Fachgesprach – 12

HVAC Pumps

For Project Managers

WTF Philosophy:
If you don't remember a certain formula,
it's OK - you can always G$_{oogle}$T$_{he}$S$_{hit}$.
But bad engineering CONCEPTS can hurt you.

WTF Institute Mission:
Teach correct engineering CONCEPTS to our PEs and PMs.

By Mat Ansari PE

General HVAC Pump Types

≤ 3"

Small In-Line Pumps

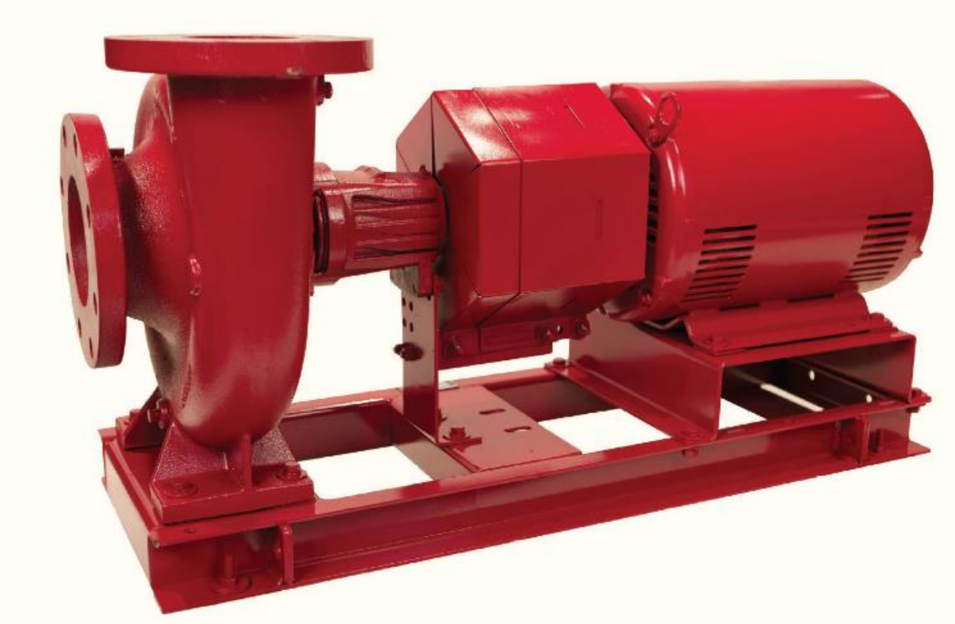
These pumps use in-line volutes and single suction impellers, but they are mounted with the shaft in a horizontal orientation. The flexible coupler and pump bearing assembly allow the use of standard motors.

2" - 4"

Close Coupled End Suction

The single suction impeller is installed directly on the motor shaft, it has no coupling, so it's called a "close coupled" pump.

3" - 8"



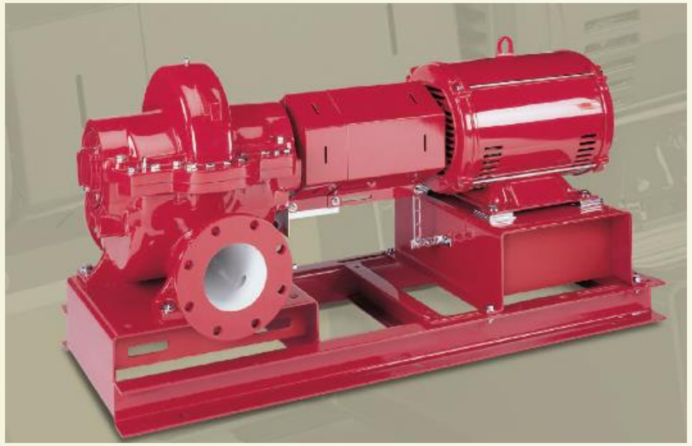
Single Suction Pumps

One of the most common types is the end-suction, base mounted, flexibly coupled pump

The sizes above have no technical basis – just a general observation of what we see in our local commercial buildings.

General HVAC Pump Types

≥ 8"



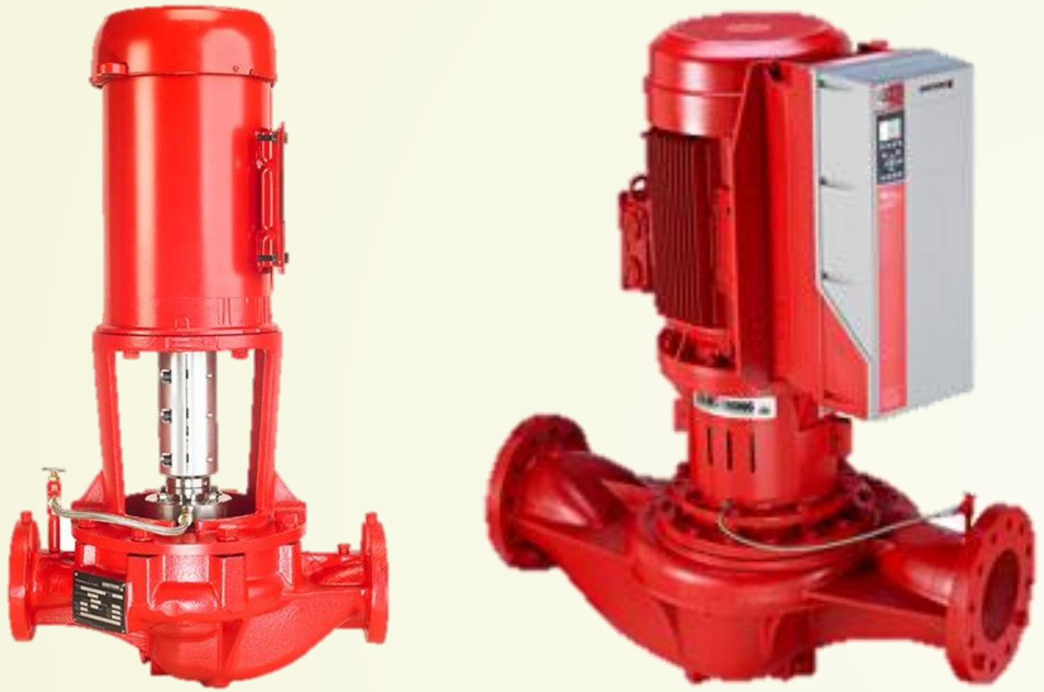
Double Suction Pumps: Single suction impellers are limited in terms of the flow rate they can handle, so double suction impellers must be used for high flow applications. These pumps are typically very large, base mounted, and flexibly coupled.
Low Axial Thrust.
Lower NPSHR.

ECM, "wet rotor", circulator uses the system fluid. The impeller is attached to the motor shaft, and the whole assembly rotates inside a stainless steel can.

AHU Coil booster pumps? See next slide for example application.

Source:
B&G TEH-1208A

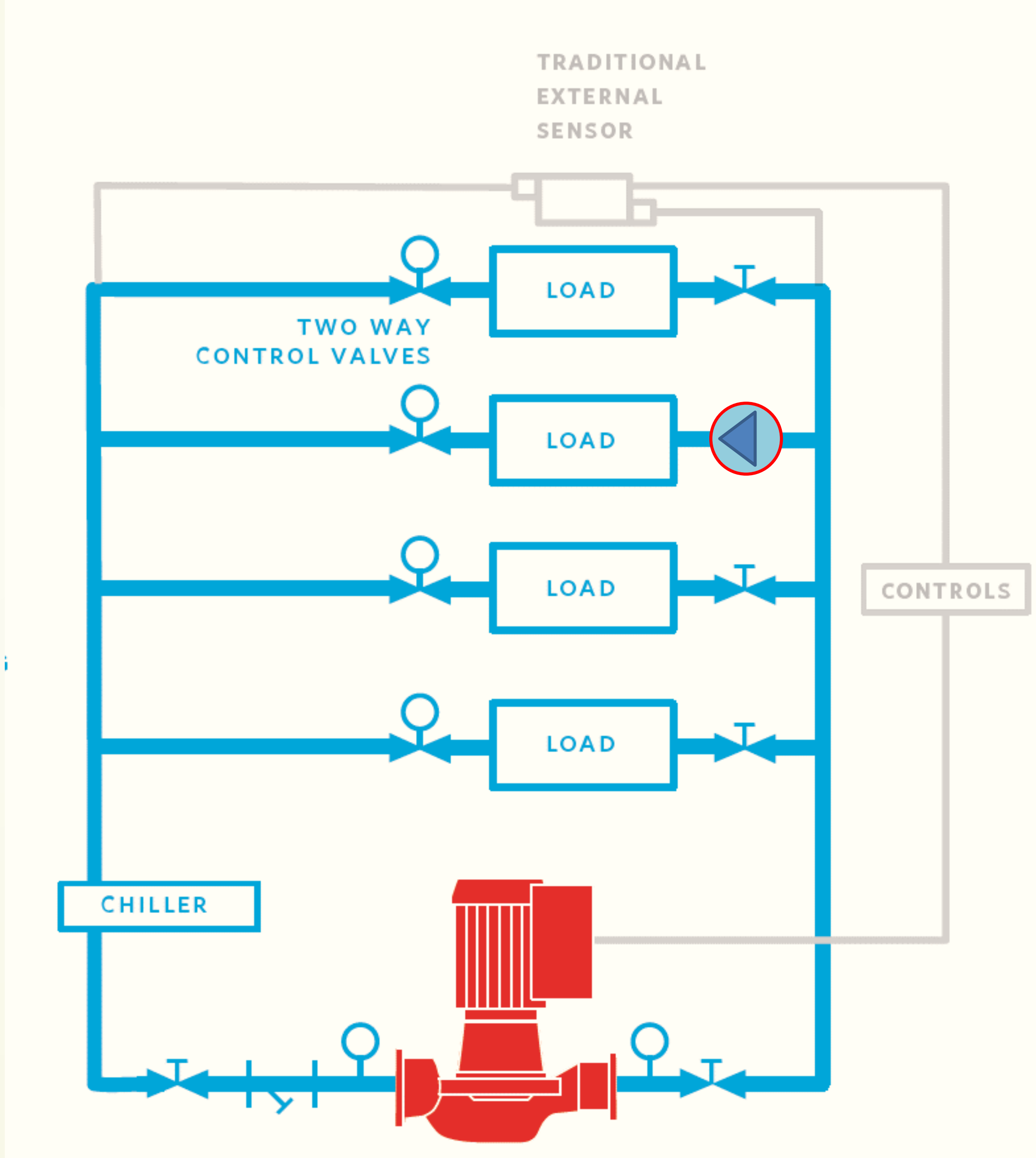
General HVAC Pump Types



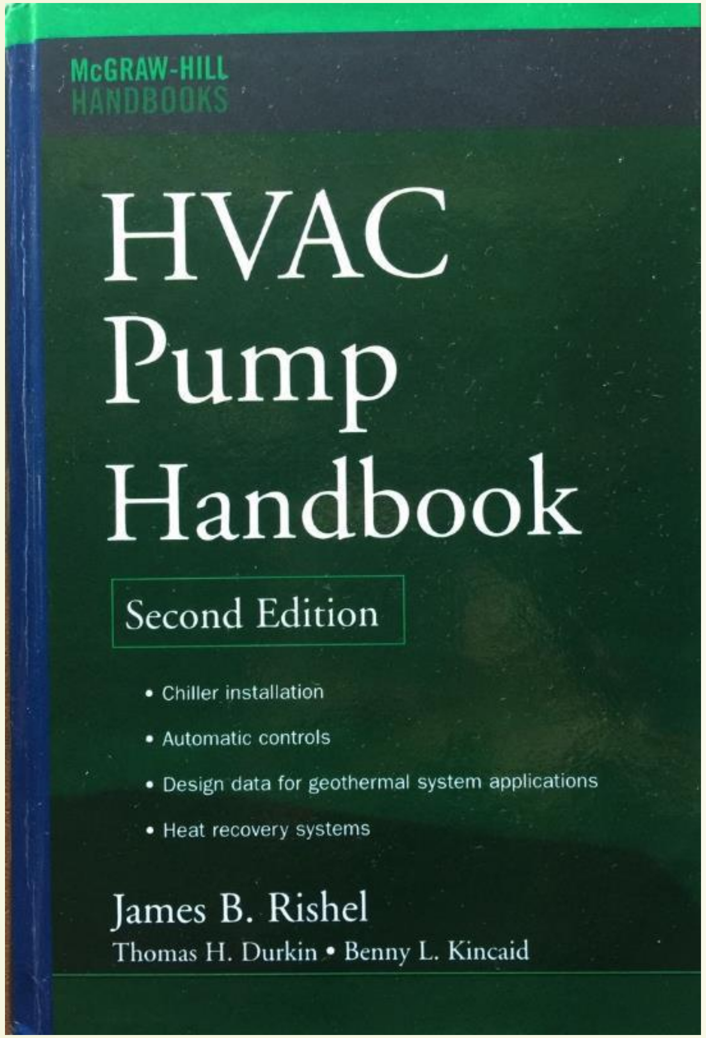
The Armstrong 4300 pipe-mounted pumps are designed for space-saving installation, high operating efficiency, and long service life

Low installed cost

- Vertical In-line design eliminates the need for inertia bases, housekeeping pads, flex connectors, and field alignment or grouting requirements



Pump References



HVAC Pump Handbook, By James Rishel

Highly recommended for HVAC Design Engineers and Project Managers

Pump Handbook, By Igor Karassik

The Bible of the pump community. (I don't have it.)

JMP Co. Videos on Hydronics

CHRIS EDMONDSON

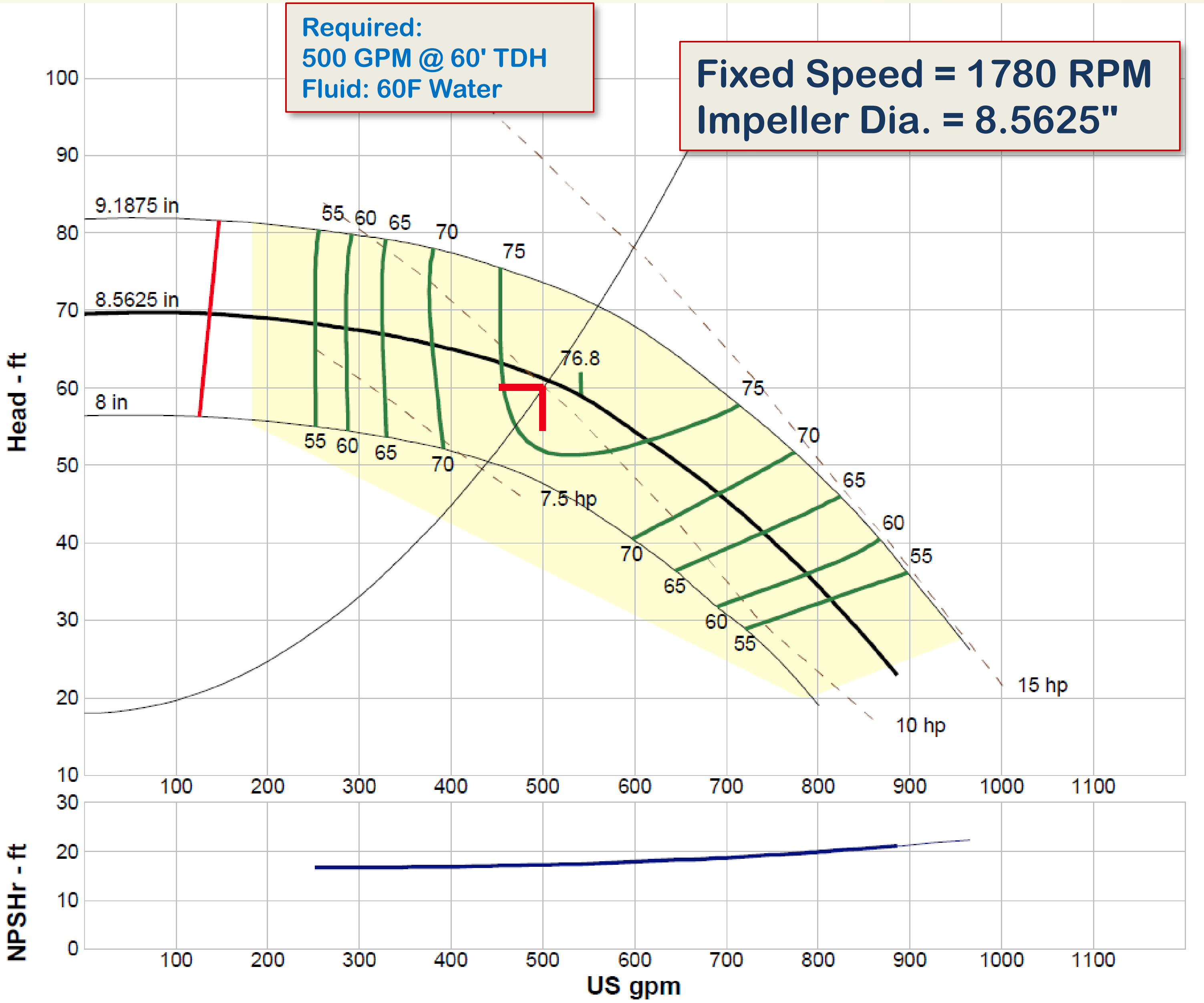
President James M. Pleasants Company, Inc.

Greensboro, NC

Good solid practical stuff.

