

# Tech Talk

## Pump TDH Calculation in Medium Consistency Pump Systems

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Medium consistency pulp suspensions between 8 and 16% clearly demonstrate non-Newtonian fluid characteristics. In 1969 Vernon Bodenheimer published a methodology for determining friction loss in systems for positive displacement pumps. That methodology has served as the basis for pump head calculations in medium consistency systems. This will review the Bodenheimer equation and examine the relative impact of the variables that influence the TDH calculations. For medium consistency systems the pump manufacturer assumes the responsibility for TDH calculations based upon the operating conditions provided and piping isometric configuration. It is therefore important for the user to understand the impact that process variables have on the pump TDH and ultimately the pump selection when specifying the design operating conditions.

To begin let's review the Bodenheimer equation for friction loss in medium consistency pump systems.

$$H_f = 7.09 \times C^{2.35} \times P^{0.15} \times F/D^{1.3}$$

Where

$H_f$  = friction loss, [ft/100 ft of pipe]

$C$  = consistency, [% OD]

$P$  = production rate, [air dry short tons/day, adstpd]

$D$  = pipe inside diameter, [in]

$F = F_1 \times F_2 \times F_3$  = dimensionless corrections for stock type ( $F_1$ ), pH ( $F_2$ ), and temperature ( $F_3$ ).

Relationships or examples for the F factors are shown below.

$F_1$  = Stock Type Correction Factor  
(Examples from 1969 Bodenheimer paper)

Stock Type	$F_1$
Sulfite (HW and SW)	0.8
HW Kraft	1.0
Screened Mechanical Pulp	1.2

$F_2$  = pH correction factor

$$F_2 = 1.7 - 0.1 [\text{pH}]$$

For  $\text{pH} < 7$ ,  $F_2 = 1.0$

For  $\text{pH} > 10$ ,  $F_2 = 0.7$

$F_3$  = Temperature correction factor

$$F_3 = 1.6 - 0.006 [^\circ \text{F}]$$

Temperature, ° F	$F_3$
150	0.70
160	0.64
170	0.58

### Effect of Each Variable

#### Production Rate

- As illustrated in **Figure 1**, the TDH variation versus production rate is relatively small.
- The flow rate through the pump obviously varies a great deal with large production rate swings or turndown ratios.
- Production rate and/or consistency variations can impact other equipment selection such as pump sizing and control valve selection.

#### Pipe Diameter

- The pipe diameter should be selected to achieve design velocities in the range of 0.5 to 1.5 ft/sec line velocity.
- Typically only 2 or 3 pipe diameters might be evaluated for use based on the velocity considerations noted above.
- For existing systems the pipe diameter is fixed thus pipe diameter is not a variable.

#### Stock Type ( $F_1$ )

- While there can be significant variation of the factor by pulp type, most systems involve only one or perhaps two different types of pulp so

there is not usually a significant variation in TDH attributable to the pulp type.

#### pH ( $F_2$ )

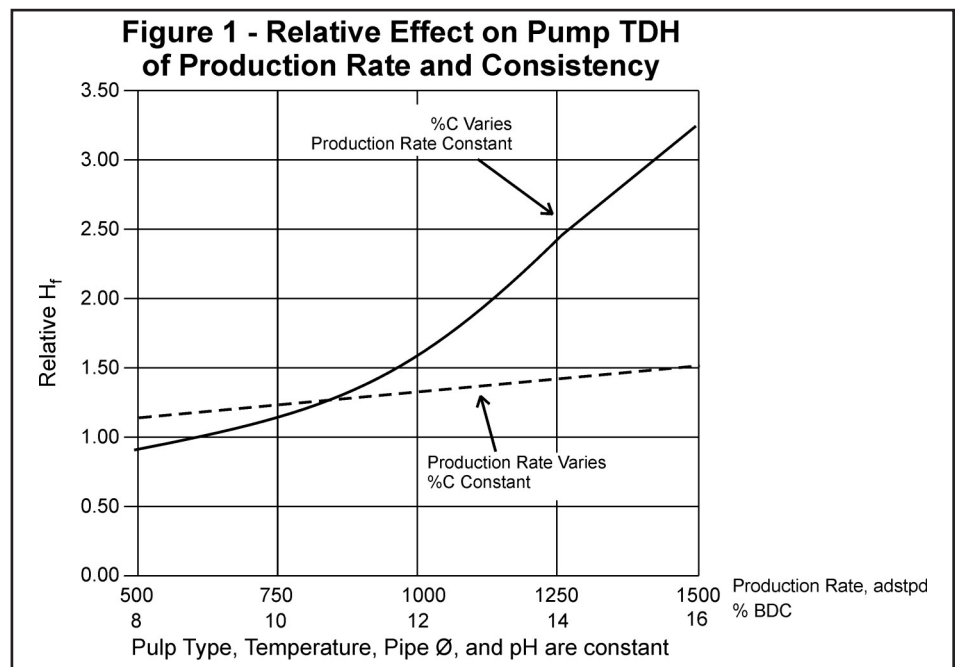
- The pH levels will depend on the service.
- There is usually not a wide variation in pH levels at the pump.
- There may be a variation of pH in the discharge line after addition of a bleach chemical such as  $\text{ClO}_2$ . A typical reduction for this case would be from about 7 to 8 down to a pH of 3.5 to 4.5.

