RESEARCH AND DEVELOPMENT PROGRESS REPORT NO. 205 • SEPTEMBER 1966

Research on Pumping Unit Studies Final Evaluation Report

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UNITED STATES DEPARTMENT OF THE INTERIOR • Stewart L. Udall, Secretary
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FOREWARD

This is the two hundred and fifth of a series of reports designed to present accounts of progress in saline water conversion with the expectation that the exchange of such data will contribute to the long-range development of economical processes applicable to large-scale, low-cost demineralization of sea or other saline water.

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Created in 1849, the Department of the Interior - America's Department of Natural Resources - is concerned with the management, conservation, and development of the Nation's water, wildlife, mineral, forest, and park and recreational resources. It also has major responsibilities for Indian and Territorial affairs.

As the Nation's principal conservation agency, the Department of the Interior works to assure that nonrenewable resources are developed and used wisely, that park and recreational resources are conserved for the future, and that renewable resources make their full contribution to the progress, prosperity, and security of the United States -- now and in the future.

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1. Introduction and Purpose of Studies

The Office of Saline Water, Department of the Interior, envisages the construction of desalination plants of 50-million-gallon-per-day capacity and larger, to supplement the water supply of coastal cities by resorting to the ocean for a source. The Bureau of Reclamation was engaged to administer contracts with pump manufacturers to supply data on large pumping units capable of withstanding aerated sea water and the hot brine solutions to be encountered in such plants. The data, as evaluated in this report, are to be made available to 15 or more architect-engineers who have been engaged to prepare conceptual designs of the treatment plants.

Contracts were awarded to Allis-Chalmers Manufacturing Company, Byron Jackson Pumps, Inc., and the Worthington Corporation for obtaining realistic data on the large pumping units of special materials that would be suitable for use in the severe conditions expected in the large treatment plants.

It was not expected that any startling new pump designs would be developed as a result of these contracts. With few exceptions, the sizes of pumps being considered are larger than those that are listed in manufacturers' catalogs. Estimated costs of these large pumps and their motors were lacking, and the study provided these data as well as choices of materials and the depth of pump settings, all of which bear on the ultimate cost of the installation.

Chronology of Events

January 22, 1965--Telephone contact with Office of Saline Water indicating need for pumping unit studies

January 25, 1965--Telephone contact with Office of Saline Water requesting Reclamation to invite manufacturers' representatives to Washington January 29, 1965, Bureau representative to be present on January 28, 1965. Invited representatives from:

- Allis-Chalmers Manufacturing Company
- Newport News Shipbuilding and Dry Dock Company
- Baldwin-Lima-Hamilton Corporation
- Worthington Corporation
- Ingersoll Rand
- Westinghouse Electric Corporation
- Byron Jackson Pumps, Inc.--Subsidiary of Borg-Warner Corporation

January 28, 1965--Bureau representative met with representatives from Office of Saline Water and Oak Ridge National Laboratories. Oak Ridge furnished pump requirements. Reclamation representative wrote invitation to prospective contractors

January 29, 1965--Discussed invitation with pump manufacturers' representatives (about 45 present)

February 25, 1965--Five proposals received

February 26, 1965--Proposed contracts mailed to five prospective contractors

March 18, 1965--Selection board met in Washington

March 19, 1965--After evaluation of proposals, negotiated reduced price on basis of reduced scope of work. Recommended awards to:

Allis-Chalmers Manufacturing Company
Byron Jackson Pumps, Inc.
Worthington Corporation

at a total cost of $69,900

March 25, 1965--Letters of intent mailed to above contractors

May 19, 1965--Contracts mailed

June 9 and 10, 1965--Bureau representative met with Allis-Chalmers personnel to review progress

June 11, 1965--Bureau representative met with Worthington personnel

June 18, 1965--Bureau representative met with Byron Jackson and International Nickel personnel

August 10 and 11, 1965--Reclamation representative presented interim report to Office of Saline Water and evaluators of 50 MGD designs

August 16 through 22, 1965--Reclamation received final reports from contractors. Mailed 22 copies to Office of Saline Water for distribution

2. Discussion of Specific Speed Versus Cost, Efficiency, and Net Positive Suction Head

Specific speed of a pump, $N_s = \frac{N\sqrt{gpm}}{H^{3/4}}$, is defined as the speed in rpm that a model would operate if reduced in size such that it would deliver one gallon per minute at 1 foot of head. Specific speed characterizes the type and shape of the impeller. High specific speeds would indicate a propeller type of impeller which are suitable for low heads, up to 30 feet per stage. Low specific speeds indicate the centrifugal type of impeller which have been used for heads up to 1,200 feet per stage. In between is the mixed-flow type. There are no definite theoretical limits between which the above types of impeller can be used since we have the following relations which apply within limits to a pump of any specific speed:

$$Q \propto N$$

$$H \propto N^2$$

$$HP \propto N^3$$

in which Q is the quantity delivered, H is the head, HP is the horsepower required and N is the speed of the pump.

Even so, a propeller-type unit cannot be used efficiently for high heads and a centrifugal type is not the most efficient for low heads. Graph No. 1 is an experience curve of head versus specific speed of pumps installed by the Bureau of Reclamation. The maximum specific speed permitted for these studies, $N_s = 69{,}000/H^{.63}$ is also shown on the curve. Pump speeds selected from this curve would result in impeller settings 5 feet below free water surface subjected to one atmosphere of pressure at sea level according to Hydraulic Institute Standards. It is well known that if the customer does not limit speed, the manufacturers will tend to offer equipment with higher speed than that which may be most efficient. The higher speed equipment would be smaller and would give the manufacturer an advantage in the bidding. Higher speeds require more net positive suction head, NPSH.

NPSH is defined as the suction head above vapor pressure at the highest point of the impeller inlet. Operation with less than minimum NPSH will cause the head and efficiency to fall off and destructive cavitation will take place on the impeller blades.

Suction specific speed, $S = \frac{N\sqrt{gpm}}{(NPSH)^{3/4}}$, is used to describe the suction characteristics of an impeller. A value in the neighborhood of 7,900 to 8,000 has been found to produce highest efficiencies. If an impeller is designed for a higher suction specific speed in order to reduce the required NPSH, the blade entrance angle must be flattened. This results in lower efficiency and a larger impeller-eye diameter for a given capacity.

Sigma is the ratio of net positive suction head to total head, NPSH/H. The critical value of sigma is determined by model tests for each impeller design. It can then be used to determine the required setting with respect to suction water level for any environment. The critical sigma factor and required NPSH increase rapidly with discharge above the best efficiency point. It is our experience that if a pump is operated at a head considerably below best efficiency head (high discharge) no amount of NPSH will prevent cavitation.

3. Data to be Supplied by Contractors

The principal data requested of the contractors were:

a. Selection of pump type considered most suitable for the specified service.

b. Layout dimensions for pump and electric motor driver.

c. Performance curves.

d. Setting with respect to free fluid surface.

e. Cost of pumping unit for three alternate pump materials, one of which was to be selected by the contractor.

f. Costs plotted on log-log paper to allow interpolation.

g. Manufacturer's recommendation of materials for the specified service.

The contracts provided that 25 copies of a final report be furnished, 1 copy to be reproducible by a photographic process.

One contractor furnished the minimum data required. Two furnished more data than required. The amount of data furnished is believed to be commensurate with the dollar value of the contracts.

4. Data Supplied to Contractors

Tables 1 and 2 list the principal data for 43 pumps furnished to the contractors. These data were originally prepared by Oak Ridge National Laboratories. Subsequent revisions were made by the Bureau of Reclamation to remove requirements which could not be met, to reduce the scope of the work, and to change the material requirements.

Prior to award of contracts these data were supplemented by letters stating:

"In response to an inquiry from one of the contractors performing subject studies I am enclosing two pages from R&D Report #25 from which the vapor pressure of saline solutions may be computed. Given density and temperature, determine chlorosity from Figure IV. Then from Figure VII determine boiling point rise. Then from steam tables determine vapor pressure at given temperature minus boiling point rise. We have calculated the following:

Solution	S.G.	Temp.	Chlor-osity	Temp. rise	VP (psia)	Suc. atmos. press. (psia)
Sea water	1.02	65	15.74	0.34	0.30	14.7
Brine	1.052	90	44.53	1.46	0.67	1.5
Brine	1.058	90	49.48	1.66	0.66	1.5
Distilled water	0.995	87	0	0	0.64	1.5
Sea water	1.013	110	16.98	0.50	1.26	18.0
Brine	1.02	200	45.78	2.31	10.99	11.4
Brine	1.05	146	55.00	2.40	3.17	3.4

"Please note that for the VTE plant brine pumps at 200° F. the suction atmospheric pressure has been changed from 9.5 to 11.4 psia. This is necessary because of the previous change of temperature from 191 to 200° F.

"In selecting and pricing motor drivers, consider that all pumps will start watered - against a closed discharge valve. Do not increase motor price because of excessive voltage drop while starting. Since the pumps would be installed adjacent to a generating plant having many times the capacity of all pumps, we would not anticipate excessive voltage drop due to starting any one pump. Also, consider direct connected exciters and indoor housings. Motors up to 5,000 horsepower may be air cooled. Larger motors should be water cooled. * * *

"It is required that data be furnished for sea water pumps in three capacities, 125,000, 350,000, and 800,000 gallons per minute, each at three heads making a total of nine sea water pumps. Prices for each of the above pumps should be given for three different materials and for furnishing one or three pumps, making a total of 54 prices for sea water pumps.

"The upper speed limit was established to avoid unreasonable submergence requirements since there are too many unknowns to arrive at a general cost per foot of NPSH. For final designs, architect-engineers will have to give consideration to the economics of speed, efficiency and submergence for particular pump types and site conditions. It is desired that your report contain general information which will guide architect-engineers in such studies.

"To help you in selection of speed, use 6.2 mills per kwhr for energy and consider continuous operation. You should also consider that large desalination plants will most likely be built by public agencies with interest rates of 3-1/8 percent and with a payout period of 30 years. Under these conditions you will find that there can be very little sacrifice of efficiency to reduce capital costs. It is for this reason we would not favor a very low NPSH impeller design which would sacrifice efficiency in favor of submergence."

The contracts include under Statement of Work, "The objectives of this study are:

"a) to obtain realistic data on a number of special pumping units of capacities and heads suitable for 50 million gallon per day, and larger, water conversion plants. The data will be made available to conceptual design contractors to assist in making layouts and in estimating costs.

"b) pumps shall be selected to deliver rated capacity at rated head at the point of best efficiency. The efficiency shall be as high as practicable and there shall be no sacrifice of efficiency in order to minimize submergence. The maximum specific speed allowable for this study is $69,000/H^{.63}$ where H is the head per stage.

"c) in selecting the type of pump for each capacity, head, and service, consideration shall be given to the requirement for long periods of continuous service. The type of pump and arrangement of pump and motor shall provide for ease of maintenance."

Table 3 lists the 43 pumps, the principal data supplied to the contractors, and the contractor's designation for each pump.

5. Selection of Pump Types

Selection of pump type was the responsibility of the contractors. The following are general types which could have been used:

a. Centrifugal, single stage spiral cased: single volute, double volute, or diffusor; horizontal or vertical; wet or dry pit. Centrifugal pumps are used for capacity ranges from the smallest to the largest and for very low heads to the highest. Pumps of medium size and head are often of the double-volute type to equalize hydraulic side thrust and for structural reasons. Large and/or high-head pumps must be of the diffusor type for structural reasons.

b. Vertical column pumps: single or multistage; propeller, mixed-flow, or centrifugal-type impeller; wet or dry pit. This general type covers a wide-head range. The propeller type is good up to 30 feet per stage, mixed flow may be used from 30 to 60 feet per stage and centrifugal or turbine type up to 100 feet per stage. The largest pump of this general type which the Bureau of Reclamation has used is a single-stage, variable-pitch mixed-flow unit of 315,000 gpm capacity, designed for 55 feet total head. Multistaging can reduce required NPSH while maintaining a desirable specific speed.

c. Double-suction pumps: horizontal or vertical. This type has the advantage of a higher permissible rotative speed for a desirable specific speed. It is usually of the centrifugal type and covers a wide range of heads. Its capacity has been limited to date.

Of the types suitable, the contractors picked the following:

Allis-Chalmers Manufacturing Company, vertical centrifugal dry pit pumps for all except Items 32 and 41 which are horizontal, double-suction pumps. These latter two pumps are relatively small, the heads are high, and the suction conditions do not require deep submergence.

Byron Jackson Pumps, Inc., selected vertical shaft pumps for all conditions. They assumed that the low capacity pumps for each service went with a small plant, the intermediate-size pumps went with an intermediate-size plant, etc. Their selection is therefore influenced by an attempt to make all pumps for a given sized plant either dry-pit or wet-pit type.

Worthington Corporation, with three exceptions (No. 32, 33, and 35), selected vertical centrifugal dry pit pumps for sea water

service and vertical column (can) pumps for brine and product. The exceptions are relatively high-head pumps with high available NPSH.

All of the 800,000-gpm pumps are for sea water service and are vertical centrifugal dry pit type. For 350,000 gpm all are vertical centrifugal except that Worthington used vertical column wet-pit type for brine service, Items 28, 37, and 40.

Discussion

It is impossible for a pump expert to make the proper selection of a pump unless he knows all of the conditions. If every condition is put before him he can make a fairly intelligent selection based on experience. A final selection should be made following an economic analysis of two or more possibilities.

All conditions applicable to 15 conceptual designs could not be given to the contractors. Two contractors for pump studies were also engaged in conceptual designs. One was not; so he was advised to contact several conceptual designers to get an idea of their physical requirements. Even so, they could not anticipate the conditions the remaining conceptual designs would present. Therefore it cannot be said that the selection of any contractor represents the optimum for all conceptual designs.

At the time these contracts were solicited, one design had been reviewed. At the time of this writing, six conceptual designs have been reviewed.

In two cases reviewed it is apparent that one conceptual designer gave a manufacturer erroneous data. In another case the designer furnished requirements which were unnecessarily difficult to meet. Both resulted in improper selection of pumps. It therefore behooves an architect-engineer to have a pump expert who can ask intelligent questions of the manufacturer or else place the entire problem in his hands. For the incomplete data furnished for this study the contractors were in agreement in two respects:

a. The large sea water pumps should be vertical centrifugals.

b. The brine and distillate pumps requiring deep settings should be of a vertical-shaft type.

It is surprising that horizontal, split-case, double suction pumps were selected by only one contractor for only two cases. It has the advantage of higher speed for a given specific speed, balanced hydraulic thrust, and easy access for maintenance.

Byron Jackson did not select this type for any of the given conditions. They did, however, suggest a further development along the same lines. Instead of one double-suction impeller they suggested eight double-suction impellers on one shaft. For a given condition this arrangement allowed the speed of a single-suction pump to be quadrupled resulting in considerable savings in weight and cost. The proposal is interesting and deserves consideration; however, one could not expect the efficiency to equal that of a single-suction pump equally well designed and finished because of Moody's scale factor.

Table 4 is a tabulation of pump types and sizes selected by the contractors.

6. Setting Requirements

The contractors have furnished the net positive suction head (NPSH) required for each pump. These are shown on Table 5. This means that if a pump were pumping a fluid which was flashing at the surface, the highest point of the inlet edge of the impeller should be submerged the amount of NPSH in feet.

From this we can compute $\sigma = \frac{NPSH}{H}$. Knowing σ, we can compute the setting required for any environment. $H_s = \sigma H - (H_a - H_v) + H_f$ or $H_s = \sigma H - (P_a - P_v)\frac{144}{\gamma} + H_f$ in which H_s is the submergence in feet, H is the head per stage, P_a = atmospheric pressure (psia), P_v = vapor pressure (psia), γ = specific weight of fluid (lb/cu ft), and H_f is the friction head in the suction piping in feet. H_s has been computed for each pump (neglecting friction) and these are tabulated in Table 5. A minus H_s would indicate the pump could be set above suction water level if means for priming are provided.

