COMBINED HEAT & POWER INDUSTRIAL PLANTS WITH GAS TURBINES & HEAT RECOVERY STEAM GENERATORS – FEASIBILITY STUDY METHOD AND CASE ANALYSIS

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The Combined Heat & Power Industrial Plants (CHPIP) using Backpressure Steam Turbines (BST CHPIP) have low ratios power vs. heat. Therefore is difficult for them reaching the norms for "high efficiency cogeneration" (HEC). That's why the paper analyzes the CHPIP with Gas Turbines & Heat Recovery Steam Generators (GT&HRSG CHPIP). The main paper's objectives are, from the theoretical point of view: establishing an accurate methodology, giving advices for choosing the main equipments and making the technical section of feasibility studies on GT&HRSG CHPIP. From the practical sight: applying the methodology in a case study for a CHPIP, in order to establish if this one could reach the Romanian HEC norms.

Keywords: CHP, high efficiency.

1. Introduction

The main features of the Combined Heat & Power Industrial Plants (CHPIP) are [1]:

- Have flat load curves, with small differences between winter and summer.
- Should constantly supply the heat consumer; having good availability. Any supply disruption could generate important damages.
- Usually deliver superheated steam, its parameters being imposed by the typical processes. In heating processes, the imposed parameter is the steam's pressure; it determines the liquefying temperature. This one should be higher than the desired temperature in the process. To avoid the condensing in transport pipes, the delivered steam should have a temperature with about 15 to 25 degrees Celsius higher than the saturation one. If the steam feeds turbines, which turn process compressors, it must have higher pressures and superheating temperatures.

Even if they have high global efficiencies, (electricity + heat) vs. fuel's primary energy, the CHPIP using Backpressure Steam Turbines (BST CHPIP) have, because of high thermal level of the delivered steam, low ratios power vs. heat.

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Therefore is difficult for them reaching the norms for "high efficiency cogeneration[4]" (HEC) [1, 2, 3, 4].

That's why the paper analyzes the CHPIP with Gas Turbines & Heat Recovery Steam Generators (GT&HRSG CHPIP). The main paper's objectives are:

A) From the theoretical point of view: establishing an accurate methodology, and giving advices for choosing the main equipments and making the technical section of feasibility studies on GT&HRSG CHPIP.

B) From the practical sight: applying the methodology in a case study for a CHPIP delivering an important quota of High Pressure (HP) superheated steam for process turbines, in order to establish if this one could reach the Romanian HEC norms.

2. Methodology; main input data and options for the case study:

The main steps of a technical branch of the feasibility studies on GT&HRSG CHPIP are:

2.1. Establishing, together with the study's beneficiary, a realistic heat demand prognosis, and generating the associated load curve.

For the case study we selected a chemical factory requiring steam at two levels: Low Pressure (LP), at 10 bar abs / 195°C, and HP, at 64 bar abs / 450°C. The thermal load curves have two zones: winter and summer, and for each of them the load was considered having a crop Gaussian distribution, characterized by average values and standard deviations. Fig. 1 shows the yearly heat load curve.

2.2. Selecting the appropriate GT number and their type.

Referring to the GT number, we mention that:

- ✦ A single unit GT&HRSG CHPIP reduces the investment's costs, but lessens the availability and reliability, requiring quickly steam supply backup equipment.
- ✦ If a medium time steam supply disruption could generate important damages, it is proper to use two GT (2*50 %).

Referring to the GT data, we mention that, in order to attain a high power vs. heat ratios, and a good GT&HRSG CHPIP global efficiency, it is suitable to choose GT:

- ✦ from the thermodynamically point of view, having, in the same time, an elevated electric efficiency ($\eta_{el\ gen\ cl}$) and high flue gases exit temperature ($t_{ex\ gas}$) [5, 6];
- ✦ related to their size, allowing to recover an amount of thermal flow rate equivalent to the average summer need.

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[4] That signifies that a CHP realizes a required fuel economy comparatively with the separate generation. The Romanian norms offer a "bonus" for each electricity unit produced in HEC, delivered in the National Grid, and sold on the competitive market, if the comparative fuel economy is higher than 10 %.

