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How can process integration help me?

Process integration (PI) is a very efficient approach to improving the energy efficiency of large and complex industrial facilities. PI refers to the application of systematic methodologies that facilitate the selection and/or modification of processing steps, and of interconnections and interactions within the process, with the goal of minimizing resource use. PI can be used in new designs, or in existing installations, in order *to* ***ensure that energy, water, and raw materials are used optimally.*** Among PI techniques, pinch analysis is the most often used.

Pinch analysis is a systematic procedure for investigating the energy flows in a given process, and for quantifying the minimum practical utility demands for process heating and cooling. The latter information is very useful, as it allows us to compare the actual energy consumption with a minimum, and to identify the real potential for improvement. It allows us to benchmark the plant's energy consumption against its minimum achievable energy consumption. Maximum potential for cogeneration, and the viability of heat pump applications can also be analyzed with PI tools.

Once the targets for minimum energy consumption are identified, pinch analysis can be used to identify energy-saving projects that allow us to approach these targets in practice (taking into consideration plant constraints, such as current piping location). These projects may be located in the various processes/units, or in utility systems (steam production and distribution systems, cooling systems, etc.), and can be the basis of long-term investment planning.

Aspects of conventional energy audits (boiler efficiency, compressed air systems, insulation, steam traps, etc.) can be included with the PI approach, in order to complete a global and systematic analysis of the entire process. It is essential to use specialist software to assist in processing the large amount of data involved in a PI analysis. There is suitable software available that allows the rapid calculation of energy-saving potential, and provides an environment to rapidly design or redesign optimal heat exchanger networks.

The most important requirements for performing a PI study are practical process knowledge in the relevant industry, and significant experience in applying PI techniques. The ideal time to apply pinch analysis is during the planning of major investments, and before the finalization of process design. Maximum improvements in energy efficiency, together with reduced investment, can be obtained for new plant design because many of the plant layout constraints can be overcome through redesign. Additional benefits include reduced capital cost in the utility systems, as well as improved utility performance.

In retrofit projects, by comparison, improvements in energy efficiency usually require some capital expenditure. In this case, PI can be specifically directed towards ***maximizing the return on investment***. PI techniques ensure that combinations of project ideas are evaluated simultaneously, to avoid both "double-counting" savings, and conflict between projects. Indeed, the final investment strategy for the available opportunities will ensure that site development is consistent and synergistic.

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Whether for an existing plant retrofit or a new plant design, pinch analysis generally begins with carrying out a heat and material balance that is representative of each process. A model is then built from this balance, in order to represent the heat load for heating or cooling each relevant process stream. This model allows us to:

- Define the minimum utility consumption targets for process heating and cooling (steam, cooling water, chilled water, etc.);
- Identify the possibilities for process-to-process and utility-to-process heat transfer improvements;
- Identify how to change the existing process operation to further reduce energy consumption.

A model of the site utility system may be produced in parallel with the PI study. Through this model, all savings identified within the processes can be directly related to savings in purchased utilities. This avoids the common error of recommending utility-saving projects in one part of the site, while shifting the problem to another point on the site. A common example of this error is where apparent savings of low-pressure steam in one process leads to steam venting elsewhere.

The following table summarizes typical percentage savings in total purchased fuel, for a range of simple payback periods, as identified through PI techniques—mainly pinch analysis. (For Pulp & Paper, the percentages are expressed in terms of total steam production from boilers and recovery boiler).

Energy-Saving Potential through Process Integration (%)				
Industrial Sector	Quick Win	Payback 1-3 years	Payback 3-6 years	Total Potential *
Oil Refining	up to 5	10-15	up to 15	10-25
Petrochemicals	up to 5	5-10	up to 20	10-25
Iron & Steel	up to 5	5-15	10-20	10-30
Chemicals	up to 5	10-15	up to 25	15-35
Food & Drink	5	15-25	up to 25	15-40
Pulp & Paper	5	10-25	25	10-35

* Total potential is not simply the summation of all columns because some long-payback projects may be an alternative to some of the quick-win and medium-payback options.

Additional energy savings, typically between 5% and 15%, can be obtained through good housekeeping (steam traps and leaks, furnace tuning, cleaning of fouled heat exchangers, etc.), as well as through monitoring and targeting, process modifications, etc. The numbers vary, depending on the amount of attention that energy receives at the facility before these methods are applied, as well as on other factors such as complexity, and the fouling potential of the materials being handled.

The following specifics on PI for the pulp and paper sector are based on the worldwide experience of applying PI in this sector. The results are generic and not adjusted for local conditions of geography and climate.

Application of PI to the pulp & paper industry

Since pulp and paper is a water-based industry, it is important to understand the interactions of water and energy, and to ensure that the heat and material balance represents these accurately. Due to the complexities of water systems, it is important, in this type of work, to employ personnel who are both PI experts and industry specialists.

