PUMP SELECTION METHOD OF SOLUTION

PIPE-FLO's pump selection module selects and evaluates centrifugal pumps. Centrifugal is a broad classification of pumps which use kinetic energy to move the fluid. They use the centrifugal force of a rotating impeller to impart kinetic energy to the fluid (as opposed to jet pumps and eductors).

The *Hydraulic Institute Standards* (Reference 1) is the basis for the pump selection module. The Hydraulic Institute is composed of organizations and individuals who manufacture and sell pumps in the open market. When there is a discrepancy between the current revision of the *Hydraulic Institute Standards* and the program method of solution, the Standards take precedence.

PIPE-FLO selects pumps from a pump catalog and evaluates their operation in an application. Within the range of the manufacturer's recommendations, the program allows you to adjust the pump parameters and see the effect it has on the pump operation.

Definitions

The definitions that follow are found in Reference 1 and are used in this method of solution.

Head The quantity used to express a form (or combination of forms) of the energy content of the liquid, per unit weight of the liquid, referred to any arbitrary datum. All head quantities are in terms of foot-pounds of energy per pound of liquid, or feet of liquid.

Flow The unit of flow rate in the United States is expressed in units of gallons per minute (gpm). The standard fluid for all pump curves is water at 60 °F.

NPSH The net positive suction head is the total suction head in feet of liquid (absolute) determined at the suction nozzle and the referred datum less the vapor pressure of the liquid in feet (absolute). NPSHa is the net positive suction head available in the pumping system. NPSHr is the net positive suction head required by the pump.

Pump Input The horsepower delivered to the pump shaft (designated as brake horsepower).

Pump Efficiency The ratio of the energy delivered by the pump to the energy supplied to the pump shaft (the ratio of the liquid horsepower to the brake horsepower).

Pump Head Curve

Pump vendors perform pump tests to determine the operating characteristics of the pumps they manufacture. The pumps are tested as outlined in Reference 1. All pump data used by the program is supplied by the pump manufacturers who are solely responsible for their content.

Pump Sizing

Each pump in the catalog can have up to ten impeller diameters or speed curves. Each curve can have up to twenty data points describing the pump operation. The data points for the curve consist of the flow rate and head, and optionally the pump's efficiency (or power) and NPSHr.

When the design point of the pump falls between a set of known curves, the program interpolates between them to arrive at a calculated curve. Often manufacturers allow impeller diameters to be adjusted only in fixed increments of their choosing. For example, a manufacturer can force the program to limit the impeller diameter increments to 0.125 inch. Or, they may not allow any trimming of the impellers.

The Affinity Laws

In hydraulically similar pumps, the head and capacity of a pump vary with the rotational speed of the impeller in such a way that the pump head curves retain their characteristic features. The variation of head, capacity, and brake horsepower follow a set of ratios that are known as the Affinity Laws. These laws are expressed in equations 1a, 1b and 1c

$$(Q_1/Q_0) = (N_1/N_0)$$

equation 1a

$$(H_1/H_0) = (N_1/N_0)^2$$

equation 1b

$$(P_1/P_0) = (N_1/N_0)^3$$

equation 1c

Q = Capacity in gpm
N = Impeller speed in rpm
H = Pump head in feet
P = Pump power in hp
Subscripts
$_0$ = Pump test speed
$_1$ = New pump speed

Multi-stage Pumps

Pumps which have multiple impeller stages are designated as multi-stage pumps. For these pump types, the single stage base impeller curves and the impeller trim increment are specified in the manufacturer's catalog along with the range of allowed impeller combinations.

During the pump selection process, PIPE-FLO determines the number of full diameter impeller stages necessary to achieve the design point. Once the number of stages has been determined, the program calculates the impeller diameter needed to go through the design point.

