CHEMICAL ENGINEERING TRANSACTIONS

VOL. 32, 2013

A publication of AIDIC
The Italian Association of Chemical Engineering
www.aidic.it/cet

Chief Editors: Sauro Pierucci, Jiří J. Klemeš
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ISBN 978-88-95608-23-5; **ISSN** 1974-9791

DOI: 10.3303/CET1332037

Computer Aided Evaluation of Eco-Efficiency of Refinery Combustion Process

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The combustion becomes the mechanism to generate energy in industrial equipment such as furnaces and boilers. In terms of trends, progress and processes designed and implemented seek to increase energy efficiency, reduce pollution emissions, increase productivity and develop processes for burning gas of variable chemical composition. The recent research focuses on the implementation of operational control systems to minimize errors in operation and reducing the risks of industrial accidents. In this sense, the eco-efficiency contributes to sustainable development and competitiveness. This concept means adding more value to products and services, using less raw materials, producing less pollution through environmentally and economically efficient procedures and safety process.
This paper evaluates the combustion process using fuzzy logic, in finding methods to achieve efficient processes that harmonize with the care of the environment and ensure process safety. The criteria used in the evaluation process were energy efficiency, the amount of CO_2 and stack temperature, to obtain indicators that allow the management of eco-efficient process, using approximate reasoning based on fuzzy subsets.
Comparing the simulation results with the process historical data, suggest that the index of ecoefficiency calculated describes the performance of the combustion process in furnaces of refinery.

1. Introduction

Combustion equipment in the oil refining industry in general and in the chemical industry can use mixtures of gases generated in the various plant processes. Heater fuels include refinery gas from the crude units and reformers as well as waste gases blended with natural gas. Fuel is regulated from exit feed temperature and firing rate is determined by the level of production desiderate and combustion air flow is regulated by positioning the stack damper (Showers, 2002).
Furnaces used gas with widely varying caloric content as fuel, this can produce large variations in heat delivered in the radiant section, temperature control of the process tubes and reactions is critical in reforming and cracking operations. The challenges are to maximize heat delivery of the process-side feed while minimizing fuel consumption, maximize heat delivery with varying fuel quality, minimize heater structural wear, minimize stack emission and maximize safety levels (IEA, 2010).
Unsafe operation of heaters or burner problems leads to premature failure, structural damages or tube leaks due to flame impingement, secondary combustion and flue gas leaks. Factors affecting safe and efficient process heater performance include safety, burner operation and environmental emissions (United Nation 2010).
This paper presents the use of fuzzy logic as a tool to evaluate the performance of the combustion process taking into account energy efficiency, the amount of CO_2 emitted and the temperature as a parameter to determine the damage of equipment. In the following sections and subsections describe the concepts of fuzzy theory, fuzzy inference system, to evaluate the combustion of variable composition, the methodology followed, the proposed model, the results and conclusions of the study.

Please cite this article as: Saavedra J., Merino L., Kafarov V., 2013, Computer aided evaluation of eco-efficiency of refinery combustion processes, Chemical Engineering Transactions, 32, 217-222 DOI: 10.3303/CET1332037

2. Theoretical bases

2.1 Combustion process

The combustion reaction study includes chemistry kinetics and gas theory, in this regard, in the area immediately after the flame, the combustion products are in chemical equilibrium or very close to equilibrium, so that it can develop methods for calculating the adiabatic flame temperature and the composition of the combustion products.

In order to perform the calculations of chemical equilibrium, thermodynamic properties and predict the conditions of combustion reactions for gas fuel, have been used equations of state in order to predict the behavior of natural gas, as their determination experimental can be difficult and costly. Cubic equations of state are traditionally used for modeling in the oil industry because they offer good results and are mathematically simple (Valderrama, 2003). Numerous investigations have been raised in order to compare the quality of the predictions of the thermodynamic properties from these equations (Alfradique, 2007) the equation Peng and Robinson is the most widely used equation (Skander, 2007).

Gas fuel composition is usually specified in volumetric percentage of different gases that composes it, and the calorific value is a function of the composition and calorific value of each component. Program Aspen HYSYS allows the evaluation of the combustion process in that it provides values of adiabatic temperature, efficiency and products of combustion for combustible gas mixtures.

2.2 Fuzzy logic

In 1965, based on the fundamental concept of temperature variation or multivalency, Professor Lotfi A. Zadeh, Department of Electrical Engineering, University of California at Berkley, formalized fuzzy sets theory (Zadeh, 1965). Graduation was proposed membership of the elements in the sets; an element can be 30 % of a set X and 70 % of the set X '. This explains the transition from a state set X to a set in state X 'as a continuous process in the physical world and to describe as the boundaries tend to be subjective.

