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Identify Process Improvements for Energy Efficiency

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The energy efficiency improvement potential of chemical processes is often overlooked. A process flow diagram review is the first step toward reducing your plant's energy consumption.

The most neglected area of energy efficiency evaluation in the chemical process industries (CPI) is within the process. This is due, in large part, to a concern that changes could adversely affect product quality and/or production rates. Although this is a legitimate concern, it leads facilities to ignore many viable energy-saving opportunities. Also, because each process is unique, the evaluation and development of an improvement methodology typically requires specialized expertise. As a result of these obstacles, utility systems (*e.g.,* steam) and specific pieces of equipment (*e.g.,* furnaces) that have well-known parameters and standard improvement options typically receive the most energy efficiency attention.

This article introduces a general approach to identifying and evaluating energy-efficiency improvement opportunities within a chemical process. While the focus is on improving existing CPI operations and identifying retrofit projects, many of the principles can also be applied to the evaluation and improvement of new plant designs.

The process flow diagram review

A process flow diagram (PFD) review is the first step in identifying improvement options. Each process unit (*e.g.,* hydrotreater, crude unit, etc.) should have its own PFD that identifies the major equipment items, their interconnections, and the basic heat and material balances across the units. All of the fired heaters, columns, and heat exchangers should be included, with temperatures, flowrates, and pressures at the inlets and outlets of each piece of equipment labeled. It is also prudent to include the duty for each fired heater, heat exchanger, or block of exchangers if this information is available. In addition, any place where steam is used or generated should be indicated on the PFD with the flowrates labeled.

The PFD review procedure is similar to that of a hazard and operability (HAZOP) study. Plant operations, technical support personnel, and energy-efficiency specialists review each of the main streams, equipment items, and systems to identify inefficiencies and improvement opportunities. The site-specific knowledge provided by plant operations and technical staff, combined with the specialists' knowledge of similar processes and the improvements that have worked at other facilities, create a robust knowledge base from which to draw ideas.

Typically, a PFD review team identifies a large number of ideas that may range from setpoint and operating target adjustments, new control schemes, minor piping changes, and simple equipment modifications, to completely new processes and novel technologies. All of the possible solutions should be documented during the PFD review and then later evaluated to quantify the potential savings, estimate the implementation costs, identify technical risks, and determine applicability.

Variations of the standard PFD review can be conducted with successful results, and are typically implemented when a face-to-face meeting with plant operations, technical support, and energy-efficiency personnel is not logistically feasible, or if there is limited time available for the effort. Although discussion between the internal and external personnel is preferable during the idea-generation phase of the PFD review, it is also possible for the external specialist(s) to conduct the initial review, and analyze and discuss the results remotely with the internal team.

Another approach is the kaizen treasure hunt; the word kaizen is Japanese and means "good change." Pioneered in the U.S. by Japanese car manufacturer Toyota *(1),* the technique has been applied successfully in the process industries (although typically at small facilities). A cross-functional team of site employees and external experts meets on-site for a few days (typically three) to investigate a facility's energy use. The team observes equipment operation, collects data, compares the facility's energy consumption to that of similar facilities, identifies potential improvements, and completes detail sheets that describe each improvement opportunity and its associated cost and potential savings. This approach engages all levels of personnel in energy-efficiency activities *(2)*.

Although a PFD review or a kaizen treasure hunt may only take a short period of time, they require a great deal of preparation to ensure that the right people are trained and present, and that the necessary data are available.

A diverse range of energy improvement solutions may be identified during a PFD review. Some require capital investment, while others only require a basic change to operating procedures.

Process heat integration

Heat integration enables a plant to make more efficient use of its process energy, and is a key topic in most PFD reviews. There are several standard heat-integration configurations that can be replicated in a wide variety of different processes.

