

Variable Frequency Drive Applications for Process Control

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ProNamics Control Inc.

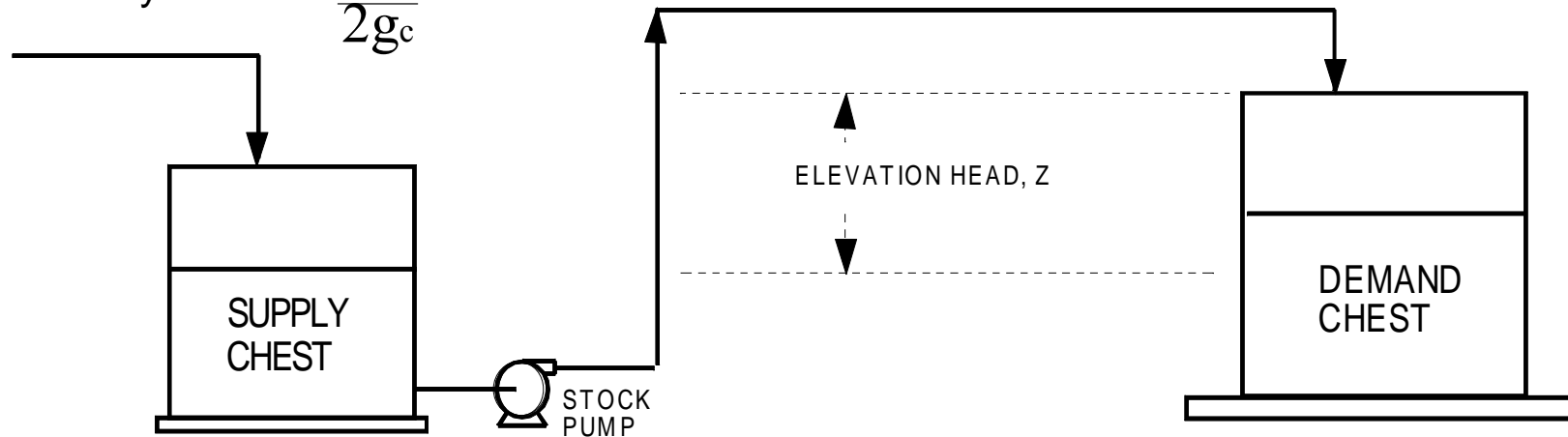
Principles of Flow Control

HOW MUCH ENERGY IS REQUIRED TO MOVE 1 LB OF STOCK

Elevation Head $Z_2 - Z_1$
 Pressure Head $V(P_2 - P_1)$
 Velocity Head $\frac{V^2}{2g_c}$

Bernoulli's Equation

$$\frac{V_1^2}{2g_c} + z_1 \frac{g}{g_c} + P_1 V_1 = \frac{V_2^2}{2g_c} + z_2 \frac{g}{g_c} + P_2 V_2$$



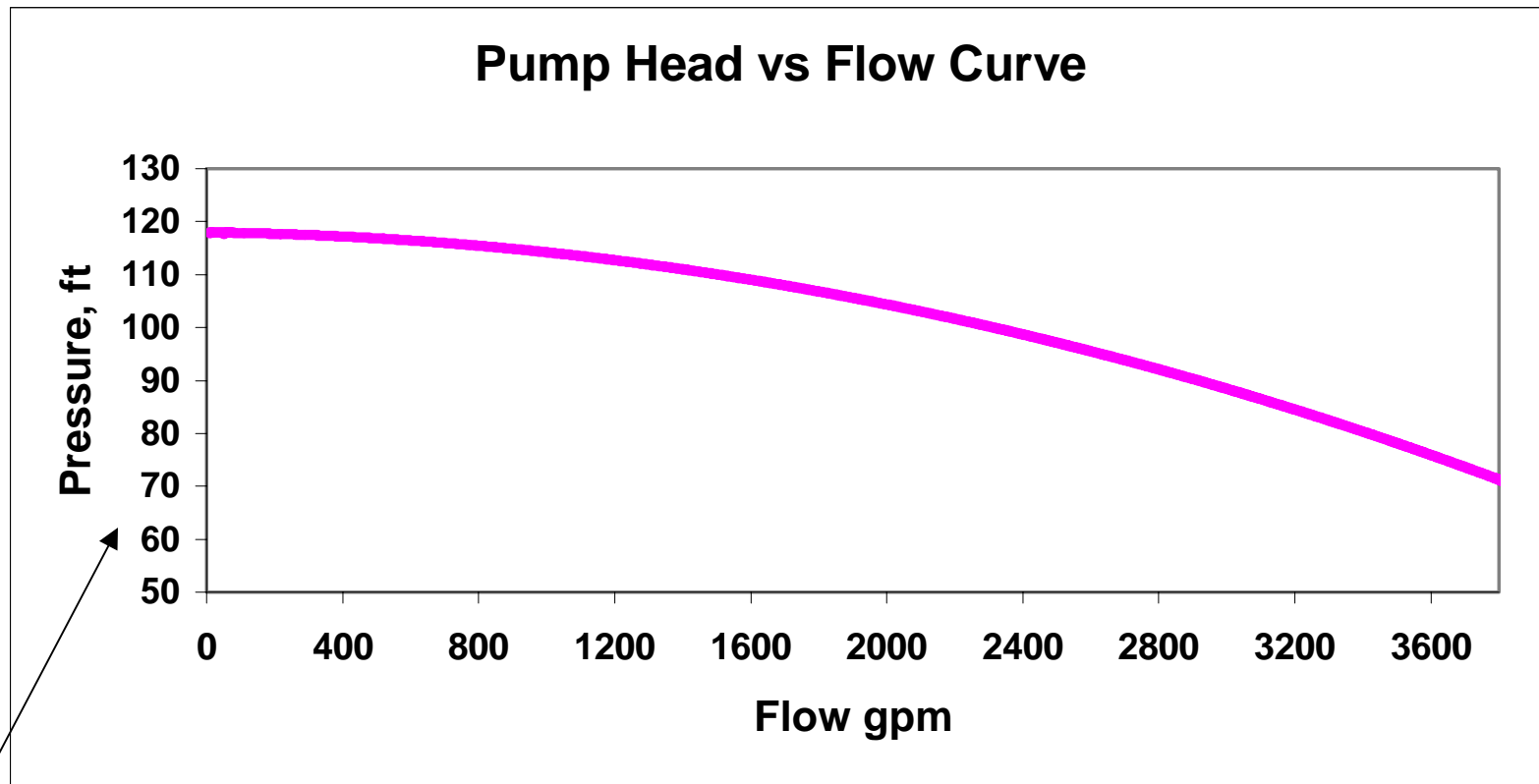
Static Head = Elevation Head + Pressure Head

