Optimisation of energy consumption

The true values of fuel, power and steam costs are needed for reliable estimation of energy saving projects

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Refineries add value to crude oil by converting feed into marketable products using energy. **Figure 1** shows the net margin of a crude oil refinery.

In a typical refinery, the terms shown in **Figure 1** can be described as follows:

- **Product value** is the value received from the sale of products. Because most refined products are commodity items, their values are related to their prices on the open market; thus, engineers can adjust the operation of the plant to maximise the most profitable stream. This is a good start point to develop process improvement projects
- **Feedstock cost** is the cost of the refinery feed stream, taking into account any transport costs
- **Fixed costs** are generally the costs of running the refinery, the infrastructure, taxes, people, and corporate costs
- **Variable costs** include fuels, catalysts, additives, purchased utilities, and maintenance costs.

Margin = **Product value** – **Cost of feedstocks** – **Variable costs** – **Fixed costs**

Figure 1 Refinery profit margin

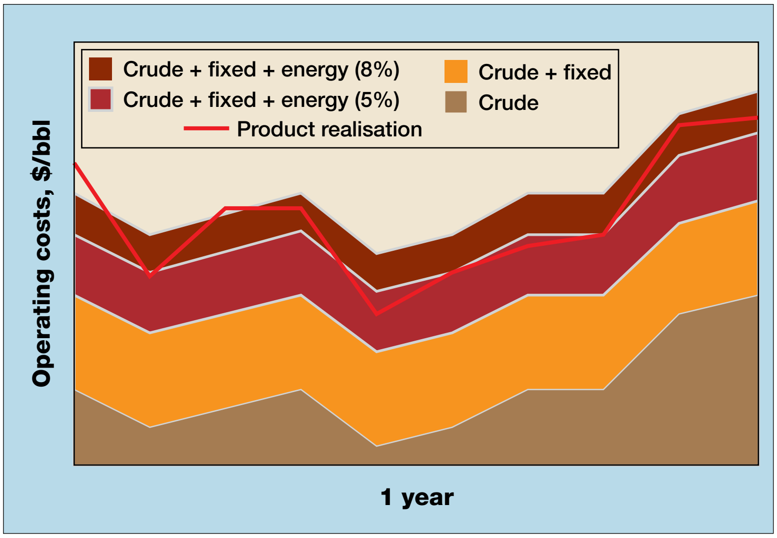

Figure 2 Energy impacts on profitability

Assume that a 100 000 b/d refinery consumes energy at a pacesetting level – roughly 5% of the feed input. Assuming the cost of fuel at about $100/t, the total energy bill is about $25 million/year. By contrast, an inefficient site consuming approximately 8% of purchased crude as energy receives an energy bill of $40 million/year, $15 million higher than the pacesetter site.

Figure 2 shows the change in crude oil cost, product slate value, and energy cost for the 100 000 b/d conversion refinery over a year. This figure uses data gathered from two refineries (one consuming 5% fuel and the other consuming 8% fuel on crude) at each end of the typical energy efficiency spectrum.

During this period, the efficient refinery showed a mostly positive net margin, whilst the inefficient one operated mostly at a net loss, indicating the critical role of energy consumption on refining profitability. Depending on the fuel cost, the annualised loss of profit for the inefficient refinery is $20 million/y (around $50/bbl).

Assuming average energy consumption of 6.3% on crude for a refinery with 100 000 b/d crude oil processing capacity, total energy usage is 6300 b/d FOE or 400 Gcal/h. A breakdown of this is shown in **Table 1**.

The energy balance of this typical refinery is further illustrated in **Figure 3**. The assumed energy consumption – that is, 400 Gcal/h – includes all types of fuel which can be further broken down into three main categories (see **Table 2**).

Table 2 indicates the major area of interest. Burning fuels in furnaces incurs the highest energy cost in a refinery. Consequently, this was the driving force for extensive research and development projects which were the beginning of a number of new design concepts in the early 1980s.

