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Efficiency Improvements in Combined Cycle Cogeneration Plant Through the Adoption of Heat Reclaimer

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Abstract: Due to the large seasonal difference between water and power demand matching power and water generation has been a general problem in the Middle East and has been the cause of several inefficiencies in combined power and desalination plant operation for long periods during the year particularly when power demand is low.

In particular while power demand is mainly dictated by the seasonal air conditioning load, it is well known that the water demand remains almost constant for the whole year.

In this situation the unbalance between the heat required by the thermal desalination plant and the heat available from the power plant becomes unbalance and to maintain the heat load for the desalination plant a substantial supplementary firing is generally required.

The paper aims at analyzing the fuel and carbon savings that could be achieved through the implementation of a state of the art heat reclaimer and the possible configurations that could be achieved. This paper also aims at providing an indicative financial return that justifies the financial viability of this concept.

Key words: Combined Cycle Plant, Heat Reclaimer, HRSG, Thermal Desalination Plant, CO_2 savings

1. Introduction

In the most of the Combined Cycle Power Plant in the Middle East connected to a thermal desalination plant, i.e. MSF (Multi Stage Flash), the steam, generated in the HRSG's and expanded in the steam turbines, is driven

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to heat the brine water feed at the Multi Stage Flash unit of desalination. After the condensation in the hot well condenser of the desalination unit, the condensate is pumped back to the HRSG's, closing the water cycle.

In the actual configuration, generally, water is heated by the exhaust gas coming from the Gas Turbines. In the most of the cases, a supplementary firing is required, overheating the steam, in order to achieve the most efficient pressure conditions occurring to the steam turbines.

The Low pressure steam generation from the heat reclaimer results in reduction in the HP steam generation in the HRSG and eventually the duct firing.

The positive environment benefit envisaged because of the project activity is additional heat utilization and steam generation for water production by reducing the duct burner firing and improve the heat rate.

The case studied is the Fujairah F1 IWPP. The existing Fujairah 1 Independent Water and Power Plant produces an electrical power load of 760 MW of exported power and is capable of maintaining a constant water production of 100 MIGD. The technology used for the generation of electricity is Combined Cycle Power Plant consists of Gas Turbine, HRSG and Steam Turbine, whilst water production is a hybrid plant composed by a combination of MSF evaporators and RO Plant.

Before entering to brine heater of each MSF, LP steam is being reduced to 0.8 barg before condensate is injected which reduces and controls steam condition to 120 ºC (at 0.8 barg).

The Control system is made by Siemens Teleperm. The Fuel utilized is Natural Gas and Distillate Oil only in back-up status.

The plant is design with a gross power ratio of 750 MW/ 12.5 x 5 MIGD but with a net power ratio of 12 MW/MIGD.

However, in reality due to fluctuations in the power dispatch the PWR is generally lower. This PWR tends to be quite low and indicates that the steam generation is more balanced towards the distillation process than to the power generation process. When the power plant is at 40-60% of the load the PWR can go down to 4-5 MW/MIGD and therefore a substantial amount of steam is bypassed from the HP line to the LP line to maintain a stable MSF operation.

The maximum economy of scale for the generating plant and maximum cost effective power output will occur when the heat recovered from the HRSG's is designed to exactly match the heat demand from the desalination plant.

If the power plant is sized in this way, any reduction in power demand will result in a reduction in heat available to the desalination plant as the power output of the CCGT is reduced.

During periods of reduced power demand some of the power units will be used at less than full capacity and the average load factor will reduce.

The steam demand for the desalination plant will be met by supplementary firing.

The installation of the Heat Reclaimer will enable recovery of previously vented (waste) heat for production of LP steam for desalination units, thus reducing the need to produce steam at this pressure level through auxiliary firing in the furnaces of the HRSGs and reduce the overall plant fuel requirement and the subsequent CO2 emission reduction.

This solution will increase the plant efficiency beyond normal levels, and will contribute to reduce the environmental footprint of power and water production.

Along the year, either the heat demand (in this case the steam load for the desalination plant) or the power demand (in this case the dispatch requirements for power export) are lower than the full capacity of the power plant, either the thermal efficiency suffers because the plant is operating off-design or the operating hours for some of the installed plant reduces.