#### Temperature ( $F_3$ )

- Frequently temperature can have the second greatest impact on the design TDH versus the actual TDH.
- A wide operating range variation in temperature can add significant extra TDH to the design conditions.
- Realistic targets should be established for temperature ranges versus production rate ranges such as high temperature with high production rate and lower temperatures at low production rates.

#### Consistency

- This variable has the greatest impact on the TDH.
- Designing for a wide consistency range can result in excessively high TDH and HP requirements when compared to actual operating consistencies.
- The same holds true should units be designed for unrealistically high consistency levels. Often equipment before the pump will limit the consistency the pump will see.



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## TDH Variation with Changes in Variables from Design Conditions

System Variable Change	Calculated System TDH, ft	$\Delta$ TDH Change, ft	$\Delta$ TDH Change %	Comment
Design Condition	307'	0	0	Used design conditions to calculate TDH
1400 to 1100 adstpd	294'	-13'	-4%	Small impact on TDH, flow shift for pump.
2.5 pH to 8 pH	304'	-3'	-1%	Very small impact
160 to 190° F	277'	-30'	-10%	Significant change
Piping from 16" to 20"	290'	-17'	-6%	Moderate reduction by increasing pipe size.
14 to 11% Consistency	262'	-45'	-15%	Largest change in TDH

Table 1

## TDH Variation from Design Conditions by Operating Range

Operating Condition	Calculated System TDH, ft	$\Delta$ TDH Change, ft	$\Delta$ TDH Change %	Comment
Design Condition 1400 adstpd, 14% 60°F	307'	0	0	Used design conditions to calculate TDH
Frequent Condition: 1100 adstpd, 12%, 185°F	240'	-67'	-22%	Impact results from consistency and temperature difference.
Minimum Condition: 700 adstpd, 12%, 185° F	221'	-86'	-28%	Impact results from consistency and temperature difference with large flow shift seen by pump.

Table 2

## Actual TDH Variations from Friction Losses Vs Developed TDH for Impeller Diameter Required

Operating Condition	$\Delta$ TDH Actual, ft	Actual Valve $\Delta P$ , psi	% Valve Opening	Comment
Design Condition 1400 adstpd, 14% 60°F	0'	16	70%	Design target for control valve opening for medium consistency systems.
Frequent Condition: 1100 adstpd, 12%, 185°F	-100'	55.5	39%	Minimum desired valve opening is 40% for normal operating ranges encountered by the system.
Minimum Condition: 700 adstpd, 12%, 185° F	-154'	72	29%	Well below minimum opening desired for control valve to ensure best operation.

Table 3

## SYSTEM EXAMPLE

### System Operating Variables D2 Stage Feed Pump

Production Rate	1400 adstpd (Design) 1100 adstpd (Normal) 700 adstpd (Minimum turndown)
Consistency	14 % BD (Maximum) 12% (Normal) 11% (Minimum)
Temperature	190° F (Normal) 160° F (minimum)
pH	8 before mixer 2.5 after mixer
ClO <sub>2</sub> Addition Rate	130 GPM at design production rate

From the above operating data the pump design conditions are derived. They are:

### Pump Design Conditions

Production Rate	=	1400 adstpd
Consistency	=	14 % BD
Temperature	=	160° F
pH	=	2.5 after mixer
Pipe Diameter	=	24"
Pulp Type	=	Softwood Kraft

Using the operating variations from this example let's examine the variations in the TDH as a function of changes to each individual variable. This data is shown in Table 1. Table 2 now shows the changes in TDH based on combining the impact of the various sets of operating conditions.

The TDH values reflected in Tables 1 and 2 are based on calculations for only the conditions indicated. They do not reflect the actual TDH developed by the pump at the appropriate flow rate for each condition.

Table 3 reflects the actual TDH variation from the friction loss required by the system compared to the TDH developed for the impeller diameter required to meet the indicated flow (production rate) conditions. Also included in Table 3 is the control valve opening in per cent for the operating conditions given.

### Design Consideration Summary

From the above example and related experiences it is possible to outline the following design considerations for medium consistency pump systems.

