Recommendation

Install a more efficient pump with a variable frequency drive (VFD) to feed water into the boiler. This will allow the bypass valve to be fully open and reduce associated annual energy consumption by 74%.

Annual Savings Summary

Source	*Quantity*	*Units*	*Cost Savings*
Electrical Consumption	211,958	kWh (site)	$10,174
Electrical Demand	225	kW Months / yr	$1,780
Total	**723**	**MMBtu**	**$11,954**

Implementation Cost Summary

Description	*Cost*	*Payback (yrs)*
Before Incentives	$11,773	1.0
After Incentives	$3,532	0.3

Facility Background

The facility has three 75 HP Gould's 3316 M, 3 x 2 - 11 pumps to feed water into the hog fuel boiler. Only one pump operates at any given time. Pump operation cycles between pumps to maintain pump efficiency and allow facility personnel to perform maintenance on the pumps. The pump inlet diameter is 3", the outlet diameter is 2", and the impeller diameter is 10".

Feed water is introduced to the system in the deaerator tank at a pressure of 6 psig. This water is then gravity fed into the pump inlet. When feeding the boiler, the change in pressure across the pump is about 250 psig. When the bypass valve is closed, the change in pressure across the pump is about 300 psig. When exiting the pump, pressurized water travels through a 2" diameter pipe up to the boiler. When the bypass valve is closed, the water is redirected into a 5/16" diameter pipe that feeds the deaerator tank.

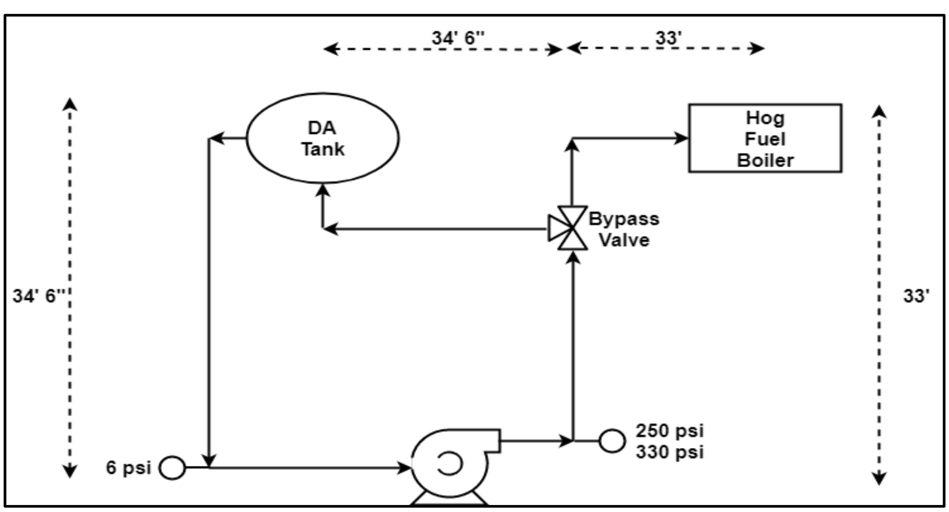

Figure 3.3.1: Feed Water Distribution Diagram (not to scale)

Opportunity Background

Using valves to control water flow is an inefficient control method. A partially closed valve increases system head, increasing the amount of resistance the pump must overcome. Pumps are designed to work at a Best Efficiency Point (BEP) on the flow versus head performance curve. Closed valves take the pump outside of its BEP and decrease efficiency. A more efficient control method is using a Variable Frequency Drive (VFD).

With a VFD installed, a pump's speed varies based on demand of feed water. Reduction in speed results in a decreased flow rate, and a decrease in the power required by the system. Affinity laws, as defined in the Pumps Appendix of this report, define the pump's hydraulic horsepower as proportional to the cube of the pump speed. This means that even small reductions in pump speed will greatly reduce the input power to the system.

Proposal

Install a VFD on the boiler feed water pumps and fully open the bypass valve. This will reduce the average pump motor speed and reduce the associated annual energy consumption. Annual cost savings are estimated at $11,954 after an implementation cost of $11,773, resulting in a simple payback period of 1.0 years.

Vendor Data

Analysts received a quote from a vendor for a 50 HP pump priced at $6,800. Three vendors provided quotes for a 50 HP VFD [2][3][4], ranging from $2,436 to $2,840.

Implementation

Install a new feed water pump, with a VFD, in the hog fuel boiler room. The VFD will adjust the pump's speed based on the demand of feed water. To determine this demand, an ultrasonic flow sensor must be installed on the boiler's steam output line. This sensor will communicate to the VFD the current demand of steam, and the pump's speed will be determined to service that flow.

