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REDUCING ENERGY COSTS AND CO_2 EMISSIONS OF AN AMMONIA PRODUCTION PLANT

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Pinch analysis is a technique for integrated network design with significant potentials for improving energy recovery in industrial processes, which can lead to relevant reductions of fuel consumption in ammonia production plants. D. Velázquez, F. Rossi, J. Rodríguez, A. Vilches and F. Galindo report on a comprehensive energy study in an ammonia site, including the re-design of the heat recovery network of the plant, according to the guidelines and energy targets of Pinch analysis. Total energy savings of 19,5% of current fuel consumption have been obtained with the proposed revamp, aside from 13,0% of fuel consumption reduction previously detected through an in-depth equipment energy audit.

INTRODUCTION

Framework

Ammonia sites are great sources of greenhouse gas emissions, due to the high fuel consumption required by the energy-intensive ammonia production process. Even within the most efficient regions, natural gas costs represent more than 80% of total ammonia production costs, reaching 90% in some cases. It is thereby an indisputable fact that the profitability of ammonia production plants is increasingly endangered by fuel prices and the recent law scenarios, that impose more stringent restrictions for European Union in matters of CO_2 [1],[2]. In this scenario, continuous energy efficiency improvement is needed in ammonia sites, aimed at reducing energy consumption and CO_2 emissions levels.

In this respect, comprehensive efficiency studies represent a valuable aid to the progressive reduction of specific consumptions, tending to the achievement of best specific consumption values globally registered [3],[4],[5],[6]. In order to identify the real potentials of improvement and thus maximize the obtainable savings in energy costs, in-depth studies are needed, which integrate rigorous methodologies and effective techniques to detect and assess energy efficiency projects.

Advanced methodology for industrial energy audits

Recent energy studies have been carried out with excellent results in ammonia sites, involving powerful methodologies as Pinch analysis and in-depth evaluation and simulation of the steam network and main equipment of the facility [5],[6]. The main objectives of these studies are the maximization of the energy recovery from the process, the identification of the optimal performance of each equipment, and the assessment of the impact of the proposed changes on the behaviour of the steam network.

In the present study the methodology developed by DVA Energy has been employed, presented in former studies [6]. On the one hand, an equipment audit has been carried out, aimed at evaluating the current status of the main equipment of the plant, to subsequently optimize its operation. On the other hand, a Pinch analysis has been performed to maximize the thermal recovery from the process, allowing as well the detection of new energy sources required for the implementation of new projects identified in the equipment audit phase. The assessment has been supported by a simulation model developed for the steam network and power generators of the facility. The modl has been used to evaluate the global impact of energy saving projects on the system and to corroborate the reliability of the obtained results.

In this paper, the results are presented of a comprehensive energy audit carried out for an ammonia production site located in Spain, including an efficiency assessment of the main equipment, together with Pinch analysis and steam network modeling.

PLANT ENERGY CONSUMPTION – BASE CASE

The ammonia site at issue has a design capacity of 600 t of NH_3 per day, via catalytic steam reforming of natural gas, employing UHDE technology. Its utility services are connected to urea and nitric plants, located in the same production site.

The largest fuel consumer of the site is the primary reformer furnace, which represents 76% of the total fuel consumption of the factory. The other fuel consumers are indicated in Figure 1, representing the thermal energy use distribution of the site:

- HP boiler: A radiant boiler generating high pressure (HP) steam. Its load is regulated according to the steam demand that can not be covered by the other heat recovery boilers of the site;

- MP boiler: An auxiliary boiler that supplies steam to urea and nitric acid plants of the site; it is another relevant consumer, as it represents 18% of the total fuel consumption;
- Desulphurization furnace.