There are several defuzzification methods in the literature, the two most commonly used are the center of gravity and the maximum average. The average maximum, the output should be obtained from the average of the two extreme elements in the universe corresponding to the highest values of the consequent membership function. With the center of gravity, the output is the value in the universe that separates the area under the curve of the function in two equal parts. The applications are limitless, and adaptable to all areas.

2.3 Fuzzy Inference System

In the fuzzy inference is interpreted in the input values, and then based on some rules, values are assigned to the output. Figure 1 represents a diagram containing a general scheme describing the fuzzy system.

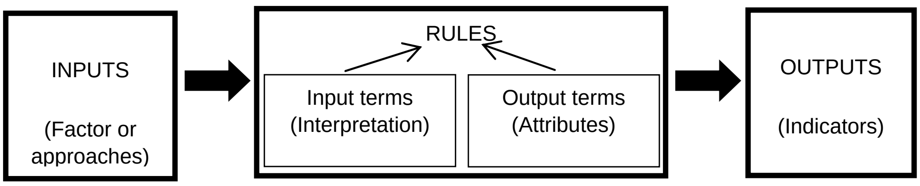

Figure 1: Fuzzy System scheme

The establishment of a fuzzy inference process is performed using a set of rules, which are phrases like structure with an IF / THEN that are interpreted by the system. It is noteworthy that there is a natural parallelism rule, as they are tested, this being one of the most important aspects of fuzzy logic systems. It provides a range of values for each variable analyzed case, as well as what is the meaning of each linguistic term. The fuzzy inference is the process of assigning a given input to an output using fuzzy logic. In this process, we have: membership functions, fuzzy logic operators and rules of the type IF / THEN. Type: [R] IF antecedent THEN consequent (weight).

3. Methodology

The fulfillment of the objectives included collecting historical data from refinery process furnaces and their statistical analysis, followed by computer simulation of the combustion process and development of the fuzzy inference process; these stages are illustrated in Figure 2.

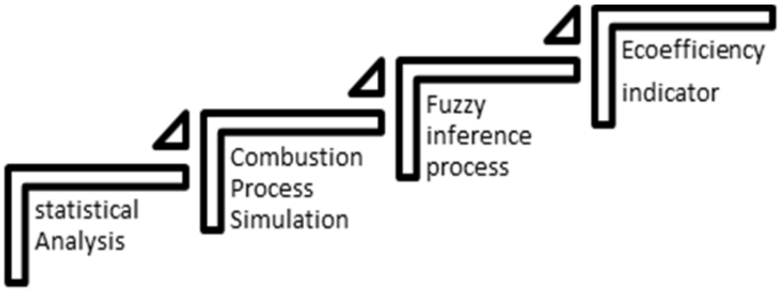

Figure 2: Stages of the methodology

3.1 Statistical analysis of historical data of combustion process at refinery furnaces:
The review of historical production data includes measuring the flow or load, record input and output pressure, inlet temperature, outlet and wall tube and measuring the calorific value, were taken two years period of analysis of historical data.
Data chromatographies of streams identified as contributors to the combustible network were reviewed. Variability of the gas composition, the ranges of each of the identified compounds and analyzing the frequency deviation in the concentration was analyzed by StatGraphics program.

3.2 Combustion Process Simulation
ASPEN HYSYS was used, which is specialized software for simulation of processes chemical and petrochemical industry. Data on energy efficiency, temperature and flue gas compositions were obtained.

3.3 Fuzzy inference process
Data of energy efficiency, adiabatic temperature and amount of CO_2 were used as input in Mandani model, defined rules and defuzzyfication was performed by the centroid method.

3.4 Eco-efficiency indicator
In the post-processing stage each sample by defuzzyfication corresponding to individual ratings between the composition of a position measurement as the mean or the median. In this particular case, the median was used for the characteristic of not being affected by extreme values. Importantly, the output value of the post-processing step can be again converted into the form of linguistic terms. Model results allow identifying the fuel mixtures that promote eco-efficiency in the combustion process.

4. Results

4.1 Simulation process
Based on the simulation scheme for the combustion process shown in Figure 3, fuel gas composition was changed according to boundary established by statistic analysis.