Friction Head $\Delta H / L = F K D^{-\gamma} V^\alpha C^\beta$

Mechanical Energy Balance $\Delta \frac{V^2}{2g_c} + \Delta z \frac{g}{g_c} + V \Delta P + \sum F + w_f = 0$

W_f = external energy added (by the pump)

Principles of Flow Control



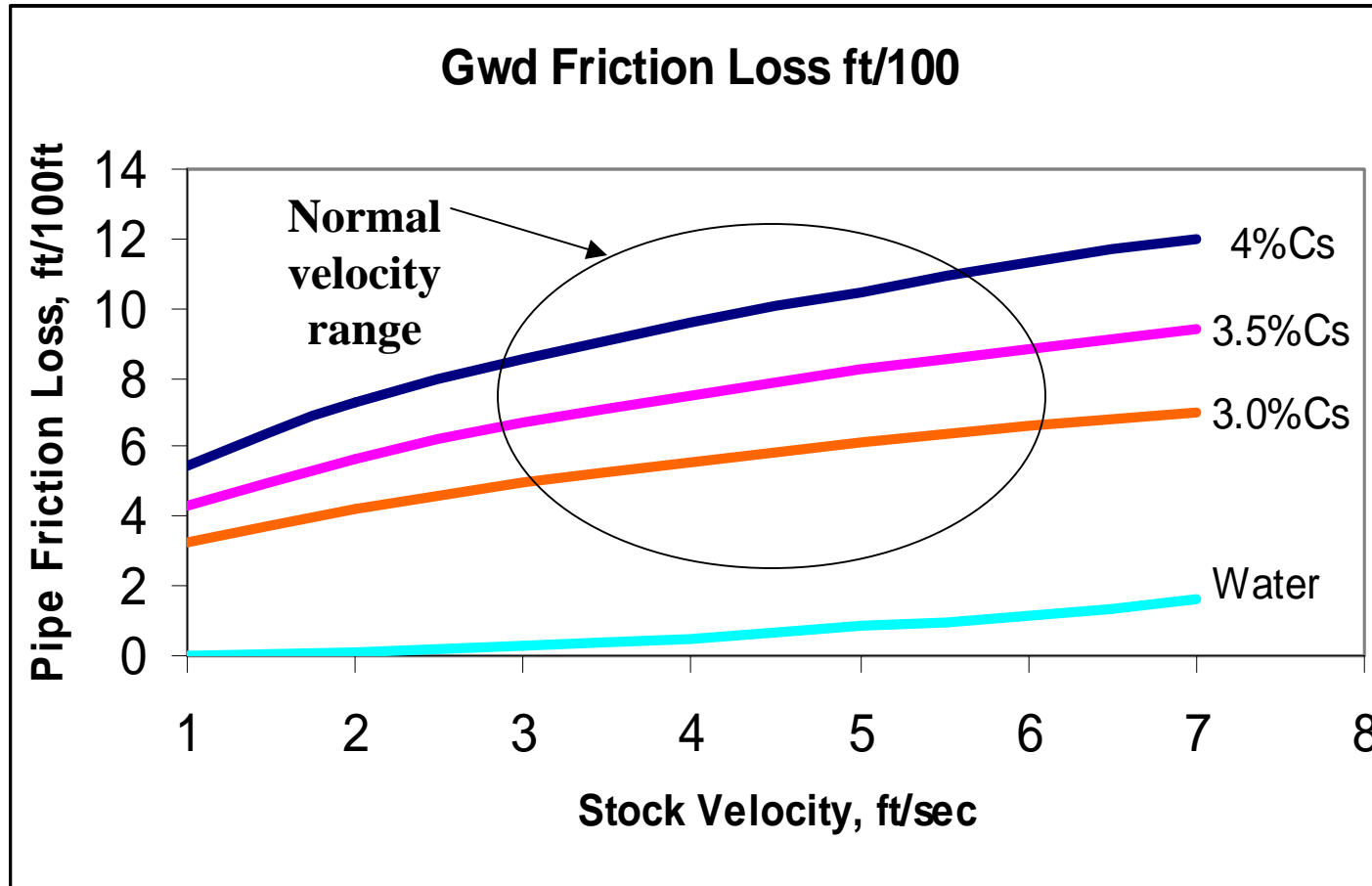
Pressure Energy added by the pump $\frac{\text{lb}_f - \text{ft}}{\text{lb}_m}$