Incentives

Companies paying a public purpose charge may qualify for cash incentives. Incentives are calculated on a case-by-case basis and are based on the results of a technical analysis study. Electricity trimming projects may qualify for an incentive of $0.23 per annual kWh saved, up to 70% of the project cost.

Calculation Methodology

Current energy consumption is the sum of the energy the pump uses when feeding the boiler and when it is bypassing the boiler. Using the pump curve, analysts determined the flow rate at both the feeding state and the bypass state. The impeller diameter and the total dynamic head were used to identify the flow rates. The total dynamic head is based on the change in pressure across the pump, and change in elevation between the pump and the boiler/deaerator tank.

Based on the boiler's nameplate, at 100% firing rate, the boiler produces 960,000 pounds of steam per day. Analysts assumed the boiler is always operating at 100% firing rate. This means that the pump must provide this volume of liquid water to the boiler in a day. The quantity of time the pump feeds the boiler in a day is the quotient of the daily mass by the flow rate into the boiler. The time the pump is bypassing the boiler is 24 hours less the time feeding the boiler.

Using the same procedure, the pump energy required to feed the boiler or the bypass valve can be determined. The brake horsepower is determined from the pump curve, and is then divided by the motor efficiency to yield electrical horsepower. Electrical horsepower is converted to kW and multiplied by the appropriate hours per year, either for feed or bypass. The incremental electricity cost, outlined in the site data section of this report, is then multiplied to determine the annual cost. Demand charges were estimated by taking the electrical power, in kW, of the pump when feeding the boiler, and multiplying it by 12 mo/yr. This value was then multiplied by the incremental demand cost.

Proposed energy consumption is the energy the new pump will require to deliver the same hydraulic horsepower as the current pump. This proposal recommends installing a VFD to eliminate the need to bypass the boiler, therefore, 100% of the energy currently used for bypass is saved.

The required hydraulic horsepower is the product of the current brake horsepower in the feeding state with the pump efficiency from the pump curve. The new pump and motor efficiencies were then multiplied by the hydraulic horsepower to determine the new electrical horsepower. This value was converted into kW and multiplied by the boiler feed time to determine the annual energy requirement. The annual demand of this new system is equal to the electrical power of the motor times 12 mo/yr. The total operational cost of this system is equal to the annual energy requirement times the incremental electricity cost, plus the annual demand times the incremental demand cost.

The implementation cost of this project is based on three parts; the cost of the VFD, Pump, and associated labor. The cost of the VFD is the maximum of three prices obtained from separate vendors. The labor cost was estimated from the RSMeans handbook for electrical labor costs [5]. The handbook estimates the number of electricians, their labor rate, and the time required to complete this project. The product of these three numbers yields the total labor cost. The sum of the VFD cost, pump cost, and the cost of labor is the implementation cost.

Next Steps

The next step in pursuing the savings outlined in this report is to collect data on the current electrical requirement of the pumping system. Analyst assumptions were made to ensure the savings outlined are conservative. Pump efficiency can greatly degrade overtime, therefore the current system may be consuming more energy than estimated in this report. Providing a vendor with your boiler pressure and desired flow rate will allow them to size a pump that is more efficient.

Notes

Analysts assumed the boiler is always operating at 100% firing rate to use the most conservative amount of bypass time.

Analysts assumed the boiler's maximum firing rate still produces as much steam as is listed on the nameplate.

Analysts assumed the pump's efficiency and impeller diameter have not degraded over time.

References

[1] “Pumping System Assessment Tool,” Office of Energy Efficiency. [Online]. Available: https://www.energy.gov/eere/amo/articles/pumping-system-assessment-tool. [Accessed: 9-April-2018].

[2] “Variable Frequency Drive,50 HP,380-480V,” Grainger, 2018. [Online]. Available: https://www.grainger.com/product. [Accessed: 12-April-2018].

[3] “GS3-4050,” AutomationDirect, 2018. [Online]. Available: https://www.automationdirect.com/adc/Shopping/Catalog/Drives. [Accessed: 25-April-2018].

[4] "Lenze AC Tech SMV Series Drive: 50 HP," Walker Industrial, 2018. [Online]. Available: https://www.walkerindustrial.com. [Accessed: 27-April-2018]

[5] A. Charest, *RSMeans Electrical Cost Data.* Norwell, MA: RS Means, 2016, pp. 277.