Adjustable Speed Pumps

Some pump manufacturers have pumps available in an Adjustable speed class. These pumps can be stored in a catalog under two different formats. Pumps that use the first format have one speed curve specified along with a maximum speed and a minimum speed. When adjustable speed pumps with this format are selected, PIPE-FLO uses the affinity laws to calculate the speed needed to pass through the specified design point. Pumps that use the second format have up to ten speed curves stored per pump. When the design point of the pump falls between a set of known speed curves, the program interpolates between them to arrive at a calculated curve.

Multiple Pump Configurations

Multiple pumps for both parallel and series configurations can be analyzed. To plot the performance curve for multiple pumps in series, PIPE-FLO multiplies the head values of the single pump curve by the number of pumps in series. The flow values for series configurations are the same as those for a single pump.

To plot the performance curve for multiple pumps in parallel, PIPE-FLO multiplies the flow rate values for a single pump by the number of pumps in parallel. The head values for parallel configurations are the same as those for a single pump.

Net Positive Suction Head

The Net Positive Suction Head (NPSH) is the value of the minimum suction head required to prevent cavitation in a pump. Cavitation is the rapid formation and collapse of vapor pockets in a flowing liquid in regions of very low pressure.

In a centrifugal pump, cavitation causes a decrease in a pump's efficiency and is capable of causing physical damage to the pump and impeller. Since cavitation has such a detrimental affect on a pump, it must be avoided at all costs. Cavitation can be avoided by keeping the NPSH available (NPSHa) greater than the NPSH required (NPSHr).

The calculated NPSHa is listed in the fly-by viewer at the bottom of the selection window. When graphing a pump, a message box is displayed if the NPSHa is less than the NPSHr for a selected pump.

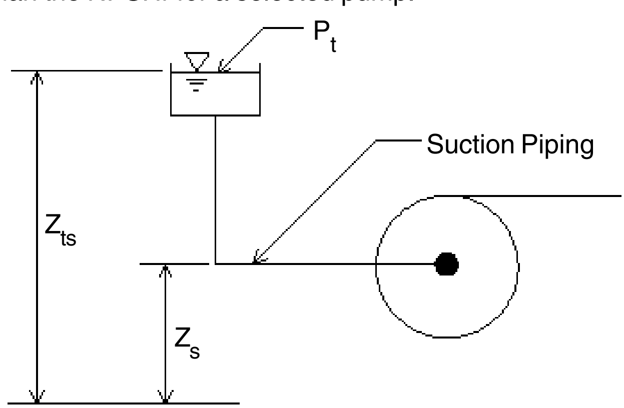

Figure 1

The formula used to calculate the NPSHa is as follows (refer to Figure 1):

$$NPSHa = ((P_t - P_{vp})/\rho) + (Z_{ts} - Z_s) - HL$$

equation 2

If calculated results are transferred to the pump selection module from a piping system model, the NPSHa is not recalculated. See Calculating NPSH Available in the PIPE-FLO Method of Solution.

P_t = absolute pressure on the free surface of the liquid in the tank connected to the pump suction
P_{vp} = pumping fluid vapor pressure in absolute pressure units at the operating temperature
ρ = fluid density
Z_{ts} = elevation of the tank surface
Z_s = elevation of the pump suction
HL = headloss due to friction in the pipeline between the tank and the pump suction.

The units of NPSH are in feet of fluid absolute.

The NPSHr for a pump is determined by the pump manufacturer and is listed in their catalog. The NPSHr values are arrived at through actual tests as outlined in Reference 1.

If the fluid is a hydrocarbon, or high temperature water, then the required NPSH of the pump may be reduced as outlined in Reference 1. Using the *NPSH Reductions for Pumps Handling Hydrocarbon Liquids and High Temperature Water* chart found in Reference 1, it is possible to reduce the NPSHr values specified by the vendor without causing cavitation.

PIPE-FLO does not perform the NPSH reduction calculations. If based on your experience you can reduce the NPSH requirements of the pump, the reduction value should be subtracted from the value presented by PIPE-FLO's pump selection module. Always check with your pump supplier when adjusting the NPSH requirements.