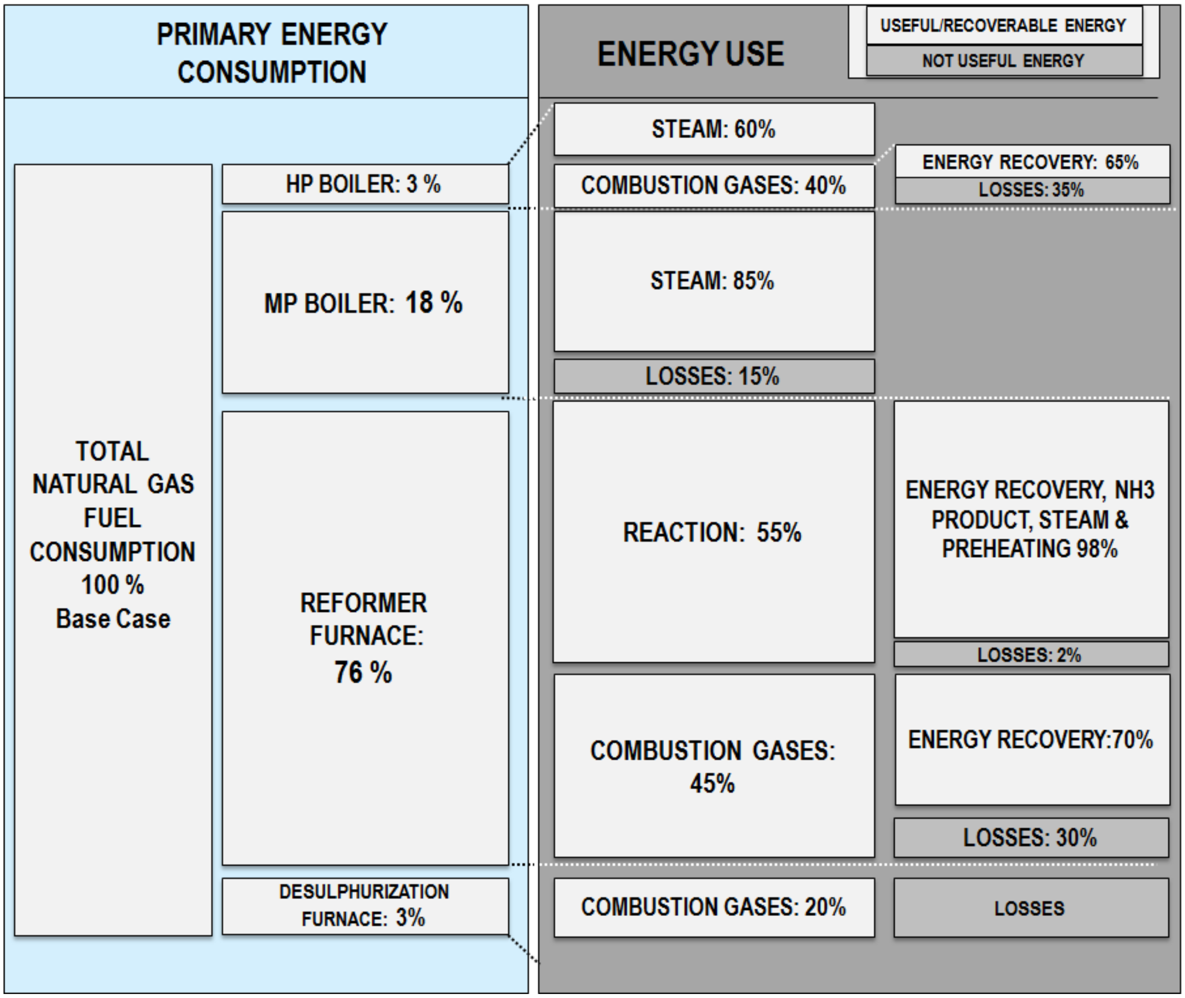


Figure 1 - Energy use distribution of the ammonia production site

ENERGY ASSESSMENT

STEAM NETWORK MODEL

A simulation model of steam network and power generation is a tool of great utility for plants of this complexity, allowing a reliable assessment of the savings associated with the projects proposed. The model, developed in Excel format and properly linked to results obtained from Pinch analysis, allows evaluating the real energetic impact of the proposed changes over the steam network and the response of the power generation system to adapt to the new energy situation after changes.

A satisfactory level of fidelity of the model was achieved through the inclusion of specific sub-models of the main components of the system (boilers, deareators, steam turbines, pumps and heat exchangers), which allow predicting its efficiency changes resulting from changes of the operating conditions. Simplified models calibrated with real data were developed for the most relevant equipments, the behaviour of which is closely interlinked with changes in steam network. For instance, the performance curves of all steam turbines of the plant were included, relating power production with live steam and extraction steam mass flows. This aspect is especially relevant taking into account the high sensitivity of energy price values (electricity and steam) to the behaviour of the system as it is generally determined by evaluating energy conversion since its source, which is the natural gas combustion. The use of wrong values for the economic assessment of the project would results in misleading saving values when analysing which projects are feasible in terms of payback times.

Another key tool of the steam model is the simulation of the gases channel of the steam reformer. As it has been presented in former studies [6], changes in natural gas consumption in the steam reformer directly affect the gases flowrates and thus HP steam generation.

EQUIPMENT EFFICIENCY ENHANCING MEASURES

Steam turbines - Reducing condensing pressure

Driving steam turbines of syngas and air compressors are the largest steam consumers of the plant, being therefore equipment of key interest for the energy costs reduction study.

Condensing pressure in steam turbines affects directly its specific consumption, as it determines the enthalpy difference associated to steam expansion through the turbine (Figure 2). Condensation is currently carried out by means of air cooled condensers, being therefore the condensing pressure and thus the steam consumption critically affected by ambient conditions. Highest steam consumption values are reached in summer months, when the equipment operates at higher temperature levels that lead to higher condensing pressure values.

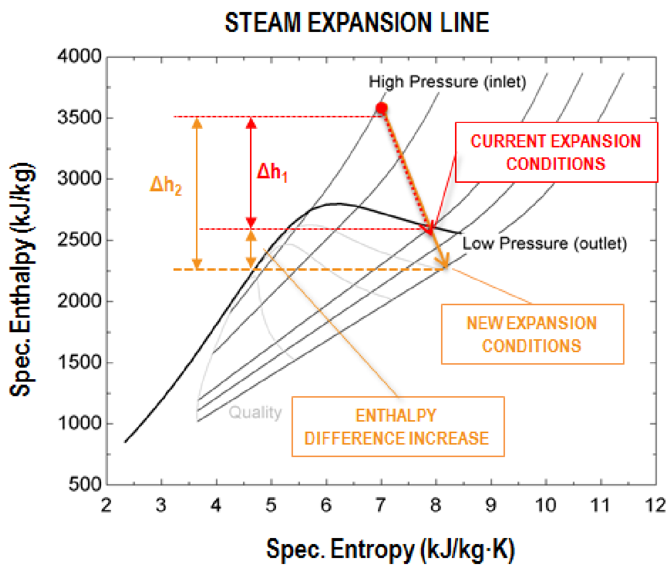


Figure 2 - Reducing condensing pressure in steam turbines. Schematic Mollier diagram

The reference condensing pressure for project assessment was set to 0,2 bara, corresponding to the average value registered during one year of operation of the condensers. Therefore, it was detected the opportunity of reducing steam consumption by enhancing the condensation system and thus reducing the operating condensing pressures in both turbines. Two options were assessed for the modification of the existing cooling equipment:

- Option 1: Substitution of the aircooler by a surface condenser. By this means, increase of condensing duty is expected, due to the mayor heat rejected by using cooling water as refrigerant.
- Option 2: Installing an evaporative cooler in the existing air cooled condenser. This equipment allows reducing the air temperature in an adiabatic process that involves heat transfer from air to water droplets for liquid-to-vapor conversion (Figure 3).

