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IDENTIFYING ENERGY SAVING OPPORTUNITIES IN A PROCESS PLANT THROUGH PRELIMINARY ENERGY AUDIT

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Abstract. Improving plant energy efficiency requires monitoring, analysis and adjustments of the appropriate plant operating parameters and in some cases, plant modifications. This involves studies of plant energy distribution and the corresponding losses associated with the various uses of energy. The scope and duration of a study may vary depending on the complexity of a plant and various operational requirements and constraints. The recommended practice is to run a preliminary energy audit on a plant before conducting a detailed retrofit project. Such exercise helps plant managers to differentiate between the immediate energy saving potentials from those requiring either some investments or further studies. This paper outlines the methodology and the scope involved in a preliminary study to improve overall plant energy efficiency. The procedure includes plant familiarization, data collection and parameter measurement, analysis of energy consumption and losses in the various sections of a process plant, analysis of the results and recommendation of measures supported by economic justifications. Examples of studies completed for two different plants are also presented.

Key word: Energy efficiency, plant modifications, energy audit, plant improvement, energy losses

Abstrak. Peningkatan kecekapan tenaga loji proses memerlukan pemantauan, analisis serta pengubahsuaian parameter operasi loji yang tertentu, dan kadangkala, modifikasi loji. Usaha ini melibatkan kajian ke atas agihan tenaga loji serta kehilangan tenaga akibat daripada pelbagai kegunaan tenaga. Skop serta tempoh kajian bergantung kepada jenis loji, keperluan operasi loji serta kekangan yang terlibat. Adalah disarankan supaya odit tenaga permulaan dibuat sebelum odit tenaga terperinci dilaksanakan. Pendekatan ini akan membantu pengurusan loji membezakan antara potensi penjimatan tenaga segera berbanding skema yang memerlukan pelaburan serta kajian lanjut. Kertas kerja ini menggariskan kaedah serta skop odit tenaga permulaan bagi meningkatkan kecekapan tenaga loji proses. Prosedur ini melibatkan pemahaman loji, pengumpulan data, analisis penggunaan serta kehilangan tenaga bagi bahagian-bahagian tertentu loji, analisis keputusan serta saranan pembaikan yang disertakan dengan justifikasi ekonomi. Contoh kajian ke atas dua jenis loji proses yang berbeza juga dibentangkan.

Kata kunci: Kecekapan tenaga, pengubahsuaian loji, odit tenaga, pembaikan loji, kehilangan tenaga

1.0 INTRODUCTION

Over the past few years, rapid growth of industrial sector has resulted in overall increase in energy demands for Malaysia. At the current rate of consumption, the Ministry of Energy, Communications and Multimedia of Malaysia has predicted that the nation's

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current conventional energy reserves would not last for more than three decades [1]. Increased consumption has caused environmental pollution at an unprecedented level. The industrial sector tops the list of Malaysia's major energy consumers at approximately 42% of the total consumption, followed by transport (39%), residential and commercial (13% and 6% respectively) sectors [1]. There is a pressing need to conserve energy by properly managing the available resources. In general, the driving force towards energy efficiency is the prospect of saving money. In the long term, saving energy reduces environmental pollution and retards the depletion of non-renewable energy resources. Towards this end, the Universiti Teknologi Malaysia (UTM) Process Systems Engineering Group is rigorously involved in promoting energy efficiency practices in the local industries. More than 30 energy conservation projects had been completed by the UTM team over the past 10 years. The projects cover industrial sectors from chemicals and specialty chemicals, ceramics and cement, pulp and paper, textile, food, beverages, pharmaceuticals and electronics. Improvement of the current operating practices and the use of efficient technologies and equipment help achieve energy saving objectives in the process industries. Compared with other sectors of the economy, it is the industrial sector that can offer the biggest scope for energy savings due to its diverse applications. A wide range of processes and process conditions combine to make the industry the prime target for energy conservation. This paper outlines the general framework towards implementation of energy efficiency measures for the process industries. Two case studies representing energy analysis projects completed for two different classes of industries are presented to illustrate the usefulness and practicality of the approach.

