THE INCREASE OF ENERGY EFFICIENCY THROUGH THE CONVERSION OF A THERMAL POWER PLANT INTO A COGENERATION PLANT

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Re-engineering obsolete industrial plants is an increasingly important issue for small and medium enterprises. This paper describes the transformation of a thermal power plant with simultaneous production of low-temperature saturated steam and hot water into a central cogeneration plant, at a company from the drug industry field.

Taking into account the economic advantage, reduced operating problems, environmental protection etc., the cogeneration solution with heat engines was appealed. By using this solution for cogeneration, the company recorded a 5-12% reduction in the monthly bills, lower than buying all electricity from the system.

Keywords: energy efficiency, cogeneration, heat engine, technical analysis.

1. Introduction

Small and average power cogeneration in the industrial processes from small and medium enterprises proved, by existing applications, that is both economically efficient, and on ensuring a power independency against the import energy sources.

In the applications for low level power of around 1-2.5 MWe, using heat to prepare hot water or low-temperature saturated steam, the most often encountered case in residential or industrial applications, the use of cogeneration units with heat engine solution proved to be the most suitable technique, both in terms of recovery period and exploitation problems, noise, environmental protection or of the connection possibility to the consumers system power supply.

In this paper the transformation of a thermal power plant with simultaneous production of low-temperature saturated steam and hot water into a central cogeneration plant, at a company from the drug industry field is presented.

The main outlines of the power consumption of the company are:
- production sections;
- deposits of raw materials, packaging and finished product;
- executive office;

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- energy department.

The main equipment and inner energy networks are:

- generation, transmission and distribution of heat as technological steam;
- production and distribution of heat as hot water;
- acquisition, distribution and supply by natural gas;
- power acquisition, distribution and supply;
- production, distribution and supply by compressed air;
- acquisition, distribution and supply by drinking and fire water.

Main machinery and equipment energy consumers for each contour defined above are:

- heat supply network - steam and hot water, which has as consumers: heat exchangers, distillation plant, dryers and manufacturing installations from technological process of pharmaceutical products preparation and HVAC equipment;
- electricity grid that supplies customers such as manufacturing and packaging equipment of pharmaceutical products, HVAC equipment (equipped with chillers, fans etc.), electric motors used in operating pumps and compressors, equipment of thermal power station, indoor and outdoor lighting, computer network etc.;
- compressed air network used to supply automation and pneumatic drive of the manufacturing equipment;
- drinking and fire water network used to feed water consumers from the production process, steam boilers of the thermal power station, social groups and facilities for fire fighting;
- natural gas network that supply the thermal power station, cogeneration plants, pharmaceutical production facilities and equipments from quality control laboratories.

2. Determination of energy needs

Regarding electricity, the company has two transformer stations equipped with transformers of 1600 kVA and 1000 kVA, supplied from a 6 kV station belonging to the company, buying electricity from the system.

Annual electricity consumption amounted to approx. 16,500 GWh. Supply voltage is about 6 kV for some consumers of high power and about 0.4 kV for the rest of consumers. Total power installed is 8346.5 kW / 9072. 28 kVA.

Thermal energy for internal utilities is provided by a central heating system equipped with following machinery and energy equipment:

- 4 firetube steam boilers with a total capacity of 16 t/h, nominal flow rate of 4 t/h/boiler at a maximal pressure of 12 bar and temperature of 190 ºC;
- 2 hot water boilers with a total capacity of 5 Gcal/h, at a pressure of 5 bar and temperature of 115 ºC;
- a softening Nobel duplex station of 20 m^3/h.

The steam is used in the production process and the hot water is used mostly for heating and partly for manufacturing processes.

The thermal plant operates on natural gas, with the possibility of using liquid fuel as backup.

Natural gas comes from a regulating station having an installed flow rate of 4000 m^3/h, (corresponding to Distrigaz Sud SA notice) and annual consumption amounts about 4900 thousands m^3_N, of which about 47% is thermal plant consumption.

Central plant (COGEN, fig. 1) is composed of two groups of heat engines operating on natural gas, which are intended to produce electricity to cover the own consumption of the company in base regime, as well as heat as hot water (90/70 ° C) replacing some of the hot water produced currently in the existing boiler.