Sigmas (σ) have been computed and they are plotted on Graph No. 2.

Discussion

Graph No. 3 shows sigma values used by the Bureau of Reclamation for determining pump settings when more specific model data are lacking. Note that the contractor's sigmas do not vary appreciably from this. The above will insure satisfactory operation if the pump is operated at its best efficiency head, but if a pump will at times be operated at less than best efficiency head the discharge increases and the critical sigma increases rapidly, approximately as indicated on Graph No. 4. Therefore pump settings should be based on the minimum head at which they may be required to operate.

7. Motor Costs and Weights

The contracts did not require motor costs and weights--only total cost of pumping unit. However, it is now apparent that some conceptual designers may elect to use a prime mover other than those specified for this study. Fortunately two contractors furnished weights and all furnished separate costs. The weights and costs are tabulated on Table 6. The costs submitted by Allis-Chalmers are plotted on Graph No. 5. The weights listed for stator and rotor will aid architect-engineers to determine the capacity of handling equipment required for maintenance. Costs should be increased 25 percent if outdoor settings are planned. Costs should be adjusted for voltages other than specified. Costs of installation and of controls should be added to the curve costs.

8. Pump Materials

Two pump material selections to be priced were specified. One pump material was left to the discretion of the contractors. Allis-Chalmers tends to substitute Monel for stainless for their material alternate. The other contractors suggested epoxy-lined steel or cast iron. None of the contractors found stainless clad steel practical because of the large percentage of stainless required and because of manufacturing difficulties. See Table 7.

Discussion

On the basis of recommendations received from the contractors, from International Nickel Company, and from other literature and experience we find:

a. Costs of pumps manufactured from the principal materials considered will increase in the following order: cast iron; epoxy-coated steel; Ni-Resist; stainless steel or nickel-aluminum bronze; and Monel.

b. For impellers and diffusers cavitation resistance must be considered along with corrosion resistance.

c. Castings are not practical for the cases and covers of the larger pumps under consideration. Welded construction is indicated.

d. Cast iron has poor cavitation resistance. It is fairly corrosion resistant in still or low velocity sea water or brine such that the protective corrosion products are not washed away exposing new metal. It is suitable for complete castings only, as it cannot be readily welded or repaired. It is subject to graphitization.

e. Epoxy-coated steel is temperature limited (120° F) at this time. Its use should be restricted to uniform low velocity sections which can be completely shop fabricated and coated. It should also be restricted to nonembedded parts which could be replaced, such as the column pipe of vertical column pumps.

f. Ni-Resist is more resistant to corrosion than cast iron but is also velocity limited. It has seen a lot of service in sea water and brine but may not serve 30 years. It is also suitable only for castings.

g. Stainless steel Type 316 wrought or Type CF-8M cast are known to be excellent in resistance to cavitation and corrosion if properly heat treated after casting or fabrication. It is also believed that it would not be subject to stress corrosion cracking, as claimed by some, if properly heat treated. However, there is a reluctance among foundrymen to do this. Therefore, for large components we often find it necessary to substitute Type 316L for fabrications and Type CF-3M for castings--waiving complete heat treatment. The result is a product of lesser quality than could be obtained from the material. Stainless steel is also subject to pitting when submerged in still sea water, making it necessary to drain and wash with fresh water whenever a pump will be out of service for an extended period.

h. Nickel-aluminum bronze is competitive in price with stainless steel. It is currently the preferred material for ships' propellers which speaks well for its cavitation and corrosion resistance in sea water. We have no knowledge of its service in high temperature brine but have no reason to question its suitability. It is a high-strength material, readily cast and fabricated, and is easily welded or repaired. It is not known to be subject to pitting in still water.

i. Monel, like nickel-aluminum bronze, has nothing in its disfavor except that large castings are difficult. It is, however, more expensive than nickel-aluminum bronze.

The concensus appears to be that Ni-Resist Type 2 or D2 will be adequate for the stationary components of smaller pumps for sea water or brine. Epoxy-coated steel will be suitable for column pipes where the temperature is less than 120° F. For larger pumps where fabrication would be more economical, Type 316L stainless steel or nickel-aluminum bronze is indicated.

Impellers should be cast of stainless steel Type CF-3M or nickel-aluminum bronze except that for temperature above 140° F, Monel should be used until the characteristics of the other alloys are better established.

For product water, 3-percent nickel cast iron cases with bronze trim should be adequate.

Shafts should be of carbon steel with stainless steel sleeves where there is exposure to the fluid except that small shafts would be more economically made of solid stainless steel.

While pumps of the above materials are expected to give satisfactory service, it is doubtful that anyone would guarantee a 30-year life. Additional research on pump materials is recommended.

9. Pump Costs

The contractors' cost curves are disappointingly erratic for estimating purposes. One contractor presented a generalized curve for all stainless steel pumps which may be used provided NPSH limitations are observed. Cost data for two material selections specified and for the contractors' material selection are tabulated on Table 8.

Discussion

From the contractors' data we have attempted to derive estimating curves more useful to designers. See Graphs No. 6, 7, 8, 9, 10, and 11. These are believed to be adequate for estimating provided the limitations applying to these studies are not exceeded. Costs of installation should be added to curve costs. Note from Graph No. 6 that for a 100,000-gpm pump at 400 feet of head, the manufacturers' cost for all stainless steel is nine times that which the Bureau of Reclamation would expect for conventional materials under competitive bidding.

10. Efficiency

Best efficiency points of the pumps selected by the three contractors are plotted on Graph No. 12. No one should draw any conclusions regarding one manufacturer's efficiencies versus another's. Whatever efficiency one contractor can obtain, other reputable manufacturers can match. The differences indicate only the degree of conservatism considered proper for the purpose of these contracts.

Discussion

In a preliminary report it was stated that efficiency of pump and prime mover will be found to be of utmost importance since the present worth of power costs due to very few percentage points of efficiency will equal the capital cost of the equipment. Further consideration that all efficiency losses of the pump are transferred into heat makes one realize that for some recirculating pumps,

efficiency is not so important after all. High efficiency will still be important for sea water pumps, brine reject pumps, and product pumps.

All contractors seem to agree that highest efficiencies will be found at specific speeds between 2,500 and 3,000. Only Allis-Chalmers seemed to have adjusted expected efficiency for size. USBR curves shown at the bottom of Graph No. 12 and on Graphs No. 13 and 14 show USBR experience in this matter. Larger sizes of pumps and motors are expected to obtain higher efficiencies.

Ideal suction conditions are essential to obtain high efficiency. Note that both manufacturers who selected wet-pit pumps recommend reduced expected efficiency for such settings.

Efficiencies indicated above must not be used for computing power costs. In the first place, the USBR would discount expected efficiencies shown about 2 percent in establishing a value required to be guaranteed. Secondly, an allowance for wear between overhauls must be considered. This may be only 1 or 2 percent. Thirdly, and most important, is the range of heads and capacities a pump may be expected to deliver.

To illustrate the latter point, let us assume a system in which a pump is expected to deliver from 50 percent to 100 percent discharge at heads ranging from 100 percent, representing 20-percent static lift and 80-percent friction in scaled and partially clogged or fouled condenser tubes, to 30 percent, representing 50-percent capacity with the same static lift and 10-percent friction in new clean tubes. See lower curves of Graph No. 15.

If a fixed-pitch, fixed-speed pump were selected for this service and if the weighted average operation were 75-percent discharge at 53.5-percent head, the discharge of the pump would have to be throttled with an average efficiency of 38.5 percent or bypassed; but bypassing is not possible over the whole range because the head on the pump would become too low. If a fixed-speed variable-pitch pump were selected, an efficiency of 82 percent could be expected. If a fixed-pitch variable-speed pump were selected, an efficiency of 88 percent could be expected. The above do not include the efficiency of the prime mover or speed reduction components. For the assumed conditions the variable-speed pump has distinct advantages. There are many methods which may be employed to obtain variable speed. Of these the steam turbine with geared reducer seems to be most attractive. Direct-current motors powered by a steam turbine driven direct-current generator should also be considered. For lesser head variation the variable-pitch, constant-speed pump is very attractive for variable discharge.

11. Recommended Procedure for Selecting and Pricing Pumps and for Determining the Required Setting

Example No. 1--Sea water pump

Given $Q = 400{,}000$ gpm constant
$H = 150$ feet constant
Temperature of water 75° F maximum
Pump to be self-priming with tide ± 3 feet
Head loss through intake channel and traveling screen--0.5 foot

Analysis: For a pump of this size one can visualize a spiral-cased centrifugal pump
For best efficiency, suction specific speed should be $S = \pm 8{,}000 = \frac{N\sqrt{gpm}}{(NPSH)^{3/4}}$

If the centerline is placed 3 feet under minimum water level = -6.5 feet, the pump will be self-priming and $NPSH = 3 \times \frac{1.02}{1.00} + (33.94 - 1.00) =$ 36 feet at 75° F

Then: $$N = \frac{(36.0)^{3/4} \times 8{,}000}{\sqrt{400{,}000}} = \frac{14.8 \times 8{,}000}{633} = 187 \text{ rpm max., say } 189$$

$$N_s = \frac{189 \times \sqrt{400{,}000}}{150^{3/4}} = \frac{189 \times 633}{42.7} = 2{,}800$$

$$HP = \frac{400{,}000}{450} \times \frac{150}{0.90} \times \frac{63.5}{550} = 17{,}100, \text{ say } 17{,}500$$

From Table 5 find that a near specific speed is Worthington's Pump No. 30, $N_s = 2{,}761$. See Worthington performance curve sheet E-203723. From the contractor's curves for this pump one can predict the characteristics of the example pump.

Now suppose that at times the pumping head may be only 120 feet or 80 percent of 150 due to overestimating tube friction. At 80 percent of best efficiency head, Pump 30 delivers 117 percent of capacity. From Graph No. 4 one finds that at 117 percent Q, σ may be 135 percent of normal σ and normal $\sigma = \frac{36}{150} = 0.24$. So σ at 80 percent best efficiency head will be $1.35 \times 0.24 = 0.324$. Then, NPSH required will be $0.324 \times 120 = 38.8$ feet, whereas at 150 feet

head, it is 0.24 x 150 = 36 feet. This means that one would have to throttle the discharge of the pump so that Q does not exceed 400,000 gpm or else set the pump deeper, 38.8 - 36.0 = 2.6 feet deeper. At a sacrifice in efficiency one could use a higher suction speed pump such as Allis-Chalmers has. See Graph No. 2, $\sigma = 0.17$ for $N_s = 2{,}800$. σ at 80-percent head = 1.35 x 0.17 = 0.229 and NPSH = 0.229 x 120 = 27.5 feet. Throttling the discharge would also reduce efficiency. See Graph No. 15. Bypassing part of the excess flow would require the same setting as above. It appears that a variable-speed drive or a variable-pitch pump is in order.

To price this pumping unit consider:

Constant speed pump of nickel-aluminum bronze or stainless steel from Graph No. 7	$1,550,000
Motor 17,500 hp at 189 rpm from Graph No. 5	450,000
	$2,000,000

Example No. 2--Brine recirculation pump

Suppose a pump of the same capacity and total head as above were required, i.e.

$Q = 400{,}000$ gpm

$H = 150$ feet

but instead of pumping sea water, in which case we arbitrarily set the centerline 3 feet under minimum tide level to afford self-priming, we are pumping flashing brine having a specific gravity of 1.058, a temperature of 90° F, and a vapor pressure of 0.66 psia. In this case $H_a - H_v = 0$, so the NPSH obtained will mean the highest point of the inlet edge of the impeller vanes will be submerged by the value of NPSH in feet.

If we limit specific speed to $N_s = 69{,}000/H^{.63}$ as for the subject studies, we could go to a maximum specific speed of $N_s = 69{,}000/150^{.63} = 2{,}940$ and $N = \frac{2{,}940 \times 150^{3/4}}{633} = 200$ rpm.

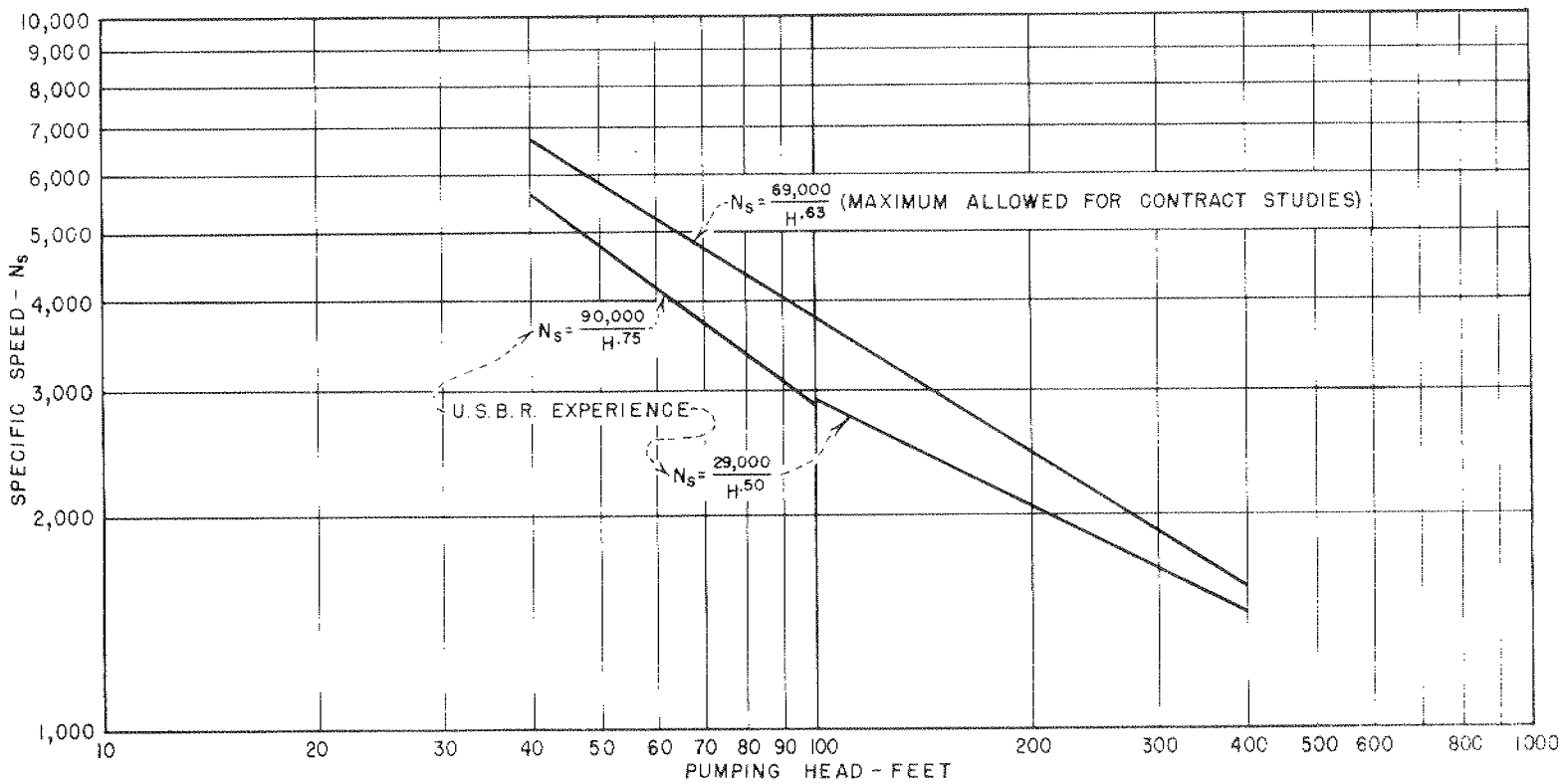
Now for best efficiency suction specific speed of about 8,000,

$$NPSH = \left(\frac{N\sqrt{gpm}}{S}\right)^{4/3} = \left(\frac{200 \times 633}{8{,}000}\right)^{4/3} = 15.85^{4/3} = 40 \text{ feet.}$$

This is a lot of submergence. It can be reduced by reducing the rotative speed with an increase in pump size and price. If the speed were reduced to 189 rpm, the pump size would be the same as for Example No. 1. If the pump N_s were reduced to 2,350 per USBR curve, N would be $\frac{2,350 \times 43}{633} = 160$ or 163.7 synchronous.

