Make Your Plant More Energy Efficient

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Improve energy management by optimizing current equipment and operations, implementing economic investments, and engaging in sustainment activities

Rising oil and natural gas costs in recent years have led to a growing interest in energy management. Energy is essential to all chemical processes, and in many cases profitability increases as we use more energy — for example, by using more energy, we may increase throughput or improve product yields. The goal of effective energy management, therefore, is not the blind pursuit of minimum energy consumption. Rather, it is the efficient use of energy — that is, the minimum use of energy subject to production requirements, environmental considerations and other constraints.

When assessing the benefits of energy savings, we must be careful to identify the actual credit based on energy imported at the plant gate. This may be very different from the credits assigned by the plant's accounting system. For example, each plant typically assigns a fixed value per unit of steam used. However, for a particular project, the incremental value of steam may be near zero if the site vents excess steam from waste heat boilers. In this situation, there may be virtually no change in purchased fuel use as the steam demand varies over a significant range. Prudent planning credits a steam-saving project based on the probable plant energy balance during the project's operation rather than on the current allocated cost *(1).*

A second reason for pursuing energy efficiency is good stewardship of resources, which is closely linked to sustainable development, waste minimization and pollution prevention. Environmental standards have risen and continue to rise; it is no longer socially, politically or legally acceptable for companies to be seen as polluters, and this includes the pollution associated with inefficient energy use. Not surprisingly, many energy efficiency activities are linked to pollution prevention programs *(2).*

Industry response

About 49% of the U.S. chemical industry reported engaging in at least one energy-management activity in 1998 *(3),* and similar levels of activity were reported in oil refining and other process sectors. The scope and technical approach of these activities vary considerably, ranging from very limited programs focusing on individual equipment items to comprehensive management systems that attempt to address a wide range of energy issues throughout large corporations. The top four reported activities to improve the efficiency of energy use were energy audits, electricity load controls, equipment or facility modification to improve direct machine drives, and purchase of electricity under special electricity rate schedules (*e.g.,* interruptible or time-of-use rates). Funding by government agencies and other entities (*e.g.,* utility companies) assisted a number of these activities. Several companies have published information on their energy efficiency activities, including Rohm & Haas *(4),* ExxonMobil *(5)* and Dow Chemical *(6).*

In general, there are three main dimensions to energy efficiency activities in the chemical process industries, some or all of which are included in each of the various programs that have been reported:

- operate existing facilities optimally and efficiently through applications of best practices
- identify and implement economic investment opportunities for step-change improvements
- implement strong management systems to sustain progress and drive continuous improvement.

The main elements in each of these three areas are discussed in the sections that follow. There is inevitably some overlap — *e.g.,* studies intended to identify investment opportunities often highlight opportunities to improve operating practices as well.

BEST PRACTICES IN OPERATION AND MAINTENANCE

Significant energy cost reductions are often possible with no capital investment simply by operating and maintaining existing equipment properly, or by improving commercial arrangements. Additional benefits can sometimes be obtained with minor projects to upgrade equipment at low cost. Six areas that typically yield substantial savings are electric supply, steam systems, compressed air, heat exchangers, fired heaters and process equipment.

Electric supply

Electricity supply contracts are typically complex. Utility companies often charge for peak load and time-of-use, as well as the total amount of power consumed. These terms in the rate structure can have a significant impact on how chemical plants use electric power — *e.g.*, there may be significant savings in operating power-intensive equipment only during periods when time-of-use rates are low. It may also be desirable to schedule operations that create an upward spike in electric load for times when base loading is low, to avoid creating a high peak load.

Many utility companies offer a variety of rate structures. For example, contracts for interruptible power (where the user may be required to reduce power load on short notice) are fairly common, and offer large savings to those who can take advantage of them. Significant savings may be realized through selecting or negotiating the most favorable rate structure for any given facility.

Steam system maintenance

Effective correction of steam system leaks and maintenance of the plant's drip and tracer steam trap population is an important step in energy management *(7)*. External leaks from the steam system are sometimes left unattended, and even a single steam leak to the atmosphere can cost in excess of $90,000/yr. Potentially worse instances occur when bleed lines are intentionally left open, such as on turbine inlets, where a single 1-in. bleed can cost over $100,000 annually, or on bypass lines around process equipment, where losses on a 2-in.bypass can *well exceed* $250,000 annually for large process applications (see table).

Unlike the known losses from external pipe leaks, which will generally be marked for repair, intentional steam bleeds or opened bypasses are often considered necessary for plant operations, and there is usually no plan to prevent them. The losses due to such leakage can be enormous, and the goal should be to prevent steam bleeds and bypasses wherever possible.