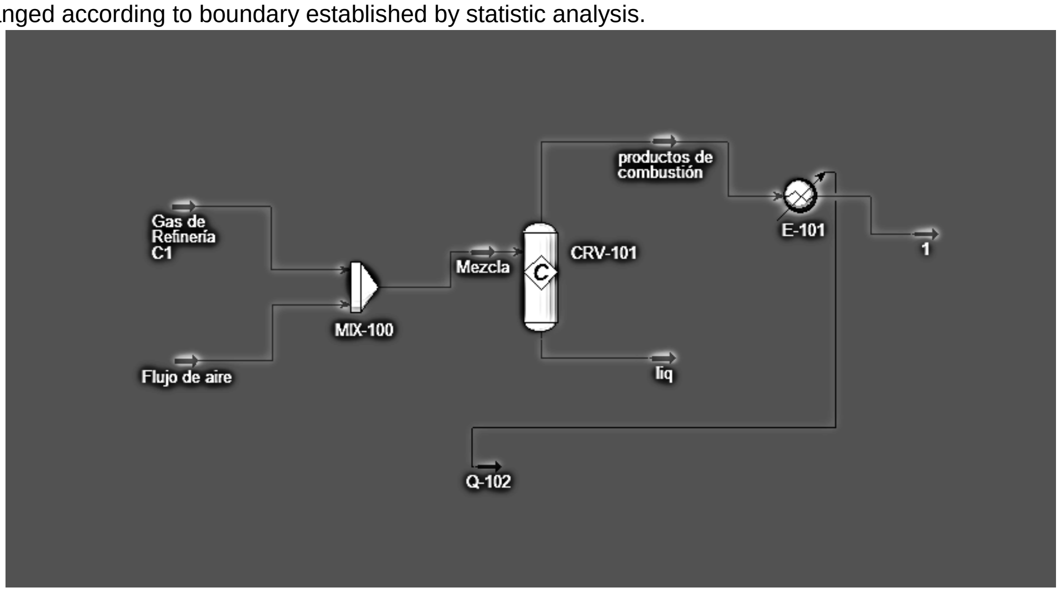

Figure 3: Simulation of combustion process in Aspen Hysys.

Combustible mixtures were simulated by varying the composition of gas components representative refinery fuels for furnaces Simulation results shows mixtures which are possible in the range of calorific value between 7,600 and 18,800 kCal/Nm^3 kCal/Nm^3.
Table 1 shows representative compositions of the possible mixtures and natural gas.

Table 1: Representative compositions of fuel gas

Compound	C1	C2	C3	C4	Natural Gas
CH_4	55	70	25	35	97
C_2H_6	10	0	8	3	1
C_3H_8	0	16	25	35	1
C_4H_{10}	4	5	10	12	0
C_2H_4	5	3	10	7	0.5
C_3H_6	2	0	5	8	0.5
H_2S	4	1	2	0	0
H_2	20	5	15	0	0

4.2 Fuzzy Model

A Mamdani type arrangement was chosen and to support the calculation we used the fuzzy logic toolbox under MATLAB environment. The input variables were corresponding to the three components identified (energy efficiency, adiabatic temperature and CO_2 quantity).
To define the membership functions has been established five levels that are shared by all components, defined levels are: very low, low, medium, high and very high, representing the state of each component and their impact on the eco-efficiency of combustion. The rating of each component determines the values obtained above model input. Table 2 shows the membership functions analyzed.

Table 2: Membership functions

FIS VARIABLES	Type	Range	Membership functions
Energetic efficiency	Input	70-98	Gaussmf
CO2	Input	9-11.1	Gaussmf
Temperature	Input	1910-2120	Gaussmf
Eco-efficiency	Output	0-1	Gaussms

Later, 90 rules were identified with possible values of the variables. For this, it was used the format a set of rules (Del brío and Sanz, 2002):

$$R^{(l)} : \text{IF } X_{1 \text{ is}} F_1^l \text{ and } \ldots \text{ And } X_n \text{ is } F_n^l \text{ THEN } y \text{ is } G^l \quad (1)$$

Note that the rules are common sense and the system behaviour is written in terms of the labels of the membership functions. From this point, it is possible to use the screen and observe the behaviour rules of the system to any changes in the parameters of the input variables.
Rules were validated by operators of refineries and the valuation was made according to the impact on the process of energy efficiency, CO_2 emissions and temperature and taking in count the interactions between them.

