Improving energy efficiency in an ammonia plant

D. Velázquez, F. Rossi and J. Rodríguez of DVA Global Energy Services and F. Galindo of Fertiberia present the results of an energy study carried out in an ammonia plant in Spain. A comprehensive energy audit of the main equipment (furnaces, syngas, air and ammonia compressors, steam turbines, cooling towers and refrigeration systems), pinch analysis and steam modelling resulted in the proposal of 34 projects, some of which have cost savings of more than one million euros per year with payback times of less than one year.

The directives 2003/87/EC and 2009/29/EC set strict CO₂ emission limits for some chemical industries and can have a significant impact on companies’ profits. Because of this, as well as the increase in the price of natural gas in recent years, many European ammonia producers have been forced to carry out important energy efficiency improvements, in order to maintain their competitiveness within the international market.

During recent years, the average specific consumption of ammonia production has been globally quantified as 36.6 GJ/tNH₃ (LHV base). Performance indicators of ammonia plants located in Canada and western Europe show the best values³.

Within the most efficient regions, natural gas costs represent more than 80% of total ammonia production costs, reaching 90% in some cases.

Current best available technologies for ammonia production from natural gas allow specific consumption levels of about 28 GJ/tNH₃ to be achieved⁴.

Among the methodologies aimed at finding energy saving opportunities, pinch analysis linked to power and steam modelling has proved to be a powerful way for determining projects to improve the overall energy efficiency of industrial sites. This procedure has been applied successfully in many industrial facilities, allowing optimal energy recovery in the process and hence reduction of fuel consumption.

**Plant description**

**Process description**

The ammonia site for which this energy audit has been carried out was designed to produce 1,130 t/d of ammonia, via catalytic steam reforming of natural gas, using Kellogg technology with ICI license.

The ammonia produced is either exported or consumed by a urea plant located in the same facility. Its utility services are also connected to a nitric acid plant. Figure 1 shows a simplified diagram of the process.

Energy structure

Steam reforming is an endothermic process, which is carried out at high temperatures. Thermal energy demand is supplied by a furnace located in the first reform-
CO₂ EMISSIONS REDUCTION

**Fig 1: Simplified diagram of the ammonia production process**

- **Fig 2: Main inlet and outlet energy flows involved in the ammonia production process**

### Table: Energy Flows

<table>
<thead>
<tr>
<th>Stream</th>
<th>Inlet Energy</th>
<th>Outlet Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feed (NG)</td>
<td>58.3%</td>
<td>60.2%</td>
</tr>
<tr>
<td>Fuel (NG)</td>
<td>39.8%</td>
<td>25.9%</td>
</tr>
<tr>
<td>Electricity</td>
<td>1.9%</td>
<td>1.9%</td>
</tr>
<tr>
<td>Ammonia</td>
<td>60.2%</td>
<td>60.2%</td>
</tr>
<tr>
<td>Cooling water</td>
<td>25.9%</td>
<td>25.9%</td>
</tr>
<tr>
<td>Steam export</td>
<td>6.1%</td>
<td>6.1%</td>
</tr>
<tr>
<td>Flue gas</td>
<td>4.8%</td>
<td>4.8%</td>
</tr>
<tr>
<td>Other loses</td>
<td>3.0%</td>
<td>3.0%</td>
</tr>
</tbody>
</table>

Total energy supplied to the process is 98.1%, with natural gas contributing 58.3% and electricity 39.8%.

High pressure steam is generated downstream of the reforming unit, as well as after the CO₂ to CO₂ conversion unit, where exothermic reactions take place. Additional high pressure steam is generated in an auxiliary boiler, whose combustion gases are sent to the same combustion exhaust gas channel of the reforming furnace. The auxiliary boiler is the second largest energy consumer of the facility, representing over 20% of total energy consumption. The third-largest thermal energy consumer is the furnace upstream of the desulphurisation reactor, where natural gas is heated.

In addition to natural gas, the purge stream of the synthesis loop is also used in the fuel feed network, as it contains high levels of hydrogen. Due to the exothermic reaction of ammonia production, the thermal energy contained in the ammonia synthesis reactor outlet stream is used to preheat the boiler feed water.