The losses through a steam trap can vary with plant conditions and trap type. Plants without a consistent and proactive trap-management program typically see a 40% failure rate *or higher* when the trap population is left unattended. This equates to losses up to $1 million/yr in plants with trap populations of 7,000–8,000. However, managed improvement in the trap population can quickly recover most of these losses. First-year net return ratios are often between 8:1 and 2.5:1.

Table. Estimated value of lost energy in external leaks, bleeds, bypasses, trap leaks and dumped condensate.

Loss Condition	600-psig Steam $7.50/1,000 lb Valuation	150-psig Steam $6/1,000 lb Valuation
0.125-in. Pipe Steam Leak to Atmosphere	> $20,000	> $5,000
0.250-in. Pipe Steam Leak to Atmosphere	> $90,000	> $20,000
0.5-in. Steam Bleed on Inlet Supply to Turbine	> $100,000	> $50,000
2-in. Open Steam Bypass Line around Process	Not Available	> $250,000
"Blowing" Steam Trap	$7,300	$5,400
"Large Leak" Steam Trap	$5,800	$4,700
"Medium Leak" Steam Trap	$3,600	$3,000
"Small Leak" Steam Trap	$1,500	$1,200
20,000 lb/h Condensate @ $0.59/1,000 lb	> $100,000	

Note: Steam leakage calculations were derived from TLV SE1 software using a discharge coefficient (DC) of 0.7 for open leaks and 0.3 for enclosed leaks. Steam trap leak calculations were derived from TrapManager software and actual test results. A Pocket PC version of SE1 software is available for free download at www.tlv.com under the "download" section.

Source: *(7)*.

A typical program entails annual or semi-annual testing of the traps, using diagnostic instruments to determine the operational status of each trap. This information is then used to generate failure reports, and based on these reports, maintenance resources are mobilized to replace defective traps and capture the losses.

Compressed air systems

Compressed air is often unmetered; thus, there is little motivation to reduce its use. A large fraction is often lost through leakage at fittings. Improved flow measurement and accounting is therefore key to reducing compressed air costs.

Leaks often occur from fittings, but the largest losses are typically from open drain points where the drainage device has failed and a valve is left open or cracked to drain condensate. Since the air loss is not visible (like a steam leak), it is often a substantial flow. Leaks of this type can contribute significantly to plant load, even to the extent that portable compressors may be required to meet the excess air demand.

Heat-exchanger-cleaning cycles

Typically, the performance of heat exchangers decays over time as fouling or scaling increases resistance to heat transfer. The rate of decay depends on the type of service and the design of the heat exchanger. Periodic cleaning is therefore required for many heat exchangers.

In many cases, heat exchangers are only cleaned when fouling causes blockages that create hydraulic limits. However, it is often economical to clean them before this happens in order to recover energy. The first step in setting up a heat-exchanger-cleaning program, therefore, is to determine which heat exchangers have the largest impact on energy efficiency.

A reduction in the heat-transfer coefficient may or may not have a significant effect on energy efficiency, depending on how the heat exchanger is being used. For example, many heat exchangers that are used as steam heaters or cooling-water coolers include over-design factors that ensure they can meet process requirements, even when they are moderately fouled. However, a loss of heat transfer in heat exchangers in other services (*e.g.*, feed/effluent heat recovery) has a direct impact on energy efficiency.

The optimum cleaning frequency depends on the cost of energy losses due to the fouled condition of the exchanger and the costs (including process debits) associated with cleaning. This trade-off can be evaluated fairly easily for single heat exchangers *(8)*. For complex preheat trains, the sensitivity of heat recovery due to fouling of individual heat exchangers is often difficult to determine, and specialized computational tools should be used.

The energy savings from optimizing the cleaning of individual energy-critical exchangers are typically several tens of thousands of dollars per year. Optimizing the cleaning of complex preheat trains can save hundreds of thousands of dollars per year.

Frequent cleaning typically requires the ability to isolate individual heat exchangers while the process is running. If facilities are not available to do this, it may be necessary to invest in additional valves, bypasses, etc. in order to secure these savings.

Fired heaters

The performance of many boilers and furnaces can be improved markedly through proper operation and maintenance *(9)*. The key measurements are stack temperature and excess oxygen. If these parameters deviate significantly from design values, it is generally possible to achieve improvements by one or more of the following:

- *better damper control.* The main goal is to reduce excess air. In addition to energy efficiency improvements, this can also reduce NO_x emissions. The improvements may simply be a matter of operator training or repair of damaged equipment, or they may require an upgrade of the control facilities (*e.g.*, installation of an O_2 analyzer or a CO analyzer).
- *leak repair.* Damaged ducting or furnace walls can cause significant losses. If the equipment is under vacuum, air will be drawn in, producing misleading excess air measurements.
- *cleaning of convection banks.* Cleaning can significantly lower stack temperatures. In some cases, it is economical to add rows of tubes to existing convection banks, or even to install entirely new air preheaters or economizers.

