EVALUATING ECONOMICAL COGENERATION OPPORTUNITIES IN THE RED MEAT ABATTOIRS AND FRIGORIFIC INDUSTRY

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Abstract: Cogeneration, the combined generation of steam and electricity, is an efficient and cost-effective means to save energy and reduce pollution. The aim of this work is to implement a technical and financial study of viability for the installation of a cogeneration system in the abattoir and frigorific industry. The system will be built considering the use of a counter-pressure steam turbine and a boiler using wood as fuel. Two systems will be considered: one system will analyze the industrial thermal demand and the other will consider a surplus of electricity, aiming self-sufficiency in the generation of electricity for the red meat abattoir and frigorific industry. There is, according to the payback on investment, which is the most attractive.

Keywords: cogeneration, energetic efficiency, abattoirs and frigorific industry.

1. INTRODUCTION

The world expectation for energy shortage and the concern with global warming have motivated the search for alternative sources of energy and the adoption of measures for energy saving and efficiency. In this context, energy cogeneration, a combined extraction of useful heat and mechanical power of energy resource, appears as an efficient alternative which can be implemented in large thermal plants and used by consumers.

In a cogeneration unit the energy that would be lost as heat can be used to provide heat in a process with up to 85% of thermal efficiency, Ferrão (2001). Therefore in enterprises that require thermal and electrical energy, cogeneration is an alternative for rational use of fuel, furthermore, helping to reduce environmental impact. Financially, the generation of energy in the place where it is consumed can reduce costs, consequently, promoting competition among industries or commercial ventures. Cogeneration systems present exceptional opportunities of both environmental and financial profits.

Nevertheless there are risks involved, since planning of long term actions may suffer changes that would compromise the financial viability such as: variation of energy retail prices, modification of production process, changing the heat/energy relation. However, the interest on cogeneration is rising, mainly due to the decline of the quality of services, the rearrangement of industrial electricity taxes and the need for expanding the supply of energy.

In Brazil, the sugar-cane alcohol, paper and cellulose industries have an already established tradition in cogeneration due to the high energy they consume, their need for the use of steam and the large quantity of biomass produced. The use of cogeneration could be applied in many other industrial sectors. Regarding the rice industry there is a projection of up to 160MW of sustainable thermal-electrical potential and of up to 245MW for the wood industry, as a result of the residues produced in the states of Rio Grande do Sul and Santa Catarina, Coelho (2002)

In a scenario of cogeneration expansion, the use of cogeneration in a business that requires electrical and thermal energy can be viable financially and ecologically sustainable as showed in this study of an abattoir and freezer plant. This industry needs 2.78kg/s of steam produced in a flame-tubular boiler which is used in the process. The average demand for electricity in this abattoir is 710kW.

The aim of this work is to implement a technical and financial study of viability for the installation of a cogeneration system in the abattoir and freezer plant. The system will be built considering the use of a counter-pressure steam turbine and a boiler using wood as fuel.

Two systems will be considered: one system will analyze the industrial thermal demand and the other will consider a surplus of electricity, aiming self-sufficiency in the generation of electricity for the red meat abattoir and frigorific industry.

2. CASE STUDY

A case study will be considered regarding the use of cogeneration in an abattoir and frigorific industry, with capacity of slaughtering 400 cows a day. In this industry cogeneration is particularly recommended due to the need for the use of electricity and steam.

The industry needs electricity for the illumination system, engines motion and, mainly, for the refrigeration system. From January 2004 to March 2006 an average demand of 710kW has been registered

The enterprise has a flame-tubular boiler with a capacity of producing steam of 2.78kg/s. The fuel used is wood with an average density of 280kg/m^3 and a rate of 0.117kg/s.

The main steam consumer is the flour production sector, 2.58kg/s. Other sectors that use steam are the slaughtering, 0.14kg/s and the laundry, 0.06kg/s.

For the technical analysis of the cogeneration system of this industry a counter-pressure steam turbine and a water-tubular boiler (with over heating fuelled by wood) will be considered. The wood has been chosen as fuel due to its low cost and availability in the industry surroundings. The use of a gas turbine has not been considered since it is not financially recommended: the high cost of natural gas associated to the lack of distribution of natural gas through a gas duct.

An efficiency (η_{cald}) of 80% was considered for the boiler with a charge loss of 0.2MPa. An increase of 3°C on the steam while exiting the pump due to mechanical friction, and a loss of 5% in the electrical conversion has been taken into account. The wood lower heat power (PCI_{lenha}) is equal to 3,100kcal/kg and the isentropic efficiency of the steam turbine is 85%, Wylen (2003).