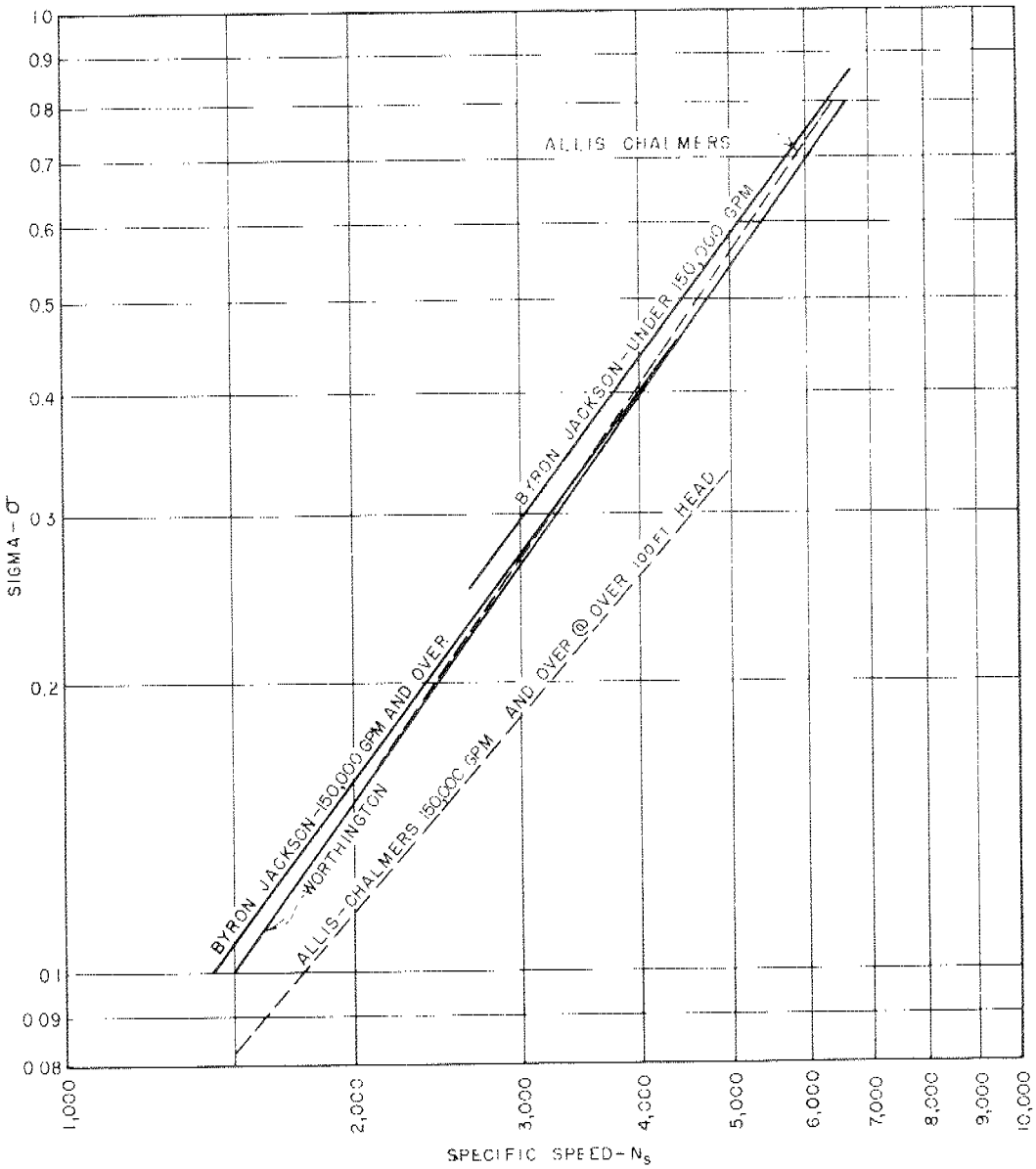
$$NPSH = \left(163.7 \times \frac{633}{8,000} \right)^{4/3} = 12.95^{4/3} = 30.5 \text{ feet.}$$

Note that by reducing speed from 200 to 163.7 we reduced the submergence by 9.5 feet, but we also increased the size from 84 inches to $84 \times \frac{200}{163.7} = 102.8$ inches approximately, or an increase in price from \$155,000 to \$195,000 for the pump and an increase in motor price from \$425,000 to \$480,000, or a total increase in price of \$95,500. One would have to seriously consider the values of reducing speed and submergence versus structure costs.

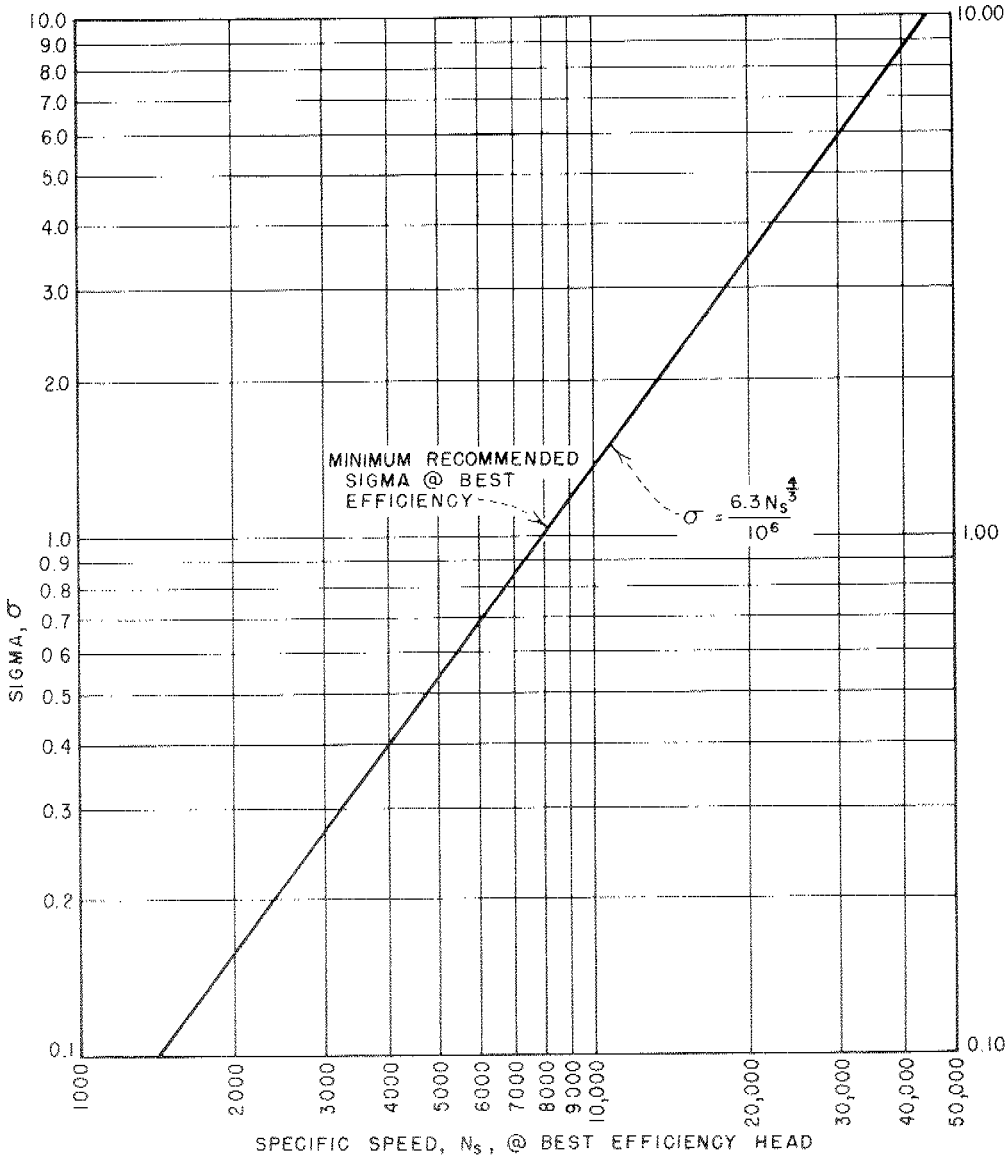


SPECIFIC SPEED vs PUMPING HEAD

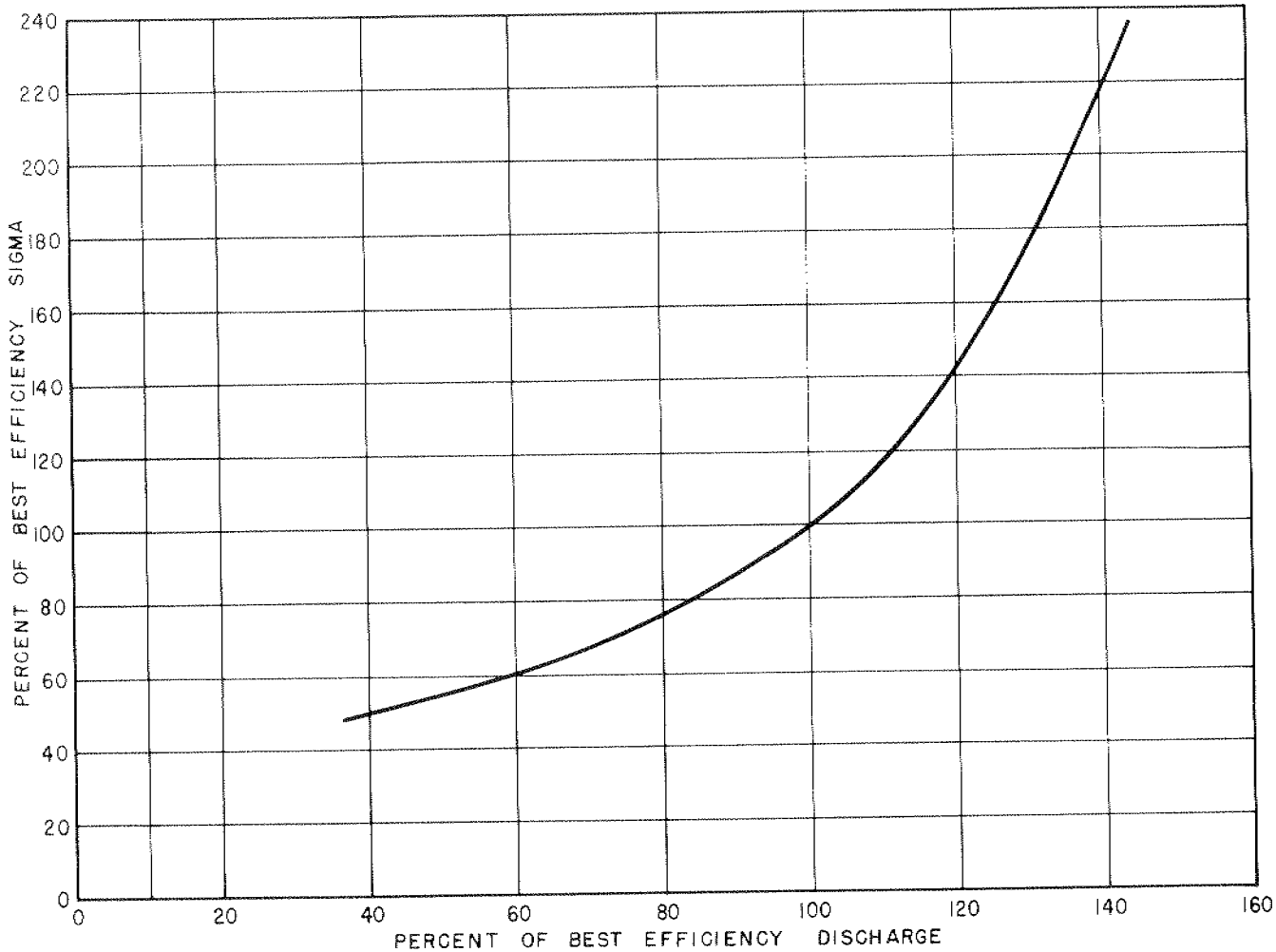
GRAPH NO. 1



COMPARISON OF CONTRACTOR'S SIGMAS

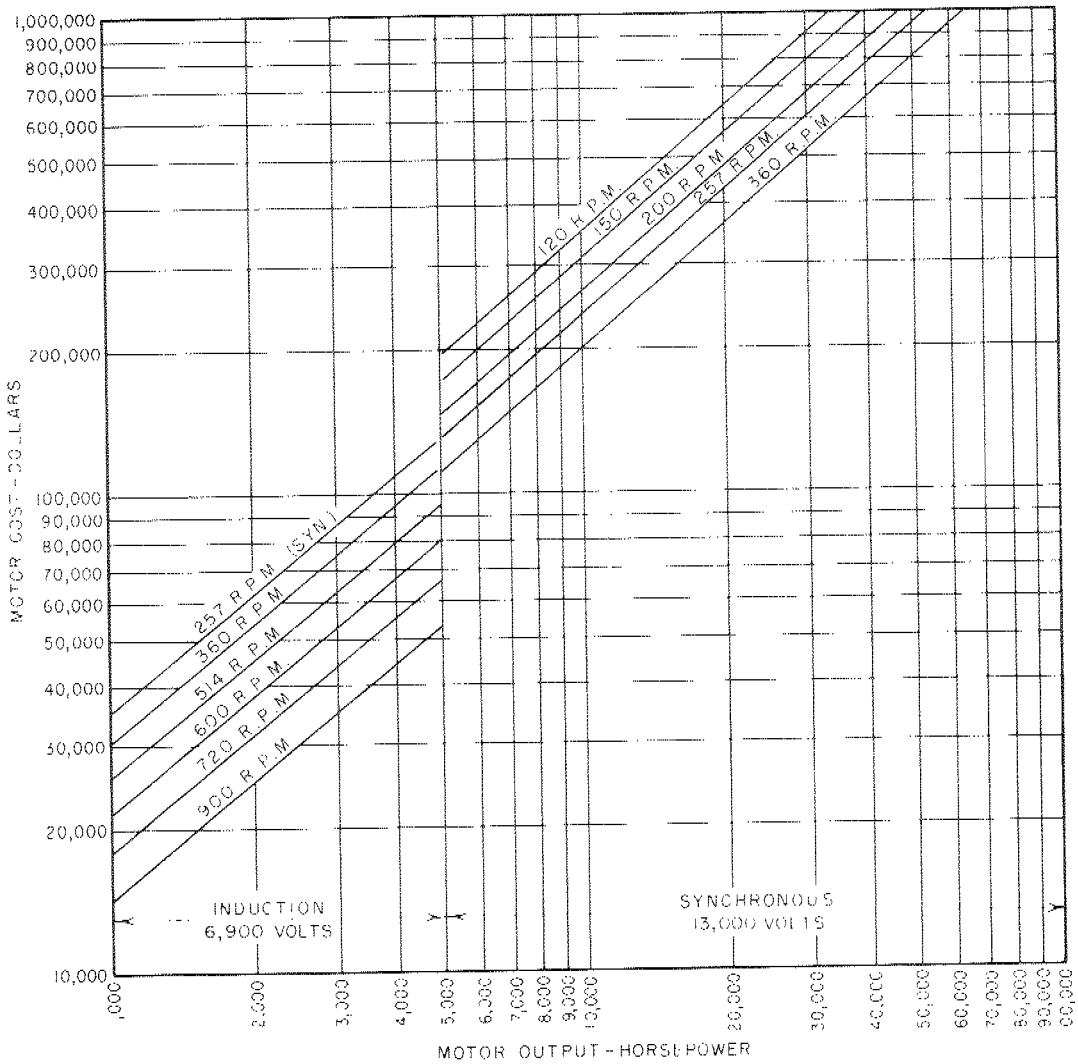


SIGMA VS SPECIFIC SPEED
U.S.B.R. (FROM STEPANOFF)



