EFFICIENCY INDICATORS IN COGENERATION SCHEMES

INDICADORES DE EFICIÊNCIA EM ARRANJOS COGERADORES

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ABSTRACT

This work makes an analysis about technical and thermodynamics indicators in cogeneration schemes. With the recent crisis of energy supply in Brazilian market, cogeneration starts to play an excellent alternative for composition of energetic matrix of the country. One of the most important step in cogeneration analysis is the identification of technical and thermodynamic indicators, that establish a comparative frame between the possible arrangements proposed. Thus the objective is to show which is the more consistent parameter between the various possible indicators. An installation with a backpressure turbine is used for reference, because this is the more complicated one. Additional operational characteristics like variable power to heat ratio is inserted in the reference plant to validate the study in a more complex scenario.
Keywords: cogeneration, fuel utilization factor, heat rate, artificial efficiency, fuel savings.

RESUMO

Trata-se aqui de indicadores técnicos e termodinâmicos aplicados em arranjos cogeradores. Com a recente crise de fornecimento de energia no Brasil, a cogeração passa a desempenhar papel importante na composição da matriz energética do país.Um dos passos mais importantes na análise de arranjos cogeradores é a identificação de indicadores técnicos e termodinâmicos, que permitam uma visão comparativa dentre as várias opções tecnológicas possíveis. O objetivo é mapear os parâmetros mais utilizados e mostrar qual deles é o mais consistente. Uma instalação cogeradora com turbina de contrapressão e taxa potência/calor flexibilizada é utilizada como referencial, por se tratar do arranjo mais complexo dentre as alternativas existentes e, assim permitir a validação do estudo no cenário mais abrangente possível.
Palavras-chave: cogeração, fator de utilização de combustível, eficiência artificial, economia de combustível.

1 - REVISION ABOUT INDICATORS

There is some general indicators used in cogeneration and in others energy conversion systems for the comparison between the technological alternatives. In a steam boiler for example, the energy input present in a fuel is compared with the energy produced present in steam. So there is an efficiency called steam boiler efficiency and defined here by $\eta c = (Q_H \div F)$, where Q_H is the heat produced in steam, mass flow of steam multiplied by the enthalpy drop of steam in the boiler, and F the energy furnished by the fuel, mass flow of fuel multiplied by its lower heating value. There is too an efficiency for conventional thermal cycles called here of $\eta_T = (W \div F)$ where W is the power produced and F is defined in the same former manner. Also there is a more usual indicator utilized by the power industry called Heat Rate and defined by HR = (F÷W), measured in BTU/kWh in English units and in kJ/kWh in SI units.

In cogeneration schemes and in conventional separate production of heat and power is defined the power to heat ratio, called here SK = (electrical power ÷ process heat), and fuel utilization factor, FUF = {(W + PH) / F} where W is the power produced, PH the process heat and F the fuel input to the plant and is the same of the previous definition. HORLOCK (1987) identify an artificial efficiency for cogeneration schemes and define it by $\eta a = W \div \{ Fcog – (PH \div \eta c)\}$. Here Fcog is the total fuel input to the cogeneration plant, PH is the process heat and ηc the efficiency of a conventional steam boiler, so the artificial efficiency is very similar to the thermal efficiency of conventional cycles. In this definition the process heat is supposed to be produced in a conventional boiler, the technological alternative for to do this, and is "subtracted" of the total fuel input of cogeneration in an "artificial" manner.

The new parameter proposed here for investigation is called fuel savings and defined by EC = (Fconv – Fcog) where Fconv is the fuel input to a conventional separate production of heat and power, and Fcog is the same for the co-generated one. So EC can be negative, zero or positive. In the first and second events the cogeneration isn't a good option relative to conventional installation, but in the third depending of the magnitude of the parameter, cogeneration is a good choice. The units employed in the parameter can be in energetic basis (kW, BTU/h, etc) or in monetary basis(currency units). In the following the parameter will be compared with the others and using a more complex cogeneration plant, with a backpressure turbine with power to heat ratio variable, will be compared with the possible operational conditions of reference plant too.