As shown in **Fig. 2**, heat supplied to the process through the combustion of natural gas is subsequently recovered for steam production (power production) and heating combustion air and other process streams. Unrecovered heat is removed by cooling towers and air coolers. High pressure steam is...
mainly consumed by turbocompressors for process air, syngas, the ammonia cooling system and injection to the reforming process. A significant amount of the steam is also exported to the urea plant.

The natural gas consumption for this site represents more than 95% of the overall energy consumption of the factory. The main objective of the proposed energy efficiency assessment is to reduce natural gas fuel consumption, corresponding to 39.8% of the total energy inlet.

**Approach**

**Equipment audit**

The largest energy consumers were identified, with the aim of performing an energy efficiency analysis and subsequent efficiency enhancement assessments for each one of them. Furnaces, boilers, compressors and cooling systems in the facility were evaluated. A steam trap and insulation infrared thermography surveys were also carried out.

**Pinch analysis**

The aim of the pinch analysis is to improve the existing energy recovery from the process streams to reduce natural gas consumption. This analysis is closely linked to the steam model that was developed for the thermal and power systems of the factory. The study also considered the identification of appropriate residual heat sources, with the purpose of assessing the feasibility of implementing an absorption refrigeration system.

**Thermal and power model**

A model was developed of the steam generation and power systems, in order to predict and economically assess the effects of the different energy savings projects identified in the previous stages of the study. The inputs to the model are linked to the results obtained from pinch analysis. All steam turbines, heat exchangers, boilers, steam generators and consumers of the facility are included in the model. In addition, the model allows the specification of steam turbine performance curves, which are needed for correct prediction of their performance under different operating conditions.

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**Fig 3: Steam model**

**Table 1: Projects summary**

<table>
<thead>
<tr>
<th>Area</th>
<th>Number of projects</th>
<th>Maximum saving (k€/year)</th>
<th>Payback (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pinch projects</td>
<td>9</td>
<td>1.214</td>
<td>0.3</td>
</tr>
<tr>
<td>Natural gas saturation</td>
<td>1</td>
<td>437</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Cooling towers enhancement</td>
<td>1</td>
<td>63</td>
<td>0.7</td>
</tr>
<tr>
<td>Natural gas expander</td>
<td>1</td>
<td>285</td>
<td>1.9</td>
</tr>
<tr>
<td>Auxiliary boiler combustion control</td>
<td>1</td>
<td>209</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Insulation maintenance</td>
<td>1</td>
<td>17</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Steam trap repairing</td>
<td>1</td>
<td>78</td>
<td>&lt;0.5</td>
</tr>
<tr>
<td>Compressors and absorption cooling</td>
<td>19</td>
<td>106</td>
<td>&gt;7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>34</strong></td>
<td><strong>2.409</strong></td>
<td><strong>&lt;2</strong></td>
</tr>
</tbody>
</table>
The model was developed in Excel format, which makes it easy to implement in any industrial facility, and represents a fast and accurate calculating tool that can be used for economic assessment of changes introduced in the plant. The reliability of the model is based on the possibility of using real operating data to adjust the efficiencies and consumptions of each unit. Figure 3 shows the main interface of the model.

Results

Table 1 shows a summary of the main energy saving projects identified and assessed in the analysis.

Pinch analysis

Pinch analysis allows the quantitative assessment of existing energy recovery, graphically represented by hot and cold grand composite curves which are shown in Fig. 4. The composite curves of the process represent the process energy demand (heating and cooling) versus their temperatures. These curves are obtained by adding the demand of hot streams, which need to be cooled, and cold ones, which oppositely need to be heated, for each temperature interval.

In spite of the proper level of existing energy recovery in the process, a big potential improvement was detected by means of retrofitting the existing heat exchanger network. For the analysis, a minimum approach of 20°C between composite curves was chosen. Figure 4 shows the optimised energy recovery case, corresponding to 20°C minimum approach.

Potential savings

Table 2 shows potential savings and objectives of energy consumption for the target situation, in which the energy recovery is improved at 20°C minimum approach. Although these values should not be considered as strict objectives to be fulfilled, they still provide a useful guideline for energy recovery enhancement from the process.