2.0 ENERGY EFFICIENCY MEASURES

Energy efficiency measures can be classified as short-term, medium-term and long-term measures according to the estimated payback period for the investment. At the onset of an energy audit exercise, it is important that some typical measures and investment associated with them are tabled and discussed with the plant management. The outcome of this discussion is important as a guideline to the auditors on the level of commitment a plant is prepared to make with regards to the required changes in operation and equipment. The typical energy conservation options for a plant may include short-term, medium-term and long-term measures as described in the following sections.

2.1 Short-Term Measures

These measures are concerned with the changes of employee's attitude, working practices, regular maintenance, control and employment of good housekeeping techniques in order to improve energy consumption. These measures are usually easy to implement without any investment, or may require minimal investment with a payback period of less than a year. Short-term measures include optimisation of boiler performance and steam distribution networks, changes in equipment parameters such as column pressure and/or reflux ratio, optimisation of compressor, refrigeration and chiller operations.

2.2 Medium-Term Measures

These measures normally involve minor modifications on the plant installations or changes to existing processes in order to improve energy performance or to enhance heat recovery. Such measures require some investment of not exceeding 3 years payback period. Examples of projects that fall into this category include utility or process heat recovery, retrofit of heat recovery network, installation of heat pumps, vapor recompression schemes and high-efficiency equipment and motors.

2.3 Long-Term Measures

These measures involve moderate to major modifications associated with capacity expansion, extensive process heat recovery and combined heat and power (cogeneration). Other possible long-term measures that require changes of high financial commitment include process automation, changes from batch to continuous operations, changes of process stream interconnections, and changes in processing technologies. Investment required for such changes normally exceeds 3 years payback period.

3.0 METHODOLOGY FOR PRELIMINARY ENERGY AUDIT

A preliminary energy audit is essentially a quick energy survey aimed at identifying and screening the scope and feasibility of improving a plant's energy efficiency [2]. It is usually focused on the improvement of utility systems and utility equipment such as boilers, steam distribution systems, compressors, dryers and chillers. This is because, it is usually much easier to gather data to perform energy balance for such equipment. The required data for this equipment could normally be derived from standard thermodynamic tables and well-established correlations in addition to performing parameter measurements. The general methodology for a preliminary energy audit exercise is described next.

3.1 Plant Familiarisation

The energy audit team would first have a discussion with the plant management on the general background of the company and on the overall process operations. Among other things, the team would try to establish the plant's level of commitment and the extent to which the plant management is willing to invest. This is followed by a tour around the plant to familiarise the team with the processes and process equipment. During the tour, major energy consuming sections and areas having potential for improvement are identified. Input from the plant tour will be helpful for the team to outline a strategy for energy conservation study.

3.2 Gathering Plant Data

Before carrying out the conservation study, energy utilisation and process operation data that are essential for the study are requested from the plant management. Some important information needed are;

(i) Monthly energy consumption profile.
(ii) Equipment list by sections.
(iii) Individual equipment and overall plant production rate.
(iv) Individual process equipment specifications.
(v) Energy consumption for the overall plant and individual process equipment.
(vi) Periods of operation and annual plant and equipment operating hours.
(vii) Fuel, type, characteristics and composition.

3.3 Parameter Measurements and Identification of Energy Losses

Having established the major energy consuming sections as the focal point of the study, a more detailed analysis of consumption and losses, i.e. energy balance for the relevant sections of the plant will be performed. In order to carry out energy

Table 1 List of the Most Commonly Used Energy Audit Instrumentation

Parameter	Purpose	Description
Flowrate	Heat recovery potential	Ultrasonic flowmeter (liquid) Pitot tube (gas, high velocity) Anemometer (low velocity)
Temperature	Heat recovery potential	Digital thermocouple (contact, detachable)
Pressure	Equipment optimisation	Electronic gauge manometer
Combustion exhaust gas	Flue gas analysis for heat recovery	Combustion gas analyzer
Smoke tester	Combustion improvement	Gas analyser and qualitative smoke tester (paper type)
Relative humidity	Improvement of dryer and air conditioner	Humidity probe (Hand-held)
Water TDS/conductivity	Boiler blowdown recovery and improvement	Electronics water conductivity meter

balance, process parameters such as stream flowrate, composition, pressure, temperature, as well as fuel and boiler stack gas properties must be gathered through direct measurements and quite often, through indirect calculations.

