EXERGETIC ANALYSIS OF THE COGERATIVE UNIT FOR CHILLED WATER CO-PRODUCTION ON THE RESEARCH CENTER USING NATURAL GAS AND BIODIESEL

Alex Álisson Bandeira Santos, alex.santos@cimatec.fieb.org.br
SENAI Cimatec – Integrated Center of Manufacturing and Technology

Ednildo Andrade Torres, ednildo@ufba.br
Laboratory of Energy and Gas, Department of Chemical Engineering, Federal University of Bahia
CiEnAm - Integrated Center of Energy and Environment – Federal University of Bahia

Abstract. *In spite of the apparent stabilization of the energy supply in the country, recent studies (National Operator of Electric System, 2004) indicated that Brazilian Northeast's capacity to produce energy will achieved about 90% of the installed capacity in 2009. Therefore it´ll be important that enterprises build their own infrastructures, which should be decentralized, to increase the process of production. Another important aspect is the cost of the electric power, which already burdens plenty the operation cost of some facilities. The study about the subject evaluates, through thermodynamics' analysis based in exergy, a preliminary project of a co-generation installation, that uses groups' engines, which possess as source of energy natural gas and the mix of diesel and biodiesel, associated with the absorption chillers for the electric power production and cold water for central air conditioned system, in a research center located in the city of Salvador - Bahia - Brazil.*

Keywords*: Exergy, Exergy Analysis, Cogeneration*

1. INTRODUCTION

With the supply's crisis of the electric energy in the country, in the begin of the 21st century, decentralized solutions of energy generation started to appear as alternative ways of potency generation to the medium and big consumers of the industrial or commercial sector.

In spite of the apparent normalization of the energy' supply, the National Electric System Operator (ONS, 2004), esteems that 90% of the electric energy capacity of production, in a critical time, will be used in 2009, which shows the real necessity of alternative solutions to guarantee the supply of energy to the society. Another relevant aspect is the differentiation on the supply tariffs of the electric energy to the business. Even though this differentiation is a fair way to charge, it brings a high impact in the business operation costs to the consumers. Therefore, the tertiary sector of the economy represented specially by the hotels, research centers, universities and park city malls, start to search for alternative solutions to produce, themselves, electric energy and important utilities to the way it works, as cold to the air conditioned systems, with the intention to become self sufficient, decreasing their operational costs.

As a result, as an alternative solution to energy's production, appear the local decentralized thermoelectric unities, installed in the own consumer's infrastructure, when are associated to a co-generation process can attend to the necessity of cold or heat as well. These unities would operate with the energy production of the natural gas or renewed fuels, burning with diesel and biodiesel.

Gean et al. (2004a) talks about the tendency of the service sector to look for the electric self sustain energy that associated to the interesting of the Brazilian government, wants to increase the natural gas introduction in the energetic matrix of the country (to increase the use in 13% in the matrix until 2010). It can transform the co-generative unities – unities that produce electric energy associated to the production of other potency like cold, heat or electric, from waste energetic stream, for example, exhaustion gases of internal combustion of motors – a good alternative to the energy decentralization.

Kanoglu et al. (2005) say that the generation of electric potency through motors, which have internal combustion, represent about 10 to 15% of the total installed capacity in all the world. They also say that the decentralized energy production offers interesting opportunities to private investors.

However, the implantation possibilities to the cogerative unities, should be preliminary evaluated through thermodynamic analyses, so these analyses can be tools to make decisions in the model definitions to be used and they also can optimized installations. From these analyses emerges the exergy, which can identify inefficiency energetic points, giving optimization to the unities with co-generation.

The exergy concept comes out in 1956 from the Rant studies (Kotas, 1985 reffering to the Rant´s work). This concept has been disseminating since the begin of the 80's with many works about the meaning, and plants evaluations of potency generation.

Gean et al. (2004b) studied a thermoelectric implantation in a specific park city mall in Salvador, evaluating the thermal and exergetic efficiency of the unity equipments, and the installations in general. They also found out through information, which were given by the producers that the best configuration to be implanted in the operation would be the use of internal combustion motors to the electric production potency.

Gean et al. (2004a) studied the implantation of a co generation system in another park city mall in Salvador. They identified the principle irreversibility of the system to serve as base to optimize the enterprise.