2.1 Thermodynamic analysis of the steam turbine

The Fig. 1 shows a cycle of cogeneration with employment of a counter-pressure steam turbine.

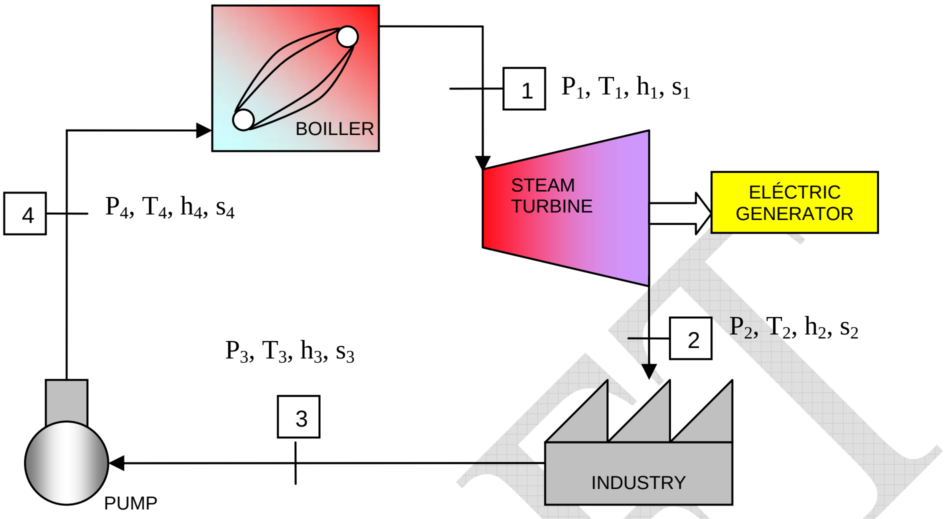

Figure 1 – Cycle of cogeneration with steam turbine of a counter-pressure

In Table 1, the main thermodynamic parameters of the cycle are introduced, as represented in Fig. 1, such as: mass flow ($\dot{m}$), pressure (P), temperature (T), enthalpy (h) e specific entropy (s). It is worth mentioning that this first arrangement is based upon a case where there is a deficit of electricity, i.e., when it is necessary to purchase the deficit of energy from the local electricity network.

Table 1 – Main thermodynamics parameters of the first arrangement.

Point	Flow (m) kg/s	Pressure (P) Mpa	Temperature (T) °C	Specific Enthalpy (h) KJ/kg	Entropy (s) kJ/kg
1	2.78	4.5000	350.0	3081	6.513
2	2.78	1.0810	193.9	2808	6.618
3	2.78	0.1013	100.0	419	1.307
4	2.78	4.7000	100.6	425	1.310

In the second array, the cogeneration system is calculated to produce an exceeding amount of electricity in order to achieve self sufficiency. In Table 2, the main thermodynamic parameters of the second arrangement are introduced.

Table 2 - Main thermodynamics parameters of the first arrangement

Point	Flow (m) kg/s	Pressure (P) Mpa	Temperature (T) °C	Specific Enthalpy (h) KJ/kg	Entropy (s) kJ/kg
1	2.78	5.5000	400	3186	6.591
2	2.78	1.0810	193.9	2854	6.618
3	2.78	0.1013	100	419	1.307
4	2.78	4.7000	100.6	425	1.31

2.2 Calculate of the power potential and power provided by the fuel of the boilers

For calculation of work of the axis turbine (W_{eixo}) has been the following equation:

$$W_{exixo} = \dot{m}(h_1 - h_2) \tag{1}$$

For calculating the electrical power produced (Ep) and the thermal energy supplied to the process (E_{CV}), Eqs. (2) and (3) are considered respectively. The performance of the generator ($\eta_{GERADOR}$) adopts is equal to 95%.

$$E_P = \eta_{GERADOR}.\dot{W}_{EIXO} \tag{2}$$

$$E_{CV} = \dot{m}(h_2 - h_3) \tag{3}$$

The work (W_{BOMBA}) performed by the pump is calculated by adopting its performance (η_{Bomba}) to be 90%.

$$W_{BOMBA} = \frac{m(h_4 - h_3)}{n_{bomba}} \tag{4}$$

The heat supplied to the water in the boiler (E_V) is calculated as a function of the steam mass flow required in the process multiplied by the difference of the enthalpies in point 1 (h_1) and point 4 (h_4), following Eq. (5).

