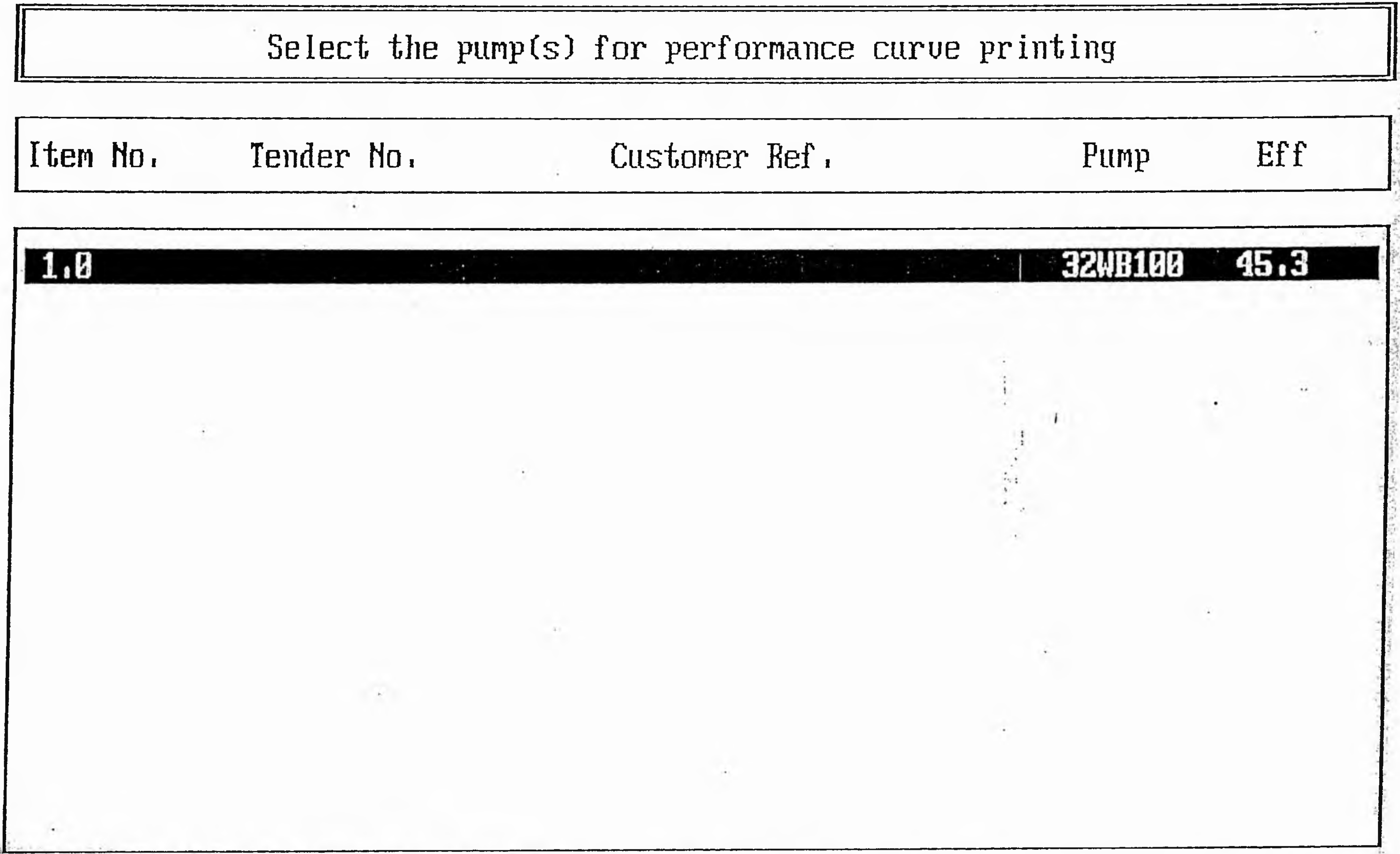


MESSAGE

Do wish to print performance curves for saved pumps?

Press (Y,N).