In the industrial sector and in the exergetic evaluation field as well, Torres (1999) evaluated a big thermoelectric unity (based on the Rankine, Brayton and combined cycles), which is responsible for the Petrochemical Polo in Brazil northeast; identifying improved possibilities in the operation ways of the unities, having the exergetic and exergoeconomic as bases.

Kanoglu et al. (2005) also evaluated a unity, which generates potency that uses internal combustion motors that operate with diesel. They identify principle sources that destroy exergy and can serve as information to optimize the unity.

The objective of this study is the preliminary evaluation from a thermodynamic analyze (based on the exergy concept, called exergetic or rational analyze), a basic project of a co generative unity for a search center in the city of Salvador. The objective of the unity is to produce electric energy from internal combustion motors, burning natural gas and diesel and biodiesel mixture, bringing to the center self sufficiency in the energy production of this utility. Another important objective to the center, which will be contemplate in the installation, is to produce cold water to the central air conditioned system, through co generation from chillers that will be getting the reject energy of the motors, like the exhaustion gases and the cooled water of these exhaustion gases. This research center, which is in the extension final phase, will have, after this extension, a search for electric energy in your full capacity (around 1 MW), besides the refrigeration capacity (around 400 TR) to the air conditioned system.

2. DESCRIPTION OF THE INSTALLATION AND THE USED METHODOLOGY

The installation in question is showed in the Figure 1. It is composed by three internal combustion motors attached to electric generators and associated to absorption chillers to cold water. Also, there is in the installation a cooled tower used to chilled water, used in the condensation of the cooled fluid and in the cooling of the absorption process; both processes are localized in the absorption chillers. The yellow lines indicate the supply of natural gas to the motors; the black lines indicate the mixture of diesel and biodiesel supply, and the blue lines show the supply of the combustion air. The strong yellow lines, present the circuit of the water and the cooling of the motors (AGRM), the red lines show the circuit of the motors exhaustion gas, the orange lines represent the cold water circuit and the green line indicate the cooled water circuit of the chillers.

