COBEQ 2018
XXII CONGRESSO BRASILEIRO DE ENGENHARIA QUÍMICA
23 a 26 de Setembro de 2018
Hotel Maksoud Plaza
São Paulo – SP

ENBEQ 2018
XVII ENCONTRO BRASILEIRO SOBRE O ENSINO DE ENGENHARIA QUÍMICA
27 a 28 de Setembro de 2018
USP
São Paulo – SP

OPTIMIZATION AND ENERGY HARNESSING OF A WASTE-WATER TREATMENT PLANT

LIMA FS[1], ALVES VMC[1], ANJOS DA[1], ALVES, JJN[1] e ARAÚJO ACB[1]
[1] Universidade Federal de Campina Grande, Centro de Ciências e Tecnologia, Departamento de Engenharia Química
E-mail para contato: felipe.lima@eq.ufcg.edu.br

RESUMO – *The treatment of waste-water is a constant concern of the modern world, given the inherent enhancement of human-life quality and wellbeing through public health improvement. The present work aims at optimizing a state-of-art waste-water treatment plant model and to propose different co-generation process configurations with the purpose of recovering energy by means of burning the biogas produced by the plant and, consequently, reducing its overall operational costs. The optimization took into account disturbances of the waste-water treatment plant feed in order to meet environmental regulations. The results from the co-generation implementation show that a reduction of up to 73% of the electrical power consumption, and all of the heating required by this plant model.*

1. INTRODUCTION

This study is based on a recent work (Jeppsson et al. 2011), which contains a reference manual for the layout of an activated sludge waste-water treatment plant with information about simulation models (already implemented in MATLAB/Simulink®), influent composition to be treated, test procedures and other evaluation criteria. However, the work of Jeppsson et al. (2011) does not refer or propose a methodology to optimize costs nor reduce energy consumption related to the plant operation (such as bioreactor aeration, pumps, mixers and heaters). On this account, the present study proposes the evaluation of a viable equipment configuration that will allow the reduction of energy costs through the use of the biogas, produced in this wastewater treatment plant, in a cogeneration process.

2. WASTE-WATER TREATMENT PLANT MODEL

The process flow diagram (PFD) proposed by Jeppsson et al. (2011) for the WWT plant is described there. The whole model was used in this work, with the co-generation process proposed attached to it, and also built on MATLAB/Simulink®. The biogas source used is the stream that comes from the anaerobic digester outlet (2,650 m^3 d^{-1} at nominal operation, 65% CH_4, 35% CO_2, on volume basis); see Jeppsson et al. (2011) for more details.

3. CO-GENERATION PROCESS DESIGN

The PFD (figure 1) consists of one air compressor, a furnace, two boilers (heat exchangers), two steam turbines (back-pressure type), one gas turbine and two pumps, for all three turbines and air compressor the isentropic efficiency assumed was 60%. The biogas product stream is being fed to the air compressor before going into the furnace. The gases coming the furnace are quenched in a boiler until they achieve the specified temperature for this turbine (approximately 1000 °C). A water pump feeds the first boiler used to quench the hot gases and the steam generated (10 bar and 500 °C) is sent to a steam turbine to produce energy. See Smith et al. (2000) for more details on the calculation procedure of the furnace and water pumps used in the co-generation process.

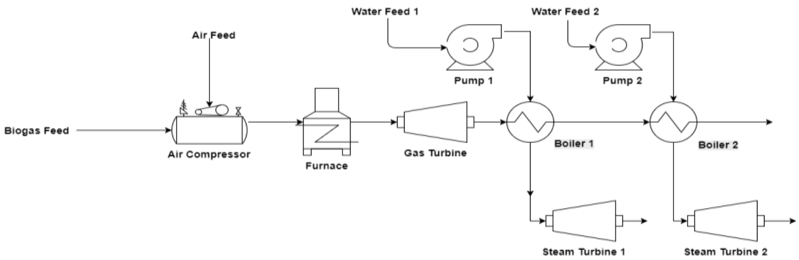

Figure 1 - Process flow diagram of the co-generation equipment configuration

4. SURROGATE MODELLING – KRIGING

According to Palmer and Realff (2002), surrogate models can be defined as mathematical simplified functions, based on data that were obtained through a rigorous model. The main goal of using a surrogate model is to substitute partially or totally the original model, in cases that the first demands a high computation effort. The basic methodology of generating a surrogate model consists in:

