

Pump-Fan-Compressor Sizing

Introduction

This program determines the fluid transportation characteristics of dominant pipeline process systems containing no loops. In addition, it determines the yearly operating costs and the operating point based on equipment performance data. A system curve is determined based upon pipe or duct pressure losses, fitting, and equipment pressure losses, and pressure losses (or gains) due changes in elevation on the discharge and suction sides of the pump or compressor. The system curve is plotted with the pump/compressor performance curve and the intersection gives the operating point. Differential pressure requirements, Hydraulic HP (watts), and NPSH available (pumps) are calculated based on the Bernoulli equation. By linking to Pipeline/Ductwork Sizing, Heat Exchanger Sizing, Flow Meter Sizing, and Control Valve Sizing modules, the corresponding frictional pressure drops can be imported into the Pump/Fan/Compressor Sizing module. The performance curves of the popular models of several ANSI pump manufacturers are provided with the program. Alternatively, the users may use their own pump performance data.

Energy is required to transport fluids from one location to another. This energy is required to overcome equipment/vessel pressures, gravity, and friction. Gravity and pressure can either be contributors or dissipaters of energy based on whether the fluid is flowing against or with these forces. Friction losses occur from contact of the fluid with the pipe walls or restrictions in the pipelines (equipment, control valves, flow meters, dampers, filters etc.). The suction and discharge differential pressures are determined by summing up the pressure changes due to the effects of friction and gravity in the suction and discharge segments, respectively. The system differential pressure is the difference between the discharge and suction differential pressures. This system differential pressure and the desired flow rate flow rate are used to select the pump/fan/compressor required for the service. Affinity Laws determine system head at various flow rates, impeller diameters, and speeds (head is proportional to the square of the flow rate; flow rate, speed, and head are directly proportional; and equipment energy is proportional to the cube of the flowrate).

Window Description

System Data Window

The screenshot shows a software window titled "SYSTEM DATA" with a menu bar (File, Options, Mode, Import, Help). The main area contains several input fields and a table.

SYSTEM FLOW, GPM	535	DENSITY, LBS/CU.FT.	61.30994
TEMPERATURE, DEG.F.	150	VAPOR PRESSURE, PSIA	3.722725
SOURCE ELEVATION, FT	2	DISCHARGE ELEV, FT.	20
SOURCE PRESS, PSIG	0	DISCHARGE PRESS,PSIG	7.5
SOURCE PIPE LOSS,PSI	1	DISCH. PIPE LOSS,PSI	12

EQUIPMENT ID	PSI	FLOWMETER ID	PSI	CONTROL VALVE ID	PSI
Heat Exchanger	3.4	FE-102	0.8	FCV-315	2.1
Spray Header	2.7	FE-115	0.6		
Filter	1.9				

SYSTEM DIFF. PSI: _____ HYDRAULIC HP: _____
 SYSTEM HEAD, FT: _____ NPSH AVAILABLE, FT: _____

System Description: Hot Water Spray System

Buttons: CALCULATE, PROPERTIES, CONVERT, SPECIFY

Pump Screen in the System Data Entry Mode

Flow Rate and Fluid Properties

Enter the design flow rate based on the type of flow (Liquid/Gas, Mass/Volumetric Flow) chosen in the **Options** menu. The fluid properties will already have been posted to the respective fields if they had been determined in the Properties window accessible from the SmartDraw screen. Alternatively, the user may either import a previously saved file, by clicking on the Properties button, or enter the required property data manually.

System Elevations

The elevation of the entrance of flow into the system (source elevation) and the point of exit of flow from the system (discharge elevation) need to be entered next (pump elevation is the datum or reference). The source elevation is the elevation of the lowest point on the suction side while the discharge elevation is defined as the highest operating elevation on the discharge side of the pump. If the pipeline elevation rises significantly above the highest discharge elevation, start-up problems may occur if additional head pressure is not added.

System Pressures

The source pressure is defined as the lowest operating pressure at the system source and the discharge pressure is defined as the highest operating pressure at the system discharge (the worst case from a pressure drop standpoint).

Pipe/Duct Pressure Drops

The pipe/duct total pressure drop for the source and discharge sections are entered next. By linking with the Pipeline/Ductwork Sizing program, these values may be imported into the respective fields. The imported values are added to any value already entered in the input field. Alternatively, these values can be determined separately and then added and entered in these fields.

