

Pumping System Assessment

Summary



Prescreening to narrow the field of focus - i.e., to select the VITAL FEW for further review



* Productivity/reliability-critical systems sent to higher priority levels

² ** Policies & practices also apply to moderate & highest priority applications





Example symptoms in pumping systems that indicate potential opportunity

- Throttle valve-controlled systems
- Bypass (recirculation) line normally open
- Multiple parallel pump system with same number of pumps always operating
- Constant pump operation in a batch environment or frequent cycle batch operation in a continuous process
- Cavitation noise (at pump or elsewhere in the system)
- High system maintenance
- Systems that have undergone change in function





First, let's try to get a big picture perspective of energy flow for pumping systems







Observations on losses in some of the power train components

Utility grid – line losses; not our problem (or are they?) Transformer – Very efficient (typically upper 90's %) Breaker/starter – Negligible Electrical ASD – Minor Motor – Minor Coupling – Minor Mechanical ASD – Minor to moderate Pump – Important Control valves – Zero to major Pipe and fittings – Minor to major Ultimate goal – Always important





The optimization path is the other side of a two way street







One of the single most important fluid energy relationships was identified in the 1700's



The combined energy, or head, associated with the fluid velocity, pressure, and elevation along a frictionless streamline is constant, even if the individual components aren't.





Bernoulli's principle: Total energy is constant along a *frictionless* streamline



 γ = fluid specific weight (lb_f/ft³) g = gravitational acceleration, 32.2 ft/sec² (9.81 m/s²) Note: Units are in ft (m) of *head*





The Bernoulli relation applies to frictionless, steady, streamline flow

- In the real world, friction exists (both within the fluid itself and between the fluid and pipe walls).
- So how much does friction cause the real world to deviate from the relationships of the Bernoulli principle?

It depends. Sometimes a little, sometimes a lot.





What are some sources of friction in pumping systems?

Pipe walls

Valves

Elbows

Tees

Reducers/expanders

Expansion joints

Tank inlets/outlets

(i.e., almost everything that the pumped fluid passes through, as well as the fluid itself)





Pipe friction loss estimates are usually based on an equation referred to as Darcy-Weisbach

This equation is very useful to examine to understand what parameters influence *frictional* losses in piping:

$$H_{f} = f \cdot \frac{L}{d} \cdot \frac{V^{2}}{2g}$$

- H_f = head loss due to friction (ft)
 - = Darcy friction factor
- = pipe length (ft)
- d = pipe diameter (ft)
- V^2
- velocity head (ft)





Schedule 40 Steel Pipe Sizing



VOLUMETRIC FLOW RATE, gpm





Piping component frictional losses are also primarily dependent on experimental data

For pipe components, frictional losses have generally been estimated based on the velocity head.

$$H_{f} = K \cdot \frac{V^{2}}{2g} \qquad K = \text{Loss coefficient}$$
$$\frac{V^{2}}{2g} = \text{velocity head}$$

K is a function of size, and for valves, the valve type, and valve % open.





Some *typical* K values for miscellaneous pipe components

Component	Component K
90° elbow, standard	0.2 - 0.3
90° elbow, long radius	< 0.1 - 0.3
Square-edged inlet (from tank)	0.5
Discharge into tank	1
Check valve	2
Gate valve (full open)	0.03 - 0.2
Globe valve (full open)	3 - 8
Butterfly valve (full open)	0.5 - 2
Ball valve (full open)	0.04 - 0.1





We can slightly modify the Bernoulli equation to account for friction



There is less hydraulic head/energy available at points 2 and 3 because of frictional losses





Modified again to accommodate the normal units of pressure in the U.S.A.





<u>Symbol</u>	<u>Represents</u>	<u>Units</u>
V	Velocity	ft/s
g	gravitational acceleration constant	ft/s ²
Р	pressure	psig
s.g.	specific gravity	none
Z	Elevation	ft
H _f	Frictional head loss	ft





The Bernoulli relationship is slightly modified to define the pump head



H_{pump} = Pump head at a given flow rate





MEASUR Pump Head Calculator



PUMP HEAD TOOL



 K_{s} represents all suction losses from the tank to the pump

 K_d represents all discharge losses from the pump to the gauge P_d

Fluid Specific Gravity Flow Rate			1.002				
			3000	gpm			
Suction			Discharge				
Pipe diameter (ID)	12	in	Pipe diameter (ID)	12	in		
Tank gas overpressure (P_g)	0	psi	Gauge pressure (P _d)	124	psi		
Tank fluid surface elevation	10	ft	Gauge elevation (Z _d)	10	ft		
(Z _s)			Line loss coefficients (K _d)	1			
Line loss coefficients (Ks)	0.5						