i. Selection of a sampling method to generate the input data;
ii. Feed the rigorous model with the input data to generate the response (Computer Experiment)
iii. Feed both input and output data to the algorithm that will generate the surrogate model (e.g. artificial networks, kriging)
iv. Cross-Validation between the surrogate model and the rigorous model in points not used in the generation of the metamodel.

The sampling method used in this work was the Latin Hypercube Sampling, and further information can be found on McKay et al. (1979). A kriging toolbox built in MATLAB® named DACE (Design and Analysis of Computer Experiments), developed by Lophaven et al. (2002) was also used. The output variables are the effluent pollutants concentrations and the Overall Cost Index of the plant. The computer experiment was carried out considering 60 cases for the disturbances and 600 cases for the manipulated variables.

5. PLANT OPTMIZATION

The model proposed by Jeppsson et al. (2011) was optimized seeking the minimization of the plant Overall Cost Index (OCI). The constraints were the environmental limits for the main pollutants found in WWTPs that need to be specified. Each term of the equation for the OCI are also described at Jeppsson et al. (2011), and they correspond to Aeration Energy (AE), Pumping Energy (PE), Sludge Production (SP), External source of Carbon (EC), Mixing Energy (ME), Methane production (MET) and Heating Energy (HE). Therefore, the optimization problem is defined by the following model:

$$\begin{aligned} &\min_{MV} OCI = AE + PE + 5SP + 3EC + ME - 6\mathrm{MET} + \mathrm{HE} \\ &subject\ to\ TN < 18 gNm^{-3} \\ &\qquad TSS \leq 30\ gSSM^{-3} \\ &\qquad COD \leq 100\ gCODm^{-3} \\ &\qquad SNH \leq 4\ gNm^{-3} \\ &\qquad BOD_5 \leq 10\ gBODm^{-3} \end{aligned} \tag{1}$$

6. RESULTS

The WWT plant described by Jeppsson et al. (2011) requires 5210 kWh d^{-1} to keep the aerators, pumps and mixers operating. Another 4180 kWh d^{-1} are required for heating at the anaerobic digester inlet, from 15 °C to 35 °C. Thus, the heating energy required by the plant can be fulfilled (the anaerobic digester inlet is the only process that requires heating), since the outlet vapor from the steam turbines, being used as a heating utility, has a rate energy of 13,000 kWh d-1. The net energy produced by this cogeneration process was 3799 kWh d^{-1}. Other variables values from the energy recovery process are described in Table 1.

Table 1 - Results obtained from the cogeneration process

Equipment	Variable	Value	Unit
Furnace	T_{outlet}	1,452	K
Gas Turbine	W_{Shaft}	5,832	kWh d^{-1}
Steam Turbine (First)	W_{Shaft}	516	kWh d^{-1}
Steam Turbine (Second)	W_{Shaft}	1,510	kWh d^{-1}
Air Compressor	W_{Shaft}	5064	kWh d^{-1}
Water Pump (First)	W_{Shaft}	1.8	kWh d^{-1}
Water Pump (Second)	W_{Shaft}	5.4	kWh d^{-1}

A cross-validation method was done to evaluate the effectiveness of the kriging response generated. Considering one hundred points that were not used to build the metamodel of the BSM2, these were evaluated both at the original and surrogate model and one of the sixty cases have their results illustrated on figure 2. All of sixty cases showed the same fitness, a 45° line, confirming the excellent prediction of the surrogate model generated via kriging. The optimization performed for the case studies was capable to find a minimum for the OCI while kept the constraints below the specified limits. The limits for the Manipulated variables considered also attended their range of operability. These results can be seen in tables 3 and 4 respectively. Four cases were randomly selected out of the sixty optimized to be shown in this work.