Equipment Pressure Drops

Three columns are provided for the addition of various types of process equipment that affect the system differential pressure. Enter the item description and its pressure drop in the respective fields. Alternatively, the equipment pressure drops may be retrieved by importing the equipment file using the **Import** menu. Open any previously saved equipment file for the type selected in the import menu, and the description and pressure drop will then be displayed in the appropriate input field. Entering a negative equipment pressure drop will assign this value to the source side of the system. This is reflected in the printouts as well.

Performance Data Window

The screenshot shows a software window titled "PERFORMANCE DATA" with a menu bar (File, Options, Mode, Type, View, Help). The window contains several input fields and tables. At the top, there are fields for Rated Flow (535 GPM), Static Head (40.68021 FT), Impeller Diameter (10 IN), Hours/Yr Operation (8400), and Manufacturer/Type (GOULDS 3196). To the right, there are fields for Friction Head (51.6262 FT), Hydraulic HP (12.22376), Adjusted Diameter (10 IN), Energy Cost (.055 \$/KWH), and Model Number (3x4-13, 1780 RPM). Below these are four columns of data for different flow rates (0, 100, 200, 300, 400, 500, 600 GPM), showing Pump Head, Energy Required, and System Head. At the bottom, there are fields for Operating Flow (565.4678 GPM), Operating Head (98.76175 FT), Yearly Energy Cost (\$6517.091), and Efficiency (76.2991%). A System Description field contains "HOT WATER SPRAY SYSTEM". At the very bottom are four buttons: CALCULATE, PROPERTIES, CONVERT, and SPECIFY.

RATED FLOW, GPM	535	FRICTION HEAD, FT	51.6262
STATIC HEAD, FT	40.68021	HYDRAULIC HP	12.22376
IMPELLER DIAMETER, IN	10	ADJUSTED DIAMETER, IN	10
HOURS/YR OPERATION	8400	ENERGY COST, \$/KWH	.055
MANUFACTURER/TYPE	GOULDS 3196	MODEL NUMBER	3x4-13, 1780 RPM

FLOWRATE, GPM	PUMP HEAD, FT	ENERGY RQD, HP	SYSTEM HEAD, FT
0	118.0118	5.002011	40.68021
100	118.0118	7.000134	42.4839
200	118.0118	10.00402	47.89498
300	116.0105	12.9945	56.91345
400	112.0079	15.99839	69.5393
500	104.0026	17.99651	85.77254
600	95.99738	19.99464	105.6132

OPERATING FLOW, GPM	565.4678	YEARLY ENERGY COST, \$	6517.091
OPERATING HEAD, FT	98.76175	EFFICIENCY, %	76.2991

System Description: HOT WATER SPRAY SYSTEM

Pump Screen in the Performance Data Entry mode

Flow, Friction/Static Head, and Hydraulic HP

This data will be pasted over from the System Data Entry window if calculated in that window. The total system head consists of the friction head (pipe losses) and static head (elevation and pressure). Only the friction head will vary with the flow rate (static head is constant). The Hydraulic HP (kW) is adjusted to the operating flow and then divided by the energy required (HP or kW) to determine the pump/fan/compressor percent efficiency.

Impeller Diameter and Speed

This allows for the adjustment of the entered performance data. If the first value matches the adjusted value (or the adjusted value is zero) no adjustment to the performance data is made. Otherwise, the equipment heads/pressures, energy requirements, and performance curve will be adjusted along with the operating points based on the Affinity Laws. Significant changes to manufacturer's data should not be made without consultation. The **Type** menu for pumps allows the user to select impeller diameter or speed as the variable.

Hourly Operation and Energy Costs

Enter the approximate hourly operation per year and the local electrical energy costs to determine equipment operating costs. The unit electrical costs from the Project Financial Analysis program (Project Management) will be shown initially.