Energy breakdown	
Process furnaces	220 Gcal/h
Boiler fuel for	140 Gcal/h
steam (200 t/h)	
power (16 MW)	
Imported power from grid (8 MW)	40 Gcal/h
Total	400 Gcal/h

Table 1

Category	Potential for energy consumption, %
Fuel for furnaces (and FCC coke)	55
Fuel for steam	20
Fuel for power and power import	25

Categories of energy consumption

Table 2

The useful power consumption of this average refinery accounts for only about 5% of total energy (24 MW or 20 Gcal/h), but incurs around 25% of the total energy cost (100/400 Gcal/h).

Some energy expenditures, such as those resulting from fired heater inefficiency or heat losses through insulation, are independent of process operations, and so can be independently managed for saving energy, regardless of how the processes operate. Some of the most typical methods are:

- Optimising overflash in distillation: too much overflash wastes energy; too little reduces distillate yields
- Pumparound duties: increased pumparound duty improves feed preheat and saves energy, but impairs fractionation quality above pumparound trays
- Use of stripping steam improves separation and therefore improves yields
- Increasing reflux ratios increases energy consumption for reboiling, but improves separation and product quality.

It can be concluded that optimising refinery energy systems requires an integrated approach comprising energy balancing, rigorous energy economics, process analysis, steam/power system analysis, analysis of process/energy interactions, and use of optimisation tools. These basic steps form a systematic approach to achieving the best energy management within the refinery. It is obvious that energy efficiency has a great impact on refining margins, and by increasing the cost of marginal fuel, the importance of sustaining an efficient operation increases. But how is energy-efficient operation defined, and can refineries be compared in terms of efficiency? Since more complex refineries are expected to consume more fuel than simpler ones, the percentage of crude input is obviously not a valid parameter. Therefore, the fuel consumption expressed as

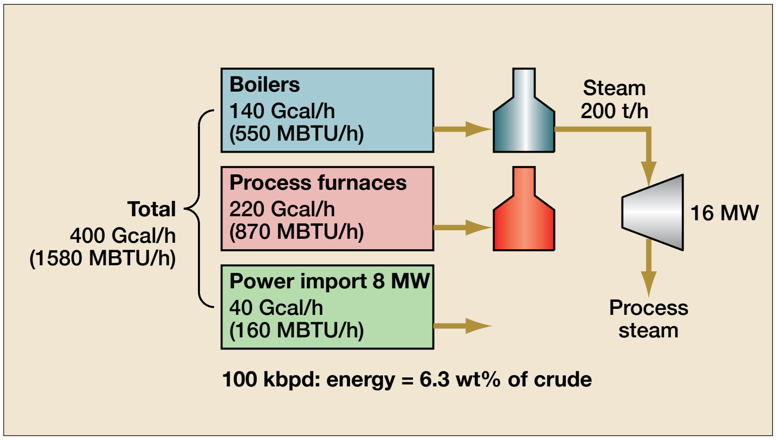

Figure 3 Energy balance of a typical refinery

BT performance indicators

BT, %	Performance	Rank	Comments
100	Ideal results	Grassroots refinery	No refinery has a 100% BT
130-149	Pacesetter	90th percentile plus	Some Japanese and European refineries
150-179	High performer	75th percentile	Good energy management
180-199	Average performer	50th percentile	Little attention to energy
200-250	Poor performer	Lower 25th percentile	Poor design/energy management
250+	Lowest performer	Below 25th percentile	Energy intensive facility - costly strategy

Table 3

a percentage of crude input is a function of both the energy efficiency and the complexity.

The basis of best technology

Developing a method encapsulated in the 'best technology' (BT)concept, enables us to compare energy efficiencies between refineries with different configurations, capacities and performances.