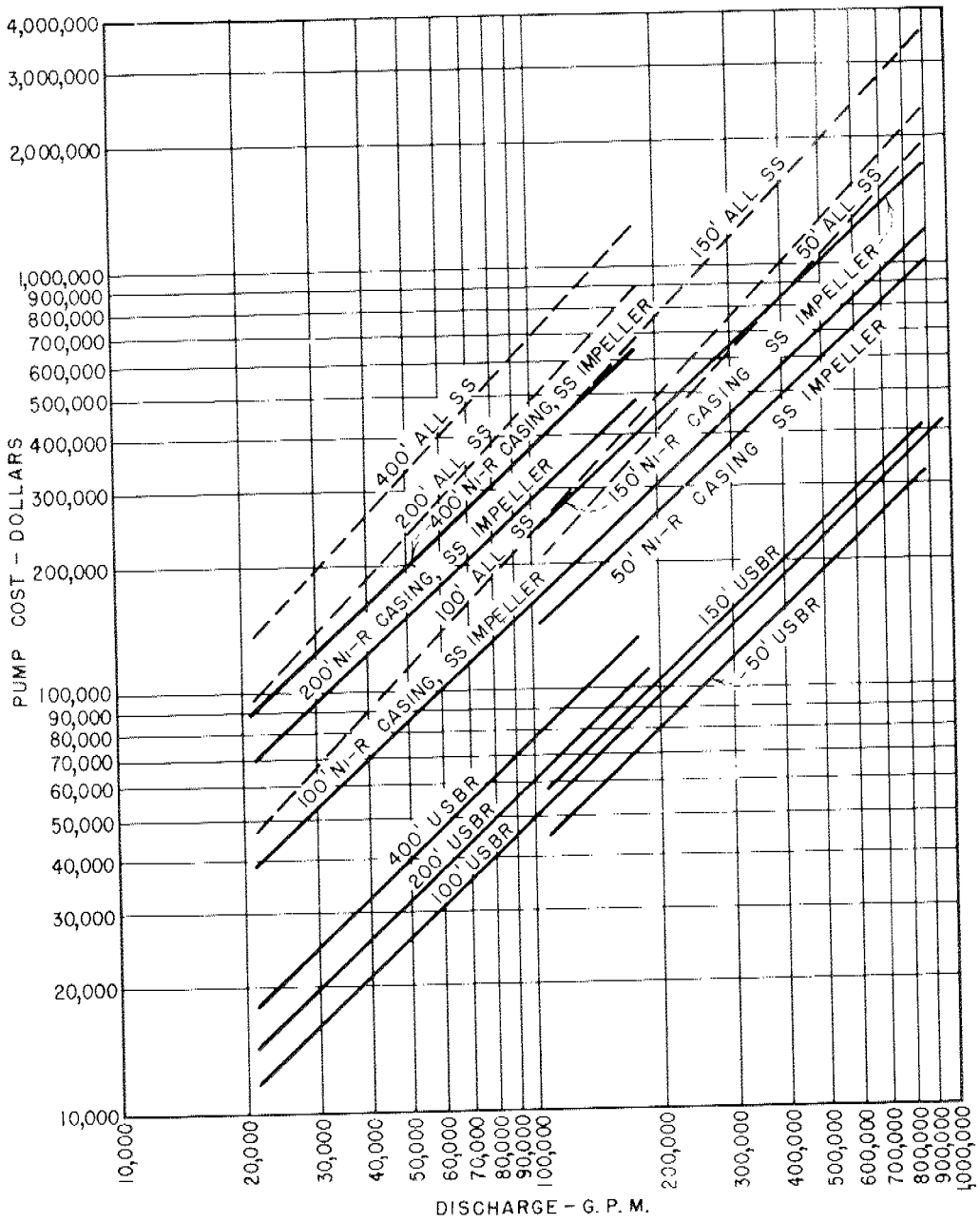
TYPICAL VARIATION OF SIGMA WITH DISCHARGE