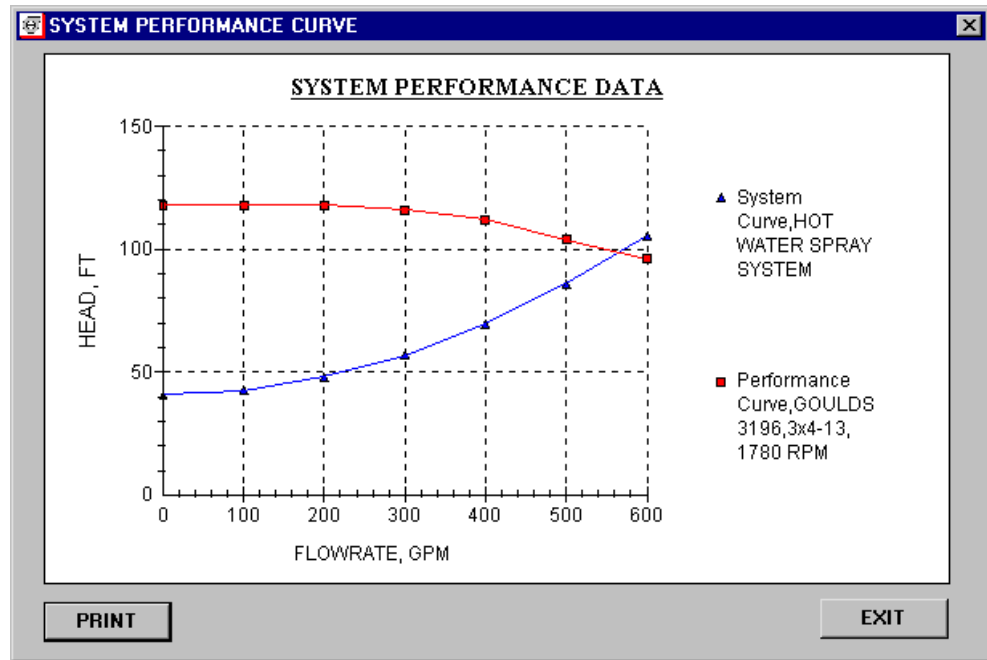
Manufacturer, Type, and Model Number

These items will appear on the System Performance curve and printouts. When loading a manufacturer's data set, they will automatically be shown when scrolling through the data using the **View** menu. The total number of curves in the data set and the current curve will be shown at the top of the window. Pump curves can be based on speed or impeller diameter as the performance variable.

Flow rate, Head, and Energy Required

This allows for entry and/or modification of manufacturer's equipment data. The system head is determined using the Affinity Laws ($\text{head} \propto \text{flow}^2$, etc.). There should be an intersection of the system curve and the operating curve to establish an operating point. When the impeller diameter or speed is adjusted and the calculation is performed, the equipment head/pressure data and power requirements will be updated.

System Performance Curve Window



The System and Performance Curves

Once an acceptable operating point is established, the *System Performance Curve* option can be selected from the **Mode** menu to graphically detail the operating conditions as shown. If an adjusted value was entered for the impeller diameter or speed, the curve will reflect the adjusted performance and operation.

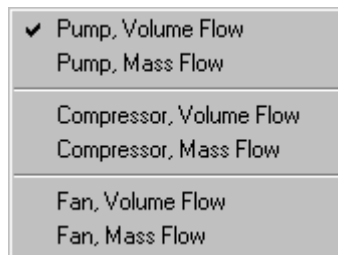
Menu Description

File Menu



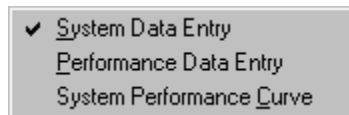
The first section of this menu offers the choices of starting a new analysis, opening and saving calculations, getting manufacturers' equipment performance data (available in the Performance Data Entry mode only), printing out the results, and viewing the help screens. The Change Units option switches between English and Metric units. In the second section, Copy and Paste, are used to copy/paste data to/from the Conversion Calculator and other input fields.

Options Menu



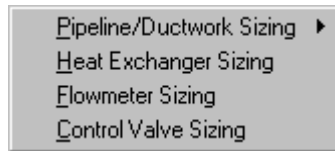
This pull down menu offers the choice of selecting either a pump, fan, or compressor and the flow rate units (either volumetric or mass flow).

Mode Menu



This menu is used to access the different windows in the program. The System Data Entry window is used for determining the design conditions of a process system. The Performance Data Entry window is used to input equipment performance data and determine system pressures at various conditions. The System Performance Curve can then be plotted with the final option (only if data entry has been completed and values calculated).

Import Menu

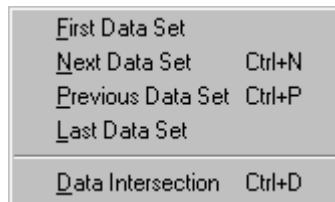


This pull-down menu offers links to the other equipment sizing programs from where the pressure drops may be imported to determine the fluid transportation requirements of a single line process system. Choose the desired program to import the pressure drop form, select the previously saved file and click OK. The corresponding pressure drop field will automatically be filled up. The user may enter the pressure drop information directly if it is already known.

Stages Menu

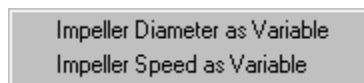
For Compressors, this adjusts the power requirements accordingly.