MEASUR Pump Head Calculator Results

RESULTS	HELP		
Result Data			
Differential Elevation Head	0.0 ft		
Differential Pressure Head	285.97 ft		
Differential Velocity Head	1.13 ft		
Estimated Suction Friction Head	0.56 ft		
Discharge Friction Head	1.13 ft		
Pump Head	288.78 ft		





Let's start with the system curve



Flow rate





Energy is required to overcome two types of resistance to in systems

- Static head
- Friction head

$$H_{total} = H_{static} + H_{friction}$$





- Static head refers to the change in elevation from the suction to the discharge
- Tank over-pressures must be included in calculations
- This is basically the change in potential energy of fluid as it moves from the suction tank to the discharge tank
- Closed systems typically do not have static head
- Static heads can be positive, negative or zero





System curves are made up of two fundamental components - static head and frictional head





Open and Closed Piping Systems

- Piping systems for water transmission can be considered in two general categories:
 - Open systems
 - Closed or sealed systems
- Open systems are piping circuits, pumped or gravity circulated, that are open to the atmosphere at some point
- Closed systems are designed and installed as hermetically sealed systems that offer several advantages





System Curves

System curves display the total head required to move different amounts of flow through the piping system

System curve equations:

$$H_{total} = H_{static} + k'Q^{1.9}$$

Closed piping systems have zero static head

Open piping systems generally have some static head





We'll use this system as an example: water is pumped from one tank to another













The static head is made up of elevation, and sometimes pressure components







The static head is made up of elevation, and sometimes pressure components







The system operating point is at the intersection of the pump and system head-capacity curves



Flow rate





Answer: we take advantage of the fact that the system and pump total heads are equal at the operating flow rate









The system total head at any flow rate is the same thing as the pump total head - so we measure the pump head







We have two points on the system curve; now we just have to figure out how to connect them







A little algebra....

$$H_2 = H_s + KQ_2^2$$

 $H_1 = H_s + KQ_1^2$

Subtracting yields

$$H_2 - H_1 = K(Q_2^2 - Q_1^2)$$
, so

K =
$$\frac{(H_2 - H_1)}{(Q_2^2 - Q_1^2)}$$
 and H_s = H₁ - KQ₁²

Although the static head is known in this case, any two flow and head combinations will suffice.





The resultant system curve







System head curves for three different systems







Pump performance characteristics



U.S. DEPARTMENT OF



There are four types of performance curves that are used to characterize pumps

- Head
- Shaft power
- Efficiency
- Net positive suction head required (NPSHR)





The Bernoulli relationship is slightly modified to define the pump head



H_{pump} = Pump head at a given flow rate





MEASUR Pump Head Calculator



PUMP HEAD TOOL



 ${\sf K}_{{\sf s}}$ represents all suction losses from the tank to the pump

 K_d represents all discharge losses from the pump to the gauge P_d

Fluid Specific Gravity Flow Rate			1.002				
			3000	gpm			
Suction			Discharge				
Pipe diameter (ID)	12	in	Pipe diameter (ID)	12	in		
Tank gas overpressure (Pg)	0	psi	Gauge pressure (P _d)	124	psi		
Tank fluid surface elevation	10	ft	Gauge elevation (Z_d)	10	ft		
(∠ _s)			Line loss coefficients (K _d)	1			
Line loss coefficients (K_s)	0.5						

Generate Example

Reset Data





MEASUR Pump Head Calculator Results

RESULTS	HELP		
Result Data			
Differential Elevation Head	0.0 ft		
Differential Pressure Head	285.97 ft		
Differential Velocity Head	1.13 ft		
Estimated Suction Friction Head	0.56 ft		
Discharge Friction Head	1.13 ft		
Pump Head	288.78 ft		





Pump affinity laws can be used to predict pump curves for different speeds and impeller diameters







The affinity laws aren't perfect for diameter changes: head curves







Considering a trim in impeller diameter?