$$\text{Pressure (psi)} = \frac{\text{Head (ft)} \times \text{SG}}{2.31}$$

$$1 \text{ atm} = 14.7 \text{ psi} = 33.9 \text{ ft wc} = 407 \text{ in wc}$$

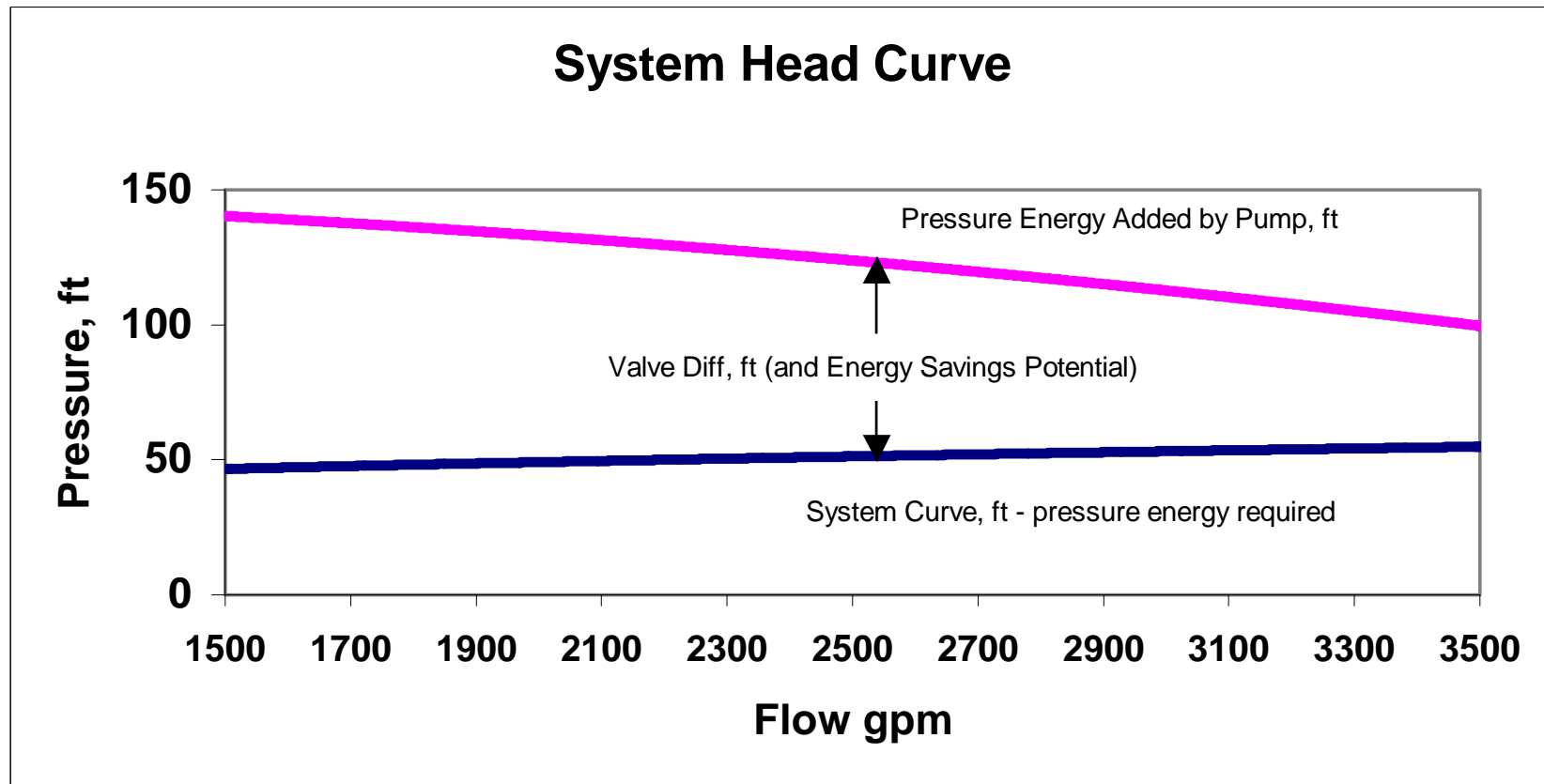
Principles of Flow Control

Friction Loss Pulp Stock



Principals of Flow Control

System Head = Static Head + Pipe Friction Head



The Control valve absorbs the excess pressure energy at the given flowrate

Principles of Flow Control - How much Power to move the fluid?

$$\text{Fluid Power} = \frac{\text{Flow Rate (gpm)} \times \text{Head (ft)} \times \text{SG}}{3960}$$

$$\text{Fluid Energy} = \text{Fluid Power} \times \text{Operating Time}$$

$$\text{Motor Power (BHP)} = \frac{\text{Head (ft)} \times \text{Flow (gpm)}}{3960 \times \text{Efficiency}}$$

Principles of Flow Control

Wasted Energy Across Valve

$$\text{Wasted Energy} = \frac{Q_{\text{gpm}} \Delta P_{\text{ft}} \text{SG}}{3960} \text{Hp}$$

Principles of Flow Control

Energy Savings Example

WW Header Pressure

Requires 1500 gpm

Pressure SP = 45 psi

Pump delivers 1500 gpm @ 70 psig

$$\text{Wasted Energy} = \frac{1500\text{gpm} \times (70 - 45\text{psi}) \times 2.31\text{ft/psi} \times 1.0 \times 0.746\text{kW/hp}}{3960}$$

$$\text{Wasted Energy} = 16.3\text{ kW}$$

$$\text{Annual Cost} = \frac{16.3\text{kW} \times \$539.6/\text{Kw} \cdot \text{Yr}}{0.6} = \$14,659/\text{yr}$$

Industry Status

Efficiency of Pumping Systems

- **Finnish study included 1690 pumps at 20 process plants**
- **Average pumping efficiency is less than 40%**
- **Over 10% of pumps are running below 10% efficiency**
- **Average efficiency of electric motors is 81%**
- **Top two factors affecting pump efficiency: valve throttling, over sizing**
- **Valves are used, historically, due to low cost and reliability**
- **VFD use on the rise due to better price and improved reliability**
- **VFD applied most often in applications with wide swings in flow**
- **Study estimates over 20% energy savings with VFD and right sized pumps**

Industry Status Design Practice

Industry Status Pump Sizing Practice

- A high percentage of centrifugal pumps are oversized. Too much energy is added to the fluid which is wasted at the control valve. The pump does not operate at the Best Efficiency Point, further increasing the energy costs
- Overall result is higher capital costs and higher operating costs. The operating costs (energy and maintenance) of a pump are usually 10 times higher than the capital cost.

