Annual Meeting
March 22-24, 2015
Marriott Rivercenter
San Antonio, TX

AM-15-43

Energy Efficiency in Capital Projects

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Energy Efficiency in Capital Projects

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Abstract

The best economics for energy efficiency improvements occur in new plant designs and major plant expansions. Basic technology selection, heat integration, specifications for equipment items such as high-efficiency motors, pumps and compressors, control schemes, insulation, and utility plant choices can all have a major impact on energy performance. Unfortunately, many opportunities to achieve these benefits are lost because of pressure to minimize investment and concerns about project schedule.

Energy efficiency workshops and process flow diagram (PFD) reviews are very effective procedures for identifying the energy-efficiency issues in any given design and identifying improvements. An energy efficiency workshop, in its simplest form, is a review of standard features that can be incorporated into a design to enhance energy performance. The review highlights the elements that have been incorporated in a preliminary design and reveals opportunities that have been left on the table.

Process flow diagram (PFD) reviews provide a very down-to-earth and practical approach to the problem of finding more specific energy efficiency improvement opportunities. Preliminary PFDs are available early in the life of most projects. The review consists of a systematic evaluation of the PFD documents, combined with structured brainstorming. Typical results from PFD reviews include process improvements ranging from simple piping modifications and changes in control philosophy to equipment upgrades and major design changes.

This paper discusses the use of these simple tools to improve project economics. Case studies are presented to illustrate the types of opportunities that are typically identified.

Background

There are many situations and circumstances when it makes good sense to pursue energy efficiency for industrial processes – but when is the best time?

Operating discipline in existing plants often leads to significant energy savings without investing capital. All that is needed is careful evaluation of operating practices and training of operators. Adding key performance indicators and real-time optimizers and making data accessible through an energy "dashboard," can increase the savings and make them more sustainable.

Dedicated maintenance and energy "housekeeping" has a demonstrated track record of energy savings. Key areas that can be improved include steam leaks and steam traps, as well as insulation, heat exchanger cleaning, and rotating equipment.

Some revamp projects are implemented specifically to enhance energy efficiency through improved heat integration, steam/power system balancing, equipment upgrades, and even (sometimes) fundamental process changes. However, even though the economics can be attractive, these types of projects are inherently difficult to justify and to implement because they require working within the confines of existing facilities. Furthermore, when you replace a piece of equipment with an "upgrade" you typically pay full price for the new item while only gaining the incremental benefit between it and the old equipment. This often results in poor economics for revamp projects.

The implication is clear: The best economics for energy efficient processes and equipment occur in new plant designs and major plant expansions.

There are many different areas where energy efficiency can be "baked in" during various stages in the design of new facilities:

Basic technology selection. Early in design the key issue is basic technology selection. There are often several competing technologies available to achieve the required process objectives, such as material transformations and separations, and many factors must be considered in choosing between them. Considerations typically include yield, selectivity, reliability, environmental impact (liquid and solid waste production, as well as exhaust gases), plot space requirements, prior experience with the same or similar technologies, and, of course, cost and energy efficiency. Due to the multi-dimensional nature of the selection parameters the most energy-efficient option may not always be the top choice – but energy should always be a serious consideration in the selection procedure.

Beyond basic technology selection there are many additional design decisions that affect the energy performance, including:

a. **Heat integration scheme.** It is often possible to recover additional energy from "waste heat" sources without fundamentally changing the underlying process technology. Pinch analysis is a good technique for identify opportunities to do this (1, 2).
b. **Equipment selection.** Pumps, compressors, turbines, motors and other pieces of mechanical equipment can vary greatly in efficiency. It is usually worth investing a little more in high-efficiency machines in order to reduce energy costs throughout the life of the project.
c. **Process and utility interfaces.** Typically individual process designs are well optimized by contractors. However, material and energy is transferred between different process units, and between process units and utility systems, and the interconnections vary from site to site. Consequently, there is no general optimization for the interfaces, and there are invariably opportunities to fine-tune the design. This can include, for example, incorporating options for hot and/or cold transfer of material from one process to another, adding steam turbines in steam systems, generating steam from surplus heat, and changing steam header pressures.
d. **Control.** A great deal of energy is consumed in process control – for example, in throttling or recycling the discharge flow from pumps. Alternative control options, including variable frequency drive control, should be considered during the facility design. In addition, excess air control of boilers and furnaces using stack gas oxygen and carbon monoxide measurements

should be incorporated in new designs where appropriate. These measures can greatly improve overall equipment efficiencies, as well as minimizing environmental impact.

