Water & Wastewater Operation:
Pipe Systems, System Curves, & Pump Curves

Matt Prosoili
PumpsPlus Inc.
30 Years in Water & Wastewater
BA in Marketing, Michigan State Univ.
MWEA Maintenance Committee 30 years
BUT FIRST---
A Public Service Announcement
How to determine if your cow has Mad Cow Disease..

If your cow sounds like this
then fire up the barbecue.

If your cow sounds like this
may we suggest the fish.
PUMP PERFORMANCE
CURVE DEVELOPMENT
IMPELLER DISCHARGE CONFIGURATIONS
SPECIFIC SPEED TYPICAL CURVES

Hd = Discharge head generated
Q = Quantity of liquid pumped
P = Power required
n = Pump efficiency
THE DIFFERENCE BETWEEN THEORETICAL AND ACTUAL PUMP CURVES
These Losses can be reduced by:

• Improving the impeller inlet conditions
• Accelerating the fluid gradually
• Improving casting technology
• Utilizing Double Volutes
The More we reduce the Shock, Turbulence, Recirculation, and Friction losses, the Higher the Efficiency.

FRANCIS VANED IMPELLERS EXTEND INTO SUCTION EYE TO ACCELERATE FLUID GRADUALLY.

DOUBLE VOLUTE SERVES TO REDUCE RECIRCULATION AND TURBULENCE LOSSES, BROADENING EFFICIENCY BANDS.
FLUID IN THE DISCHARGE CHAMBER NO LONGER IMPACTS EFFICIENCY
A TYPICAL CATALOG PERFORMANCE CURVE

POR = Preferred operating range, 70-120% of BEP

AOR = Acceptable operating range, defined by isobars on mfg. curve
Positive Displacement Rotary Lobe Pump Curve
Double Disk  Positive Displacement Pump Curve

DIADISK PUMP

Performance on Water
70 Durometer Neoprene Disks

GPM

270
240
210
180
150
120
90
60

TDH - FEET
10  20  30  40  50  60  70  80  90  100  110  120  130

3.0 HP - 0 to 350 RPM
5.0 HP - 350 to 550 RPM
7.5 HP - 550 to 750 RPM

Item:  Service:
Typical Vertical Turbine Performance Curve

Efficiency correction per stage

Performance is per stage and these pumps can have many depending on TDH
HEAD (PRESSURE)
FEET OR POUNDS.  1 PSI = 2.31 FT.

FLOW US GPM (AN AMOUNT OVER TIME)
A COUPLE OF IMPORTANT TERMS

• BRAKE HORSEPOWER = THE POWER REQUIRED TO DRIVE A PUMP.

• PUMP EFFICIENCY = OUTPUT POWER DIVIDED BY INPUT POWER.
IMPORTANT!!!

REMEMBER THIS FORMULA.

\[ \text{BHP} = \frac{(\text{GPM})(\text{TDH})(\text{SG})}{(3960)(\text{EFF})} \]

WHERE,
- GPM = US GALLONS PER MINUTE
- TDH = HEAD IN FEET
- SG = SPECIFIC GRAVITY
- 3960 = “A CONSTANT”
- EFF = PUMP EFFICIENCY
3960 IS A CONSTANT LINKING A HORSEPOWER (33,000 ft lbs./min.) TO A US GALLON (8.333 lbs.)

\[
\frac{33000}{8.33} = 3960
\]
### Job Information
- **Sales Order No.:** EP95-018
- **Customer:** HICO
- **Model:** 29-60203

### Curve Information
- **Test By:** DARREL AND RAY
- **Filename:** TC# 9718-208
- **Test Date:** 10 OCT 95

### Test Conditions
- **Impeller Test Dia.:** 20
- **Maximum Impeller dia.:** 20
- **Suction Nozzle Dia.:** 8
- **Discharge Nozzle Dia.:** 6
- **Rated Capacity (GPM):** 4500
- **Rated Head:** 450
- **Orifice Name:** 8/6.0344
- **Orifice "K" Value:** 568.792
- **Elevation Correction:** 3.27083

### Motor Data
- **Horsepower:** 150
- **RPM:** 1175
- **Volts:** 460
- **Phase:** 3
- **Hertz:** 60
- **Wattmeter Mul:** 1000
- **Book Eff%:** .945
- **Motor No.:** 1
- **Manufacturer:** LINCOLN

### Test Data
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CALCULATED VALUES FROM TEST DATA

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<th>Pump Eff%</th>
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TEST CURVE PLOTTED FROM TEST DATA
AN IMPORTANT POINT!!!!!

At a given speed, with a given impeller diameter:

The pump will perform along its characteristic curve, from run out to shut off
Shutoff and Runout
PUMP AFFINITY LAWS

- FLOW changes directly as a change in speed or diameter.