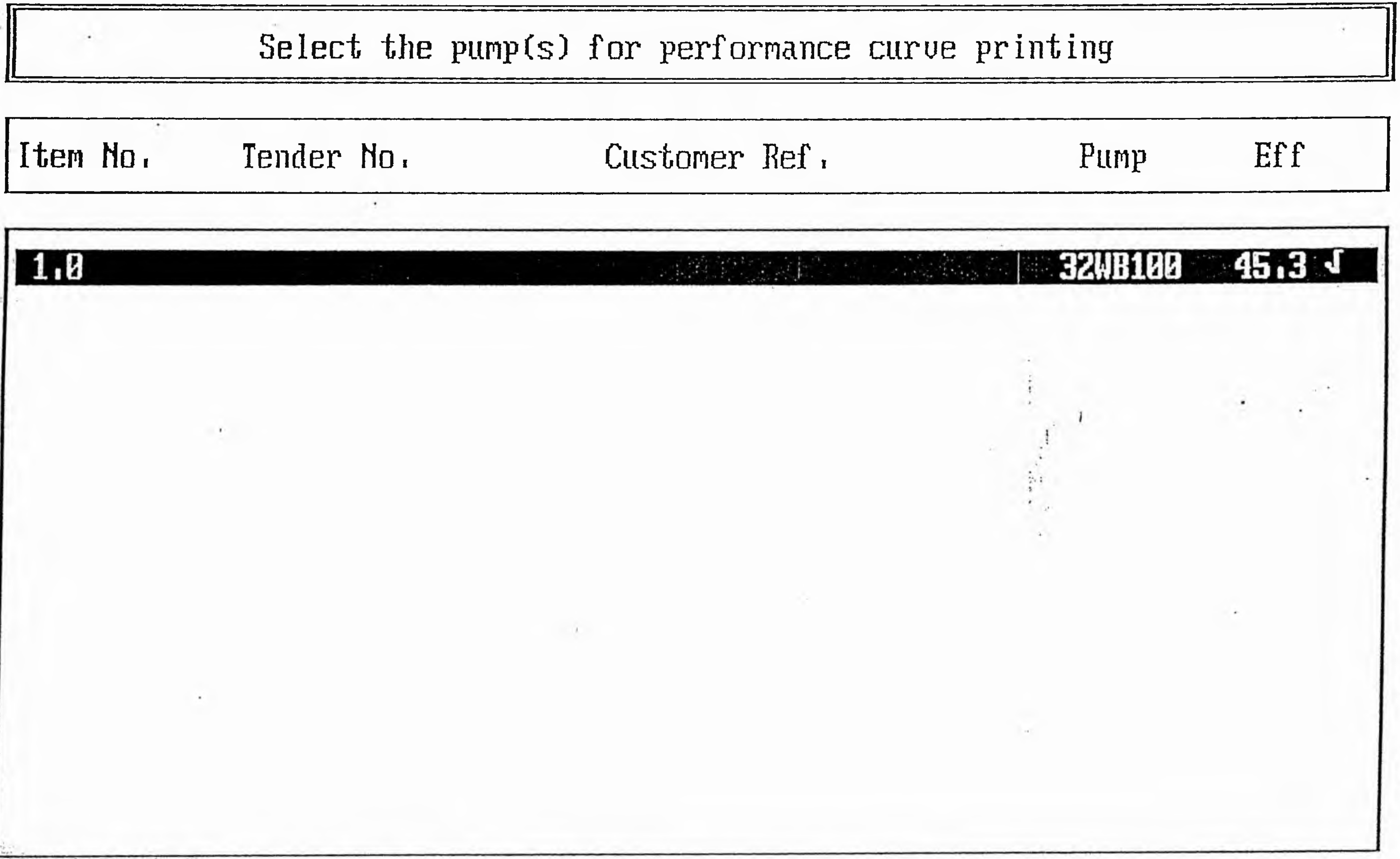
FIGURE 22.0



Select the pump(s) for performance curve printing

```
Item No.    Tender No.          Customer Ref.            Pump      Eff

1.0                                                      32WB100   45.3
```

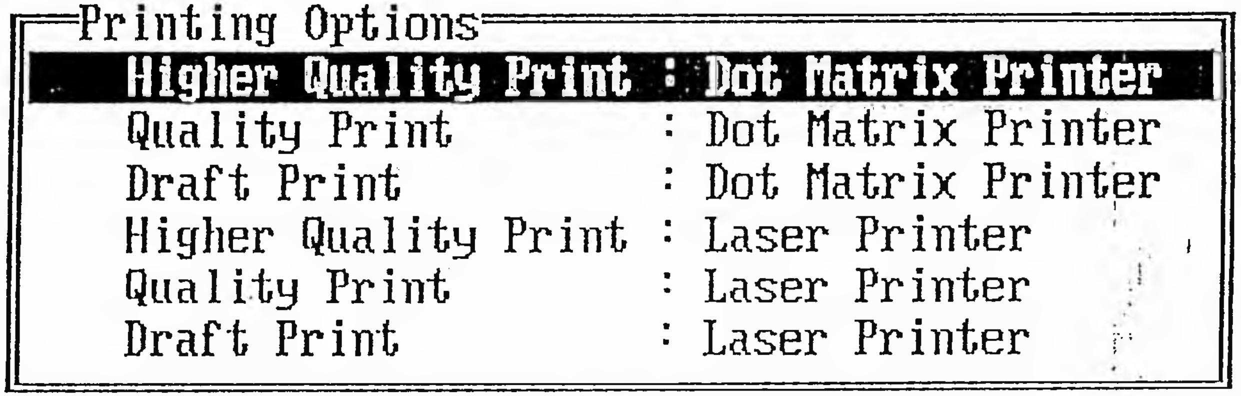
FIGURE 23.0



Select the pump(s) for performance curve printing

Item No.	Tender No.	Customer Ref.	Pump	Eff
1.0			32WB100	45.3 ✓

FIGURE 24.0



```
Printing Options
   Higher Quality Print : Dot Matrix Printer
   Quality Print        : Dot Matrix Printer
   Draft Print          : Dot Matrix Printer
   Higher Quality Print : Laser Printer
   Quality Print        : Laser Printer
   Draft Print          : Laser Printer
```