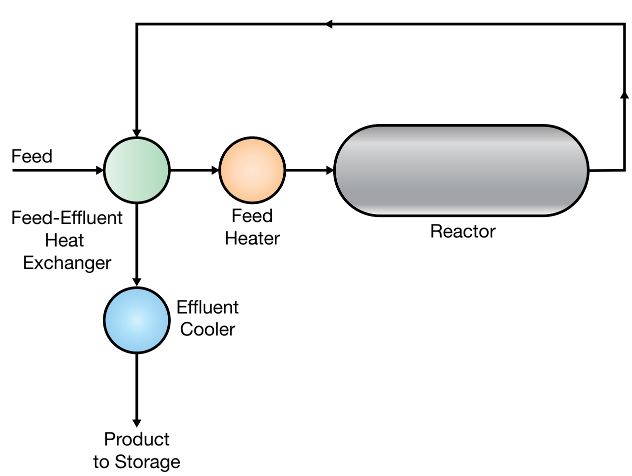
For example, the reactor in Figure 1 is integrated with a feed-effluent heat exchanger (FEHE) that uses heat from the reactor's hot effluent stream to preheat the cold feed stream. This reduces the heating load on the feed heater and the cooling duty of the effluent cooler by an amount equivalent to the heat load transferred between streams in the FEHE.

In Figure 2, a distillation column is integrated with a feed-bottoms heat exchanger (FBHE). The cold feed stream is heated by the hot stream from the bottom of the column, which reduces the amount of heat needed in the reboiler. Although this arrangement can drastically improve the energy efficiency of a column, keep in mind that there may not be a one-to-one correlation between the heat recovery in the feed and the heat load reduction in the reboiler. In addition, increased vapor traffic above the feed tray as a result of heating the feed can overload the condenser. The impacts of these concerns depend on the nature of the material being processed and the design of the distillation column. A simulation and/or plant trial is needed to quantify the results of the proposed changes.

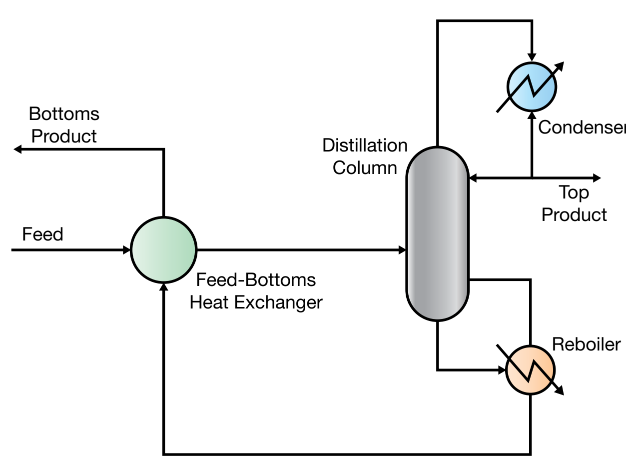
Standard configurations of heat integration may be inadequate for some processes. Those with many large streams that require heating, cooling, or both (*e.g.,* an oil refinery crude unit or fluid catalytic cracking unit [FCCU]) require more complex heat exchanger networks. Optimization tools such as pinch analysis are used to create these complex networks of heat exchangers. (Reference 3 provides additional information on pinch analysis.)

Operating targets

Virtually all processes have many key process variables, or key performance indicators (KPI), that can be adjusted to optimize energy use, such as pumparound flowrates, stripping-steam flowrates, recycle flowrates, and reboiler



▲ **Figure 1.** The feed-effluent heat exchanger (FEHE) uses the hot effluent stream from the reactor to heat the cold incoming feed. The incoming feed also cools the product stream before it is sent to storage. By pairing streams, the energy requirements of the effluent cooler and feed heater are both reduced.



▲ **Figure 2.** This distillation column system includes a feed-bottoms heat exchanger (FBHE) at the inlet to heat the feed with the hot bottoms stream. Although this reduces the energy requirements for the reboiler, the heated feed has the potential to increase vapor traffic above the feed tray of the distillation column, which may overload the condenser.

duties. These are central points of discussion during a PFD review and are typically documented for further evaluation.

After a PFD review, one of the biggest challenges is setting KPI targets. Without a thorough understanding of the process, targets could be chosen that reduce energy consumption but jeopardize yields.

These target values must be flexible. As feed rates change or operating modes shift, energy requirements also change. For example, a refinery may send its vacuum-tower gas oil straight to distillate blending in the winter, but in the summer, the gas oil is sent to the FCCU or the hydrocracker to be upgraded to gasoline. During the summer, gas oil cut points are less important, so vacuum column pumparounds should be set to optimize energy recovery rather than cut points.