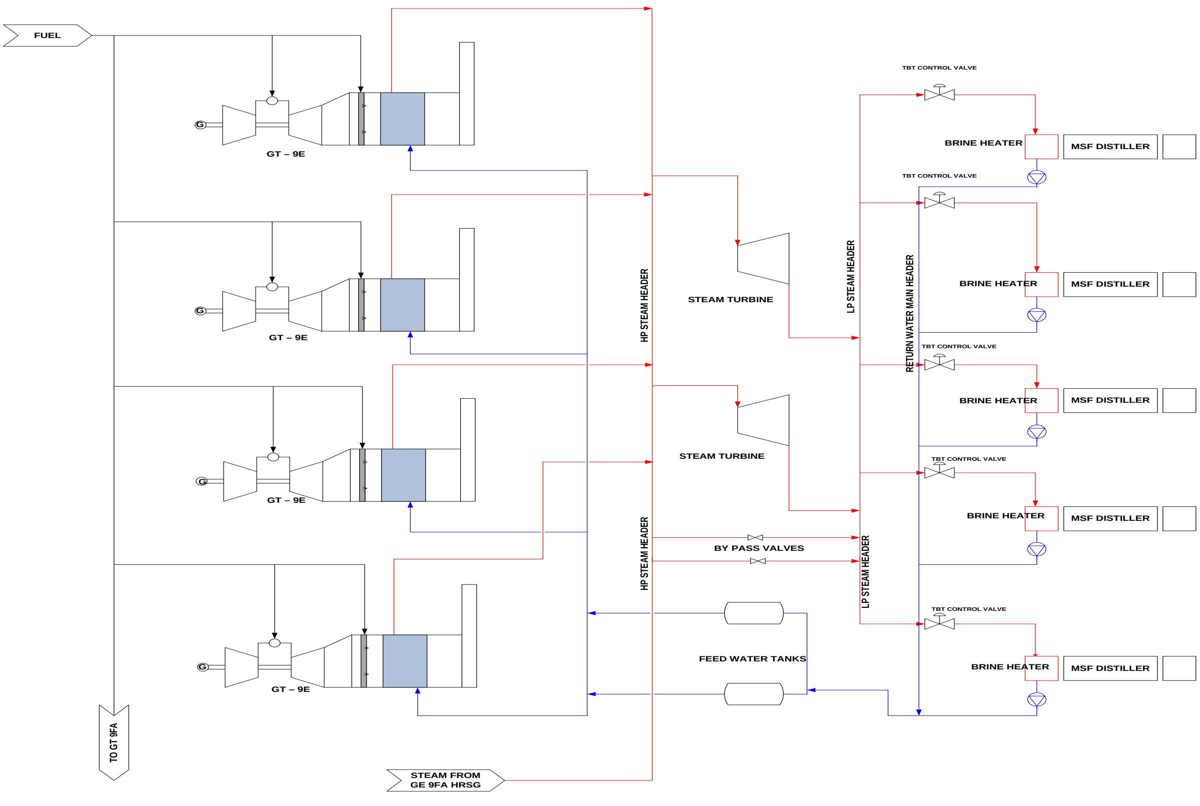

Figure 1. Actual Steam and Flow Diagram

The scheme illustrated in Figure 1 shows the existing plant. The actual configuration consists of two back pressure Steam Turbines (steam pressure at the outlet of turbines is 2.5 barg). The steam is collected from the HRSG's (HP steam) in a common header feeding the two turbines. The Steam turbines outlet is driven through two main headers up to the pressure control valve station. After the pressure regulation station, the steam is collected to a header, common for the five brine heaters.

In the present configuration the plant operates for substantial time in the year outside the matching conditions and therefore the installation of heat reclaimer provides a tool to optimize the plant performance with substantial fuel savings.

The Figure 2 below shows a flow diagram, where the heat reclaimer typical installation location is indicated in green cooler.

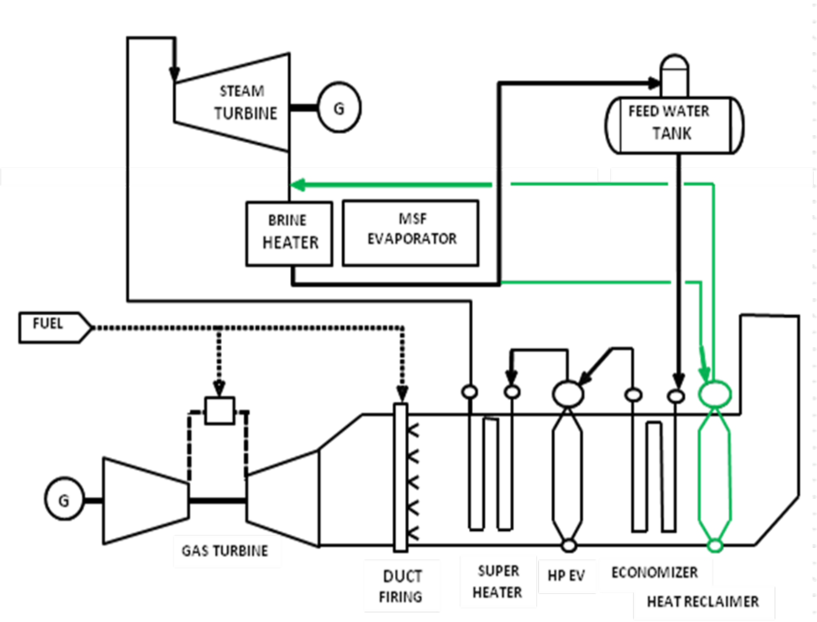

Figure 2. Heat Reclaimer Installation

The condensate flow going to the Heat Reclaimer is regulated by a valve system, in order to guarantee the same amount of steam at the MSF Brine Heater, interfering as less as possible on the steam expanded in the Steam Turbine.