Process equipment

Poor operation of process equipment items can be a major cause of energy loss. One of the most frequent inefficiencies encountered is the unnecessary cooling and subsequent reheating of process streams.

This can sometimes be rectified by simply bypassing coolers, although process constraints often demand more complex solutions. Improved process control and operator training, resulting in operating with lower tolerances, can also result in significant savings. There are also many additional opportunities that are appropriate to certain types of processes and equipment.

Exploitation of these opportunities generally requires expertise specific to the process or equipment in question.

IDENTIFYING ECONOMIC INVESTMENT OPPORTUNITIES

Improvements in infrastructure and processes can result in significant reductions in energy costs. The types of changes range from modifications of single equipment items to construction of entire new process units. Specific opportunities include upgrades of equipment (*e.g.*, installing a new catalyst) and control systems, additions of equipment items (*e.g.*, new heat exchangers), reconfigurations of process equipment (*e.g.*, re-sequencing of distillation columns or reactor trains), and resource-sharing projects (*e.g.*, sharing energy and byproducts across traditional boundaries).

The opportunities are generally site-specific, and the first step is identifying which opportunities are applicable at a particular facility. Once a range of opportunities has been determined, conventional engineering techniques can be used to evaluate the costs and benefits of each option. This results in a short list of projects that meets the company's investment criteria.

Employee contests

Many companies have used employee contests as a means of generating energy efficiency suggestions. One of the best-documented programs comes from the Louisiana Div. of Dow Chemical Co. *(2)*. Its annual contest started in 1981. The initial focus was strictly capital projects for energy conservation, but over time, this was extended to expensed projects, maintenance programs and work process improvements, involving not just energy, but waste reduction in general. Between 1981 and 1993, the contest achieved audited savings of over $110 million.

The Dow contest was originally intended for engineers, but gradually increasing numbers of non-technical personnel also participated. In this way, the observations and experience of a wide range of people familiar with different aspects of the site's processes were able to contribute ideas. Factors that have been cited as contributing to the success of the program include:

- simple paperwork
- sustained management support
- grassroots support
- winners received recognition rather than cash
- it worked through the existing line organization.

Process reviews

There are similarities between chemical processes, even when they make different products or are at different locations, and there are also similarities between utility systems. It follows that ideas that work at one plant are often transferable to others. This concept forms the basis of the process review approach.

Process reviews can take various forms, but they are typically structured brainstorming sessions where process flow diagrams are examined and compared against a list of possible process improvement options. Various lists exist in the open literature (*e.g.*, Ref. 10), and some companies have developed their own lists. A hierarchical approach can also be used to better organize such reviews *(11)*.

Ideas that appear to be applicable to the process under review are documented and then evaluated to determine their viability. This procedure will typically generate options for equipment upgrades, re-routing of process streams, and improving control schemes, although many other types of improvements may also be identified.

Pinch analysis

Pinch analysis is a systematic technique for analyzing heat flows through a process, based on fundamental thermodynamics. The key concepts are illustrated in the hot and cold composite curves (Figure 1), which represent the overall heat release and heat demand profiles of a process as a function of temperature.

The hot composite curve represents the sum of all the heat sources within the process, in terms of heat load and temperature level. The cold composite curve similarly represents the sum of all the heat sinks within the process. When the curves are shown together on a single temperature-enthalpy plot (as in Figure 1), most processes display a pinch — a region where the curves approach the minimum allowable temperature approach, ΔT_{min}. This divides the process into two distinct regions:

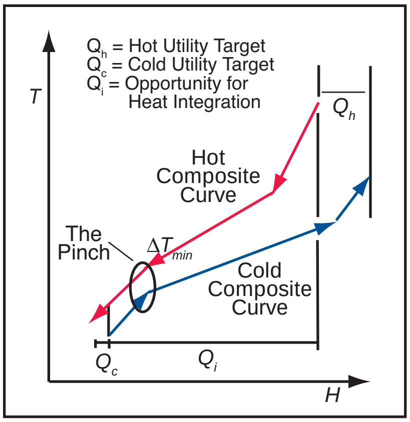

Figure. 1. Typical hot and cold composite curves.