In situations such as these, it is appropriate to assign several target KPIs that depend on the mode of operation. Rather than hard targets, operating strategies that incorporate advanced process control (APC) or real-time optimization (RTO) may be needed.

Although several methods can be used to determine KPI targets, the simplest way is through experience. Basic energy metrics, such as stripping-steam rates, can be set by comparing the current operation with industry standards and best practices. Process simulation is usually required to set targets for more complex metrics such as reboiler rates, and test runs are used for confirmation. Alternatively, targets can be set by examining a 12-month trend of a process variable to identify the value that optimizes energy efficiency. Setting a target based on that value helps to eliminate variations in data that result from shift change, operator intervention, or other normal disturbances.

Inappropriate operating practices

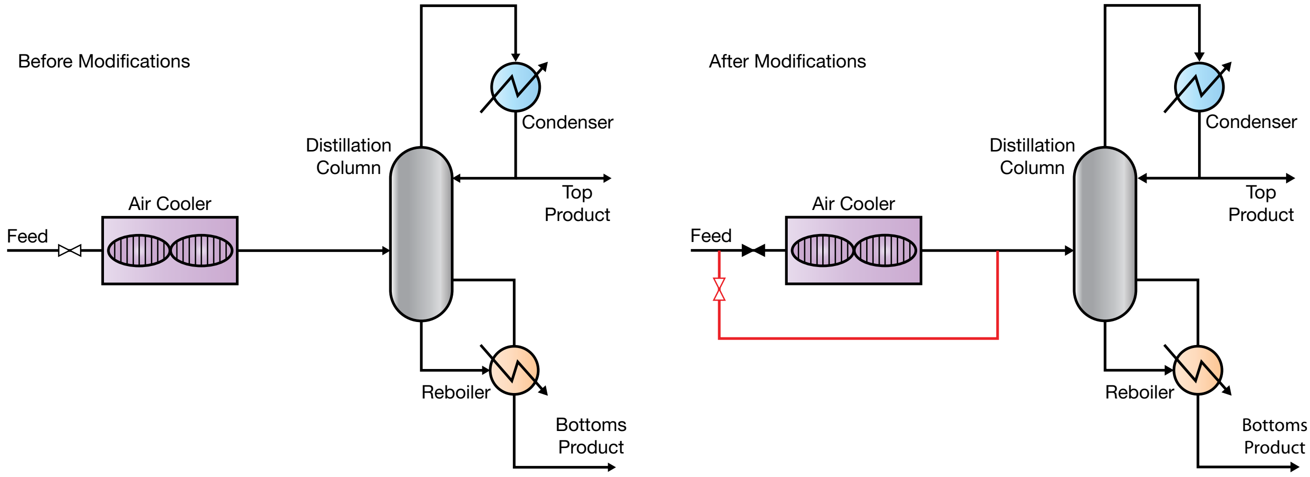
Targets for KPIs are set to minimize energy use within a normal operating envelope. However, PFD reviews often identify situations where current plant operations are significantly suboptimal in terms of energy use. For instance, if an operator places equipment in service at an inappropriate time or setting, this method of operation can become the norm, and may remain the standard for years. PFD reviews help to identify these situations.

Consider a common process plant inefficiency example — a stream that should not be cooled is cooled. A petrochemical facility installed an air cooler on the feed line of a distillation column (Figure 3, left) to prevent the condenser from being overloaded during certain abnormal operating conditions *(4)*. Although the intention was to run the air cooler only during abnormal conditions, it became an accepted practice to run it continuously. Since the feed was unnecessarily cooled, the reboiler had to work harder, which increased the steam load.

Operating procedures were changed to reflect the original intent of the air cooler, which reduced the reboiler duty by more than 30% and saved the plant more than $1 million/yr. These savings were incurred with no reduction in throughput, loss of product quality, or monetary investment.

However, even with this change, a significant amount of heat was still being wasted due to convection in the air cooler. This loss was eliminated with the installation of a bypass around the air cooler (Figure 3, right) — a minor project with a low investment cost that saved an additional $200,000/yr.