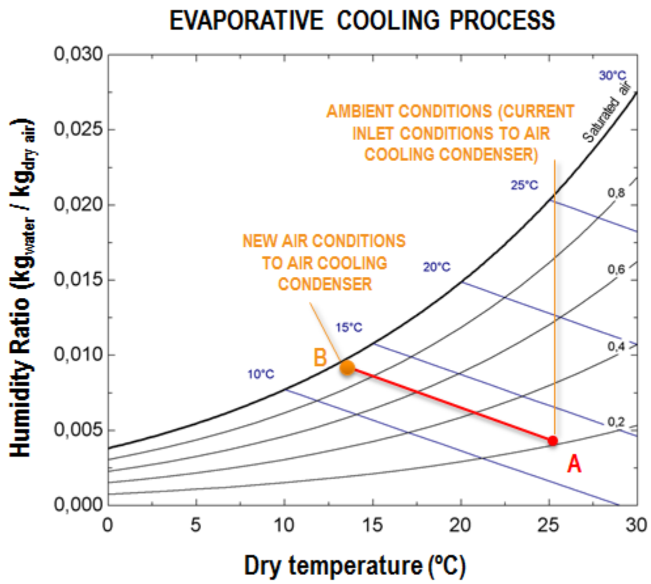


Figure 3 – Psicrometric diagram of an evaporative cooling

Although Option 2 constitutes a significant improvement in terms of lower operating temperature and cooling duty increase, greater improvement in cooling capacity is expected with Option 1, as a result of using cooling water as a refrigerant. On the other hand, higher investment costs are required for this option, associated with higher costs of a surface condenser (compared to an evaporative cooler) and the installation of a new cooling tower (to cool the water supplied to the condenser) and a new circulating pump.

An in-depth analysis of the the ambient conditions and the operating performance of cooling towers was needed, in order to reliably assess the economic feasibility of each option. A great sensitivity of the results was observed to ambient conditions:

- Surface condenser: Cooling water temperature varies according to ambient conditions which affect the performance of the cooling towers, as well as the operation of cooling towers by itself (fan and cooling water flowrates regulation, deterioration state, etc.).
- Evaporative cooler: The effectiveness of the equipment (and thus minimum reachable air temperature) is determined by the difference between the ambient wet-bulb temperature (which is determined by both temperature and humidity) and the actual ambient dry-bulb temperature.

The results for the two options are shown in Table 1:

Area	Option 1	Option 2
Site ambient temperature (ºC)	25	
Site ambient relative humidity (%)	20	
Condensing pressure in the new situation (bara)	0,09	0,13
Condensing temperature in the new situation (ºC)	45	51
Saving (k€ / year)	522	240
Investment costs (k€)	2.130	910
Payback time (years)	4,1	3,8

Table 1 - Reducing condensing pressure in steam turbines. Results

As expected, lower condensing pressure was obtained for Option 1 and thus higher savings, at the expense of higher investment cost required for the project. It shoult be stressed that, for Option 1, lower condensing pressures (concretely 0,07 bara) could be achieved, taking into account the condensing capacity provided by cooling water and design condition of the equipment. Nevertheless, the new condensing pressure was fixed to 0,09 bara, with the purpose of preventing performance deterioration of the steam turbine associated with the reduction of steam density in the last expansion stages.

Syngas compressor driving turbine - Enabling extraction

It was proposed the production of MP steam by expanding HP steam through the driving steam turbines of syngas compressors, reducing HP letdown to 0,2 t/h (Figure 4). This allows a better use of the HP steam: in the existing configuration the steam is simply expanded through a valve and no power generation takes places through this expansion. Savings of 657.000 € were obtained, with a payback time of 1 year.