$$E_V = \dot{m}(h_1 - h_4) \tag{5}$$

The energy provided by the fuel (E_{COMB}) will be calculated as a function of the heat supplied by the boiler (E_V) divided by the adopted boiler performance (η_{CAL}) of 80%.

$$E_{COMB} = \frac{E_V}{n_{CAL}} \tag{6}$$

The fuel mass (m_{comb}) will be calculated as a function of the energy supplied by the fuel (E_{COMB}) and by the inferior heat power of the wood (PCI_{lenha}).

$$m_{COMB} = \frac{E_{COMB}}{PCI_{lenha}} \tag{7}$$

The electric efficiency (η_{EL}), thermic (η_T) and global (η_G) is calculated by:

$$\eta_{EL} = \frac{E_P - W_{BOMBA}}{E_{COMB}} \tag{8}$$

$$\eta_T = \frac{E_{CV}}{E_{COMB}} \tag{9}$$

$$\eta_G = \frac{W_{EIXO} + E_{CV}}{E_{COMB}} \tag{10}$$

2.3 Feasibility study economic

For the purpose of optimization, where the calculations are done by computer programs, the use of functions of investment costs of each factor as a function of its capacity is appropriate and largely used, Tuna (1999).

The equations (12) and (13) were developed by Frangopoulos (1992) and update for Lazzarretto and Macor (1995), to determine the costs to purchase boilers (C_{cal}), condensation steam turbines (C_{TV}) and pumps(C_B). These equations also consider installation in site, electrical appliances, control systems, fire protection and acoustic insulation.

$$C_{CAL} = 784 \cdot E_{COMB}{}^{0.8} \cdot \left[1+\left(\frac{1-0.90}{1-\alpha}\right)^7\right] \cdot \left[1+5\cdot\exp\left(\frac{T_{SAIDA}-866}{10.42}\right)\right] \cdot \left[\exp\left(\frac{P_{SAIDA}-28}{150}\right)\right] \tag{11}$$

$$C_{TV} = 7490 \cdot Ep^{0.70} \cdot \left[1+\left(\frac{1-0.95}{1-\eta_{TV}}\right)^3\right] \cdot \left[1+5\cdot\exp\left(\frac{T_{Entrada}-866}{10.42}\right)\right] \tag{12}$$

$$C_B = 3540 \cdot \dot{W}_{Bomba}{}^{0.71} \cdot \left[1+\left(\frac{1-0.80}{1-\eta_B}\right)^3\right] \cdot 1.41 \tag{13}$$

The maintenance cost of the cogeneration plant can be estimated in 3% of the total cost of setting up the boiler, the turbine and the pump divided by the number of operation hours, Tuna (1999).

$$C_M = \frac{0{,}03x.(C_C + C_{TV} + C_B)}{H} \tag{14}$$

The cost of the cogeneration plant operation ($C_{OP.}$) is estimated em US$/h, as a function of the number of employees in charge of the plant operation, multiplied by the salary and divided by the number of operation hours in a month, Eq. (15).

$$C_{op} = \frac{Salario}{h/mes}.n_{pessoa} \tag{15}$$

The investment cost (I_{PL}) is given by the sum of costs of the main components of the system and multiplied by a factor around 1.3, which corresponds to the increase due to costs of transportation, insurance, building administration, engineering plans, etc., Silveira (1994).

$$I_{PL} = (C_C + C_{TV} + C_B).1.3 \tag{16}$$

Silveira (1994) estimates the cost of electricity (C_{EL}) and steam (Cv), US$/kWh, by the following equations:

$$C_{EL} = \frac{[I_{PL}.f]}{H.E_P}.F_{EP} + \frac{C_{COMB}\cdot\left(E_{COMB} - E_{CV} - \frac{Perd}{2}\right)}{E_P} + \frac{C_M.F_{EP}}{E_P} + \frac{C_{Po}.F_{EP}}{E_P} \tag{17}$$

$$C_V = \frac{[I_{PL}.f]}{H.E_{CV}}.F_{EC} + \frac{C_{COMB}\cdot\left(E_{CV} + \frac{Perd}{2}\right)}{E_{CV}} + \frac{C_M.F_{EC}}{E_{CV}} + \frac{C_{Po}.F_{EC}}{E_{CV}} \tag{18}$$

$$f = \frac{[q^k.(q-1)]}{(q^k-1)} \tag{19}$$

$$q = 1 + \frac{r}{100} \tag{20}$$

$$F_{EP} = \frac{E_P}{E_P + E_{CV}} \tag{21}$$

$$F_{EC} = \frac{E_{CV}}{E_P + E_{CV}} \tag{22}$$

$$Perd = E_{COMB} - E_P - E_{CV} \tag{23}$$

The cost of fuel (C_{COMB}) is 0.01258US$/kWh, ANP (2007).