- Above the pinch, some heat integration is possible (where the hot composite curve sits above the cold composite curve), but there is a net heat deficit and external utility heat sources (Q_h) are required.
- Below the pinch, some heat integration is possible (where the hot composite curve sits above the cold composite curve), but there is a net heat surplus and external utility heat sinks (Q_c) are required.

This analysis enables easy identification of inefficiencies in existing heat-recovery systems and facilitates the design of new, more optimal heat-exchanger networks. The trade-off between energy consumption and capital investment can be incorporated in the analysis, as well as the pressure drop implications of heat recovery. Pinch techniques can also be applied to distillation column optimization and other aspects of energy efficiency improvement *(12)*.

In energy efficiency studies at existing facilities, pinch analysis is typically applied to processes with large heating and cooling duties and complex heat-integration schemes, with the objective of recovering additional heat and reducing the demand for imported energy. The types of projects that commonly result from this analysis are re-alignments of existing heat exchangers, addition of new heat exchangers, and incorporation of enhanced heat-transfer technologies in existing heat-exchanger shells. Pinch analysis is also commonly used to improve heat-integration schemes in new process designs — to reduce either capital cost or energy demand, or both.

Steam system rebalancing

Steam is the primary medium for transporting heat in most process plants, so understanding the steam balance is a critical step in improving energy efficiency. An important tool to aid this understanding is the ladder diagram, which lays out the steam headers and flows visually in order of pressure (Figure 2). Enthalpies or heat flows can also be added.

Underlying the ladder diagram is a steam balance that represents the steam flows at a given point in time or as an average over some period. However, the steam flow on a cold weekday morning in the winter is quite different from that on a Sunday in the summer, and neither matches the annual average steam balance. Startup flows are also usually far different and merit their own special balance.

It is also wise to prepare a balance for the beginning and the end of the cycle between unit shutdowns. For example, the power required by a turbine driving a compressor rises as the compressor efficiency falls, and process heating requirements rise as interchangers foul. By analyzing steam balances, and noting how they vary with time of day, season and on-stream cycle, we can often identify inefficiencies and lost opportunities, and thus generate options for system improvements.

Computer-based models make it fairly easy to examine steam balances and screen options for improving them. Simple balances can be assembled using spreadsheets without any special features, and outputs from such models can be used to update flowrates on simple ladder diagrams automatically.

Several commercial software packages are available for more rigorous steam balances, and the U.S. Dept. of Energy offers its own system, SSAT *(13)*, which can be used for these calculations. These packages incorporate physical properties for steam and water, as well as model elements for deaerators, steam headers, steam turbines, letdown valves and other steam system components. They also generally include graphical elements to construct ladder diagrams. Some of these packages are "add-ins" for spreadsheets; others are stand-alone programs.

Whichever modeling system is used, the overall approach is to construct a model of the existing steam balance, with submodels showing significant variations (*e.g.*, summer and winter cases). As far as possible, the models are reconciled with actual plant measurements. They are then examined to identify inefficiencies, which usually take one of the following forms:

- pressure letdowns across valves (rather than through steam turbines, where power can be generated)
- vents (implying excess steam in a particular header, often caused by excessive use of low-efficiency steam turbines exhausting to a low-pressure header)
- excessive use of steam in deaeration (usually the result of inadequate preheating of feed water).

The model can then be used to test options for eliminating the inefficiencies — *e.g.*, adding steam turbines to eliminate letdowns, replacing low-efficiency turbines with electric drives or higher efficiency turbines to eliminate vents, adding preheaters for deaerator feed water to reduce deaerator steam demand.

Steam models of this kind can also be used as operating tools, to optimize the steam system in real time. The plant data-logging system acquires steam demand and power data for all users on the site, and feeds this to the model. Using a mathematical optimizer, the steam model determines the most cost-effective way of meeting the resulting steam and power demand (*i.e.*, which boilers should be loaded or unloaded, which discretionary steam turbines should be used, etc.). Optimization systems of this type can also be used to assist in determining how to take advantage of electric power contracts in real time.

Byproduct synergies

There are many situations in which byproduct synergies result in energy efficiency improvements. For example, many petrochemical facilities recover light ends material that would otherwise be flared from refineries, and there are a number of industrial parks where waste heat is exported from certain companies and imported by others through a park-wide heat grid.

There is now a growing trend, arising from the focus on sustainable development, to seek out byproduct synergies in a more systematic way. A number of recent projects have built on this concept. The underlying premise is that all "wastes" from any given process can be considered as raw materials for other processes. Of course, many plants have historically been built to produce intermediates that are fed to other processes, and many processes generate byproducts that are considered valuable. However, the "100% product" philosophy challenges industry to consider all streams that leave a process (other than the main product) as potentially valuable byproducts. Quite apart from the byproduct value that this generates, there are often significant energy benefits as a result of reducing or eliminating the processing of the raw materials that are replaced by the recovered "waste materials."