2 - METHODOLOGY AND RESULTS

A reference plant of cogeneration with a backpressure turbine and power to heat ratio variable is used for the analysis and conclusions about the consistency of the parameter proposed here. The plant is the more complex one because operates with the power to heat ratio adjustable and variable. The Figure 1 in the following shows the essential of the installation.

In the reference plant, Figure 1, a variable power to heat ratio is obtained by the control valve. When there is a need of process heat without the accompanying power the additional steam flow mv2 is diverted to the valve. The steam flow mv1 is the flow destined to the turbine for power production and process heat in the sequence. The parameter fuel savings is used here in energetic units (thermal MBTU/h) and is compared with the others for consistency evaluation. The annual operational characteristics of the plant are resumed in Table 1 and are a more realistic one. In the conventional separated generation the parameters utilized are a boiler with 80% of efficiency, and efficiency of 34% for the conventional thermal cycle. A simulation model implement in EXCEL® was made and applied to analyse reference plant in several operational conditions.

The first comparison is made between the fuel savings and artificial efficiency defined by HORLOCK (1987). The Figure 2 in the following shows the results.

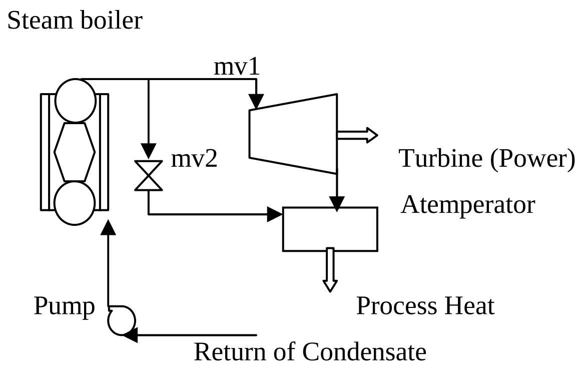

Figure 1.The Reference Backpressure Cogeneration Plant

In Figure 2 the fuel savings shows its consistency. When the cogeneration is penalized with reduction in the economy of fuel relative to a separated production, the artificial efficiency drops. When the fuel savings grows up the same happens with artificial efficiency. So there is a perfect correspondence between the two parameters.

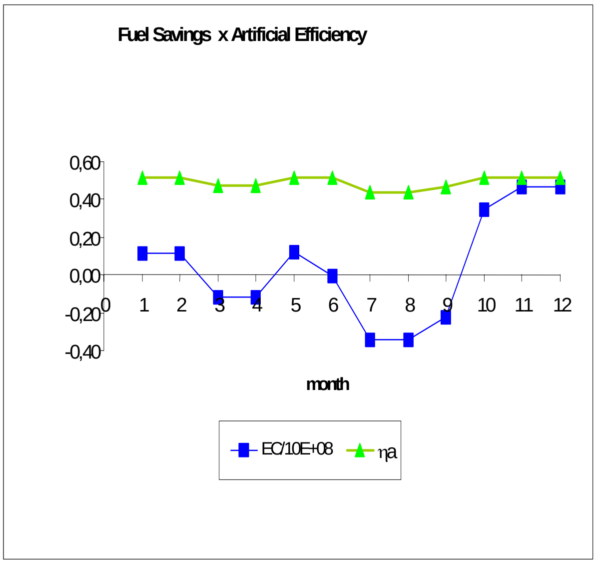

Figure 2 - Fuel savings x Artificial Efficiency

And how the artificial efficiency is a measure of the thermal efficiency of cogeneration, the coupled behavior of the two parameters shows that the fuel savings is a consistent parameter.

The next plot is Figure 3, which shows how the fuel savings to behave when there is steam extracted to the valve or to the turbine. Extract steam to the valve penalizes the cogeneration cycle because there is reduction in the power, and because the power is the more valuable of the two kinds of energy produced. Figure 3 confirms this fact. So for to maintain a variable power to heat ratio there is an additional penalty to the cogeneration plant, mainly when there is a need of more process heat. And the parameter fuel savings measures this with accuracy and precision. The continued operation of cogeneration plant in this manner makes the plant minus attractive too.

The last plot, Figure 4, is about fuel savings and heat rate, a more traditional parameter utilized in efficiency indicators. Here the fuel savings shows its consistency too. When heat rate drops, an indication of best performance of the cogeneration plant, the fuel savings grows up. And when the heat rate grows up the fuel savings drops, and the cogeneration advantages fall.