The Heat Reclaimer shall be designed with suitable material and dimension to maintain allowable differential pressure across the HR and the Duct space that is available between Economizer and stack.

Thermodynamics

The proposed project activity consists of installing one Heat Re-claimer (HR) on each of the four existing Heat Recovery Steam Generators (HRSGs). The Heat Re-claimers will enable recovery of previously vented (waste) heat for production of LP steam for desalination units thus increasing the efficiency of the whole plant by reducing input fuel consumption.

The heat reclaimers proposed will work as a low pressure evaporator system based on natural circulation and tubes are arranged in parallel to the flue gas flow.

Tubes in the cold flue gas zone works as downcomers and the most part of the heated tubes are working as evaporator tubes. Demisters are arranged in the top of the drum for separating the residual water droplets Flow measurement will be installed at the outlet of the low pressure steam line to measure the low pressure steam generated.

The Heat Reclaimer modules will be equipped with serrated in tubes and will be installed after boiler casing. It is expected that for the installation of the additional modules the existing vertical expansion bellow will be shifted towards the stack and the boiler duct will be adjusted. The modules will be connected to the streaming evaporator tubes and to the stream drum with a safety valve and a saturated steam header on top.

The drum with modules will be supported by a new cantilever steel structure, fixed onto the existing boiler structure.

At the bottom a reverse header will be connected to the down and upwards streaming evaporator tubes.

Two different scenarios have been considered:

-Scenario 1 with a Low pressure steam generated by the Heat Reclaimer of 2.5 bar and

-Scenario 2 with a Low pressure steam generated by the Heat Reclaimer 3.2 bar

In Scenario 1 the produced LP-Steam from each Heat Reclaimer (nr 4) will be supplied to a common header (ND1000) and will be connected to the LP steam downstream the TBT control valve of each MSF just upstream the brine heater unit as schematically indicated in the sketch below.

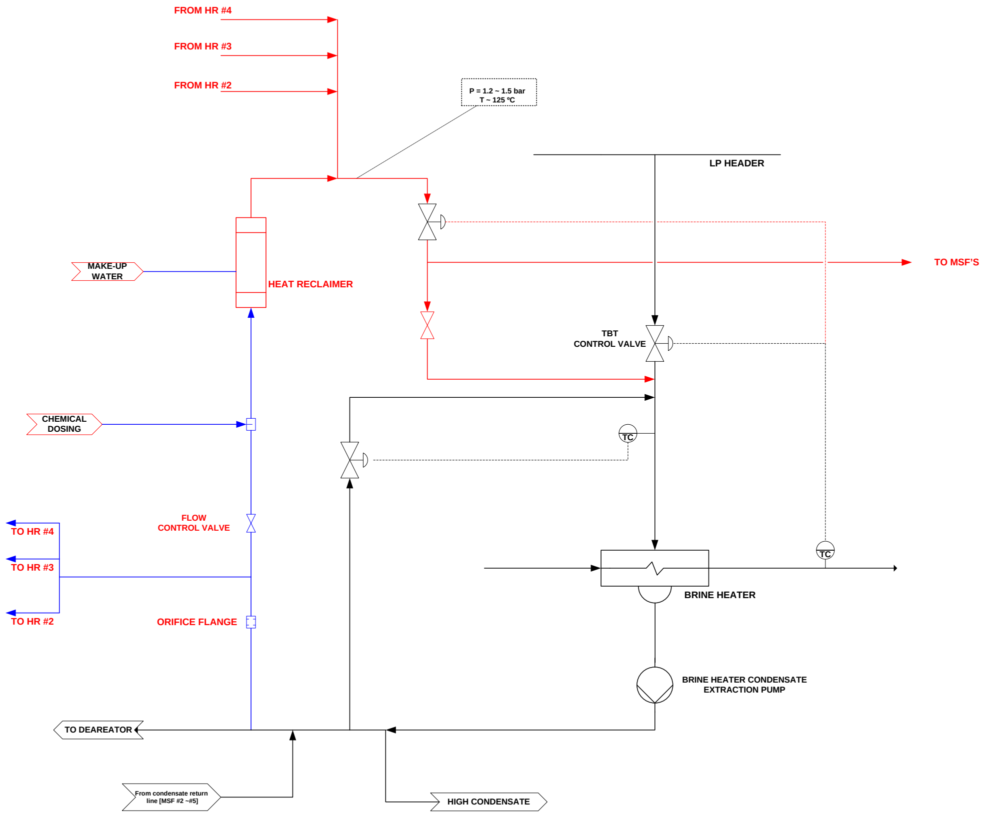

Figure 3. Scenario 1

In Scenario 2 the produced LP-Steam from each Heat Reclaimer will be supplied to a common header (ND800), connected to the existing 3.2 bar manifold immediately downstream the HP-LP existing steam reducing stations as schematically indicated in the sketch below.