- HEAD changes as the square of a change in speed or diameter.

- HORSEPOWER changes as the cube of a change in speed or diameter.
PUMP AFFINITY LAWS

IMPORTANT...REMEMBER THESE

\[
\frac{Q_1}{Q_2} = \frac{D_1}{D_2} \quad \text{OR} \quad \frac{Q_1}{Q_2} = \frac{N_1}{N_2}
\]

\[
\frac{H_1}{H_2} = \left(\frac{D_1}{D_2}\right)^2 \quad \text{OR} \quad \frac{H_1}{H_2} = \left(\frac{N_1}{N_2}\right)^2
\]

\[
\frac{BHP_1}{BHP_2} = \left(\frac{D_1}{D_2}\right)^3 \quad \text{OR} \quad \frac{BHP_1}{BHP_2} = \left(\frac{N_1}{N_2}\right)^3
\]
WHEN WE TRIM AN IMPELLER, PERFORMANCE CHANGES IN ACCORDANCE WITH THE AFFINITY LAWS.
AND AGAIN, AND AGAIN, ...
As we trim, we can’t expect the efficiency to stay the same, remember the internal losses.
As we trim, the turbulence and recirculation losses (in particular) increase.

So efficiency is reduced.
At 3,000 GPM  
82% at BEP max  
diameter impeller  
<70% at min  
diameter impeller
Variable speed curves illustrate the flexibility of a pump without changing out impellers.
WHY WORRY ABOUT NPSH?

➢ PUMPS DON’T SUCK.
NPSH

NET POSITIVE SUCTION HEAD
REMEMBER PUMP BASICS

THE FLUID NEEDS TO ENTER THE IMPELLER BEFORE THE IMPELLER CAN BEGIN ADDING ENERGY.
NPSH DEFINES THE ENERGY AVAILABLE TO THE FLUID, OR REQUIRED BY THE PUMP TO "FORCE" THE FLUID INTO THE IMPELLER VANES.
THERE ARE REALLY TWO “TYPES” OF NPSH

• $\text{NPSH}_{(R)}$ IS THE NPSH **REQUIRED** BY THE PUMP. IT IS A FUNCTION OF PUMP DESIGN. (THIS IS THE NPSH SHOWN ON THE PUMP CURVE.)

• $\text{NPSH}_{(A)}$ IS THE NPSH **AVAILABLE** TO THE PUMP. IT IS A FUNCTION OF THE SYSTEM DESIGN.
NPSH IS A LITTLE LIKE A CHECKBOOK

• NPSH(R) IS LIKE THE MONEY YOU NEED TO PAY YOUR BILLS.

• NPSH(A) IS YOUR INCOME.

• YOU NEED AT LEAST AS MUCH INCOME AS YOUR BILLS.
THE “RULE”:

\[ \text{NPSH}(A) \geq \text{NPSH}(R) \]

FOR PRACTICAL PURPOSES, FORGET THE EQUAL SIGN:
NPSH AVAILABLE MUST BE GREATER THAN THE NPSH REQUIRED.
NPSH(R)

- After design, there is little that can be done about NPSH(R).

- Chief factors influencing NPSH(R) include impeller eye area, vane inlet design, and the relationship with the casing.
NPSH(A)

• THE NPSH(A) IS INFLUENCED BY SEVERAL FACTORS, MANY OF WHICH ARE CONTROLLABLE OR MODIFIABLE.

• THESE FACTORS INCLUDE THE ABSOLUTE PRESSURE, VAPOR PRESSURE, SUCTION PRESSURE, AND FRICTION LOSSES
NPSH(A) FORMULA

• NPSH(A) = $H_{(A)} + H_{(S)} - H_{(VPA)} - H_{(F)}$
  • WHERE

• $H_{(A)}$ = ABSOLUTE PRESSURE
• $H_{(S)}$ = SUCTION PRESSURE (HEAD)
• $H_{(VPA)}$ = VAPOR PRESSURE
• $H_{(F)}$ = SUCTION PIPING FRICTION HEAD
IT IS IMPORTANT TO REMEMBER THAT IN A SUCTION LIFT SITUATION, \( H_S \) WILL BE A NEGATIVE NUMBER.
ABSOLUTE PRESSURE

• THE ABSOLUTE PRESSURE IS THE PRESSURE (ENERGY) ADDED TO THE FLUID BY AN OUTSIDE SOURCE.

• IN AN OPEN SYSTEM, THIS IS THE ATMOSPHERIC PRESSURE.
ATMOSPHERIC PRESSURE

• 1 PSI = 2.31 FT H₂O AT 70°F
  = 2.0438 MERCURY INCHES

• 14.7 PSI = 33.9 FT = 30 INCHES Hg.

