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Combustion Optimisation using Methane Number and Wobbe Index as Evaluation Criteria

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One hundred and ten (110) streams have been identified in an oil refining process as contributors to the gas fuel net used in furnaces and boilers to supply power and steam to process. According to the origin of the gases and the previous treatment, these gas streams, have a different composition than the natural gas, which creates problems that affect the operational parameters and the integrity of equipment. It is due to this, which seeks to analyse how the fuel gas flows from a refining process, taking into account the energy efficiency, environmental and safety aspects in combustion process.
Statistical analysis was developed in combustible gases to study their composition considering the origin of each of the streams represented by chromatographic analysis, which, provided the data for calculating the methane's number (MN) via method radius ratio (H/C), and the Wobbe index as criteria for analysing the potential effect of gas fuel composition in efficiency, integrity and environmental emissions equipment.
The methane's number is a parameter which describes the behaviour of the explosive self-initiated and not controlled combustion in gas zone of the front flame (referred as knock Combustion). This knock resistance index, has two reference gases, methane and hydrogen; using a reference fuel mixture in which the methane works with a MN 100 and hydrogen with a MN 0. High numbers of MN means high efficiency and hence lower CO_2. If MN is too low, knock can cause damage or loss in efficiency and performance. The results show that 45% of the streams of petrochemical area presented MN above 80 and 15% of streams presented low MN. Streams of cracking area showed lower MN. These results demonstrate the heterogeneity of currents, so that the methane number is an important reference when defining the logistic for combustible net in combustion process.
Elaborating further on the effects that this variability can generate in the thermal efficiency of each of the currents, so as combustion efficiency and the stability of the operation was evaluated Wobbe Index, and the results showed that when applying these two methods and taking into account the current regulations, a comprehensive analysis can be performed of energy issues, environmental and security in combustion process of fuel variable composition. The principal result was a proposal for a fuel net.

1. Introduction

In most industries, the fuel gas streams are important because of their application in to the generation of thermal energy. City gas, liquefied petroleum gas and natural gas, are the most used. In industries where the presence of combustible gases has high implications into the oil refining industry, the analysis of gas streams from each of the areas of production, becomes an important factor through their involvement in various aspects for the conservation to burning process characteristics.
The oil refining processes are realized on a group of industrial facilities. Crude oil is subject through a process of converting primary energy to secondary one, which results in a variety of products. The refining industry oil and natural gas has strategic value. The main problems found are operational, environmental and process. It is important to remember that large and integrated facilities to industrial centres, in which a number of raw materials have a massive consumption of energy and water is handled, can represent a variety of systemic problems. Although it can occur in different areas, problems are inherent to the

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properties of the product and also, have influence in the infrastructure of the plant. Therefore, analysis of processes have a high importance, sectored or generally.

The process developed in refineries generated lots of environmental emissions, polluted the atmosphere, water and soil. Its major pollutants emissions are carbon dioxide, nitrogen, sulphur(from combustion processes), volatile organic compounds, ammonia, sulphides, garbage, acids, amines and catalysts. The refineries' emissions to the atmosphere, besides, are responsible for the highest levels of contamination because of their points of emitted tons. The existing legislation, depending on the country, fluctuates becoming the environmental regulatory a guideline for the moment of election and application of any method and the assessment of different types of environmental problems such as those presented in refineries, CO_2, NOx, SOx and VOC´s. The methods used must be properly organized in a coherent design, taking in to account different types of properties for instance the feasibility in obtaining data in its implementation, economics and ease of application and maintenance.

In this article we will proceed to evaluate 110 streams of a particular process of refining oil. Which is composed as follows area: gas fields, 3 currents, the production area, has two sub - areas; cracking with 13 streams and petrochemicals that provides 10, the area of gas sold to external, 3 currents, the area of generation of H_2 with 2 streams, the area gas fuel consumed, is the main contributor, 3 sub - areas, refining, with 16 streams, cracking with 20, and petrochemical 21 streams, finally, we have area industrial services with 20 streams. Inside of each area, different processes are applied in the streams individualizing each of the currents. The variable concentration is the cause of turbulence that affects the combustion process, for that reason, we have to look for a burned process with a proper distribution of currents in search to keep the process stable.

2. Method

When developing an initial review of the components of streams it can be seen essentially that it consists of 16 contributors compounds. Varying in their percentages for each stream, corroborating that the heterogeneity is presented and that it would become a problem when the streams are mixing, creating turbulence that would reduce the efficiency of the burning process, increasing the chances of equipment damage and emissions to the environment.

For this particular process we use as parameters for evaluating the operating conditions Wobbe index and method number methane of the currents were applied prior to the burning process in order to know the properties of each stream and give guidance for managing the streams involved. The methane number is evaluated in order to analyse the knock resistance of each stream before the ignition, compared with a reference fuel mixture. The calculation is performed by the method of radii ratio (H / C) presented Eq(1), below:

$$\mathrm{MN} = 1.624 * (406.14 + 508.04 * \mathrm{RHCR} - 173.55 * \mathrm{RHCR}^2 + 20.17 * \mathrm{RHCR}^3) - 119.1 \quad (1)$$