In order to generate projects that build on this approach, it is necessary to develop a philosophy of resource sharing. This requires a culture change, enabling individuals and organizations to cross traditional barriers not only within their own organizations, but also between organizations, developing inter-organizational collaborations. With this culture in place, it is possible to identify and compare process inputs, outputs and byproducts across the participating facilities, and look for possible synergies. This requires brainstorming procedures similar to those used to conduct process reviews. In addition, some projects have used the six sigma statistical methodology *(14)* to assist in identifying and evaluating opportunities.

An example of this approach is the By-Product Synergy (BPS) process developed in the mid-'90s by the U.S. Business Council for Sustainable Development. In a report on the value of the BPS process *(6)*, the following annual benefits were reported from implemented synergies at various sites in Texas:

- CemStar – 130,000 tons of steel slag used in place of lime; 65,000 tons CO_2 and 800 tons NO_x eliminated; $10 million/yr saved

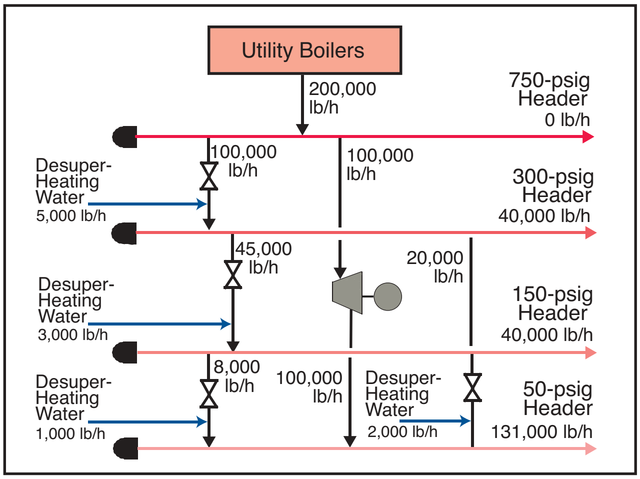

Figure. 2. Ladder diagram depicting a typical steam balance.

- ASR – 120,000 tons of auto shredder residue mined for 18,000 tons of additional metal reclamation and possible fuel; 151,000 tons CO_2 avoided; $10 million/yr saved
- graphite/copper sludge – 37,500 lbs graphite/copper sludge not landfilled
- spent caustic – 438 tons spent caustic used in place of virgin material; $2 million/yr saved
- sodium sulfate – 680 tons of spent sodium sulfate used in place of virgin material.

Results of a byproduct synergy project involving six chemical sites in Texas and Louisiana included potential energy savings of 900 billion Btu/yr if all non-chlorinated wastes across the participating sites are recovered and converted to products.

MANAGEMENT SYSTEMS TO SUSTAIN PROGRESS

Many energy efficiency programs fail due to lack of follow-through. After options for improving energy efficiency have been identified, systems must be put in place to capture the savings — not just in the short term, but also for years to come.

Most process facilities now have real-time data acquisition and plant data-historian systems. This infrastructure makes data more accessible, which greatly enhances process management. "If you can't measure it, you can't manage it!"

Accessibility of data also provides a basis for many sustainment activities. One of the most important is monitoring and targeting (M&T). This is a technique in which historical plant data are analyzed statistically to establish challenging but achievable performance targets (*e.g.*, Btu/lb of product). When plant performance deviates from the target, operators are alerted and can take corrective action. Further technical analysis of M&T output can also be used to generate energy-saving projects. Utility cost savings of between 5% and 15% have been claimed from M&T systems.

Some companies implement their own M&T applications within an existing plant data-historian environment. There are also customized commercial M&T packages available from a number of vendors.

Sustainment requires more than computer systems, however. Additional areas that need to be addressed include:

- training personnel and ensuring awareness of energy issues
- providing an adequate budget for energy efficiency efforts
- retaining human resources for energy-related activities (*e.g.*, dedicated personnel for steam system maintenance).

These needs are typically addressed through modifications of existing management systems.

Closing thoughts

There is no single "silver bullet" for improving energy efficiency in the process industries. Continuous efforts are required to optimize the performance of existing facilities by applying best practices in operation and maintenance, and through equipment upgrades and process modifications. State-of-the-art methodologies and software packages should be used to assist in identifying energy-saving opportunities. In addition, companies must invest in systems and personnel to maintain energy efficiency improvements. With this combination of activities, we can continue to make significant strides in improving energy efficiency in the process industries. CEP

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