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Economic Evaluation of Cogeneration System in Asphalt Plant

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Abstract: This article proposes the introduction of an energy cogeneration system on an asphalt paving plant, located in the municipality of Juiz de Fora, Minas Gerais. Asphalt plants generally produces bituminous asphalt at high temperatures releasing greenhouse gases into the atmosphere and cogeneration is a solution which would represents environmental and economic benefits. The work details the process of cogeneration based on natural gas taking into account thermal input and output, as well as the possibilities of produce simultaneously heat and power for the asphalt process, and the installation of a gas turbine. Energy balances were accomplished to quantify the energy flows and monetize the operational costs in order to evaluate and compare two scenarios: scenario (C1), without cogeneration and scenario (C2), with cogeneration. Moreover, an economic assessment was done evaluating the energy and monetary savings and also the payback, which resulted 2.6 years. The results validated the feasibility of a cogeneration system at the plant, which will take advantage of produce thermal energy and electricity, and as a self-producer of electricity, generate electricity surplus that can be sold to the grid.

Keywords: cogeneration; energy; economy; natural gas; asphalt.

1. Introduction

One of the necessary conditions for sustainable economic growth is investment in infrastructure, so paving of roads and highways construction is thus considered a key point of development. Without investments in this segment, it is not possible to meet the demand generated by the growth of industrial activity. In this sense, various types of asphalt for paving are produced in plants, which use dynamic weighing of aggregates, according to the speed of conveyor belts, which separate by sieving, the components of the final mixture. In this context the introduction of the cogeneration in the plant, as a practice of energy conservation, allows the simultaneous production of heat and electricity for the production process as well as the selling of electricity to the grid.

The system produces heat and electricity in a combined way, providing the use of more than 70% of the thermal energy of the inputs, and for this reason, when a renewable fuel is burnt, it supports favorably to the objectives of the policies National energy. The benefits and advantages of this system range from global energy efficiency to meeting the needs of a process unit, which uses the same primary source to produce useful energy and electricity, at high performance, virtually without electricity losses, close to the consuming unit, with reduction of environmental impact, because there will be no need for extensive transmission lines and their consequent infrastructures; moreover the system provides a reliable, low cost and uninterrupted electricity.

Cogeneration is more efficient than thermal generation on conventional bases when it is technically feasible and economically attractive. Internal combustion engines, condensers and pumps, boilers, steam turbines, gas turbines and generators are used in different thermodynamic cycles, such as the Topping cycles, where the relative sequence goes from the electromechanical power generation to the thermal energy use, or the Bottoming cycles, which supplies the useful heat at the beginning, while the electromechanical power generation takes place subsequently (Figure 1).

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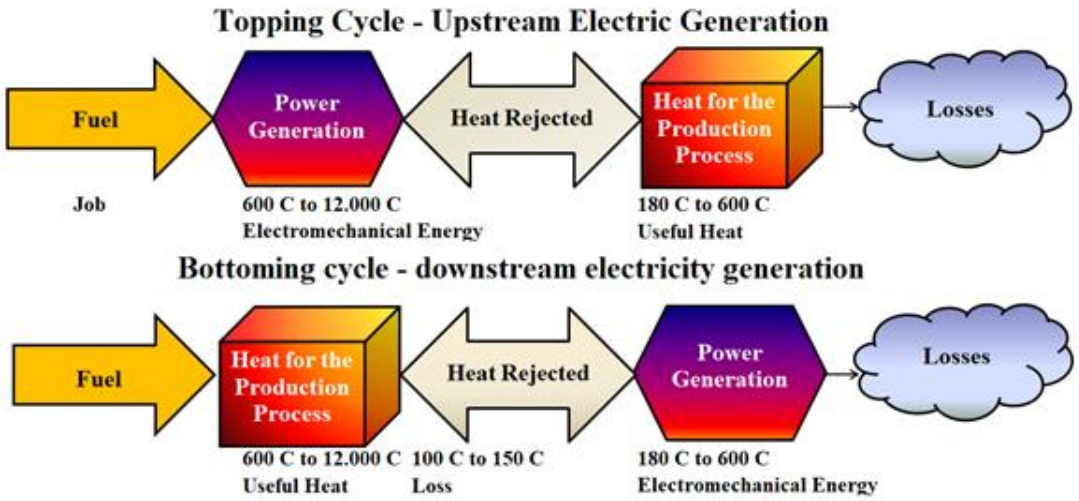

Figure 1. Cycle sequence in cogeneration system.