The Pump Curve - 1

---- Duty Point ----	
Flow:	504 US gpm
Head:	60.7 ft
Eff:	76%
Power:	10.1 hp
NPSHr:	17.3 ft
---- Design Curve ----	
Shutoff Head:	69.5 ft
Shutoff dP:	30.1 psi
Min Flow:	135 US gpm
BEP:	76.8% @ 541 US gpm
NOL Power:	12.2 hp @ 813 US gpm
-- Max Curve --	
Max Power:	14.9 hp @ 897 US gpm



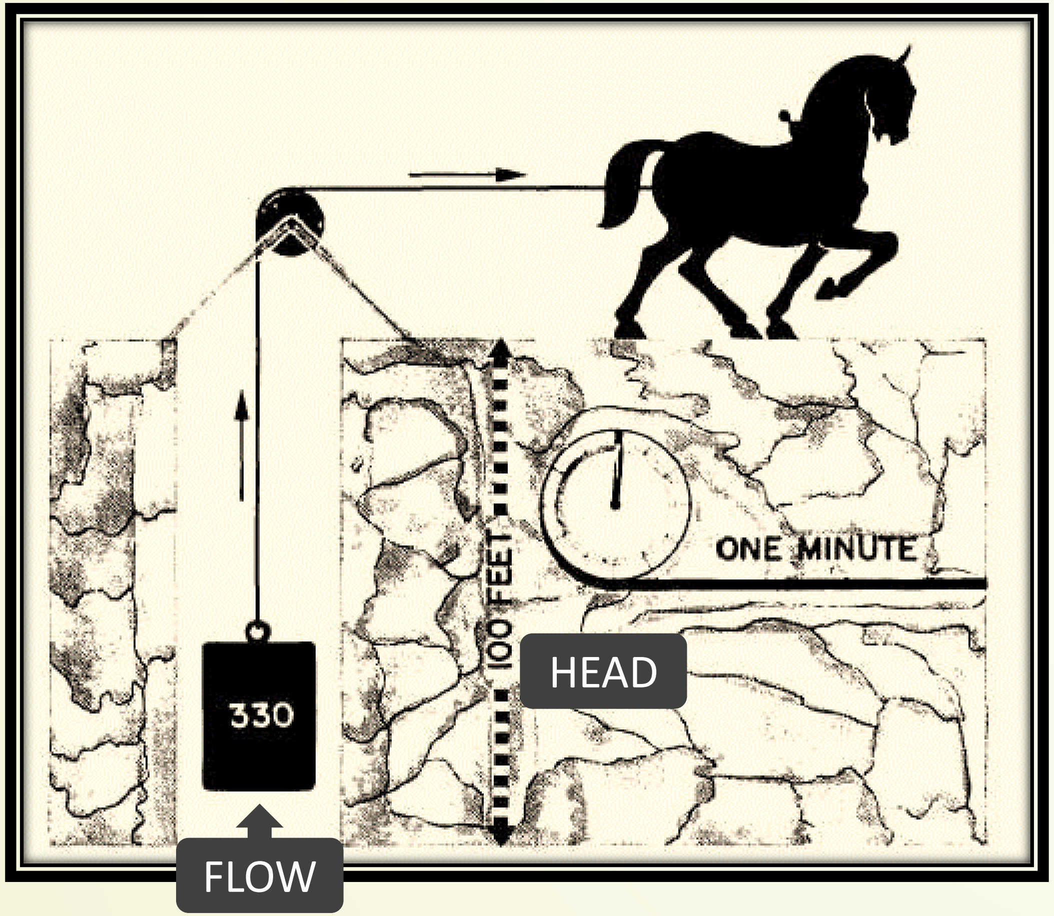
Note on the Pumped Fluid

- For this presentation the pumped fluid is water @ 60˚F

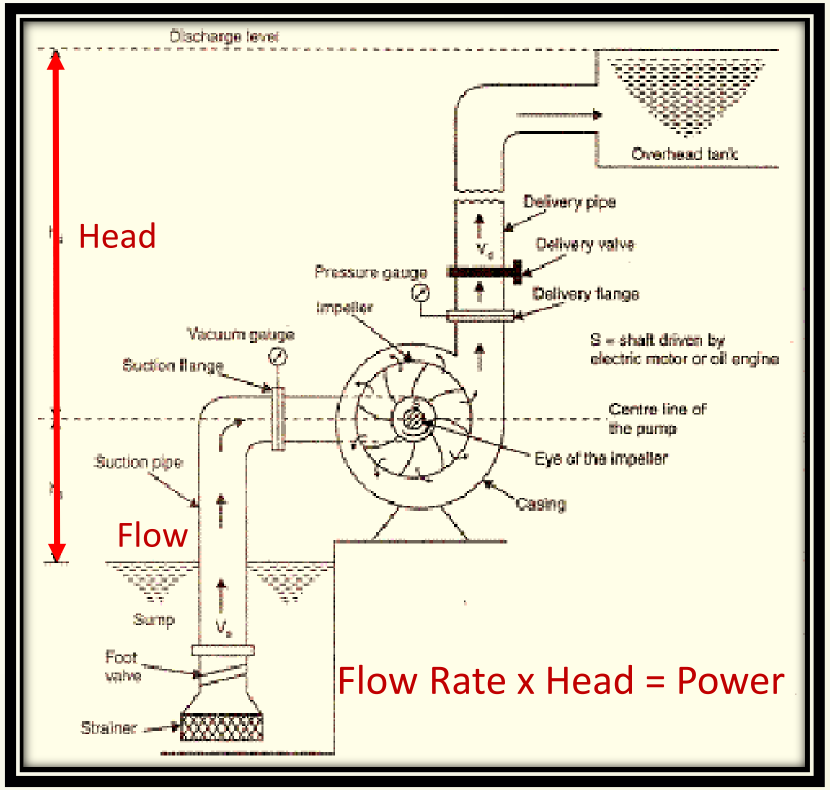
- For glycol, and very high temperature water, corrections to the formulas are necessary

IP Units of Power – ft.lb$_f$/min and ft.lb$_f$/sec or HP

In our local HVAC trade we use IP units, for e.g.:
Energy is ft.lb$_f$ or BTU
Power is ft.lb$_f$/min
1 HP = 33,000 ft.lbf/min



330 lb pulled up 100 feet in 1 minute = 33,000 ft.lb$_f$ per minute = 1 HP
33 lb pulled up 1000 feet in 1 minute = 33,000 ft.lb$_f$ per minute = 1 HP
3330 lb pulled up 10 feet in 1 minute = 33,000 ft.lb$_f$ per minute = 1 HP



The Concept of Fluid Head

HEAD is ENERGY. The units of HEAD are ft.lb_f/lb_f. Energy *per pound* of fluid.
The lb_f cancels out and so we use only ft.
It helps if you remember the full units when thinking about pumps and flow.

500 gpm
= 500 x 8.34
= 4,170 lb_f/min

Pump Selection
500 gpm @ 60 ft.

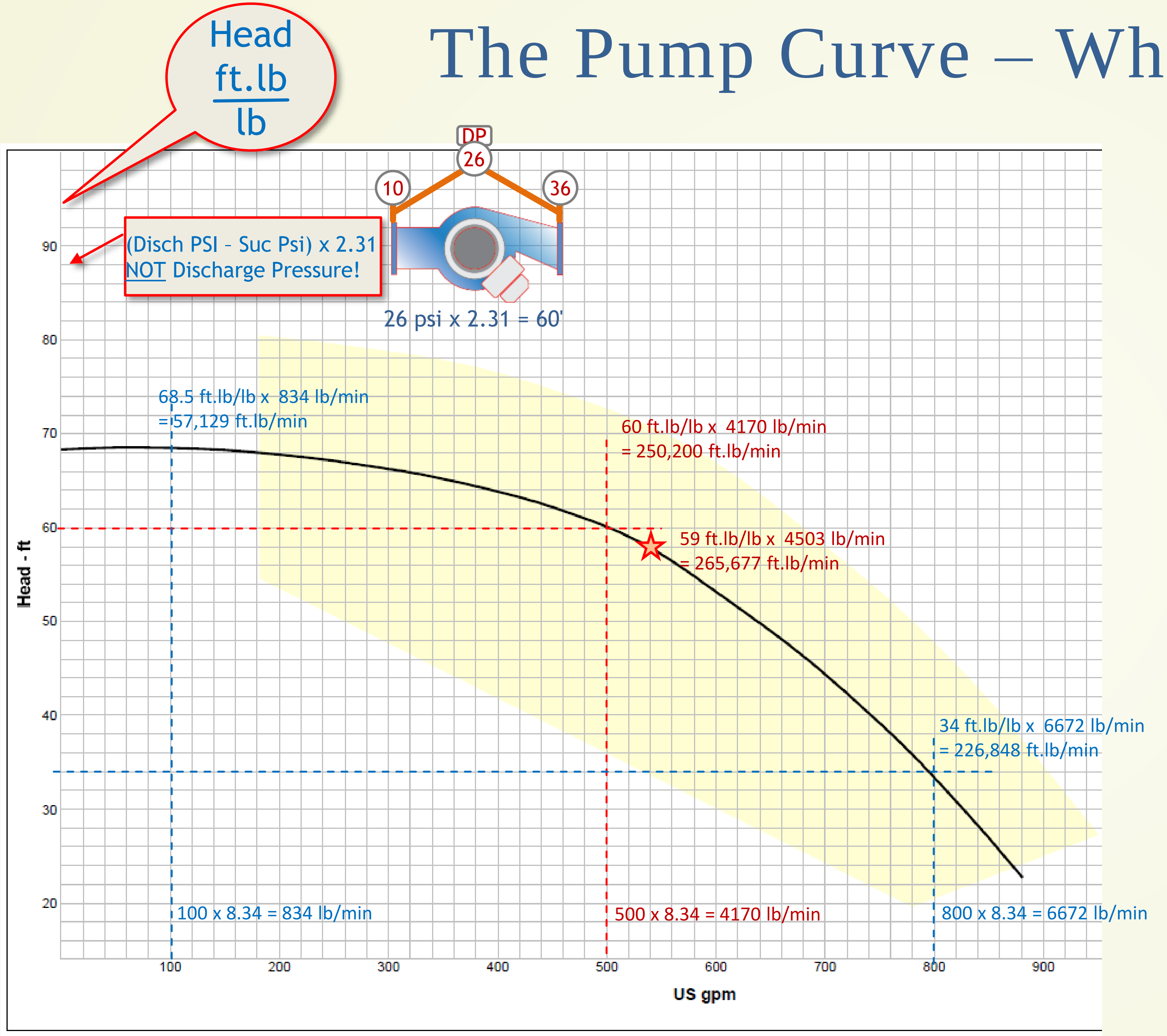
Pump Power (Water HP)
= 4,170 x 60 = 250,200 ft.lb_f/min
= 250,200 ÷ 33,000 = 7.58 WHP

500 gpm
= 500 x 8.34
= 4,170 lb_f/min

Throttled Valve
20 ft. HEAD Loss

WASTED Power (Water HP)
= 4,170 x 20 = 83,400 ft.lb_f/min
= 83,400 ÷ 33,000 = 2.53 WHP

The Pump Curve – What is it?



What is the PUMP CURVE telling us?

Very simply the Pump Curve tells us that: for any given flow (pounds/min) going through the pump, how many foot-pounds of energy will be added to every pound.

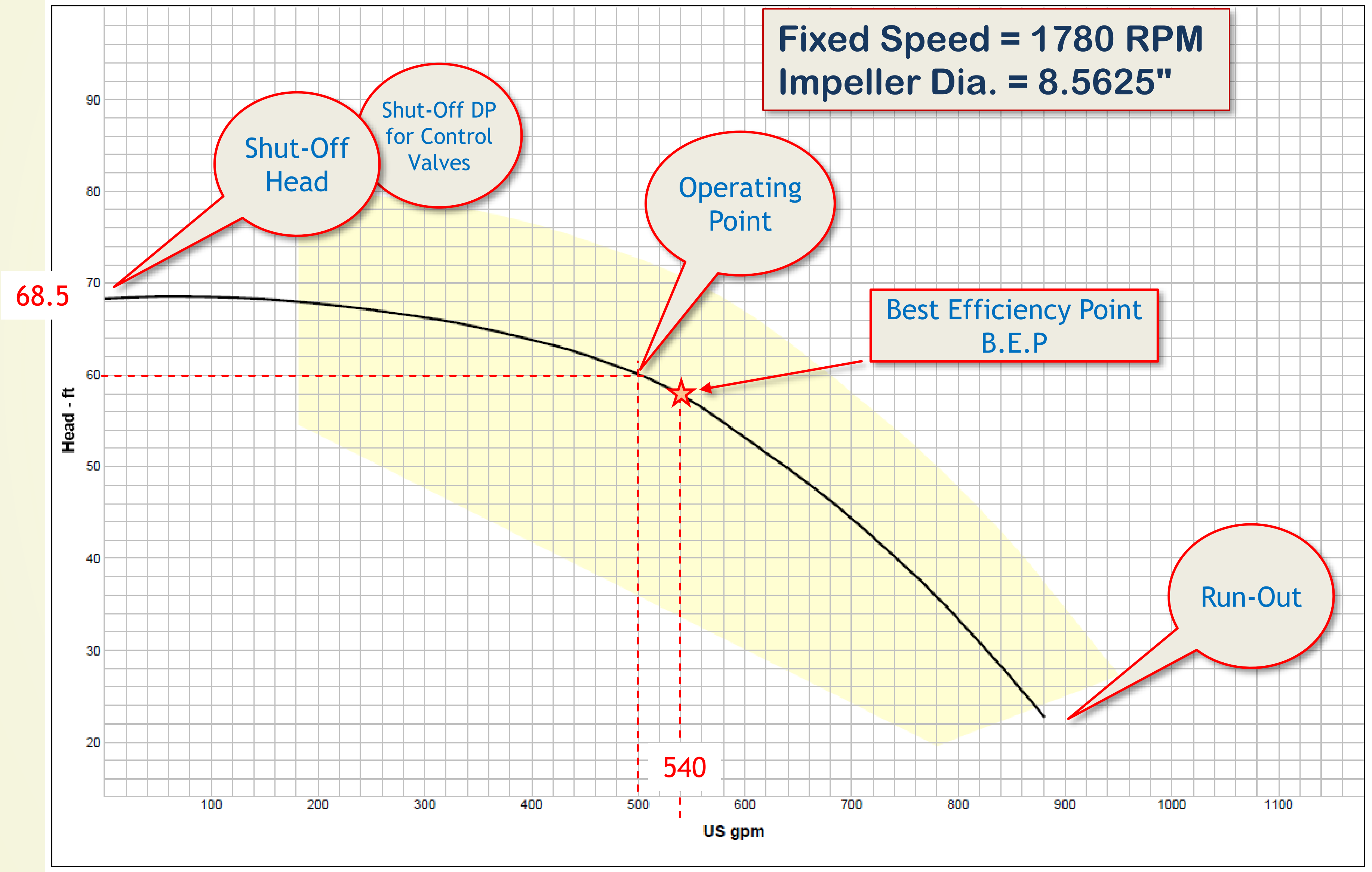
For e.g. @ 500 gpm (4170 lb/min),
60 ft.lb of energy is being added to every pound, for a total of
60 x 4170 = 250,200 ft.lb/min

The Best Efficiency Point (B.E.P) is where this product is a maximum on the curve

Note as the flow rate increases the TDH decreases or a lower TDH shows a higher flow rate

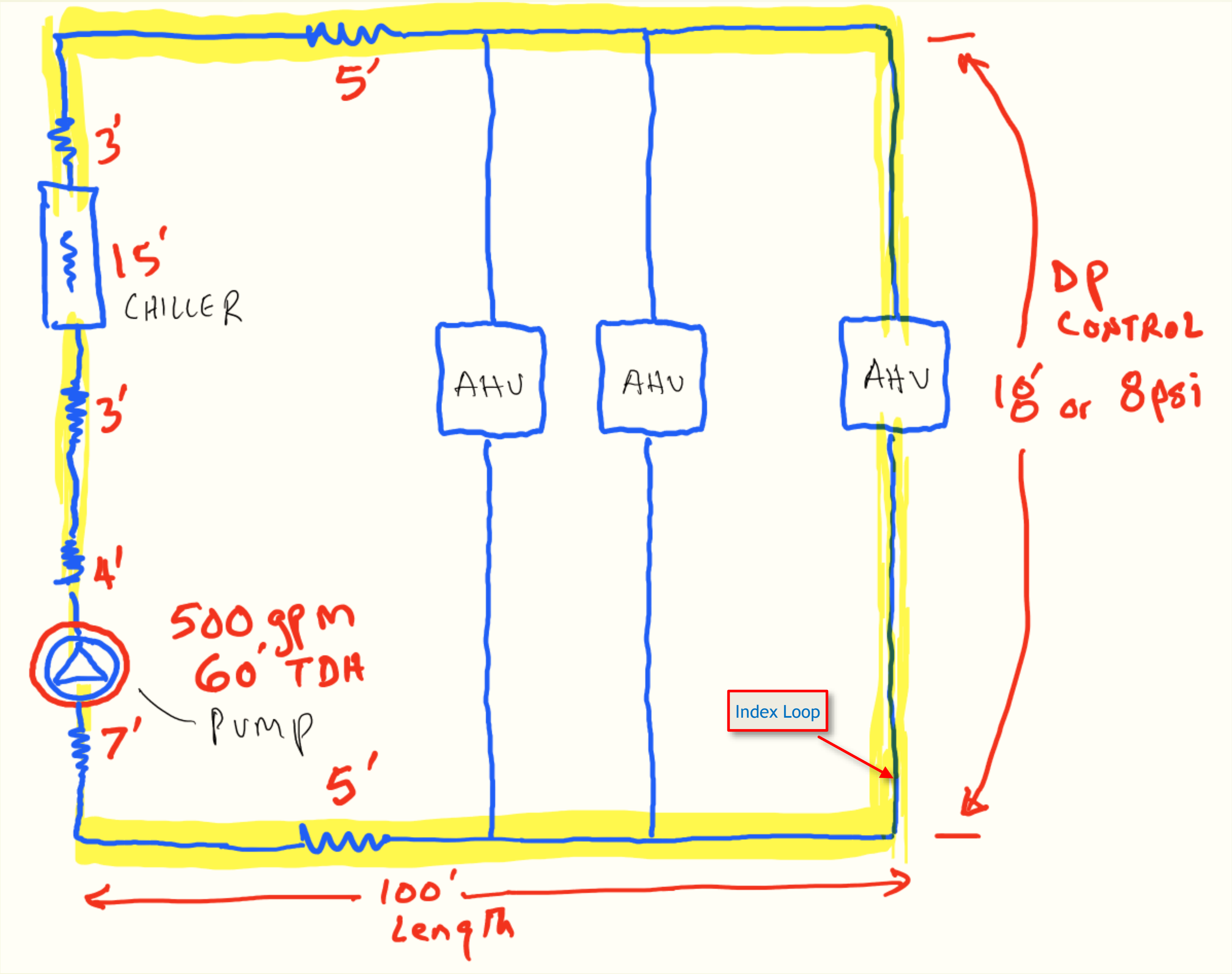
The pump can ONLY operate on its curve. If your field data plots a point elsewhere then you have a problem. (Happens all the time!)