Through process simulation, an optimised, energy-efficient design can be developed for all refinery processes, and the energy consumption of each process can be calculated as a function of throughput, feed quality, severity of operation, or other parameters. Therefore, the best economically justifiable design can be simulated according to the following rules:

- Preheat trains designed for a minimum network approach temperature of 20°C (36°F)
- All fired heaters at 92% efficiency
- Yield-efficient operation
- Efficient utility systems
- All power generated internally at 80% marginal efficiency.

Next, correlation of energy consumption for BT processes is applied to rank existing refineries. Moreover, BT allowances for individual units are calculated, taking into account actual throughput, feed quality, yields, and so on. To rationalise the comparison, energy efficiency is expressed as a single number, tonnes of equivalent fuel oil per hour (foet/h). All energy streams – fuels, steam, and power –are converted to foet/h using a systematic method of rigorous energy evaluation and costing. Their sum is the total BT (or %BT), and it can be compared with the actual refinery energy consumption. For example, an index of 180% BT means that the target refinery consumes 80% more energy than the energy consumption of a BT refinery with the same configuration, feed quality, and yield pattern. Existing refineries rarely approach the BT target, and it is not economical to bring them down to 100% BT. Practically, energy-efficient design is achievable and economically justifiable only in grassroots plants.

During the last few years, a greater focus has been put on building efficient new plants. These refineries, as well as some of the older refineries, have helped bring the average BT figure down towards the 180 point. Using the data in **Table 3**, refineries can be categorised according to their BT indexes.

Figure 4 shows some of the initial BT indices and the achievable BT after implementing the recommended energy-saving projects. There is a wide range of opportunities for the enhancement of efficiency from 20 to about 80 points on the BT scale. However, the difference between the achievable improvements resulting from different energy costs and investment policies for each site limits the number of investment related energy saving projects.

The potential for improvement can then be carried forward to a gap analysis in

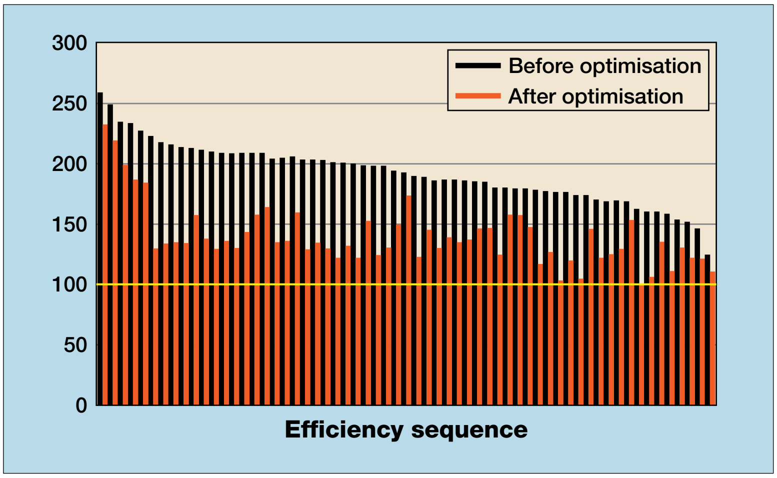

Figure 4 BT improvements

Reduction of BT score through gap analysis

			→ Reducing BT score →						
Unit	Base case	→ Pts	Furnaces at 92%	→ Pts	Opt. heat integration	→ Pts	Process improv.	→ Pts	Power at 80%
Hydrocracker	333	44	289	110	179	13	166	41	125
Naphtha hydrotreater/reformer	258	20	238	10	228	53	175	42	133
Vacuum unit	191	7	184	8	176	6	170	42	128
Visbreaker	178	3	175	50	125	0	125	23	102
Diesel hydrotreater	507	12	495	177	318	74	244	121	123
Crude unit	146	1	145	22	123	0	123	20	103
Hydrogen plant	271	0	271	0	271	96	175	31	144
FCC	135	0	135	0	135	30	105	7	98

Table 4

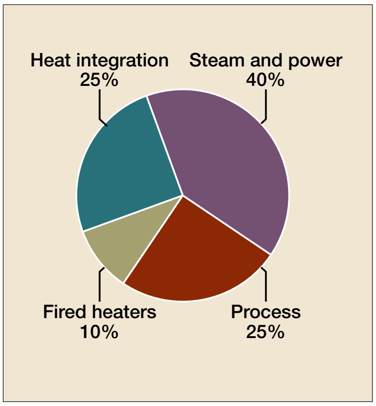

Figure 5 Breakdown of typical gap analysis

order to identify where the refinery is not meeting the BT energy performance. Trying to identify the gap, four main groups of operations should be apportioned:

- Fired heaters
- Heat integration
- Process
- Steam and power.