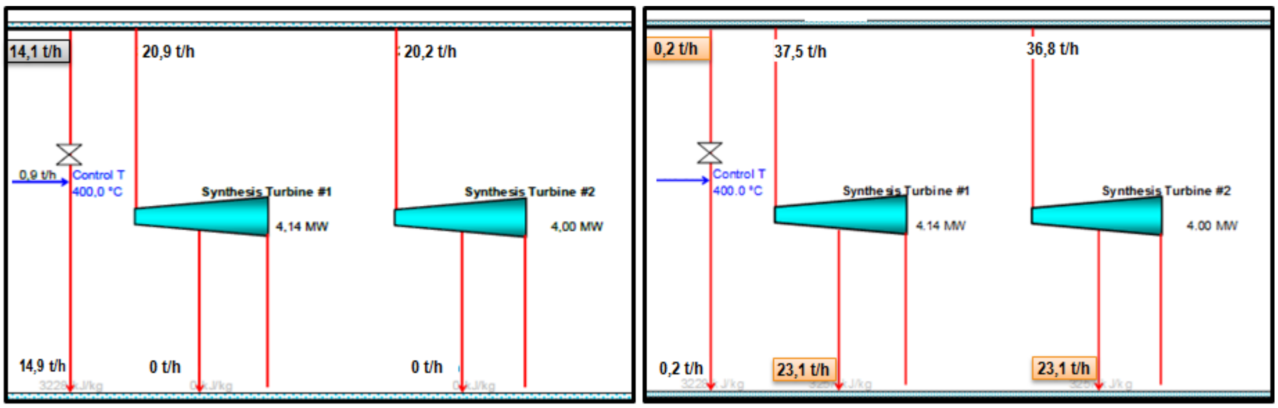


Figure 4 - Enabling extraction in syngas compressor driving turbine. Operation conditions in existing (above) and new situation

Compressors – inlet and intermediate cooling

The option of reducing inlet and intermediate flow temperatures was analyzed, to enhance the operating performance of both syngas and air compressors. Shaft work required for compressing the same mass flow is thus reduced, and steam consumption decreases in the driving steam turbines. The minimum flow temperature was set to 5ºC, for those chilling technologies that allow reaching this value, which can be considered a safe value to prevent undesirable effects such as:

- Ice formation and consequent mechanical damage to the compressor blades.
- Compressor surge, that can manifest as a consequence of excessive increase of the density of the compressed gas and the consequent reduction of the volumetric flow rate.

Different options were assessed regarding cooling options:

- Mechanical chillers.
- Absorption chillers: Libr/H_2O or NH_3/H_2O equipment were contemplated. For both cases, hot water was considered for heat supply to the generator, obtained by heat recovery from the process.

Figure 5 represents the configuration proposed for the air compressor. The cooling power supplied by the chiller through the glycoled water circuit is transferred to the cooled stream by means of a new heat exchanger. No cooling is proposed for the inlet stream to the last compression stage. This responds to security reasons, aiming at avoiding any alteration in the operation conditions (pressure and temperature) of the air stream fed to the process.

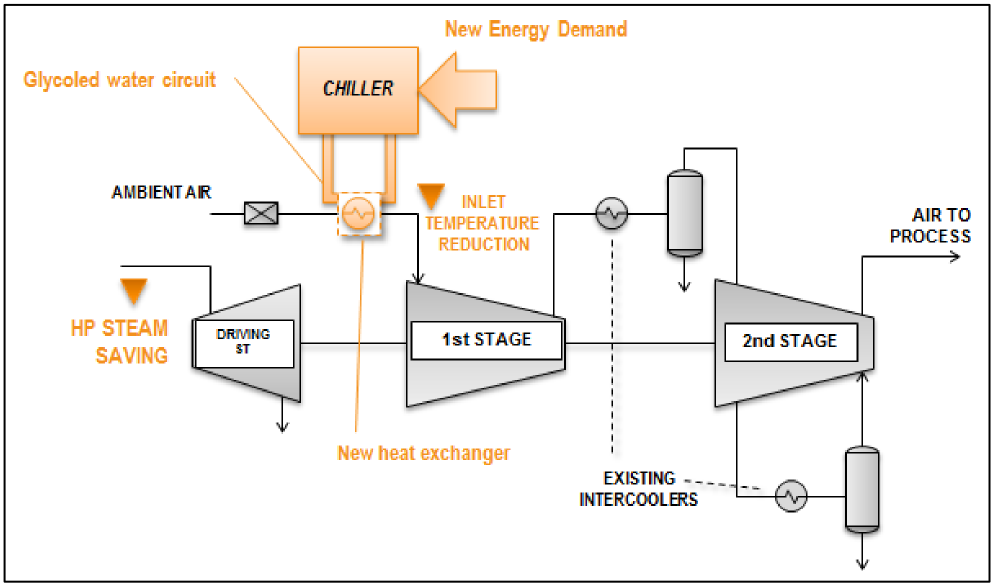


Figure 5 – Inlet and intermediate cooling in air compressor

The most feasible solutions detected for chilling were Libr/H_2O absorption system for syngas compressor and mechanical chiller for air compressor, as indicated in Table 2. For the syngas compressor project, the new energy demand (which consists of heat to generator of the new absorption chiller) would be supplied by energy recovered from the process.

	Air compressor	Syngas compressor
Chilling equipment technology	Mechanical compression	Libr/H_2O absorption
Potential saving (k€/year)	60	139
Investment costs (k€)	44	162
Payback time (years)	0,7	1,2

Table 2 - Stream cooling in air and syngas compressors. Results

Despite the attractive values of PBT, the obtained savings may not compensate the complexity of the proposed changes. At the same time, the correct operation of air and syngas compressors is critical for the process, which could be determinant to decide about the implementation of the project. Nevertheless, the results are still of interest for similar future projects, and may constitute a valid aid to the optimization in the design phase of compressing systems.

Natural gas saturator

The utilization of hot condensates upstream the reformer was proposed as an option for natural gas saturation. That way the load of MP steam boiler could be reduced, as a result of steam demand reduction of steam reforming process. Calculated economic benefit associated with this measure is 507.000 €/year and resulting payback time is less than one year.

Cooling water – Upgrading water pumping system for efficiency enhacement

The replacement of the centrifugal pumps used for cooling water circulation by more efficient ones has been proposed, as a measure of improvement for the pumps of major consumption of the plant. Existing pumps have an efficiency of 78%, and expected efficiencies of the new ones are expected to range values up to 82%. It results in potencial savings of 14.000 €/year, with a payback time of 2 years.