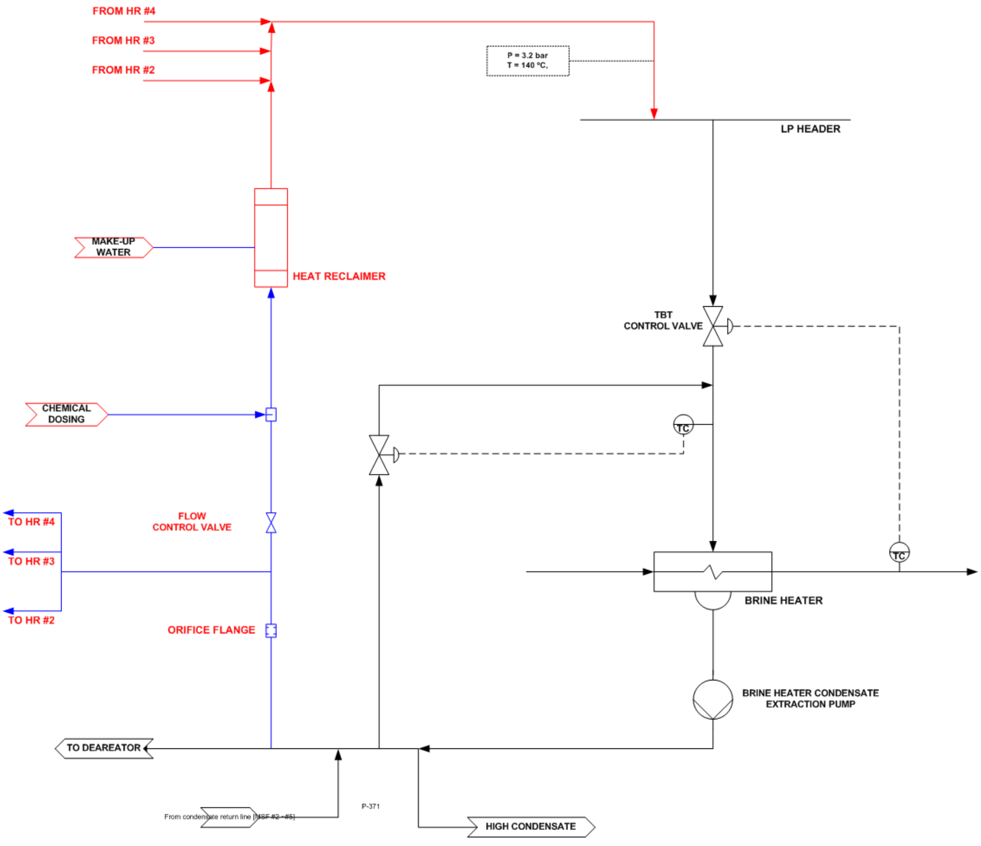

Figure 4. Scenario 2

The introduction of Heat Reclaimer increases the overall plant cycle efficiency. As the Heat Reclaimer takes advantage of the heat energy associated to the flue gases discharge in the atmosphere, the amount of heat released to the stack is reduced and thereby helping the environment. Furthermore as the utilization of energy associated to the flue gas brings about an improvement in the heat rate of the overall plant a decrease in the fuel consumption will also occur which will result in a in the reduction of the amount of fuel that is burnt for the same power and corresponding CO_2 , NO_X and SO_X.

For reasons of thermal efficiency, power output of the Combined Cycle plant is limited by steam load. In turn, the steam load is limited by performance of desalination plant (better desalination = lower steam demand).

Demand for water is flat (non seasonal). A possible winter reduction in demand of some 15% has been ignored at this initial stage of review.

Calculations have been done manually and subsequently verified with GT-PRO. The optimization of the heat rate has been done considering a gradual reduction in the by-pass steam from the HP-LP steam reducing station which was compensated by the LP generated by the heat reclaimer.

All GT-PRO simulations have been done assuming a flue gas temperature of 160C. This temperature is considered conservative given the actual flue gas profile at site.

Scenario 1: LP steam Generation 2.5 bar

For simulation purposes it has been assumed that the low pressure steam generation to match the Low pressure steam parameters downstream the TBT (Top Brine Temperature) control valve directly feeding the MSF brine heater which results in reduction in the HP steam generation in the HRSG and duct firing.