In this case where is energy exceeding the gain with energy production (G_{Pel}) is calculated by Eq. (24).

$$G_{Pel} = E_r.H.(C_{el.conces} - C_{el}) + (E_p - E_r).H.(P_{vel} - C_{EL}) \tag{24}$$

In this case where is energy deficit the gain with energy production (G_{Pel}) is calculated by Eq. (25).

$$G_{Pel} = E_r.H.(C_{el.conces} - C_{el}) \tag{25}$$

De acordo com ANEEL (2007), o preço médio de energia elétrica industrial na região sudeste é US$ 0.1108 kWh.

According to ANEEL (2007), the average price of industrial electricity ($C_{el.concess}$) in the southeast region is US$ 0.1108 kWh.

The gain in steam production is defined by the product of three factors: heat supplied to the water in the boiler, number of annual operating hours (H) and the difference between the cost of the steam produced by the existing system in the plant (Cvc = 0.020 US$/kWh) and the cost of the steam derived from the cogeneration.

$$G_{Pv} = Ev\ .\ H.\ (C_{vc} - Cv) \tag{26}$$

The expected annual income (RA), Eq. (27) is calculated by the sum of both gains associated to the production of electricity and useful heat. If this result is negative it means that the costs associated to the cogeneration plant are higher than the costs associated to the conventional systems, Tuna (1999).

$$RA = GPel + GPv \tag{27}$$

3. RESULTS

The work of the turbine axis (W_{eixo},), Eq. (1), is 759kW, the electrical power produced (E_P), Eq. (2), is 702.5kW and the thermal power of the process, Eq (3), is 6,635.5kW. The pump work is 18.5kW and the isentropic efficiency is considered to be equal to 80%.

The heat provided by the water in the boiler, Eq. (5), is 7,377.8kW. The energy provided by the fuel, Eq. (6), is 9,922.2kW. The mass of fuel, Eq. (7), is 0.71kg/s.

A performance electric (η_{EL}), Eq. (8), is 0.076, thermic performance (η_T), Eq. (9), is 0.720, so global performance (η_G), Eq. (10), is 0.802.

The boiler cost, Eq. (11), considering 80% of efficiency in the combustion compartment, was calculated in 1,003,516.76 US$. The turbine cost Eq. (12) was 763,724.89 US$ and the pump cost, Eq. (13), is 79,308.51 US$.

The number of operation hours (H) in a year is 7,200 hours. Therefore, the maintenance cost Eq. (14), is 7.69 US$/h.

Once the proposed cogeneration plant is not large, smaller than 1MW, it will be considered one employee to operate the plant with a monthly salary of 2,000.00 US$. Substituting these values in Eq. (15), it results that the operational cost of the cogeneration system is 3.33 US$/h.

The total cost to install the cogeneration system, with the system working with thermal parity, and considering the previous results, is 2,400,515.20 US$.

In this first simulation, the system is presented in the case of energy deficit, once the required energy (E_R) is 710kW, higher than the energy produced (E_P) of 702.5kW. Therefore, in this case the gain with energy production (G_{Pel}) is calculated by Eq. (24) and the gain with steam production, by Eq. (26).

The annual income results (RA), Eq. (27), as function of the annual interest rates and of the payback (k) is presented in Fig. 2. The annual rate of interest (r) varies from 6% to 14% and payback (k) varies from 0 to 20 years.