e. **Design for Ease of Maintenance.** Various maintenance activities are important for sustaining energy efficiency over the life of a project, and these requirements should be considered during design. Examples include provision of bypass piping and valves to allow on-stream cleaning of key heat exchangers; washing facilities for turbines and compressors, and cleaning facilities for boilers and furnaces.

Standardized Opportunities

Process design is a complex combination of science and art, and energy efficiency must never be handled in isolation from other design considerations. This makes it difficult to identify the most appropriate options for any given facility. However, there are some steps that should be embedded in the project systems, notably:

Engineering standards can be used for many common types of equipment. For example, the standards can define circumstances where premium (high-efficiency) electric motors should be used, and what types and thicknesses of insulation are required for various applications. The standards should be based on available technologies and current economics specific to the project.

Procurement protocols should require that energy efficiency is considered when equipment is evaluated for use in the new facilities. The project organization should advise potential suppliers of this fact, and where possible highlight specific issues related to individual types of equipment.

These standardized approaches capture many of the basic measures that enhance energy efficiency in a refinery or chemical process. However, to some extent every process is different, and not everything is amenable to standardization. Additional measures are needed to probe for project-specific opportunities that can lead to exceptional energy performance with realistic economics. An energy efficiency workshop provides a practical way of achieving this.

Energy Efficiency Workshops

The term “energy efficiency workshop” is commonly applied to a program of work intended to review and improve the energy efficiency of a process design. In its simplest form, the workshop is just a review of standard features that can be incorporated into a design – essentially a verification step to ensure that engineering standards and procurement protocols have been properly followed. However, the scope of the energy efficiency workshop can be expanded to include activities that seek additional opportunities to enhance energy performance. These include pinch analyses, which are primarily used to evaluate and improve heat integration, and process flow diagram (PFD) reviews, which can provide insights into a wide range of different types of efficiency improvements. Pinch analysis has been discussed extensively elsewhere (1, 2). The current article focuses primarily on PFD reviews (3).

PFD Reviews

A PFD review is essentially a "structured brainstorming" activity. Preliminary PFDs are generally produced early in the design of a new process unit, showing the major equipment items and their interconnections, together with the basic heat and material balance across the unit. These provide all the information that is needed for the review.

The procedure for a PFD review is somewhat similar to that customarily used for "HAZOP" studies. With the marked-up PFD, a team reviews each of the main streams, equipment items and systems to identify inefficiencies and areas of opportunity. The review team should include not only engineers from the project with design experience, but also personnel with experience in operations, control and maintenance, an energy efficiency specialist, and a facilitator. The individual team members bring a wide range of experience and perspectives. Engineers from the project bring their experience of the current design. The plant operations and technical staff bring their knowledge of day-to-day plant issues to the table. Energy efficiency specialists bring insights from similar processes at different locations, and the types of energy efficiency opportunities that have worked in them. This mix of expertise allows the team as a whole to unearth issues and opportunities that would otherwise be missed. Together the team members brainstorm ideas for the process unit or units under consideration.

Typically a large number of ideas will be identified during a PFD review. When the approach is used for new plant designs, it typically reveals opportunities to substitute types of equipment (e.g., motors and steam turbines), change designs to improve plant flexibility, re-route piping, or modify control schemes, and enhance heat integration. Occasionally, it also reveals opportunities to use completely new processes and "step-out" technologies. All of the opportunities should be documented during the PFD review and then later evaluated in more detail to quantify the potential savings, estimate the impact on project costs, identify technical risks, and determine applicability.

