FLEXIBILITY IN THE USE OF COGENERATION
FOR THE PRODUCTION OF TISSUE PAPER AND ITS ADAPTATION TO THE ELECTRICAL SYSTEM

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L.C. Paper 1881 S.A., a company located in Besalù, in the autonomous community of Cataluña, currently operates two paper machines: PM2, Fourdrinier configuration, used for the combined production of MG paper and tissue, and PM3, a CF machine, entirely dedicated to the production of tissue.
In 2014, L.C. Paper has decided to rebuild PM2 in cooperation with Toscotec. At the time, PM2 was producing packaging paper and paper tablecloths, using 100% recycled fibers. This rebuild has adopted the same solution which was already working on PM3, that is using the exhaust gas coming from a gas engine to heat up the air inside the Yankee hoods of the paper machine. The goal of this solution was to uphold the mill's green philosophy, which has made it into the leader of environmental management in paper production.
In this article the authors aim at illustrating the practices used in managing both the thermal energy coming from the gas engine to be used in the hoods and the quota of electrical energy, which, according to the relevant Spanish regulation, can be sold to the system, benefiting the power grid and the system itself as it serves as backup.

Introduction
The use of cogeneration by definition allows significant energy savings in the field of papermaking. Cogeneration consists in the supply of electricity quota and the recovery of residual heat generated in the process of electricity production itself. In this respect, it is normal to get electricity production efficiency in the range of 32% and 35% when using a gas turbine. However, this efficiency increases to 45% when using a gas engine. If we consider the recovery of the residual heat of the cycle and mainly the heat resulting from the exhaust gases coming from the generator, then the electricity production efficiency can get to figures close to 100%.
One should investigate the validity of a cogeneration system based on the type of electrical system in use, in order to evaluate its profitability. Given the natural gas average cost of 29.3 €/MWh (Spain, 2015), the cost of electricity production from cogeneration is approximately 97 €/MWh, which is rather high if compared with the average purchase price of electricity from the national grid.
Since primary energy savings are the object of crucial debates in any country, the savings themselves can provide precious support in the process of making the installation of a cogeneration system a profitable business.
At the same time, you should take into account the fact that the use of cogeneration is not equally profitable across the whole year, as it depends on the variability of the prices of the electricity market, established by the local provider. The prices depend also on the grid consumption and on the generation mix of the system, as well as on the quota from renewable energies. This applies in Spain as in any other European country, in Italy in particular.

Figure 1 – PM3 (left) and gas engine for electricity generation (right) at LC Paper.

The application of cogeneration at LC Paper
LC Paper's plant in Besalù installs two gas engines integrated with two tissue machines. The cogeneration system is equipped with two Wartsila gas engines, of 6 MW each (see Figure 1 on the right). Electricity yield is equal to 43%. Although, if we consider internal self-consumption, the figure drops to 41.5%. The generator produces electricity at 6 KV, which is then increased to 25 KV to feed the plant and again to 132 KV for grid connection. The business model chosen by the mill is to purchase all the electricity necessary for papermaking from the grid and to give the quota generated from cogeneration entirely back to the grid (this mechanism is called "todo-todo"). In this context, the amount of electricity that is being sent back to the grid at every given hour can be guaranteed rather precisely, this being a minimum requirement of the Spanish national power grid.
The gases, which the system produces in the amount of 11Kg/s at 420°C degrees, are utilized according to two working principles:
1) Using the gases which are sent directly to the wet end and then through a cascade system are blown to the dry end, with both burners running at a minimum or turned off;
2) Using the gases sent directly to the dry end, with the dry burner running at a minimum or turned off. These gases mix with the gases of the wet end, which works as a separate system parallel to it, and uses a wet burner, operating even in conditions of very high temperature.
The gases coming out of the hoods at the temperature of approximately 300 °C, are blown to a recovery boiler running at 17 bar(g). These gases exit the boiler at a temperature of 220°C, going through an air-to-air heat exchanger which pre-heats the combustion air of the wet end hood (in the second configuration) and then they are fed to a recovery boiler working at the low pressure of 0.5 bar(g) to generate steam to be fed to a steam box. The 17 bar(g) is a hybrid boiler equipped with a gas burner to reach the maximum value required for steam generation. We calculate thermal efficiency by considering the efficiency of each usage. In general, this value is the quotient of the electrical energy generated at the clamp of the power station (efficiency equal to 43%) multiplied by the sum of the gas used in the power station and the heat recovered, divided by the typical efficiency of its next usage. For instance, if we re-use the heat in a boiler, the efficiency is considered equal to 90%, whereas if the heat is re-used in a drier, the efficiency is equal to 82%.
In the case of the analyzed application, the definition of the efficiency is the following:

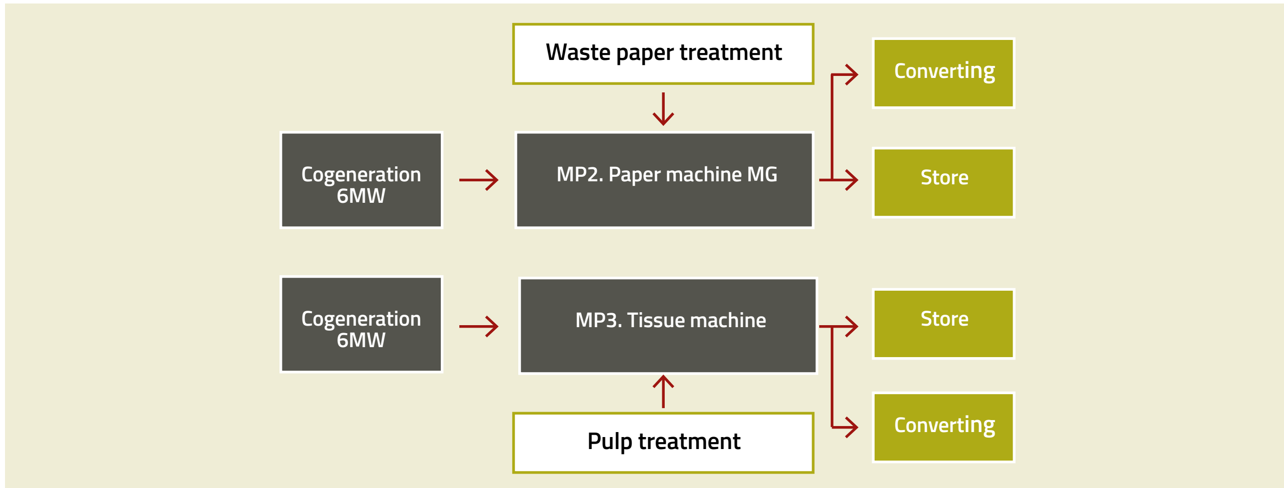

Fig.2 – Simplified flow scheme of LC Paper

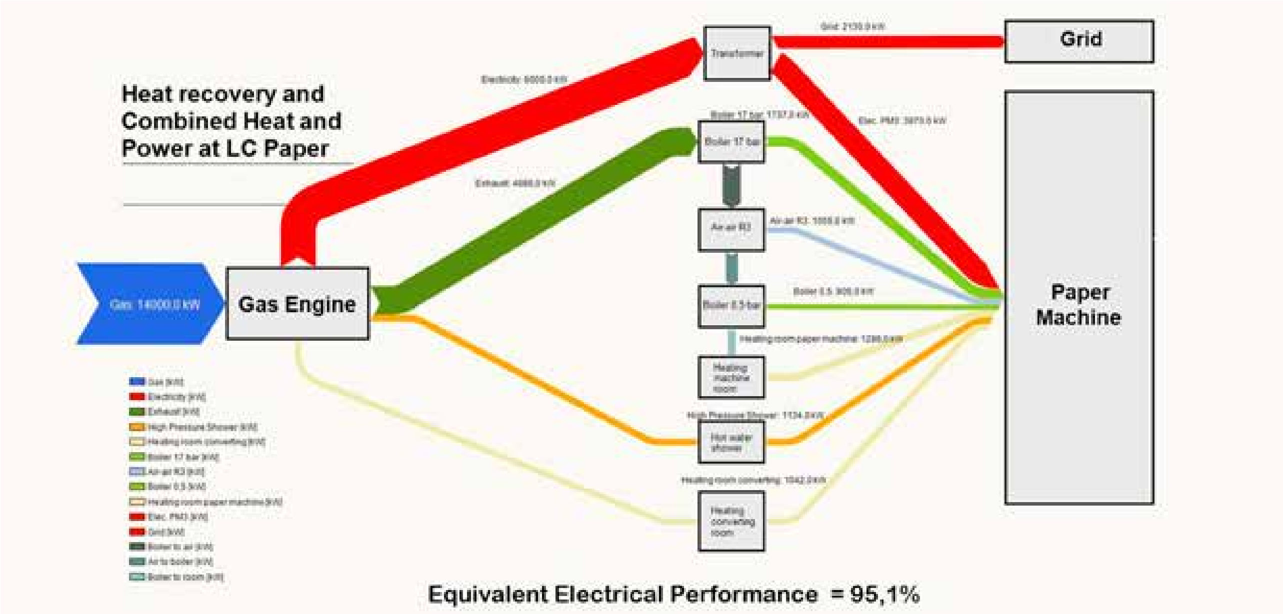

Fig. 3 – Simplified Sankey Diagram PM#3

REE=EE/(Qg+Qh/0,82+Qbhp/0,90+QR1/0,88+QBlp/0,9+QR2/0,7)

Eq. 1

EE= the Electrical Energy produced
Qg= the used gas heat
Qh= the heat recovered in the hood
Qbhp= the heat recovered in the hood @ 17 bar
QR1= the heat recovered in the air-to-air heat exchanger
QBlp= the heat recovered in the boiler @ 0,5 bar/0.9
QR2= the heat recovered in the air-to-water heat exchanger, used to heat the building/0.7.

Exhaust gases keep a 120°C temperature and a temperature of 160°C before the low-pressure boiler. The hot water produced is used in the manufacturing process, to dilute the chemicals and to feed the wire and felt high-pressure showers, as well as being used in the ventilation of the building.
The resulting process is highly efficient, considered that every quota of the produced thermal energy is then recovered in the different phases of its usage.
Fig. 3 below shows the Sankey diagram for LC Paper's PM#3.

Cogeneration management in a tissue plant in Spain

Since the tissue machine runs 355 days/year, the market price of Electrical Energy makes this operation non-profitable. In this case, the cogeneration plant shut down. In 2015, the cogeneration plant worked for 5460 hours, and it was not operating during working time. From an electrical point of view, these shutdowns do not represent a problem, since they are working according to the above-mentioned principle of "to-do-todo". From a thermal point of view, this situation needs an alternative to the heat generation operated by LC Paper, like in other plants, through the installation of a burner in the wet and the dry end hood. This burner can run or it can stand by. You

MONTHS	Average Price of EE in Spain in 2015 [€/MWh]
January	51,60
February	42,57
March	43,13
April	45,34
May	45,12
June	54,73
July	59,55
August	55,59
September	51,88
October	49,90
November	51,20
December	52,61

Tab. 1 Prices of EE in Spain in 2015. (Rif. http://www.omie.es/)

shouldn't install a burner in the 0.5 bar boiler, as the steam box works only with recovered steam.
In the table below (see Tab. 1) are indicated the market prices of EE in Spain in 2015.
From February to June 2015, the price fell down, due to the introduction into the grid of EE from renewable energies (wind) and hydraulic energy. If we analyse the month of February of this year *(http://www.omie.es/)*, we shall notice that for several days the price of EE is lower than 40 €/MWh, during these days it was necessary to shut down the power plant completely or to keep it operating only for 8 hours/day.
This criterion would allow us to keep the cogeneration system profitable even in the future, considering the potential of new low-cost energy sources for electrical energy generation (nu-