Fig. 1. General view of the cogeneration plant

The two groups have each an electrical power of 600 kWe and a heat output of 750 kW (0.65 Gcal / h) [1]. The cogeneration groups are produced by GE - Jenbacher Austria and operate at the load curves base, following automatically the power consumption on the feeders on which they are connected, so as to ensure consumption in the self-production scheme. Consumption peaks are taken from the National Power Grid (N.P.G.) for electricity and from the existing hot water boilers for the heat.

The power generated voltage of each group is 400 V followed by a 6 kV transformation through the booster transformers of 0.4/6 kV and 1000 kVA to connect to the cells from the company connections station.

This ensures a maximum transfer of power to the contracting-party consumer without major losses and also a maximum consumption of low temperature heat as hot water. Hot water produced by the engine at temperature of 90/70 ° C (turn/return) is used in the thermal power plant for two purposes:

- one part for the de-aerator makeup water preheating in step I;
- the rest, which is the most important part of about 85%, is used in series on hot water boilers circuit for heating in winter and technological processes that require heat at this level during the year.

In both cases heat transfer is achieved through Alfa Laval plate heat exchangers.

Cogeneration plant consists of two supercharged internal combustion engines running on natural gas provided by the urban gas network, Distrigaz. Each heat engine trains a synchronous electric power generator of 910 kVA (601 kW at terminals) and voltage of 0.4 kV. Connection is made in the company connection station on the two arrival feeders from Electrica SA power grid, via two booster transformers 0.4/6 kV of 1000 kVA (one for each group). The system is completely monitored in real time and is provided with electronic equipment for tracking momentary power consumed on each feeder, in order to avoid injection of power into the power grid in the opposite direction, in cases where the company consumption is below the cogeneration plant production.

Thermal energy is delivered as hot water at 90/70 ℃ and is produced by heat recovery in surface heat exchangers (plate and tubular type) from the engine cooling system and flue gases respectively. The heat recovered is used for two purposes: the preheating of the de-aerator makeup water and for technological use and building heating, in series with the existing hot water boilers.

The main technical characteristics for each cogeneration group are set as follows:

- electric power at terminals: 601 kWe/group → 1202 kWe/all;
- nominal thermal power: 732 kWt/group → 1464 kWt/all.

The real scheme of heat recovery on the different cooling systems is presented in fig. 2 (first stage turbocharger cooler, oil cooler, engine block and cover cylinder cooling and exhaust gases cooling).

From total electricity consumption of the company, about 7.1 GWh/year is purchased from SC Electrica SA and 9.4 GWh/year from cogeneration plant, representing about 82%, at a price of 10% lower than that of Electrica.

Total heat produced as steam and hot water is about 20,500 MWh/year (1760 toe), of which about 57% as steam. About 83% of heat produced as hot water comes from cogeneration plants.
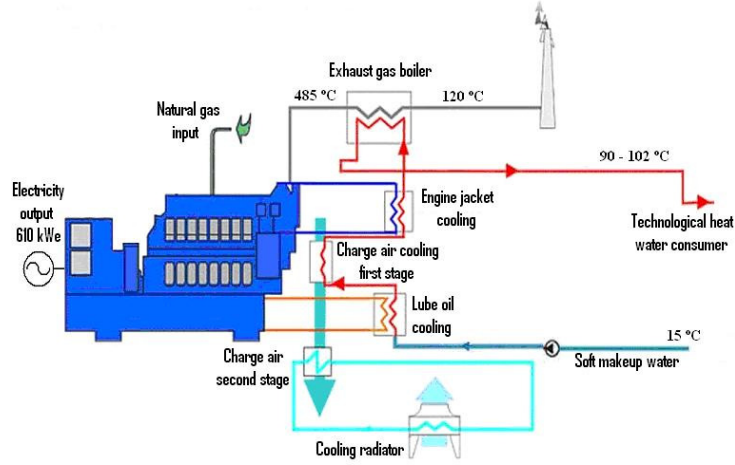
Fig. 2. Thermomechanical basic diagram of thermal energy recovery from engine

3. Technical analysis of cogeneration energy efficiency solution

Economic and technical analysis of the cogeneration plant implementation is based on energy balance, involving the conservation laws of mass, energy and momentum [2,3,4].