In the world, traditionally, the main form of reuse of the heat generated from the burning of coal and oil consisted of investing in heating systems, such as water heaters for working towns and villages, arranged in the industries vicinity. Although this this practice implies a great loss of heat through the pipeline when distances are significantly, this cogeneration model was widely used in Europe and the United States.

However, the advent of national electrical systems, interconnected, meeting the demand, supplying cheaper energy produced in a growing scale, with quality and in a safely way, emerged in the decade of 50 of the TWENTIETH century, according to Nogueira and Martins (1997) "As responsible for the disuse and consequent reduction of cogeneration participation in the global energy matrix ".

Power source	Biomassas	Natural Gas	Biogas	Sub Total	Solar	Sub Total	Micro Mini GD
Ventures	438	56	22	516	75	591	+70 mil
Percentage evolution (1)	74,11%	9,48%	3,72%	87,31%	12,69%	100,0%	Does not apply
Installed Capacity (GW)	14,8	3,1	0,4	18,3	2,1	20,4	0,81
Percentage evolution (2)	72,55%	15,20%	1,96%	89,71%	10,29%	100,0%	Does not apply
ACR Auctions + Construction (GW)	1,4	0,001	0,04	1,441	1,9	3,341	Does not apply
Percentage evolution (3)	41,90%	0,03%	1,20%	43,13%	56,87%	100,0%	Does not apply

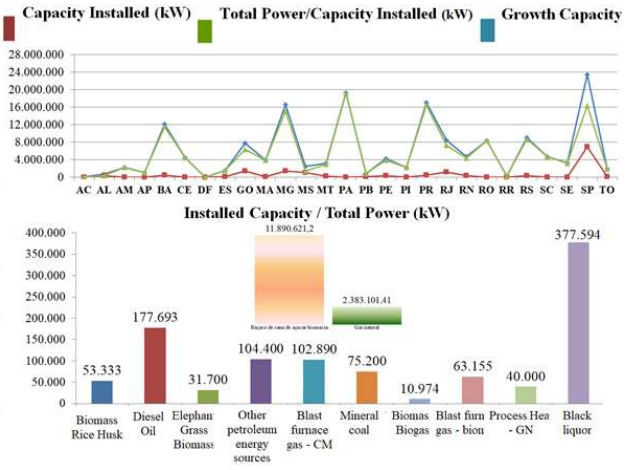

Figure 2. Installed capacity of cogeneration in Brazil by power source.
Source: modified, COGEN (2019).

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Cogeneration is employed in several segments, and discussions in the energy field are concentrated in the possibilities of enabling these systems as a means of energy conservation. Figure 2 shows the growth of cogeneration in Brazil in different sectors of economic activity with installed capacity in 2019 of 164 GW. Without considering the social benefits in the system there are more than 591 enterprises, and from these, the biomass represents 74%, natural gas 9.5%, biogas 3.7%.

The asphalt for paving segment has thermal requirements similar to that of other segments that practice cogeneration. For this reason the present study focuses on the production process of EMPAV company, an asphalt plant located in the municipality of Juiz de Fora, in Minas Gerais, the company that by means of natural gas produces bituminous asphalt with equipment, modelDrum Mixer, which has a boiler or drum heater with internal coils where the final process takes place with the receipt of the CAP (oil tar) for the drafting and drying from a centrifugal pump of high flow at a temperature between 150 to 195 °C, and with a circulation pressure that is enough for the cogeneration requirements of the bottoming cycle according to Figure 3.

Figure 4 shows the scheme, which was assumed to engage the gas turbine and auxiliary cogeneration equipment.



Figure 3. Mix end in CAP boiler and powder return to exhaust silo.
Source: EMPAV (2019).