A typical breakdown of gap distribution is shown in **Figure 5** in which:

- **The fired heaters gap** is the difference between ideal and actual efficiency of fired heaters. The BT of fired heaters should be at least 92% efficient, corresponding to 3% excess oxygen and a stack temperature of 160°C (320°F). In practice, a significant portion of the gap is lost through poor stack heat recovery. Adding extra convection banks is difficult to justify economically.
- **The heat integration gap** can be easily identified as the difference between the actual performance and the pinch targeted energy consumption. There are normally a number of economically justifiable projects that can cover a large portion of this gap. But it is assumed that a small gap remains.
- **The process gap** refers to the actual design compared to the BT design. Unless the plant is state-of-the-art, gap-closing options can usually be identified, but they should be discussed with process specialists to guarantee no loss of yield.
- **The steam and power gap** is normally the largest gap and, after its implementation, an acceptable achievement can be readily made. Because all the previous projects affect the steam and power balance, this is usually the last to be addressed. The gap incorporates any inefficiency from steam letdowns and poor choices on turbines. Closing the gap usually significantly reduces the loss of efficiency from imported power.

Table 4 shows the impact of the BT score on the efficiency of refining units through gap analysis. Due to the scale of most refineries, it is often difficult to evaluate all the choices to reach optimum energy efficiency. A reliable approach to overcome this problem is to simulate the steam and power system using Thermo-flow (Bent Lorezenten) or Pro-Steam (KBC) software. The model can then lead to the introduction of

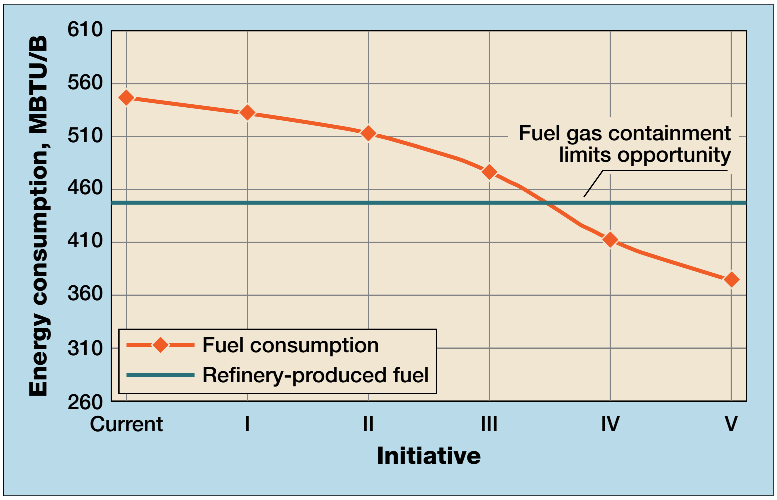

Figure 6 Fuel gas containment can limit savings options

a project roadmap, where interactions are considered and the best financial options can be realised. Moreover, constraints within the refinery may also limit the opportunity to reduce energy consumption (see **Figure 6**).

Fuel costing

Energy conservation does not necessarily make money for the refinery. For example, venting steam or not repairing steam traps may increase refinery profitability whilst refinery heat recovery projects can reduce profitability. Therefore, energy cost reduction is the true objective. The first step in any programme is to develop a thorough understanding of the refinery's energy economics and costs, from which appropriate cost reduction strategies can be planned.