The plot of fuel savings and fuel utilization factor shows no consistency and makes evident that fuel utilization factor is a poor indicator of cogeneration performance, fact showed and discussed by POLSKY (1983,1985).

Table 1. Annual Characteristics of Reference Plant

Mês	Power		Process Heat	
	KW	**BTU/h electrical**	**KW thermal**	**BTU/h thermal**
January	2.300	7,85E+06	11.723,00	4,00E+07
February	2.300	7,85E+06	11.723,00	4,00E+07
March	5.800	1,98E+07	10.433,47	3,56E+07
April	5.800	1,98E+07	10.433,47	3,56E+07
May	10.420	3,56E+07	93.783,99	3,20E+08
June	11.332	3,87E+07	116.057,69	3,96E+08
July	8.100	2,76E+07	116.057,69	3,96E+08
August	8.100	2,76E+07	116.057,69	3,96E+08
September	9.200	3,14E+07	116.057,69	3,96E+08
October	9.200	3.14E+07	58.614,99	2,00E+08
November	10.420	3,56E+07	58.614,99	2,00E+08
December	10.420	3,56E+07	58.614,99	2,00E+08

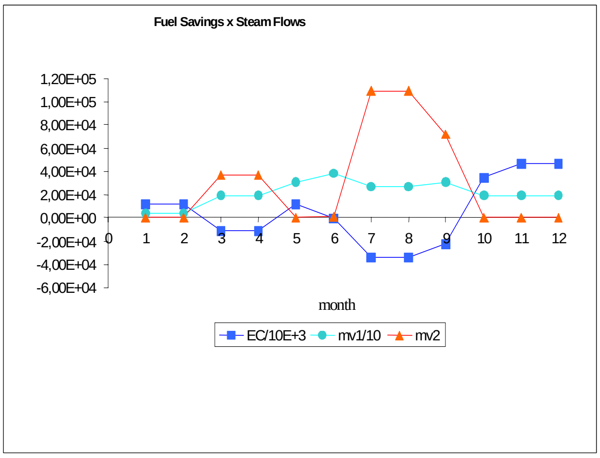

Figure 3. Fuel savings x Steam Flows

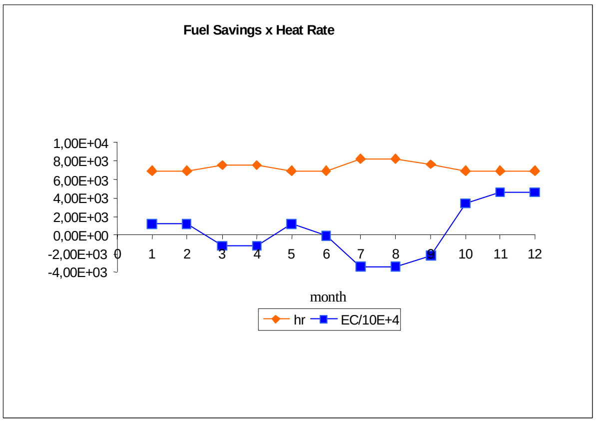

Figure 4. Fuel savings x Heat Rate

3 - CONCLUSION

With the applied methodology, simulation model, and the resulting plots of the various comparisons, one waits to have showed that fuel savings is a good parameter for evaluate cogeneration plants compared with separated generation or conventional generation. The parameter was utilized here in energy basis but same conclusions are true if used in monetary basis.

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Symbols.

η_a	Artificial Efficiency
η_c	Steam Boiler Efficiency
η_t	Thermal Efficiency of Conventional Steam Cycles
PH	Heat Process
EC	Fuel savings
F	Fuel Input to the conventional thermal plants
Fcog	Fuel input to Cogeneration Plants
Fconv	Fuel input to the separated generation of heat and power
FUF	Fuel Utilization Factor
HR	Heat Rate
mv1	steam flow to the turbine in reference plant
mv2	steam flow to the valve in reference plant
QH	Thermal input to steam in a conventional boiler
SK	Power to Heat Ratio
W	Power