Temperature Variations

Variations in the temperature of the fluid being pumped cause changes in the fluid density. Any reduction in the fluid density results in a reduction of the liquid horsepower, along with a proportional reduction to the input power. As a result, there is little or no change in the pump's efficiency.

Viscosity Variations with Hot Water

The viscosity of a fluid has the greatest impact on the pump curves. Variations in fluid viscosity also have an influence on the pump's efficiency. The changes in efficiency are due to:

- Internal leakage losses within the pump
- Disc friction losses
- Hydraulic skin friction losses

When pumping hot water in circulating pumps, Reference 1 allows vendors to adjust the performance data of their pump using an empirical formula. PIPE-FLO, however, does not perform the efficiency variation corrections for circulating hot water.

Viscosity Variations with Viscous Fluids

The viscosity of oils and other viscous fluids (as compared to water) has a more pronounced impact on the operating conditions of the pump. Pumps that are tested with water but are used to transport viscous fluids must have their head, flow, and efficiency values corrected to approximate their performance with the viscous fluid.

Figures 71 and 72 from Reference 1 contain Performance Correction Charts for Viscous Liquids that were developed by utilizing data from a series of tests using conventional, single stage pumps. The tests were performed with a wide range of pumps and petroleum oils. The curves are based on empirical data from the tests.

The correction values shown in Figure 71 are averaged from tests that utilized pumps with impeller sizes of 1 inch and below. This chart is used when the flow rate at best efficiency is less than 100 gpm. The correction values shown in Figure 72 are averaged from tests that utilized pumps with impeller sizes ranging from 2 to 8 inches. This chart is used when the flow rate at best efficiency is greater than 100 gpm. Reference 1 cautions the user not to extrapolate outside the range of the published curves. The correction factors are based on purely empirical data and if it is important to have accurate pump data for the working fluid, the pump should be tested under the expected operating conditions.

The reason PIPE-FLO employs correction factors for pumping viscous fluids is that they are universally accepted by both pump vendors and users alike. When the fluid being pumped has a viscosity of 4.3 centistokes or greater, PIPE-FLO automatically performs the corrections to the pump performance data found in the pump catalog. It determines which correction factors to use for each pump from the flow rate at the best efficiency point (BEP) of the highest impeller diameter curve. If the BEP flow rate is less than 100 gpm, the correction factors corresponding to Figure 71 are used. If the BEP flow rate is greater than 100 gpm, the correction factors corresponding to Figure 72 are used.

NOTE: If a pump has power data stored in the catalog instead of efficiency data, PIPE-FLO calculates the BEP by converting the power data to efficiency data. This conversion is only performed if the pump manufacturer has specified that option for their catalog. If the manufacturer elects not to convert the catalog power data, or if it the catalog has no efficiency data, the pump performance cannot be corrected for viscosity.

Since there are no formulas available for the viscosity correction factors presented in Reference 1, PIPE-FLO uses a set of equations that are derived from the nomographs (Figures 71 and 72) to calculate the factors. These correction factors are a function of the pump capacity, the head of the first stage impeller, and the viscosity of the pumping fluid. Using the basic equation shown below (Equation 3), a correction coefficient designated as CC is produced. The slopes of the lines in the nomograph provide the exponents for the variables in this equation. This correction coefficient is used in equations 4, 5, 6, 7, 8, and 9a through 9d for the capacity, efficiency, and head correction factors. A CC correction coefficient is calculated for each impeller trim using its BEP flow rate and head. For example, a pump with ten impeller trims would have ten different CC correction coefficients and thus 10 sets of correction factors, one for each impeller trim.

The equations are bounded in the program to ensure that they are not extended outside the viscosity, head, and flow rate ranges specified in Reference 1. The equation bounds are shown below. If a pump has impeller trims which are outside of the equation bounds, the performance data for the pump is still corrected using the equations, but it is noted in the Graph Window and on the data sheet report that the pump is out of range.