For the same natural gas consumption in the auxiliary boiler and desulphurisation furnace, high pressure steam generation could be increased by 7.9 t/h.

Auxiliary boiler

Savings shown in Table 2 suggest the potential for reducing natural gas consumption in the boiler while maintaining the same total steam production (229.6 t/h).

Load reduction in the boiler can be compensated by enhancing thermal energy recovery from the process through the installation of new heat exchangers.

Thermal and power effects in the primary reformer

All combustion gases of the plant are sent to the primary reformer gases channel, where thermal recovery takes places for the heating of different streams. The stack of the desulphurisation furnace is connected to the gases channel in the last section, affecting only air heating. It is worth noting that a reduction of natural gas burned in the boiler and/or primary reformer will have important effects on the performance of heat exchangers used for energy recovery in this duct. The gas channel was simulated and it was observed that the exchangers most affected are the boiler feed water and combustion air preheaters. Since steam generation is linked to the whole steam and power model, the global steam balance is affected once the amount of burned natural gas is changed. This also affects the flow rate of high pres-

<table>
<thead>
<tr>
<th>Utility</th>
<th>Base</th>
<th>Target energy use</th>
<th>Energy saving potential</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural gas</td>
<td>30.012 kW</td>
<td>30.012 kW</td>
<td>0</td>
</tr>
<tr>
<td>Low pressure steam (consumed)</td>
<td>6.254 kW</td>
<td>0</td>
<td>6.254 kW 10.6</td>
</tr>
<tr>
<td>High pressure steam (generated)</td>
<td>175.543 kW</td>
<td>181.583 kW</td>
<td>6.040 kW 7.9</td>
</tr>
<tr>
<td>Condensate</td>
<td>13.798 kW</td>
<td>13.798 kW</td>
<td>0</td>
</tr>
<tr>
<td>Air</td>
<td>14.562 kW</td>
<td>14.562 kW</td>
<td>0</td>
</tr>
<tr>
<td>Cooling water</td>
<td>109.167 kW</td>
<td>101.955 kW</td>
<td>5.913</td>
</tr>
<tr>
<td>NH₃</td>
<td>13.682 kW</td>
<td>12.383 kW</td>
<td>1.299</td>
</tr>
</tbody>
</table>

Table 2: Potential savings
sure steam expanding through the turbines and therefore generated shaft work. Heat recovery in the gases channel was therefore carefully modelled with the aim of accurately quantifying these effects and linking it to the general steam and power model.

Projects

Table 3 summarises the identified and proposed projects resulting from pinch analysis.

Nine different projects were identified, which indicated relevant reductions of natural gas consumption at the site. Economic savings achieved by single projects are between €200,000 and €1,200,000, with payback times of less than one year for most of them. The high profitability of one of the proposed projects is worth highlighting and is described in the following section. This project considers the installation of a new low-pressure steam generator in the gases channel.

Low-pressure steam generator in gas channel

As previously mentioned, pinch analysis showed the possibility of increasing high pressure steam generation and reducing the natural gas consumption by 9% in the auxiliary boiler. Further reduction of natural gas consumption would affect the heat recovery process through the exhaust gases channel, preventing the possibility of achieving a new thermal and power equilibrium in the whole plant unless major investments were carried out to revamp the current heat exchanger network.

This project proposes the installation of a new LPS (low pressure steam) generator in the gases channel with the aim of achieving 9% reduction of fuel consumption, while maintaining steam generation. The amount of LPS generation predicted by the steam model was 7.2 t/h. The appropriate place for the installation of the LPS generator in the gases channel is before the last thermal recovery section, dedicated to combustion air preheaters.

The reduction of fuel consumption affects the energy recovery through the gases channel downstream of the auxiliary boiler, altering the operating conditions of all the coils downstream. Figure 5 shows these new operating conditions. In the proposed situation, combustion gases will be exhausted at a lower temperature (approximately 125°C) than the current 154°C. A total cost saving value of €729,000 per year for the project has been calculated. Considering cost savings associated with CO₂ emissions reduction, total savings increase up to €801,000 (CO₂ emission tax: 150€/t).