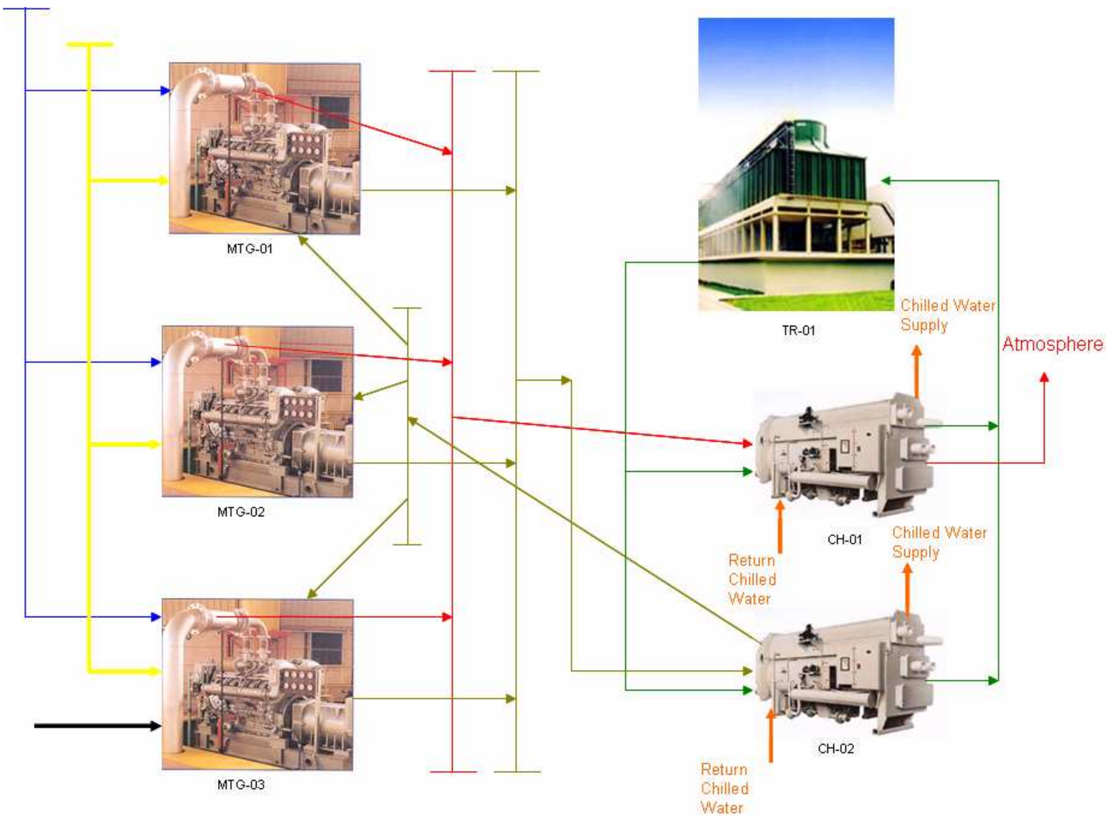

Figure 1. Installation of the Cogerative Unity

The preliminary specifications of the principal equipments in the installation (generator mottos group and absorption chillers), selected from the demand of the research center are presented in the following Table 1:

Table1. Preliminary Specifications of the Generator Mottos Groups and Absorption Chillers.

ITEM	DESCRIPTION	SPECIFICATION
MTG-01	Generator motto group Otto cycle having natural gas as fuel.	Generator motto group with unitarian potency of 395 KWe.
MTG-02	Generator motto group Otto cycle having natural gas as fuel.	Generator motto group with unitarian potency of 395 KWe.
MTG-03	Generator motto group Otto cycle having natural gas /diesel-biodiesel as fuel.	Generator motto group with unitarian potency of 395 KWe.
CH-01	Absorption chiller having exhaustion gas as hot fountain.	221 TR with 1.38275 COP (performance coefficient) of freezer capacity
CH-02	Absorption chiller having motors cooling water as hot fountain.	258 TR with 0.75175 COP of freezer capacity

The information to the thermodynamic evaluation of the installation is presented in the Table 2. These information were collected with the producers of the pre-selected equipments to the installation, besides some estimated conditions, which information wasn't given by the producers.

Table 2. Thermodynamic Properties in the Installation.

COLLECTION POINT	DESCRIPTION	T (ºC)	P (kPa)	m (kg/s)	h (kJ/kg)	s (kJ/KgK)	Ex (kW)
01	Air entrance to motors	25	101.30	0.747*	298.60	5.695	0.06175
02	Natural gas entrance to MTG-01/02 motor.	25	202.60	0.023*	-	-	1182
03	Natural gas entrance to MTG-03	25	202.60	0.0052*	-	-	267.3
04	Diesel/biodiesel entrance to MTG-03 motor	25	202.60*	0.0208*	-	-	17.06**
05	Way out of cooling water at the motors.	99	303.90*	1.513*	415	1.295	50.48
06	Way out of exhaustion gases at the motors.	478	303.90*	1.194*	69831	220.10	4368**
07	Cooling water way out of the tower.	30	150.00*	158.06*	125.8	0.4365	41.08
08	Cooling water entrance of the tower.	35.50	152.00*	158.06*	318.70	0.5117	133.10
09	Chilled water entrance in the absorption chillers (CH-01)	12	160*	37.22	50.52	0.1804	48.97
10	Chilled water way out in the absorption chiller (CH-01)	7	160*	37.22	29.57	0.1063	91.74
11	Chilled water entrance in the absorption chillers (CH-02)	12	160*	43.33	50.52	0.1804	57.01
12	Chilled water way out in the absorption chiller (CH-02)	7	160*	43.33	29.57	0.1063	106.80

*Estimated values, once there is not a completely definition of the equipments.
** To the mixture of 2% of biodiesel to diesel.

The methodology of the implemented analyze was the evaluation using the concept of exergy as basis; from this methodology were evaluated the exergetic efficiencies (the second law) of the generator mottos groups in the installation, comparing the found values with the thermal efficiencies of the first law.
The free energy that is available (exergy), is calculated from the water taxes and from the exhaustion gases, and it was found from the concept of the specific exergy (ex), spreading in many literatures, like Wylen et al. (2003), is presenting as:

$$ex = (h - h_0) - T_0 (s - s_0) \tag{1}$$

The symbol "h" is the specific entalphy and the "s" is the specific entrophy, and "ho" and "so" are the values of the specific entalphy and entropy to the references of the conditions.