Recommendations:

- 1. Get actual performance curves from the manufacturer, especially if the trim change being considered is large
- 2. Do a field performance test of the existing pump







But the affinity laws generally hold up very well with speed changes



Note: same pump as previous slides, impeller size = 17.9 inches

U.S. DEPARTMENT OF

IFR





Parallel and series pumping "laws", like the pump affinity laws apply to the pump curves **only**

- Parallel pumps sum the flow rates at a given head
- Series pumps sum the heads at a given flow rate







Parallel pumps can help adapt to changing system requirements <u>and</u> provide redundancy







Unlike pumps can also be used in parallel, but with caution







More pumps does not necessarily mean much more flow



Pumps operating	Flow rate, gpm	Head, ft	% increase in flow
1	3500	176.1	0
2	4185	206.8	19.6%
3	4325	213.8	23.6%





How about parallel pump operation with different system types?







Parallel Pumping Example



RTMENT OF



Parallel Pumping Example

Parallel Pumps



Flow (GPM)

Identical pumps in series; add head at a given flow rate to estimate overall performance







Change in speed for the all frictional system results in maintenance of constant pump efficiency (Pump 2)







Change in speed for the 100-ft static system with Pump 2 results in loss of flow at ~78% speed







Parallel pump response also depends on the nature of the system and pump curves (P2)







Pumping faster than necessary increases friction losses – Homework Problem

A municipal water treatment plant needs to deliver 1.5 million gallons per day of fresh water into the system. An energy study has suggested the plant pump at a slower rate for a longer time to reduce the cost of pumping. The data below applies to this system. If electricity costs \$0.08/kWh and demand costs \$15.25/kW, calculate the annual operating cost for each flow rate.

Flow Rate (gpm)	Head (feet)	Time (hr/day)
1700	294.1	14.71
1900	302.3	13.16
2100	311.4	11.90
2300	321.5	10.87
2500	332.5	10.00





Pump and motor efficiencies



Figure 21. Pump and motor performance data from Floway test facility





The analysis

Flow	Head	Time	Wire to Water	Required	Annual	Annual	Annual	Annual	Total	Savings vs.
Rate	(feet)	(hr/day)	Efficiency (%)	Pump Power	Energy	Demand	Energy	Demand	Annual	2500 gpm
(gpm)	(reet)	(nr/day)	Efficiency (%)	(kW)	(MWh)	(kW)	Cost (\$)	Cost (\$)	Cost (\$)	Rate
1700	294.1	14.71	81.5	115.57	620.49	1386.79	49639	21149	70788	22190
1900	302.3	13.16	83.5	129.58	622.44	1555.00	49795	23714	73509	19469
2100	311.4	11.9	85.0	144.93	629.51	1739.18	50361	26522	76883	16094
2300	321.5	10.87	83.0	167.83	665.88	2013.98	53270	30713	83984	8994
2500	332.5	10	80.0	195.74	714.46	2348.91	57157	35821	92978	0







Open the MEASUR Software





Welcome to the most efficient way to manage and optimize your facilities' systems and equipment.

Create an assessment to model your system and find opportunities for efficiency or run calculations from one of our many property and equipment calculators.

Ħ

F

Get started with one of the following options.



Create Assessment Model a system and explore multiple optimization scenarios.



Create Pump Assessment formerly DOE Pumping System Assessment Tool (PSAT)

Create Process Heating Assessment formerly DOE Process Heating Assessment and Survey Tool (PHAST)



Motors	E Steam
Process Cooling	Compressed Air
Pumps	Eighting
Fans	Waste Water
Process Heating	General



Inventory Management Create and manage equipment inventory.

Properties & Equipment Calculators

Generate detailed properties and test a variety of adjustments.

8 rgy



Better

Click on Create Pump Assessment



Pumping tool before MEASUR was PSAT

- The first Pumping System Analysis Tool developed by US DOE was PSAT
- PSAT download comes with another program, <u>Valve</u> <u>Tool</u>, that is very useful
- Valve Tool has not been added to MEASUR yet
- PSAT and Valve Tool can be downloaded from the following website
- https://www.energy.gov/eer e/amo/downloads/pumpingsystem-assessment-toolpsat







Valve flow coefficient curve



U.S. DEPARTMENT OF



The valve tool works from the fundamental valve relationships



$$\mathbf{Q} = \mathbf{F}_{p} \mathbf{C}_{v} \sqrt{\frac{\Delta \mathbf{P}}{\mathrm{s.g.}}}$$

In U.S. units:

- Q = Flow rate (gpm)
- F_p = Geometry factor
- C_v = Valve flow coefficient
- ΔP = pressure drop, psi

s.g. = specific gravity







ENEKGY