Why?

- Safety margins were added and pump size was rounded up
- Future production rate increases were anticipated
- Purchased the same pump as the last one (also oversized)
- Generous allowance for unknowns such as valve selection, pipeline fouling/scaling etc.

Industry Status Design Practice

Industry Status – Control Valves

- Most control valves are oversized to ensure adequate flow now and in the future. Unknowns such as pump performance, pipe-line fouling / scaling, and future production rates all bias towards over sizing
- *More than 50%* of all control valves normally operate at less than 50% open
- *Appropriate valve characterization* is often not selected or applied. This results in a high degree of non-linearity and therefore inconsistent control performance

Why?

- Inadequate information – especially available valve pressure drop at highest flow rates
 - Tendency to select valve to be 1 size smaller than pipe
 - Allowing a minimum 15 psi pressure drop across the valve at normal flow rate
 - Valve used last time (also oversized)

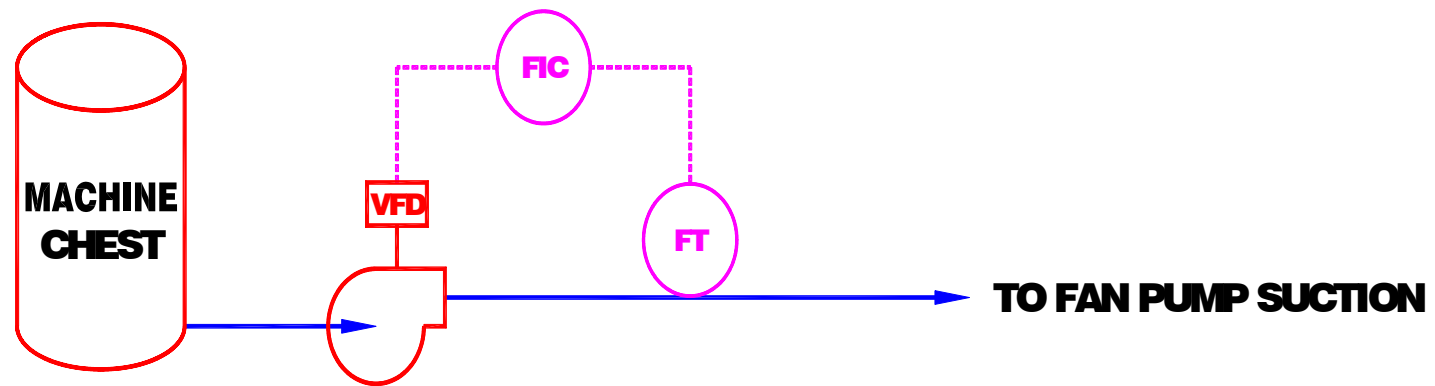
Industry Status— Impact of Design Practice on Control Performance

- High pressure drop across the control valve. The control loop has a high process gain
- Control Valve operates in a relatively closed position and over a narrow range. The process resolution will be relatively poor.
- The process dynamics are highly non-linear over the operating range of the loop, resulting in overly sluggish response during some operating conditions, and oscillation during other conditions
- Process variability can be high due to magnified impact of valve tracking non-linearities such as *backlash* and *stiction*

Why Use a VFD - Philosophy

The use of a control valve can be thought of as the same as the case where an automobile's engine is operated at full speed while the brake is manipulated to control the speed of the car. Conversely, using a VFD can be thought of as operation of the auto with the brake completely released and the speed of the engine used to control the vehicle speed.

Alternative Strategy Using VFD



Why Use a VFD?



As a Final Control Element we can realize

- **Energy Savings**
- **Improved Control Performance**
- **Life Cycle Costs**

How does a VFD Work?

VFD Input

- Accept 3 phase, 460 volt (North America), 60 Hz power that would normally be connected to an across-the-line starter

Output of VFD

- Wired to a 3-phase, AC induction motor
- Changes frequency delivered to motor
- Variable from 0 - 180 Hz (practical limitations to 60 Hz)
- Output voltage, speed & horsepower directly proportional to frequency the motor is receiving

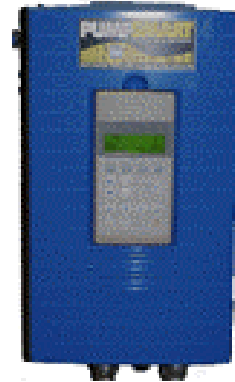
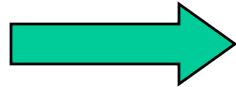
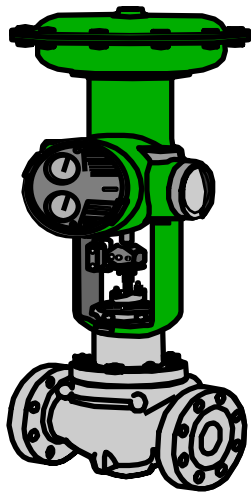
Why Use a VFD

Advantages for Process Control

- **Faster Speed of Response versus Fixed Speed Pump / Control Valve**
- **No Process Deadtime**
- **Insignificant Backlash and Stiction in a VFD. Poor control valve performance is the single biggest source of process variability.**