Case Studies

The following examples illustrate the types of opportunities that typically surface using energy efficiency workshops and, in particular, when PFD reviews are included.

Example 1. Use of Steam Turbines

A new hydrotreater to be added to a refinery included a large compressor. The preliminary design used a backpressure steam turbine operating between the refinery's high pressure (600 psig) and medium pressure (150 psig) headers to drive this machine. The exhaust steam was used for reboilers within the hydrotreater, with excess steam available for other consumers across the refinery (Figure 1).

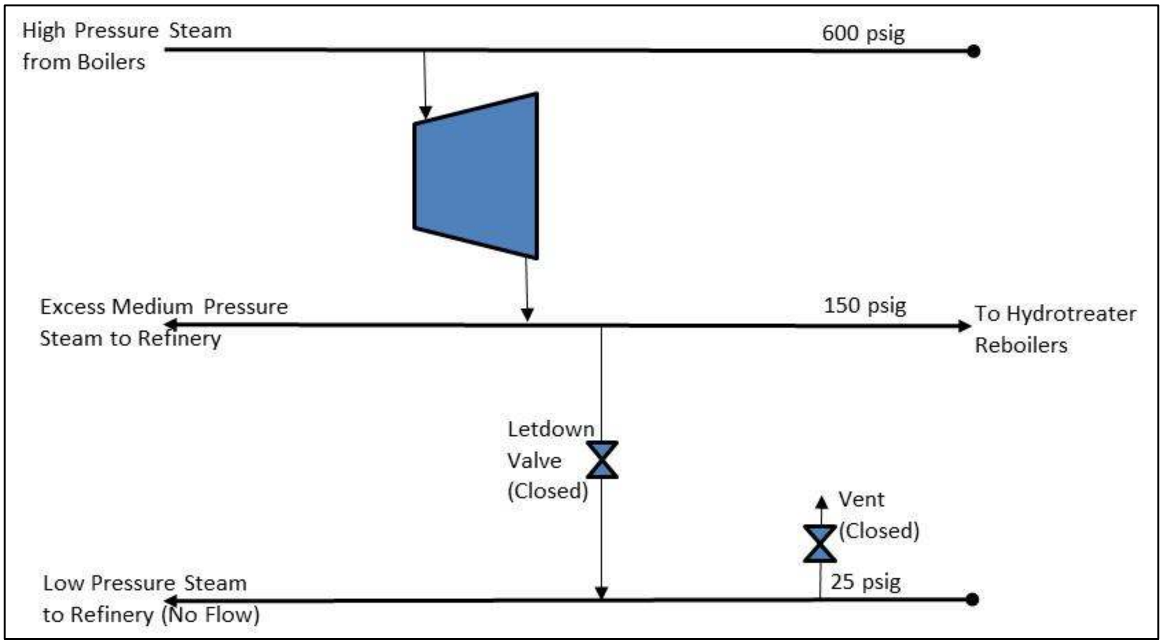

Figure 1. In the reference case, exhaust steam from the backpressure steam turbine is entirely utilized by either reboilers within the new hydrotreater or by other medium pressure steam consumers within the refinery.

Backpressure steam turbines often provide a great opportunity to enhance efficiency and reduce overall energy costs. The usual alternative is a motor. This depends on electricity which is typically generated with a thermal efficiency of around 33%. In contrast, the steam used to drive the backpressure turbine is typically generated in boilers at an efficiency of 80% or more; and provided the exhaust steam from the turbine is used beneficially (e.g., by reboiling distillation columns), the only significant losses that need to be considered are those at the boiler itself. Consequently, the primary energy used to run the compressor with a backpressure steam turbine is typically less than half of that required with an electric motor.

However, there is a catch: The exhaust steam must have a beneficial user. The review of this particular design showed that the steam demands on the various steam headers vary considerably, depending on seasonal factors and the operating modes of the various units within the refinery. As a result, although the backpressure turbine is a good fit with the refinery's steam balance in its reference case operation, for much of the year this is not the case. At times the net demand for medium pressure steam is less than the exhaust flow from the new backpressure turbine. In these cases the excess is let down to the low pressure (25 psig) header, where some of it can be used – but there is still a net excess, and a large portion of the exhaust steam would be vented (Figure 2).