Viscosity Correction Formulas

Correction Coefficient

$$CC = 8 * \nu^{1/2} /(H^{1/8} * Q^{1/4})$$

equation 3

$$\nu = \mu * 62.424 / \rho$$

equation 3a

ν = viscosity in centistokes
H = head in feet of fluid
Q = flow rate in gal/min
μ = viscosity in centipoise
ρ = fluid density

Formula for Pumps With BEP < 100 gpm

The range of operation for the formula for pumps with best efficiency points less than 100 gpm is as follows:

$4.3 < \nu < 2200$
$6 < H < 400$
$10 < Q < 100$

Flow

$$CQ = 1.016147 - 4.256395E\text{-}03*CC - 8.609936E\text{-}04*CC^2 + 1.866053E\text{-}05*CC^3 - 1.174946E\text{-}07*CC^4$$

equation 4

Bounds of CQ $0.10 \leq CQ \leq 1$

Efficiency

$$CE = 1.079527 - 3.413289E\text{-}02*CC - 2.747891E\text{-}04*CC^2 + 1.927002E\text{-}05*CC^3 - 1.649636E\text{-}07*CC^4$$

equation 5

Bounds of CE $0.03 \leq CE \leq 1$

Head

$$CH = 0.9724525 + 8.957773E\text{-}03*CC - 6.784939E\text{-}04*CC^2 + 1.085695E\text{-}05*CC^3 - 5.587139E\text{-}08*CC^4$$

equation 6

Bounds of CH $0.67 < CH < 1$

Formula for Pumps With BEP > 100 gpm

The range of operation for the formula for pumps with best efficiency points greater than or equal to 100 gpm is as follows:

$$4.3 < \nu < 3300$$
$$15 < H < 600$$
$$100 \leq Q < 10{,}000$$

Flow

$$CQ = 0.9949888 + 4.000308E\text{-}03*CC - 7.056285E\text{-}04*CC^2 + 8.27823E\text{-}06*CC^3$$

equation 7

Bounds of CQ $0.53 \leq CQ \leq 1$

Efficiency

$$CE = 1.03884 - 3.450184E\text{-}02*CC + 2.726508E\text{-}04*CC^2 + 5.229687E\text{-}07*CC^3$$

equation 8

Bounds of CE $0.19 \leq CE \leq 1$

Head

Head corrections factors are calculated at 60, 80, 100, and 120 percent of the best efficiency point flow rate. For flow rates at other percentages, PIPE-FLO interpolates between these calculated correction factors.

$$CH.6 = 1.003993 - 1.927655E\text{-}03*CC - 9.839067E\text{-}05*CC^2 - 1.012695E\text{-}06*CC^3$$

equation 9a

Bounds of CH.6 $0.78 \leq CH.6 \leq 1$

$$CH.8 = 1.004737 - 2.562881E\text{-}03*CC - 2.03951E\text{-}04*CC^2 + 2.132138E\text{-}06*CC^3$$

equation 9b

Bounds of CH.8 $0.72 \leq CH.8 \leq 1$

$$CH1.0 = 1.011042 - 5.992841E\text{-}03*CC - 1.053868E\text{-}04*CC^2 + 9.923402E\text{-}07*CC^3$$

equation 9c

Bounds of CH1.0 $0.68 \leq CH1.0 \leq 1$

$$CH1.2 = 1.010846 - 9.467801E\text{-}03*CC + 1.715598E\text{-}05*CC^2 - 7.677713E\text{-}07*CC^3$$

equation 9d

Bounds of CH1.2 $0.63 \leq CH1.2 \leq 1$

If, during the calculations, any of the coefficients are outside of the bounded values, the limits are used for the correction factors.

The coefficients for the correction curves were calculated using 33 data points from Figure 71 and 30 data points from Figure 72. These data points were used in a regression analysis to develop the formulas. All coefficients were calculated using the nth order regression program outlined in Reference 3.

NOTE: When selecting pumps from Sundstrand Fluid Handling Corporation's SUNFLO catalogs, PIPE-FLO uses their viscosity correction method. Contact Sundstrand if you need more information.