The superior control performance will reduce process variability

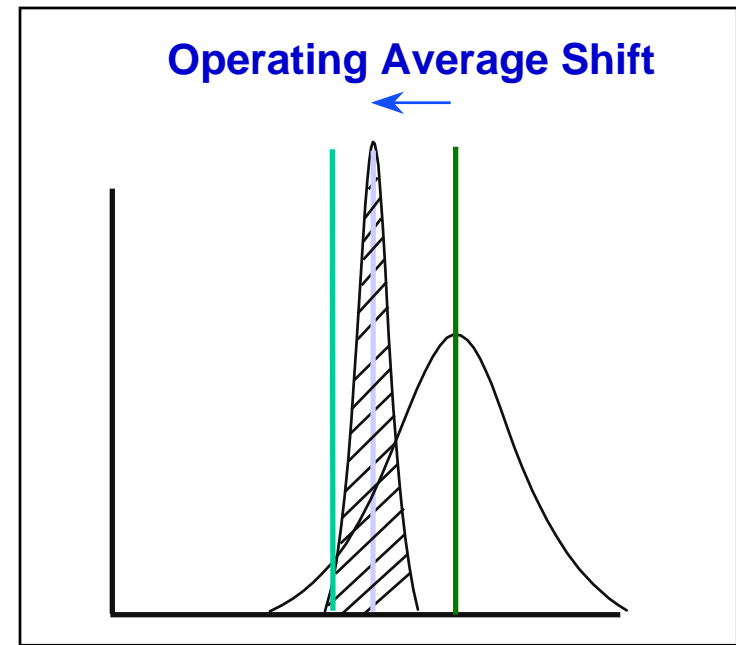
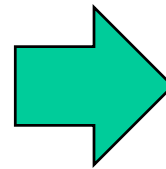
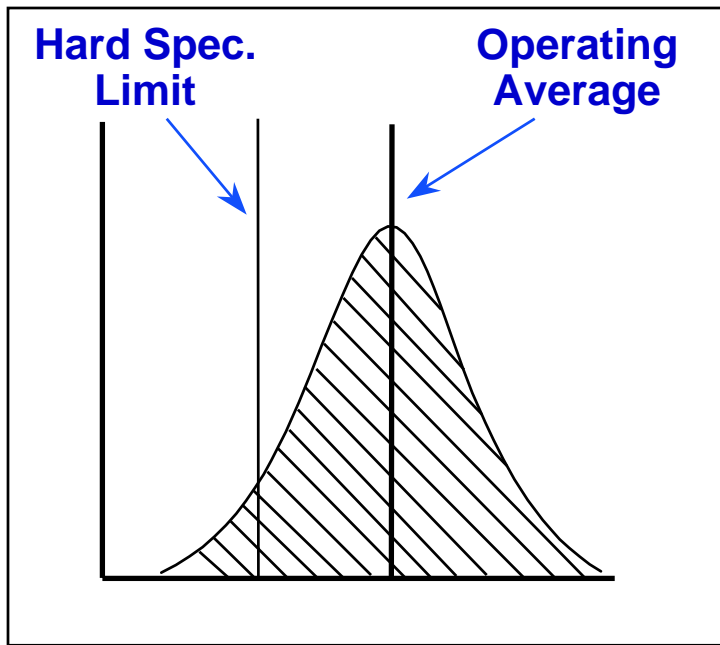
Comparison of Valves to VFDs as the Primary Control Element



Valve.....Pump
Actuator.....Motor
Positioner.....VFD

A VFD is inherently a more accurate and repeatable control element

Impact of Improved Control on Process Variability



Chemical, Material and Energy Cost

Productivity and Yield

Product Quality



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Why Use a VFD

Impact on Maintenance

- Throttled / Oversized Pumps run outside BEP
 - **operate less efficiently,**
 - **generate radial loads & wear faster**

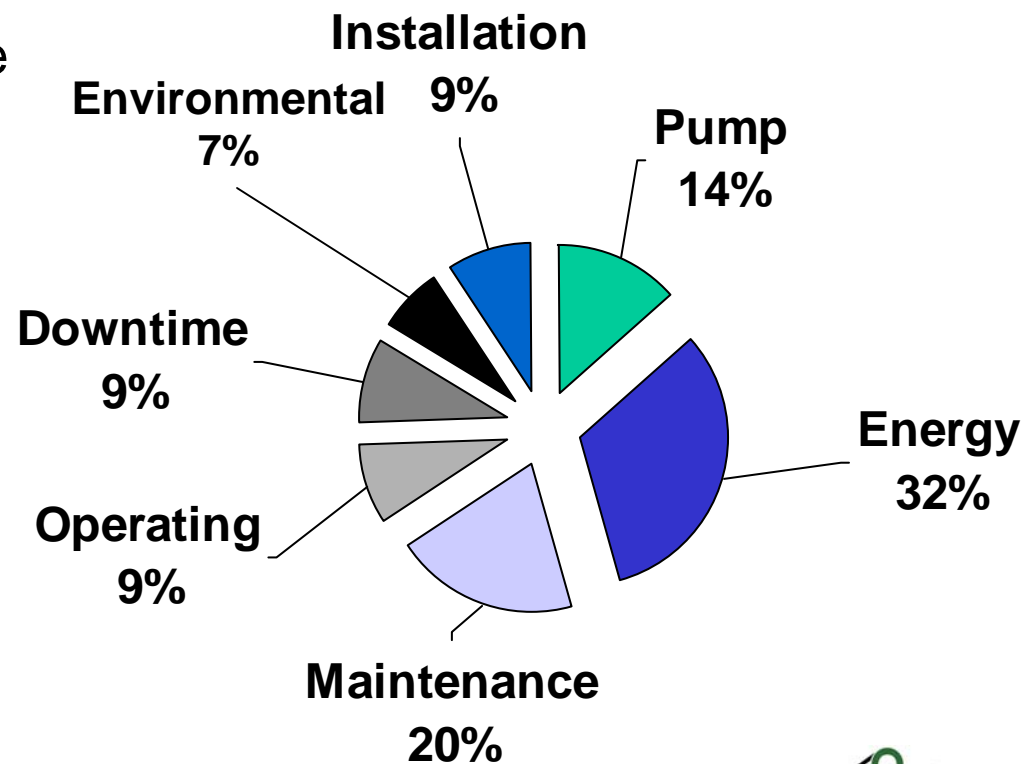
....whereas

- Accurately Sized Pumps and Systems
 - **reduce maintenance costs**
 - **increase seal, bearing, shaft life**
 - **increase MTBF**
 - **decrease labor maintenance**
 - **reduce production loss**

LCC Components

- **Life Cycle Cost** is the total lifetime cost to purchase, install, operate, maintain and dispose of that equipment.