A more subtle example of a PFD review identifying inappropriate equipment use comes from a refinery that is



▲ **Figure 3.** This distillation system includes an air cooler that was designed to run only during abnormal conditions, but was run continuously instead. Identifying this equipment misuse and turning off the air cooler saved energy. Even after the operational change, additional heat was still being lost to convection in the cooler, so a bypass was installed (right, red).

considered to be an excellent energy performer *(5)*. Searching for further improvements, it conducted a PFD review on its highest energy-consuming units.

The isomerization unit (Figure 4, left) was targeted as a high energy consumer. It has two naphtha splitters, T-1 and T-2. Splitter T-1 has two reboilers: E-1, which uses low-pressure (LP) steam as the heating medium, and E-2, which uses the hot naphtha feed to T-2 as the reboiling medium. T-2 has only one reboiler, E-3, and it uses medium-pressure (MP) steam as the heating medium.

Heat was supplied to T-1 predominately by E-1 to maximize the amount of cheaper LP steam used in T-1 and reduce the amount of the more-expensive MP steam needed in T-2. The PFD review challenged this logic. An increase in the feed preheat to T-2 did not save E-3 reboiler duty in direct proportion; however, using naphtha in E-2 would save LP steam in direct proportion. Furthermore, the 150°C feed temperature to the naphtha splitter was unnecessarily high.

Modeling of the steam system showed that MP steam was only slightly more valuable than LP steam. In addition, a simulation of the naphtha splitter indicated that the feed preheat recovery factor was only 0.5–0.6 (*i.e.,* for every Btu of preheat, the reboiler duty decreased by 0.5–0.6 Btu). Therefore, to improve operational efficiency, the duty of E-2 was increased and the T-2 feed temperature was reduced to 120°C (Figure 4, right). Even though this increased the MP steam use in E-3 by 4 m.t./hr, it reduced the amount of LP steam to E-1 by 7 m.t./hr, which saved the facility $215,000/yr.

Equipment modifications and additions

As illustrated by the previous examples, energy savings may be achieved by simple operating changes that require no investment and can be implemented quickly. Additional savings can often be realized with a minor modification that requires minimal time and money. Other solutions, however, may require more significant investments to modify or add equipment.

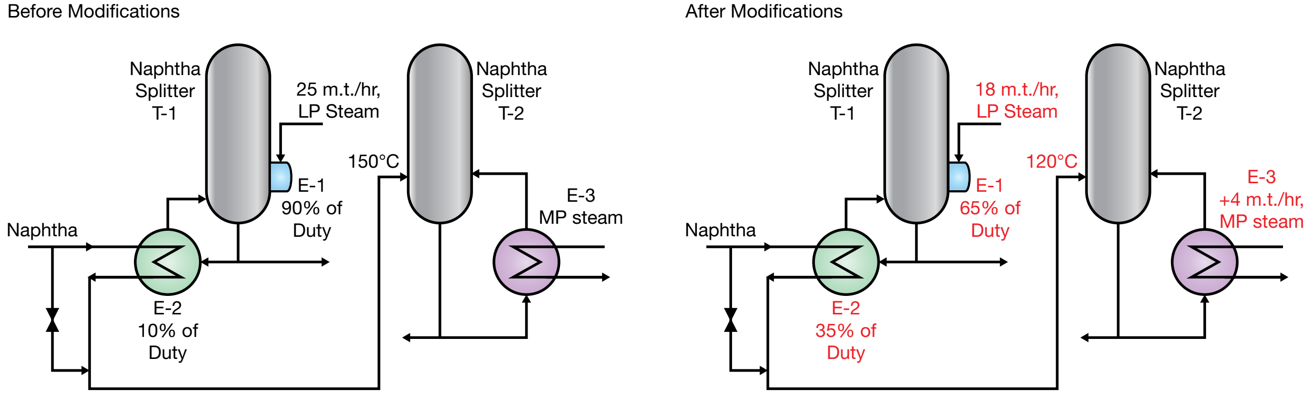
For processes with reactors or distillation columns, a PFD review should confirm that the standard heat exchangers (*e.g.,* FEHE [Figure 1], FBHE [Figure 2], etc.) are included. If they are not, the review should determine whether it would be cost-effective to install them. The evaluation should also determine whether there is an economic incentive to install additional heat exchangers or modify existing units to increase heat recovery.

