Energy is the second single largest component of variable refinery operating expense, representing some 40 - 50% of total operating costs, excluding the cost of purchasing raw crude. Fuel and power consumption is also directly related to CO₂ emissions production, and there are also strong economic and environmental pressures to reduce greenhouse gas (GHG) emissions.

The energy efficiency of a refinery is typically measured by the Solomon Energy Intensity Index (EII), which normally ranges from 60 up to 140, where a lower number represents greater energy efficiency. The EII value is a validated and standardised measure of energy usage that accounts for scale, location, and complexity of the production facility and operational performance. For a typical 100 000 bpd refinery, an EII reduction of one point is worth approximately US$ 1.7 million/yr at US$ 5/MMBTU fuel price.

The operational energy performance of a complex site depends on the individual process unit technologies, efficiencies of individual equipment items, and the effectiveness of the utility system design and the level of heat integration inside and outside of the process unit boundaries. It is possible to have highly efficient individual process unit designs but poor overall site energy performance, due to missed opportunities for inter unit integration, inappropriate steam header pressures, and inappropriate steam header pressures.

Xiquan Zhang, China National Offshore Oil Corporation, China, and Gwangskik Jang, Bin Wei and Ian Moore, Aspen Technology, describe how taking an integrated approach to energy performance early in the design phase can deliver significant improvements in refinery energy efficiency.
and a site utility system that does not fit well with the process plant utility demands. Typical manifestations of such situations are venting of low pressure steam and, in some cases, flaring of excess fuel gas.

Therefore, a site wide perspective on energy supply and use is an essential requirement to achieve world class energy performance, rather than simply relying on optimising the standalone energy performance of the individual process units.

Guang-Dong refinery

By 2010, China plans to lower its energy consumption (per unit GDP) by 20% compared to 2005. China is under pressure to control GHG emissions at the same time as maintaining high GDP, and one step towards this goal is ensuring that new process unit and site designs achieve world class energy performance. This article describes how an integrated approach to refinery process design can have a significant impact on energy efficiency within a site.

The Guang-Dong refinery, which is owned by China National Offshore Oil Corporation (CNOOC), was in its basic design stage when AspenTech's advanced process design (APD) team was invited to undertake a site wide energy optimisation study. Sinopec Engineering Institute (SEI) was the general engineering contractor for the overall project.

CNOOC recognised that the most economically attractive time to influence a refinery's energy performance is at the design stage. Energy reduction projects always show better economics when incorporated as part of a new design than in a retrofit situation. This is true for several reasons. Firstly, there are less process constraints at the design stage in terms of layout, pressure drop and finding space for new equipment. Secondly, higher levels of process heat recovery reduce the size (and hence capital investment) of furnaces, steam heaters and air fin coolers, cooling water systems etc. Therefore, in a new design situation it is often possible to reduce energy use whilst also reducing the overall capital cost. In a retrofit situation, this equipment has already been purchased so there is no capital saving, unless additional heat removal capacity is required.

With the increasing energy price worldwide and the increasing total energy consumption within China, CNOOC's goals were:

- To optimise energy consumption in the new refinery at the design stage.
- To achieve the ‘best in class’ energy intensity index (EII) of 75 or lower.

The Guang-Dong refinery consists of the following major process units including a cogeneration facility:

- Crude/vacuum distillation unit (CDU).
- Steam reformer unit (H₂ plant).
- Catalytic reformer/BTX unit.
- High pressure/medium pressure hydrocracker.
- Fluidised catalytic cracking.
- Delayed coker.
- Gasoline/diesel hydrotreater.
- Alkylation/MTBE.
- Gas processing/desulfurisation/sulfur plant/sour water stripper.

An artist’s impression of the finished refinery complex is shown in Figure 1.

Typically in a grassroots project, the process design of the licensed units is executed by the individual licensors, whilst the main engineering contractor will design the non licensed units and the overall utility system. The client and main engineering contractor will provide guidance to the licensors on the level of energy performance required.

An integrated approach to process design using software simulation and optimisation tools can deliver significant improvements in operational performance compared to conventional process design approaches. This kind of approach integrates the following design methodologies to realise maximum benefits:

- Rigorous and predictive steady state modelling.
- Pinch analysis for optimum energy recovery of individual process units.
- Thermodynamic analysis of distillation columns (column targeting).
- Site wide pinch analysis to consider potential heat integration between units (often via local utility systems).
- Utility system modelling and development.

AspenTech’s APD team has successfully applied this approach on projects with a large number of refining and petrochemical companies, including Total and KPCChem. Applying the same approach in a systematic way when undertaking the energy optimisation study for the Guang-Dong site ensured that no energy saving opportunities were overlooked. The overall methodology for the project is shown in Figure 2. The AspenTech team was involved in the shaded steps shown in Figure 2. The energy optimisation study was executed in three phases.

Phase 1
At the start of such a project, the main contractor has
to provide basic engineering design data (BEDD) to the licensors to allow them to start their designs. The BEDD data contains information on the site steam levels and other utilities available to the licensed units, as well as economic data including energy costs. Common practice is that the licensor then uses the energy cost provided to trade off the energy cost reduction against increased heat recovery equipment, e.g. heat exchangers. However, the licensor is usually not able to include the reduction in capital cost in the utilities system as a result of improving energy performance in this analysis, as most utility equipment is refinery wide and not just local to the unit. Other information provided at this stage may include guidance on product transfer temperatures between process units, and recommendations on inter unit heat integration. This information is often based on experience from previous projects, rather than the specific needs of each new site. It is therefore conventional practice to design the process units to fit with the specified utility infrastructure, rather than to design the utility system to fit with the inherent utility requirements of the process units.