The purchase price is typically less than **15%** of the total ownership cost.



Pulp and Paper Applications

Recognizing Opportunities for VFDs

Some Symptoms:

- **Primary flow line control valves operating at <50%**
- **By-pass control valves relatively open and operating over a wide range.**
- **Very narrow control valve operating range over a wide operating range. A high process gain could be a result of excessive valve pressure drop. High control loop process gain limits process resolution.**
- **Control speed of response is too slow and limits attenuation capability**
- **Presence of cavitation at pump or control valve**
- **High pump / valve maintenance costs (Pump operates far away from BEP)**

Pulp and Paper Applications Opportunities for VFDs

- **Windows of Opportunity**
 - **BW Flow Control**
 - Requires excellent flow control resolution, and relatively linear control dynamics over the operating range
 - **White water Delivery Systems**
 - Often a large operating range, especially if there are intermittent users on the system
 - Dilution flow demand is a function of production rate
 - **Stock Blending systems**
 - Flow loops operate over a wider range to accommodate production rate changes and furnish ratio changes. Pumps and valves tend to be substantially oversized.

Pulp and Paper - Opportunities for VFDs

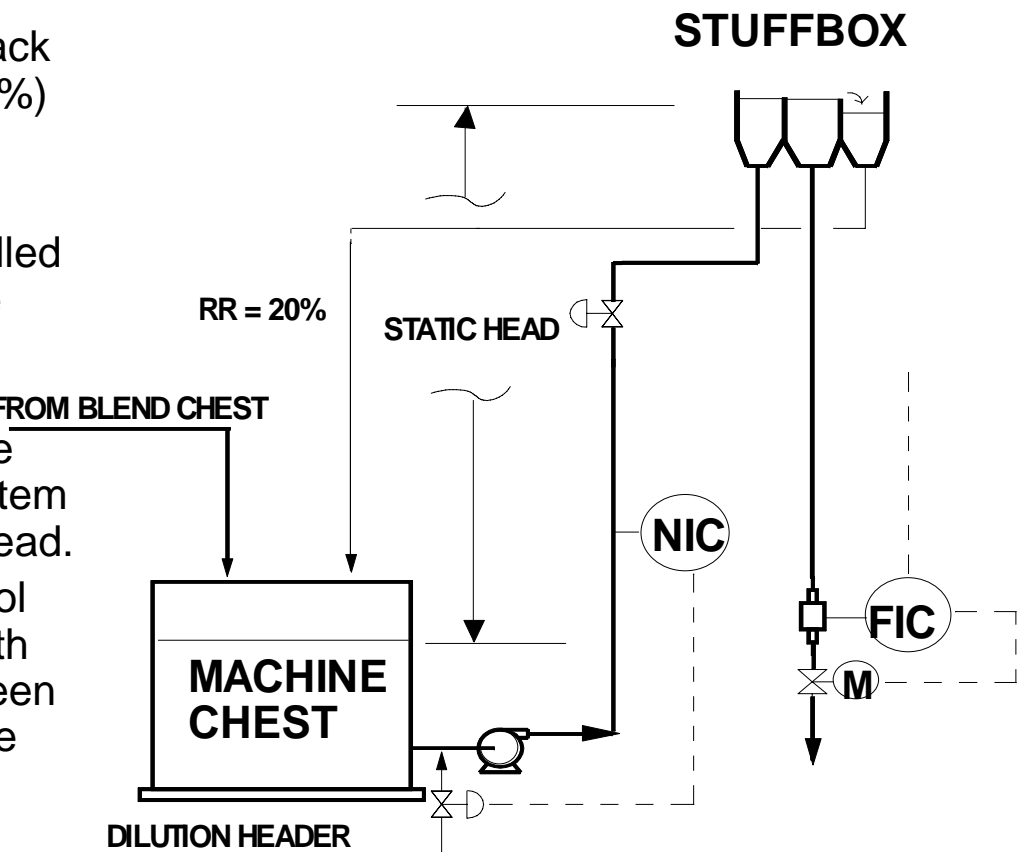
- **When are Windows of Opportunity Open?**
 - **BW Flow Control**
 - Replace Stuffbox / BW Valve combination (especially if Electric valve replacement is being considered)
 - Replacement of pneumatic control valve to improve flow control resolution
 - Reduce cavitation around the BW Control Valve
 - Machine upgrade which requires Stuffbox piping modifications
 - **WW Header for dilution supply**
 - Need to reduce variability in WW delivery header pressure in order to reduce consistency variability
 - Need to reduce energy consumption
 - **Stock Blending Systems**
 - Replacement of oversized valves are being considered.
 - Reduce energy consumption

Pulp and Paper Applications

BW Flow Control - Old Paradigm

FIXED SPEED PUMP / STUFFBOX / ELECTRIC ACTUATED VALVE

- Static Head is between 25 and 35 ft
- Some flow to the Stuffbox is recycled back to the Machine Chest (typically 10 to 20%)
- BW Flow gravity feeds to the Fan Pump suction
- The Stuffbox Level is sometimes controlled to target by throttling the flow rate to the Stuffbox
- The system curve plots represents the energy *required* to move the stock at the given flow rate to the *Stuffbox*. The system curve may be dominated by the static head.
- The pressure drop across the BW control valve is not constant. It will decrease with flow rate since pipe friction losses between the Stuffbox and the FP suction increase with flow rate.