The engine's mechanical efficiency is defined as the ratio between the energy as mechanical work at the engine shaft (Q_m) and the entered energy (Q_i):

$$\eta_m = \frac{Q_m}{Q_i} \cdot 100 \ [\%] \tag{1}$$

The electrical efficiency at generator terminals is defined as the ratio between electrical power produced by the engine (Q_{el}) and the mechanical energy.

$$\eta_{el} = \frac{Q_{el}}{Q_m} \cdot 100 = \frac{Q_{el}}{\eta_m \cdot Q_i} \cdot 100 \ [\%] \tag{2}$$

Consequently, electricity produced at the terminal is:

$$Q_{el} = \eta_m \cdot \eta_{el} \cdot Q_i \ [kW] \tag{3}$$

The cycle thermal efficiency is defined as the ratio between the heat recovered from cooling systems + engine exhaust gases (Q_t) and primary energy:

$$\eta_t = \frac{Q_t}{Q_i} \cdot 100 = \frac{Q_i - Q_{el} - Q_p}{Q_i} \cdot 100 = \left(1 - \frac{Q_{el} + Q_p}{Q_i} \right) \cdot 100 \ [\%] \tag{4}$$

where Q_p represents the energy losses.

Considering the relations defined above, the overall efficiency of cogeneration plant can be written as:

$$\eta_{gl} = \frac{Q_u}{Q_i} \cdot 100 = \eta_{el} + \eta_t \ [\%] \tag{5}$$

where Q_u is useful power output.

Engine fuel specific consumption expressed in energy units are calculated by the relation:

$$b = \frac{D_{gn} \cdot P_{ci}}{Q_m} \ [\text{kWh/kWh}] \tag{6}$$

where the lower heating value of the fuel (P_{ci}) is expressed in energy units, kWh/m^3_N.

Based on hourly energy balances carried in the company, the results presented in Table 1 have been obtained.

Table 1

Hourly values of electrical and thermal energy produced by the cogeneration plant

Hour	PARAMETER			
	Total electrical energy produced [kWh/h]	Total electrical energy delivered [kWh/h]	Total thermal energy produced and delivered	
			[kWh/h]	[Gcal/h]
7	944.9	932.6	1048.4	0.901
8	1120.2	1104.7	1207.4	1.038
9	1136.6	1120.4	1221.9	1.051
10	1063.3	1048.6	1156.8	0.995
11	1121.7	1106.1	1208.8	1.039
12	1112.7	1097.5	1200.7	1.032
13	1113.0	1097.7	1201.1	1.033
14	1071.7	1056.8	1164.3	1.001
15	1112.1	1096.9	1200.3	1.032
16	1105.3	1090.3	1194.2	1.027
17	1100.7	1085.7	1190.1	1.023
18	1109.1	1094.0	1197.6	1.030
19	1191.6	1174.3	1269.7	1.092
20	1171.9	1155.1	1252.6	1.077
21	1097.8	1082.9	1187.6	1.021
22	1095.5	1080.5	1185.5	1.019
23	1136.6	1120.7	1221.9	1.051
24	1129.8	1113.4	1215.9	1.045

Based on the balance relations presented in the previous paragraph, the electrical, thermal and global efficiency and specific fuel consumption relative to the produced electricity have been determined.

Values resulting from calculations are shown in Table 2 and their graphical variation in Fig. 3.