The variance of enthalpy, entropy and the heat specific of the exhaustion gases is given by the following correlations:

$$\Delta h = \int c_P \Delta T, \quad \Delta s = \int \frac{c_P}{T} dT \quad e \quad c_P = \sum_j x_i c_{pi} \tag{2}$$

$c_{pi}=A_i+B_iT+C_iT^2$ (Calen, 1960) and represent the calorific capacity of the i compound, presenting in the exhaustion gases, calculated from the composition of the natural gas and the mixture of diesel/biodiesel, masses of air and fuel, considering the proportion of the elements in a composition combustion.

Yet, the exergies of the used fuels were determined from the formulation, which was presented by Kotas (1985) referencing Szargut and Styrylska (1964), which determine a factor φ to calculate the associated exergy to the fuel, from the elementary composition in mass of the fuel, and from the calorific inferior power (PCI). This factor, to liquid fuels, is given in the following way:

$$\varphi = 1.0401 + 0.1728\frac{h}{c} + 0.0432\frac{o}{c} + 0.2169\frac{s}{c}\left(1 - 2.0628\frac{h}{c}\right) \tag{3}$$

The "h", "c", "o" and "s" are percentages in mass of the elementary analyze of the fuel. To the natural gas, this value is tabled and presents 1.04 +/- 0.5% (Kotas, 1985). The exergies of the fuels will be found from the multiplication of this factor with the PCI of each analyzed fuel as:

$$ex_{Comb.} = \varphi * PCI_{Comb.} \tag{4}$$

The pressure and ambient temperature conditions of reference, which were established to the work, were 101.30 kPa and 25 ºC.

The thermal, electric and global calculated efficiencies, from first and second law, were based on presented concepts by Kotas (2005) and by Gean et al. (2004b). The formulations to the efficiency calculations to the equipments, and also to the installations are summarized in the Tables 3 and 4.

All the analyzes were elaborated through the simulation model elaborated in the EES platform (Engineering Equation Solver).

Table 3. Formulations to the Calculation of the First Law Efficiency in the Installation.

ITEM	FORMULATION
Thermal	
MTG-01/02	$\eta_{Motor} = \frac{W_{Motor}}{\dot{m}_{gas} PCI_{gas}}$
MTG-03	$\eta_{Motor} = \frac{W_{Motor}}{\sum \dot{m}_{comb.} PCI_{comb.}}$
Installation	$\eta_{Instalação} = \frac{\Delta H_{chilled-water}}{\sum \dot{m}_{comb.} PCI_{comb.}}$
Eletric	

Installation	$$\eta_{Instalação} = \frac{W_{total\ eletric}}{\sum \dot{m}_{comb.} PCI_{comb.}}$$
Global Installation	$$\eta_{Instalação} = \frac{\Delta h_{chilled\ water} + W_{total\ eletric}}{\sum \dot{m}_{comb.} PCI_{comb.}}$$

Table 4. Formulations to the Calculation of the Second Law Efficiency in the Installation.

ITEM	FORMULATION
Thermal MTG-01/02	$$\psi_{Motor} = \frac{W_{motor}}{\dot{m}_{gas} PCI_{gas} \varphi_{gas}}$$
MTG-03	$$\psi_{Motor} = \frac{W_{motor}}{\sum \dot{m}_{comb.} PCI_{comb.} \varphi_{comb.}}$$
Installation	$$\psi_{Instalação} = \frac{\Delta Ex_{chilled\ water}}{\sum \dot{m}_{comb.} PCI_{comb.} \varphi_{comb.}}$$
Eletric Installation	$$\psi_{Instalação} = \frac{W_{total\ eletric}}{\sum \dot{m}_{comb.} PCI_{comb.} \varphi_{comb.}}$$
Global Installation	$$\psi_{Instalação} = \frac{\Delta Ex_{chilled\ water} + W_{total\ eletric}}{\sum \dot{m}_{comb.} PCI_{comb.} \varphi_{comb.}}$$

3. RESULTS AND DISCUSSIONS

The first (η) and the second (Ψ) efficiencies laws found to the motors and to the installations are presented in the following Tables 5 and 6:

Table 5. The First Law Efficiencies of the System.

ITEM	η (%)
Thermal	
MTG-01/02	34.75
MTG-03	34.51
Installation	49.35
Eletric	
Installation	34.67
Global	
Installation	57.51

Table 6. The Second Law Efficiencies of the System.