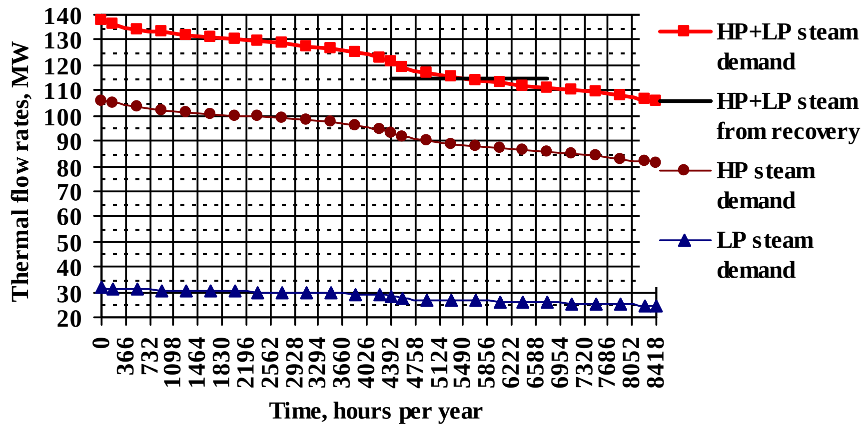

Fig. 1 Thermal load curve for the case study

In our case study we selected 2x SGT-800 GT, with $\eta_{el\ gen\ cl}$=37.55%, and $t_{ex\ gas}$=544.5°C. In fig.1 we show the amount of thermal flow rate recovered from the two GT at ISO conditions, computed with Gate Cycle soft [6].

2.3. Choosing the HRSG design and the GT&HRSG CHPIP general schedule (see Fig. 2). For the aforesaid reasons we selected a two pressures HRSG design. For covering the winter heat demands, higher than the recoverable heat from GT exhaust gases, we provided the HRSG with a Duct Burner (DB), using exit flue gases as oxidant.

2.4. Modeling the GT&HRSG behavior at various thermal delivered flow rates, off design conditions, within the yearly load curve range, and the associated generated power. The winter loads, and some of the summer ones, are with the Combustion Chamber Burner (CCB) at full load, provide the nominal electrical load, and, for achieving the required thermal flow rate (bigger than the recoverable one), use the duct gas burner. The summer partial loads use the CCB at part load, provide a smaller power flow rate, and do not use the DB.

2.5. Establishing the curves describing the yearly evolution of generators clams output, and thermal flow rates associated to fuel's burning, for its Low Heat Value (LHV).

2.6. Computing the yearly energy input and output flows and the performances indicators for the entire GT&HRSG CHPIP.

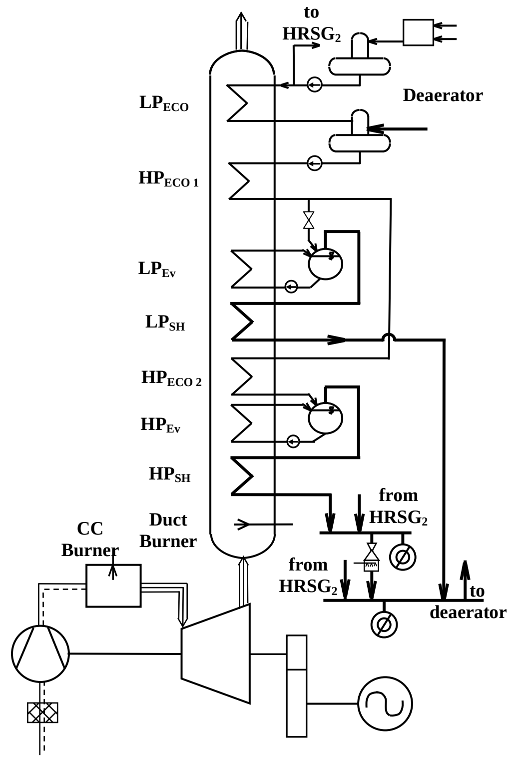

Fig. 2 The GT&HRSG CHPIP design in the case study

3. Results:

Fig. 3 & 4 illustrate the GT&HRSG CHPIP behavior, for the case study, at winter and summer thermal loads bigger that the recoverable ones, using the DB. They put into evidence that for each 1 MW $_{th}$ required steam heat flow rate increase, it is necessary to add around 1 MW $_{th}$ heat flow rate increase at DB.