ADWDEND	DESCRIPTION	SELLING PRICE QUOTA VALUE	COSTS	YEARLY GROSS MARGIN
Ri	Surcharge of the electrical system proportionate to the investment (plant functioning at 30% of its annual production capacity)	22.496 €/month		
Ro	Sold Energy (EEv) multiplied by the factor 48,67 €/MWh.	EEv.*48.67 €/MWh.		
R3	Product of the sold Energy by the price recognized by the market	EEv.*53.31 €/MWh.		
R4	Savings obtained in the mill from the use of the thermal energy produced	22,5 €/MWh		
	Cost of natural gas		29,3 €/MWh	
	Cost of production of EE		70,55 €/MWh	
	Plant maintenance cost		9 €/MWh	
	Tax		7%	
Total		124.48€/MWh + 22.496 €/month	83.55€/MWh	45.48€/MWh= 3.129.070€

Table 2 – Economic analysis of the investment in 2015

clear, hydraulic, wind and photovoltaic).
The distribution of subsidies for the installation of a cogeneration plant in Spain requires that applicants take part in an open competitive examination organized by the relevant ministry.
Table 2 shows the main factors that contribute to definition of the selling price and it analyses the various items of cost and the resulting operating margins.
If we assume to have a specific amount for the investment equal to 623.000 €/MW installed power, then the investment value for a plant of 12 MW would be equal to 7,476,000 Euro, resulting in a payback period of 2.6 years.
Along with the above said costs, we should consider the advantage of getting a better price on the natural gas due to the high consumption. Similarly, we should consider the quota of energy used to heat the water employed in the air conditioning of the building where the tissue machine is installed and the energy used on the machine's high-pressure showers.
During 2015, the cogeneration plant shut down for 3300 hours, partly due to maintenance (94% of availability) but mainly due to profitability issues. If necessary, the plant can shut down during the night shift. In this case, the tissue machine can continue to run thanks to the usage of burners installed both on the hoods and on the steam-generating boiler.
Thanks to the regulation of the EE purchasing and distribution system in Spain, another operating possibility is to tap into the backup system.
When the electrical grid registers an energy loss, because one power plant shuts down, it is necessary that another plant offset that power loss. This activity is called "primary regulation", when you have the immediate re-integration of the energy loss.

It is called "secondary regulation" when the re-integration of the energy loss is implemented a few minutes after the loss is notified and finally you have "tertiary regulation" when the re-integration is implemented in the following days.
Generally, these three re-integration modes are carried out by:

- In the case of primary regulation: hydraulic plants or plants that do not work at full capacity, therefore they can release a quota of energy to integrate the loss;
- In the case of secondary regulation: working thermal plants which are in standby;
- In the case of tertiary regulation: thermal plants, which are not operational and therefore need a few days to be "warmed up" and re-started up.

The Spanish standing regulation allows any operating power plant to access the secondary regulation system with a minimum input of 10 MW. According to this provision, LC Paper is applying for the permit to access the grid, during the above-mentioned shutdown period of 3300 hours per year. Under these conditions, the profitability of the cogeneration plant would rise and new opportunities would open up for cogeneration, which could be regarded as a substantial input to integrate electrical energy losses on the grid.

Considerations on the energy savings resulting from cogeneration

From the point of view of energy reduction, there are numerous benefits granted by the use of cogeneration in a tissue plant. You need to adapt and find specific solutions for the circuit. We mentioned earlier how you can recover the cogeneration gases in a sequential way, in order to use them as thermal energy. The thermal energy savings in a factory that uses a cogeneration plant of 6 MW and a tissue machine producing 4.6 t/d could be summarized as follows:

- Dry end hood heat recovery 1.836 kWh
- 17 bar boiler heat recovery 1.115 kWh
- R3 (air/water) scrubber recovery 836 kWh
- 0,5 bar boiler recovery 612 kWh
- HVAC water heating recovery 1.102 kWh
- Total energy recovered from produced gas 5.501 kWh, (Tgas da 420°C a 48°C)

Moreover, you could use part of the water coming from the heating, using the exhaust gases of the gas motor, in order to feed the tissue machine's high-pressure showers or the flooded nip shower. In this case, the main problem is monitoring the hardness of the water, which may have to undergo decalcification through reverse osmosis. Once the treatment is completed, you could heat up approximately 10 m3/tonn of water (corresponding to LC Paper's fresh water consumption) with water at 80°C, therefore increasing the amount of recovered heat to 968 KWh, to achieve a total 7.566 KWh.