ITEM	ψ (%)
Thermal	
MTG-01/02	33.41
MTG-03	32.52
Installation	2.59
Eletric	
Installation	33.11
Global	
Installation	35.70

The evaluation of the efficiency values of the first and the second law makes us affirm that the big fountain of the reduction of system efficiency is the process of the heat transference in the chillers, which generated low second law efficiency, even thought it has a first law bigger than the motors ones and bigger than the electricity generation ones. It shows the low capacity of the system to generate cold with higher quality. In a more consistent analyze, it was necessary to analyze each equipment of the system to identify the principal fountain of exergy. Therefore, the irreversibility of the equipments was calculated.

The irreversibilities (I) of the equipments of the system is presenting in the Table 7. The percentage values of the global available exergy distribution in each equipment are also presenting.

Table 7. Irreversibity and Destruction of the System's Exergy.

ITEM	I (kW/K)	EXERGY DESTRUCTION (%)
MTG-01	787.3	11.78
MTG-02	787.3	11.78
MTG-03	819.5	12.26
CH-01	4278	64.00
TR-01	12.29	0.18

The irreversibility was calculated from the calculation of the equipments' second law efficiency. The calculation of the efficiency to the chillers and tower, because they are dispersing equipments, was based on the thermodynamic perfection degree. The analyze of the information gives to us the possibility to observe that the loss of the efficiency in the system is caused by the motors and CH-01 chiller; by the chiller in special. The chiller uses exhaustion gases with high temperature, as energy fountain, in the process of transferring heat; therefore, it has a high level of exergy destruction, showing the influence of the heat transferring to the exergy destruction.

The irreversibility value that was found to CH-02 was very low, because of the high perfection's thermodynamic degree, which calls attention to the necessity of analyzing this equipment more carefully, when all the information to this equipment is defined.

The analyzes, which were elaborated, until this time in this article, were based on the MTG-03, using a mixture of 2% of biodiesel in the mixture of diesel/biodiesel.

For a better effect's analyze of the biodiesel addition in the motor MTG-03, and its influence in the efficiency of the unity, it was simulated the percentage variation of the addiction in the motor, according with the nomenclature defined by the Brazilian government (for example, B2: grade of mixture of 2% of biodiesel in the diesel). The levels of addition, which were tested, were 2, 5, 10 e 20%. In the Table 8 is presenting the efficiency values found in the first and in the second law.

Table 8. Efficiencies with Biodiesel grade variation in the mixture with Diesel.

ITEM	B2	B5	B10	B20
MTG-03(1ª Law)	34.51	34.60	34.76	35.07
MTG-03(2ª Law)	32.52	32.60	32.73	33.00
Thermal Efficiency 1ª Law(Installation)	49.35	49.40	49.47	49.62
Electric Efficiency 1ª Law(Installation)	34.67	34.70	34.75	34.85
Global Efficiency	57.51	57.56	57.65	57.82

1ª Law(Installation)				
Thermal Efficiency 2ª Law (Installation)	2.60	2.60	2.60	2.60
Electric Efficiency (2ªLaw (Installation)	33.11	33.14	33.18	33.27
Global Efficiency 2ª Law (Installation)	35.70	35.72	35.77	35.87

The results of the evaluation in the Table 8 allow us to affirm that the use of biodiesel in the percentages of analyzed mixtures doesn't bring better quality and efficiency energetic to the system. The big impact, which can be producing with the use of biodiesel is in the reduction of pollutants; it will probably be evaluated in case the undertaking happens.

4. CONCLUSIONS

The article evaluates the energetic and exergetic efficiency of a preliminary basic project of a thermoelectric unity with cold water generation to a research center in Salvador/Ba. The analyze of the results, which was found, allows us to conclude that:

- The installation has low thermal efficiency and low energetic quality in its processes.
- The big fountain of exergy destruction in the system is caused by the process of cold water production in the chiller, which uses exhaustion gases of the motto generation groups as energy fountains.
- The use of biodiesel in the evaluated grades (B2, B5, B15 e B20) does not bring significant increasing of energetic efficiency to the system, however it can decrease the emission of the pollutants.
- If the undertaking happens, to make energetic improvements possible and the operation more efficient (and with better energetic quality), more consistent energetic and exergetic analysis of the system must be made, with the complete definition of the system's basic project.

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