To reverse this conventional approach, CNOOC and SEI asked AspenTech to carry out a preliminary site wide pinch analysis to provide a true picture of the process utility demands early in the design process. There is a tendency to delay such a study to a time when good information on process heating and cooling is available from the licensors for all of the process units. However by this time it becomes costly both in terms of budget and schedule to make changes to the design basis. Therefore for the Guang-Dong project this first analysis was based on preliminary design heat/material balances for process units. Where information was not available, AspenTech created pinch models based on typical data for similar units.

This preliminary total site analysis for the Guang-Dong project confirmed that four steam pressure levels were appropriate for the site, and highlighted the importance of selecting low pressure (LP) to enable matching against some key reboiler duties. The site analysis considered the potential for internal power generation in back pressure steam turbines, and the scope for low grade heat integration such as hot oil, hot water loops or local steam mains.

The preliminary analysis allowed the optimum intermediate product transfer temperatures between units to be defined and specified to the licensors. For example, VGO might be cooled against MP steam generation on an upstream unit, and then preheated on the FCC unit by slurry pumaround at the expense of HP steam generation.

In this case, transfer at a higher temperature effectively shifts heat duty from MP to HP steam generation.

A model of the site utility system was also developed at this time. This allows steam use within the utility plant to be quantified including low pressure steam use for deaeration. The model also quantified the scope for preheating demineralised water to the site deaerators by process heat recovery. Combined with the total site analysis that identifies those process units with large amounts of excess low grade heat, opportunities for heat integration between selected process units and the utility system were identified and included in the licensor scope as required.

With the preliminary design information, the overall refinery energy index (EII) was assessed to quantify the ‘before design improvement’ energy performance. The energy intensity index of Guang-Dong refinery for the preliminary design was 71, which placed the refinery within the top 18% of Pacific refineries and within the top 10% of worldwide refineries. It turned out that the refinery achieved one of its goals (EII lower than 75) even at this early stage in the study.

Phase 2

Phase 2 was focused on pinch analysis of individual process units based on the heat and material balances provided by process designers.

During this design phase, the licensor typically has little visibility of the heating and cooling demands of process units outside the scope of that licensor’s work, so is normally optimising heat integration purely within its own process units. On a previous AspenTech project, a licensor designed a very energy efficient heat pump system for a standalone C3 splitter column reboiler, whilst the total site analysis showed there was plenty of waste heat available on a nearby process unit that could be used to reboil the column via a hot water loop. Capturing this synergy at the design stage saved both energy and capital cost. By ensuring that a global view is taken across the project on energy performance, these local suboptimisations can be avoided.

The Guang-Dong study team identified design change options for energy saving which included:

- Energy target based on optimised minimum approach temperature.
- Optimisation of preheat exchanger networks.
- Optimisation of pumaround duties and circulation rates.
- Capital energy trade off evaluation for proposed changes.

Figure 3 shows an example of how column thermal analysis was applied to optimise heat removal from a vacuum tower pumaround system.

A large number of project ideas were generated, and the proposed design changes were reviewed and screened with CNOOC/SEI. Then the selected project options were transferred to the unit designers, so they could be incorporated in the final design.

Phase 3

With the final process design information and utility summaries available for the individual process units, the total site analysis was updated to confirm that the proposed utility levels were still optimum, to update the potential
for power generation from steam turbines, and to identify any additional opportunities for improvement caused by changes during the individual process unit design.

Site wide hydrogen/fuel network analysis was also performed, which led to a significant reduction in the amount of hydrogen that would be required from steam reforming by recovering more hydrogen from process offgases in an economic way.

A detailed simulation model of the plant utilities system based on the final steam system design was developed using the Aspen Utilities application. This model provides additional advantages in an online/offline, real time environment to perform daily optimisation and management of the refinery utilities systems such as:

- Defining optimum economics of cogeneration versus imported electricity.
- Defining the optimum strategy for the operation of equipment drives (motors/turbines).
- Performing sensitivity analysis on the utilities system operation and costs against a wide range of possible operating scenarios.

This analysis recommended installation of a second cogeneration unit compared to the original design, which has a significant impact on energy performance.

By developing the model in Aspen Utilities it would allow the same model used for the design to be used in the subsequent start up and economic operation of the refinery.

**Energy performance results**

The EII was reassessed based on the final ‘frozen’ design to identify the design improvement achieved as a result of the study. The final design case EII was 64.6, placing the CNOOC Guang-Dong refinery in the top 5% of Pacific refineries and the top 3% of worldwide refineries. The reduction in EII was 6.4 points, which would be equivalent to approximately US$ 28 million/yr energy cost saving. The refinery is also expected to be world class in terms of its low level of CO$_2$ emissions.

Most other refineries above this energy performance class have a third party low grade heat sink integrated with the refineries, such as a district heating network. As an isolated refinery complex, there is still a significant amount of low grade heat that is rejected to air coolers or cooling water that is of no direct use to the refinery but that does impact EII. If a scheme such as a district heating system were possible it could be expected to reduce EII by a further 2 - 4 points, thereby placing Guang-Dong at the top of the energy efficiency league of complex refineries.

**Conclusion**

By taking an integrated approach to energy performance early in the design phase, the joint CNOOC, SEI and AspenTech team ensured that significant improvements in energy efficiency were achieved despite an already high baseline energy performance.