The Pump Curve – Nomenclature



Accurate DP gage for troubleshooting Pump systems

System Head Loss Calc.



PD calcs documentation is now Code.

Always run actual pump head calcs. Shouldn't take more than 30 minutes.

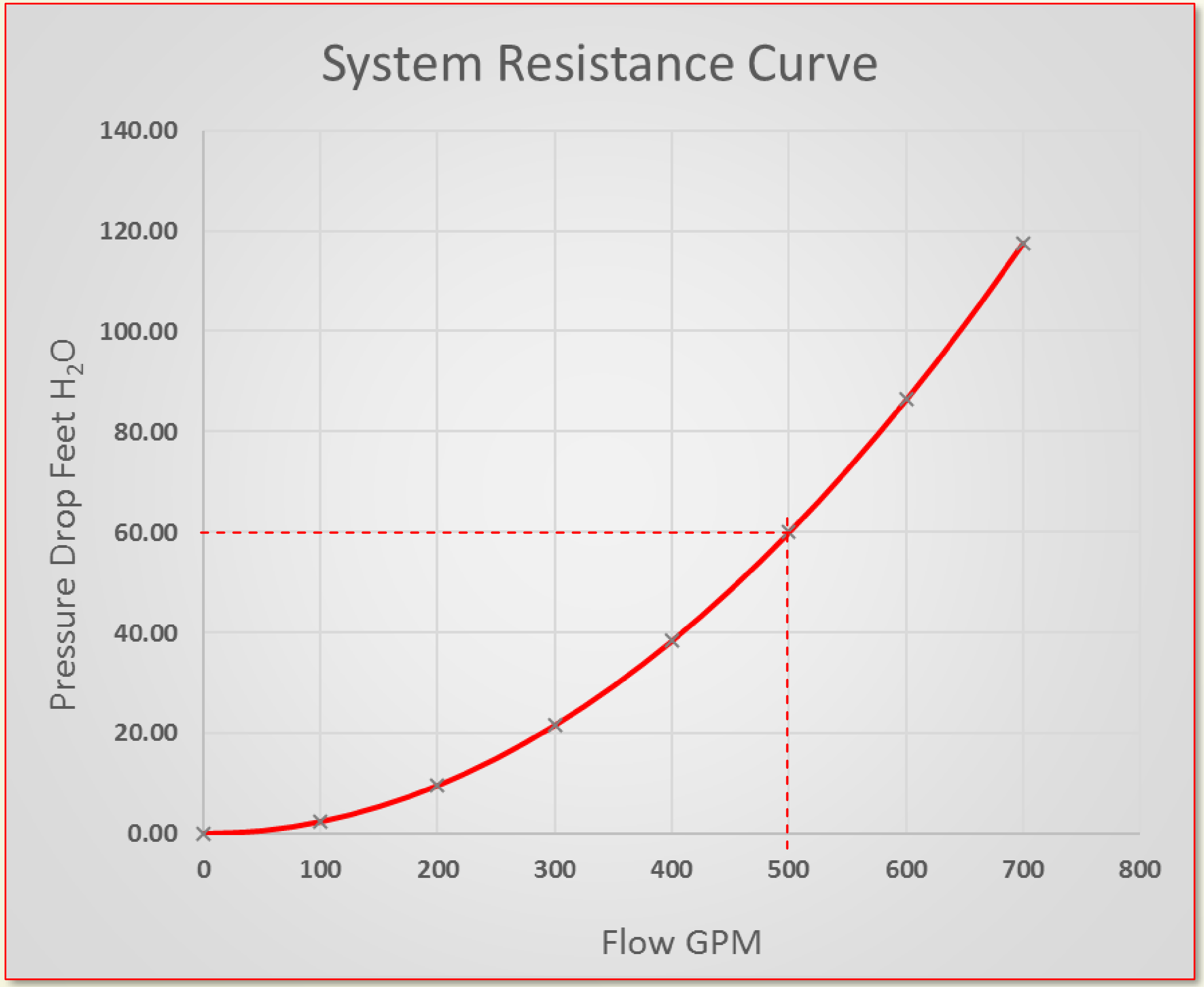
Note the "fixed" DP control. Acts as a constant "static" head on the pump.

Variable Primary System. Bypass not shown.

Rough approximation of Power:

(500 gal/min x 8.34 lb/gal x 60 ft) / 33,000 ft.lb/min
= 7.58 WHP
@ 75% Pump Eff.
= 7.6/0.75 = 10 BHP

The System Resistance Curve – No Static Component



$$\frac{\Delta Head_{new}}{\Delta Head_{known}} = \left[\frac{GPM_{new}}{GPM_{known}}\right]^2$$

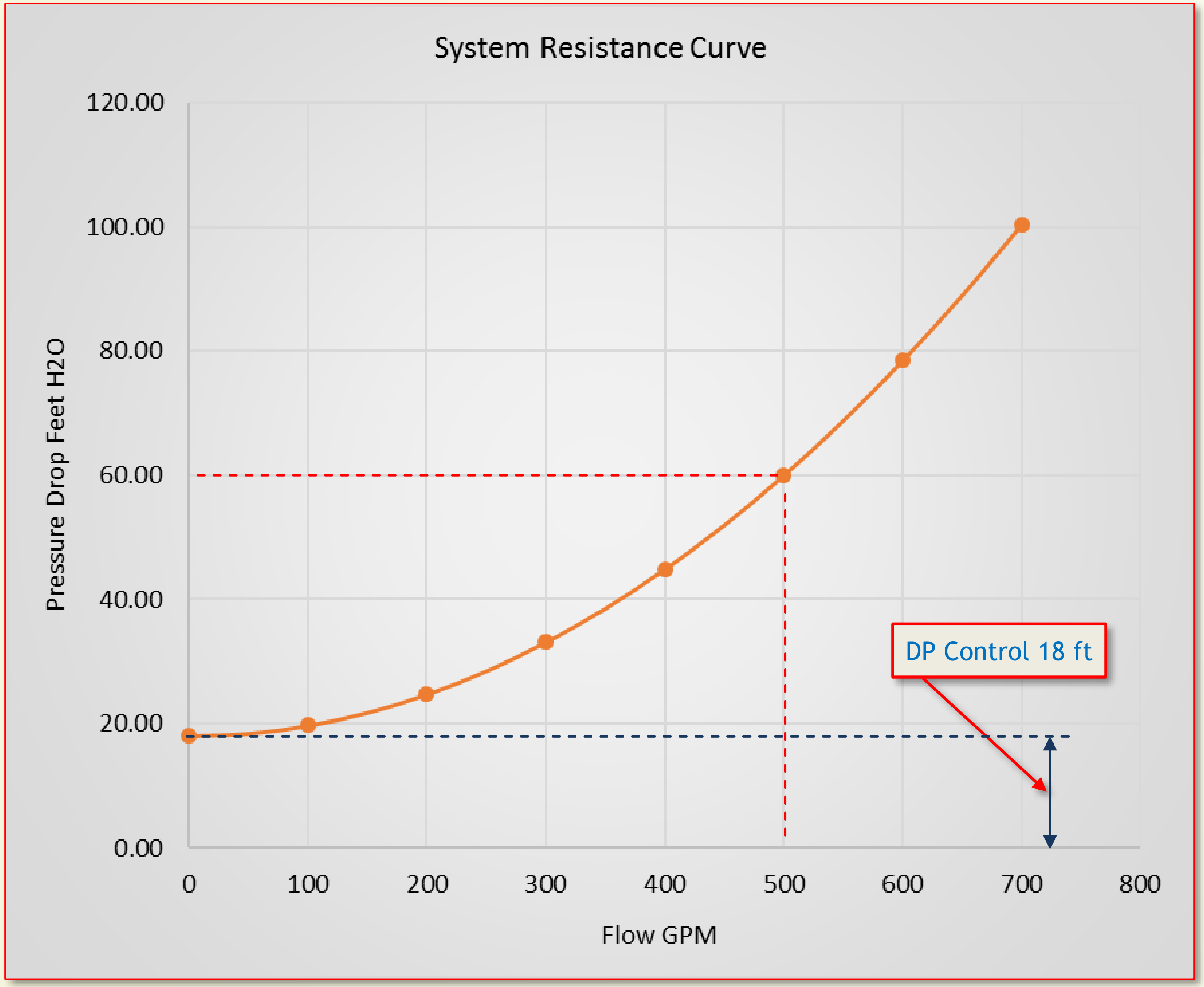
$$\Delta Head_{new} = \left[\frac{GPM_{new}}{GPM_{known}}\right]^2 \text{ x } \Delta Head_{known}$$

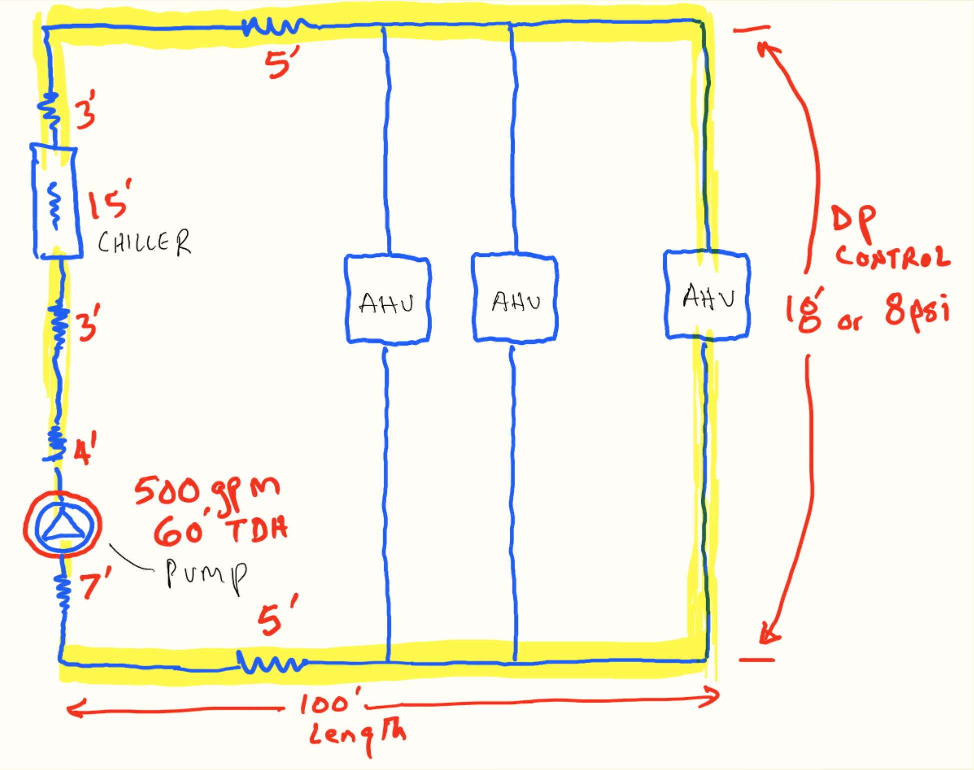
$$\Delta Head_{new} = \left[\frac{GPM_{new}}{500}\right]^2 \text{ x } 60$$

$$\Delta Head_{new} = \left[\frac{400}{500}\right]^2 \text{ x } 60 = 38.4'$$

Note: Some experts recommend a slightly lower exponent than 2 above. But based on the accuracy of the underlying pipe and fitting pressure drop data, the added complexity is just not justified.

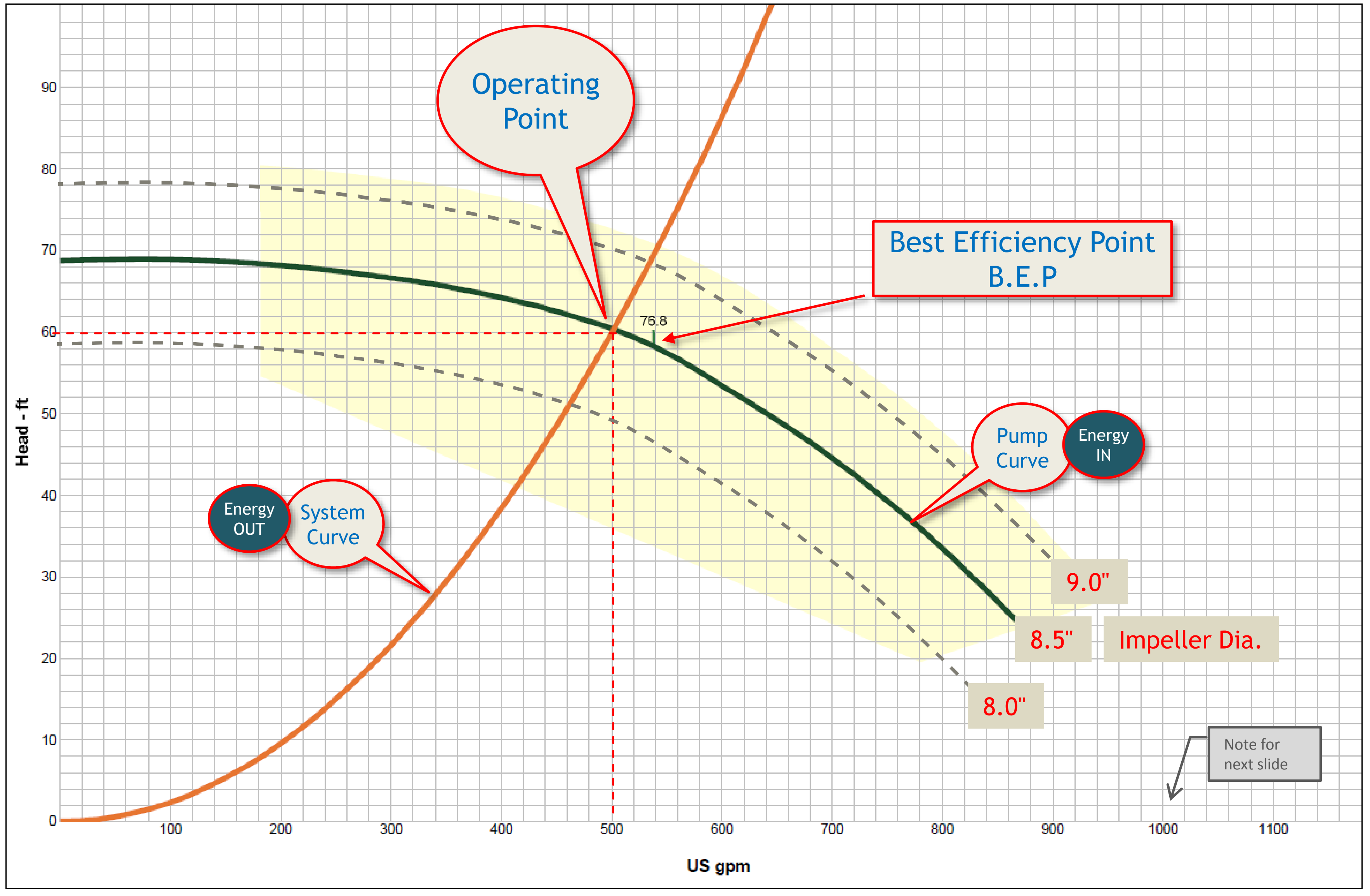
The System Resistance Curve With DP Control (Static Head)





The curve can still be plotted using the square relationship in the previous slide, modified by the constant offset of the static head.

The Operating Point



NOTES:
The Pump Curve and the System Curve are two totally separate entities and yet when put together, the pump can ONLY operate where the system curve and the pump curve intersect.
Energy IN = Energy OUT

Pump impeller may have to trimmed to get the desired operating point.

(Or the Pump speed may have to be adjusted to get the desired operating point.)

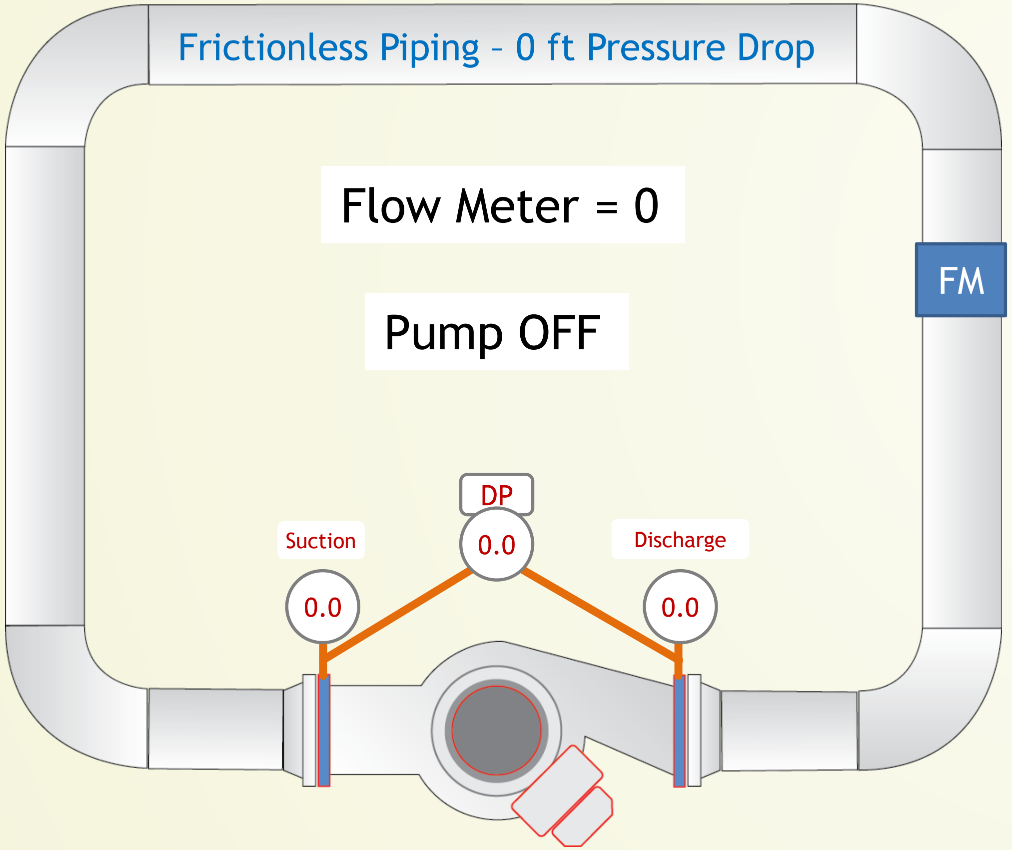
Operating point is seldom fixed because the System Curve moves up and down as the control valves (or manual valves) change position.