GRAPH NO. 4



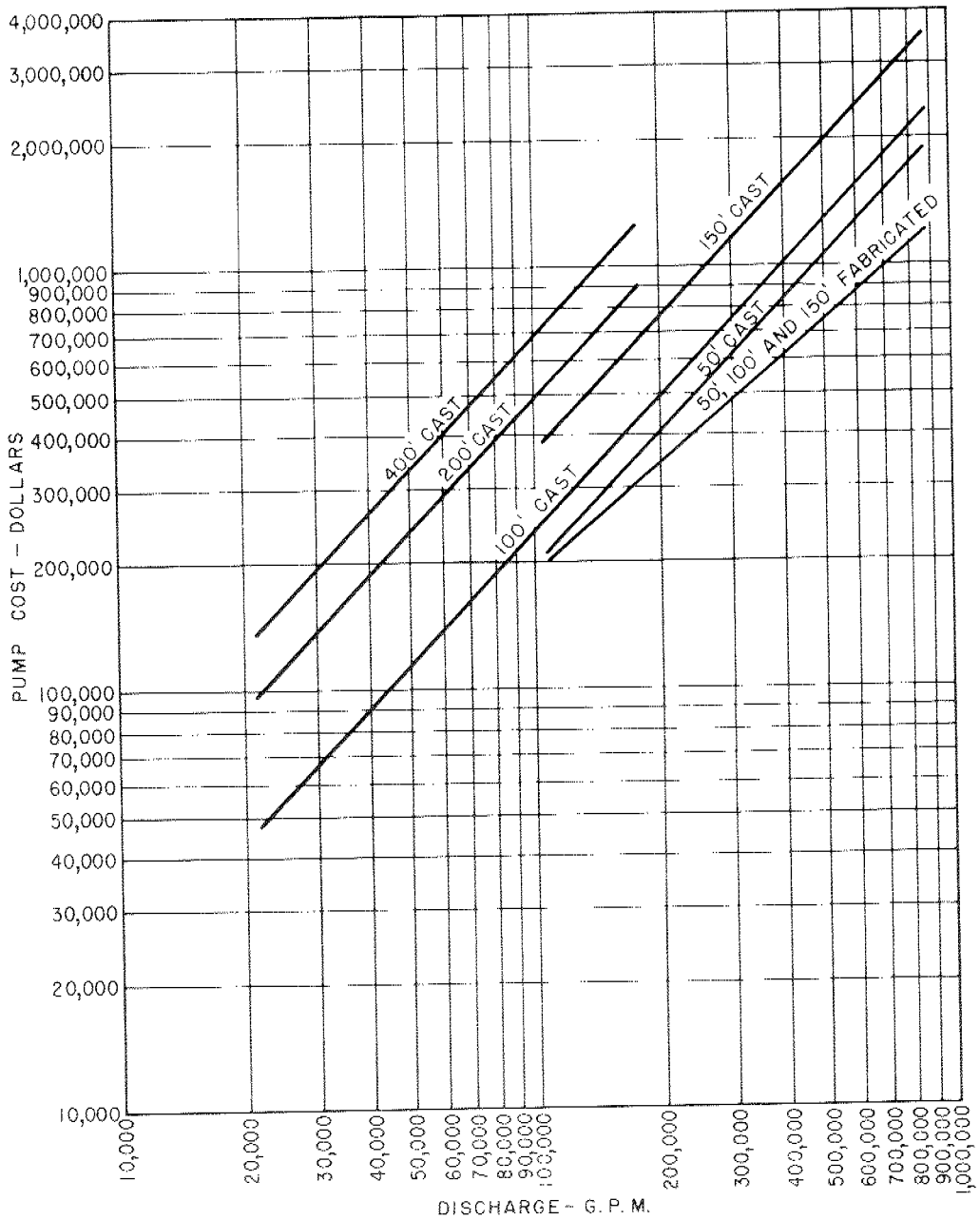
MOTOR COST vs. MOTOR OUTPUT

FOR ELECTRIC MOTOR WITH INDOOR HOUSING, FULL VOLTAGE STARTING AND DIRECT CONNECTED EXCITER

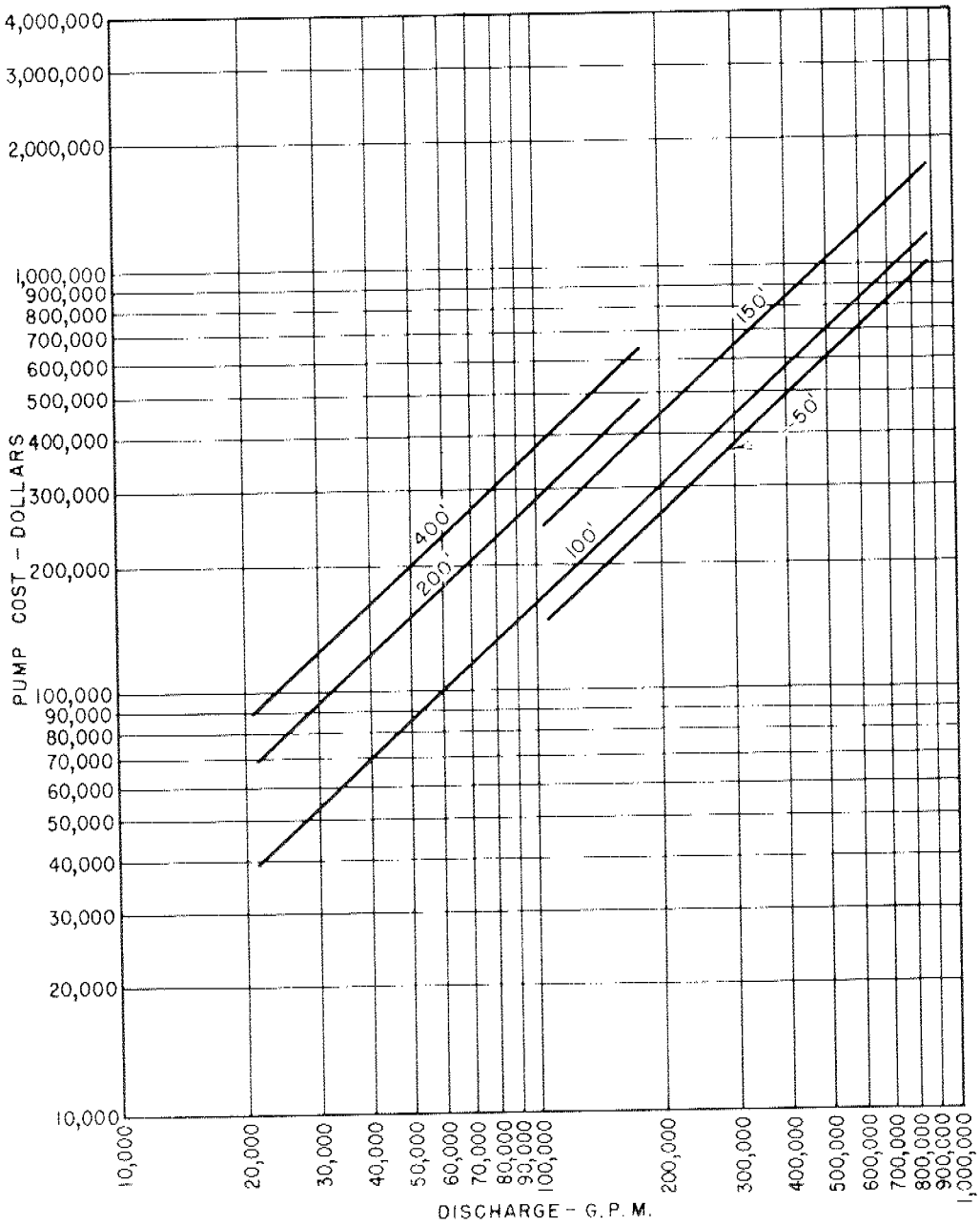


COST COMPARISON - SEA WATER PUMPS

USBR PUMPS ARE CAST IRON OR STEEL



COST OF SEA WATER PUMPS
MATERIAL ALTERNATE No. 1
ALL STAINLESS STEEL

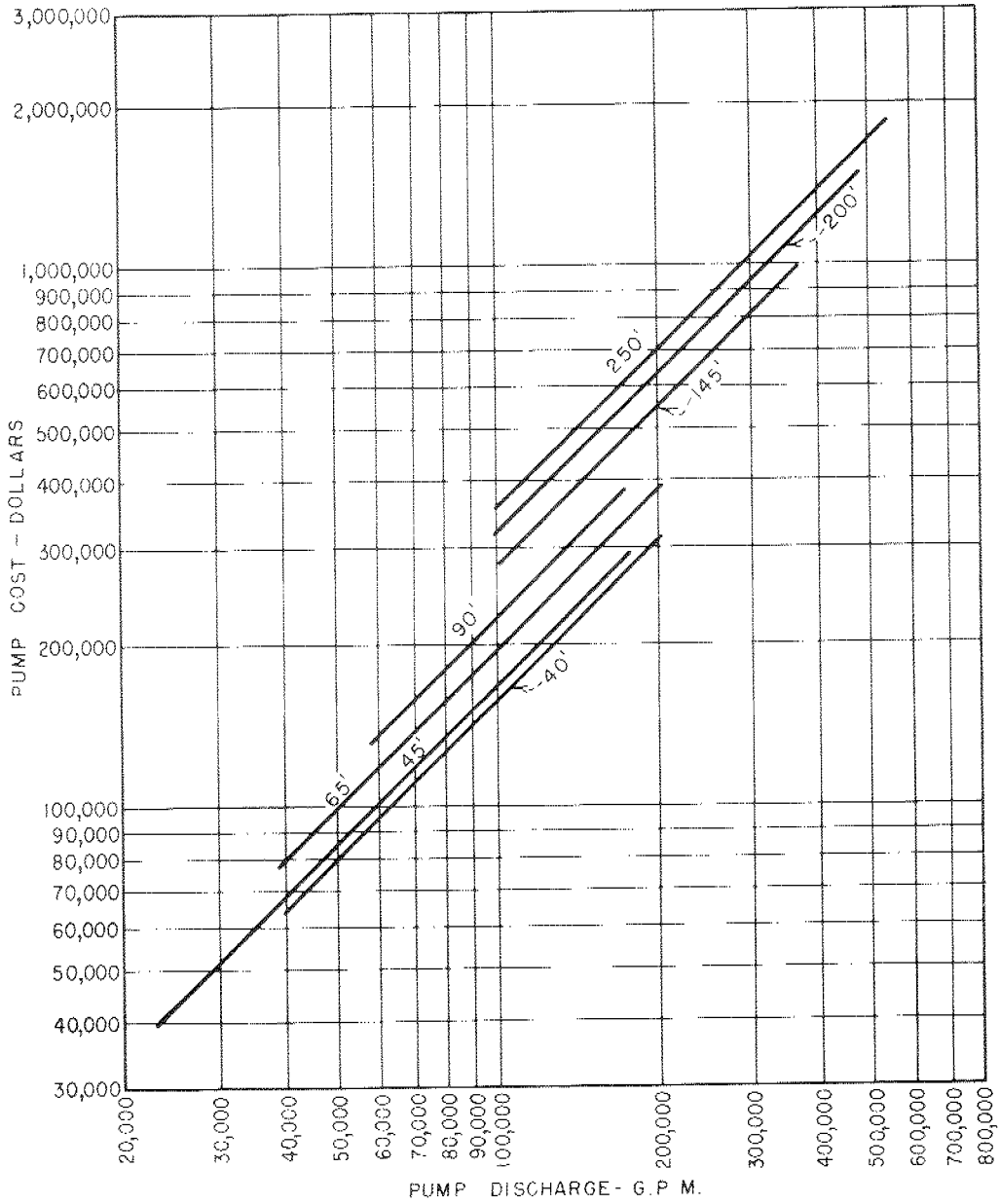


COST OF SEA WATER PUMPS

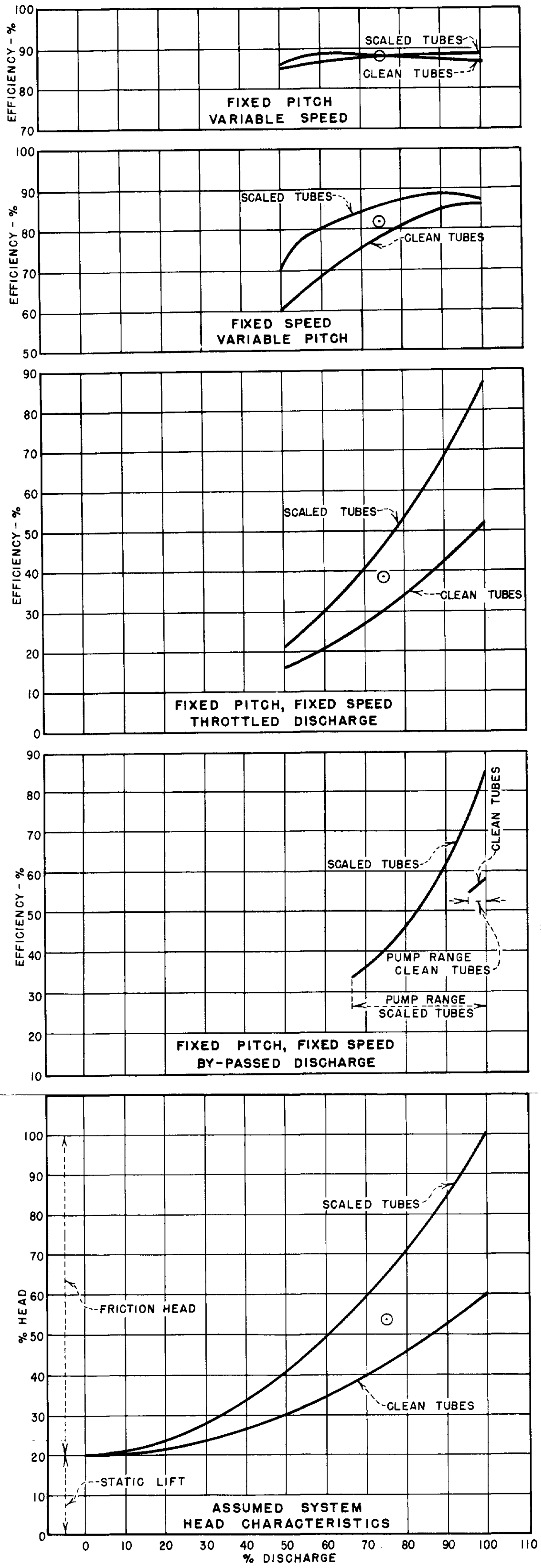
MATERIAL ALTERNATE No. 2

CASING - NI-RESIST

IMPELLER - STAINLESS STEEL

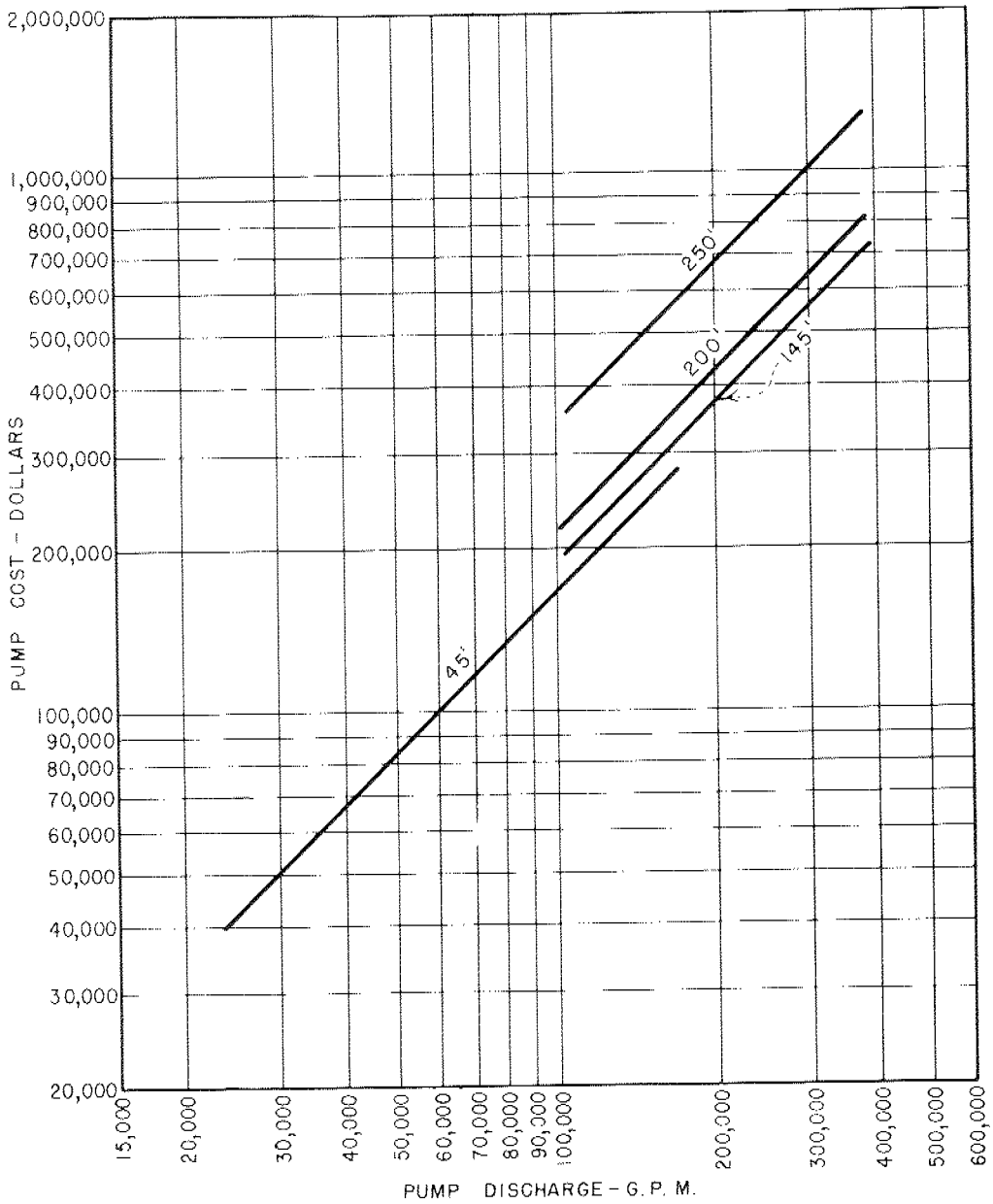


COST OF BRINE PUMPS
VERTICAL TURBINE-WET PIT TYPE
CASING - NI-RESIST
IMPELLER - NI-AL-BRONZE
NSPH REQUIRED - 27.5' TO 33.8'

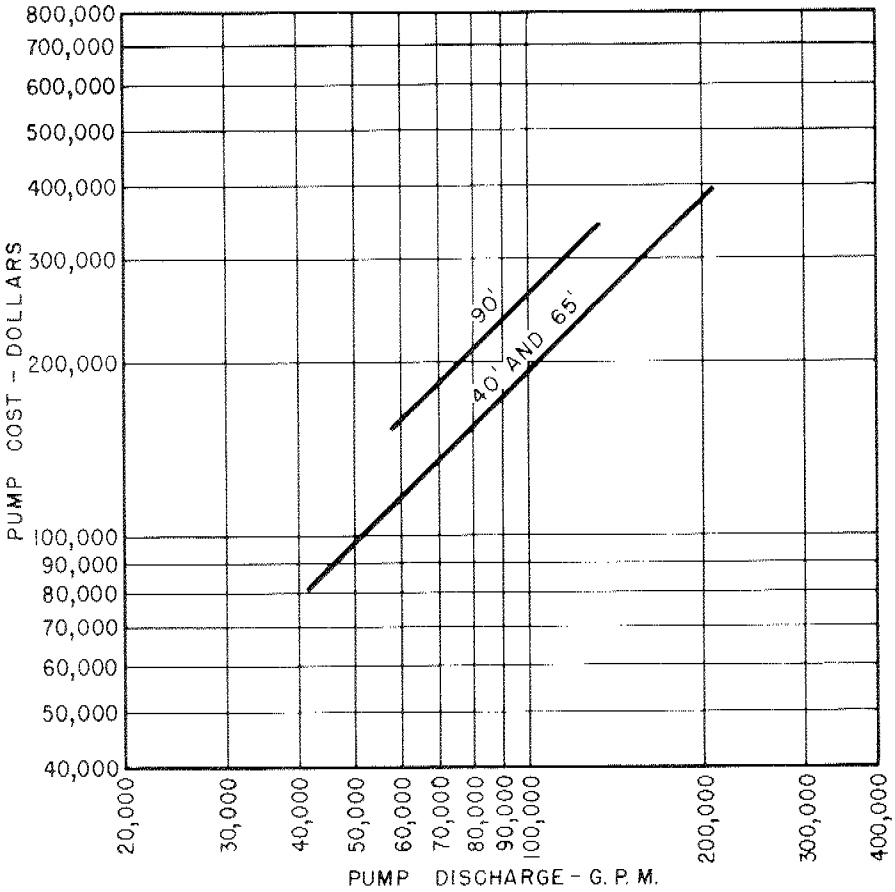


COMPARISON OF SYSTEM EFFICIENCIES
FOR SEVERAL METHODS OF FLOW CONTROL
NOT INCLUDING PRIME MOVER EFFICIENCY

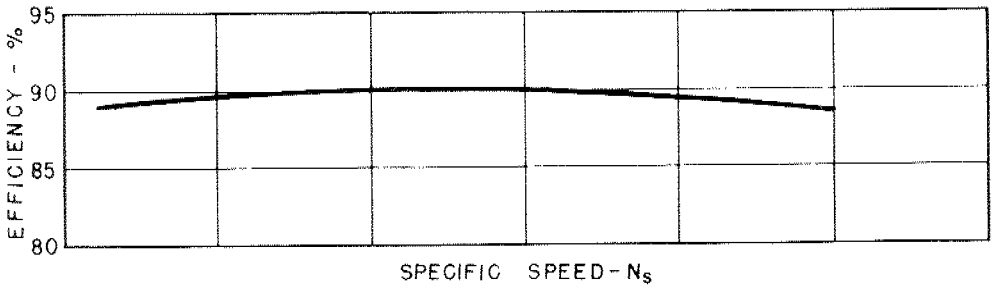
GRAPH NO. 15



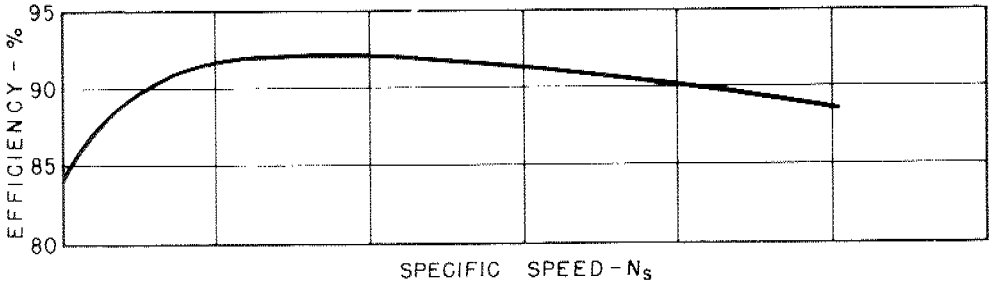
COST OF BRINE PUMPS
VERTICAL TURBINE - WET PIT TYPE
CASING - NI-RESIST
IMPELLER - STAINLESS STEEL
NSPH REQUIRED - 31.8' TO 33.8'



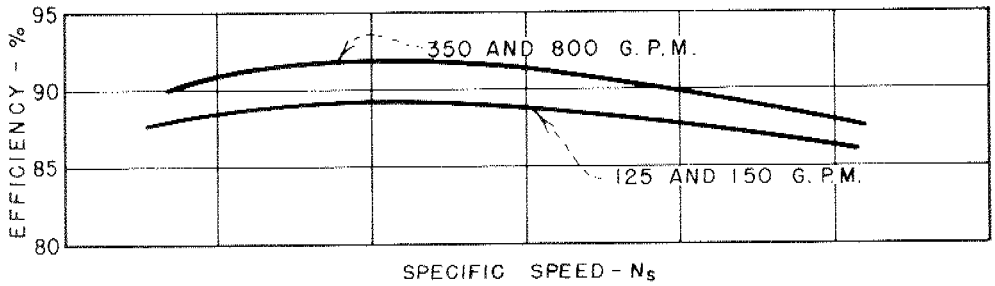
COST OF BRINE PUMPS
VERTICAL TURBINE - WET PIT TYPE
CASING - NI-RESIST
IMPELLER - MONEL
NPSH REQUIRED - 40' AND 90';
27.5' TO 29.9'; 65'; 31' TO 33'



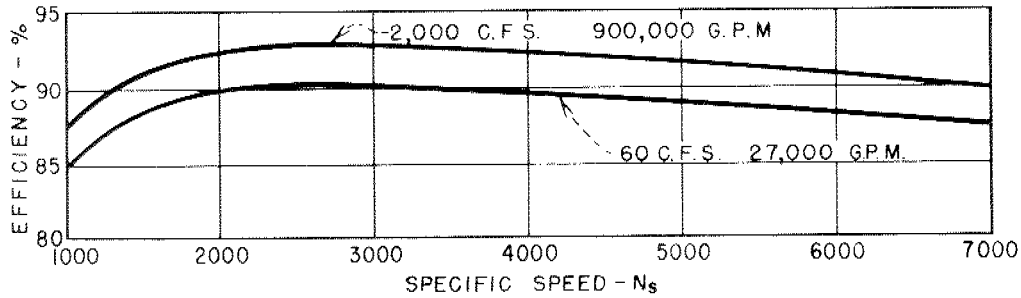
WORTHINGTON EXPECTED PUMP EFFICIENCY
FOR VERTICAL CENTRIFUGAL PUMPS
BEST EFFICIENCY WET PIT PUMPS
EFF. = 87% OVER 100,000 G.P.M.
EFF. = 86% 100,000 G.P.M. OR LESS