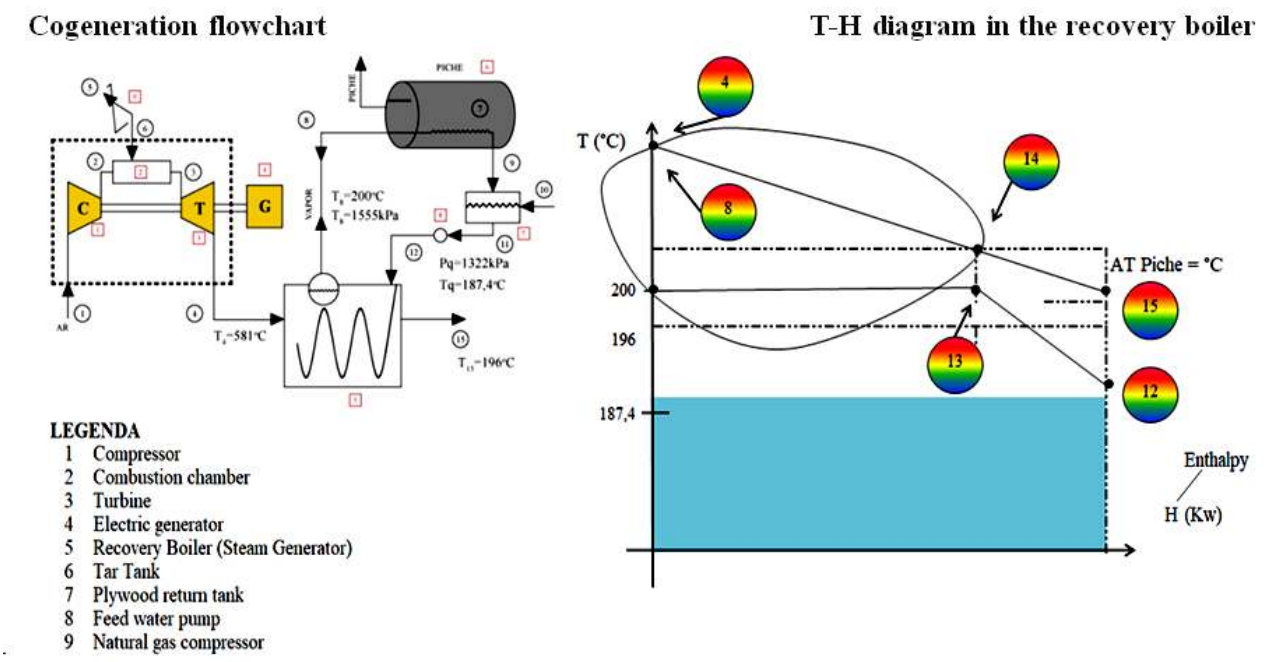

Figure 4. Representative scheme of cogeneration in EMPAV.
Source: PALACIOS-BERECHE (2019)

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2. Material and Methods

The database for the cogeneration technology selection of the asphalt plant began with the calculations of: $\alpha = E_C/Q_C = 0.21$ e $\beta = E_P/Q_U = 0.55$ from the average energy demands. Because of β is greater than α there is availability of surplus electric energy ($S_{URPLUSES}$), because thermal energy is known $Q_{ANUAL} = 497{,}196.74$, namely: $S_{URPLUSES} = Q_{ANUAL} \times (\beta - \alpha) = 497{,}196.74 \times (0.55 - 0{,}21) = 169$ GW/year, equivalent to electric energy that must be negotiated with the concessionaire.

The next step is the study of economic viability, the methodology developed as an instrument to support the decision on investment is presented in Table 1

In Table 1, scenario C1 took into account the current productive reality established by the average consumption of electricity and natural gas, with tariffs defined by the respective concessionaires.

The result of $ 1,573,349.76 corresponds to the total costs of asphalt production in the plant or the operating cost for an equivalent production.

$$\mathbf{Y}conv = [-(Yec.Wcm) + (Yed.Dmax) + (Yconv.Qu/eb)] \quad (1)$$

Table 1. Description of the procedure used for sceneries comparison of cogeneration in the asphalt plant.

Economic Viability			
Operation without Cogeneration = Yconv	**Method**	**Year**	
[Purchase Price of Electric Energy x Average Electric Power Purchased]	= Yec,Wcm	$	65,690.76
[Purchase Price of Electric Energy x Contracted Demand Value]	= Yed,Dmax	$	36,340.06
[Conventional Sist Fuel Price x Average Demand for Useful Thermal Energy/Conventional System Yield]	= Yconv,Qu/eb	$	1,471,318.94
Overall Sum ∑ =		**$**	**1,573,349.76**

In Table 2, scenario C_2, the data from C_1 were used, adding the result of the thermal balance, that is, the amount of energy of the process, the prices of the electricity and the cogenerated natural gas and the price of the investment of the equipment. The result was $156,543.47.

The difference between these scenarios was positive: C_1 ($ 1,573,349.76) – C_2 ($ 1,122,475.69) = ($ 450.874,07), then, the investment in cogeneration equipment that was of $ 2,972,980.79 was divided by this value, generating simple payback of 2.63 years, enabling cogeneration in asphalt plant, confirmed by calculations and analysis of economic indicators.

$$Ccog = [-(Yec.Wdef) + (Yed.Dmax) - (Yev.Wexc) + (Ycog.Wcog/ncog) + (Yconv \times Qcomp) + (O\&M \times I) + (Ocivil \times I)] \quad (2)$$

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Table 2. Description of the procedure used for sceneries comparison of cogeneration in the asphalt plant.