Based on the above, the equivalent efficiency is (see Eq. 1):

$$Ree=6.000/(13.800-7.566)=99,8\%$$

Eq. 2

In this respect, it is worth reminding that the efficiency is the same and it considers the efficiency of each supply of primary energy. For this reason, it can exceed 100%.

About the Italian electrical system and the use of cogeneration

As the basis for this brief account, we have referred to Tuscany's companies, which are comparable to LC Paper in size (in terms of self-produced energy of 6-6.5 MW).

These companies purchase EE and gas through the Consorzio Toscana Energia SpA. The breakdown of the purchasing price of EE is: energy + transport and distribution + dispatch + system costs. In order to cut on system costs, it is very important to establish the company's classification from the point of view of energy consumption *(art. 39, Law Decree n.83 of the 22nd June 2012)* and its consumption of EE purchased from the grid. As a reference value, we will consider the PUN National Standard Price (which has a rather complex structure) and in the specific case, we will consider an average cost of 95-102 €/MW.

The provider Servizi Energetici Spa operates the sale through the mechanism of Dedicated Assignment, that is a simplified procedure where the produced electrical energy is transferred. The EE introduced on the grid by producers is given a value by GSE at "the average area price per hour", i.e. the average monthly price according to the time slot – generated on the electrical energy market – corresponding to the market area to which the plant is connected. The so-called unbalance factor affects the definition of the price and it depends upon the costs defined by the operator Terna, which regulates the balance of the grid when new energy is introduced. You could also take part in consortia of EE producers, which act as an intermediary vis-à-vis GSE and guarantee the minimum amount

Prices 2016 (Euro/MWh)

Range F1

ZONE	January	February
North Central	49.26	36.76
South Central	48.50	36.16
North	58.26	41.72
Sardinia	49.06	36.76
Sicily	45.98	39.93
South	37.16	36.40

Range F2

ZONE	January	February
North Central	48.29	36.04
South Central	47.51	35.10
North	49.10	37.47
Sardinia	49.77	37.99
Sicily	51.34	44.75
South	43.62	35.54

Range F3

ZONE	January	February
North Central	36.10	29.26
South Central	35.81	29.39
North	38.26	29.07
Sardinia	34.55	29.81
Sicily	39.71	33.51
South	32.06	29.09

Fig. 4 – Current prices in Italy for the sale of EE in the first 6 months of 2016. Fonte GSE - http://www.gse.it/

of EE introduced on the grid. The members of a consortium have access to better prices. In any case, the selling price is rather low if compared with the cost of production. The tables below show the monthly average prices in Euro/MW, in respect with the time slots and market areas (see figure 4)

Conclusions

According to the existing regulations and relevant tariffs in Italy, as opposed to what happens in Spain, it is not profitable to sell the electrical energy produced with cogeneration back to the grid. In fact, the average selling price is equal to 40-50% of the production cost and it is much lower than the purchase price from the grid. It is essential, in the new plants, to self-produce EE (and limit purchasing energy from the grid as much as possible) and to use the exhaust gases, hence maximizing energy recover. It would be worth looking into the white certificates on a separate dissertation. The situation in Italy is therefore very different from that in Spain, where it is possible to "do business" by supplying/purchasing energy from the grid, as we illustrated in this paper. In respect with Spain, it is worth pointing out that technological decisions substantially affect the possible results. In fact, the use of gas motors, just like in the analysed case, allows great flexibility and adaptability to tariff variations, which are linked primarily to the increasing use of renewable energies (and time slots).

Thanks

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