Scenario 2: LP steam Generation 3.2 bar

For simulation purposes it has been assumed that the low pressure steam generation to match the back pressure steam parameters from the steam turbine feeding the MSF header which results in reduction in the HP steam generation in the HRSG and duct firing.

2. Methodology

Calculation and Procedures

The Calculations have been carried out in accordance to the original Heat and mass balance and with the aim to decrease HP-LP bypass as much as practicable.

The heat transfer surface that can be installed can be calculated as 50,000 m^2 , with an overall convective heat transfer coefficient of 25 W/m^2 K with a usable ΔT of 15-18 °C the heat reclaimer can reclaim the heat which is indicated in the following diagram.

For the LP steam generation case the intention is to use the heat in the flue gas and produce more steam. It is to be noted that in this case it is not possible to reduce the supplementary firing as the steam generation is already lower in the base case.

The intention is to generate more steam with the same amount of duct firing as in the base case by extracting the heat available in the flue gas.

Based on this it is possible to generate total steam of 989.3 (HP+LP) at 3.2bar and 989.51 (HP+LP) at 2.5bar. It can therefore be seen that it has been generated more steam at the same firing rate.

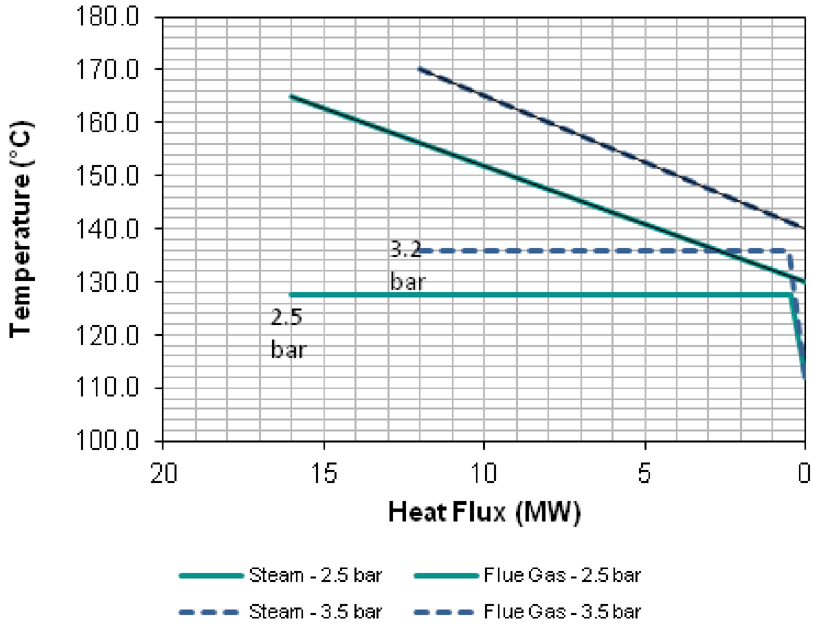

Figure 5. Heat Flux reclaimed vs Flue Gas Temperature

As it can be seen the adoption of lower pressure allows in principle an additional heat reclamation of about 3-5 MW. Clearly the lower the pressure of the heat that is reclaimed, the lower also the specific heat transfer area requirements (m^2/W K) becomes.

Material Selection

Though it is assumed that the flue gas exhaust temperature would be in the range above the sulphuric acid dew point and that the sulphur content in the fuel gas contains no or negligible sulphur, it is recommended to provide a material better than carbon steel in the low temperature end of the HRSG.

Alloy steel with presence of chromium, copper and nickel have been found to have good resistant properties against sulphuric acid attacks. In any case it should be considered that the heat transfer turbines at least for the peripheral parts of the reclaimer need to sustain higher temperature in case of boiler or HRSG changes in operational patterns and therefore needs to be designed in terms of life duration for an exhaust temperature of 160-180 °C.

Results and Operational Savings

These scenarios are interesting for the calculation of the Carbon credits as they indicate the modified system fuel requirements versus the original one.

However the site log sheets we have analyzed show that as a consequence of the boiler and Gas Turbine performance de-rating and actual conditions the stack temperature is substantially higher as indicated in the Figure 6 below and generally it does not go below 150°C in whatsoever operational conditions.