When a modification affects the energy systems of a site, it is necessary to identify exactly what those effects are. The marginal mechanism may depend on where in the refinery the change is made. For example, reducing furnace firing may reduce refinery fuel consumption and result in additional fuel oil sales, or it may simply increase flaring. The following example can be used to illustrate the marginal cost mechanism.

If 1t/h of low pressure steam is saved somewhere in a process, this will normally reduce the amount of fuel burned in the boilers, but at the same time it will change the deaeration steam demand, the quantity of the returned condensate, and the amount of boiler blow-down or flash steam. The steam balance may be changed, perhaps reducing back pressure power generation through the turbogen and increasing condensing power generation or power import. Less boiler feed water may be required and this will reduce the pumping power. The related terms can be defined as follows:

- **Cost of fuel** This equals the sales value of fuel oil. If balancing fuel is an intermediate product (for example, the vacuum residue), the marginal fuel cost is the value of the vacuum residue when used as blending stock. It means that its value is evaluated from its sulphur content and viscosity, the 'sulphur and viscosity parity' calculation.
- **Carbon trading** The introduction of carbon (CO_2) trading schemes has presented a new aspect to marginal mechanisms. Its essence is to set limits on CO_2 emissions produced by industries. If a refinery can emit less CO_2 than the target value then it can sell this credit to an over-producer and gain additional revenue. Over-running the target value means that the refinery must pay additional credit. Nowadays, carbon credit is traded in the open market and is susceptible to price swings.
- **Power costing** In most cases, the mechanism for supplying incremental electric power is either increased power import or reduced power export. In the case of a self-balanced site, there may be an increase in the use of gas turbines or condensing turbine generators. Frequently, refineries have an option to choose between generating their own power and importing it.
- **Steam costing** Many refineries still evaluate steam on the basis of heat content or enthalpy. Since the enthalpy of steam does not vary considerably versus pressure, low pressure steam has slightly less value than high pressure steam. This concept may lead to a gross error of steam/power economics and may drive the refinery in the opposite direction from an economically sound energy strategy. The correct method for costing steam takes into account the amount and the cost of any power generated from the steam when its pressure is reduced. For high pressure steam, it normally increases the load on the marginal boiler. The marginal cost of high pressure steam is equal to the cost of its production, which is mainly the cost of fuel. Low pressure steam can be supplied either via back pressure turbines or simply through a letdown valve. Using the latter option, the potential for generating power from steam is irreversibly lost. In this case, the net cost of providing low pressure steam is calculated as follows:

LP steam value = HP steam value-Power credit

So the marginal value of low pressure steam is affected by a number of variables as follows:

- **Boiler cycle efficiency**: if the boiler cycle efficiency increases, the value of low pressure steam will decrease
- **Enthalpy of high pressure header**: if the enthalpy of the high pressure header decreases, the fuel requirement for boilers and power credit will decrease
- **Power price**: if the cost of

Refinery base case months

	Summer period	Winter period
Base case month	July 2012	January 2013
Number of days in month	31	30

Table 5

Refinery measured energy consumption before data reconciliation

Type	Fuel lower heating value (LHV)	Use	Energy	
Summer				
Fuel gas	10.68 Gcal/t	103.3 t/h	1103.1 Gcal/h	1283 MW
Fuel oil	9.86 Gcal/t	5.9 t/h	58 Gcal/h	67.4 MW
Power import	2.46 Gcal/MWh	0 MW	0 Gcal/h	0 Gcal/h
Summer total			1161.1 Gcal/h	1350.4 MW
Winter				
Fuel gas	10.68 Gcal/t	96.6 t/h	1032 Gcal/h	1200.3 MW
Fuel oil	9.86 Gcal/t	21 t/h	207.4 Gcal/h	241.2 MW
Power import	2.46 Gcal/MWh	0 MW	0 Gcal/h	0 MW
Winter total			1239.4 Gcal/h	1441.4 MW
Summer/winter				
Fuel gas	10.68 Gcal/t	100 t/h	1068.2 Gcal/h	1242.3 MW
Fuel oil	9.86 Gcal/t	13.3 t/h	131.4 Gcal/h	152.9 MW
Power import	2.46 Gcal/MWh	0 MW	0 Gcal/h	0 MW
Summer/winter total			1199.6 Gcal/h	1395.2 MW

Table 6

power decreases, the power credit will also decrease. In contrast, the value of low pressure steam will increase.