Table 2

Hourly values of the efficiency calculated for the cogeneration plant

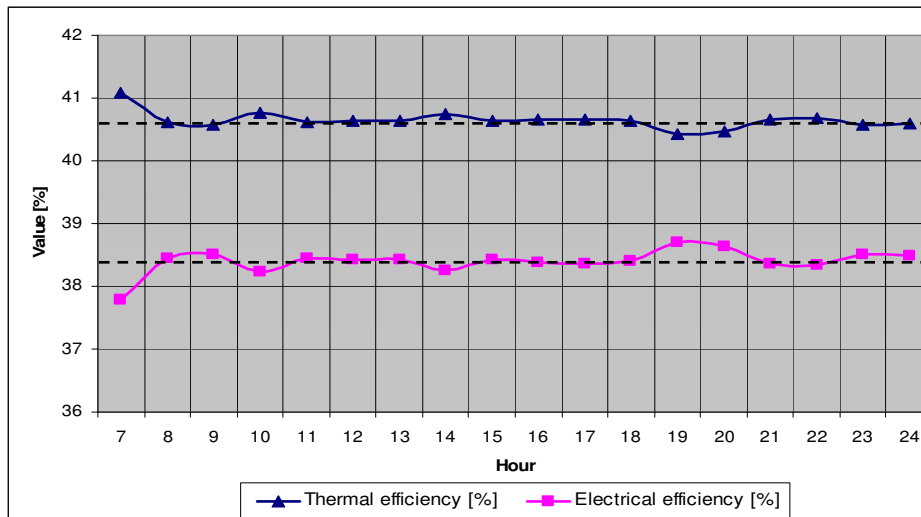| Hour	PARAMETER			
	Electrical efficiency [%]	Thermal efficiency [%]	Global efficiency [%]	**Fuel specific consumption [kWh/KWh]**
7	37.78	41.08	78.86	**2.620**
8	38.45	40.61	79.06	**2.601**
9	38.51	40.57	79.08	**2.597**
10	38.23	40.76	79.00	**2.616**
11	38.45	40.61	79.06	**2.601**
12	38.42	40.63	79.05	**2.603**
13	38.42	40.63	79.05	**2.603**
14	38.26	40.74	79.00	**2.613**
15	38.42	40.63	79.05	**2.603**
16	38.39	40.65	79.04	**2.605**
17	38.37	40.66	79.04	**2.606**
18	38.41	40.64	79.05	**2.604**
19	38.71	40.42	79.14	**2.583**
20	38.64	40.47	79.11	**2.588**
21	38.36	40.67	79.03	**2.607**
22	38.35	40.68	79.03	**2.607**
23	38.51	40.57	79.08	**2.597**
24	38.48	40.59	79.07	**2.599**

Fig. 3. Hourly variation of electrical and thermal efficiency for the cogeneration plant

4. Long-term analysis of the cogeneration plant operation
   ## (parameters, results, savings)

Values measured in a limited period of operation do not highlight the overall long-term operation of the installation.

For creating a complete image of operation performances of the cogeneration plant, the results of monthly records for one year of operation have been therefore processed.

Based on annual recordings and applying relations for the determination of thermal balance sheet items, the electrical and thermal efficiencies as monthly averages have been calculated. Other indicators such as gross or net average power, energy produced and delivered, specific fuel consumption etc. have been also calculated.

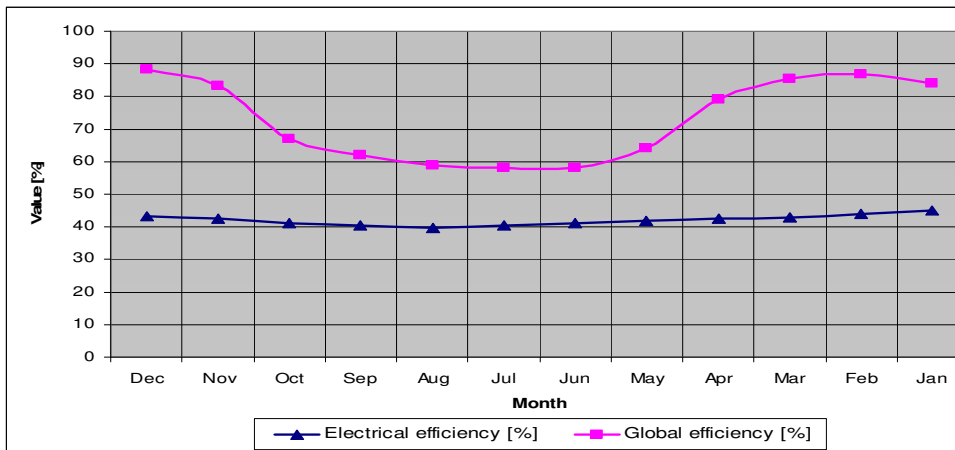The results are graphically presented in the fig. 4 and fig. 5.