View Menu



This allows quick access to different models within a manufacturer's equipment data set (data entry sheet and file format are shown at the end of this section). First select the data file using the *Get Data* option in the **File** menu (Data Entry mode only) which will show the current model number and total models available. Selection of the *Data Intersection* option will go to the first curve which meets the system flow and head requirements. When only one curve is available for a given model, the maximum diameter or speed is displayed.

Type Menu



This menu allows the user to select the variable (Performance Data Entry Mode).

Calculation Basis

The Bernoulli equation and the Affinity Laws form the basis of this design. The differential pressure requirements, hydraulic horsepower and NPSH are calculated using the Bernoulli equation and is used to specify the pump/fan/compressor required for the service. The Affinity Laws are used to determine the system and performance data at different flow rates, speeds and impeller diameter.

Assumptions

1. Liquids are assumed to be incompressible and “Newtonian”.
2. Gases are assumed to be ideal.

Limitations

1. Fluid transportation requirements are determined for simple, non-looped systems.
2. Results displayed are for centrifugal pumps, fans and compressors.

Equations

Pump

$$\text{NPSH} = H_s - H_{\text{VAP}} + H_{\text{ATM}}$$

$$H_s = \frac{144P_1}{\rho} + H_{\text{EL}} - H_{\text{PIP}} - H_{\text{EQ}}$$

$$H_D = \frac{144P_2}{\rho} + H_{\text{EL}} + H_{\text{PIP}} + H_{\text{EQ}}$$

$$H_{\text{TOT}} = H_s + H_D = \frac{144P}{\rho}$$

$$\text{HP}_{\text{PUMP}} = \frac{\text{WH}_{\text{TOT}}}{550 \times 3600}$$

Compressor

$$H_{\text{AD}} = \left(\frac{\gamma}{\gamma - 1} \right) \text{RT} \left[\left(\frac{P_2}{P_1} \right)^{\frac{\gamma - 1}{\gamma}} - 1 \right]$$

$$\text{HP}_{\text{COMP}} = \frac{\text{WH}_{\text{AD}}}{550 \times 3600}$$

Fan

$$HP_{\text{FAN}} = \frac{144Q(P_2 - P_1)}{550 \times 3600}$$

Nomenclature

H	head, ft. water (60 F)
HP	power, hp
NPSH	net positive suction head available, ft. water (60 F)
P	pressure, psig
Q	volumetric flowrate, cu.ft./hr
R	gas constant, (=1545.0) ft.-lb/lbmol/R
T	temperature, R
W	mass flowrate, lb/hr.
γ	ratio of specific heats (C_p/C_v)
ρ	density of water (60 F), lb/cu. ft.

Subscripts

1	suction
2	discharge
AD	adiabatic
ATM	atmospheric pressure
COMP	compressor
D	total discharge
EL	elevation
EQ	equipment losses
FAN	fan
PIP	pipe losses
PUMP	pump
S	total suction
TOT	total system
VAP	vapor pressure

Recommendations

1. The flow rate and the suction and discharge pressures must be based on the temperature of the fluid being pumped.
2. If system requirements for reciprocating pumps are being determined, allowance must be made for the NPSH available due to the acceleration head.

3. Modification to manufacturers' data is not recommended without their consultation.

References

1. Westaway, C. R. and Loomis, A. W., ed., Cameron Hydraulic Data, 16th edition, Ingersoll-Rand, Woodcliff Lake, NJ (1979).
2. Jorgensen, R., ed., Fan Engineering, 8th edition, Buffalo forge company, Buffalo, NY (1983).
3. Walas, S. M., Chemical Process Equipment Selection and Design, Butterworth-Heinemann, Stoneham, MA (1990).
4. Engineering Data Book, Volume I, 10th edition, Gas Processors Suppliers Association, Tulsa, OK (1994).
5. Perry, J. H, et al., Chemical Engineers' Handbook, 3rd. ed., McGraw-Hill, New York (1950).

Example Problem

Example 1

A hot process water spray system needs a pump to meet the process requirements: 535 GPM (121.5 m³/hr) of heating water from 150°F to 180°F (65.6°C - 82.2°C) and then sprayed in a 7.5 PSIG (51.7 KPA) pressure vessel. The source and discharge elevations are 2 ft and 25 ft. respectively. For source and discharge pipe losses and pressure drop due to other equipment are shown in the figure on the next page.