Desulphurization furnace - Optimizing combustion

One of the most critical factors in the efficiency of furnaces and other generating equipment (boilers, etc.) is the excess of air used for the combustion. For each fuel, determined values of air excess are established to ensure a complete combustion. Any increase in the air mass flow above the optimum excess value leads to important efficiency losses, as heat is wasted through exhaust gases.

For this study, a saving opportunity was detected in reducing the existing %O_2 levels in exhaust gases from its existing values down to 3%, which ensures the optimal combustion of natural gas. The current operating value in the desulphurization furnace surpassed the optimum, being measured in 14%. For this project, the implementation of an automatic combustion system which maintains %O_2 in its optimal value was proposed. For the desulfurization furnace, potential savings of 60.000 €/year with a payback time lower than 1 year were obtained.

MP steam boiler - Boiler feedwater pumping system optimization

Currently, boiler feedwater (BFW) is supplied to HP (85 barg) and MP (42 barg) boilers by a unique pumping system. The great difference between these pressure levels suggested the option of separating BFW circuits, being thus MP BFW supplied by a new independent pump with significantly lower shaft power required. By this means, estimated savings of 22.700 € were obtained, with payback of less than 1 year.

Compressor driving - Replacement of steam turbine by an electric motor

Shaft power supply to any pumping or compression system can be carried out by means of electric motors or driving steam turbines. Apart from specific aspects of the operation which could force to one single option, the election of which solution is more profitable is determined by energy prices. In this case, the use of an electric motor was proposed for driving the air compressor located in the nitric plant, due to upcoming regulation laws that would lead to significative electricity prices reduction. Achievable economic saving were estimated of 1.591.000 €/year, with a payback time of less than 1 year.

PINCH ANALYSIS

An improvement study of the existing heat exchanger network was carried out by means of Pinch analysis, aiming at identifying opportunities to maximize the thermal recovery from the process.

The potential for heat recovery enhancement could be assessed through the determination of the thermal composite curves, representing the process energy demand versus their temperatures. These curves are obtained by adding the thermal demand of hot and cold streams involved in the process, which need to be cooled and heated respectively, for each temperature interval. Figure 6 shows hot and cold composite curves including thermal utilities of the site.