A key aspect to a successful PI study in the P&P industry is to get a good understanding of:

- The site configuration;
- Local marginal economics (cost of the most expensive steam, electricity, etc., as opposed to their average cost);
- Seasonal heat and material balance;
- Impact of different departmental availabilities.

The PI track record shows that, for revamping projects, energy savings and expansion objectives are met at lower capital costs than when conventional energy assessment techniques are used. In new plant design, the emphasis is on selection of the optimum process configuration, and cost savings can be even higher than for revamping projects. Significant energy and capital will be saved because plant layout can be configured to minimize the energy consumption at reduced infrastructure costs. PI techniques may be applied alongside of the engineering company's design process, with no adverse effect on the engineering schedule. Indeed, time can be saved through the early elimination of suboptimal alternatives, and the concentration of effort on the best solutions.

In the pulp and paper industry, as in many other industries, PI is the holistic approach to problem solving, offering a fundamental understanding of the interactions between the sub-parts that constitute the whole.

PI can be used to achieve:

- Energy savings and GHG emissions reduction;
- Water rationalization and reuse;
- Integration of new processes (new machine, new line, etc.);
- Debottlenecking, expansion;
- Optimization of evaporator integration with the background process heating loads;
- Optimization of any process operation that requires heat;
- Review of process development plans in the context of the best available technology and the impact on utility demands;
- Production rate optimization to maximize the output for existing equipment.

PI studies can include aspects of conventional energy audits, such as steam traps replacement, and control of oxygen excess in boilers. However, for the purposes of the remainder of this document, only the benefits attributable directly to PI activities are enumerated and quantified.

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Typical subsectors and size considerations for worthwhile PI study

Typical processes that should consider PI studies include bleached Kraft and bisulphite pulp mills (continuous and batch), integrated Kraft and bisulphite mills, TMP and paper mills, as well as large recycling and papermaking facilities that generate their own steam and power, and that use large quantities of water. This is not an exhaustive list and other specialized production types should not be ignored as potential PI candidates. In general however, it is for integrated pulp and paper plants and for chemical pulp plants that the greatest savings can be found.

PI studies will present projects with good returns if the marginal costs are high, i.e., if purchased power is expensive, and/or a significant part of the steam generated on-site is based on fossil fuel. For medium-to-large energy consumers, the expected savings benefits are higher, and a more detailed PI study will be warranted.

Benefits of PI

Traditionally, capital spending on outright energy conservation projects has not been a priority in North American industries. In Canada, the recent ratification of the Kyoto Protocol should change this focus. The PI approach, combined with conventional energy efficiency audit, and with monitoring & targeting techniques, is probably the best approach that can be used to obtain significant energy savings and GHG emissions reductions. PI can lead to the following benefits:

- Quick-win projects save approximately 5% of steam consumption with no or little investment;
- Short payback projects can typically reduce the steam consumption from a further 10% to 15% with a one- to two-year payback period;
- Medium-payback projects can typically reduce the steam consumption from a further 5% to 10% with a two- to four-year payback period;
- Long-payback projects can produce ultimate additional savings of up to 25% of the site’s total steam production, with overall payback times of around four-to six years.

Overall, the savings opportunities identified by PI studies in pulp and paper plants typically amount to between 10% and 35% of the total steam consumption.

The track record for this sector indicates that between 40% and 70% of recommendations for improvement are taken to the implementation stage. These usually include the quick-win projects and the most attractive medium-payback projects. Long-payback projects (typically, utility infrastructure projects, such as a gas turbine with heat recovery steam generation system) are more often implemented when they provide additional economic incentives to their stand-alone energy payback (e.g., production increases, avoidance of capital spending, security of electricity procurement, etc.), making them attractive compared to existing investment plans. In retrofit situations, plant layout, construction materials, and maintenance of product/operating integrity are key influencing factors in the economic viability of implementing heat recovery improvement projects.

The implementation record for projects identified by pinch analysis has been a function, primarily, of economic factors, particularly, the lack of availability of capital, and the low cost of energy in the past few decades. The competitive capital market and organizational focus on product quality, product enhancement, and environmental compliance-driven investments have been important influencing factors. The implementation rate of longer-payback projects could, however, progressively increase within the new context of the Kyoto Protocol.

General Approach used to carry out a PI Study

A PI study is usually carried out in two main phases: a phase where minimum energy consumption targets for process heating and cooling are determined, and a design phase. Whether on an individual unit, or on a broader, site-wide basis, the first phase of work is to quickly, but accurately, identify the scope for energy savings, prior to undertaking detailed design activities in the second phase. This phase is traditionally based on a heat and mass balance, produced from test run data, typical operating data, process simulations, or a mixture of these data sources. A simulation of the site processes and the water handling systems will normally be prepared if not already available, as this will be needed to verify the effect of proposed changes on the water balance and on the energy balance. The data required include process flow rates and temperatures, as well as heat loads across all major exchangers for a representative operating case. Where available, heat transfer coefficients are important for effective capital cost targeting, i.e., for determining the required investment costs to achieve in practice the identified energy-saving potential. (Small heat transfer coefficients will imply larger heat exchangers, and thus, larger investments, and vice-versa.) Economic data for steam and fuel costs, and acceptable investment criteria are also important. Where possible, meter readings may be used for cross-checking, and for reconciling conflicting data.