Hydraulic Corrections

In some cases, it may be necessary to apply correction factors to a pump's performance data. For example, with vertical turbine pumps, the performance can vary depending on the material used for the impeller. Solids in suspension also affect the operation of a pump, depending on the both the percentage and nature of the solids. The Reference 1 does not offer a recommendation for the modification of the pump data in these cases. However, through the use of hydraulic correction factors, PIPE-FLO allows for the modification of the pump data for specific pumping applications.

To adjust the pump data, the program multiplies the appropriate water pump data (head, flow rate, or NPSHr) by the corresponding hydraulic correction factors specified by the user. For the efficiency, the user can either specify a multiplication correction factor or specify a value by which to increment or decrement the efficiency.

The hydraulic correction factors are values that a user should have obtained from his or her own experience or preferably from the pump manufacturer. In the case of slurries, pump vendors should be consulted regarding the impact of solids in suspension on the operation of specific pumps.

Motor Sizing

Motor size tables used by PIPE-FLO can contain up to four different standards. Each standard can have a maximum of four enclosure types. For each standard and enclosure type, the table contains speed, frame, and motor efficiency data. When specifying the standard and enclosure type to use, the user also specifies the sizing criteria. There are three different criteria available: the power required at the design point flow rate, the maximum power required on the design curve, and the maximum power required for the maximum impeller diameter.

Based on the sizing criteria specified by the user, PIPE-FLO automatically sizes the motor for each pump that is put on the selection list. The smallest motor that meets the sizing criteria is selected. When performing operating cost analyses, the program uses the efficiency data stored in the motor size table.

Operating Cost

The operating cost is the cost of the power required to run a pump for one year. PIPE-FLO can calculate the annual operating cost for pumps running under both fixed and variable speed conditions. This cost information provides another parameter for consideration when comparing the advantages of using one pump over another. It also provides useful information for determining if the cost savings associated with operating a variable speed pump justifies the cost of the variable speed drive.

PIPE-FLO uses information from the operating load profile and the manufacturer's pump curve to calculate the operating cost. If the cost is being calculated for a variable speed drive pump, the resistance curve information is used as well. The pump and motor efficiencies are also factored into the calculation.

For a fixed speed pump, the sequence outlined below is followed for each load specified in the operating load profile.

The brake horsepower is calculated:

$$bhp = Q*TDH* \rho /(247{,}000 * eff_p)$$

equation 10

bhp = brake horsepower
Q = flow rate in gallons per minute
TDH = total dynamic head in feet
ρ = fluid density in lb/ft^3
eff_p = pump efficiency

The electrical horsepower is calculated:

$$ehp = bhp / eff_m$$

equation 11

ehp = motor electrical horsepower
eff_m = motor efficiency

The cost for the load is calculated:

$$\text{Cost/Load} = \text{ehp} * T * \text{COST}$$

equation 12

T = duration of load, hrs/yr
COST = power cost, $/kWh or $/hp hr

Once this process is completed, the total annual operating cost is determined by summing up the costs calculated for each specified load in the profile.

Calculating the cost for a variable speed pump requires two more steps for each load specified in the operating load profile. First, the speed of the pump is determined so that the pump curve intersects the primary resistance curve at the required flow rate. Next, the operating condition of the pump is determined for the required speed using the affinity laws. The procedure then follows that for the fixed speed drive as outlined above. Note that for both fixed and variable speed pumps, PIPE-FLO allows the user to adjust the motor efficiency for each load in the load profile.

References

1 Hydraulic Institute Standards for Centrifugal, Rotary & Reciprocating Pumps, 14th edition, Hydraulic Institute, 1983.

2 Pump Handbook, Igor J. Karassik, William C. Krutzsch, Warren H. Fraser, and Joseph P. Messina, editors; McGraw-Hill, Inc., 1976.

3 Science and Engineering Programs, edited by John Heilborn, McGraw-Hill, Inc., 1981.