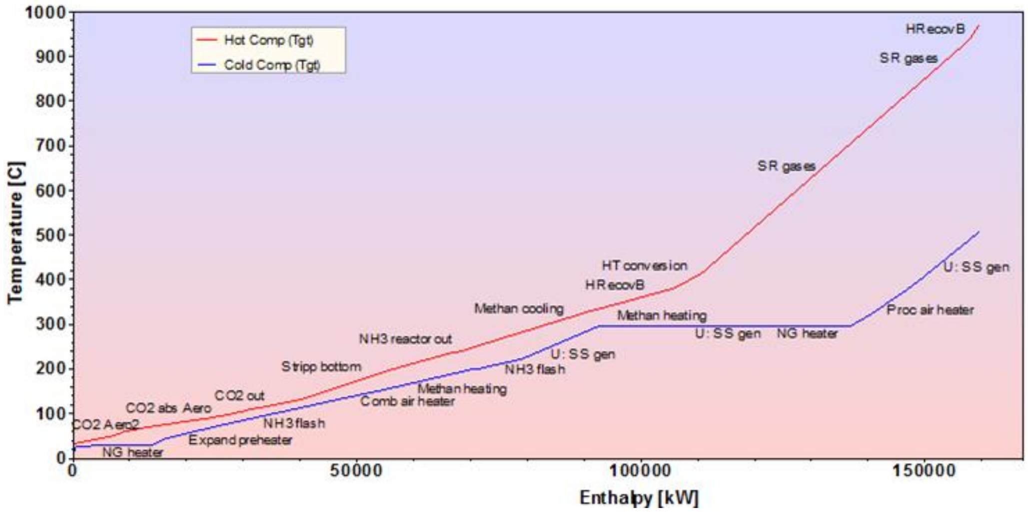


Figure 6 – Heating and cooling demand of the process. Thermal composite curves

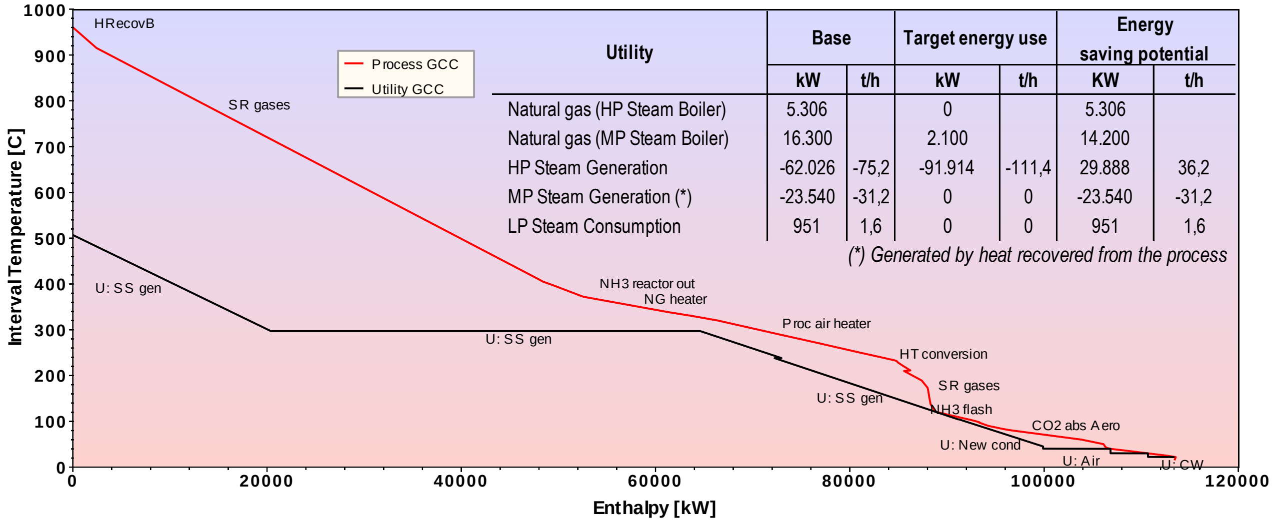
An essential phase of the Pinch analysis is a previous preparation of the operating data (flowrates, composition, pressure and temperature of process streams) which will be used for the analysis. A careful data gathering and its subsequent analysis (heat and mass balances) was carried out, aiming at reproducing representative operating conditions of the plant. The sources for the obtention of the preliminary database were the following:

1. Most frequent operational parameters in stable production conditions, supplied by plant staff.
2. Measured data registered in the distributed control system (DCS) of the plant.
3. Documentation of the plant: process flow diagrams (PFD), equipment specification data sheets, etc.
4. In situ field-measurements.

Plant simulations with specific software were carried out, to compensate errors contained in measurements and calculate the variables not directly measurable, until a consistent database was obtained, representative of the operation of the site.

Proposal for re-desing of heat recovery network

Figure 7 shows the grand composite curve, which provides a graphical representation of the thermal integration that could be theoretically implemented to optimize the thermal recovery from the process. Values indicated in the figure indicate the results obtained in terms of energy consumption, both for the current situation and the target for maximum energy recovery. These results (obtained considering a minimum approach of 20ºC between composite curves) provide a useful orientation and can be considered as a guideline for the improvement of the existing heat exchanger network.



Utility	Base		Target energy use		Energy saving potential	
	kW	t/h	kW	t/h	KW	t/h
Natural gas (HP Steam Boiler)	5.306		0		5.306	
Natural gas (MP Steam Boiler)	16.300		2.100		14.200	
HP Steam Generation	-62.026	-75,2	-91.914	-111,4	29.888	36,2
MP Steam Generation (*)	-23.540	-31,2	0	0	-23.540	-31,2
LP Steam Consumption	951	1,6	0	0	951	1,6

(*) Generated by heat recovered from the process

Figure 7 - Grand composite curve and potential energy savings

A high potential for steam generation increase was detected, using thermal energy recovered from the process. Two main options were analyzed, consisting of HP and MP steam production increase respectively. The option presenting higher saving potential is the former (HP steam generation), which corresponds to shutting down MP steam boiler and keeping HP steam boiler operating at its minimum load, to maintain control over operating pressure in HP steam header. Increasing MP steam generation would lead to energy savings comparable with the first option, but with the drawback that both boilers would be switched off, which would cause the undesirable effect of a loss of control over pressure in HP steam header.

From the data indicated in Figure 7 the following information can be derived:

- Heat recovered from the process currently used for MP steam generation can be redirected to HP steam generation.
- Associated to the above statement, an increase of 36,2 t/h HP steam generation can be achieved, by means of thermal recovery from process.
- Even though it is only perceptible in the steam model, this new scenario implies steam pressure reduction from HP to MP by means of throttling valves, and the activation of steam extractions from the driving turbine of synthesis compressor.

Although results indicate a potential of thermal recovery for complete shutdown of the HP steam boiler, in practice the option was chosen of keeping it operative, for the following reasons:

- As previously commented, to prevent the undesirable effect of control loss over operating pressure in HP steam header.
- A modest external supply of MP steam would still be required (as indicated by 2.100 kW fuel consumption in Figure 7), which would imply maintaining the MP boiler operative, at a load percentage too low to be considered acceptable.

For all these reasons, the final proposal includes the shutdown of MP steam boiler and the operation of HP steam boiler at minimum load. In this way the entire MP steam demand would be supplied by HP-to-MP steam reduction station and steam turbine extraction.

Following the targets previously set by pinch analysis, a re-design of the existing heat exchanger network was proposed.