In the second phase of work, systematic design techniques are used to develop the individual projects that will achieve the savings-potential identified in the targeting phase. More detailed equipment design considerations, plant operating and layout issues, and economic cost estimates are developed in order to more accurately define the achievable potential energy-savings and their related costs within each unit.

Typical Deliverables of a PI Study

The deliverables of a PI study are a function of the size, complexity, and particular issues of the plant, as well as the specific requirements of plant management. The typical deliverables may include the following:

- Assessment of current energy consumption efficiency;
- Heat and mass balance of the process, including a process simulation, when appropriate;
- Identification of the minimum energy consumption targets for process heating and cooling;
- Identification of projects that reduce energy consumption within and between the processes, and that swap high cost utility use for lower cost utility; Projects may include process modifications and water reuse projects that can reduce the minimum energy targets even further;
- Analysis of the potential for heat pumps;
- Specification of a utility scheme tailored to the site's specific requirements;
- Evaluation of marginal cost for steam and electricity production;
- Calculation of the potential for on-site power generation to reduce dependence on external supply;
- A simulation of the site's steam and condensate systems for "what if" project-evaluation, and, ultimately, for day-to-day optimization;
- Preliminary engineering- and cost-evaluation of recommended projects; and
- A consistent strategy for energy-related investment. As the mill changes, only small updates to the original study are needed to incorporate future changes.

Generally, the deliverables will take the form of a report, with details and schematics for each recommended project. Heat and mass balance and simulation can be provided in computer files.

Typical Projects

Projects identified during a PI study are plant-specific and depend on the following: size and arrangement of the plant, required pipe distances and routes, space constraints, operating limitations, and level of engineering needed to overcome local hazards or influencing conditions. The paybacks presented below may differ from plant to plant. A non-exhaustive list of typical projects includes the following:

- Quick Wins:
  - Closer control of evaporator and digesters blow heat;
  - Closer control of water consumption and related utility use (e.g. improve control of tank levels to prevent overflows);

- Reuse of white water streams that do not require any treatment and better management of clean warm and hot water streams (re-piping projects);
- Enhanced evaporator performance (e.g. minimize feed dilution such as spills recovery).

- Short-payback projects, typically with a one- to two-year payback:

  These projects tend to recover high-grade heat to send it into warm and hot water, demineralized water, etc. For example, heat recovery from:

  - Evaporator condensates;
  - Bleach plant effluents;
  - Boiler blowdowns;
  - Boiler exhaust;
  - Machine exhaust.

  If these hot streams are presently not used, project paybacks can be even better (typically lower than a year).

- Medium-payback projects, typically with a two- to four-year payback:

  These are typically projects that include a lot of redesign of existing systems in order to improve heat recovery without using a very high temperature difference between the hot and cold streams (ΔT) in heat exchangers. For example:

  - Process-to process heat recovery;
  - Digester heat recovery, such as preheating white liquor;
  - Evaporator reconfiguration;
  - TMP heat recovery through a reboiler.

- Long-term payback, typically with a four- to six-year payback:
  - Cogeneration systems;
  - Increasing the number of effects of the evaporator plant;
  - Heat recovery from kiln exhaust;
  - TMP heat recovery from non-pressurized refiners;
  - Heat pumps.

Errors in PI application

The most common errors made during a PI study (in no particular order) are:

- "Let's get the low-hanging fruit first." This generally leads to much lower savings because some projects are conflicting and segmented, which makes the cost of remaining heat-recovery projects prohibitive;
- Ignoring possible changes in the upcoming 2–5 years (regulation, equipment replacement, expansions). This may result in projects that are obsolete by the time plant personnel is ready to implement them, or that don't achieve the forecasted payback;
- Ignoring possible process changes, such as modifications to set points (e.g., temperature of hot water). This generally results in many low-payback projects being overlooked. In order to evaluate possible plant-wide process changes, the PI analyst must have specific experience in the pulp and paper industry;
- Not working with plant personnel. This often results in projects not being implemented, or not being understood;
- Carrying out only a steam balance, and using that as a starting point. Such an approach generally does not fully reveal potential, and may lead to significant errors;
- Errors in analyzing marginal economics (e.g., boiler minimum turndown, drives vs. turbo generators, fuel used in boilers for header pressure control, and wet biomass firing), or in analyzing changes in economics (e.g., better boiler control, better steam and power management, and changes in production to take advantage of night-time energy costs (e.g., increase the use of the TMP)).

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