• (WATCH THE WEATHER REPORT)
## ATMOSPHERIC PRESSURE vs. ALTITUDE

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<th>ALTITUDE ABOVE SEA LEVEL</th>
<th>FEET OF WATER</th>
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<tr>
<td>10000</td>
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# VAPOR PRESSURE OF WATER VERSUS TEMPERATURE

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<th>°F</th>
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VAPOR PRESSURE CURVE
NPSH — SOME EXAMPLES
EXAMPLE 1--- OPEN SYSTEM WITH LIQUID RESERVOIR ABOVE PUMP.

\[
\text{NPSH(A)} = H_{(A)} + H_{(S)} - H_{(VPA)} - H_{(F)}
\]

\[
41.12 = 33.9 + 10 - 0.78 - 2
\]
EXAMPLE 2-
OPEN SYSTEM WITH LIQUID RESERVOIR
BELOW PUMP

\[
NPSH(A) = H(A) + H(S) - H(VPA) - H(F)
\]
21.12 = 33.9+(-10)-.78 -2
SYSTEM CURVES
START WITH THE SYSTEM

- The Pump is Only one Component in the System.
- It is Most important in any Discussion to Start With the System.
- Without a Thorough Understanding of the System, there will be Little Chance of Selecting the Right Pump.
SYSTEM CURVES

Q

OPEN SYSTEM

H

STATIC HEAD

x

y

z
TOTAL DYNAMIC HEAD
Total Dynamic Head (TDH) = (P2 - P1) x 2.31
Specific Gravity + Z2 + Hfs + Hfd
REMEMBER THAT THE SYSTEM CURVE REPRESENTS FLOW THROUGH A PIPING SYSTEM AT A GIVEN TIME

• If we change the piping, we change the system curve.
SYSTEM CURVE DEVELOPMENT

\[ \frac{H_1}{H_2} = \left( \frac{Q_1}{Q_2} \right)^{1.85} \]

OR, MORE COMMONLY
(Known as a Standard
‘Second Order’ Curve)

\[ \left( \frac{Q_2}{Q_1} \right)^2 = \frac{H_2}{H_1} \quad \text{(HEAD WILL CHANGE AS THE SQUARE OF FLOW)} \]

H1= FRICTION HEAD AT DESIGN FLOW Q1
H2= FRICTION HEAD AT ASSUMED FLOW Q2
WHERE A PUMP OPERATES

POINT OF PUMP OPERATION
RESULTS OF PART LOADING OR SYSTEM CURVE DEVIATION ON PERFORMANCE
RUNNING MORE THAN ONE PUMP AT A TIME
PARALLEL PUMPING
PUMP PERFORMANCE WITH PARALLEL PUMPING

AT ANY GIVEN HEAD, FLOWS ARE ADDITIVE.
SERIES PUMPING
SERIES PUMPING
PUMP PERFORMANCE WITH SERIES PUMPING

AT ANY GIVEN FLOW, HEADS ARE ADDITIVE.
COMBINED SERIES AND PARALLEL PUMPING
COST OF PUMPING
CALCULATING OPERATING COSTS: (PUMP “A”)  
DESIGN POINT: 3200GPM @ 160’TDH
COST PER HOUR OF PUMPING

\[
CPH = \frac{(.000189)(\text{US GPM})(\text{TDH}[\text{ft}])(\$/\text{KWH})(\text{SG})}{\text{WWE}}
\]

WWE = WIRE TO WATER EFFICIENCY

FIXED SPEED WWE = (PE) (ME)

VARIABLE SPEED WWE = (PE) (ME) (DE)
WHAT’S THE .000189?

• ANOTHER CONSTANT!!
  1HP = 33000 ft lbs = .746 kW
  1 GALLON H₂O = 8.333 LBS

\[
\frac{.746}{3960} = .000189
\]

.000189 LINKS A HP TO A KW TO A FT OF H₂O TO A GALLON
CALCULATING OPERATING COSTS

- ASSUME $0.10 /KWH
- ASSUME 92% MOTOR EFFICIENCY
- ASSUME 2 PUMPS
- ASSUME 24 HRS / DAY
- ASSUME 365 DAYS / YEAR
CALCULATING OPERATING COSTS

- ASSUME $.10 / KWH, ME = .92, 24 HRS / DAY, 365 DAYS / YEAR, 2 PUMPS.

  \[ \text{CPH} = \frac{.000189 \times 3200 \times 160 \times .10}{.845 \times .92} \]

  \[ = \frac{9.6768}{.7774} \]

  \[ = \frac{12.45}{.7774} \]

  \[ = \$12.45 / HR / PUMP \]

  \[ \times 2 \text{ PUMPS} \times 24 \text{ HRS/DAY} \times 365 \text{ DAYS/YEAR} \]

  \[ = \$218,124 / \text{YEAR} \]
CALCULATING OPERATING COSTS
DESIGN POINT: 3200 GPM @ 160’TDH   (PUMP “B”)
CALCULATING OPERATING COSTS