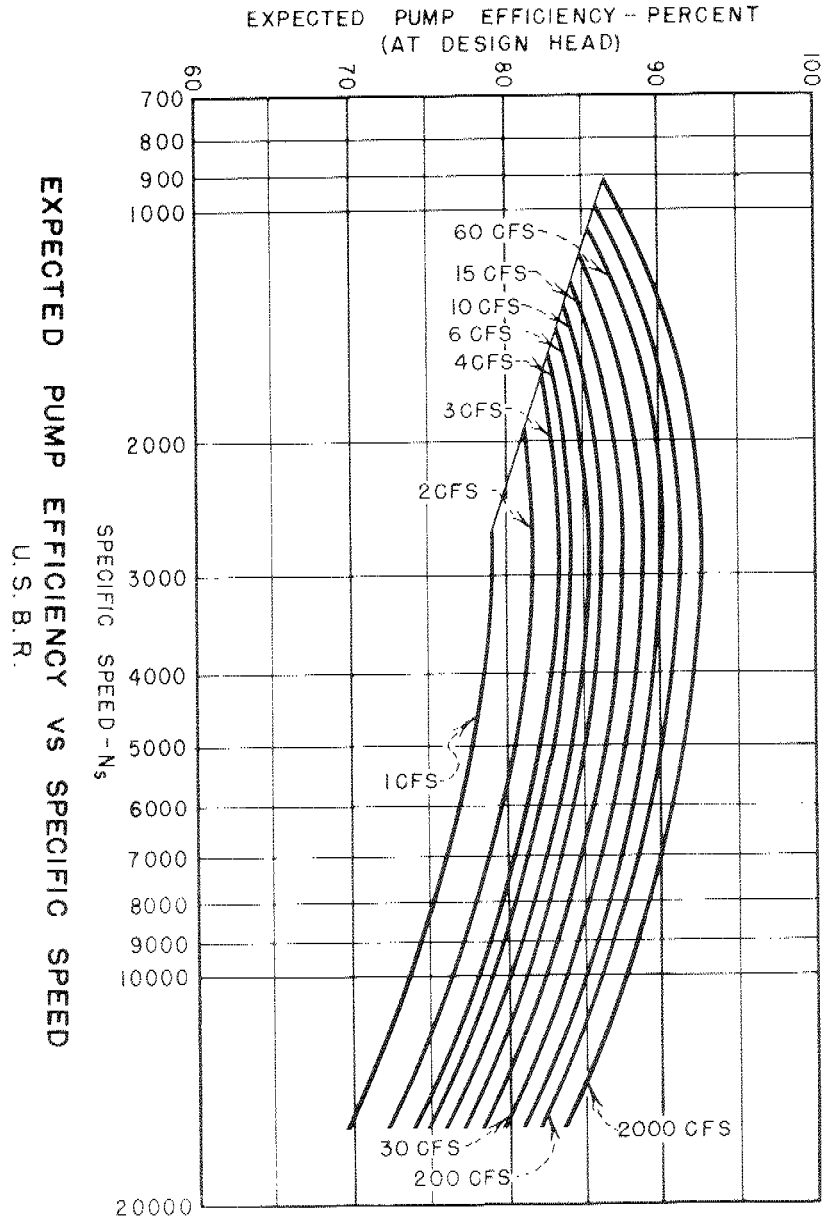
BYRON JACKSON EXPECTED PUMP EFFICIENCY
FOR PUMPING RATES IN EXCESS OF 50,000 G.P.M.
DEDUCT 2% FOR WET PIT PUMPS



ALLIS-CHALMERS EXPECTED PUMP EFFICIENCY

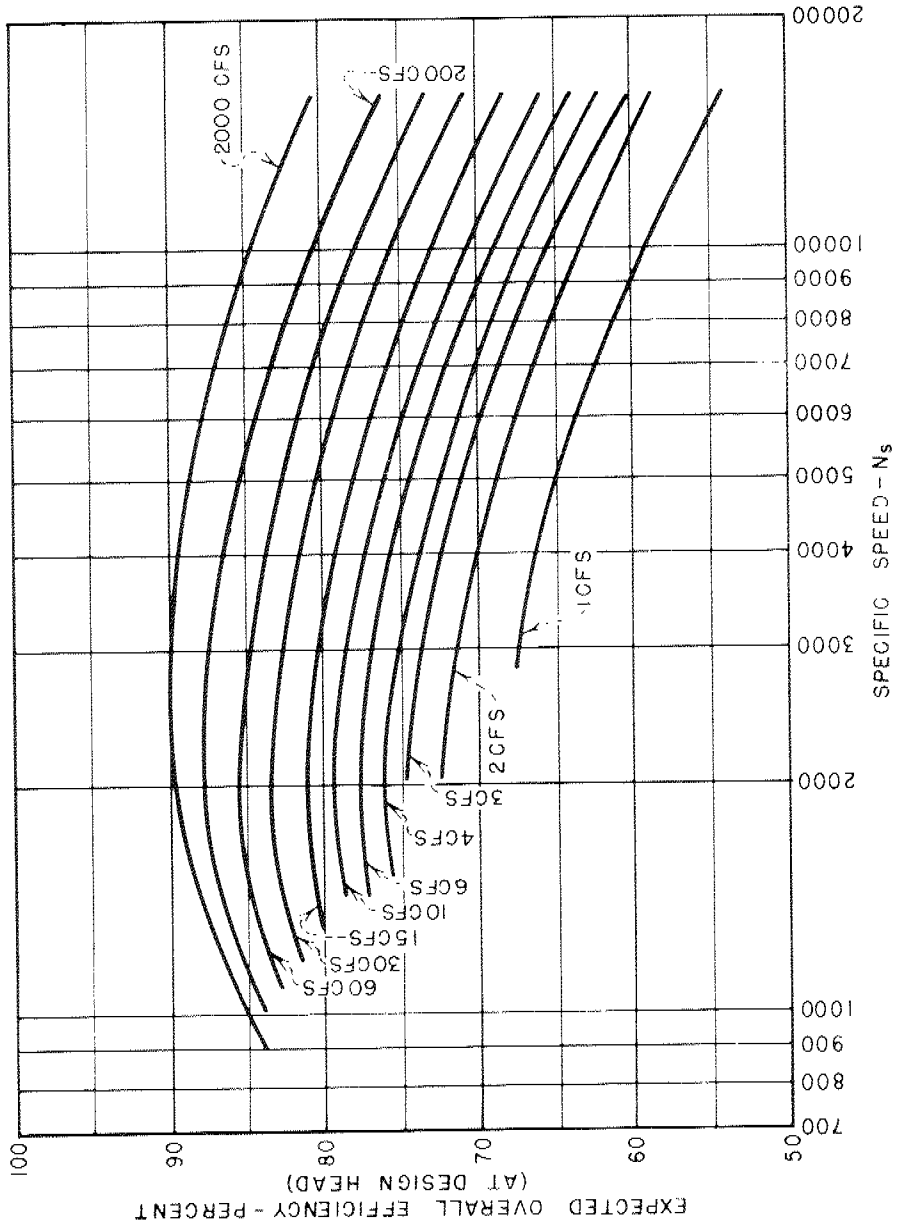


U. S. B. R. EXPECTED PUMP EFFICIENCY



EXPECTED PUMP EFFICIENCY VS SPECIFIC SPEED
U.S.B.R.

GRAPH NO. 13


EXPECTED OVERALL EFFICIENCY VS SPECIFIC SPEED
U.S.B.R.
SPECIFIC SPEED - N_s
EXPECTED OVERALL EFFICIENCY - PERCENT
(AT DESIGN HEAD)
100
90
80
70
60
50
700
800
900
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
20000
2000 CFS
200 CFS
1 CFS
2 CFS
3 CFS
4 CFS
6 CFS
10 CFS
15 CFS
30 CFS
60 CFS

January 29, 1965 ORNL
Revised February 3, 1965 USBR
Revised March 29, 1965 USBR
Revised May 18, 1965 USBR
Revised June 22, 1965 USBR

SPECIFICATION DATA SHEET FOR LARGE MSF PLANT PUMPS

	Sea Water	Brine Recirculation	Brine Reject	Product
Number of Units[1]	1 and 3	2 and 6	2 and 4	2 and 4
Fluid	Sea Water	Brine	Brine	Distilled Water
Temperature (°F)	65	90	90	87
Suction Atmospheric Pressure	14.7 psia	1.5 psia	1.5 psia	1.5 psia
Total Head (ft)[2]	50, 100, 150	145, 200, 250	45	70
Specific Gravity	1.02	1.052	1.058	.99
Voltage	13.8 KV, 3 Ph, 60 Cy	13.8 KV, 3Ph, 60 Cy	4160 V, 3 Ph, 60 Cy	4160 V, 3 Ph, 60 Cy
Type Motor	Synchronous 1.0 PF	Synchronous 1.0 PF	Squirrel Cage	Squirrel Cage
Capacity, gpm[3]	125,000, 350,000 800,000	125,000, 2~~3~~00,000 ~~000~~,~~000~~, 350,000	25,000, 75,000 150,000	20,000, 50,000 100,000
Materials: Large shafts may be of forged (or fabricated) carbon steel. Portions in contact with sea water or brine shall be 316 stainless steel clad 1/4" minimum thickness. Smaller shafts shall be of Type 316 stainless steel.	Steel, with Type CF-8M stainless steel impeller and all parts in contact with water 316 stainless steel or 316 stainless steel clad 1/4" minimum thickness. Ni-Resist Type 2, or Type D2 where stress dictates, Type CF-8M stainless steel impeller. Manufacturer's recommendation.	Ni-Resist Type 2 or Type D2 or with Type CF-8M stainless steel impellers. Ni-Resist Type 2 or Type D2 where stress dictates. Ni-Al bronze impeller and trim. (B-148, 9D-HT). Manufacturer's recommendation.	Ni-Resist Type 2 or Type D2 or with Type CF-8M stainless steel impellers. Ni-Resist, Type 2 or Type D2 where stress dictates. Ni-Al bronze impeller and trim. (B-148, 9D-HT). Manufacturer's recommendation.	Manufacturer's recommendation.

[1]Give increased cost above base cost for smaller quantities listed.

[2]Maximum specific speed, $N_s = \frac{69,000}{H^{.63}}$ where H = total head per stage. $(69,000/H^{.63})$

[3]Throttling may be required during startup and for process control.

January 29, 1965 ORNL
Revised February 3, 1965 USBR
Revised March 29, 1965 USBR
Revised May 18, 1965 USBR
Revised June 22, 1965 USBR

SPECIFICATION DATA SHEET FOR VTE PLANT PUMPS

	Brine Feed	Brine Recirculation	Brine Recirculation
Number of Units[1]	2 and 4	2 and 4	2 and 4
Fluid	Sea Water	Brine	Brine
Temperature (°F)	110	~~190~~ 200	146
Suction Atmospheric Pressure	18 psia	11.4 psia	3.4 psia
Total Head (ft)[2]	100, 200, 400	40, ~~60~~ 90	40, 65
Specific Gravity	1.013	1.02	1.05
Voltage	4160 V, 3 Ph, 60 Cy[4]	4160 V, 3 Ph, 60 Cy	4160 V, 3 Ph 60 Cy
Type Motor	Squirrel Cage[4]	Squirrel Cage	Squirrel Cage
Capacity, gpm[3]	25,000, 50,000 150,000	63,000, 125,000 ~~247,000~~	47,000, 100,000 175,000
Materials:			
Large shafts may be of forged (or fabricated) carbon steel. Portions in contact with sea water or brine shall be 316 stainless steel clad 1/4" minimum thickness. Smaller shafts shall be of Type 316 stainless steel.	Steel with Type CF-8M stainless steel impeller and all parts in contact with water 316 stainless steel or 316 stainless steel clad 1/4" minimum thickness. Ni-Resist Type 2 or Type D2 where stress dictates, Type CF-8M stainless steel impeller and trim. Manufacturer's recommendation.	Ni-Resist Type 2 with Monel impeller and trim. Ni-Resist Type 2 with Ni-Al bronze impeller and trim. Manufacturer's recommendation.	Ni-Resist Type 2 with Monel impeller and trim Ni-Resist Type 2 with Ni-Al bronze impeller and trim. Manufacturer's recommendation.

[1]Give increased cost above base cost for smaller quantities listed.

[2]Maximum specific speed, $N_s = \frac{69,000}{H.63}$ where H = total head per stage. $(69,000/H^{.63})$

[3]Throttling may be required during startup or for process control.

[4]Use 13.8 kv and synchronous over 5,000 horsepower.

PUMP COSTS

Pump No.	For Lesser No. of Units, From Spec. Data Sheet: Material Alt. No. 1 A.C.	Material Alt. No. 1 B.J.	Material Alt. No. 1 W.	Material Alt. No. 2 A.C.	Material Alt. No. 2 B.J.	Material Alt. No. 2 W.	Contractor's Mat'l. A.C.	Contractor's Mat'l. B.J.	Contractor's Mat'l. W.	For Larger No. of Units, From Spec. Data Sheet: Material Alt. No. 1 A.C.	Material Alt. No. 1 B.J.	Material Alt. No. 1 W.	Material Alt. No. 2 A.C.	Material Alt. No. 2 B.J.	Material Alt. No. 2 W.	Contractor's Mat'l. A.C.	Contractor's Mat'l. B.J.	Contractor's Mat'l. W.	No. Units Lesser	No. Units Larger
1	82,100	66,800	87,450	80,100	56,300	72,610	83,700	53,600	53,000	81,850	61,500	82,500	79,850	51,000	68,500	83,450	48,300	50,000	2	4
2	108,500	121,600	132,500	106,500	100,800	111,300	111,700	95,600	75,260	99,750	115,100	125,000	97,750	94,300	105,000	102,950	89,100	71,000	2	4
3	163,200	138,700	174,900	160,200	122,000	145,220	168,200	115,000	100,700	155,450	131,700	165,000	152,450	115,000	137,000	160,450	108,000	95,000	2	4
4	183,000	153,600	235,320	173,720	125,500	203,520	211,960	118,300	126,140	173,960	146,300	222,000	164,690	118,200	192,000	202,920	111,000	119,000	2	4
5	228,940	449,000	359,340	216,300	412,000	290,440	285,700	400,000	195,040	219,330	419,000	339,000	206,680	382,000	274,000	285,080	370,000	184,000	2	4
6	29,400	36,800	48,230	28,400	39,000	48,230	31,600	34,600	31,800	29,150	33,800	45,500	28,150	36,000	45,500	31,350	31,600	30,000	2	4
7	109,700	73,400	139,920	107,700	75,500	139,920	112,900	63,300	117,660	100,950	67,400	132,000	98,950	69,500	132,000	104,150	57,300	111,000	2	4
8	210,260	355,000	289,380	202,940	362,000	289,380	245,220	338,000	193,980	200,840	335,000	273,000	193,530	342,000	273,000	235,800	318,000	183,000	2	4
9	199,400	143,000	291,900	197,090	133,000	165,900	228,330	124,000	69,300	175,300	123,000	278,000	172,990	113,000	158,000	204,230	104,000	66,000	1	3
10	484,010	653,000	834,750	482,460	620,000	477,750	574,320	572,000	220,500	451,380	589,000	795,000	449,830	556,000	455,000	541,690	508,000	210,000	1	3
11	1,043,520	1,216,000	2,047,500	1,035,780	1,141,000	1,207,500	1,252,560	1,056,000	598,500	994,690	1,140,000	1,950,000	986,950	1,065,000	1,150,000	1,203,730	980,000	570,000	1	3
12	65,700	88,400	92,750	64,700	74,100	81,090	67,500	69,800	57,770	65,450	83,100	87,500	64,450	68,800	76,500	67,250	64,500	54,500	2	4
13	168,900	200,400	181,260	165,900	156,600	153,700	173,900	148,200	100,700	161,150	193,400	171,000	158,150	149,600	145,000	166,150	141,200	95,000	2	4
14	202,940	437,000	359,340	192,140	395,000	301,040	237,060	386,000	189,740	193,580	407,000	339,000	182,780	365,000	284,000	227,690	356,000	179,000	2	4
15	-	-	-	-	-	-	41,900	20,050	31,000	-	-	-	-	-	-	41,650	16,250	28,700	2	4
16	-	-	-	-	-	-	119,700	45,700	55,620	-	-	-	-	-	-	119,450	39,300	51,500	2	4
17	-	-	-	-	-	-	199,100	65,600	111,240	-	-	-	-	-	-	191,350	53,600	103,000	2	4
18	73,400	120,200	166,420	71,100	96,600	140,980	74,400	91,700	60,420	73,150	113,700	157,000	70,850	90,100	133,000	74,150	85,200	57,000	2	4
19	174,200	202,300	315,350	171,500	153,300	267,650	178,200	143,000	177,550	164,200	195,000	297,500	161,500	146,000	252,500	168,200	135,700	167,500	2	4
20	45,900	42,900	63,000	33,100	39,100	40,420	34,100	37,300	40,420	39,650	38,400	60,000	26,850	34,600	38,500	27,850	32,800	38,500	2	4
21	91,000	67,400	130,200	61,400	61,800	83,480	63,500	57,600	83,480	83,500	61,400	124,000	53,900	55,800	79,500	56,000	51,600	79,500	2	4
22	319,100	166,000	380,100	224,500	153,000	191,100	231,100	139,000	191,100	292,430	146,000	362,000	197,830	133,000	182,000	204,430	119,000	182,000	1	3
23	292,500	248,000	359,100	183,500	240,000	222,600	191,000	233,000	222,600	281,750	230,000	342,000	172,750	222,000	212,000	180,250	215,000	212,000	2	4
24	442,350	649,000	997,500	436,160	605,000	535,500	523,330	570,000	535,500	411,680	585,000	950,000	405,490	541,000	510,000	492,660	506,000	510,000	1	3
25	1,003,060	1,136,000	2,415,000	990,170	1,081,000	1,375,500	1,204,360	1,026,000	1,375,500	955,390	1,060,000	2,300,000	942,500	1,005,000	1,310,000	1,156,690	950,000	1,310,000	1	3
26	229,600	221,000	219,440	226,100	235,000	219,440	233,600	217,000	141,440	216,270	210,000	211,000	212,770	224,000	211,000	220,270	206,000	136,000	2	6
27	292,370	313,000	369,200	287,730	320,000	369,200	344,980	300,000	260,000	278,070	285,000	355,000	273,430	292,000	355,000	330,680	272,000	250,000	2	6
28	452,920	490,000	728,000	452,920	515,000	728,000	543,230	452,000	530,400	435,850	460,000	700,000	435,850	485,000	700,000	526,160	422,000	510,000	2	6
29	354,600	155,000	561,750	246,100	139,000	246,750	253,600	130,000	246,750	327,930	135,000	535,000	219,430	119,000	235,000	226,930	110,000	235,000	1	3
30	549,350	574,000	1,459,500	541,710	546,000	882,000	804,950	509,000	882,000	514,720	510,000	1,390,000	507,080	482,000	840,000	770,320	445,000	840,000	1	3
31	1,102,790	1,076,000	3,255,000	1,092,380	1,131,000	1,995,000	1,327,900	981,000	1,995,000	1,051,620	1,000,000	3,100,000	1,041,210	955,000	1,900,000	1,276,730	905,000	1,900,000	1	3
32	51,300	54,400	137,020	38,500	50,300	89,780	38,500	48,700	89,780	51,050	49,900	130,500	38,250	45,800	85,500	38,250	44,200	85,500	2	4
33	135,400	99,800	370,650	86,000	89,000	207,900	89,900	81,200	207,900	127,400	93,800	353,000	78,000	83,000	198,000	81,900	76,200	198,000	2	4
34	279,400	221,000	260,000	274,400	229,000	260,000	284,400	205,000	176,800	266,070	210,000	250,000	261,070	218,000	250,000	271,070	194,000	170,000	2	6
35	550,900	245,000	1,000,650	334,900	238,000	486,150	347,900	231,000	486,150	540,150	227,000	953,000	324,150	220,000	463,000	337,150	213,000	463,000	2	4
36	305,060	373,000	499,200	298,870	388,000	499,200	360,710*	350,000	322,400	290,560	345,000	480,000	284,370	360,000	480,000	346,210*	322,000	310,000	2	6
37	480,910	510,000	1,031,680	478,900	530,000	1,031,680	580,520	481,000	719,680	463,340	480,000	992,000	461,330	500,000	992,000	562,950	451,000	692,000	2	6
38	249,950	288,000	551,200	246,000	313,000	551,200	254,000	279,000	322,400	235,650	277,000	530,000	231,670	302,000	530,000	239,670	268,000	310,000	2	6
39	311,400	363,000	889,200	305,940	372,000	889,200	367,100	350,000	556,400	296,330	335,000	855,000	291,370	344,000	855,000	352,530	322,000	535,000	2	6
40	492,980	560,000	1,643,200	494,530	570,000	1,643,200	585,890	520,000	1,071,200	475,350	530,000	1,580,000	476,900	540,000	1,580,000	568,260	490,000	1,030,000	2	6
41	66,500	61,200	202,120	49,000	53,900	123,380	49,000	52,800	123,380	66,250	56,700	192,500	48,750	49,400	117,500	48,750	48,300	117,500	2	4
42	182,850	128,400	537,600	120,550	113,000	290,850	124,850	108,500	290,850	173,480	122,400	512,000	111,180	107,000	277,000	115,480	102,500	277,000	2	4
43	527,450	268,000	1,359,750	350,200	255,000	598,500	361,450	248,000	598,500	516,080	250,000	1,295,000	338,950	237,000	570,000	350,080	230,000	570,000	2	4