Pump Curve

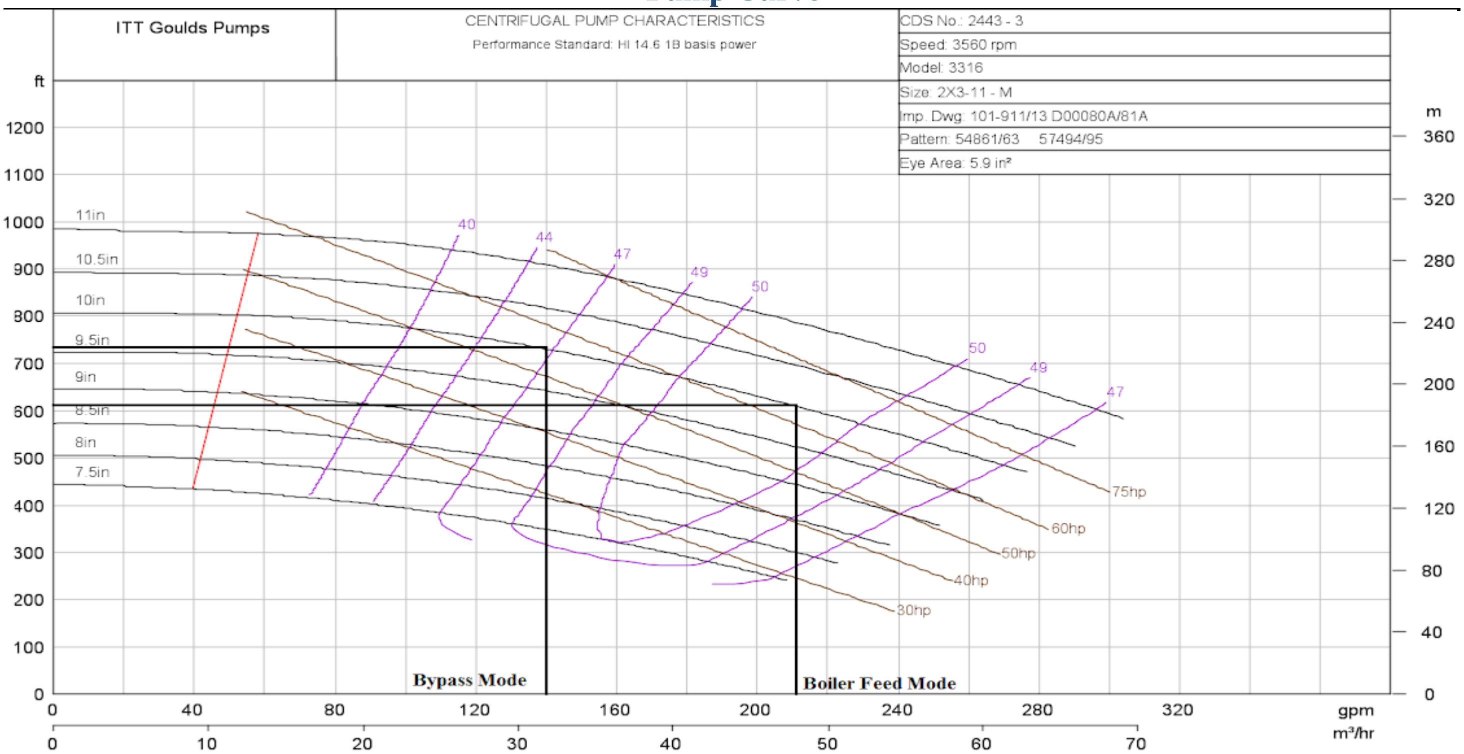

Figure 3.3.2: Gould's 3316 2x3-11 Pump Curve

Pump Head Analysis

Boiler Feed Mode

Pump Change in Pressure	(Pr_{Bo})	*250*	psi	**(N. 1)**
Change in Elevation	(ΔZ_{Bo})	*33*	ft	**(N. 2)**
Total Head	(H_{Bo})	***611***	ft	**(Eq. 1)**
Resulting Flow Rate	(V_{Bo})	*205*	gal/min	**(N. 3)**
Resulting Brake Horsepower	(BHP_{Bo})	*63*	hp	**(N. 3)**
Resulting Pump Efficiency	($\eta_{P.C}$)	*50%*		**(N. 3)**

Bypass Mode

Pump Change in Pressure	(Pr_{By})	*300*	psi	**(N. 1)**
Change in Elevation	(ΔZ_{By})	*34.5*	ft	**(N. 2)**
Total Head	(H_{By})	***728***	ft	**(Eq. 1)**
Resulting Flow Rate	(V_{By})	*140*	gal/min	**(N. 3)**
Resulting Brake Horsepower	(BHP_{By})	*55*	hp	**(N. 3)**