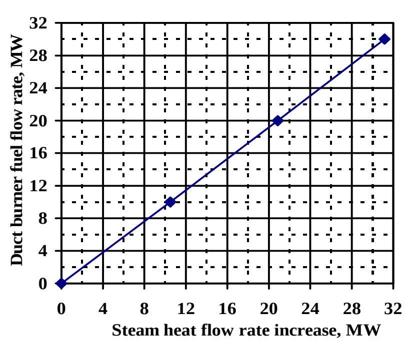

Fig. 3 Duct burner fuel flow rate vs. steam flow rate increase (winter)

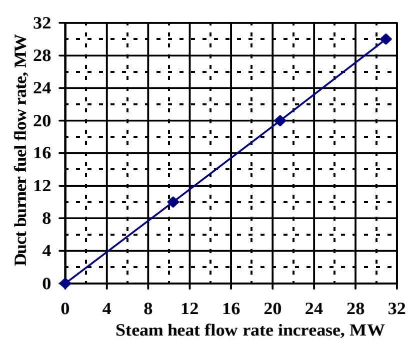

Fig. 4 Duct burner fuel flow rate vs. steam flow rate increase (summer)

Fig. 5 & 6 describe the temperature profile in HRSG without and with DB in use. Their comparison is relevant, and do not require special comments.

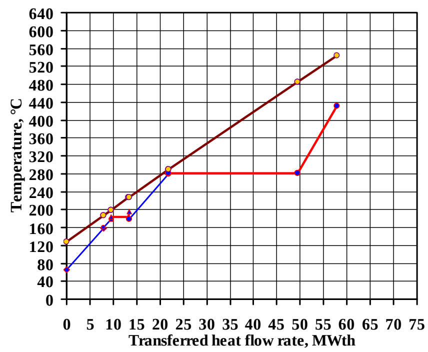

Fig. 5 The temperature profile in HRSG without DB in use

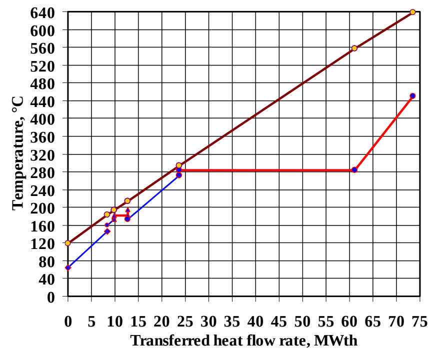

Fig. 6 The temperature profile in HRSG with DV in use

In summer thermal part loads, under the recoverable heat flow rate, for maintaining the global efficiency, the thermal fuel CCB flow rate should diminish. Fig. 7 & 8 explain the GT&HRSG CHPIP behavior, in the case study, at summer thermal part loads.

★ Fig. 7 shows that for each 1 MW $_{th}$ required steam heat flow lessen, under the recoverable one, it is necessary to decline the CCB fuel's flow thermal rate with about 2.64 MW $_{th}$.

★ Fig. 8 shows that 1 MW $_{th}$ CCB fuel's flow thermal rate diminish, corresponds to a generators clams reduction with about 0.432 MW $_{el}$.

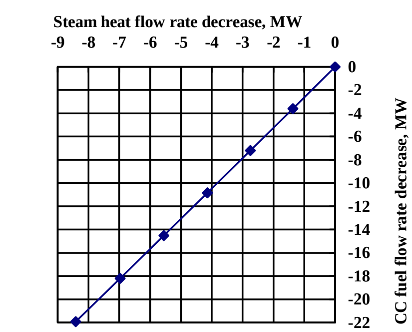

Fig. 7 CC fuel flow rate decrease vs. steam flow rate decrease (summer)

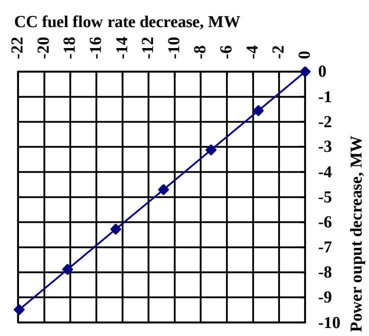

Fig. 8 Power output decrease vs. CC fuel flow rate decrease (summer)

As a result of these, the generators outputs in these off design conditions are smaller than the nominal one. On the other hand, in winter off design conditions the generators clams power output will be higher than the nominal one. As a result, we obtained the electrical load curve from Fig. 9.