The project investment for a new LPS generator, piping and insulation is of the order of €155,000, which means a payback time of less than four months.

Equipment audit

Compressors

Two energy efficiency enhancement projects resulted from the compressors assessment, both of them aimed at reducing the consumption of their driving steam turbines:

- Surge control improvement for the ammonia refrigeration centrifugal compressor. During periods of cold weather (5 months per year) the compressor operates at reduced loads, which causes the surge control to act...
to prevent it from malfunctions. The installation of an automatic surge control system was proposed that minimises operating hours with opened recycle valve. This system adjusts the set-point of these valves as a function of current operating conditions and dynamic surge curves.

- Recovering residual heat to produce cold glycol water in LiBr/H₂O or NH₃/H₂O absorption chillers. Results from the economic assessment of these projects showed high payback times (>7 years), mainly due to the high investment required for heat recovery equipment, absorption chillers and dedicated cooling towers.

**Cooling water system**

The cooling water system is properly operated. Nevertheless, it was proposed that the existing cooling tower fans be replaced with more efficient and better designed ones. This results in a reduction of the electric consumption of the driving motors. The estimated saving was €63,000/year with a payback time of less than one year.

Improvements were also detected in the cooling network design; a new configuration was proposed, in which warm water is substituted with cold water for steam condensing.

**Combustion control**

Combustion control was operated manually. Combustion optimisation is not a priority and was not performed on a continuous basis, the main focus of the operators being to maintain the production of the plant. Therefore an automatic control system was proposed for the combustion equipment in the auxiliary boiler and primary reformer. The installation of an automatic control system could be difficult considering the age of the primary reformer and the number of burners. The proposed project may therefore require a complete revamp of the combustion system, thus requiring careful evaluation from the company. Total savings of £200,000/year were assessed for the auxiliary boiler and primary reformer, with a payback time of less than one year for the auxiliary boiler.

**Natural gas saturator**

The saturation of natural gas using hot condensates upstream of the primary reformer was simulated and assessed. This measure leads to a reduction of steam injection demanded by steam reforming and thus the possibility of reducing steam generation of the auxiliary boiler. Estimated savings for this project are €437,000, with a payback time less than one year.

**Natural gas expander**

Natural gas fuel is currently expanded from 45-50 barg pressure to 2 barg through a valve system. Therefore, the possibility of using this expansion to produce electric power was evaluated. The nominal electric power of the proposed expander is 450 kW, which generates economic benefit of €285,000/year. The investment associated with the acquisition and installation of the expander results in a payback time of two years. The feasibility of the project depends on the speed and reliability of the control system when opening the relief bypass in case of failure of the expander.

**Maintenance**

Two main areas were assessed:

- Thermal losses, caused by insulation conditions, mainly located in the reformer furnace and main pipelines were evaluated. The economic losses correspond to €17,000/year.
- Steam traps do not usually draw the attention of maintenance personnel, either because they are not sufficiently accessible or because they are not considered to have a big effect on global energy efficiency. Through an exhaustive ultrasound analysis of steam traps, among the 300 steam traps in the facility, 20 were found to be not working properly, which translates to economic losses of €78,000 per year.

**Future steps**

The installation of an energy management system (EMS) is recommended with the aim of maintaining the achieved savings predicted in the study. The objective of the EMS is to keep track of the energy efficiency of the whole site, main equipment and areas, defining achievable objectives for energy efficiency and acting to correct the deviation from those defined targets.

In an energy management system it is of paramount importance to properly define the main energy efficiency indicators (EEI) and its variables of influence (VI). The company therefore developed a powerful tool, iManergy™ (Fig. 6), that allows the definition of dynamic references for the EEI correlated to its variables of influence. The software allows the client to compare its performance with best historical values under homogeneous conditions, which significantly helps to improve the daily operational performance of the plant from an energy point of view.

Ammonia producers, considering the need for continuous improvement in its operations should consider the installation of energy manager software.

**References**

4. Methodology for the free allocation of emission allowances in the EU ETS post 2012. Ecofys, Fraunhofer ISI, Öko-Institut
5. Pinch Analysis: For the efficient use of energy, water and hydrogen. Natural resources Canada.