Most of this presentation will use a pump selected at:
500 gpm @ 60' Head (26 psi)

What Does a Pump Do? - A Thought Experiment

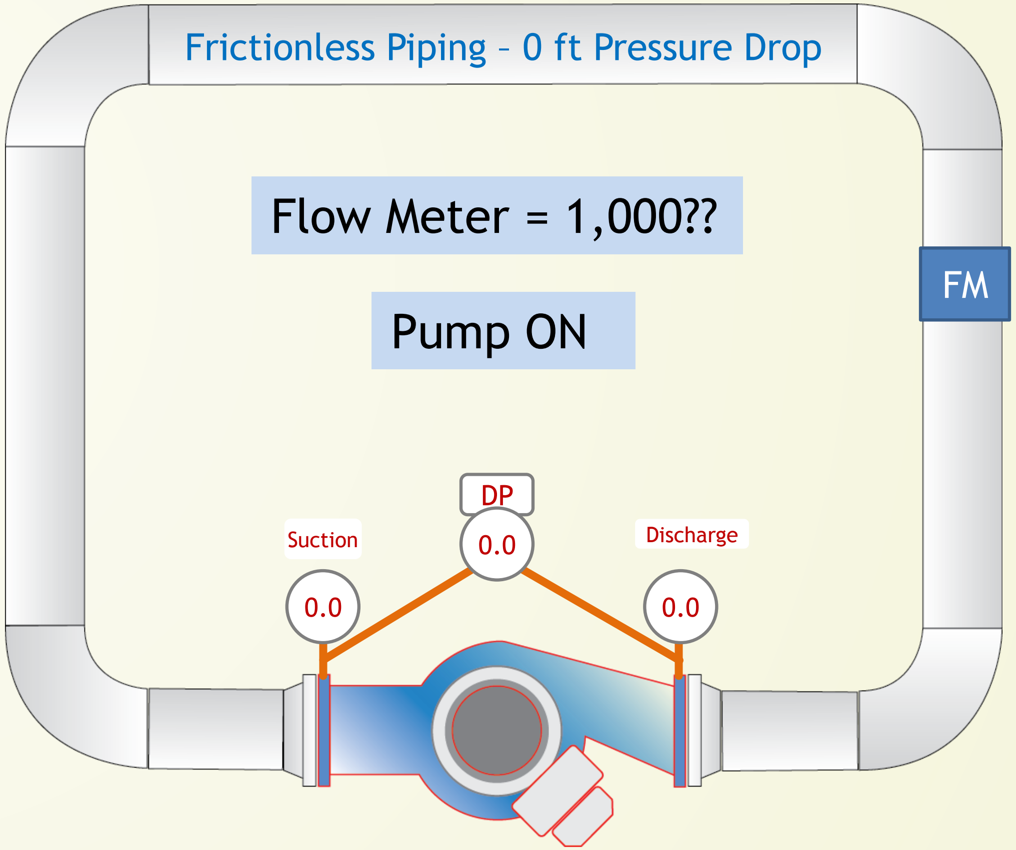
"Thought" experiment because of frictionless and the fact that the pump would quickly destroy itself in the real world! (We will discuss why in a later slide.)
Also we are ignoring pump internal pressure drop and system water expansion.

PLAN View – All Piping At The Same Elevation



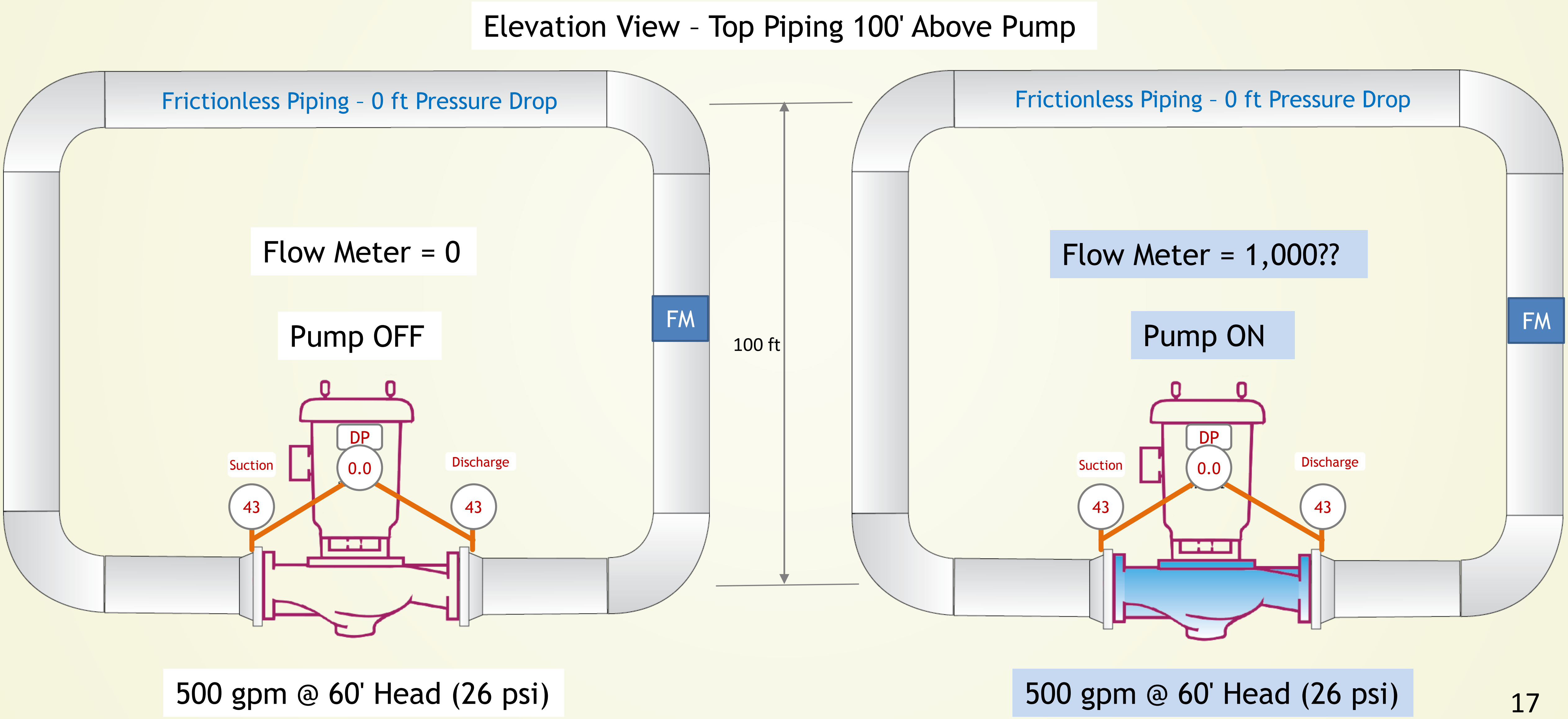
500 gpm @ 60' Head (26 psi)

All gages in PSI



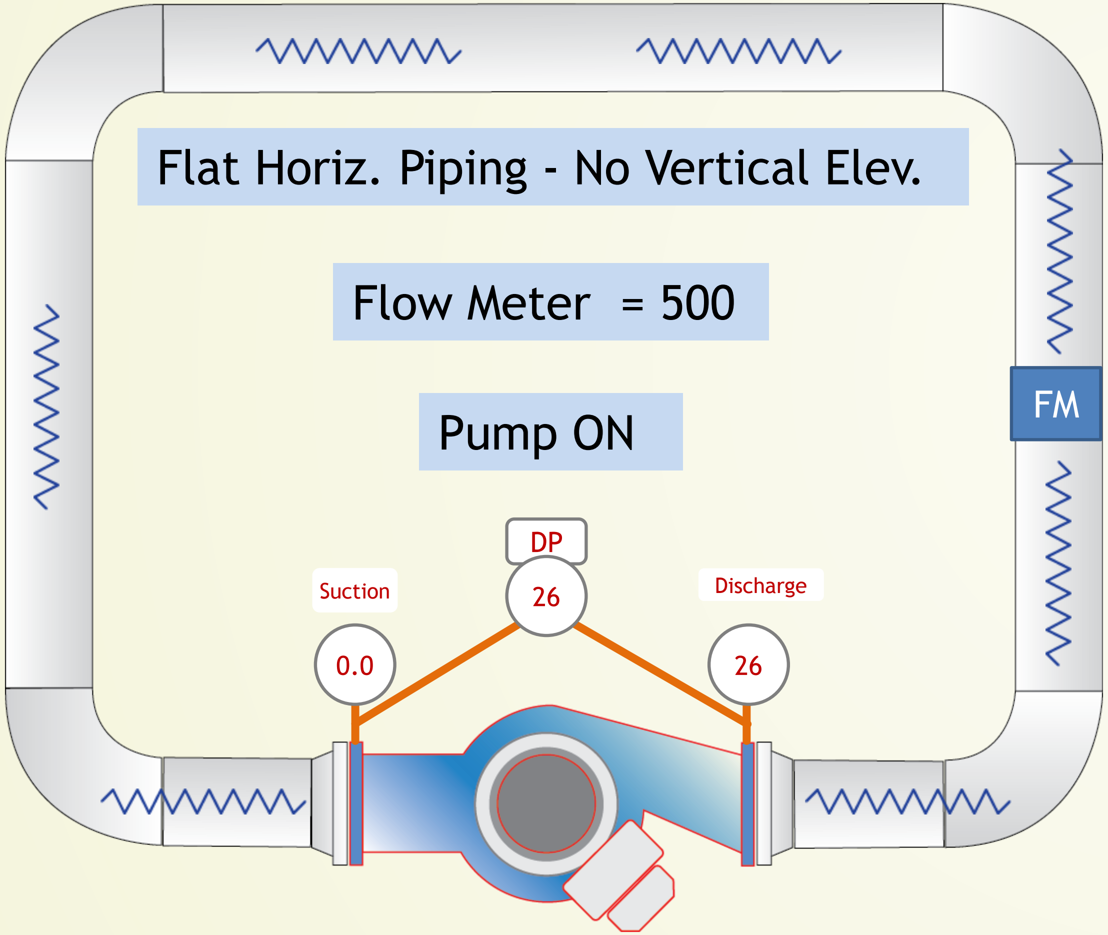
500 gpm @ 60' Head (26 psi)

What Does a Pump Do? - Thought Experiment -2

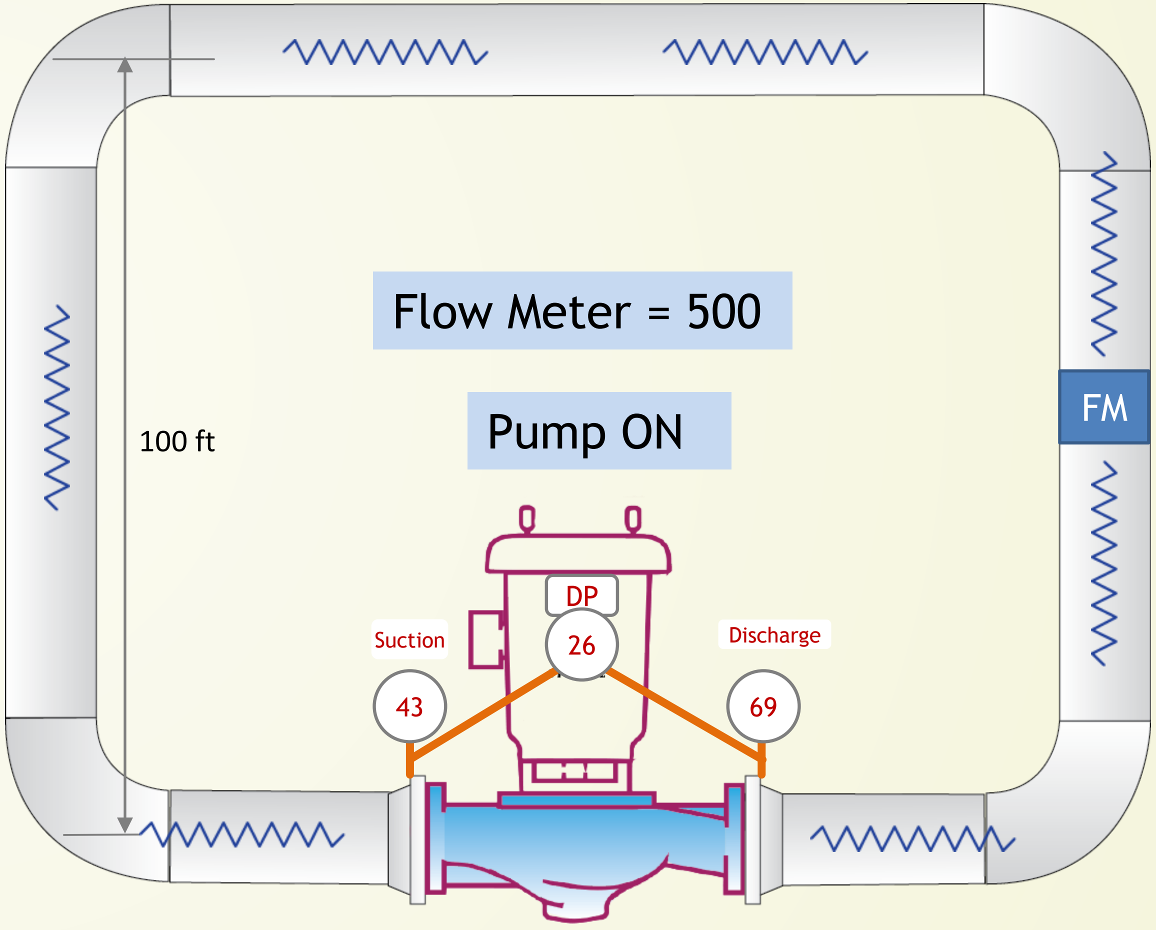


What Does a Pump Do? - Thought Experiment -3

Real System – 60 feet (26 psi) PD @ 500 gpm flow

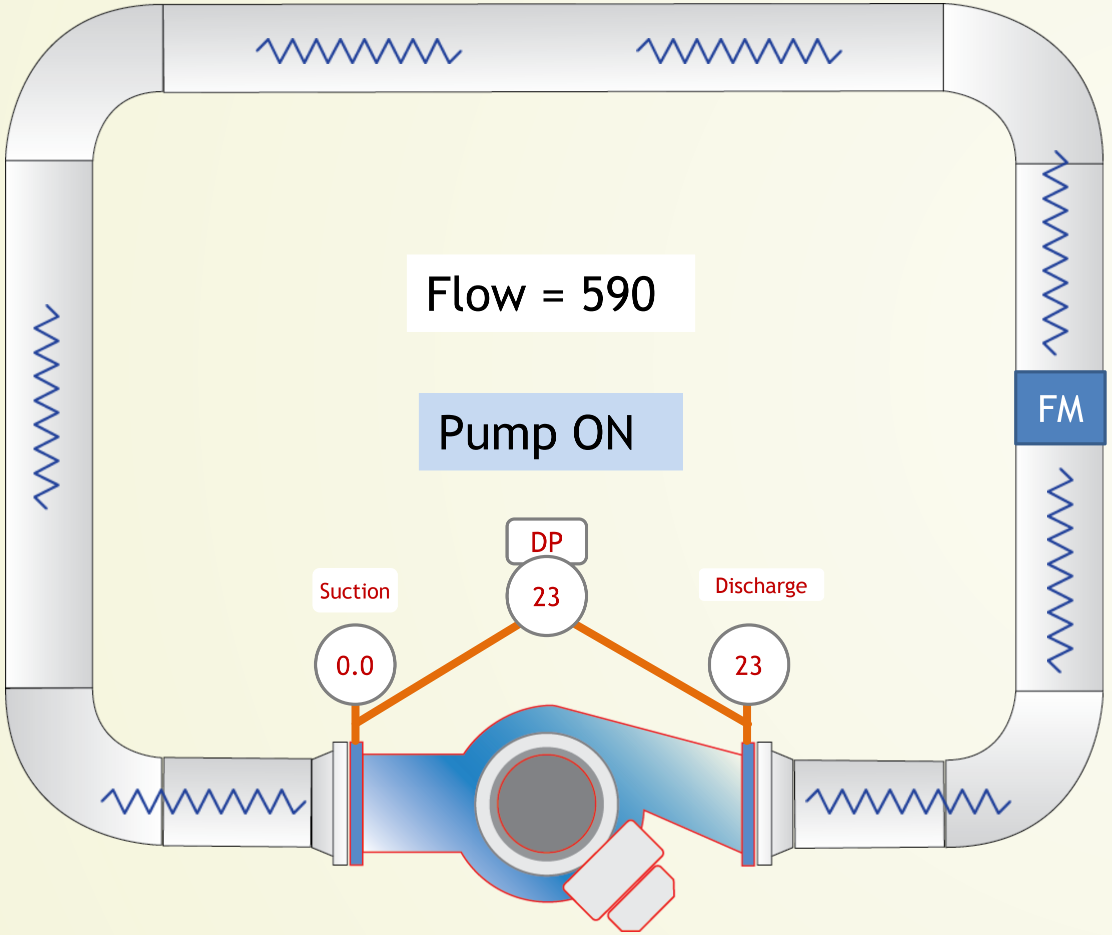


500 gpm @ 60' Head (26 psi)