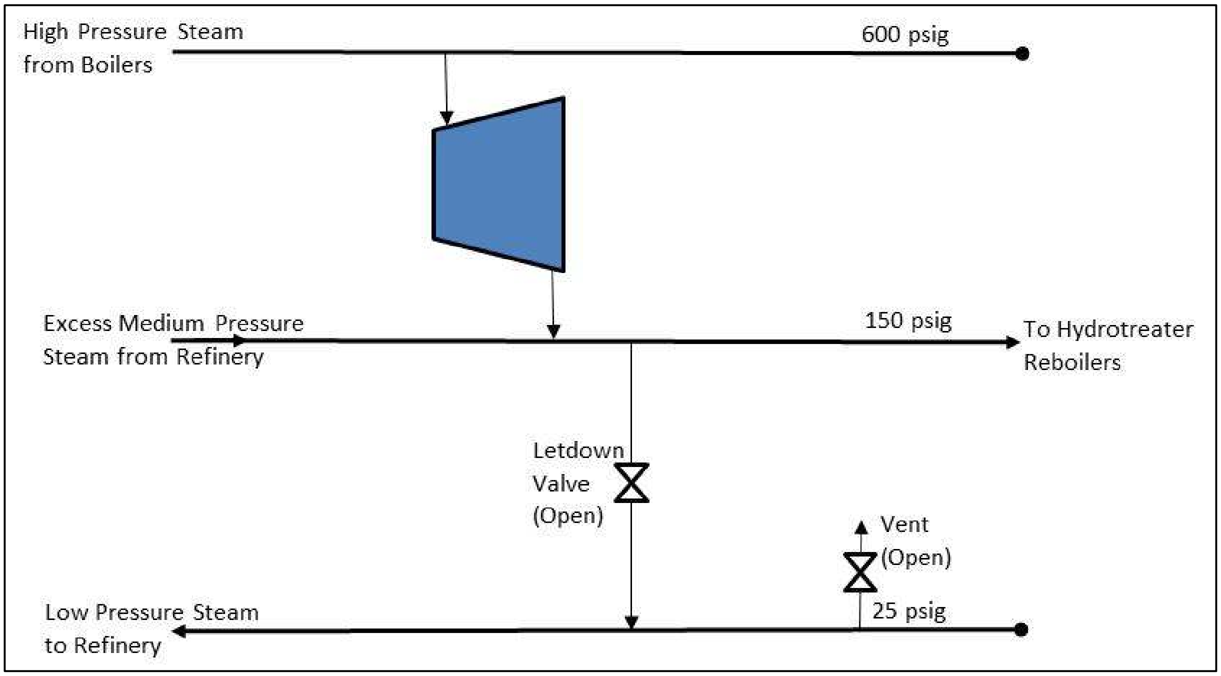

Figure 2. As steam demands vary across the refinery, situations arise where excess exhaust steam has to be let down to the low pressure header, and a large amount is vented.

The review of this unit identified an extraction turbine as a potential solution to this problem. The extraction turbine takes steam in from the high pressure header, but it can exhaust steam to both the medium (150 psig) or low (25 psig) pressure headers.

When steam expands through a turbine from 600 psig to 150 psig, the specific steam consumption is roughly 31 lb/kWh. However, if it expands from 600 psig to 25 psig, the specific steam consumption is roughly 17 lb/kWh – 45% less. It follows that the maximum inlet flow to the extraction steam turbine is required when the bulk of the steam exhausts at the 150 psig header. This approximates to the original backpressure turbine design. If the demand for medium pressure steam goes down, a portion of the exhaust steam is routed through the low pressure exhaust port until the medium pressure header is balanced (Figure 3). The total steam use of the turbine goes down, because of the lower specific steam consumption. Consequently, even though a portion of the steam from the extraction turbine goes to the low pressure header, the quantity is considerably less than amount that is let down with a backpressure steam turbine (Figure 2), and there is no vent in any of the expected operating modes.