Pulp and Paper Applications

BW Flow Control

FIXED SPEED PUMP / STUFFBOX / ELECTRIC ACTUATED VALVE

Advantages

- Hydraulic decoupling point
Disturbances coming from the Machine Chest level or stock pump are largely attenuated by the Stuffbox. Minimal impact on BW Flow.
- Stuffbox allows some entrained air in the stock to escape
- Very common system and you won't get fired.

Disadvantages

- Typically the highest energy usage system since more stock is pumped at a higher static head
- Potential for air entrainment via Stuffbox overflow. The potential is higher if the overflow level is not controlled, and recirculated stock free-falls in Machine Chest
- Backlash and stiction in the BW valve can compromise control performance
- Electric actuated valve is a constant velocity device, resulting in non-uniform response time constant. Slower than a VFD
- The BW Flow loop process gain may be relatively nonlinear versus a VFD.

BW Flow Control Comparison VFD versus Electric Actuator

VFD Option

Advantages

1. Fastest. control element.
2. Speed resolution of 0.2 rpm or better-excellent flow positioning resolution.
3. There will be zero backlash and stiction.
4. The power savings are often enough to justify the cost of the VFD.

Disadvantages

1. A shutoff valve may be required
2. The VFD speed controller needs to be tuned (adds another loop)

Electric Actuator

Advantages

1. Positioning resolution is at least 0.1% valve position.
2. This technology is the most well established

Disadvantages

1. Valve response time constant is much higher than a VFD and also is a function of step size.
2. No Energy savings
3. The valve is vulnerable to backlash and stiction



Pulp and Paper Applications

Stock Blending

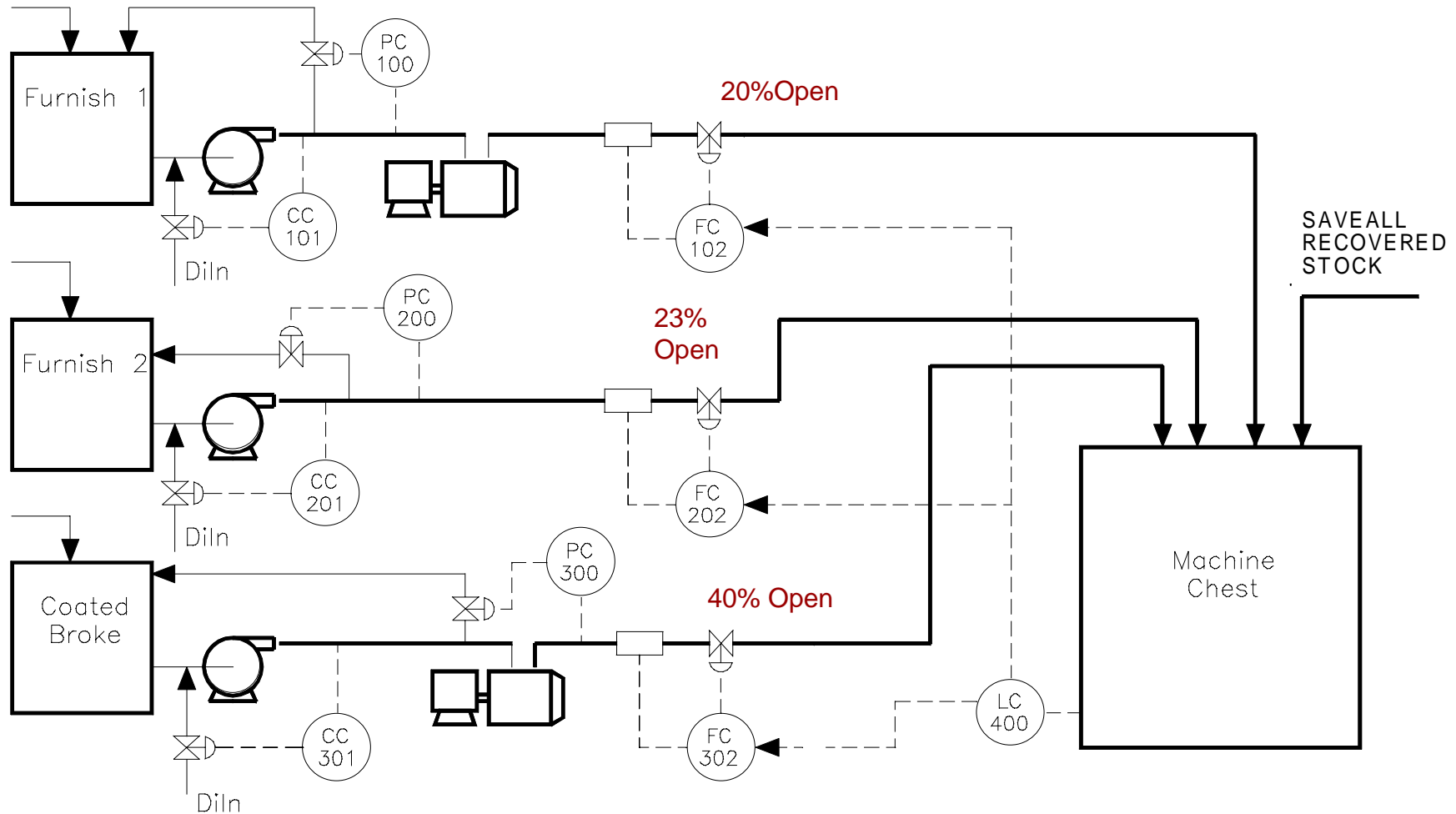
- **Why are stock blending systems good candidates?**

There is often a wide flow range due to production rate changes *and* furnish ratio changes.