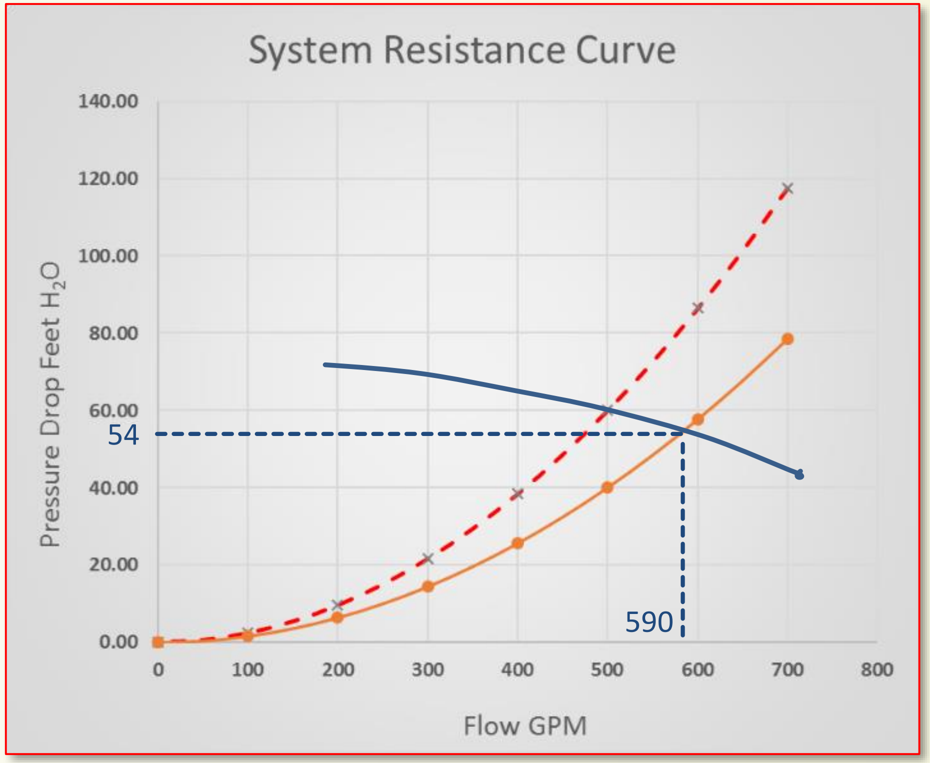


500 gpm @ 60' Head (26 psi)

What Does a Pump Do? - OVER-SIZED Pump



Selection 500 gpm @ 60' Head (26 psi)



54 ft ÷ 2.3 ft/psi ≈ 23 psi

Red Dashes – Pump Selection
Red Solid - Actual

What Does A Pump Do? - Takeaway CONCEPTS

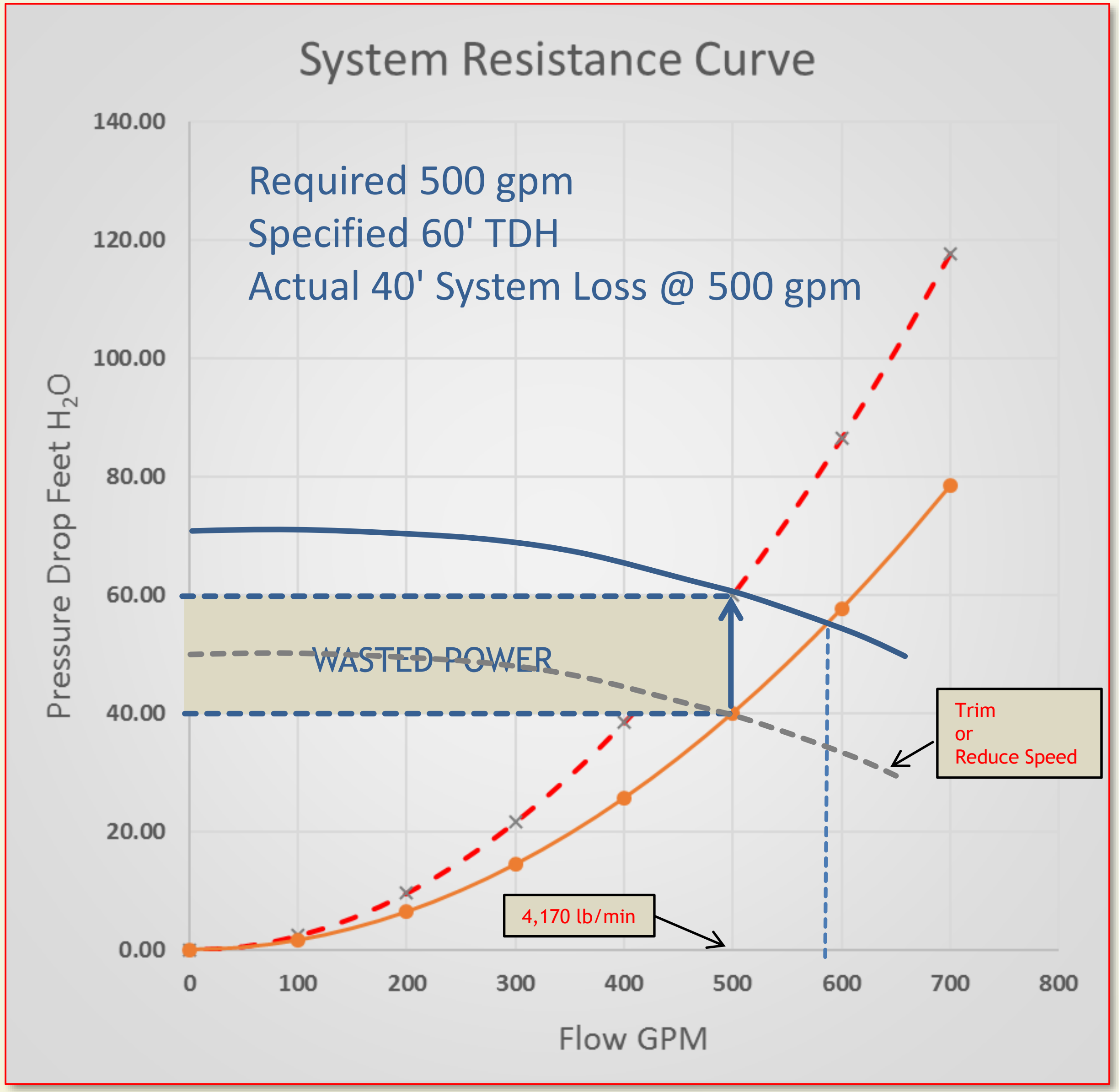
The Pump does not control the Differential Pressure reading across its flanges. The System Resistance does.

For a healthy pump, a lower DP will always be caused by MORE flow NOT LESS flow. (☹ See why you cannot troubleshoot with bad concepts? ☹)

The Pump does not "see" the static pressure of the system. (Of course, within working pressure limits of damage.)

The Pump cannot pressurize its tail. The suction pressure can drop (or remain the same) when the pump starts but cannot increase.

What Happens When A Pump is Oversized?



Valve Pressure Drop = 20 feet (choked)

(Remember POWER is ft.lb$_f$/min)

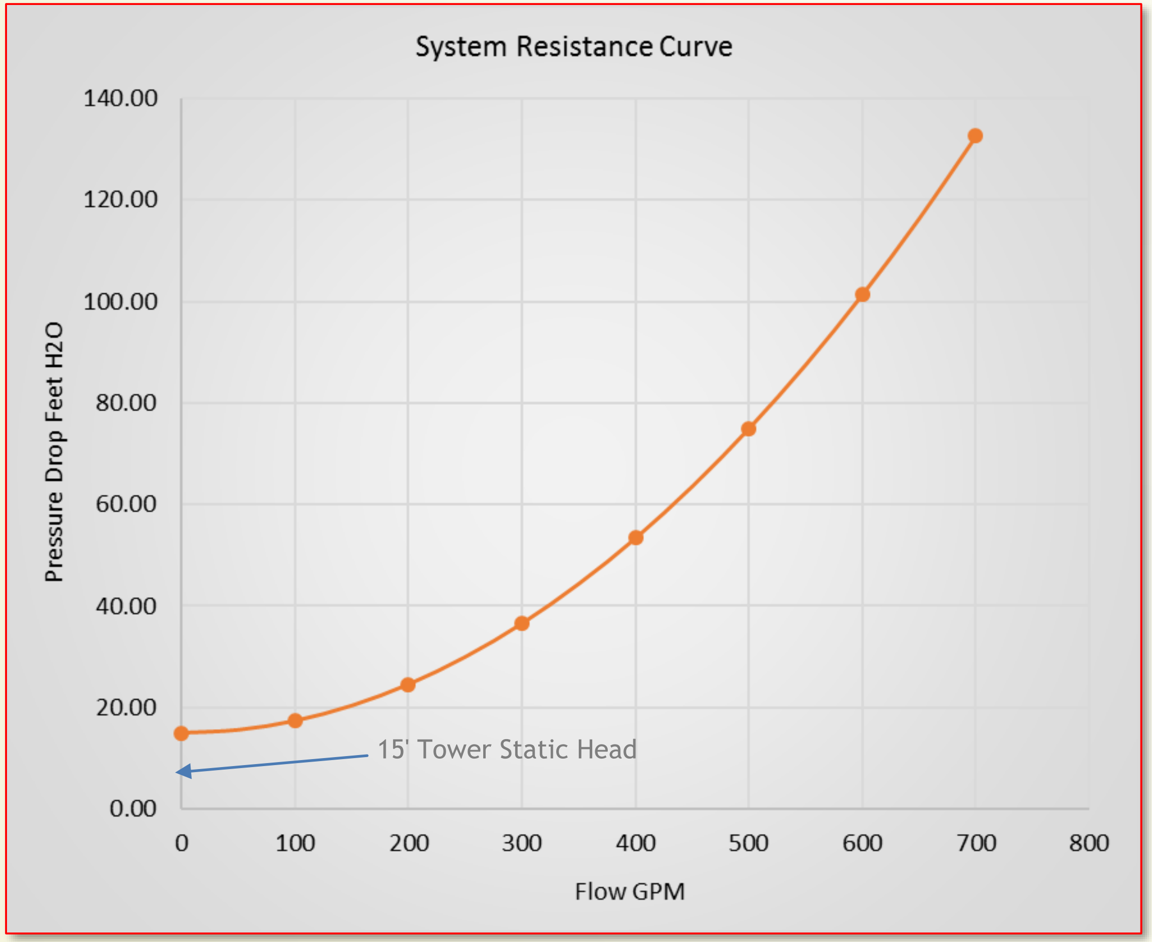
$$20 \frac{ft.lb_f}{lb_f} \times 4170 \frac{lb_f}{min} = 83,400 \frac{ft.lb_f}{min}$$

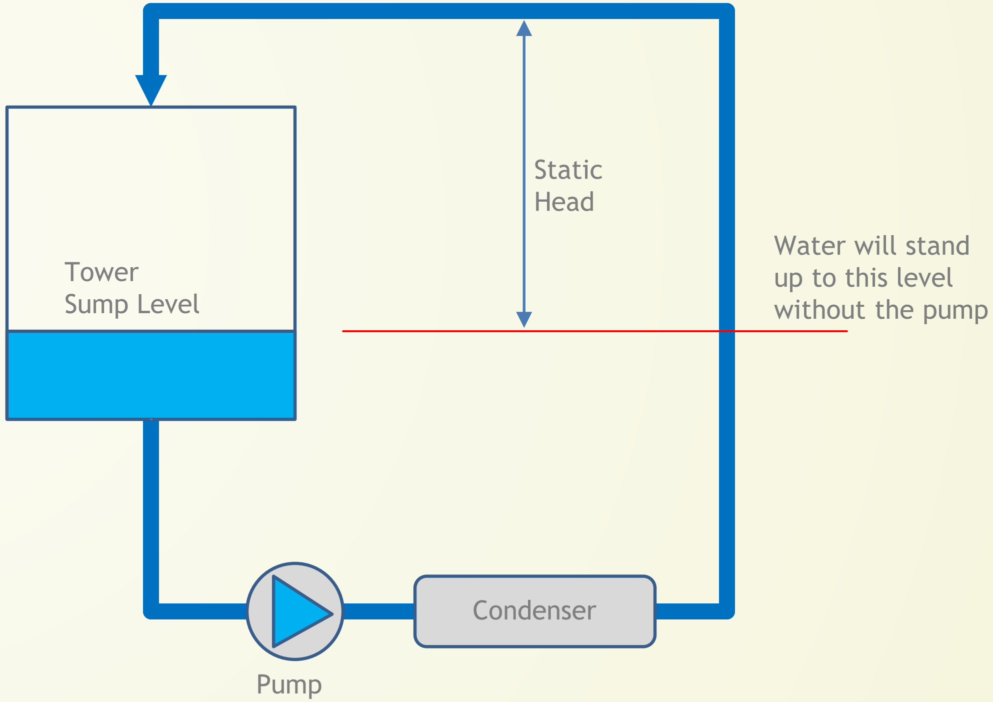
$$83,400 \frac{ft.lb_f}{min} \times \frac{1 \quad HP}{33,000 \frac{ft.lb_f}{min}} = 2.53 \quad WHP$$

2.53 ÷ 76% Pump Eff. = 3.33 BHP

NOT ACCEPTABLE!
Per new energy codes, either trim the impeller or provide a VFD

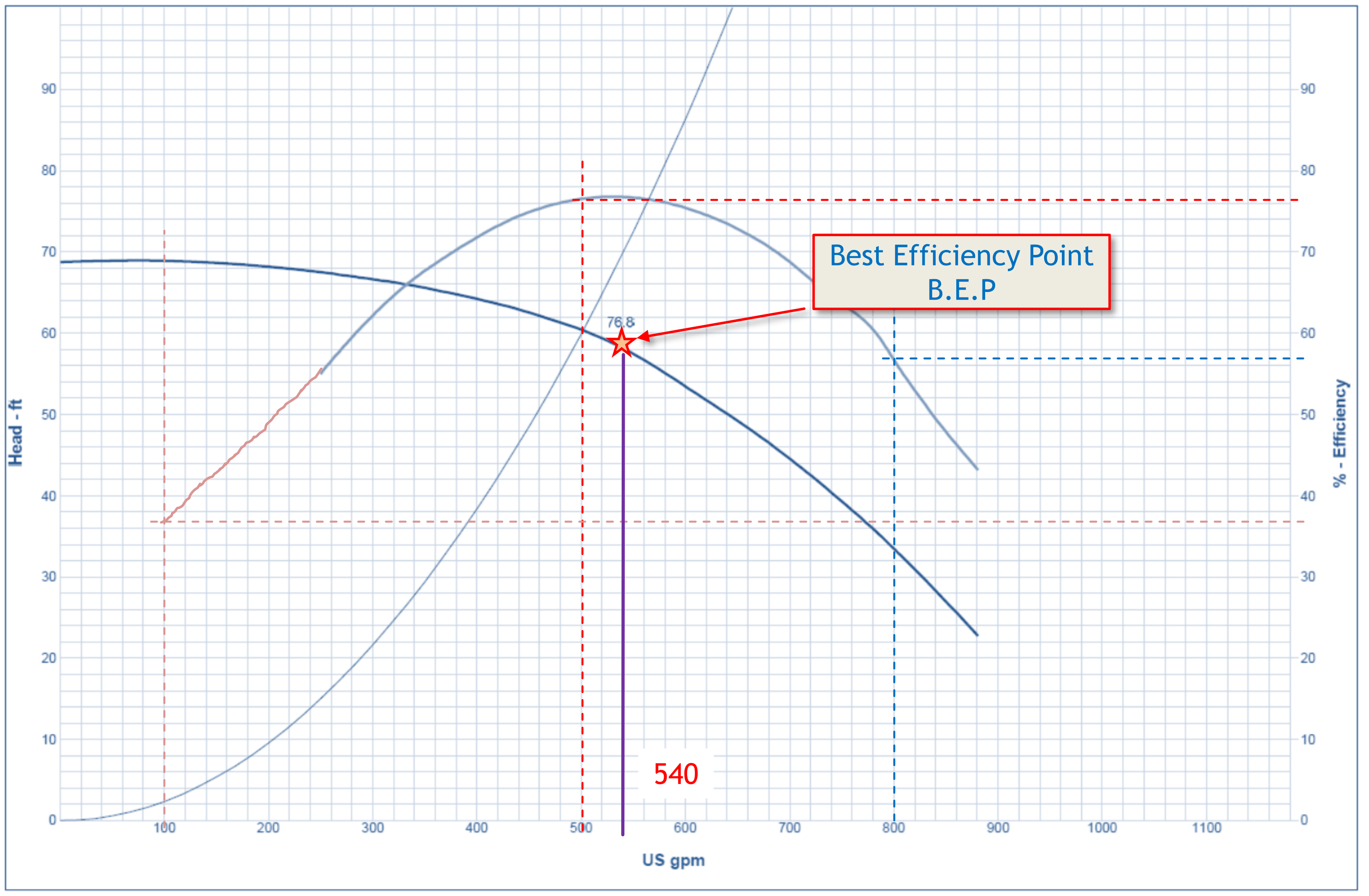
The System Resistance Curve – Open Cooling Towers