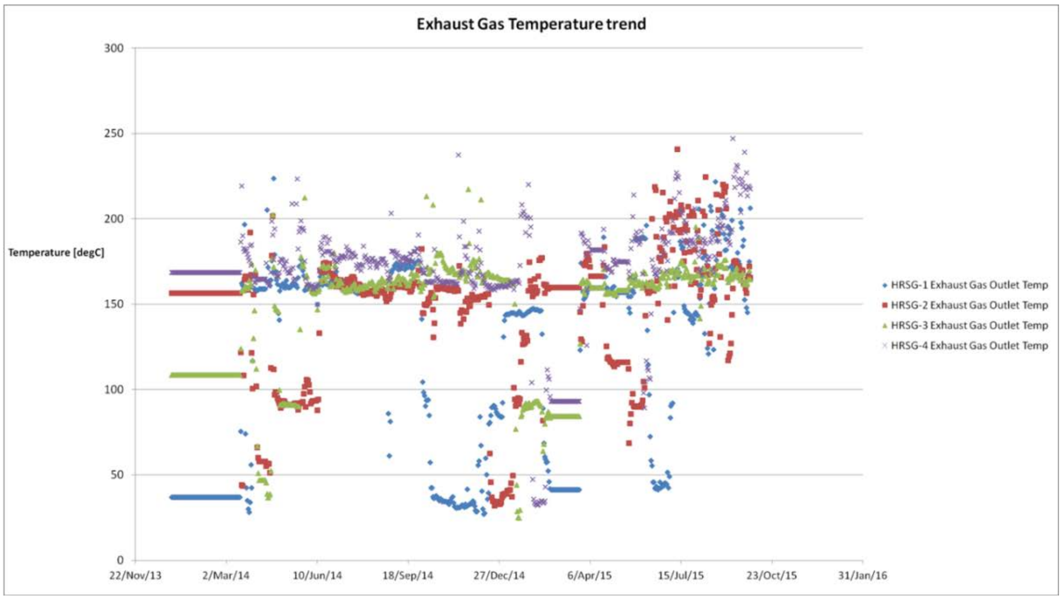

Figure 6. Exhaust Gas Temperature Trend

In this case the operational data will change as projected in the table below.

The summary operational savings against these scenarios are summarized in the tables below. The table show the comparison between the 4 operation load cases without Heat Reclaimer and with Heat Raclaimer installation.

The savings, in term of USD/MMBtu of fuel saved and expressed in USD/year have been calculated as reported in the formula

Fuel Savings=Operation hours x (ΔHeat rate) x Fuel price x 85%

Where:

*Δ*Heat Rate represents the different between the overall plant Heat Rate in case of Heat Reclaimers installation and the actual Heat Rate

The Fuel price is set at 3.62 USD/MMBtu, as per United Arab Emirates Standard

A safety factor of 85% has been considered.

Table 1. Plant Load Cases Operation

Description	Unit	Load Case A	Load Case B	Load Case C	Load Case D
Total net power output referred to the Reference Power Capacity	%	100	80	60	40
Annual operating hours	h/a	2160	2880	2160	1440

Table 2. Scenario 1 vs Base Conditions

	Net Power Generated	Total Steam to MSF	Fuel Consumption	Suppl. Firing Fuel	HRSG Stack Temperature	Actual Heat Rate Cycle	Fuel Saving		CO_2 saving	CO_2 saving (operation mode)	Oper Hrs	Savings
	MW	ton/hr	ton/hr	ton/hr	ºC	kJ/kWhr	ton/hr	MMBTU/hr	ton/hr	ton	hr	USD/yr
100%												
Base	760	1,425	162	14.89	160	9803	-				2,160	
LP HR	760	1,425	158	10.81	126	9556	4.08	151.24	11.22	24,235	2,160	1,182,230
80%												
Base	610	1,425	145	18.93	159	10250	-					
LP HR	610	1,425	142	16.06	125	10040	2.88	103.20	7.92	22,810	2,880	1,075,670
60%												
Base	460	1,425	131	16.21	160	11560						
LP HR	460	1,425	127	14.17	125	11360	2.04	74.12	5.61	12,118	2,160	579,401
40%												
Base	305	1,075	99	24.04	160	14930						
LP HR	305	1,075	95	20.61	127	14410	3.43	127.78	9.43	13,583	1,440	665,891
											TOTAL	3,503,192

Table 3. Scenario 2 vs Base Conditions

	Net Power Generated	Total Steam to MSF	Fuel Consumption	Suppl. Firing Fuel	HRSG Stack Temperature	Actual Heat Rate Cycle	Fuel Saving		CO_2 saving	CO_2 saving (operation mode)	Oper Hrs	Savings
	MW	ton/hr	on/hr	ton/hr	ºC	kJ/kWhr	ton/hr	MMBTU/hr	ton/hr	ton	hr	USD/yr
100%												
Base	760	1424.5	161.87	14.89	160	9803	-				2160	
LP HR	760	1424.5	157.99	11.03	128	9596	3.86	143.28	10.62	22928	2160	1,120,007
80%												
Base	610	1424.5	145.08	18.93	159	10950	-					
LP HR	610	1424.5	142.38	16.16	127	10740	2.70	103.20	7.43	21384	2880	1,075,670
60%												
Base	460	1424.5	115.53	16.21	160	11560						
LP HR	460	1424.5	113.47	14.15	127	11350	2.06	77.83	5.67	12236	2160	608,371
40%												
Base	305	855	98.9	24.05	161	14930						
LP HR	305	855	94.91	20.06	126	14320	3.99	149.89	10.97	15800	1440	781,142
											TOTAL	3,585,190

The graphs indicated in Figure 7 ~ Figure 8 show the overall fuel consumption against the various operation configurations and basically depicts the data indicated in the Table 2 and Table 3 above in a graphical form.