4.3 Eco-efficiency indicator

The procedure of this model is to calculate the fuzzy membership degree in fuzzy sets all of the dimensions of input from relevant evaluations for each fuel gas mixture. After this, the eco-efficiency level indicator is determined by fuzzy inference process, which uses a set of rules and then the fuzzy output defuzzyfication. Figure 4 shows an example of eco-efficiency indicator calculated with the following parameters:
Energetic efficiency: 76.7
CO2: 9.01
Temperature: 2120
As shown in figure 4, the model, in Matlab automatically calculates the membership functions according to the rules assigned, and it selects the best result for Eco-efficiency, in this case, using centroid method, obtaining a result of: 0.239 (Very low) eco-efficiency, according with the input parameters.
According to the model, Eco-efficiency indicator shows high values when the combustion process involving mixtures similar to natural gas composition, which is in accordance with the design of the furnaces; eco-efficiency indicator begins to present low values when the efficiency of the furnaces is low, which directly affects the heat supplied by the furnace to the refining process.

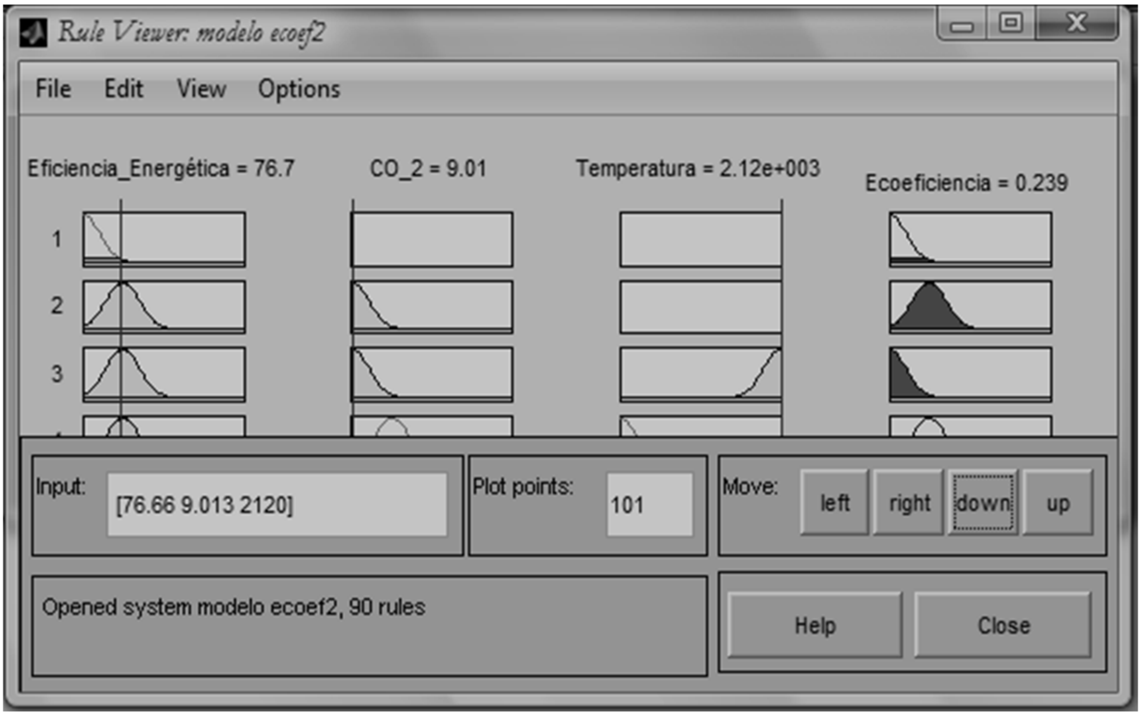

Figure 4: Eco-efficiency indicator

5. Conclusions

The simulation of fuel mixtures in HYSYS program helped assess the combustion characteristics by varying the fuel composition, allowing stable ranges for the percentage of energy efficiency, percentage of CO_2 and adiabatic temperature. The simulation data agree with the process data.

A fuzzy model- based approach for calculated an eco-efficiency indicator was presented. The effectiveness of the model was verified through simulations with data obtained from historical data process at refinery industry.

Rules identified for combustion process were easy attained with fuzzy sets, relating to the fundamental process knowledge.

The model outputs would be used to calculated real-time combustion quality measures, considering a measure for eco-efficiency that integrate safety, environmental emissions and efficiency energetic.

The eco-efficiency indicator allows identify which mixtures can achieve eco-efficiency of processes by integrating energy efficiency factors, the adiabatic temperature and CO_2 emissions. The results show that eco-efficiency indicator is strongly influenced by the energy efficiency of the combustion, presenting a high value when the energetic efficiency is high.

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