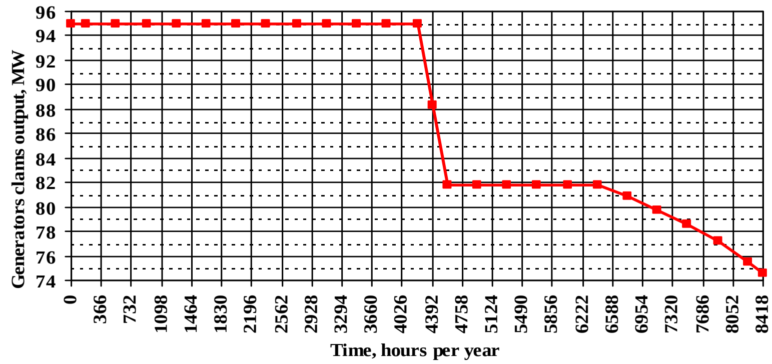

Fig. 9 The power load curve resulted in the case study

The curves from Fig. 10 describe the yearly evolution of thermal flow rates associated to fuel burning (LHV), and steam flow rates from recovery, respectively from duct burning, in the case study. Numerically integrating the obtained results, we computed: the energy amounts, the efficiencies, and the power vs. heat ratios, without and with DB (see Table 1). With these data we build the diagrams shown in Fig. 11 & Fig. 12, putting in the evidence the average energy flow rates, and the energy quotas, per seasons and yearly.

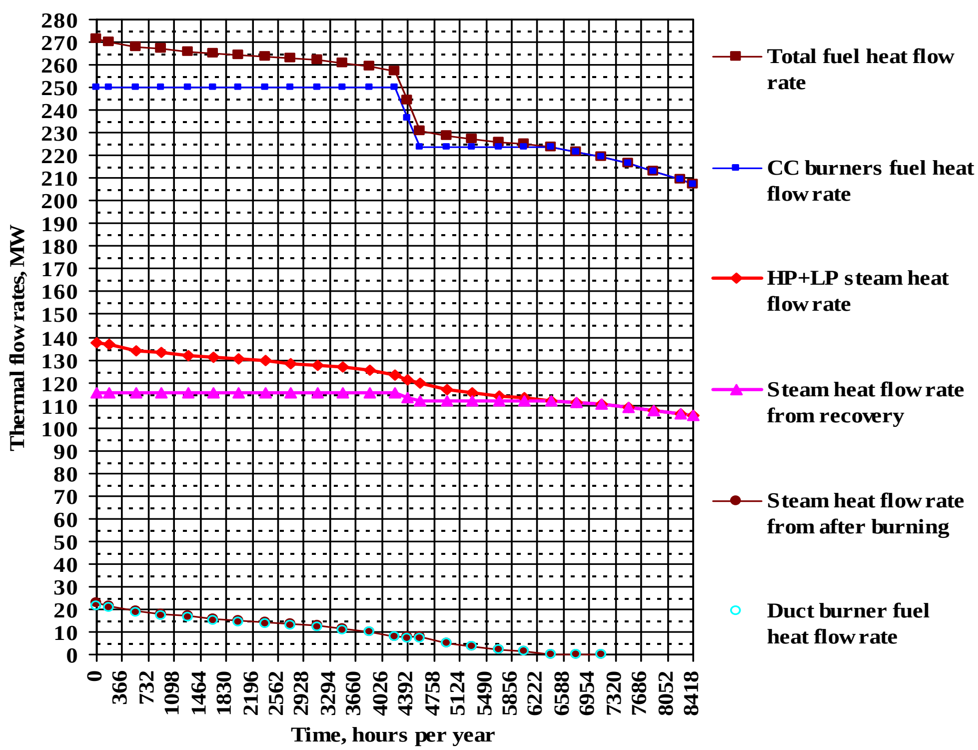

Fig. 10 The yearly evolution of thermal flow rates associated to fuel burning (LHV), and steam flow rates from recovery and from duct burning

Table 1

The energy amounts, the efficiencies and the power vs. heat ratios for the analyzed CHPIP, without and with DB

No	Computed data	Units	Values		
			winter	summer	yearly
1	Heat produced by fuel at DB (LHV)	MWh_{th}	64 356	9 646	74 003
2	Heat produced by fuel at CCB (LHV)	MWh_{th}	1 097 561	886 451	1 984 012
3	Total heat generated by fuel (LHV)	MWh_{th}	1 159 032	893 173	2 052 205
4	Electricity at generators clams	MWh_{el}	417 141	323 058	740 199
5	HP steam heat consumption	MWh_{th}	438 093	347 277	785 370
6	LP steam heat consumption	MWh_{th}	132 088	104 615	236 703
7	Total steam heat cons. = prod.	MWh_{th}	570 181	451 892	1 022 073
8	Gas turbines electrical efficiency	%	38.01	36.44	37.31
9	GT global efficiency, without DB	%	87.201	87.038	87.112
10	Power vs. heat ratio, without DB	kJ_{el}/kJh_{th}	0.772568	0.720322	0.749105
11	CHPIP global efficiency, with DB	%	85.19	86.76	85.87
12	Power vs. heat ratio, with DB	kJ_{el}/kJh_{th}	73.16	71.49	72.42