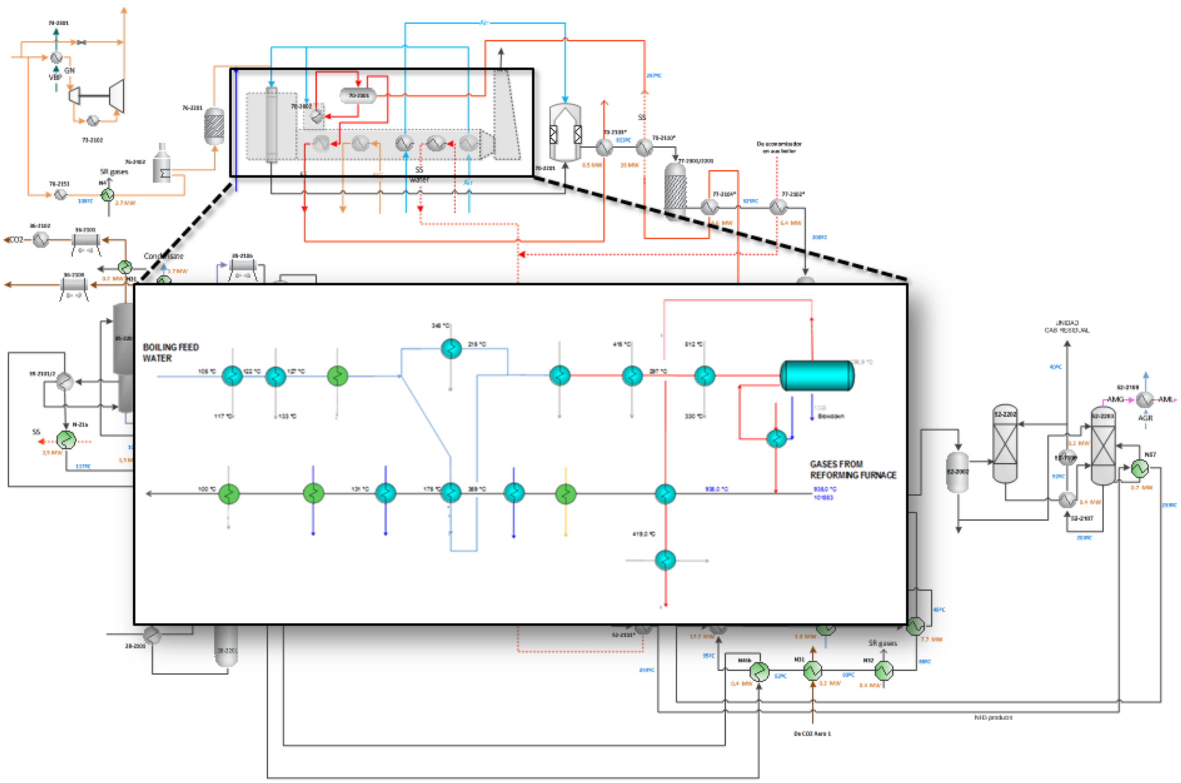


Figure 8 - Heat recovery exchanger re-design

A substantial revamp of the heat recovery network was proposed, including reforming furnace gases channel. The figure shows the new configuration, after the installation of new heat exchangers. Total savings of 6.820.000 €/year were detected, with a payback time of 5 years.

RESULTS SUMMARY

Table 3 contains a summary of the main energy saving projects, identified and assessed in the study. Economic benefit and payback time are indicated for each one of them, both for equipment enhancing measures and re-design proposal of the heat exchanger network. Total savings indicated correspond to the contemporaneous implementation of projects fully compatible among them:

Area	Maximum saving (k€/year)	Payback (years)
EQUIPMENT ENHACENMENT PROJECTS		
P1 - Enabling steam extraction in syngas compressor turbine	657	<1
P2 - Substituting of steam turbine by a electric motor for compressor driving	1.591	-
P3 - Natural gas saturator	507	<1
P4.a - Reducing condensing pressure in steam turbine: Substitution of aircooler by a surface condenser	522	4,0

P4.b - Reducing condensing pressure in steam turbine: Installing evaporative cooler in existing aircooler	240	3,8
P5 - Optimizing combustion in desulfurization furnace: Adjustment of the air-to-fuel ratio	60	<1
P6 - Upgrading cooling water pumpimp system	14	1,7
P7 - Inlet cooling in air compressor with mechanical chiller	60	<1
P8 - Inlet and intermediate cooling in syngas compressor with absorption chiller	139	1,2
P9 - Boiler feedwater pumping system optimization in MP steam boiler	23	< 1
Total equipment enhancement projects (P1+P2+P3+P4.a+P5+P6+P7+P8+P9)	**3.573**	**<1**
HEAT RECOVERY NETWORK RE-DESIGN		
Total (Includes project P1)	**6.820**	**5,2**

Table 3 - Projects summary

As commented above, heat recovery network re-design includes necessarily the enablement of steam extraction of syngas driving turbine for MP steam supply (implementation of project P1 indicated in the table).

Figure 9 shows the potentials for global reduction of energy consumption of the site, as a consequence of the implementation of the whole set of equipment saving measures, as well as the energy savings associated with the re-design of existing heat transfer network.

