AN ANALYSIS OF MOTOR SYSTEM OPTIMIZATION OPTIONS
A Question of Diminishing Return on Investment

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ABSTRACT

This paper presents the verified results of a pump system optimization project at a major midwestern brewery. A 150-horsepower "sweet water" pump circulates a glycol/water solution to cool tanks of beer during fermentation. To keep the pump from overloading the motor, the discharge throttling valve was kept mostly closed, reducing flow and increasing pressure drop. The result was inadequate cooling and energy waste. A systems analysis showed that trimming the impeller would cut the required pumping energy by more than half. The impeller was trimmed and the energy savings paid for the entire project including the systems analysis in only six months. Further optimization efforts are currently under way on this system.

BACKGROUND

The G. Heileman Brewery in La Crosse WI, now owned by Stroh Brewery, employs several hundred people, and produces millions of barrels of beer per year. In the highly competitive beer market, even small cost savings are important. Heileman's plant engineering staff and management have worked hard to decrease the energy cost per barrel of beer produced. These efforts have paid off and Heileman now uses less energy to produce a barrel than it did a decade ago.

Heileman's numerous energy saving projects began with a realization that you have to be able to monitor and control the equipment that consumes the most electricity. The plant has a comprehensive energy management system which monitors and controls temperatures, pressures, operating status, electric and gas use, and many other functions. One of several energy-saving measures that the brewery employs is an aggressive demand-limiting program that cycles off nonessential equipment when demand approaches a new peak. Other measures taken include:

- The CO_2 system was modified from freon to ammonia, which improved the process and saves more than $20,000 annually in electric costs.
- The boiler controls were replaced and upgraded from pneumatic to electronic resulting in gas savings of an estimated 250,000 therms annually.
- A program to detect failed steam traps is in place and regular preventative maintenance is performed on the many traps at the plant.
- Motors are regularly specified as energy efficient and variable speed drives are used when appropriate.
- Lighting retrofits were done with many of the projects completed before the advent of utility rebate programs.

Heileman works closely with their local utility—Northern States Power Company—on many energy studies involving refrigeration, cogeneration, compressed air, and lighting. Being open to new ideas, knowing your own internal processes, and having a strong desire to reduce energy consumption has made Heileman a leader in energy conservation among industrial facilities in Wisconsin.

<u>Responsible Power Management Program</u>

Mike Herro, Key Account Engineer for Northern States Power Company conducted a screening survey at Heileman to determine potential for cost-effective system improvements. Herro was trained to recognize such opportunities at performance optimization workshops offered through the Energy Center of Wisconsin's Responsible Power Management Program (see PERFORMANCE OPTIMIZATION OF A FAN SYSTEM elsewhere in these proceedings). After the screening, Herro, a fluids engineer, and plant personnel performed a walkthrough audit, which identified a 150-horsepower pump on the glycol cooling loop as a significant source of inefficiency. With funding assistance provided by NSP, Michaels Engineering of La Crosse, WI, performed a detailed systems analysis—a feasibility study—to determine what modifications would be most practical and how much energy they would save. NSP also provided monitoring equipment used to measure the electric flow characteristics of the existing setup.

EXISTING SYSTEM CHARACTERISTICS

Brewing cycle

The tank cooling system, or glycol system, is the heart of the beer fermentation process. After brewing is complete, the beer is pumped into one of several dozen fermentation tanks. These tanks range in capacity from about 3000 gallons to 186,000 gallons. The beer ferments in the tank for about 72 hours, during which time yeast metabolizes sugar to produce alcohol, with carbon dioxide and heat as a byproduct. After this initial fermentation, the beer is maintained at a specific temperature for five to seven days. It is at this point that cooling is applied via the glycol system. When this step is complete, the beer is "crash cooled," or quickly cooled to below 40 °F. This puts an arduous load on the glycol system, especially when the larger tanks are being used. Crash cooling takes two to four days. Twice-brewed, or "krausened" products then undergo a second fermentation for up to three weeks.

After all the fermentation is complete, the product is called "ruh" beer. Then the beer is centrifuged to remove the yeast and filtered.

Cooling requirements

This system was designed 15 years ago by Heileman's corporate engineering department and was originally made up of three150-horsepower pumps circulating cooled glycol through a closed-loop pipe arrangement. The glycol—made of 36 percent food grade propylene glycol and water—is first pumped through a chiller with an approximate capacity of 400 tons. This chiller cools the glycol to 26 °F using ammonia provided from the central refrigeration plant. The chilled glycol is then pumped to 47 different beer tanks that are either jacketed for cooling or use two-inch stainless steel piping as a heat exchange surface. It then returns to the suction side of the pumps at a temperature near 30 °F where it continues back to the chiller. Because there is always beer in different stages of fermentation, the glycol system runs 24 hours per day, seven days per week.