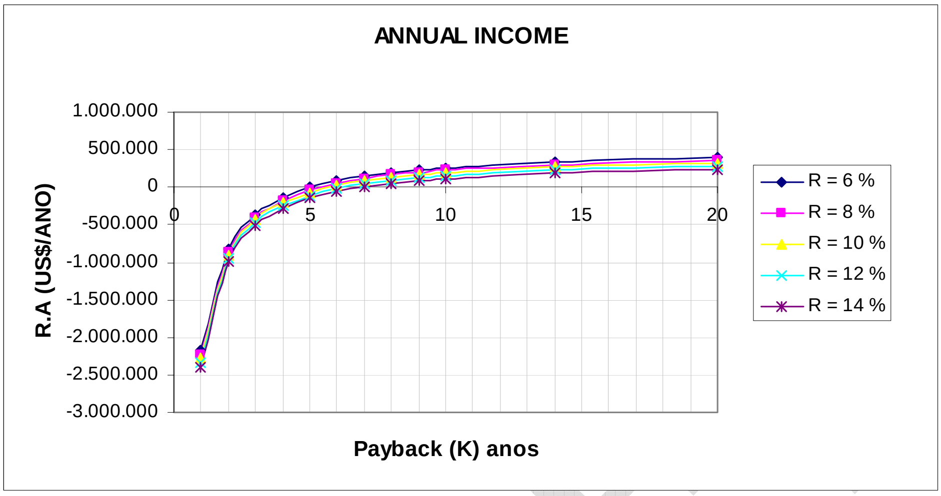

Figure 2 – Income annual of the cogeneration system operating with deficit energy.

Figure 2 illustrates that the payback for the cogeneration system, considering that the energy production deficit of this industry, is 6 years with an annual interest rate of 6%.

The second simulation presents an energy surplus once the energy required (E_R), 710kW, is lower than the energy produced (E_P) 858kW. Therefore, in this case, the gain with energy production (G_{Pel}) can be obtained from Eq. (25) and the gain with steam production, from Eq. (26).

Figure 3 illustrates the values of the annual income, Eq. (27), as a function of the payback and of the annual interest rates. In this case the investment return in the cogeneration system operating with energy surplus is 5 years with an annual interest rate of 6%.

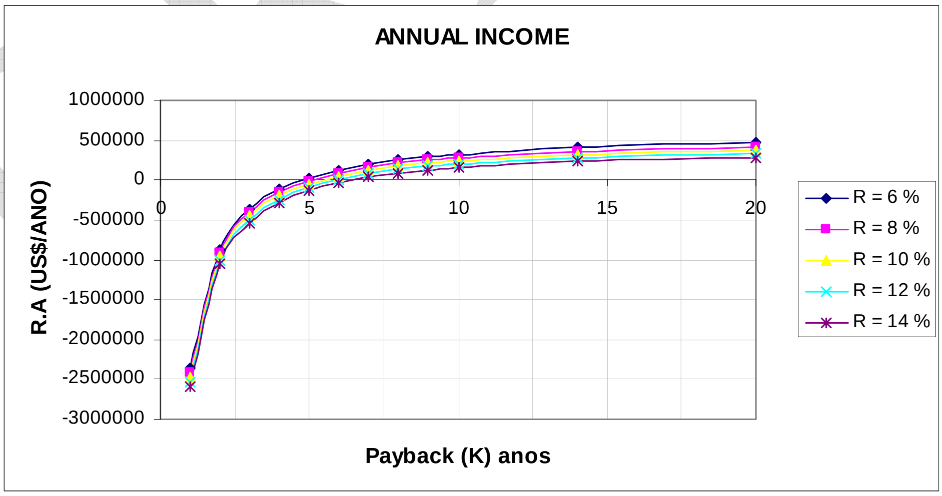

Figure 3 – Income annual of the cogeneration system operating with energy surplus.

4. CONCLUSION

This work has analyzed the use of a cogeneration system applied to an abattoir and freezer plant. For this purpose, the system thermodynamic parameters were determined taking into account the installation of a counter-pressure turbine and a boiler for the production of over heated steam using wood as fuel. A technical-financial analysis has been done for both proposed systems. The first system meets the demand of steam required for the process and the second system has the aim of generating energy surplus.

The energy produced (E_P) in the first system is 702.5kW, lower than the energy required (E_R) of 710kW, and therefore generating a deficit of energy. In this case the payback of the cogeneration system in relation to the industry is 6 years with annual interest rate of 6%. The cost of electricity production is 0.04019 US$/kWh e cost of steam is 0.02511, US$/kWh.

In the system where there is a surplus of energy, (E_P) 858 kW, the produced energy is higher than the energy required (E_R), 710 kW. In this case the investment return is 5 years with annual interest rate of 6%. The cost of electricity production is 0.040 US$/kWh e cost of steam is 0.027, US$/kWh.

According to the data presented above, it can be concluded that the installation of a cogeneration system to be the electrical and thermal power source in a small industry, such as this abattoir and freezer plant, is an exceptionally viable technique.

Acknowledgements

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