A wide range of portable instruments are available for energy audit. The most frequently required plant measurements and the relevant instruments are listed in Table 1.

3.4 Analysis of the Results

Data collected from individual equipment are used to perform energy balance for the sections of the process under study. The qualitative as well as quantitative energy terms to be established include the energy input into a unit operation, energy output from a unit operation, energy losses from a unit operation (include the avoidable and unavoidable losses) and the energy generated within a unit operation.

The energy terms are calculated by using the established First and Second Law energy balance equations (for pure components and mixtures), steam and pure component thermodynamic tables, enthalpy correlations and some readily available charts/nomographs (e.g. humidity charts and vapour pressure nomographs). In addition, some empirical correlations developed by the audit team such as the correlation between the amount of individual gaseous concentration and the excess air and the relation between flue gas temperature and the excess air have proven to be instrumental in performing boiler efficiency calculations.

3.5 Presentation of the Audit Report

For preliminary energy audit, an audit report is usually prepared on site by the energy audit team. The content of the report include energy balance figures on the equipment studied. The areas of potential energy savings, the recommended measures to save energy, the amount of savings and the estimated investment are among the key items to be highlighted. The report is presented by the auditors to the plant management at the end of the study session. During this session, some recommendations on how to optimise the energy usage in the plant are highlighted. Some of the recommendations calling for investment may require follow-up studies on the detailed engineering. At this stage, discussion between both parties concerned will focus on the implementation strategy and the possible implementation constraints.

4.0 CASE STUDIES

4.1 Textile Factory [3]

The study conducted on the textile factory was focused on improvement of the boiler, steam distribution system, chillers, air-conditioning system and compressed air distribution network.

4.1.1 *Methodology*

The plant management was requested to supply pertinent data on the general plant operations (as mentioned in Section 3.2). These included the plant energy profile, plant production rate, energy consumption and utilisation. Flue gas analysis and boiler blowdown analysis were performed to help calculate the combustion and heat utilisation efficiency and evaluate the boiler performance. Measurements of parameters related to air-conditioning and compressor operations were also obtained.

4.1.2 *Analysis and interpretations of the results*

(a) Boilers system

There were two boilers installed. The instantaneous energy balance for each boiler was done by taking sample of the flue gas from the boiler stack using an electronic flue gas analyser. The measurements recorded by the flue gas analyser include oxygen (O_2) content, carbon dioxide (CO_2) content and flue gas temperature. Measurement results for both boilers are in Table 2.

Table 2 Measurement results for the boilers

Boiler	1	2
Fire rate	Low	Low
Capacity	14 ton/hr	14 ton/hr
Steam pressure	6 bars	6 bars
Air temperature	34°C	34°C
Flue gas temperature	190°C	198°C
O_2 content	7.4%	4.6%
CO content	20 ppm	24 ppm
Smoke test	7	7
Flue gas losses (sensible heat)	9.33%	8.13%
Flue gas looses (latent heat)	0.009%	0.009%
Wall losses	3.88%	3.88%
Instantaneous efficiency	86.781%	87.981%

Based on the results of the measurements, the following observations were made:

- Combustion analysis performed on each boiler shows an apparently fair combustion (low oxygen and carbon monoxide content – below 10% and 100 ppm respectively). However, there is a large proportion of soot in the flue gas (smoke test index above 6).

- As compared to the rated capacity for each boiler at 14 ton/hour (only 18%), the average hourly steam production of around 2.5 ton/hour was rather low. However, due to the peak demand that occurred during the start-up of process equipment, the factory management found that it was necessary to operate with more than one boiler.

Energy saving opportunities can be realised by implementing the following measures:

(i) *Combustion improvement*
Measurements done on Boilers 1 and 2 showed potential for combustion improvement. This can be achieved by modifying the boilers' burners. The existing burners employed mechanical pulverization. The use of steam pulverization burner can help reduce excess air as well as the soot in the flue gas. Thus, for one boiler, with a reduction of O_2 content to 2%, 1.4% of energy can be saved (717.9 GJ/year), thereby reducing the fuel bill by RM 7179 (for the fuel price of RM 0.01 per MJ). An investment of RM 50,000 would be required.