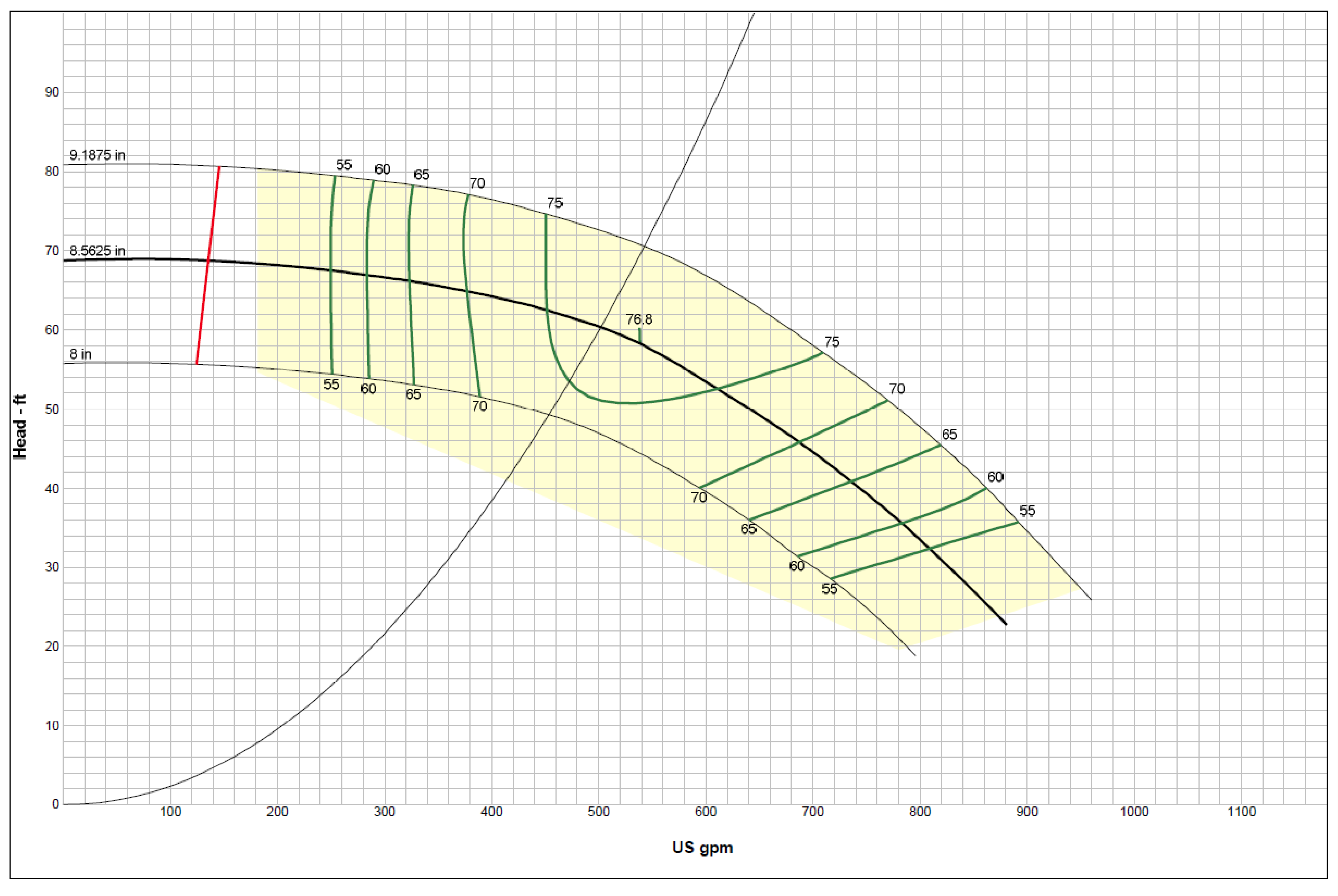


Remember nozzle pressure
drop for counter-flow towers
10' to 15' ??

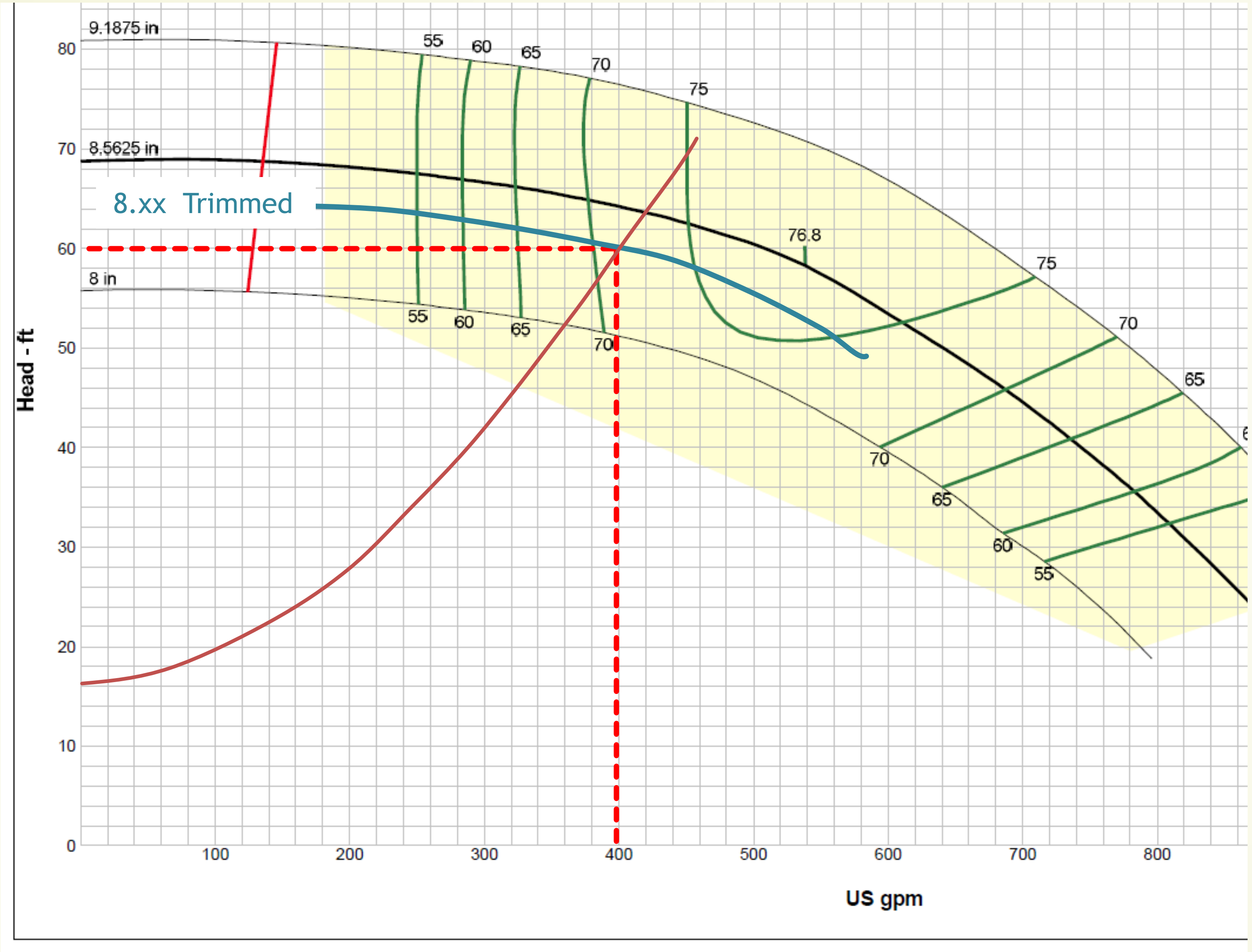
The Pump – Efficiency Curve



The Pump – Iso-Efficiency Lines



The Pump – Impeller Size & Trimming



Suppose that for some reason we want to operate our pump at:

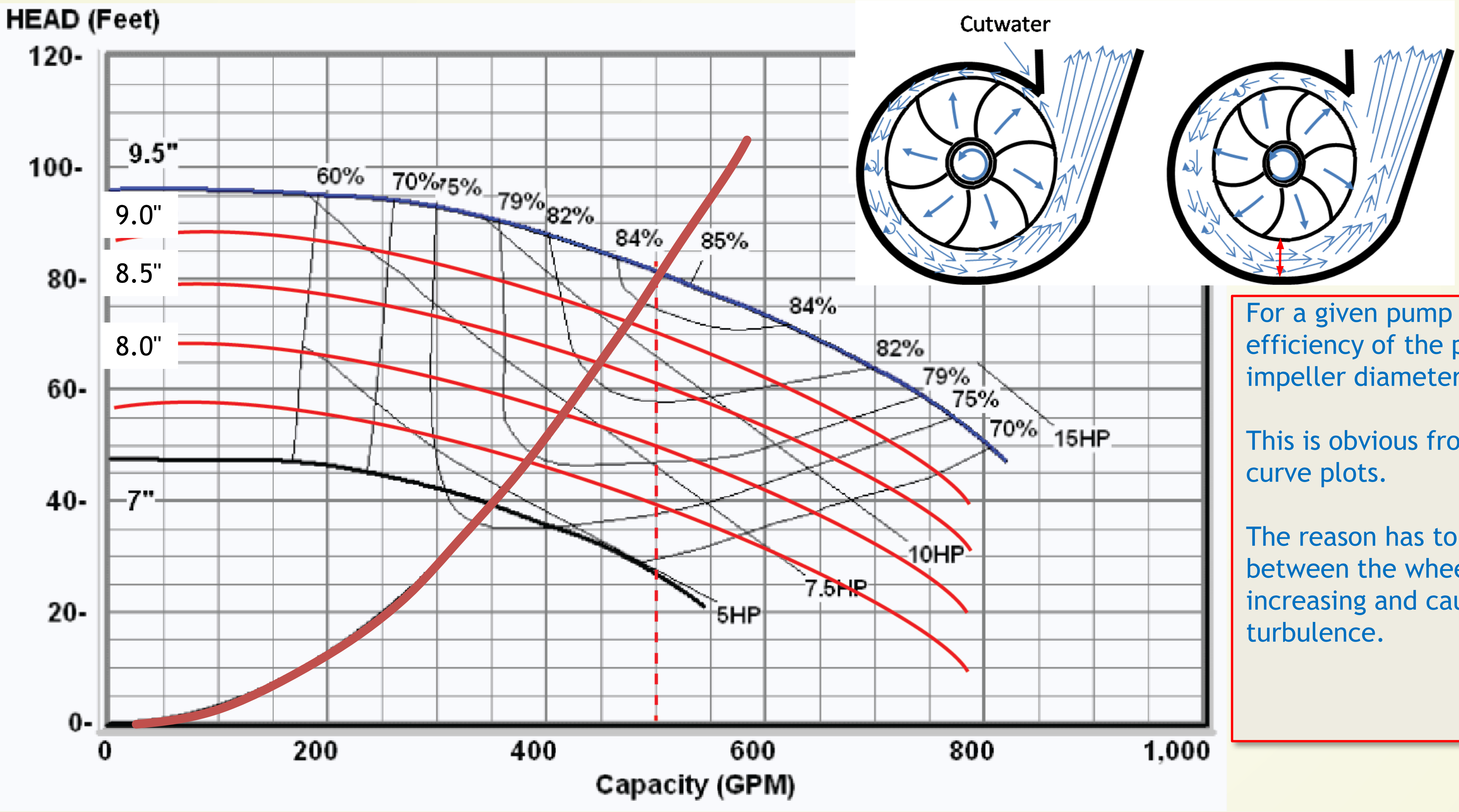
400 gpm @ 60 TDH

We could trim the impeller as shown to get a new operating point.

Notice what happens to the efficiency when you trim the impeller.

Note:
Remember the new codes want us to either trim the impeller or use VFD to slow down the pump, whenever the pump discharge valve is significantly choked for balance.

The Pump – Impeller Size & Efficiency

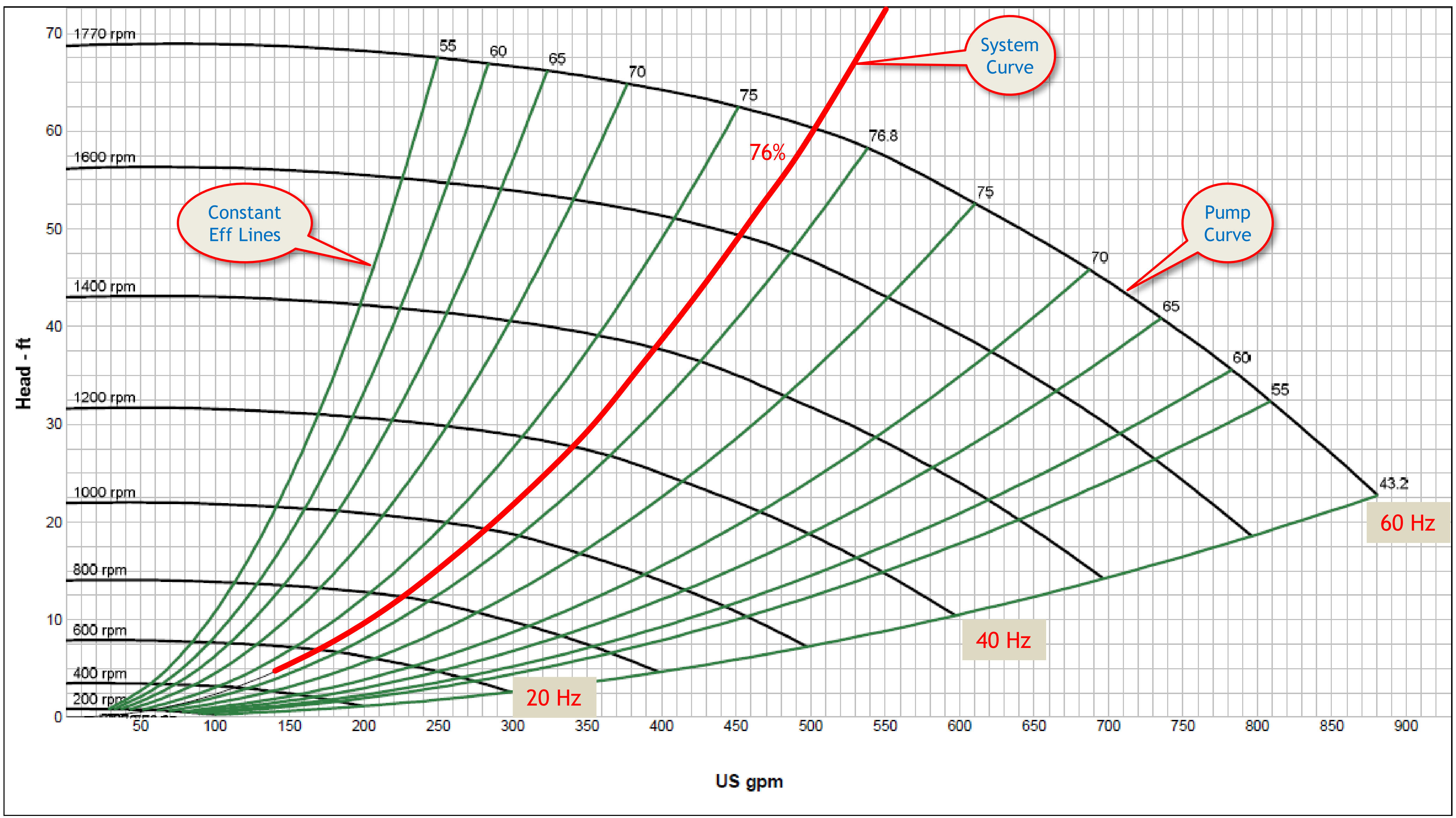


For a given pump impeller housing, the efficiency of the pump decreases as the impeller diameter decreases.

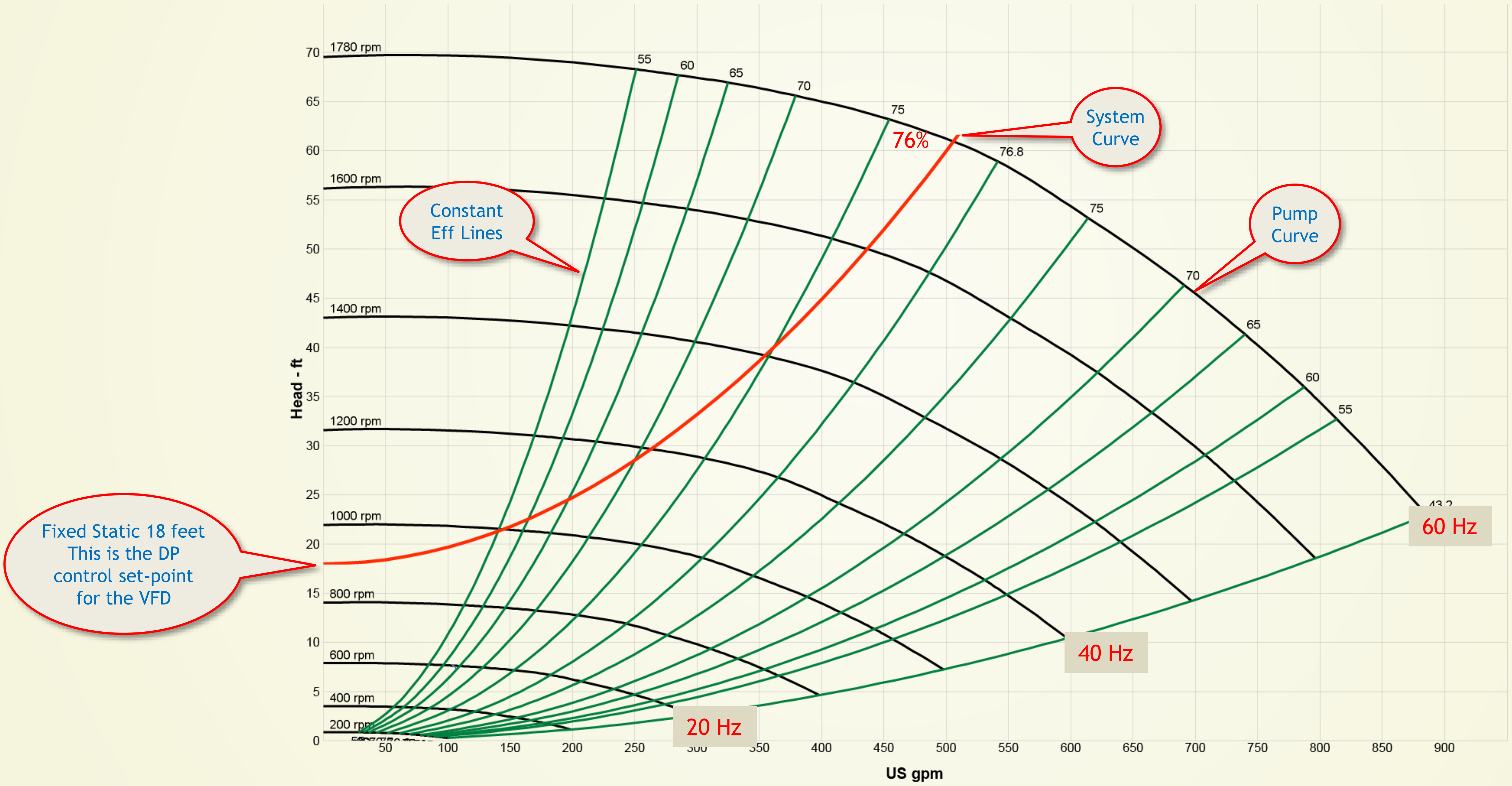
This is obvious from all manufacturer's curve plots.