Equations

Eq. 1) Total Head ($H_{Bo,By}$)

$$Pr_i \times \frac{2.31\, ft_{H_2O}}{psi} + \Delta Z_i$$

Notes

N. 1) Recorded from a pressure gauge on the boiler controls on site.

N. 2) Measured by analysts on site with a laser distance meter.

N. 3) Estimated from the above pump curve, shown in Figure 3.3.2.

3 - AR No. 3 - Data Preparation

Data Collected

General Data

Operating Days	(t_D)	*260*	day/yr	**(N. 4)**
Boiler Fire Rate	(B_{FR})	*100%*		**(N. 5)**
Boiler Rated Steam Production	($\dot{m}_S$)	*40,000*	lb/hr	**(N. 6)**
Boiler Feed Water Demand	($\dot{m}_W$)	*114,778*	gal/day	**(Eq. 2)**
Feed Mode Flow Rate	(V_{Bo})	*205*	gal/min	**(N. 7)**
Bypass Mode Flow Rate	(V_{By})	*140*	gal/min	**(N. 7)**
Time in Pump Stage: Feed Mode	(t_{Bo})	*9.33*	hr/day	**(Eq. 3)**
Time in Pump Stage: Bypass Mode	(t_{By})	*14.67*	hr/day	**(Eq. 4)**

Bypass Mode Analysis

Brake Horsepower	(BHP_{By})	*55*	hp	**(N. 7)**
Motor Efficiency	(η_M)	*94.0%*		**(N. 8)**
Input Power	(P_{By})	*44*	kW	**(Eq. 5)**
Bypass Annual Energy Consumption	(E_{By})	*166,469*	kWh/yr	**(Eq. 6)**

Boiler Feed Mode Analysis

Brake Horsepower	(BHP_{Bo})	*63*	hp	**(N. 7)**
Motor Efficiency	(η_M)	*94.0%*		**(N. 8)**
Input Power	(P_{Bo})	*50*	kW	**(Eq. 5)**
Feed Annual Energy Consumption	(E_{Bo})	*121,305*	kWh/yr	**(Eq. 6)**
Feed Annual Demand	(D_{Bo})	*600*	kW-mo/yr	**(Eq. 7)**

New Pump Analysis

Current Feed Conditions

Brake Horsepower	(BHP_{Bo})	*63*	hp	**(N. 7)**
Pump Efficiency	($\eta_{P.C}$)	*50.0%*		**(N. 7)**
Required Hydraulic Power	(WHP_{Bo})	*32*	hp	**(Eq. 8)**

Proposed Conditions

Pump Efficiency	($\eta_{P,P}$)	*80.0%*		**(Rf. 1)**
Brake Horsepower	(BHP_P)	*39*	hp	**(Eq. 9)**
Motor Efficiency	(η_M)	*94.0%*		**(N. 8)**
Input Power	(P_P)	*31*	kW	**(Eq. 5)**
Time in Feed Mode	(t_P)	*9.33*	hr/day	**(Eq. 3, N. 9)**
Feed Annual Energy Consumption	(E_P)	*75,815*	kWh/yr	**(Eq. 6)**
Feed Annual Demand	(D_P)	*375*	kW-mo/yr	**(Eq. 7)**

Equations

Eq. 2) Boiler Feed Water Demand ($\dot{m}_W$)

$$\dot{m}_W \times B_{FR} \times \frac{1day}{24hr} \times \frac{1gal_{H_2O}}{8.34lb_{H_2O}}$$

Eq. 3) Time in Feed Mode (t_{Bo})

$$\frac{\dot{m}_W}{V_{Bo}} \times \frac{1hr}{60\,min}$$

Eq. 4) Time in Bypass Mode (t_{By})

$$24hr - t_{Bo}$$

Eq. 5) Input Power ($P_{By,Bo,P}$)

$$\frac{BHP_i}{\eta_M} \times \frac{0.746kW}{1hp}$$

Eq. 6) Annual Energy ($E_{By,Bo,P}$)

$$P_i \times t_i \times t_D$$

Eq. 7) Feed Annual Demand ($D_{Bo,P}$)

$$P_P \times \frac{12mo}{yr}$$

Eq. 8) Required Hydraulic Power (WHP_{Bo})

$$BHP_{Bo} \times \eta_{P,C}$$

Eq. 9) Proposed Brake Horsepower (BHP_P)

$$\frac{WHP_{Bo}}{\eta_{P,P}}$$

Notes

N. 4) Provided by boiler operator.

N. 5) Assumed by analysts to yield the least amount of bypass time.

N. 6) Acquired from the hog fuel boiler nameplate.

N. 7) Developed in the previous page of this analysis.

N. 8) Acquired from the boiler feed water pump nameplate.

N. 9) Motor and VFD power draw is negligible when not pumping.

Key Input Data

Utility Data

Incremental Electricity Charge	(IC_E)	*$0.048*	/kWh	**(N. 9)**
Incremental Demand Charge	(IC_D)	*$7.91*	/kW-mo/yr	**(N. 9)**