Production problems

When there were several tanks being crash cooled simultaneously, the system could not provide adequate cooling, particularly in summer. Inadequate cooling produces excessive amounts of CO_2 in the tank that releases the pressure safety devices. Although the quality of the product is not compromised, substantial amounts of CO_2 that could be collected for use in other parts of the beer-making process are lost. CO_2 released into the aging cellar also creates a safety hazard when the CO_2 displaces available oxygen, creating an unbreatheable atmosphere.

Because of the sizes of the pumps, motors, and pipes, it was impossible to run the system efficiently. The system could never be run with more than one pump running at a time and the gate valve at the discharge of the pump open more than 25 percent. Deviating from this caused the thermal overloads on the pump motors to trip, shutting down the entire system. So the brewery would always run one of three 150-Hp motors wide open with the pump discharge valve 75 percent closed. This created enormous inefficiency.

The brewery had once attempted to rectify the problem by trimming the impeller, but because the system analysis at that time lacked flow measurement, they failed to solve the problem. Based on flawed assumptions about pressure and flow, they trimmed the impeller slightly and replaced the 150-Hp pump motor with a 75-Hp unit. But when they attempted to start up the system with the discharge valve wide open, the pump overloaded the motor. The new 75-Hp pump was abandoned in place, and one of the two remaining 150-Hp pumps took over the job, with the second used as backup.

In the recent project described in this paper, a more thorough and accurate analysis discovered a way to use the 75-Hp pump successfully.

SYSTEMS ANALYSIS

System metering was performed to verify the pump curve and to determine the load duty cycle, flow, system differential pressure, and electric input power. An additional objective was to determine what is causing inadequate cooling under certain conditions.

Instrumentation included an ultrasonic flow meter, pressure transducers, and temperature sensors. All instruments were interfaced to a data logger, which was also configured to monitor volts, amps, and watts. The chiller refrigerant valve control signal was also tied into the logger. All instrument readings were logged at 15 minute intervals for three weeks in February and March.

Metering revealed that the pump differential pressure, flow rate, and electrical draw were virtually constant regardless of cooling load. Of the total head of about 300 feet produced by the pump, at least 70 percent of it was consumed by the partially closed gate valve on the pump discharge. Under maximum flow conditions, the system consumes only 90 feet of head out of the 210 feet available. Thus the flow is less dependent on what is happening in the system, and is governed more by the fixed resistance of the gate valve. System bypasses appear to contribute to a significant percent of the flow. A manual bypass is used in one branch-piping loop to maintain availability of chilled glycol for a yeast-growing process (yeast brink). Automatic bypasses are used in two other branch piping loops to control pressure. Both the manual and automatic bypasses allow more flow as the tank control valves close and pressure rises in the secondary loop served. The control valves and heat exchangers on the horizontal tanks are large (two-inch pipe) and allow significant flow whenever they are open. This flow will increase if the pressure is higher, thus consuming more flow than necessary.

Technical Options

The technical options considered for improving efficiency included trimming the pump impeller, installing a new pump sized to meet the load, and installing a new pump with a variable speed drive.

Trim Pump Impeller

The system requirements (as opposed to what the pump was producing) were 1200 gallons per minute at 90 feet of head. Performance test results from the feasibility study indicated that these requirements could be met by the existing—and unused—75-Hp pump with its impeller further trimmed. Trimming had been attempted before, but because the trimming was not drastic enough the pump could only be operated with the gate valve on the discharge partially closed, which in turn resulted in inadequate flow. A more drastically trimmed impeller would allow the pump to operate with the gate valve fully open, allowing the pump to ride out on the curve.

Information from the performance testing provided the hard engineering data needed to make this decision. It also provided confidence that the modification would be successful.

Install New Pump

Even with the impeller trimmed down as much as possible, the 75-Hp pump has greater flow and head capabilities than needed. In addition, the trimmed pump operates well off its maximum efficiency point, at 76 percent. Installing a new pump—sized at 40 Hp to match system requirements—would boost the efficiency to 83 percent. To provide insurance against low flow, it may be necessary to run the 75 HP pump occasionally to satisfy peak cooling demands.

Install New Pump with Adjustable-Speed Drive

This option only applies if the system is modified to eliminate bypasses and provide a means to limit flow to the horizontal tanks. If these modifications are made, the flow through the system will vary according to changing load, rather than staying constant. The adjustable-speed drive would be controlled by pressure-differential sensors installed between the supply and return of selected secondary loops. As the control valves in the system close under low load conditions, the pressure will rise in these branches, which will provide the signal necessary to allow the pump speed (and power) to be reduced.