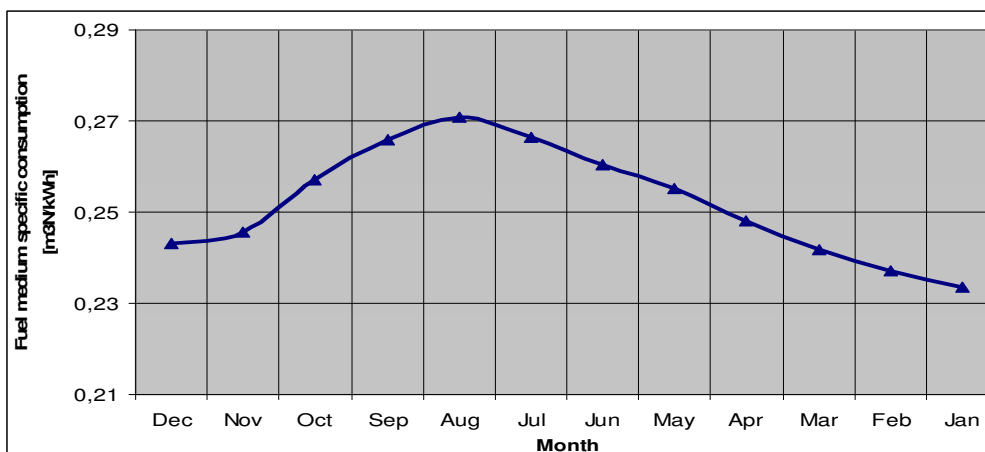Fig. 4. Monthly variation of the electrical and global efficiency

Fig. 5. Monthly variation of fuel medium specific consumption

5. Conclusions

From the results analysis of the cogeneration plant energy balances, the
following conclusions have been drawn:

a) for the hourly real records
- The natural gas fuel consumption reported at normal state ranges in
  the levels set by the manufacturer in the technical documentation, not
  exceeding any of the maximum consumption measured values,
  corresponding to the nominal load;
- the electric power produced by the cogeneration groups ranged at
  relatively high values, between 950 and 1150 kW, which shows an
  average load of about 96%;
- the thermal power delivered to SC Izovolta had values ranged
  between 1050 and 1200 kW, lower than the nominal, leading to an
  acquisition rate ranged between 72% and 82%. This was due to the
  environmental temperatures relatively high that leads to lower heat
  demand;
- the electrical efficiency determined during measurements period
  ranged between 40.5% and 41.3% with an average of 40.7%, values
  that are very close to the maximum presented by the supplier in the
  validation log during testing period;
- thermal efficiency has lower values of about 10% than the nominal
  ones, ranging between 37.8% and 38.8%. This is due to the reduced
  capacity of the beneficiary to take over the heat as hot water, in
  particular as return high temperature (above 70-75 °C) from heating
  system. It is recommended the hydraulic balancing of the pipeline
  network, especially by diaphragmation of the source closest
  consumers;
- in terms of specific fuel consumption expressed in energy units, it
  varies depending on the electric charge between 2.585 and 2.620
  kWh / kWh, and fall entirely within the range presented in the
  technical documentation.

b) for the monthly real records during 2006
- the monthly produced active electrical power ranges between 720
  and 850 MWh/month, with an average of approx. 800 MWh/month,
  which corresponds to a loading capacity of 93% and monthly
  average electrical efficiency of 40.3%. From this point of view it's
  estimated that cogeneration plant is operated under optimum
  conditions. The power reduction is justify by the low power
  consumption (under the nominal values of the generator) on the first

feeder, on Sundays and short shut-downs for maintenance operations;

- the heat has discrepant monthly values from one month to another. In winter time, heat undertaking reaches thus monthly values from 500 to 750 Gcal/month, considering heating consumption. In the warm period the heat consumption as hot water dramatically reduces, reaching the limit values from 300 to 350 Gcal/month. Therefore, the annual overall efficiency reduces to about 73%, with over 13% less than the equivalent nominal load;
- in terms of average fuel consumption, it falls in the range presented in the equipments technical documentation.
- from the economically point of view, by using the cogeneration plant, the company recorded monthly invoices with values between 5% and 12% lower than the case when all power is purchased from the system.

R E F E R E N C E S

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