The reason has to do with the clearance between the wheel and the volute increasing and causing recirculation and turbulence.

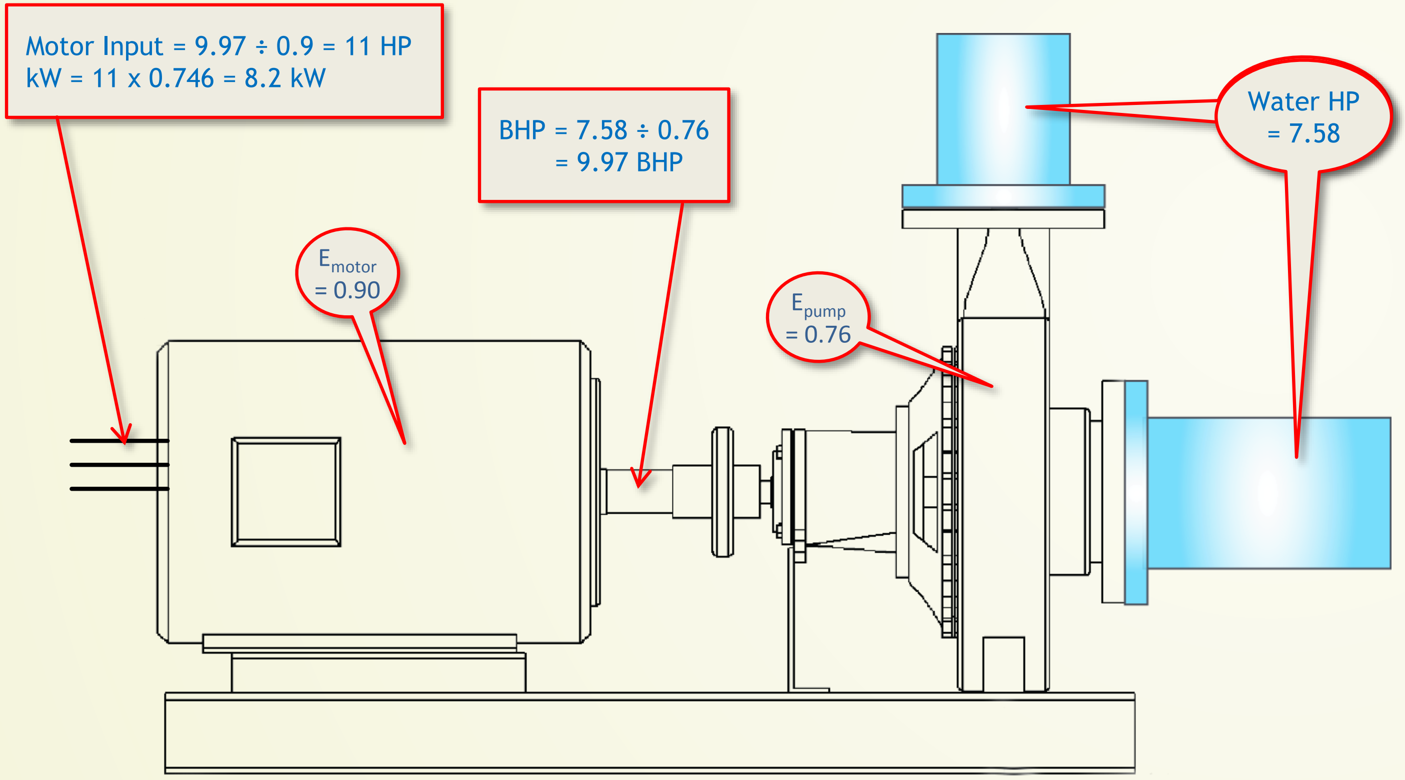
The Pump – VFD & Efficiency (VFD Peddler's Curve)



The Pump – VFD & Efficiency (Real World Curve)



Pump - POWER



$$WHP = \frac{GPM \times Head}{3960} \times Sp.\ Gr.$$

Our Selection:
500 gpm @ 60 TDH
= 7.58 WHP

Motor BHP
= 7.58 ÷ 0.76 = 9.97 BHP

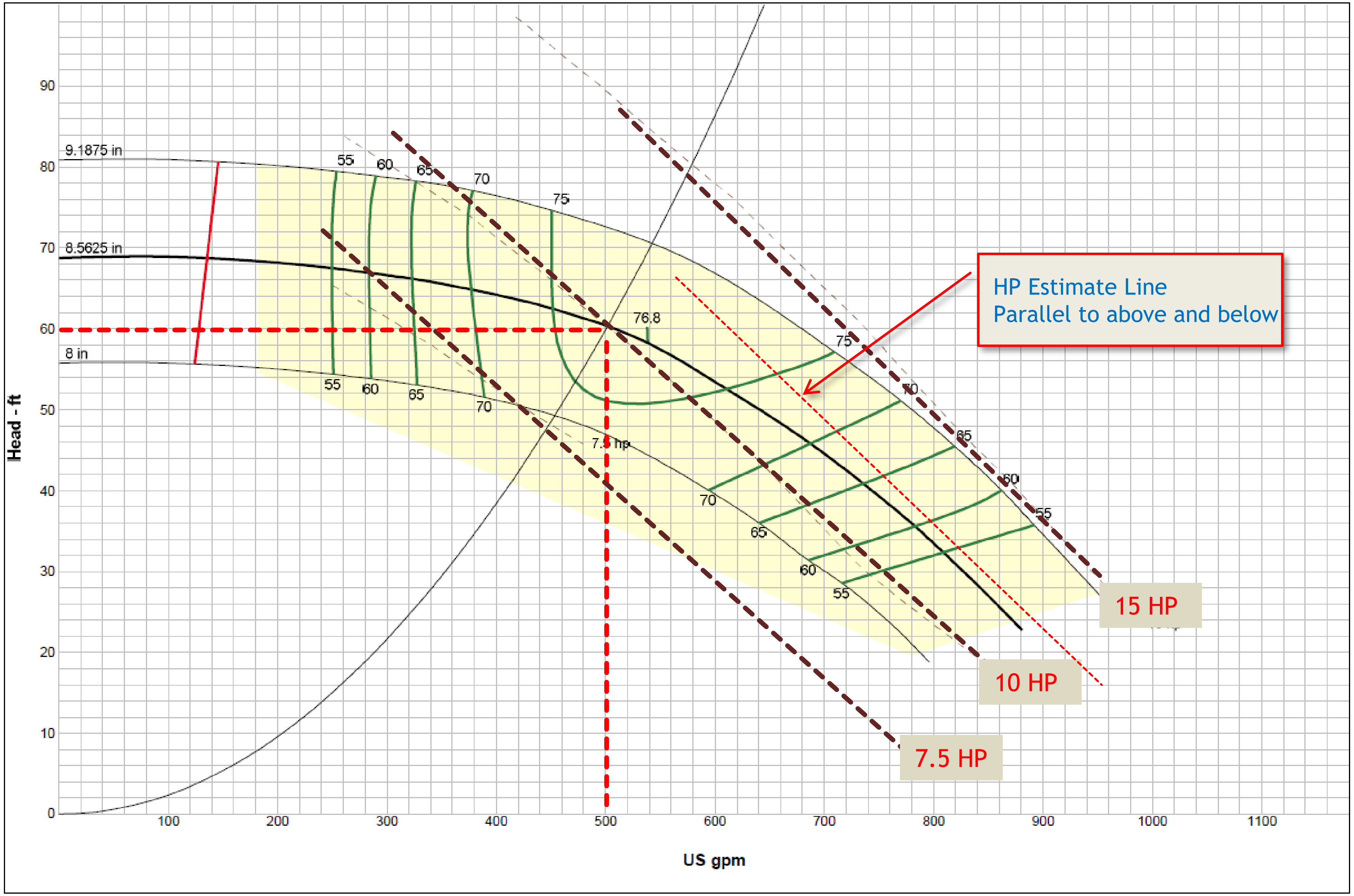
Motor Power Input
= 9.97 ÷ 0.9 = 11 HP
= 11 x 0.746 = 8.2 kW

WHP in kW = 7.58 x 0.746 = 5.65kW

Wire to Water Efficiency:
5.65/8.2kW = 69%

On an actual pump, you would measure the kW input to the motor by a Wattmeter for calculating WWE.

The Pump – HP Lines



The (often abused) Pump Affinity Laws

$$\frac{GPM_1}{GPM_2} = \left[\frac{RPM_1}{RPM_2}\right]$$

$$\frac{Head_1}{Head_2} = \left[\frac{RPM_1}{RPM_2}\right]^2$$

$$\frac{BHP_1}{BHP_2} = \left[\frac{RPM_1}{RPM_2}\right]^3$$

So if RPM is halved, the BHP goes down to $(0.5)^3 = 0.125 = 12.5\%$

1. You cannot use these relationships for systems with "static" resistance. Most HVAC systems have a constant or static component. For e.g. our chilled water system example has 18' constant DP.

2. You cannot use these relationships to compare before and after you change system curve by throttling valves.

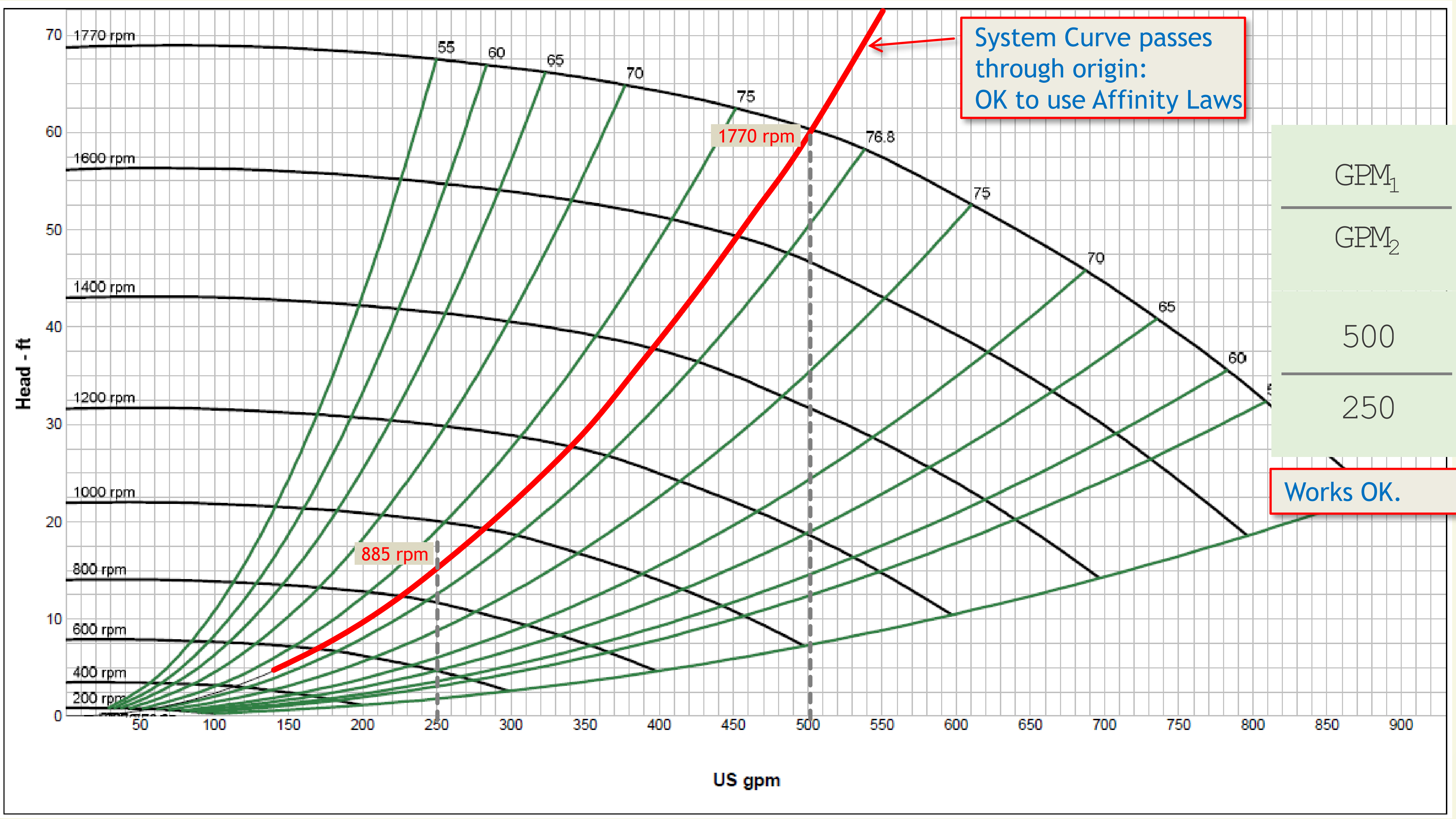
3. See previous VFD slides.

$$\frac{GPM_1}{GPM_2} = \left[\frac{Dia._1}{Dia._2}\right]$$

$$\frac{Head_1}{Head_2} = \left[\frac{Dia._1}{Dia._2}\right]^2$$

$$\frac{BHP_1}{BHP_2} = \left[\frac{Dia._1}{Dia._2}\right]^3$$

The (often abused) Pump Affinity Laws -2



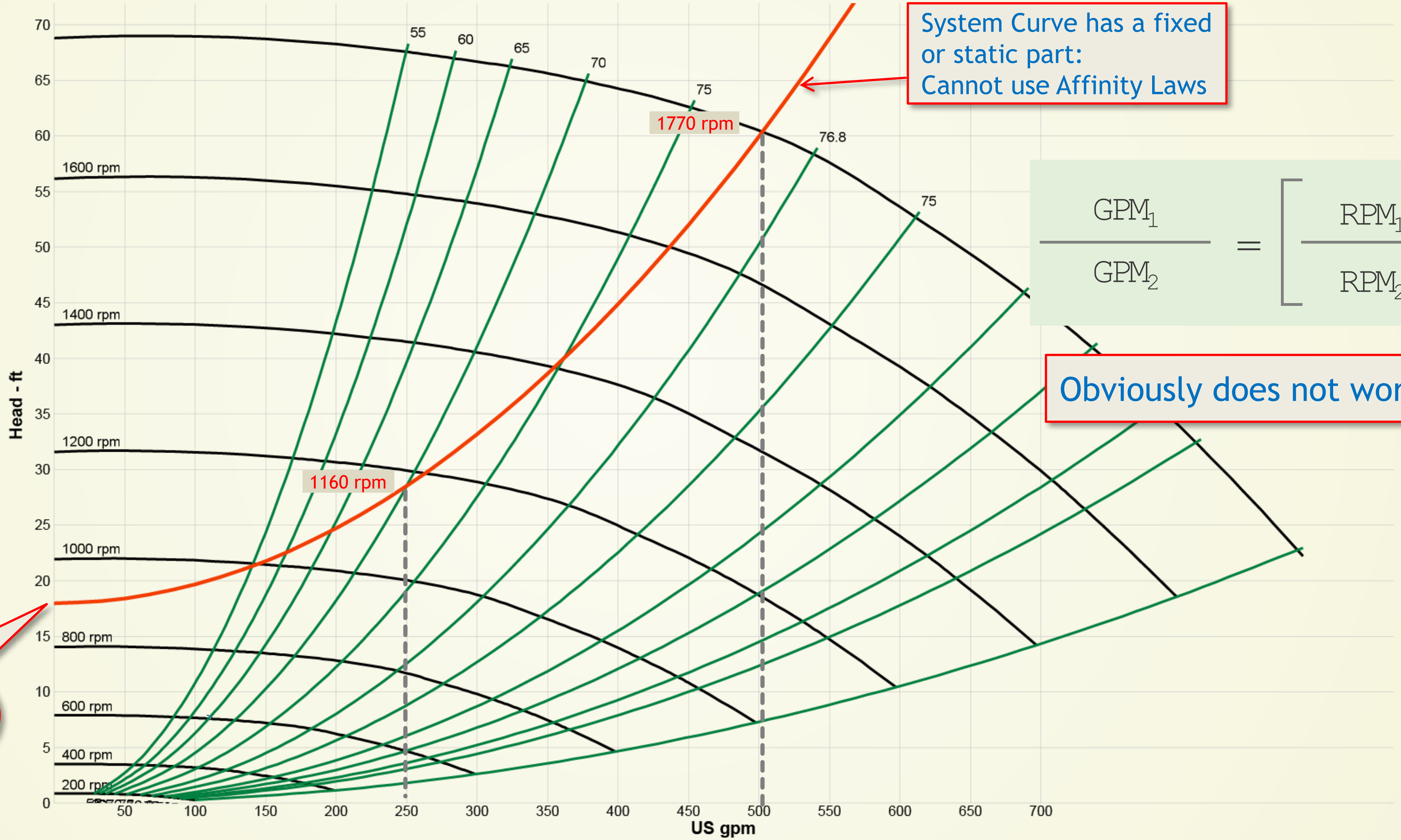
System Curve passes through origin:
OK to use Affinity Laws

$$\frac{GPM_1}{GPM_2} = \left[\frac{RPM_1}{RPM_2}\right]$$

$$\frac{500}{250} = \left[\frac{1770}{885}\right]$$

Works OK.