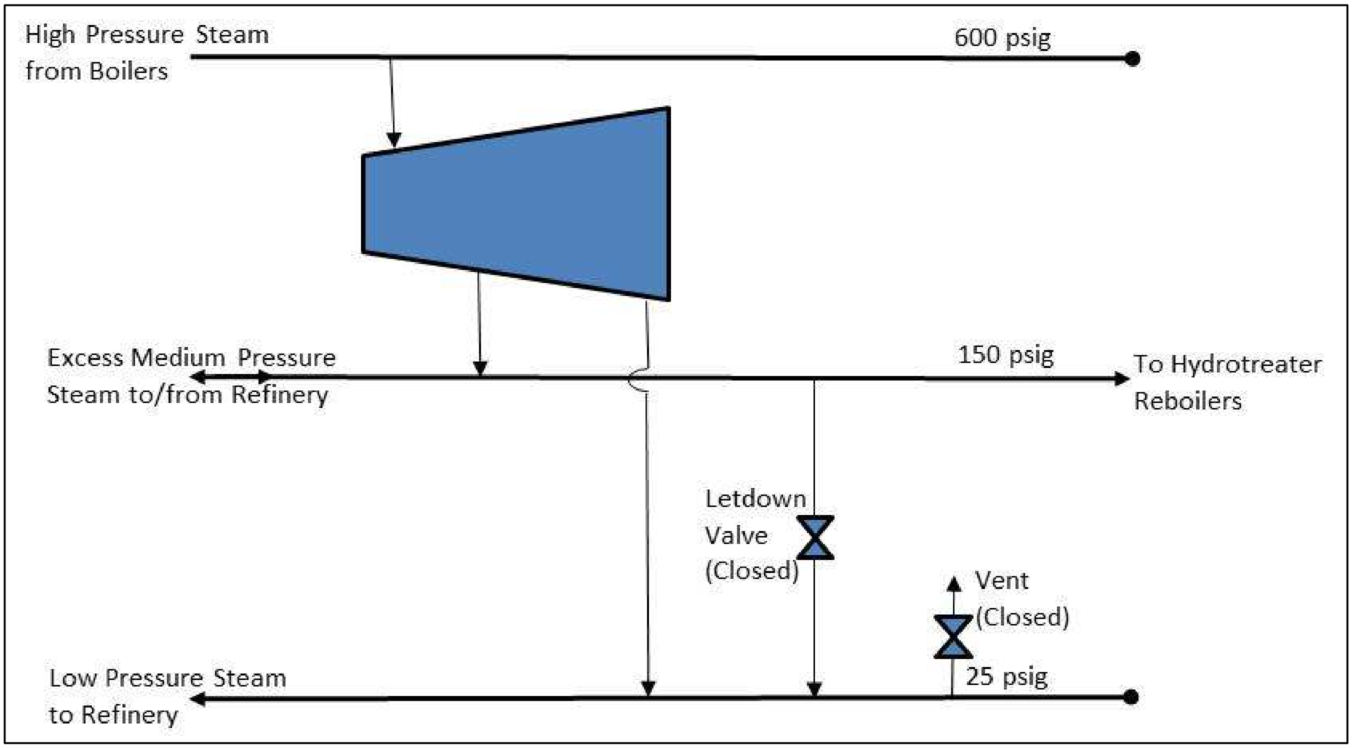

Figure 3. Replacing the backpressure steam turbine with an extraction turbine provides additional flexibility and eliminates the steam vent in all of the operating cases.

The extraction turbine for this process is more expensive than the backpressure turbine, and its control is more complex. The added cost was estimated at $1,000,000, with operating savings of $400,000/year, or a simple payback of 2.5 years.