*It appears that the $388,960 in A.C. Table 4 should be $338,960

TABLE 3

DATA FURNISHED AND CONTRACTOR'S DESIGNATION

Pump No.	Pump						Motor			Contractor's No.		
	H (ft)	Q (gpm)	Service	SP.GR.	T(°F)	Suc. Pres (psia)	Type	Volts	Cooling	A.C.	D.J.	W.
1	40	47,000	Brine	1.05	146	3.4	Ind.	4,160	Air	1	6-1	42HF
2	40	63,000	Brine	1.02	200	11.4	Ind.	4,160	Air	2	5-1	54HF
3	40	100,000	Brine	1.05	146	3.4	Ind.	4,160	Air	3	6-3	60HF
4	40	125,000	Brine	1.02	200	11.4	Ind.	4,160	Air	4	5-3	72HF
5	40	175,000	Brine	1.05	146	3.4	Ind.	4,160	Air	5	6-5	84HF
6	45	25,000	Brine	1.058	90	1.5	Ind.	4,160	Air	6	3-1	30HF
7	45	75,000	Brine	1.058	90	1.5	Ind.	4,160	Air	7	3-2	54HF
8	45	150,000	Brine	1.058	90	1.5	Ind.	4,160	Air	8	3-3	78HF
9	50	125,000	Sea W	1.02	65	14.7	Syn.	13,800	Air	9	1-1	60MC1
10	50	350,000	Sea W	1.02	65	14.7	Syn.	13,800	Water	10	1-4	96MC1
11	50	800,000	Sea W	1.02	65	14.7	Syn.	13,800	Water	11	1-7	144MC1
12	65	47,000	Brine	1.05	146	3.4	Ind.	4,160	Air	12	6-2	42HF
13	65	100,000	Brine	1.05	146	3.4	Ind.	4,160	Air	13	6-4	60HF
14	65	175,000	Brine	1.05	146	3.4	Ind.	4,160	Air	14	6-6	84HF
15	70	20,000	Dist.	0.995	87	1.5	Ind.	4,160	Air	15	3-4	30HF
16	70	50,000	Dist.	0.995	89	1.5	Ind.	4,160	Air	16	3-5	42HF
17	70	100,000	Dist.	0.995	87	1.5	Ind.	4,160	Air	17	3-6	60HF
18	90	63,000	Brine	1.02	200	11.4	Ind.	4,160	Air	18	5-2	54HF
19	90	125,000	Brine	1.02	200	11.4	Ind.	4,160	Air	19	5-4	72HF
20	100	25,000	Sea W	1.013	110	18.0	Ind.	4,160	Air	20	4-1	24MC1
21	100	50,000	Sea W	1.013	110	18.0	Ind.	4,160	Air	21	4-4	36MC1
22	100	125,000	Sea W	1.02	65	14.7	Syn.	13,800	Air	22	1-2	60MC1
23	100	150,000	Sea W	1.013	110	18.0	Ind.	4,160	Air	23	4-7	60MC1
24	100	350,000	Sea W	1.02	65	14.7	Syn.	13,800	Water	24	1-5	96MC1
25	100	800,000	Sea W	1.02	65	14.7	Syn.	13,800	Water	25	1-8	144MC1
26	145	125,000	Brine	1.052	90	1.5	Syn.	13,800	Water	26	2-1	66HF
27	145	200,000	Brine	1.052	90	1.5	Syn.	13,800	Water	27	2-4	84HF
28	145	350,000	Brine	1.052	90	1.5	Syn.	13,800	Water	28	2-7	114HF
29	150	125,000	Sea W	1.02	65	14.7	Syn	13,800	Water	29	1-3	54NA77
30	150	350,000	Sea W	1.02	65	14.7	Syn.	13,800	Water	30	1-6	84NA128
31	150	800,000	Sea W	1.02	65	14.7	Syn.	13,800	Water	31	1-9	120NA184
32	200	25,000	Sea W	1.013	110	18.0	Ind.	4,160	Air	32	4-2	24FA2
33	200	50,000	Sea W	1.013	110	18.0	Ind.	4,160	Air	33	4-5	36FA2
34	200	125,000	Brine	1.052	90	1.5	Syn.	13,800	Water	34	2-2	66HF
35	200	150,000	Sea W	1.013	110	18.0	Ind.	4,160	Water	35	4-8	54FA2
36	200	200,000	Brine	1.052	90	1.5	Syn.	13,800	Water	36	2-5	84HF
37	200	350,000	Brine	1.052	90	1.5	Syn.	13,800	Water	37	2-8	114HF
38	250	125,000	Brine	1.052	90	1.5	Syn.	13,800	Water	38	2-3	72HF
39	250	200,000	Brine	1.052	90	1.5	Syn.	13,800	Water	39	2-6	90HF
40	250	350,000	Brine	1.052	90	1.5	Syn.	13,800	Water	40	2-9	120HF
41	400	25,000	Sea W	1.013	110	18.0	Ind.	4,160	Air	41	4-3	24NA54
42	400	50,000	Sea W	1.013	110	18.0	Ind.	4,160	Water	42	4-6	36NA65
43	400	150,000	Sea W	1.013	110	18.0	Ind.	4,160	Water	43	4-9	54NA112

TABLE 4

PUMP SELECTIONS BY CONTRACTORS

Pump No.	Type			Number of stages			Speed (RPM)			Size in/out (INS.)		
	A.C.	B.J.	W.	A.C.	B.J.	W.	A.C.	B.J.	W.	A.C.	B.J.	W.
1	VCC	VTD	VTW	1	1	1	440	392	445	42/42	54/50	54/42
2	VCC	VTD	VTW	1	1	1	391	353	395	48/48	66/60	63/54
3	VCC	VTD	VTW	1	1	1	319	320	322	54/54	84/72	78/60
4	VCF	VTD	VTW	1	1	1	289	294	295	60/60	90/78	87/72
5	VCF	VCC	VTW	1	1	1	250	168	245	72/72	88.25/945	102/84
6	VCC	VTW	VTW	1	1	1	584	504	705	30/30	56.5/36	38/30
7	VCC	VTD	VTW	1	1	1	390	392	345	48/48	72/66	64/54
8	VCF	VCF	VTW	1	1	1	270	196	272	72/72	79.25/87.5	96/78
9	VCF	VTW	VCC	1	1	1	300	300	300	60/60	109/84	60/60
10	VCF	VCF	VCC	1	1	1	180	144	180	108/108	118/131/5	96/96
11	VCF	VCF	VCC	1	1	1	120	95	120	154/154	179/196	144/144
12	VCC	VTD	VTW	1	1	1	507	392	505	42/42	54/48	54/42
13	VCC	VTD	VTW	1	1	1	349	320	355	54/54	84/72	78/60
14	VCF	VCC	VTW	1	1	1	270	235	272	72/72	78/86.5	102/84
15	VCC	VTW	VTW	1	1	1	709	588	705	24/24	44.5/32	36/30
16	VCC	VTD	VTW	1	1	1	508	446	505	42/42	60/50	52/42
17	VCC	VTD	VTW	1	1	1	350	353	355	54/54	84/72	78/60
18	VCC	VTD	VTW	1	1	2	391	353	395	48/30	66/54	63/54
19	VCC	VTD	VTW	1	1	2	292	294	295	60/54	90/78	87/72
20	VCC	VTW	VCC	1	1	1	709	705	705	30/24	46.5/34	24/24
21	VCC	VTD	VCC	1	1	1	504	504	505	42/30	60/50	36/36
22	VCC	VTW	VCC	1	1	1	327	327	327	60/54	104/78	60/60
23	VCC	VCF	VCC	1	1	1	293	294	295	72/54	64.75/70	60/60
24	VCF	VCF	VCC	1	1	1	200	200	200	108/84	99/106.5	96/96
25	VCF	VCF	VCC	1	1	1	129	90.5	133	162/121	150/159	144/144
26	VCC	VTW	VTW	1	2	2	327	327	300	60/54	112.5/78	88/66
27	VCF	VCF	VTW	1	1	2	257	257	240	72/60	71/70	111/84
28	VCF	VCF	VTW	1	1	2	200	200	180	108/84	93.5/91	147/114
29	VCC	VTW	VCC	1	1	1	327	327	327	60/54	94/72	60/54
30	VCF	VCF	VCC	1	1	1	200	200	200	108/84	92.75/90	96/84
31	VCF	VCF	VCC	1	1	1	138	138	133	162/121	140/134	144/120
32	HZS	VTW	VCC	1	2	1	708	705	705	30/24	46.5/34	30/24
33	VCC	VTD	VCC	1	2	1	503	504	505	42/30	60/50	42/36
34	VCC	VTW	VTW	1	2	3	360	257	300	60/54	104/72	88/66
35	VCC	VCF	VCC	1	1	1	327	327	322	72/54	56.5/56	60/54
36	VCF	VCF	VTW	1	1	3	277	257	240	72/60	70.25/65	111/84
37	VCF	VCF	VTW	1	1	3	212	200	180	108/84	86.5/83.75	147/114
38	VCC	VTW	VTW	1	3	4	360	257	300	60/54	113/72	84/72
39	VCF	VCF	VTW	1	1	4	300	257	240	72/60	66.5/63	108/90
40	VCF	VCF	VTW	1	1	4	225	200	190	108/84	88/78.75	144/120
41	HZS	VTW	VCC	1	3	1	891	705	705	36/24	45/32	30/24
42	VCC	VTD	VCC	1	3	1	600	514	585	42/30	60/48	42/36
43	VCC	VCF	VCC	1	1	1	360	360	322	72/54	51.25/46.5	60/54

VCF = Vertical Centrifugal-fabricated
VCC = Vertical centrifugal-cast
VTW = Vertical turbine-wet pit
VTD = Vertical trubine-dry pit
HZS = Horizontal double suction