The (often abused) Pump Affinity Laws -3



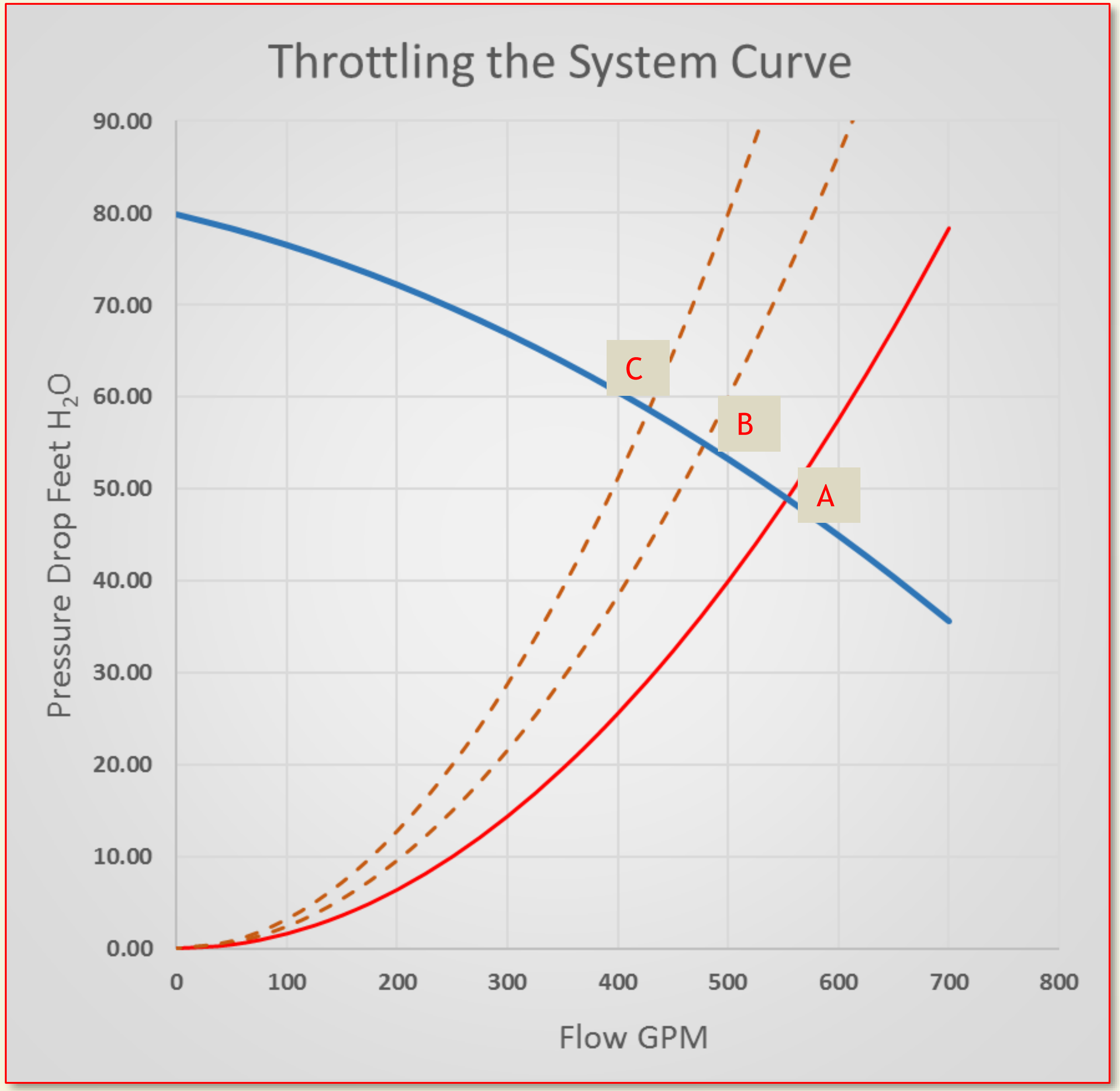
System Curve has a fixed or static part: Cannot use Affinity Laws

$$\frac{GPM_1}{GPM_2} = \left[\frac{RPM_1}{RPM_2}\right]$$

Obviously does not work!

Fixed Static 18 feet
This is the DP control set-point for the VFD

Valve Operation and the System Curve



Throttling a manual or automatic valve in the index loop of a hydronic system moves the whole system resistance curve up.

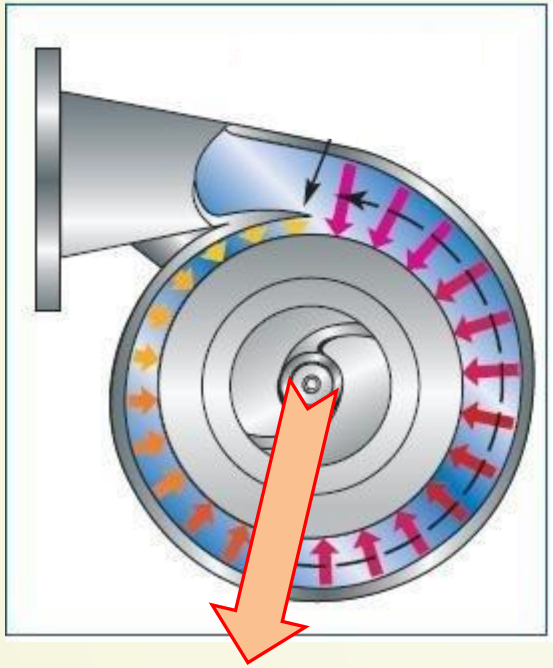
Suppose a 2-way valves starts to modulate close in the index circuit of a hydronic system.
The system curve will then "ride" the pump curve from point "A" to point "B" and then "C" etc.

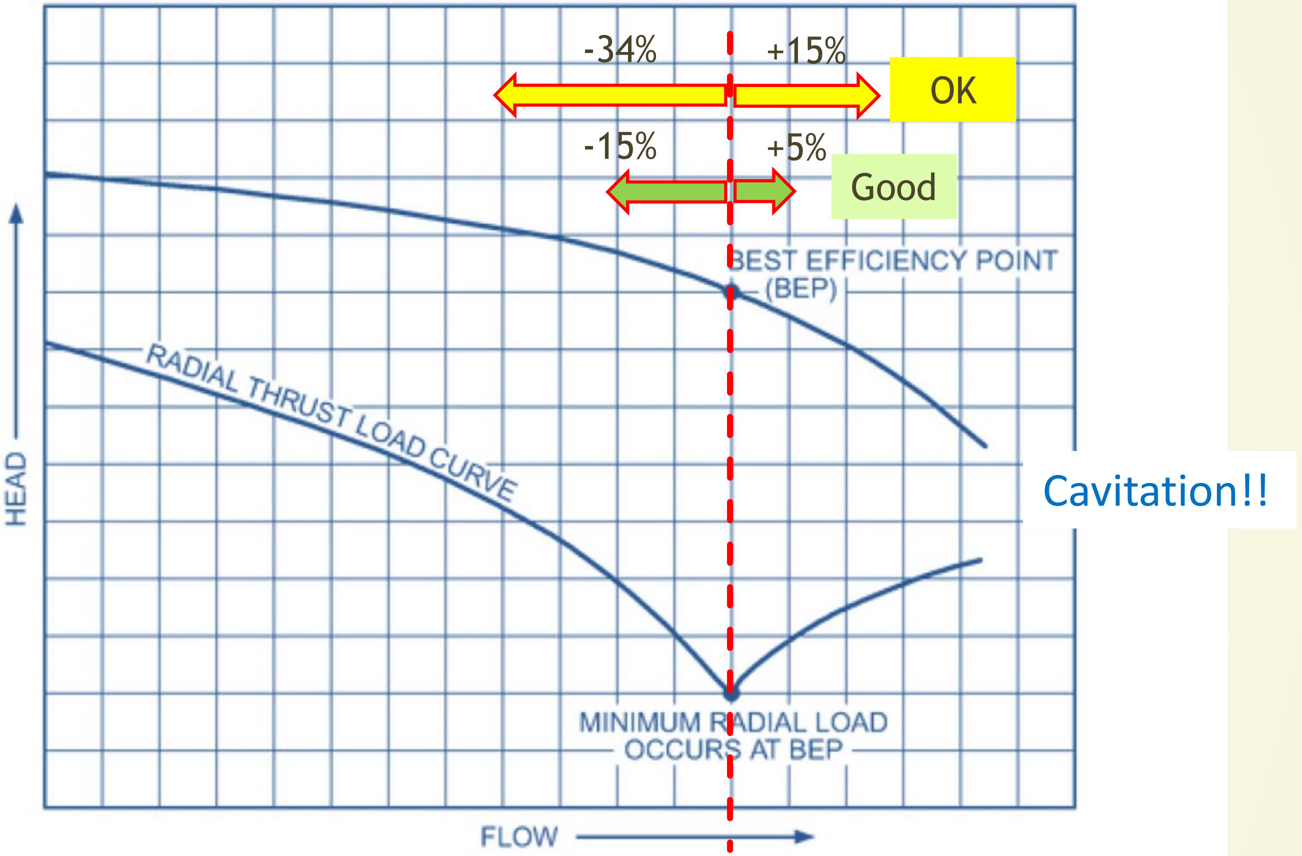
You cannot use any Affinity laws to predict the flow or head at points B and C.

And you cannot use the square system curve flow and relationship either.

Very common rookie mistake.

Single Volute - Radial Thrust & Pump Selection Region



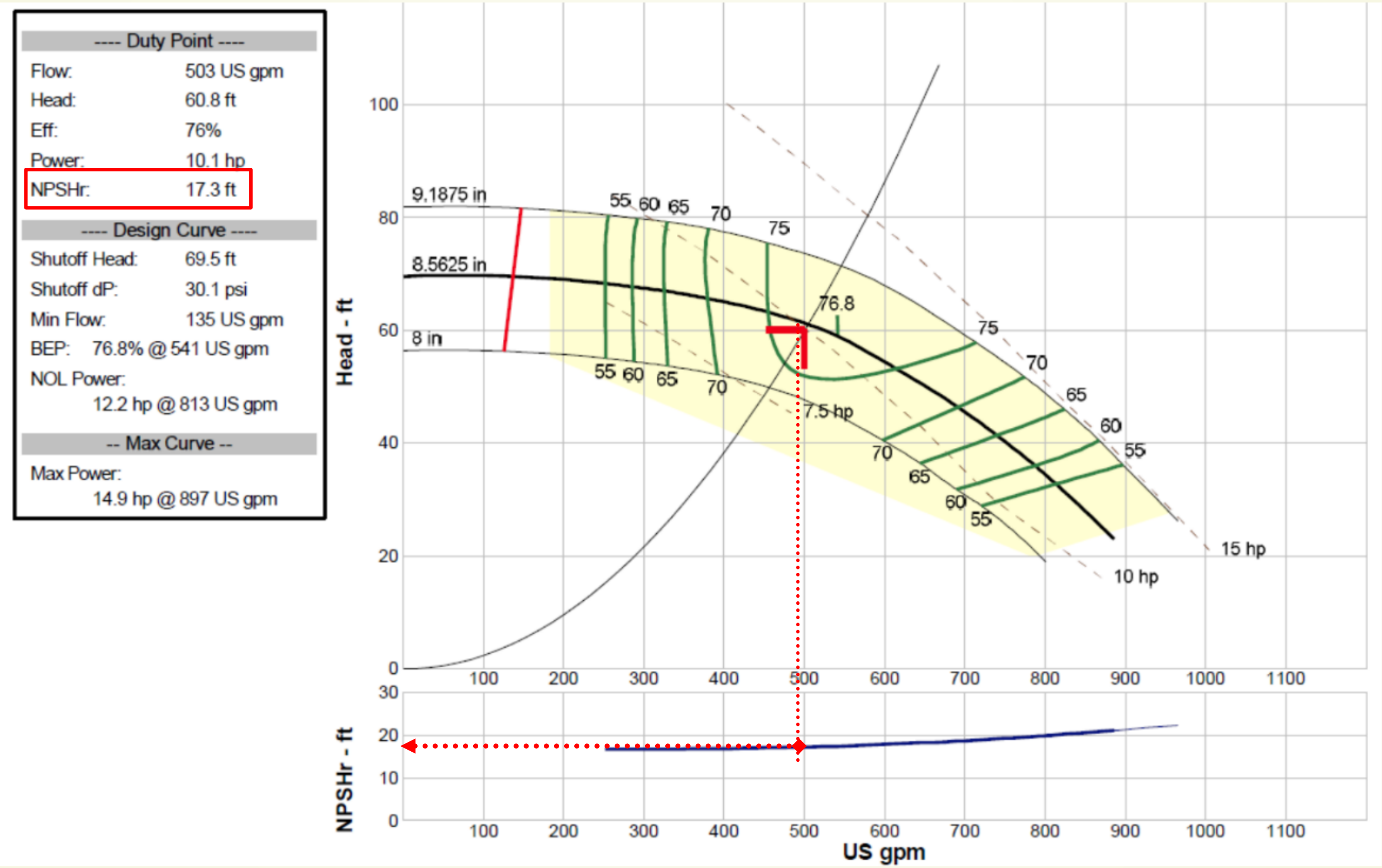


Adapted from ASHRAE Sys & Equip Chap. 44

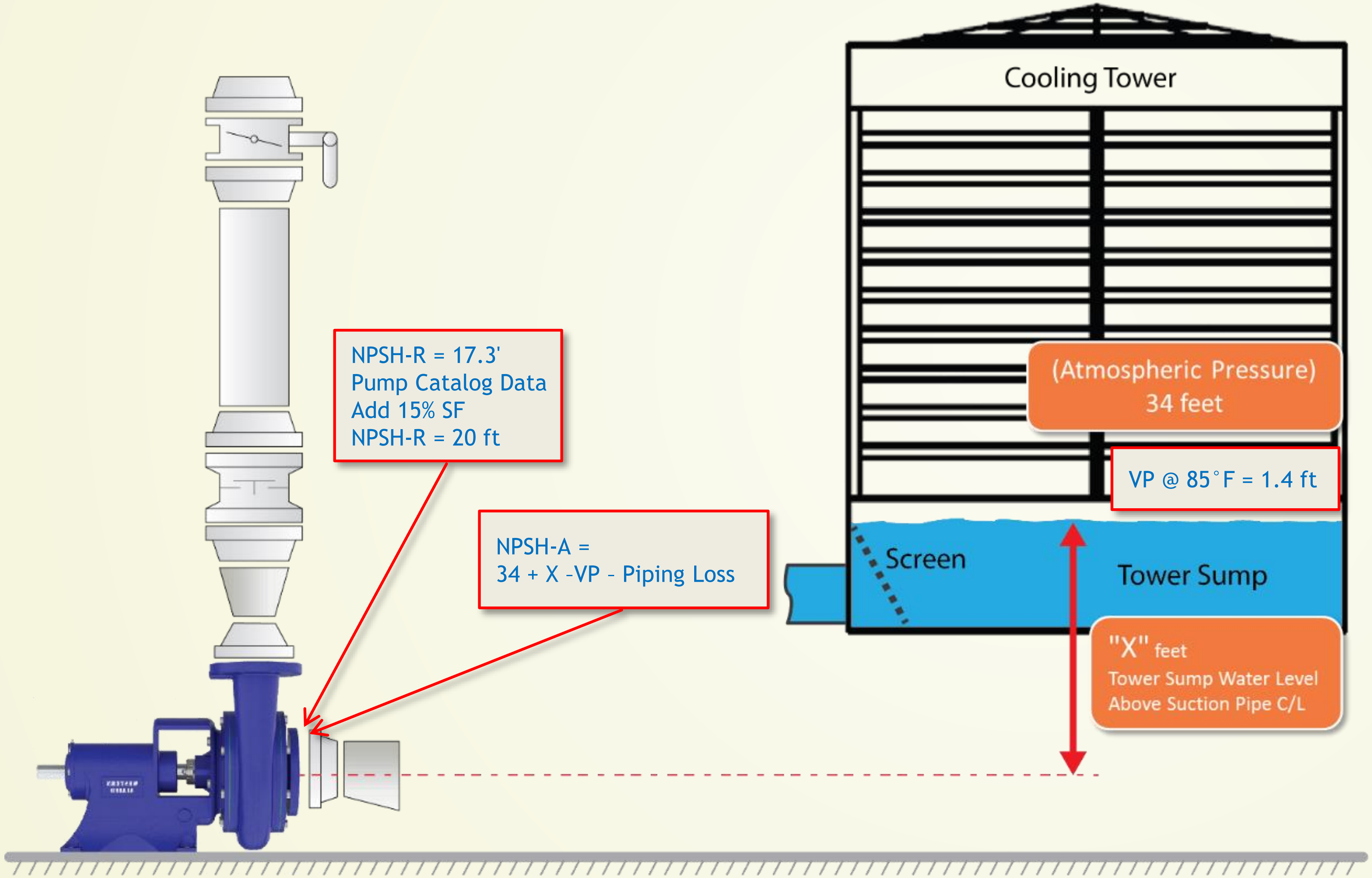
Figure 29. Radial Thrust Versus Pumping Rate

"Figure 5.19 (ASHRAE Fig. 29 above) is one of the most important figures in this book for the water system designer and user of volute-type pumps." Rishel, *HVAC Pump Handbook*

NPSH-R(equired)



NPSH-R(equired) Vs NPSH-A(vailable)



OUR PUMP IS NOT A GOOD SELECTION FOR THIS DUTY.

CHOOSE A PUMP WITH LOWER NPSHR.

When both tower and pump are on the roof, or on the same floor:

- Keep suction piping short with minimum changes in direction.
- Keep pump close to the tower. (Not the condenser.)
- When the height X in feet is less than 4 or 5 feet, pay special attention to the pump suction piping. Reduce the pump suction pipe velocity below 6 FPS.
- Select Condenser Pump with low NPSHR
- If X is less than 2 feet, reduce the suction pipe velocity to 4 FPS and relocate pump suction strainer to the discharge side.

The Pump Curve RECAP

---- Duty Point ----	
Flow:	504 US gpm
Head:	60.7 ft
Eff:	76%
Power:	10.1 hp
NPSHr:	17.3 ft
---- Design Curve ----	
Shutoff Head:	69.5 ft
Shutoff dP:	30.1 psi
Min Flow:	135 US gpm
BEP:	76.8% @ 541 US gpm
NOL Power:	12.2 hp @ 813 US gpm
-- Max Curve --	
Max Power:	14.9 hp @ 897 US gpm