Energy Analysis

Current Conditions

Current Energy Consumption	(E_C)	*287,773*	kWh	**(Eq. 10)**
Current Energy Cost	($C_{C,E}$)	*$13,813*	/yr.	**(Eq. 11)**
Current Demand	(D_C)	*600*	kW-mo/yr	**(N. 10)**
Current Demand Cost	($C_{C,D}$)	*$4,746*	/yr.	**(Eq. 12)**

Proposed Conditions

Proposed Energy Consumption	(E_P)	*75,815*	kWh	**(N. 10)**
Proposed Energy Cost	($C_{P,E}$)	*$3,639*	/yr.	**(Eq. 11)**
Proposed Demand	(D_P)	*375*	kW-mo/yr	**(N. 10)**
Proposed Demand Cost	($C_{P,D}$)	*$2,966*	/yr.	**(Eq. 12)**

Savings

Energy Savings	(E_S)	*211,958*	kWh	**(Eq. 13)**
Demand Savings	(D_S)	*225*	kW-mo/yr	**(Eq. 14)**
Cost Savings	(S)	*$11,954*	/yr.	**(Eq. 15)**

Equations

Analysis Equations

Eq. 10) Current Energy Consumption (E_C)

$$E_{By} + E_{Bo}$$

Eq. 11) Energy Cost ($C_{C,E}$,$C_{P,E}$)

$$E_i \times IC_E$$

Eq. 12) Demand Cost ($C_{C,E}$)

$$D_i \times IC_D$$

Eq. 13) Energy Savings (E_S)

$$E_C - E_P$$

Eq. 14) Demand Savings (D_S)

$$D_C - D_P$$

Eq. 15) Cost Savings (S)

$$\left(C_{C,E} - C_{P,E}\right) + \left(C_{C,D} - C_{P,D}\right)$$

Notes

N. 9) Developed in the Utility Analysis section of this report.

N. 10) Developed on the Data Preparation page of this recommendation.

3 - AR No. 3 - Implementation

Oregon State University | Energy Efficiency Center

Install VFD of Feed Water Pump, style 2018 v1.0

Vendor Data

VFD Quotes

Vendor Quote #1	($V_{VFD,1}$)	*$2,624*	**(N. 11)**
Vendor Quote #2	($V_{VFD,2}$)	*$2,436*	**(N. 12)**
Vendor Quote #3	($V_{VFD,3}$)	*$2,840*	**(N. 13)**

Pump Quotes

Vendor Quote #1	($V_{P,1}$)	*$6,800*	**(N. 14)**

Implementation Cost Analysis

Labor Costs

Number of Electricians	(n_L)	*2*		**(N. 15)**
Electrician Labor Rate	(R_L)	*$35.32*	/hr	**(N. 15)**
Electrician Labor Hours	(t_L)	*30.2*	hours	**(N. 15)**
Total Labor Cost	(C_L)	*$2,133*		**(Eq. 14)**

Economic Results

Annual Cost Savings	(S)	*$11,954*	/year	**(N. 10)**
Implementation Cost	(C_I)	*$11,773*		**(Eq. 15)**
Simple Payback	(t_{PB})	*1.0*	years	**(Eq. 16)**

Incentive Data

Annual Energy Savings	(E_s)	*211,958*	kWh	**(N. 16)**

Equations

Eq. 14) Total Labor Cost (C_L)

$$n_L \times R_L \times t_L$$

Eq. 15) Implementation Cost (C_I)

$$V_{VFD,\max} + V_{P,1} + C_L$$

Eq. 16) Total Labor Cost (C_L)

$$\frac{C_I}{S}$$

Notes

N. 11) Price obtained from Grainger [2].

N. 12) Price obtained from Automation Direct [3].

N. 13) Price obtained from Walker Industrial [4].

N. 14) Third party quote for a pump that can produce 205 gpm of flow at 650 ft of head.

N. 15) Based on the RSMeans handbook for electrician labor costs [5].

N. 16) Developed on the Analysis page of this recommendation.

Incentive Analysis Summary

Description	*Incentive*	*After*	*Payback* (yrs)	*Notes*
Tacoma Power	*$8,241*	*$3,532*	*0.3*	*$0.23 per annual kWh saved up to 70%*