Not all PFD reviews focus on small portions of processes, such as a single distillation column and its peripherals, a reactor system, or a distillation train. Some reviews identify opportunities that span much larger process areas, or even an entire process.

In processes where the conversion in the reaction step is low, unconverted feed material has to be recovered and recycled. The separation processes (*e.g.,* distillation, crystallization, extraction, etc.) that recover this unconverted material consume significant amounts of energy. Additional energy is consumed to recycle the recovered material back to the reactor (*e.g.,* pumping, compressing, conveying). For these reasons, it would seem that increasing conversion and reducing recycle rates would save energy.

However, increased conversion often reduces reaction selectivity. This can increase costs for additional feedstock and disposal of unwanted byproducts. For example, high-severity operation of FCCUs increases the production of low-value fuel gas, which can render the energy saving endeavor uneconomical.

Complex optimizations like these should be documented during a PFD review for subsequent evaluation. The results are sometimes counterintuitive.



▲ **Figure 4.** The isomerization unit (left) has two naphtha splitters, T-1 and T-2. Splitter T-1 has two reboilers — E-1 uses low-pressure (LP) steam and E-2 uses the hot naphtha feed to T-2 as the reboiling medium; Splitter T-2 has one reboiler, E-3, that uses medium-pressure (MP) steam as the heating medium. Originally, E-1 supplied most of the heat to T-1 in order to maximize the amount of LP steam used and reduce the amount of MP steam used. Increasing the duty of E-2 and reducing the feed temperature to T-2 from 150°C to 120°C (right) significantly reduced the amount of LP steam required and saved the facility $215,000/yr.

Consider a chemical plant that processes a very-high-value feed material whose cost dominates all other costs. Rather than run this process at a high conversion and a low recycle rate, the optimum solution was to reduce the conversion and increase the recycle rate to minimize losses of the expensive feed material. This increased energy consumption, but saved $1 million/yr in overall operating costs due to reduced feedstock requirements. This solution required no facility modifications, only operational changes. Because the optimum recycle rate depends on the costs of energy and feedstock, among other factors, it should be monitored routinely as a KPI.

In contrast, the solution to an oil refinery's operational inefficiencies required a significant capital investment. Engineers determined that an increase in conversion would save energy, but the reaction system needed to be reconfigured and the internals of a distillation column had to be changed to handle the reduced flowrates. The project saved more than $1 million/yr in energy costs. The project also removed bottlenecks in the reaction and separation systems, thereby increasing production capacity.

Post-review evaluations

Most ideas that arise from PFD reviews need to be carefully scrutinized before they are accepted as feasible endeavors. Basic project attributes, such as energy savings and costs, need to be quantified and the potential impacts detailed.

The PFD review ideas should be assessed as soon as possible after the review, when the thought and methodology behind the plan are fresh and accessible. This stage does not develop definitive designs and accurate cost estimates, but rather screens the ideas to weed out those that do not provide a realistic, viable return on investment. The goal is to produce a shortlist of the most attractive projects, ranked by their estimated return. The plant operations group can implement operational changes that do not require facility modifications, and projects that require an investment are referred to the corporate project engineering group for action.

Estimating energy savings. To evaluate energy savings, three questions need to be answered:

- How much energy will be saved?
- What type of energy?
- What does that energy cost?

Determining the amount of energy saved can be simple. For example, if the solution is to shut off a pump, the energy savings is likely equivalent to the electric power used to power the pump motor. Although this may seem simple, it is important to check that the solution does not have additional impacts — *e.g.*, shutting off one pump could increase the power requirement of another pump.

A furnace with an 80% thermal efficiency requires 25% more fuel than the process heat load.

It may be necessary to simulate or set up a spreadsheet model of a section of the process to determine a credible savings estimate. This is generally true for the addition of a FBHE or a preheat-train heat exchanger, for most modifications to distillation columns, and for changes that affect the operation of multiple pieces of equipment.

The type of energy being saved — *i.e.,* thermal and/or electric — also needs to be considered. Thermal energy, or heat, may be provided directly from a fired heater or indirectly by steam or some other heat-transfer medium. If steam is used, it is important to specify which pressure levels are involved. As the isomerization splitter example (Figure 4) demonstrates, multiple pressure levels may be impacted.