- The wider flow range results in more over sizing and control valve operation well below 50% open. The process gain on these loops is usually too high, and the process is vulnerable to control valve non-linearities.
- The oversized pump results in energy inefficiency
- Improving control performance can reduce the percentage of 'expensive fibre'. The best control performance will be delivered by a VFD.
- The dynamics of the furnish flow control loops sometimes compromises the ability to achieve desired speed of response.
- Broke flow rates usually varies more than other blended stocks

Pulp and Paper Applications – Stock Blending

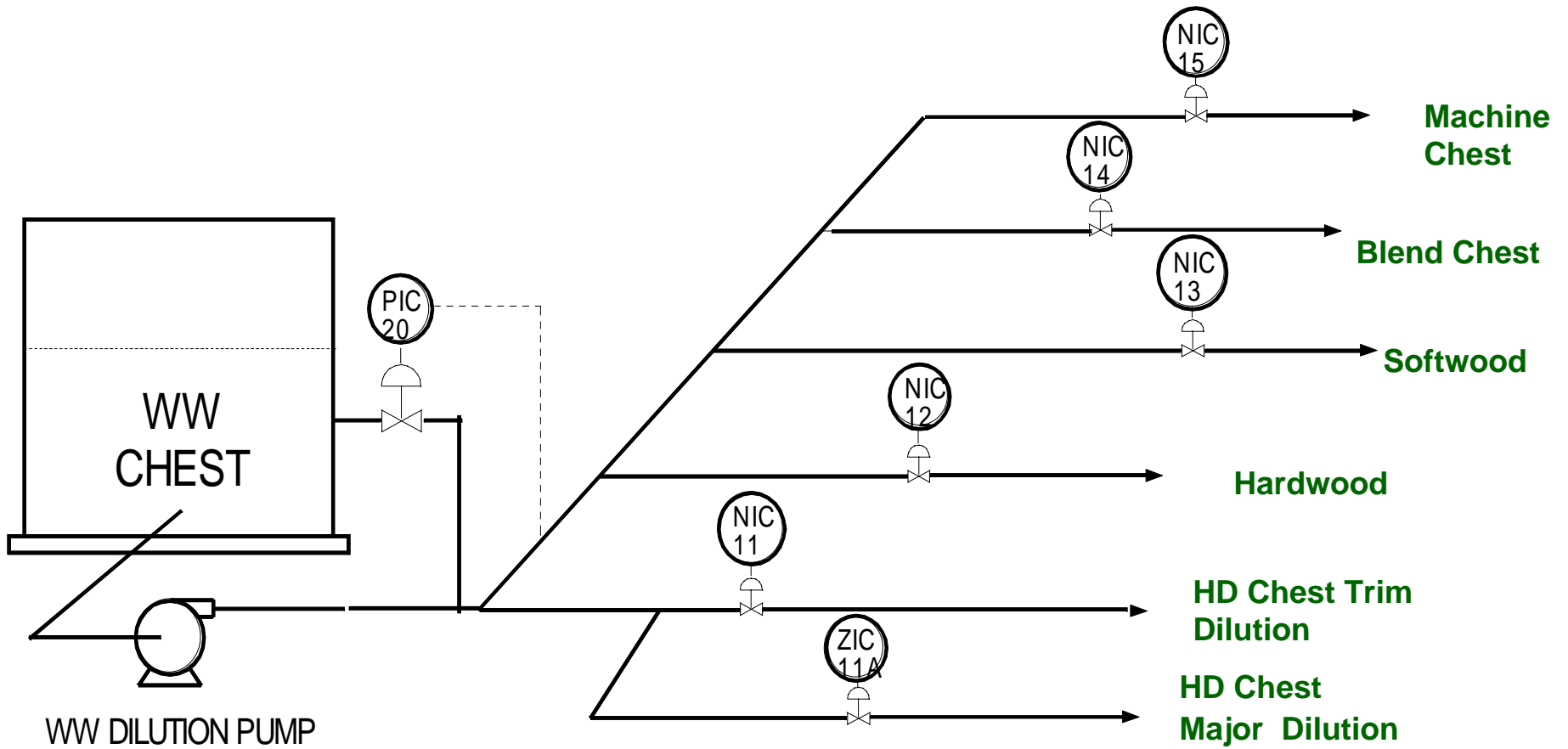
Fine Paper Machine



Pulp and Paper Applications – White water Delivery Systems

- **Why are white water dilution supply systems good candidates?**
 - There is often a wide flow range due to production rate changes and consistency disturbances. Often there are intermittent users and the pump is oversized for normal flow conditions and operates at low efficiency
 - A header pressure control loop is often used to decouple interaction between the downstream consistency loops. The pressure control loop closed loop dynamics need to be very fast in relation to the downstream consistency loops to accomplish this decoupling. The consistency loop should ideally be tuned for a Lambda value of 10 to 15 seconds. The VFD is the only final control element that can realistically achieve Lambda values of less than 5 seconds.
 - The vast majority of the system losses are due to friction losses.

Pulp and Paper Applications – White water Delivery Systems



Conclusions

- Poor control valve performance is the largest single identifiable source of process variability.
- VFDs are mature and present an attractive option to fixed speed pumps and throttling valves.
- VFDs are underutilized in the Pulp and Paper Industry
- VFDs provide not only energy savings but more importantly, vastly improved control performance.
- Process areas to investigate are:
 - Basis Weight Flow Control
 - White Water delivery systems
 - Stock Blending

Barriers to Implementation

- Widespread belief that VFDs are unreliable
- VFD Technology is not as well established as control valve technology
- Requires the effort of several engineering disciplines (electrical, mechanical, chemical)
- Initial installed cost is greater than traditional fixed speed pump and valve.
- “We have always done it this way”

Thank You for your participation!