Energy savings for the three options are shown in Table 1. Simple return on investment is calculated as shown in Equation (1).

All options in Table 1 are evaluated relative to the "existing system" case.

$$\text{simple ROI} = \frac{1}{\text{simple payback (years)}} \times 100\% \qquad \text{Equation (1)}$$

Table 1. Energy savings of performance optimization options

	Existing system	Trimmed impeller	New 40-Hp pump	New pump/ASD
Flow (GPM)	1200	1500	1200	1200
Head (feet)	310	120	90	90
Efficiency (%)	72	76	83	83
Pump load (bHp)	140	70	35	35
Motor size (Hp)	150	75	40	40
System control	constant flow	constant flow	constant flow	variable flow
Demand (kW)	112	56	28	29
Energy consumption (kWh/yr)	980,000	490,000	245,000	150,000
Annual energy cost ($)	36,000	18,000	9000	6500
Cost savings		18,000	27,000	29,500
Project costs				
Feasibility study ($)		7500	7500	7500
Equipment and installation ($)		1500	12,000	40,000
Total cost ($)		9000	19,500	47,500
Simple payback (years)		0.5	0.7	1.6
Simple Return on Investment (%)		200	138	62

Data in boldface are measured values.

DIMINISHING RETURN ANALYSIS

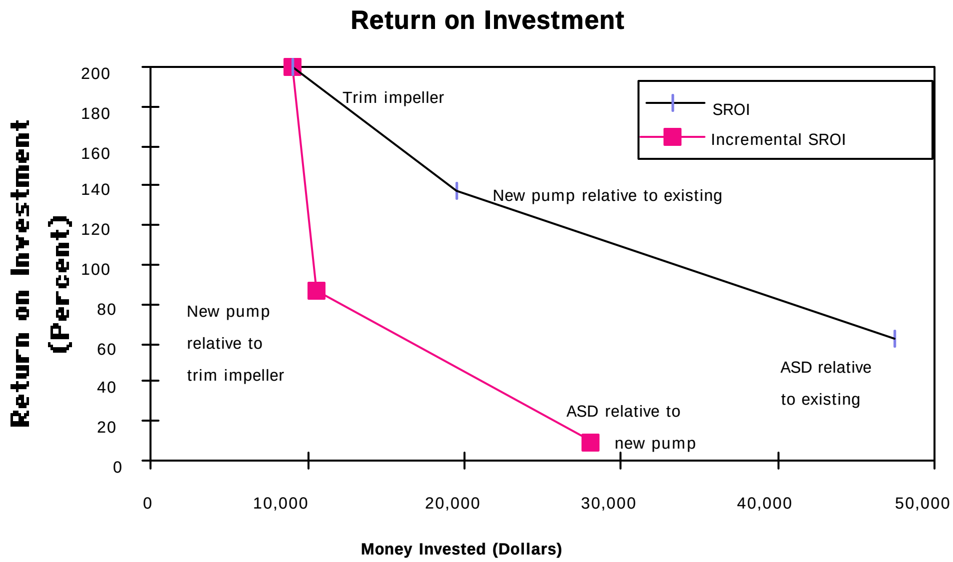
Based on information in Table 1, one could conclude that the new pump with ASD option—with a 1.6-year payback and the highest overall savings—is most economical choice. But looking at the options relative to each other leads to a different conclusion. Instead of comparing the return on investment relative to the existing situation, one could view the return on investment relative to the lower cost options. Table 2 shows that relative to trimming the impeller, the optimal new pump has an annual savings of $9000; relative to the existing situation the savings is $19,500. Similarly, the savings of installing an ASD on the new, optimally selected pump is $2,500, not $29,500 as expressed relative to the existing situation. When viewed in this light the ASD has a simple ROI of only nine percent, not 62 percent.

Figure 1 illustrates the difference between simple return on investment (as shown in Table 1) and incremental simple return on investment (Table 2).

Table 2. Incremental cost/benefit analysis

	Trimmed impeller	New 40-Hp pump (relative to trimmed impeller)	New pump with ASD (relative to new pump)
Incremental cost ($)	9000	10,500	28,000
Incremental savings ($)	18,000	9000	2500
Incremental simple payback (yrs)	0.5	1.2	11.2
Simple return on investment (%)	200	86	9

Figure 1. Incremental Return on Investment.