Example 2. Seasonality in Distillation

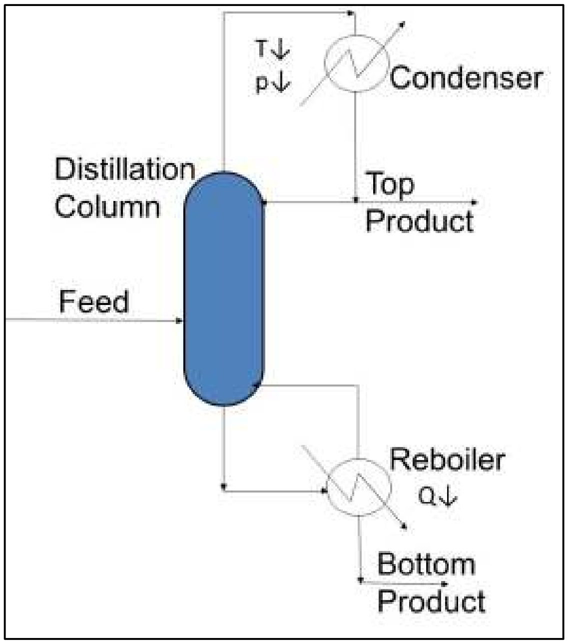

Figure 4. Seasonal temperature variations can be exploited to operate the distillation column at lower temperatures in winter months, reducing reboiler duty.

A review of a process unit with a large distillation column showed the design operating conditions were the same in both summer and winter. The utility balances, however, showed that the cooling water would be 35°F cooler in the winter than in the summer. This potentially allows the overhead to be operated at significantly reduced temperatures in the winter months by maintaining cooling water flow. This reduces the column pressure and improves the relative volatility of the material being separated, which in turn reduces the reboiler duty (see Figure 4).

As a result of the review the design was checked to see if there were any constraints that would prevent the column from operating at lower temperature during the winter. In this case no such constraints were found. As the reference design could handle the modified conditions, the only changes that were required in this case were to update the heat and material balances for the winter case, and to modify the operating instructions. The estimated operating savings were $100,000/year, with no increase in project cost.

Often the operators of distillation columns allow the tower pressure to fluctuate with seasonal temperature changes even if this issue not addressed in the operating instructions, but this is not always so. Some try to keep the conditions as constant as possible year-round, in the interest of stability. By highlighting the issues in the design stage, the operating company was able to address them and capture the energy saving potential inherent in the column design immediately upon start-up.

The examples above illustrate the types of opportunities that can be expected from an energy efficiency workshop. A typical workshop for a multi-process hydrocarbons complex will yield a large number of attractive opportunities of various types with a range of magnitudes of savings and paybacks. One reported workshop, which included both PFD reviews and pinch studies, resulted in 460 million Btu/h in energy savings (worth $15-20 million/year for the facility). The return on investment for the individual changes ranged from 25% to greater than 100% (4).

Integrating the Energy Efficiency Workshop into a Major Project

The scope and timing of the energy efficiency workshop need to be considered carefully.

Energy efficiency workshops vary greatly in scope and duration. In most cases the "workshop" is not a single event, but rather a series of activities interwoven with the project. Even small projects generally warrant at least a basic review to ensure that standard energy efficiency measures have been incorporated. A PFD review is usually justified for larger projects, and pinch analyses should be added for projects with larger heating and cooling duties and complex heat integration systems.

Timing is important. If the workshop is carried out too late there may be no way to incorporate the opportunities that are identified without adversely impacting the overall project schedule and budget. The simple rule of thumb is that work on the workshop should start as early as possible consistent with availability of basic process data. This generally means that the workshop should start as soon as preliminary PFDs and heat and material balances are available.

It is also important to have the right people in the workshop. While it is obviously important to make use of energy efficiency specialists and skilled facilitators, it is also important to engage the members of the project team who are in the best position to incorporate the results into the final design. Ownership of the workshop and its results is important if the work is to be accepted and the ideas derived from it are to be implemented.

Conclusion

At a time when many large hydrocarbons projects are underway, it is important to ensure that our new facilities achieve high standards of energy efficiency. Not only is this essential for reasons of environmental impact and sustainability; it is also good economics. When properly managed an energy efficiency workshop, typically including a PFD review, can lead to significant energy savings over the life of the project, with minimal impact on schedule and an excellent return on investment.

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