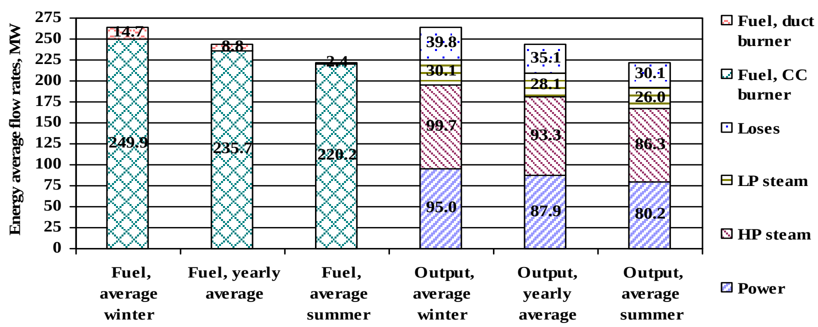

Fig. 11 The average energy flow rates in the case study, per seasons and yearly

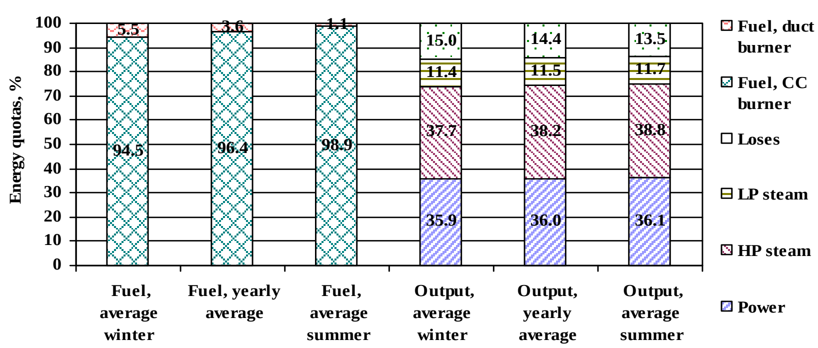

Fig. 12 The average energy quotas in the case study, per seasons and yearly

The obtained results led us to the indicators shown in the Table 2, where we can see the quotas of fuel energy converted in electricity, respectively in heat. These data were put in the formula required by Romanian norms, in order to determine the fuel economy obtained by CHP generation, comparatively with the separate one. In the last row of Table 2 we can observe that the analyzed CHPIP realizes a comparative fuel economy higher than 19 % all over the year, taking or not into consideration the duct burner contribution. Consequently it could be classified as a “high efficiency cogeneration plant”, and it may receive the bonus for all the produced electricity.

Table 2

Calculated indicators for the CHPIP case study, per seasons and yearly, without and with the duct burner’s contribution

Calculated indicators	**Without DB**			**With DB**		
	Winter	**Summer**	**Yearly**	**Winter**	**Summer**	**Yearly**
Share of fuel energy converted in electricity, %	38.01	36.44	37.31	35.99	36.17	36.07
Share of fuel energy converted in heat, %	49.19	50.59	49.80	49.19	50.59	49.80
Comparative fuel economy, %	21.55	20.65	21.14	19.09	20.32	19.63

4. Conclusions:

On the market there is a large variety of CHP technologies and equipments, having different manufacturers and thermodynamic designs. The authors selected to analyze the CHPIP, because, due to the previous mentioned features, is more difficult for them satisfying the norms for HEC. The technical solution is choosing the GT&HRSG CHPIP proper technologies and equipments.

The paper is organized in two connected steps. The first one is principally methodological, but, in the same time, identifies the main input data for the case study, and gives advices for equipments and design options. The succeeding step consists in the case study and the graphically and numerically analysis of the obtained outcomes.

The results are useful for power utilities, respectively for power & heat auto producer’s staffs, facilitating them to choose the proper CHP technologies and equipments, and predicting the technical GT&HRSG CHPIP energy flows balance, for improving the cost-effective flows, by benefiting from the HEC bonus.

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