Step by Step Solution Procedure

1. Enter the Thermophysical Properties window from the SmartDraw screen or the CHEMPRO Home Page. Type in a temperature of 150°F. Select water from the drop down list at the bottom of the screen. Click the Calculate Properties button and then click OK to exit the window after the properties are displayed.
2. Click on the Pump/Fan/Compressor Sizing button from the CHEMPRO Home Page or the SmartDraw screen. Select Pump (volume flow) from the Option menu, and System data from the Mode menu.
3. Key in the input data i.e. flow rate (535 gpm), the source pressure (0 psig) and discharge pressure (7.5 psig), the source elevation (2 ft) and discharge elevation (25 ft).
4. Key in the source and discharge pipe losses. If the pipelines have already been sized (as in this case), the pressure loss in the source and discharge segments would be known and may be entered directly. If the pipelines have not been sized, they can be sized and the pressure drops obtained by linking to the Pipeline/Ductwork sizing program. To do this, select Pipeline/Ductwork Sizing from the Import menu. Select Discharge Segment. This will activate the Pipeline Sizing screen. After selecting the material, size and type of pipe from the menus, fill in the input values, retrieve fluid properties and then click on calculate to obtain the pressure drop in the discharge segment. From the File menu click on Exit to return to the pump screen. The field for the pressure loss in the discharge segment would have been filled in. To obtain the source pipe pressure loss, select Source Segment from the Pipeline/Ductwork Sizing option on the Import menu. Repeat the above procedure to obtain the pressure drop. For this example, directly type in the pressure drops for the source and discharge piping as shown in the figure.
5. Pressure losses through flow meters, control valves or other equipment if present on the line must be filled in. The names may be entered as shown in the figure, and the pressure drop values filled in. If the pressure losses in the control valve and flow meters are unknown, you may link with these programs to obtain the pressure drops through them. For this example, directly type in the pressure drops for the source and discharge piping as shown in the figure.

6. The input is now complete. Click on Calculate to obtain the results.

SYSTEM FLOW, GPM	535	DENSITY, LBS/CU.FT.	61.30994
TEMPERATURE, DEG.F.	150	VAPOR PRESSURE, PSIA	3.722725
SOURCE ELEVATION, FT	2	DISCHARGE ELEV, FT.	20
SOURCE PRESS, PSIG	0	DISCHARGE PRESS.PSIG	7.5
SOURCE PIPE LOSS,PSI	1	DISCH. PIPE LOSS,PSI	12

EQUIPMENT ID	PSI	FLOWMETER ID	PSI	CONTROL VALVE ID	PSI
Heat Exchanger	3.4	FE-102	0.8	FCV-315	2.1
Spray Header	2.7	FE-115	0.6		
Filter	1.9				

SYSTEM DIFF, PSI: 39.66374 HYDRAULIC HP: 12.38046
 SYSTEM HEAD, FT: 93.20743 NPSH AVAILABLE, FT: 25.43385

System Description: Hot Water Spray System

CALCULATE PROPERTIES CONVERT SPECIFY

System Data Screen of Pump for Example 1

SYSTEM FLOW, GAL/MIN	535	FRICTION HEAD, FT	57.57354
STATIC HEAD, FT	35.62455	HYDRAULIC HP	12.38046
IMPELLER DIAMETER, IN	10	ADJUSTED DIAMETER, IN	0
HOURS/YR OPERATION	8400	ENERGY COST, \$/KWH	.055
MANUFACTURER/TYPE	GOULDS 3196ST, 17	MODEL NUMBER	3x4-10H

FLOWRATE, GPM	PUMP HEAD, FT	ENERGY RQD, HP	SYSTEM HEAD, FT
0	115	7.5	35.62455
100	115	9.5	37.63603
200	115	11	43.67046
300	115	13	53.72786
400	102	15	67.8082
500	98	16	85.91151
600	90	18	108.0378

OPERATING FLOW, GPM: 540.1261 YEARLY ENERGY COST, \$: 5690.308
 OPERATING HEAD, FT: 94.78991 EFFICIENCY, %: 77.13141

System Description: Hot Water Spray System

CALCULATE PROPERTIES CONVERT SPECIFY

Performance Data Screen of Pump for Example 1

7. To obtain the performance data, select the *Performance Data Entry* option from the **Mode** menu to activate the Performance Data screen. The manufacturer's data is displayed. This data may be altered or a different manufacturer's data may be obtained by selecting the *Get Data* option in the **File** menu. The desired data file may be selected here. From the **View** menu, select the Data Intersection option to obtain the pump that will fulfil the requirements. You may also scroll up or down from the **View** menu to access the various pump data and specifications. Click on **Calculate** to obtain the results.
8. To view the system performance curve, select this option from the **Mode** menu.