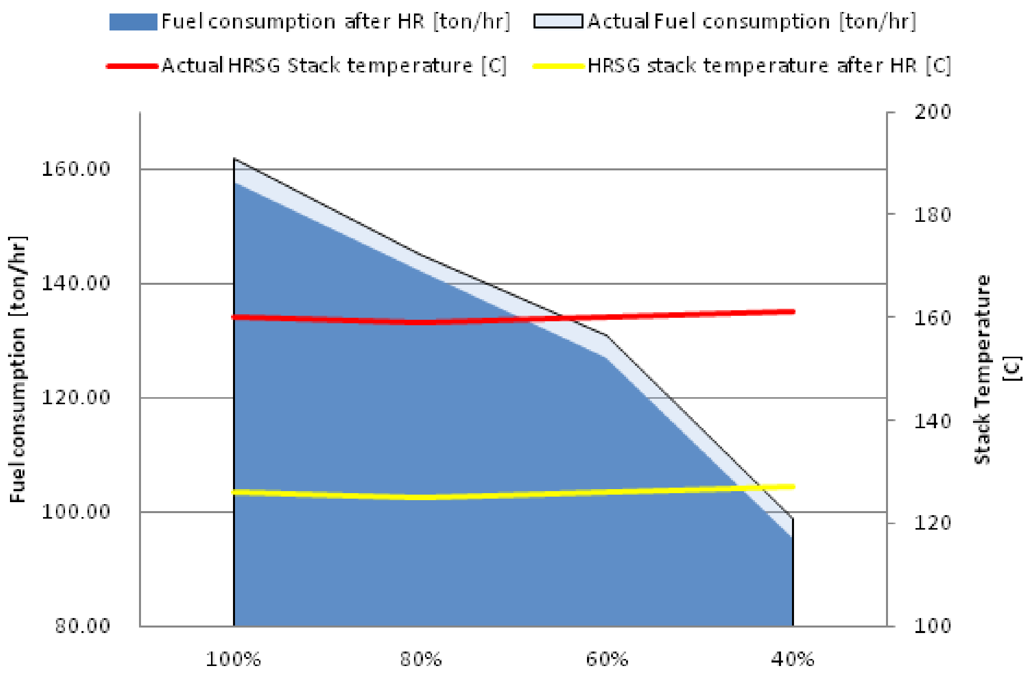

Figure 7. Scenario 1 - Fuel Saving & Stack Temperature vs Operation Mode

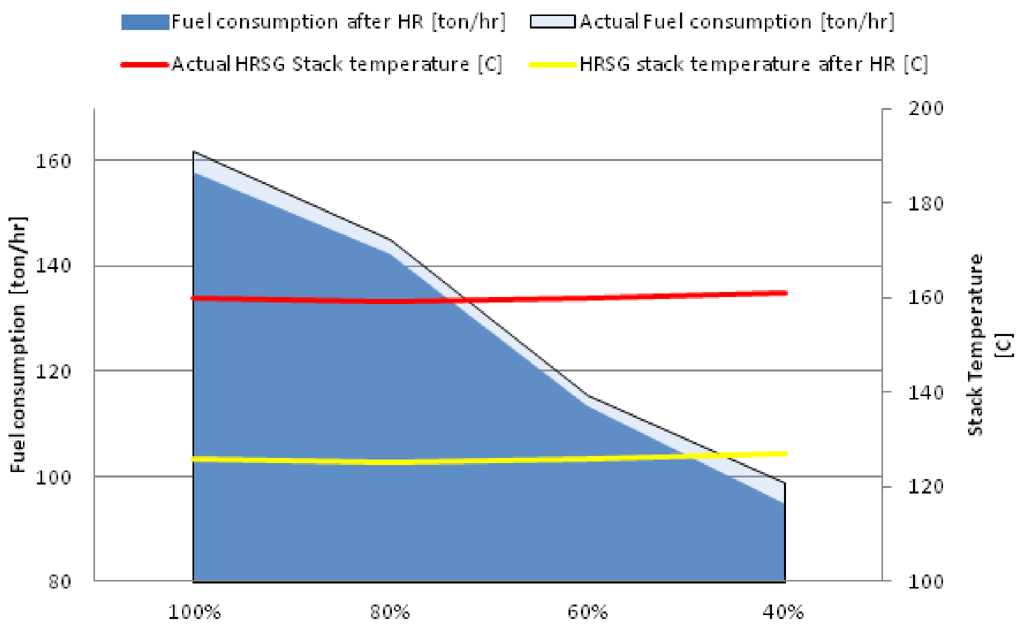

Figure 8. Scenario 2 - Fuel Saving & Stack Temperature vs Operation Mode

Potential benefit of CO_2 emission reduction / calculation of CER (Credit Emission Reduction)