Case study

Data gathering

An oil refinery located in the Middle East is selected to benchmark and develop an energy conservation programme. The programme follows these steps:

1. Data collection
2. Benchmarking
3. Calculation of complexity factors
4. Identification of inefficiency
5. Technoeconomic evaluation.

A number of different techniques are used to validate and reconcile energy consumption data, which are: boiler and furnace efficiencies, boiler fuel consumption, refinery steam and power balance, measured fuel gas rates, gas turbine fuel consumption, and process data (for example, process furnace fuel consumption and heat exchanger duties). It is supposed that data are collected for both the hot and cold representative period of operation. **Table 5** shows the period of operation for the target refinery.

To perform the study, the following data are gathered:

- Boiler steam production
- Refinery steam balance
- Power balance
- Furnace and boiler efficiency
- Fuel balance
- Process unit.

The data collected for the hot and cold operating periods are used to determine the total refinery energy consumption, such that:

Total energy = Total fuel consumption + Power import/Generation efficiency

Furthermore, the following assumptions are considered for this calculation:

- The required power is provided from an external site, generating power with an efficiency of 35% which is equal to fuel consumption of 2.46 Gcal/MWh
- The monthly average energy consumption is calculated.

Measuring energy consumption

During the period of study, the target refinery consumed two types of fuel: fuel gas (includes some imported natural gas) and fuel oil (mostly heavy fuel oil).

Table 6 shows the measured energy consumption collected from the target refinery before data reconciliation.

Reconciliation of energy consumption

Table 7 shows the energy consumption data after validation and reconciliation. It is assumed that the boilers consume 35% of the refinery's total fuel oil consumption during summer operation, and the fuel gas burned in the utility boilers has a LHV equal to 10 470 kcal/kg. The reconciled data show that the total energy consumption of the target refinery for winter and summer is 1200 Gcal/h and 1279 Gcal/h, respectively, with an average value of 1239 Gcal/h. Total energy consumption in winter is about 6% higher than in summer because more energy is required for heating.

Specifying energy consumption

A relatively simple method for determining the energy performance of a refinery is to calculate the existing specific energy consumption (SEC). SEC is the total energy consumption per unit mass or volume rate of crude. From the data provided (see **Table 8**), the SEC for the refinery is 0.55 Gcal/t in summer and 0.59 Gcal/t in winter, with an average value of 0.57 Gcal/t.

Because the refinery configuration (complexity) and the process unit operation (for instance, hydrocracker conversion) are not considered, the energy performance of the refinery is not reliable. BT takes into account these factors, so benchmark energy performance is accurately estimated in the second step of this programme. **Figure 7** shows the SEC and energy consumption of the target refinery for both summer and winter base case months.

Process unit feed rates and energy consumption

In addition to the overall energy consumption of the refinery, the energy consumed by individual units for both base cases is calculated. In order to develop a realistic heat balance for this refinery, it is essential to carry out data validation and reconciliation.

Energy intensive equipment

A number of the main energy intensive facilities contributing to the overall energy consumption of the refinery are identified. For each facility, the energy intensive items of equipment are listed in **Table 9**.

Comparison of the target refinery with other refineries

Figure 8 demonstrates the energy consumption and the existing SEC in the target refinery and in three others in the Middle East.