LIFE CYCLE SAVINGS ANALYSIS

A more rigorous economic analysis of these alternatives can be made through Life Cycle Savings analysis. LCS is the Net Present Value of the savings minus the initial cost, adjusted as appropriate for fuel escalation, tax effects and an appropriate discount rate or Minimum Attractive Rate of Return (MARR). Any project with an LCS greater than zero is worth implementing, meaning that it will provide a return on the investment which is greater than the MARR. In a case like this with mutually exclusive alternatives, the project with the greatest LCS will provide the greatest economic benefit.

We performed an LCS analysis for the three alternatives using nominal values for fuel escalation at three percent, an effective tax rate of 50 percent, a MARR of 25 percent, and a useful life for the project of 10 years. Table 3 shows the results.

This analysis shows that all alternatives are cost effective, but the optimal new pump is the most economical. This is in general agreement with the findings of the diminishing returns analysis, which showed that the impeller trim and the new pump were both worthwhile, but the adjustable-speed drive was not.

IMPLEMENTATION

Heileman trimmed their impeller as recommended, and is now using the 75-Hp pump. Brewery engineering staff chose this option for two reasons: it was easy and it had a low first cost.

The original flow rate of 1200 GPM has increased now to a varying rate between 1300 and 1500 GPM. The pumping energy has been reduced from 112 kW to 56 kW, which saves Heileman about $18,000 per year.

Table 3. LCS analysis of efficiency improvement options.

Option	Life Cycle Savings ($)
Trimmed Impeller	30,656
Optimal New Pump	40,528
New Pump with ASD	24,404

OTHER BENEFITS

In addition to the energy savings, the brewing process has improved as a result of the trimmed impeller. The system now provides more cooling flow to the process, which has resulted in fewer nuisance overheating incidents, even though the brewery has increased production. Overheating, which causes tanks to release CO_2 into the aging cellar, forces evacuation of personnel while exhaust fans purge the facility.

ADDITIONAL OPTIONS

In addition to the technical options previously described, there are some general system improvements that the brewery is pursuing to allow the system to better meet cooling needs under peak loading, as well as capturing additional savings

Eliminate Manual Bypass Valve

A manual bypass in one of the branch piping loops was installed to keep cold glycol available for the "yeast brink" when there is no other flow for an extended period. This objective could also be accomplished by replacing the manual bypass valve with a modulating control valve. This valve would be controlled from the measured supply temperature at the end of each secondary loop. This would achieve the desired intention of keeping chilled glycol available instantly while limiting bypass flow to only what is necessary.

Balance System Flow

A second improvement would be to make modifications to limit the flow that can be drawn by any one tank, especially on the horizontal tanks. The heat exchangers serving these tanks are two-inch stainless steel pipe, the control valves are two-way, and branch piping is direct return. Whenever one of these tanks is calling for cooling, it can draw an excessive amount of flow, especially if the tank is located close to the main supply and return pipes. This effect was confirmed by production staff, who reported that crash cooling in these tanks can typically be accomplished in one day rather than the two days normally allowed. With the additional flow being provided by the modified 75-Hp pump, it is possible that glycol flow through the tanks may not be a problem. However, even if the system is only being limited by chiller capacity, reducing the cooling rate on the horizontal tanks will make more cooling available throughout the system, and should help alleviate the current difficulties cooling some tanks during peak loads.

Balancing these tanks so they receive no more than their required maximum flow rate would allow more flow and cooling to be available to other tanks in the system, while still keeping the cooling rate within the desired range. Excess glycol flows must also be eliminated if the system is to be converted to variable flow. Also, once the new flow and pressure requirements are known, the new pump option can be implemented if desired.

FUTURE PROJECTS

Heileman is continuing their leadership role in energy efficiency by exploring new potential projects that have short payback periods and improve process efficiencies. A comprehensive compressed-air survey recently identified many options to provide adequate compressed air for less horsepower. The following recommendations are now being studied for implementation by plant engineering staff:

- Multicompressor control strategy
- Demand-side control system with intermediate control
- Compressor resizing study
- Venturi nozzles for grain movement

CONCLUSION

The Responsible Power Management Program's performance optimization project at G. Heileman brewery illustrates one of the many opportunities in industry to improve productivity and reduce costs. The results have paid off. The brewery's new owners, the Stroh Brewery Company, has recognized the Heileman plant's low-cost production capability, and is therefore shifting production to this plant from older, less efficient plants. It appears that for the first time in the Heileman plant's history, they may be running at nearly full capacity. Heileman's new plant engineer, Joe Weiss, commented, "Someone at Stroh's obviously thinks, 'Hey we've got a shiny penny here—let's use it!'"