The final question — what does energy cost? — is more complicated than it may appear. Electric energy savings usually translate into a reduction of power imported from the grid, so the cost of this power needs to be determined. Although this seems basic, electricity contracts can be complex. In addition to basic energy charges, contracts may include demand charges and time-of-use components, as well as various other factors.

Determining thermal energy costs can also be compli-

The PFD Review as a Motivational Tool

The central focus of a PFD review is to determine a technical solution. But a PFD review also provides an opportunity for site personnel to showcase their ideas. Engagement in the review process and subsequent solution motivates people to work toward a successful result.

This phenomenon was demonstrated in a PFD review when a plant control engineer presented a new control algorithm that he had developed to optimize the operation of a large compressor. The new application had been ready for several months, but it had not been implemented because the operations department was concerned it might impact the operability of the plant; the operations supervisor originally objected to any changes to the existing control scheme. During the PFD review, the control engineer demonstrated that the energy savings with the new operating mode were far greater than the operations supervisor had anticipated, and the new control scheme was endorsed by the visiting energy-management specialist, based on previous experience. This convinced the operations supervisor that the change was appropriate, and he became committed to testing and ensuring the success of the new control scheme.

cated. In addition to the type (*i.e.*, pressure) of steam used, the cost depends on whether the condensate is recovered and recycled, as both energy and water could be lost.

When thermal energy is supplied by a fired heater, the cost of the fuel is an important consideration, as well as the efficiency of the furnace. A furnace with an 80% thermal efficiency needs 25% more fuel than the process heat load. In some cases, energy-efficiency projects can affect the efficiency of a furnace. For example, increasing feed preheat to a charge furnace may increase the stack gas temperature, thereby reducing the furnace efficiency. Changes in efficiency should be included in energy-savings evaluations.

Estimating costs. Cost estimates calculated during the project screening activities do not need to be extremely precise, but they should be realistic. A common error made when estimating the cost of small projects is to assume the cost will be roughly equivalent to the main equipment costs. However, there are many additional elements that must be included in the cost of any project, including foundations, piping, and controls, as well as engineering, labor, and overhead. Additionally, most energy-efficiency projects are revamps, which tend to be more costly than new installations because they require work in and around existing facilities. Costs can be even higher if the work has to be carried out during turnarounds.

While it is not necessary to quantify each of these components during the project screening stage, it is important to provide an overall cost estimate that reflects the total cost of implementation. Corporate cost-estimating groups typically can provide total installed cost data or simple correlations for key equipment items to facilitate the development of acceptable cost estimates. If recent data for a similar project at the same site are available, they can be used as the basis for the cost estimate of the new project. Other resources such as software tools and literature can also be used for cost estimate information.

Technical feasibility. PFD reviews can challenge existing operating philosophies and operating boundaries. Often these challenges are justified, but the ability of the existing equipment and systems to tolerate the proposed operating conditions must be verified. If they cannot, the necessary equipment upgrades need to be included in the project scope and their costs included in the cost estimate.

Some PFD review ideas involve transformational technologies — concepts or applications that are not yet proven. While this should not disqualify an idea from consideration, it may suggest that a significant amount of time, money, and risk will be necessary to bring the idea to fruition. The company needs to ensure that the new technology fits into its research and development program and budget and that the risk is manageable.

Final thoughts

PFD reviews can be used to identify and organize opportunities for energy-efficiency improvements in virtually any type of process plant. They frequently serve as the basis for a larger initiative, such as an overall site energy assessment, or as a step in the development of an energy management system (EnMS). They are also often used in conjunction with pinch analysis to explore a range of energy-efficiency options for a process or production site. While PFD reviews involve numerous considerations and can be plagued by hidden traps, the investment of time and resources to conduct a thorough review invariably pays big dividends. CEP

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For More Information

This article is an adapted chapter of a soon-to-be-published book, tentatively titled *Energy Management and Efficiency for the Process Industries*, by Alan P. Rossiter and Beth Jones. The book will be published by the AIChE/Wiley partnership in Spring 2015.

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