Refinery reconciled energy consumption

Type	Fuel lower heating value (LHV)	Use	Energy	
Summer				
Fuel gas	11.06 Gcal/t	103.3 t/h	1142.4 Gcal/h	1328.6 MW
Fuel oil	9.86 Gcal/t	5.9 t/h	58 Gcal/h	67.4 MW
Power import	2.46 Gcal/MWh	0 MW	0 Gcal/h	0 Gcal/h
Summer total			1161.1 Gcal/h	1350.4 MW
Winter				
Fuel gas	11.06 Gcal/t	96.6 t/h	1068.9 Gcal/h	1243.1 MW
Fuel oil	9.86 Gcal/t	21.3 t/h	210.2 Gcal/h	244.5 MW
Power import	2.46 Gcal/MWh	0 MW	0 Gcal/h	0 MW
Winter total			1279.1 Gcal/h	1487.6 MW
Summer/winter				
Fuel gas	11.06 Gcal/t	100 t/h	1106.3 Gcal/h	1286.6 MW
Fuel oil	9.86 Gcal/t	13.5 t/h	132.8 Gcal/h	154.5 MW
Power import	2.46 Gcal/MWh	0 MW	0 Gcal/h	0 MW
Summer/winter total			1239.1 Gcal/h	1441.1 MW

Table 7

Refinery SEC

	Summer	Winter	Average
Crude feed rate (fresh feed)	2178.46 t/h 378 000 BPD	2178.46 t/h 378 000 BPD	2178.6 t/h 378 000 BPD
Total energy consumption	1200.4 Gcal/h 1396 MW 4763.5 MMBtu/h	1279.1 Gcal/h 1487.6 MW 5076 MMBtu/h	1239.1 Gcal/h 1441.1 MW 4917.2 MMBtu/h
Existing SEC (energy per ton of crude)	0.55 Gcal/t 0.3 MMBtu/bbl	0.59 Gcal/t 0.32 MMBtu/bbl	0.57 Gcal/t 0.31 MMbtu/bbl

Table 8

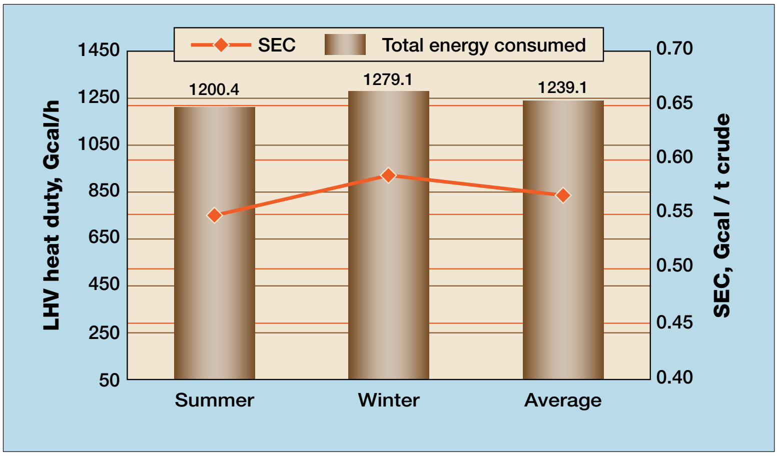

Figure 7 Energy consumption

Conclusion

In this article, a method of calculating the true monetary benefit of saving energy was discussed. Moreover, the correct mechanism for estimating the price of energy, leading to better economic evaluation, was presented. It was shown that basic building blocks should be constructed before executing energy conservation programmes for a refinery.

Additionally, it was confirmed that best technology (BT) benchmarking can highlight the efficiency of a target refinery against BT to show the potential for optimisation programmes. In order to provide correct figures for energy efficiency ideas in a refinery, reliable evaluation of fuel, power and steam costs were demonstrated.

Four refineries were surveyed. The first apparently had the lowest SEC numbers. However, this was compromised because energy consumption was a function of both refinery complexity and crude feed rate. Consequently, to benchmark the energy performance of a refinery accurately, some complexities should be considered in addition to the crude feed rate. Hence BT methodology was used as a practical tool for benchmarking the energy performance of that refinery.

Further reading

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