- Assume $.10 / KWH, ME = .92, 24 HRS / DAY, 365 DAYS / YEAR, 2 PUMPS.

\[ \text{CPH} = \frac{.000189 \times 3200 \times 160 \times .10}{.90 \times .92} \]

\[ = \frac{9.6768}{.828} \]

\[ = \$11.69 / \text{HR} / \text{PUMP} \]

\[ \times 2 \text{ PUMPS} \times 24 \text{ HRS/DAY} \times 365 \text{ DAYS/YEAR} \]

\[ = \$204,809 / \text{YEAR} \]
THE DIFFERENCE IS SAVINGS

THE DIFFERENCE IN PUMP EFFICIENCY BETWEEN THE 84.5% EFFICIENT PUMP “A” AND THE 90% EFFICIENT PUMP “B” RESULTS IN REAL OPERATING COST SAVINGS

PUMP “A” OPERATING COST = $218,124. / YEAR
PUMP “B” OPERATING COST = $204,809. / YEAR

$ OP.COST SAVINGS = $13,315. / YEAR
WHAT HAPPENS IF THE SYSTEM CURVE IS OFF?

Assume friction loss is off by 29% (probable worst case?!---If we exclude):

Safety factors by suppliers
Safety factors by designers
“As built” differences from design
Mistakes
RESISTANCE WILL DROP FROM THE EXPECTED 160'}
TO 114’ (71% OF 160’)

[Image of a performance characteristic curve for a centrifugal pump, with an arrow pointing to a specific data point on the graph.]
TO 114’ (71% OF 160’ [AT DESIGN FLOW!!])
WHAT HAPPENS IF THE SYSTEM CURVE IS OFF?

PUMP “A” RUNS OUT TO ITS “SECONDARY OPERATING POINT”, ...

(SINCE WE HAVEN’T CONSIDERED ANY OF THE “SAFETY FACTORS”, LET’S USE 4600GPM @114’TDH)
CALCULATING OPERATING COSTS
(PUMP "A")  DESIGN POINT: 3200 GPM @ 160°TDH
SECONDARY OPERATING POINT: 4600 GPM @ 114°TDH
CALCULATING OPERATING COSTS

Assume friction loss is off by 29%. (Probable worst case).
Assume $0.10 / KWH, M.E. = .92, 24 HRS / DAY, 365 DAYS / YR, 2 PUMPS

PUMP “A” runs out to its “SECONDARY OPERATING POINT”, 4600 USGPM @114’TDH.

\[
CPH = \frac{.000189 \times 4600 \times 114 \times .10}{.725 \times .92} \\
= \frac{9.911}{.667} \\
= \frac{14.86}{.667} \\
= $14.86 / HR / PUMP \times 2 \text{ PUMPS} \times 24 \text{ HRS/DAY} \times 365 \text{ DAYS/YEAR} \\
= $260,347 / \text{YEAR}
\]
What Happens if the System Curve is "Off"?

• ASSUME FRICTION LOSS IS “OFF” BY 29% (PROBABLE WORST CASE?!)  

• PUMP B “B” RUNS OUT TO ITS SECONDARY OPERATING POINT (@114’TDH)
CALCULATING OPERATING COSTS
(PUMP “B”) DESIGN POINT: 3200 GPM @ 160’TDH
SECONDARY OPERATING POINT: 4500 GPM @ 114’TDH
CALCULATING OPERATING COSTS

ASSUME FRICTION LOSS IS OFF BY 29%. (PROBABLE WORST CASE).
ASSUME $ 0.10 / KWH, M.E. = .92, 24 HRS / DAY, 365 DAYS / YR, 2 PUMPS

PUMP “B” RUNS OUT TO ITS “SECONDARY OPERATING POINT”, 4500 USGPM @114’TDH.

$0.000189 \times 4500 \times 114 \times .10$
$\times .85 \times .92$

= $9.696$
$\div .782$

= $12.40 / HR / PUMP \times 2 PUMPS \times 24 HRS/\text{DAY} \times 365 \text{DAYS/YEAR}$

= $217,248. / \text{YEAR}$
The Difference Is Savings

OP. COST “A” = $260,347./YR
OP. COST “B” = $217,248./YR.
SAVINGS = $43,248./YR.

(IF LIFE IS 20 YEARS, OPERATING COST SAVINGS, THEN, IS SOMEWHERE BETWEEN $266,300 AND $865,900!!!!)
Are There any Questions?