Economic Viability				
Operation with Cogeneration = Ccog		**Method**		**Year**
[Purchase Price of Electric Energy x Electric Energy to be purchased from the Concessionaire]	=	Yec, Wdef	$	65,690.76
[The Sale price of the Electricity Surplus x Contracted Demand Value]	=	Yed, Dmax	$	28,970.07
[Selling Price of Surplus Electricity vs, Average Surplus Electricity to be sold]	=	- (Yev, Wexc)	$	(26456, 17.80)
[Fuel Price of the Cogeneration System x (Medium Cogeneration Electric Energy / Cogeneration Electrical Performance)]	=	Ycog,Wcog/ncog	$	535,177.96
[Fuel Price of conventional system x Complementary Thermal Energy]	=	Yconv, Qcomp	$	200,333.14
[Operation and Maintenance vs, Investment]	=	O&M I	$	318,759.94
Overall Sum ∑ =			**$**	**1,122,475.69**
Economic Viability				
Operating Economy Result		**Method**		**Year**
Operation without Cogeneration	=	CoSsemcog	$	1,573,349.76
Operation with Cogeneration	=	CoScomcog	$	1,122,475.69
Difference of ∑ =			**$**	**450,874.07**
Cogeneration Equipment				
Description				**Value**
Combustion Chamber		ton/h	$	179,142.15
Recovery Boiler (steam generator)		ton/h	$	119,428.1
Condensers		MW	$	298,570.25
Electric Generator		MW	$	21,836.50
Natural Gas Micro Turbine (c/generator)		MW	$	89,061.02
Condensed return tank		ton/h	$	2,176,793.47
Feeding water pump		ton/h	$	29,729.07
Cooling Towers/Natural Gas Compressor		m^3	$	58,420.25
Equipment ∑ =			**$**	**2,972,980.79**

3. Results and Discussion

The revenues derived from the selling of electricity surplus were not incorporated into the calculations, whereby it opens an option to deepen the theme, essentially, in the segment of asphalt production.

To reach the financial result of the proposal of cogeneration in the asphalt plant it was necessary to add the costs of the alternative (C_1) without cogeneration, and, subtract from the sum of costs (C_2) with cogeneration.

The result ($C_1 - C_2$) of $ 450,874.07 corresponds to economy savings. The decision process also involved other factors besides the financial, such as strategic, social, environmental and legislation, determinants of viability, as well as: the costs of natural gas, electricity and revenues with the thermal utilization.

It is observed that the time of simple payback was 2.63 years, occurring in the year in which the accumulated cash flow becomes positive, but does not take into account the correction rate of money at the current date. Because to recover only the same value in the future, this Payback would not reflect the capital update, obviously the cogeneration project would not cost. This is because it is not advantageous to exchange a value today, for the same value in the future.

The composite Payback was 6.59, the difference between them is 12.06, and with investment of the order of $ 2,972,980.79 the maximum rate of attractiveness was 11,50% and IRR of 13.65%, 2.15% higher than the acceptable minimum for the realization of the investment for the NPL of $ 395,064.68, and the Profitability Rate 1.13%. Therefore the investment is positively indicated,

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showing to be interesting, because the NPL is greater than 0 (Zero) and the IRR is greater than the maximum rate of attractiveness.

4. Conclusion

For the supply of concurrent demands of thermal and electromechanical energy, in order to define a better way to achieve the objective, a set of processes was established to obtain, from natural gas, the fraction of asphalt, under conditions support energy conservation practices. Fortunately, under the current conditions, cogeneration in the asphalt plant is economically viable, and the solution with gas turbine was selected, but there are obstacles, and in this context, it takes a great effort from the authorities in favor of different changes , in particular, the necessary and fundamental in the legislation of distributed generation, in favor of cogeneration, can help in mitigating the effect of climate change, in view of the social perspectives that a new economic model can emerge , founded on socio-environmental concerns, it's not just a role of the cogeneration system. In question, cogeneration emerges in the Anthropocene of a public policy of energy efficiency, with conservation of resources. It is added the concept that the system can be considered as the unique known alternatives of electricity generation, with a reduction in the novice effects to the environment. Its logic is the emission levels reduction, with simultaneous utilization of the energy of production processes. In this way societies, as occurred in the past after the second war, should seek to rebuild their infrastructures, with asphalt paving and process engineering, potentiating socially more accepted practices in energy and transport systems, and in this way, costs will achieve acceptable levels. It is imperative to initiate a process of transforming the forms of how it is produced, and the way how energy consumption is accomplished, with the cogeneration in prominence, contributing to transport, food, housing, finally, with the social balance and not only economic of planet**.**

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