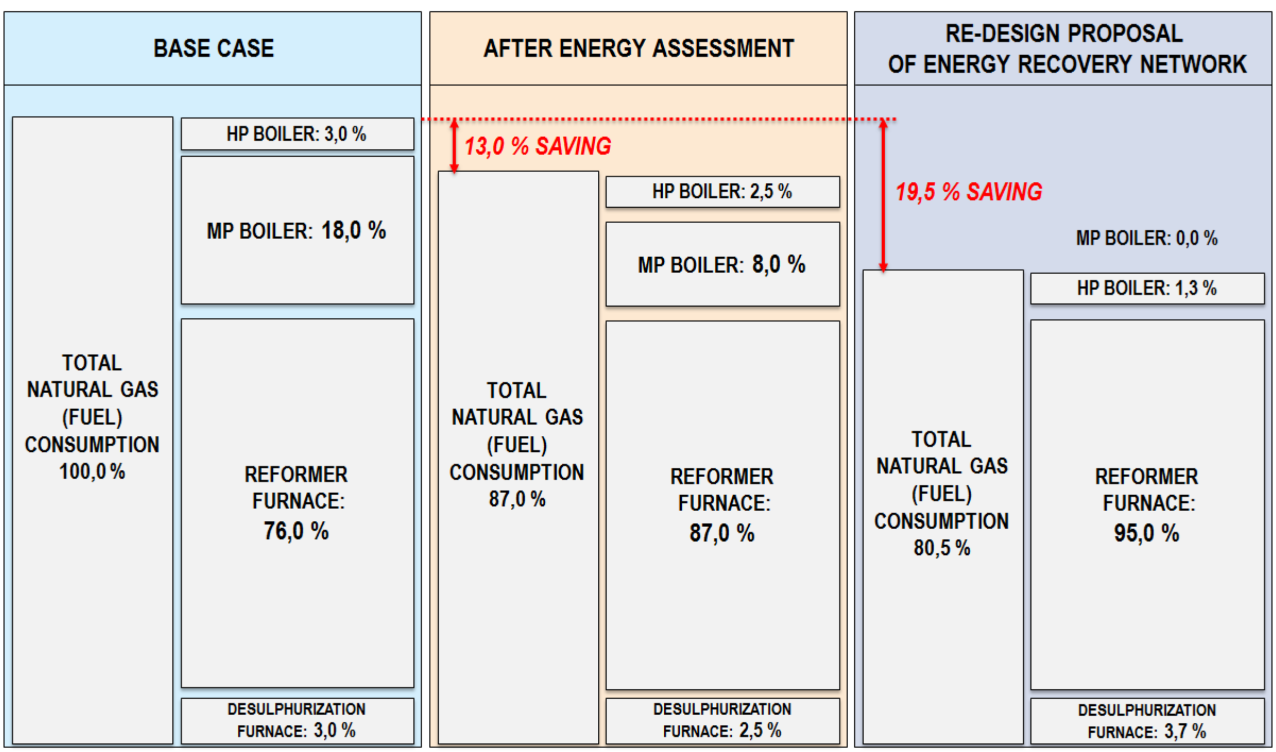


Figure 9 - Global potential for reduction of energy consumption of the site

CONCLUSIONS

A study has been presented for energy efficiency enhancement of an ammonia production site, and potentials for energy and economic savings have been assessed. The complexity level that characterizes this kind of plants justifies the use of the advanced methodologies employed in the analysis, including steam and condensate network modeling (aside from the main equipment), necessary to ensure that the real impact of the proposed changes over the system is rigorously determined. Several improvement measures have been detected for the equipment of the site, leading to a global saving of 13% of burned fuel in the plant. Despite the high level of existing thermal integration in the site at issue, an in-depth Pinch analysis was carried out, aimed at detecting further improvement potentials for enhancing the existing thermal recovery from the process. The study demonstrates the significant benefits attainable with the application of this technique during the design stage of the heat exchanger network. The high enhancement potentials of Pinch analysis are specially reflected in this design stage, due to the absence of the constraints that are always present when studying existing plants, and that often make impossible the implementation of energy conservation projects. The reasons that affect the viability of such projects are both technical and economic, and in most cases these restrictions are not critical in the phase of plant design or revamp. As demonstrated by this study, Pinch analysis is a powerful tool that should always be considered for the design or the revamp of new ammonia sites, since it ensures that optimal recovery from the process and thus minimum fuel consumption is achieved. Energy savings were detected of 19,5% of fuel currently consumed in the site, through the re-design of the existing thermal network at the service of the plant.

Future developments

Actions carried out in the industry aiming at improving energy efficiency are more effective if an energy management system (EMS) is subsequently implemented, which keeps track of the energy efficiency of the facility, ensuring the maintenance over time of the efficiency levels reached once the improvements have been implemented. As a result of this necessity, the standard ISO 50001 [7] is increasingly being implemented in big companies. This standard defines the main objectives that any EMS should fulfill (personnel involved, documentation needed, etc.). Nevertheless, the contents of ISO 50001 are not exhaustive regarding the definition of specific guidelines for the proper development and implementation of the EMS. Moreover, EMS services should be improved regarding the following aspects:

- Expert personell in energy efficiency, which, in conjunction with technical experts in management systems and ISO standards, fulfill the successful implementation of EMS, achieving and mantaining real reduction of energy costs. Over its experience in implementing EMS according to ISO 50001, DVA has proved the necessity of considering this aspect in any project of this nature. This expertise provides a specific energy efficiency approach over the course of the project and ensures that adequate results are obtained.
- Energy management, analysis and optimization tools, which provide plant staff with effective real-time monitoring software to carry out the energy management of the process.

With the purpose of filling this existing gap in the market, the company has developed and successfully implemented the software iManergy™ in several industrial sites, which enables the user to keep track of the efficiency of the plant [8],[9]. iManergy™ displays in hourly, dayly, monthly and yearly basis, a complete energy map of the process, and its specific areas. It also provides dynamic references of the Key Performance Indicators (KPI) which chacaterize the energy efficiency status of the facilities. The reference lines calculated by the software are the following:

- Optimal operation: Reference of optimal reachable operation under the actual conditions (such as production levels, ambient conditions, production mix, etc.).

- Energy baselines: References for the usual performance of the plant, based in values frequently registered in the past. Due to the lack of advanced methodologies and tools, baselines commonly handled in industrial plants do not always provide the necessary reliability required by ISO 50001 standard.

For these reasons, ammonia producers may consider the installation of this energy manager software, as a valid aid for continuous energy improvement of operation.

Figure 10 – iManergy™ - Energy management software

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