CO_2 **s**avings can range between 42,000 tons in the event the plant operates close to the original design to 125,000 tons of CO_2 for the purpose of the financial return CO_2 credits have been considered at USD 9.8/ tons of CO_2 disbursable for a period of 4 years.

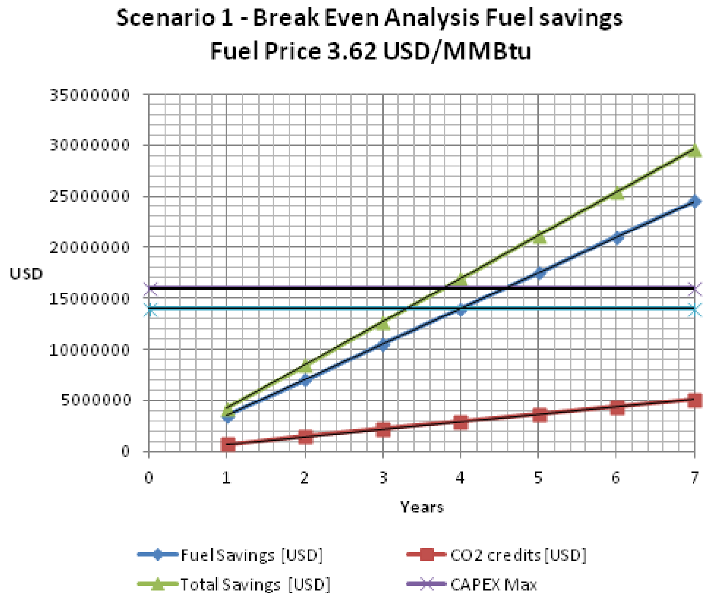

Figure 9. Scenario 1 - Break Even Analysis Fuel Saving

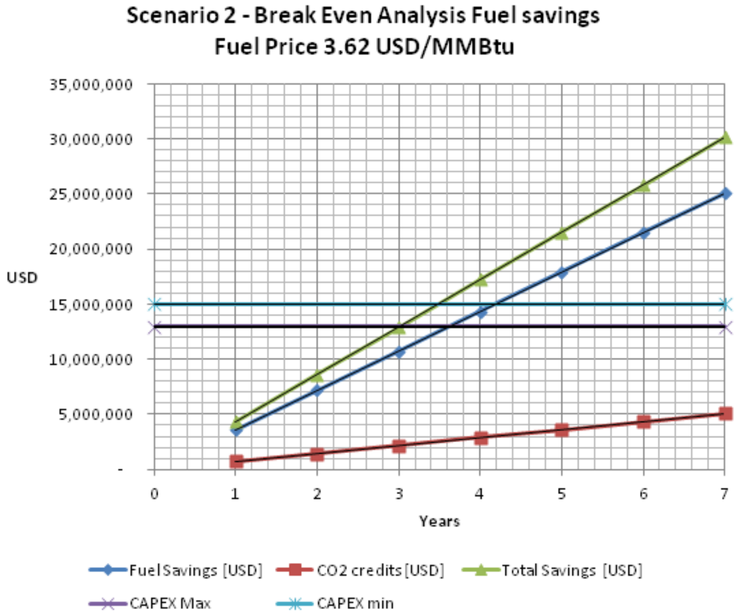

Figure 10. Scenario 2 - Break Even Analysis Fuel Saving

3. Conclusion

Preliminary investigations carried out show a substantial advantage technical, economic and environmental in the installation of the Heat Reclaimers.

The estimation have been carried out calibrating the model with the existing data and running the Heat Reclaimers case assuming conservative values for the gas outlet at the stack.

In the most conservative case scenario which corresponds to the highest CAPEX assumption without any grant from the CO_2 credit, it is possible to notice that on a present net value the investment is returned within 4 to 5 years. In the most likely scenario the investment is going to be returned within 4 years without CO_2 credits.

The financial model however does not take into account any lost production required for plant shut down in case of tie – in.

Apart from these quantifiable considerations there will be additional advantages associated to the implementation of the Heat Reclaimers. These include a higher availability of the LP steam system, and flexibility in the mode of operation of the plant and lower risk.

Acknowledgements

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