SETTING REQUIREMENTS

Pump No.	Specific Speed A.C.	Specific Speed B.J.	Specific Speed W.	NPSH Required (ft) A.C.	NPSH Required (ft) B.J.	NPSH Required (ft) W.	Sigma A.C.	Sigma B.J.	Sigma W.	Suc. Cond. (Psia) Pa	Suc. Cond. (Psia) Pv	℄ Impeller Below W.S.(Hs) (ft) A.C.	℄ Impeller Below W.S.(Hs) (ft) B.J.	℄ Impeller Below W.S.(Hs) (ft) W.
1	6,000	5,346	6,066	30	25.4	27.505	0.750	0.635	0.688	3.4	3.17	29.495	24.895	27
2	6,160	5,570	6,234	30	27.0	27.927	.750	.675	.698	11.4	10.99	29.073	26.073	27
3	6,340	6,370	6,402	30	32.1	28.005	.750	.802	.700	3.4	3.17	29.495	31.595	27.5
4	6,430	6,540	6,698	30	33.5	29.927	.750	.838	.748	11.4	10.99	29.073	32.573	29
5	6,570	4,420	6,444	30	18.2	29.505	.750	.455	.738	3.4	3.17	29.495	17.695	29
6	5,320	4,590	6,416	25	23.5	33.831	.556	.522	.752	1.5	0.66	23.169	21.669	32
7	6,140	6,180	5,438	30	35.0	32.831	.667	.778	.730	1.5	0.66	28.169	33.169	31
8	6,030	4,550	6,063	25	20.2	31.831	.556	.449	.707	1.5	0.66	23.169	18.369	30
9	5,640	5,640	5,641	30	34.3	32.000	.600	.686	.640	14.7	0.30	-2.565	1.735	-0.565
10	5,680	4,550	5,663	30	23.6	32.000	.600	.472	.640	14.7	0.30	-2.565	-8.965	-0.565
11	5,680	4,510	5,708	30	23.3	32.000	.600	.466	.640	14.7	0.30	-2.565	-9.265	-0.565
12	4,810	3,710	4,783	32	25.4	31.005	.490	.391	.477	3.4	3.17	31.495	24.895	30.5
13	4,820	4,420	4,904	30	32.1	32.505	.460	.494	.500	3.4	3.17	29.495	31.595	32
14	4,930	4,300	4,989	20.5	28.5	33.005	.315	.438	.508	3.4	3.17	22.095	27.995	32.5
15	4,150	3,450	4,120	30	24.8	28.994	.429	.354	.414	1.5	0.64	28.006	22.806	27
16	4,710	4,070	4,666	32	30.5	33.994	.457	.436	.489	1.5	0.64	30.006	28.506	32
17	4,570	4,610	4,639	30	36.8	33.994	.429	.526	.485	1.5	0.64	28.006	34.806	32
18	3,360	3,030	5,706	30	27.0	27.927	.333	.300	.620	11.4	10.99	29.073	26.073	27
19	3,535	3,560	6,003	32	33.5	29.927	.356	.372	.665	11.4	10.99	31.073	32.573	29
20	3,540	3,520	3,525	32	36.8	32.000	.320	.368	.320	18.0	1.26	-6.119	-1.319	-6.119
21	3,565	3,560	3,571	32	37.0	32.000	.320	.370	.320	18.0	1.26	-6.119	-1.119	-6.119
22	3,660	3,660	3,656	32	38.5	32.000	.320	.385	.320	14.7	0.30	-0.565	5.935	-0.565
23	3,590	3,600	3,613	32	34.5	32.000	.320	.345	.320	18.0	1.26	-6.119	-3.619	-6.119
24	3,730	3,740	3,742	32	36.4	32.000	.320	.364	.320	14.7	0.30	-0.565	3.835	-0.565
25	3,650	3,770	3,762	32	36.8	32.000	.320	.368	.320	14.7	0.30	-0.565	4.235	-0.565
26	2,770	3,660	4,269	35	28.0	31.820	.241	.396	.439	1.5	0.67	33.180	26.180	30
27	2,960	2,750	4,320	26.2	35.0	31.820	.181	.241	.439	1.5	0.67	24.380	33.180	30
28	2,830	3,000	4,286	25	39.7	31.820	.172	.274	.439	1.5	0.67	26.080	37.880	30
29	2,700	2,700	2,697	35	38.5	32.000	.233	.257	.213	14.7	0.30	2.435	5.935	-0.565
30	2,760	2,930	2,761	24.5	39.3	32.000	.163	.262	.213	14.7	0.30	-5.165	6.735	-0.565
31	2,880	2,890	2,775	27.5	38.7	32.000	.183	.258	.213	14.7	0.30	-0.865	6.135	-0.565
32	2,110	3,520	2,096	25	36.8	32.000	.125	.368	.160	18.0	1.26	-13.119	-1.319	-6.119
33	2,115	3,560	2,123	32	37.0	32.000	.160	.370	.160	18.0	1.26	-6.119	-1.119	-6.119
34	2,390	2,870	4,546	36	28.0	31.820	.180	.280	.477	1.5	0.67	36.140	26.180	30
35	2,380	2,380	2,345	36	40.0	32.000	.180	.200	.160	18.0	1.26	-2.119	1.881	-6.119
36	2,330	2,160	4,600	27.5	35.0	31.820	.138	.175	.477	1.5	0.67	25.980	33.180	30
37	2,230	2,360	4,564	25.5	39.7	31.820	.128	.198	.477	1.5	0.67	26.680	37.880	30
38	2,020	3,300	4,772	38	28.0	31.820	.152	.336	.509	1.5	0.67	36.180	26.180	30
39	2,130	1,828	4,828	38	35.0	31.820	.152	.140	.509	1.5	0.67	36.180	33.180	30
40	2,110	1,994	5,057	38	39.7	33.820	.152	.159	.541	1.5	0.67	36.180	37.880	32
41	1,575	2,840	1,246	27	36.8	32.000	.068	.276	.080	18.0	1.26	-11.119	-1.319	-6.119
42	1,500	2,930	1,462	34	38.0	32.000	.085	.285	.080	18.0	1.26	-4.119	-0.119	-6.119
43	1,559	1,560	1,394	34	45.2	32.000	.085	.113	.080	18.0	1.26	-4.119	7.081	-6.119

MOTOR CAPACITIES, WEIGHTS, & COSTS

Pump No.	Rated Horsepower			Est. Motor Cost ($)				A.C. Weights (lbs.)			B.J. (lbs.) Wt
	A.C.	B.J.	W.	A.C.	Add'tl*	B.J.	W.	Stator	Rotor	Total	Motor
1	600	600	600	19,590		$ 25,500	27,500	3,700	6,100	11,900	12,200
2	900	800	800	28,970		33,000	45,000	4,900	6,500	15,000	13,000
3	1,500	1,250	1,250	46,690		49,000	55,000	8,700	11,800	29,300	80,000
4	1,750	1,500	1,500	55,300		59,000	73,000	10,600	10,500	26,000	85,000
5	2,500	2,000	2,250	77,130		111,000	91,000	13,500	18,300	41,500	120,000
6	350	350	350	8,020		19,000	12,500	2,050	3,050	7,000	5,800
7	1,250	1,000	1,250	37,170		37,000	45,000	8,200	8,200	21,500	12,500
8	2,250	2,000	2,250	69,110		100,000	82,000	12,000	16,600	38,300	90,000
9	2,000	2,000	2,000	68,210	5,700	60,000	82,000	21,000	12,000	42,000	50,000
10	6,000	5,500	5,500	202,660	17,570	216,000	205,000	99,000	36,000	205,000	150,000
11	13,000	12,000	12,000	442,210	40,750	480,000	450,000	135,000	72,000	280,000	350,000
12	1,000	600	1,000	25,860		38,000	35,500	3,900	6,650	12,500	11,400
13	2,000	2,000	2,250	56,830		69,000	77,000	10,600	10,500	26,000	85,000
14	2,500	3,500	3,500	96,840		135,000	136,000	20,200	14,500	50,800	120,000
15	450	450	450	9,700		12,000	14,800	2,100	3,100	7,100	5,400
16	1,250	1,000	1,250	30,970		35,000	35,500	4,100	7,200	13,400	12,000
17	2,250	2,000	2,250	61,710		67,000	77,000	9,700	13,000	31,500	80,000
18	1,750	1,750	1,750	48,420		61,000	73,000	9,800	9,700	24,500	80,000
19	3,500	3,500	3,500	94,840		113,000	132,500	13,500	18,300	41,500	120,000
20	800	800	800	15,450		16,300	20,000	2,550	4,000	8,450	6,300
21	1,500	1,500	1,500	34,960		43,000	48,500	5,600	7,100	16,500	13,400
22	4,000	4,000	4,000	94,980		89,000	138,000	34,000	15,000	72,000	70,000
23	4,500	4,000	4,500	118,020		103,000	138,000	21,200	15,500	52,800	130,000
24	10,000	10,000	10,000	261,670	6,410	293,000	350,000	113,000	41,000	240,000	200,000
25	25,000	22,500	25,000	679,900	17,110	720,000	740,000	220,000	92,000	400,000	350,000
26	5,500	5,500	6,000	131,940	1,810	161,000	174,000	37,000	17,000	80,000	110,000
27	9,000	9,000	9,000	218,350	11,330	224,000	265,000	63,000	40,000	130,000	110,000
28	15,000	15,000	16,000	378,460	20,090	390,000	460,000	92,000	50,000	210,000	275,000
29	5,500	5,500	5,500	131,940	1,810	152,000	165,000	37,000	17,000	80,000	80,000
30	16,000	15,000	15,000	396,730	21,290	380,000	460,000	97,000	53,000	220,000	275,000
31	35,000	35,000	35,000	907,780	49,010	950,000	1,000,000	270,000	100,000	430,000	400,000
32	1,500	1,500	1,500	21,040		28,500	34,500	3,700	4,500	10,000	88,000
33	3,000	3,000	3,000	63,180		75,000	102,000	9,000	11,100	25,000	20,000
34	8,000	8,000	8,000	767,050		208,000	205,000	42,000	20,000	90,000	110,000
35	9,000	9,000	9,000	203,550	18,330	193,000	297,000	50,000	23,000	105,000	110,000
36	12,000	12,000	13,000	255,960	6,350	280,000	340,000	97,000	53,000	220,000	110,000
37	22,500	20,000	22,500	522,240	13,160	514,000	628,000	115,000	75,000	250,000	350,000
38	10,000	10,000	10,000	200,330		247,000	245,000	50,000	23,000	108,000	110,000
39	15,000	15,000	16,000	315,640	18,190	343,000	395,000	100,000	48,000	190,000	110,000
40	27,500	25,000	27,500	606,830	18,380	635,000	720,000	120,000	78,000	260,000	350,000
41	3,500	3,000	3,000	38,990		52,000	57,500	6,700	16,000	26,000	20,000
42	6,000	6,000	6,000	117,390		135,000	163,000	30,000	20,000	72,000	120,000
43	18,000	18,000	18,000	336,680		356,000	555,000	70,000	50,000	150,000	110,000

*Include additional for high starting torque

TABLE 7

PUMP MATERIALS

Pump No.	Requirements Alt. 1	Requirements Alt. 2	Contractors' Alternate A.C.	Contractors' Alternate B.J.	Contractors' Alternate W.	Contractors' Recommendation A.C.	Contractors' Recommendation B.J.	Contractors' Recommendation W.
1	NR/M/NR	NR/NAB/NR	NR/SS/	NR/SS/SS	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
2	NR/M/NR	NR/ NAB/NR	NR/SS/	NR/SS/SS	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
3	NR/M/NR	NR/NAB/NR	NR/SS/	NR/SS/SS	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
4	NR/M/NR*	NR/NAB/NR*	NC/SS/NE	NR/SS/SS	NR/SS/SE	NC/SS/NC	NR/SS/SS	NR/SS/NR
5	NR/M/NR*	NR/NAB/NR*	NC/SS/NC	NR/SS/SS	NR/SS/SE	NC/SS/NC	NR/SS/SS	NR/SS/NR
6	NR/SS/NR	NR/NAB/NR	NR/SS/	NR/SS/SF	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
7	NR/SS/NR	NR/NAB/NR	NR/SS/	NR/SS/SF	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
8	NR/SS/NR*	NR/NAB/NR*	NC/SS/NC	SF/SS/SS	NR/SS/SE	NC/SS/NC	SS/SS/SS	NR/SS/NR
9	SS/SS/SS	NR/SS/NR	NC/SS/NC	NR/SS/SF	NCI/TB/	NC/SS/NC	NR/SS/SF	NCI/TB
10	SS/SS/SS	NR/SS/NR	NC/SS/NC	SF/SS/SS	NCI/TB/	NC/SS/NC	SF/SS/SS	NCI/TB/
11	SS/SS/SS	NR/SS/NR	NC/SS/NC	SF/SS/SS	NCI/TB/	NC/SS/NC	SF/SS/SS	NCI/TB/
12	NR/M/NR	NR/NAB/NR	NR/SS/	NR/SS/SS	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
13	NR/M/NR	NR/NAB/NR	NR/SS/	NR/SS/SS	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
14	NR/M/NR*	NR/NAB/NR*	NC/SS/NC	NR/SS/SS	NR/SS/SE	NC/SS/NC	NR/SS/SS	NR/SS/NR
15	-	-	SS/SS/	CI/B/S	CI/TB/S	SS/SS/	CI/B/S	CI/TB/S
16	-	-	SS/SS/	CI/B/S	CI/TB/S	SS/SS/	CI/B/S	CI/TB/S
17	-	-	SS/SS/	CI/B/S	CI/TB/S	SS/SS/	CI/B/S	CI/TB/S
18	NR/M/NR	NR/NAB/NR	NR/SS/	NR/SS/SS	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
19	NR/M/NR	NR/NAB/NR	NR/SS/	NR/SS/SS	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
20	SS/SS/SS	NR/SS/NR	NR/SS/	NR/SS/SF	NR/SS/	NR/SS/	NR/SS/SF	NR/SS/
21	SS/SS/SS	NR/SS/NR	NR/SS/	NR/SS/SF	NR/SS/	NR/SS/	NR/SS/SF	NR/SS/
22	SS/SS/SS	NR/SS/NR	NR/SS/	NR/SS/SF	NR/SS/	NR/SS/	NR/SS/SF	NR/SS/
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24	SS/SS/SS	NR/SS/NR	NC/SS/NC	SF/SS/SS	NR/SS/	NC/SS/NC	SF/SS/SS	NR/SS/
25	SS/SS/SS	NR/SS/NR	NC/SS/NC	SF/SS/SS	NR/SS/	NC/SS/NC	SF/SS/SS	NR/SS/
26	NR/SS/NR	NR/NAB/NR	NR/SS/	NR/SS/SF	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
27	NR/SS/NR*	NR/NAB/NR*	NC/SS/NC	SF/SS/SS	NR/SS/SE	NC/SS/NC	SS/SS/SS	NR/SS/NR
28	NR/SS/NR*	NR/NAB/NR*	NC/SS/NC	SF/SS/SS	NR/SS/SE	NC/SS/NC	SS/SS/SS	NR/SS/NR
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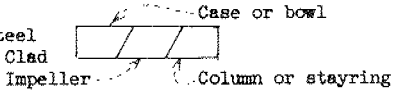
30	SS/SS/SS	NR/SS/NR	NC/SS/NC	SF/SS/SS	NR/SS/	NC/SS/NC	SF/SS/SS	NR/SS/
31	SS/SS/SS	NR/SS/NR	AC/SS/NC	SF/SS/SS	NR/SS/	NC/SS/NC	SF/SS/SS	NR/SS/
32	SS/SS/SS	NR/SS/NR	NR/SS/	NR/SS/SF	NR/SS/	NR/SS/	NR/SS/SF	NR/SS/
33	SS/SS/SS	NR/SS/NR	NR/SS/	NR/SS/SF	NR/SS/	NR/SS/	NR/SS/SF	NR/SS/
34	NR/SS/NR	NR/NAB/NR	NR/SS/	NR/SS/SF	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
35	SS/SS/SS	NR/SS/NR	NR/SS/	SF/SS/SS	NR/SS/	NR/SS/	SF/SS/SS	NR/SS/
36	NR/SS/NR*	NR/NAB/NR*	NC/SS/NC	SF/SS/SS	NR/SS/SE	NC/SS/NC	SS/SS/SS	NR/SS/NR
37	NR/SS/NR*	NR/NAB/NR*	NC/SS/NC	SF/SS/SS	NR/SS/SE	NC/SS/NC	SS/SS/SS	NR/SS/NR
38	NR/SS/NR	NR/NAB/NR	NR/SS/	NR/SS/SS	NR/SS/SE	NR/SS/	NR/SS/SS	NR/SS/NR
39	NR/SS/NR*	NR/NAB/NR*	NC/SS/NC	SF/SS/SS	NR/SS/SE	NC/SS/NC	SS/SS/SS	NR/SS/NR
40	NR/SS/NR*	NR/NAB/NR*	NC/SS/NC	SF/SS/SS	NR/SS/SE	NC/SS/NC	SS/SS/SS	NR/SS/NR
41	SS/SS/SS	NR/SS/NR	NR/SS/	NR/SS/SF	NR/SS/	NR/SS/	NR/SS/SF	NR/SS/
42	SS/SS/SS	NR/SS/NR	NR/SS/	NR/SS/SF	NR/SS/	NR/SS/	NR/SS/SF	NR/SS/
43	SS/SS/SS	NR/SS/NR	NR/SS/	SF/SS/SS	NR/SS/	NR/SS/	SF/SS/SS	NR/SS/

B = Bronze
CI = Cast Iron
M = Monel
NAB = Ni-Al-Bronze
NC = Ni-Copper

NCI = Ni-Cast Iron
NR = Ni-Resist
S = Steel
SS = Stainless Steel
SE = Steel Epoxy Clad

SF = Steel Fiberglass Clad
TB = Tin Bronze



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