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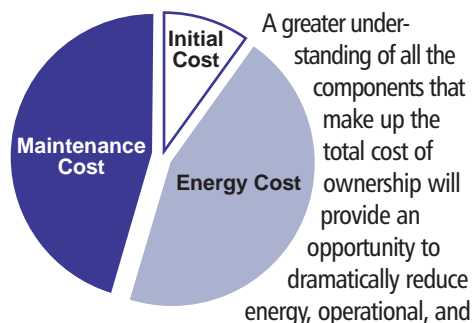
- 1) Design criteria for the pump TDH will normally be based on the following variables:
  - a) Highest % Consistency
  - b) Maximum production rate
  - c) Lowest operating temperature
  - d) Lowest pH
  - e) Static elevation for system
- 2) Design maximums will be driven by % consistency.
- 3) Be aware of multiple operating conditions.
- 4) Carefully review operating extremes especially wide variations in % C and temperatures.
- 5) Target level control valve opening to be 70% for the design conditions and in the 40 – 70% range for other operating conditions under consideration.
- 6) Avoid low control valve openings (< 40% open)!
- 7) Review consistency range for limits which can be delivered to the pump – washer types, repulper screw HP limits, steam peg mixer limits, etc.
- 8) Oversizing for unrealistic consistency levels can result in low level control valve openings with large valve  $\Delta P$ .
- 9) If large TDH swings such as pumping to multiple HD storage towers or multiple operating production conditions exist, consider variable speed devices and a level control valve for trim for minimum operating conditions.
- 10) When using pump discharge pressure from an existing positive displacement pump to size a centrifugal medium consistency pump, be certain to account for the following:
  - a) Increase the TDH by 20% to account for the higher friction resulting from air removal in the centrifugal pump.
  - b) Add approximately 30' to the TDH for the control valve used with the medium consistency centrifugal pump.
  - c) Always check this estimate against calculations based on a piping isometric for the service involved.

It is hoped this review of the head calculation basics coupled with an understanding of the impact of key variables from a process standpoint will allow design engineers to better evaluate proposed medium consistency pump systems. ■

## Pumping System Life Cycle Costs, An Overlooked Opportunity?

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Pumping systems account for nearly 20% of the world's electrical energy demand and range from 25-50 % of the energy usage in certain industrial plant operations. They also account for a significant portion of the maintenance costs in an industrial plant. Significantly, once a pump is installed, the ongoing annual costs are fixed for the typical 15 to 20 year life of the installation. The figure below illustrates the major costs of owning and operating a pumping system.



maintenance cost. Excessive waste and energy usage are also important factors in global environmental pollution.

Life Cycle Cost (LCC) analysis is a management tool that can help companies minimize waste and maximize utilization for many types of systems. For many years LCC analysis has been an integral part of the design of military equipment, particularly large systems such as aircraft and tanks. In more recent years the techniques have begun to be applied to industrial systems including pumping systems.

Life Cycle Cost analysis is particularly important in pumping systems because the most significant components of LCC are frequently overlooked.

This overview provides highlights from "A Guide to Life Cycle Cost Analysis for Pumping Systems," developed by the Hydraulic Institute and EUROPUMP to assist plant owners/operators in applying the LCC methodology to pumping systems. A copy of the Guide can be obtained

from the Hydraulic Institute ([www.pumps.org](http://www.pumps.org)) later this year.

### What is Life Cycle Cost?

The life cycle cost (LCC) of any piece of equipment is the total "lifetime" cost to purchase, install, operate, maintain, and dispose of that equipment. Determining LCC involves following a methodology to identify and quantify all of the components of the LCC equation.

When used as a comparison tool between possible design or overhaul alternatives, the LCC process will allow the most cost-effective solution within the limits of the available data.

The LCC equation can be stated as:

$$LCC = C_{ic} + C_{in} + C_e + C_o + C_m + C_s + (env + Cd)$$

- C = cost element
- ic = initial cost, purchase price (pump, system, pipe, auxiliary)
- in = installation and commissioning
- e = energy costs
- o = operating cost (labor cost of normal system supervision)
- m = maintenance cost (parts, man-hours)
- s = down time, loss of production
- env = environmental costs
- d = decommissioning

### Why Should Organizations Care About Life Cycle Cost?

Many organizations only consider the initial purchase and installation cost of a system. It is in the fundamental interest of the plant designer/manager to evaluate the LCC of different solutions before installing major new equipment or carrying out a major overhaul. This evaluation will identify the most financially attractive alternative. As national and global markets continue to become more competitive, organizations must continually seek cost savings that will improve the profitability of their operations. Plant equipment and operations are receiving particular attention as a source of cost savings, especially minimizing energy consumption and plant downtime.

Existing systems provide a greater opportunity for savings, through the use of LCC methods, than new systems for two reasons. First, there are at least 20 times as many pump systems in the installed base as are built each year; and,