(ii) *Installation of steam meters*
To better understand the steam demand profile of the factory, there is a need to install a steam flow meter for each boiler so that the boilers' operation can be better managed.

(iii) *Stopping operation of one boiler*
This can be done only after having overcome the problem associated with the peak demand of the processes. Based on the wall losses estimated earlier, stopping one boiler will help reduce the wall losses by 1,382 GJ/year, saving RM 13,820 in the fuel bill. This will require no additional investment.

(iv) *Installation of economiser after gas substitution*
For an average flue gas temperature of 205°C and an average CO_2 content of 11% for the existing boilers, the use of natural gas as fuel will allow the flue gas to be cooled to 120°C through heat exchange with the boiler feedwater in a finned tube economizer. For an energy price of RM 0.01 per MJ, approximately 5.1% of energy can be reduced through fuel substitution. This represents a saving of RM 25,890. Installation of an economizer in this case will cost around RM 30,000.

(b) Chillers and air-conditioning systems

Three chillers of sizes 600, 400 and 300 RT (refrigeration tonnes) were installed. The 600 RT chiller being a new, high efficiency unit was capable of satisfying the plant requirement on most days. Additional chillers were only operated on days when there was exceptionally high load. During the night, the outside air enthalpy (86.2 kJ/kg) was lower compared to the return air enthalpy (95.7 kJ/kg). Hence, the fresh outside air provide a cheaper alternative as recycle air to the chiller on most days of the year. A system of manual control could be instituted for this purpose. Assuming 4 hours of daily operation with fresh air, the estimated annual energy saving is 721,000 MJ per year or RM 7,210 per year.

(c) Compressed air system

There were 14 compressors installed with substantial air usage in the spinning plant and weaving plant. For the same pressure ratio, lowering the inlet air temperature will reduce compressor power consumption. Lowering the inlet temperature by 11°C would result in an estimated annual energy saving of 1,550,000 MJ per year or RM 15,500 per year.

4.2 Oleochemical Plant [4,5]

The site audited comprised of two separate plants, manufacturing fatty acids and fatty alcohols as the main products. Glycerol and methyl ester were also produced on site as by-products. The study focused on an audit of plant energy distribution and consumption, improvement of the utility systems and retrofit of the existing heat recovery network.

4.2.1 *Audit of the Plant Energy Consumption and Distribution*

An analysis on the steam distribution showed a ratio of steam consumption of 46:51 between the fatty alcohols and fatty acid plants respectively. Steam was used at two pressure levels of 63 and 5 bars. High Pressure Steam (HPS) at 63 bars was mainly used in fat splitting, fatty alcohols hydrogenation and fatty acid fractionation as well as distillation sections. Part of the steam was supplied by direct injection. Low Pressure Steam (LPS) was supplied to the rest of the processes, mainly to the evaporation and methanol recovery sections. Condensate was recovered from all sections except from ejectors, live steam and storage.

4.2.2 *Energy Saving Opportunities*

(a) Thermal Integration

Even though the existing plant employed a fairly extensive process heat recovery system, a careful analysis of the process flow diagram indicated that further recovery was possible. For a practical and cost-effective recovery, the steam selected has to satisfy the following criteria.

(i) Possess a large heat capacity flowrate.
(ii) Exists at a reasonably high temperature (normally more than 100°C).
(iii) Feasible by plant layout.
(iv) Does not affect the process and product quality.
(v) Does not involve any major modifications on the process.

A common source of wastage in process plants is rapid cooling of product streams by externally supplied cold utilities (e.g. cooling water). The streams being cooled may be used to preheat feed streams or some other streams that are externally heated (by steam, hot oil, etc.). The pairs of streams chosen for heat exchange should be conveniently located from one another for heat integration to be physically and economically viable. Given the quality (conditions) and quantity of the stream to be cooled, energy savings from recovery of process heat can be easily determined. The ratio between annual savings from utility reductions to the cost of installing heat transfer equi pment yields the simple payback period for investment. Table 3 gives the summary of the possible energy saving opportunities from process streams heat recovery for the oleochemical plant audited.