Table 2 - Manipulated Variables for BSM2 Optimization.

$K_la_3\ (d^{-1})$	$K_la_4\ (d^{-1})$	$K_la_5\ (d^{-1})$	$Q_{intr}(m^3d^{-1})$	$Q_r\ (m^3d^{-1})$	$Q_w\ (m^3d^{-1})$
84.75066	92.89022	94.48983	71,506.46	41,222.77	320
93.9075	84.46492	85.31165	60,465.14	41,189.16	320
90.99753	90.00675	81.59818	74,997.37	41,109.28	320
80.77911	82.45039	80	71,241.02	41,174.15	320

Table 3 - Non-linear constraints (Effluent pollutants concentration) and objective function (OCI) results.

TN (gNm^{-3})	COD $(gCOD.m^{-3})$	SNH $(gN.m^{-3})$	TSS $(gSS.m^{-3})$	BOD_5 $(gBOD.m^{-3})$	OCI $(kWh.d^{-1})$
9.367052	52.22729	4	17.56664	2.520502	8,655,658
15.60611	48.74598	0.351053	15.09672	2.248937	7,286,463
18	45.4172	0.223511	14.33232	2.051964	6,601,467
7.29227	49.02893	2.764697	16.62075	2.44972	8,368,251

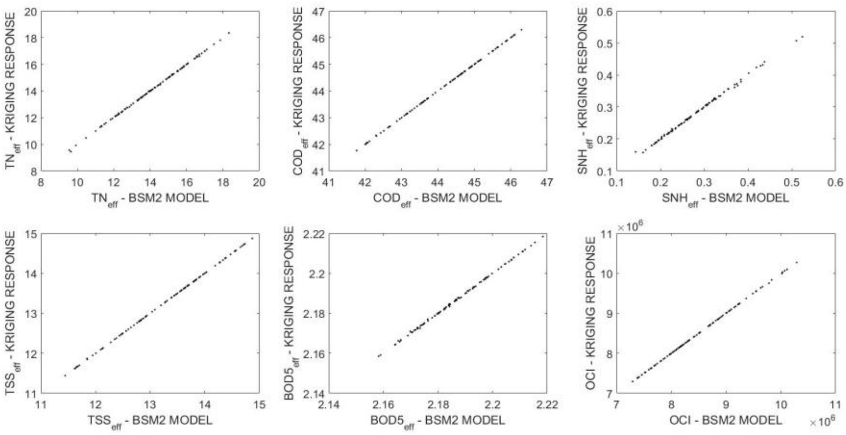

Figure 2 - Kriging response vs BSM2 model response.

7. CONCLUSIONS

The Kriging metamodel generated was capable of representing the original BSM2 model. Therefore, reducing the difficulty of optimizing the process itself. For the co-generation, it is possible to achieve a reduction of, approximately, 73% in the electrical energy consumption, and meet the heating energy demand entirely.

8. REFERENCES

JEPPSSON, U., ALEX, J., BENEDETTI, L., COPP, J., GERNAEY, K., NOPENS, I., PONS, M., ROSEN, C., STEYER, J., AND VANROLLEGHEM, P. (2011). Benchmark simulation model no 2 (BSM2).

LOPHAVEN, S., NIELSEN, H. B., AND SØNDERGAARD, J. (2002). Dace a matlab kriging toolbox. Technical Report 2, University of Denmark, Denmark.

MCKAY, M. D., BECKMAN, R. J., AND CONOVER, W. J. (1979). A comparison of three methods for selecting values of input variables in the analysis of output from a computer code. Technometrics , 21(2):239–245.

PALMER, K. AND REALFF, M. (2002). Metamodeling approach to optimization of steady-state flowsheet simulations. Chemical Engineering Research and Design, 80(7):760–772

SMITH, J. M., VAN NESS, H. C. AND ABBOTT, M. M. (2000). Introduction to chemical engineering thermodynamics. 6 ed. New York: McGraw-Hill.