Table 3 Heat recovery by thermal integration between process streams

Unit	Stream rejecting heat	Stream requiring heat	Equipment	Annual bill reduction	Cost of investment
Fatty acid fractionator	Distillation bottom product	Crude fatty acid feed	74 kW spiral heat exchanger	RM16 850	RM 40 000
Evaporator and distillation	Ester from evaporator	Ester feed to distillation	125 kW spiral heat exchanger	RM 28 710	RM 37 000
Methyl ester fractionator and reactor	Column product	Column feed	203 kW spiral heat exchanger	RM 46 629	RM 60 000
Fatty acid distillation	Column product	Column feed	47 kW spiral heat exchanger	RM 10 795	RM 25 000

(b) Heat Exchanger Network Retrofit

Detailed heat exchanger network retrofit was carried out to correct mismatch between streams pairs selected for heat exchanger in the existing plant. Such analysis helped to identify the better choice of stream coupling to achieve maximum energy recovery. Plant layout constraints was considered in order to minimise plant changes and hence, the capital investment. Retrofit was done in such a way that existing heat exchanger network area was put to better use while heat recovery was enhanced through the addition of extra heat transfer area at the appropriate and cost-effective locations.

(c) Vapor Recompression

The modification involved the thermal upgrading of a multi-effect evaporation system. For the plant under study, increasing the thermal level of the second effect evaporator to heat the first effect in the methanol evaporation system allowed a 20% reduction of the specific energy consumption for the evaporation system, i.e. from 0.362 to 0.290 kg of steam per kg of water removed per hour. The annual steam saving was calculated at RM 35 777, and the investment estimated at RM 40 000.

(d) Steam Generation and Distribution Systems

Most of the changes required in this section would involve the change of attitude and operating practices. Routine maintenance and good housekeeping is essential for energy conservation. As such, the investment costs incurred to affect changes in this section were either relatively small or nonexistent. Similar calculations as presented in the previous case studies were carried out to improve the boiler systems. The energy saving opportunities for the utility section is presented in Table 4.

Table 4 Energy saving opportunities for the boiler and steam distribution system

Plant	**Plant A**		**Plant B**
Boiler pressure	1 × 70	3 × 10	1 × 40
Combustion improvement Bill reduction Investment	 RM 7790 Nil	 RM 5961 Nil	 RM 12 371 Nil
Economizer after gas substitution Bill reduction Investment	 RM 20 793 RM 50 000	 RM 48 620 RM 70 000	 Not practical – low flue gas temperature
Condensate recovery Bill reduction Investment		To all boilers RM 32 430 RM 60 000	

5.0 CONCLUSIONS

In the global scenario, energy planning has taken big strides over the last couple of decades but there is still room for further work in this area in Malaysia. When addressing the energy issues, it should be realised that there are a number of difficulties encountered, notably, a lack of database required for comprehensive energy planning and management. This factor stymies the development of a reliable energy planning and forecasts. Despite considerable interests generated in energy planning at national level, awareness among industrial energy planners is still limited, and therefore, has scope for improvement.

The energy planning strategy should include extensive set of energy conservation incentives and relief. The strategy should not be confined to minimising energy wastage but also to motivate technological innovations for industrial energy users in order to rationalise production processes and to balance customers' energy requirements. In the industrial sectors, energy efficiency can be increased by appropriate short term energy conservation measures with little or no investment whilst the medium and long term measures call for research and capital investments which may result in changes in production processes and plant modifications.

The basic problems in promoting energy conservation that needed attention are:

(i) The insufficient emphasis given to energy management by the industries.
(ii) The energy consumption and efficiency, and their role on the profitability of a company are not fully appreciated by most of the company management.
(iii) The lack of equipment for measuring purposes and data collection.
(iv) The lack of energy conservation awareness among management team and operating staff.
(v) Appropriate legislation to curb energy wastage has not been properly addressed to the industries.

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