Where RHCR represents the relations between the radius of hydrogen and carbon to the radius is given by, Eq(2):

$$\begin{aligned}\mathrm{RHCR} = (&\%\mathrm{methane} * 4 + \%\mathrm{ethane} * 6 + \%\ \mathrm{propane} * 8 + (\%\ \mathrm{sobutene} + \%\ \mathrm{n-butane}) * 10 \\ &+ (\%\ \mathrm{isopentane} + \mathrm{n-pentane}) * 12 + (\%\ \mathrm{hexane\ and\ longer\ hydrocarbon\ chains}) \\ &* 14)\ /(\%\mathrm{methane} * 1 + \%\ \mathrm{ethane} * 2 + \%\ \mathrm{propane} * 3 + (\%\ \mathrm{sobutene} + \%\ \mathrm{n} \\ &- \mathrm{butane}) * 4 + (\%\ \mathrm{isopentane} + \%\ \mathrm{npentane}) * 5 \\ &+ \%\ (\mathrm{hexane\ and\ longer\ hydrocarbon\ chains}) * 6)\end{aligned} \quad (2)$$

We can define the method of the methane's number as the volume percentage of methane mixed with the hydrogen is equal to an unknown mixture, that under the same conditions produced the same reaction, an audible sound, which produces high temperatures and high pressure degrade materials used in equipment and corrodes, called auto ignition. Inert gases are excluded in the methane's number equation, therefore unaffected value when applied method. It is through the analysis of the resulting dimensionless values, which are in a range where the limits represent the association of each of the members guide mixture, for example for this case study, the flow was evaluated to have a value 0, what means having a resistance equal to a mixture which is 100 % hydrogen and a value of 100 means having a resistance equal to the ignition which is a blend of 100 % methane. Therefore, there may be values greater than 100, which would mean that the assessed current have an even greater resistance to a mixture of 100 % methane, representing high percentages, a new range of assessment as a starting point a mixture 100 % methane.

On the environmental side the methane number provides information for managing CO_2 emissions mainly because consistent, stable and relatively high values prevent an increase in emissions.

$$w = PCS/\sqrt{d} \tag{3}$$

Where:
W= Wobbe Index, kWh/m^3
Wobbe index for a mixture can be calculated using Eq(4).

$$w_m = \frac{[PCS]_m}{\sqrt{d_m}} = \frac{X_i[PCS]_i}{\sqrt{X_i d_i}} \tag{4}$$

Where,

W_m= Wobbe index for a mixture, kWh/m^3
PCS_m = High calorific value for mixture, kWh/m^3
PCS_i = High calorific value for compound i, kWh/m^3

The resulting values are evaluated with respect to the Table 1.
Table 1, provides information on the optimal mixture that can be burned expecting the maximum reduction of the negative aspects that directly affect the process, mainly focused on the integration of environmental, safety and efficiency. Taking in to account that Wobbe index develop primarily an analysis of interchange ability possessed by each stream to ensure the quality of the mixture of gases which will be burned, since the variation of the index can occur even in two natural gases, since the composition of each varies depending of the source of which is extracted. In the analysis we performed using this index, in turn, we performed an evaluation of the calorific value of each stream, as its variation greatly affects the development process.
These two indices provide information of the optimal mixture can be burned waiting for minimizing the negative aspects that directly affect the process and reducing emissions of greenhouse gases to the atmosphere, primarily focused in the integration of aspects of safety, environmental and efficiency. Subsequently, the results are evaluated according to the incidence of each of the integrated aspects (environmental, safety and energy), giving more importance to the issues of interest to the refinery which is being evaluated. Analysing both the feasibility of implementing a network of combustible gases, as a study of the environmental, energy and security issues present in the current and being bounded by the corresponding regulations. The proposed integrated management system can be defined as follows. Include certifiable standards that determine the management system performed to ensure that the generation of the type mixture will be optimal. The rules that are considered for this management system are; ISO 14001:2004, ISO 50001:2011 and in turn, the rules governing the functioning of the parameters used for the evaluation of the 110 streams studied are taken into account.
The methodology used to minimize any problems caused by burning, can be described as follows. As a first step we proceed to make an inventory of the streams of the burning process, assessed the process itself. It seeks to assess the possibilities of disturbances that affect process characteristics at the time of burning and future. Then the problems which are most important for the refinery are classified thus defining aspects to be assessed. Based on the results obtained and on data collected are defined the particular parameters and the integral problem to minimize. Then, we proceed to apply each of parameters in streams based on the premise

Table 1 Classification of gaseous fuels as Wobbe index (at normal pressure and temperature)

FAMILY	DENOMINATION		W[kWh/m^3]
	Manufactured Gas		6.5-9.0
	Group A	City Gas	6.5-8.0
FIRST	Group B	Coke Gas	7.0-9.0
	Group C	Hydrocarbon-Air gas mixture	6.5-8.0
		Natural Gas	11.0-17.0
SECOND	Group H	High W	13.5-17.0
	Group W	Low W	11.0-13.5
THIRD	Liquefied natural gas		21.5-26.0

that each stream represents a different fuel gas, which constitute the food for the burning process. Based on the results of each parameter on the streams of gases the process could describe the status of the process at that time. Taking into account the evaluated results and areas; we can determine the distribution of flows in relation to the parameters and possibilities of implementation of a network of combustible gases. Then, It is evaluated the correlation between parameters and their integration. According to this, we can chose the range of work, based on the values of each parameter in the natural gas, the excellence gas for combustion, and supported in a complete system of rules governing both the aspects and the parameters used. Searching for locate the streams so that mixtures resulting can be similar in composition to the natural gas. The resulting gas network is based in this variety of ranges that determined by maintain the optimal mixture constant.

3. Results

Results of applying each parameter in each of the current are presented, taking the average by area. This, in order to present the heterogeneity of the mixtures prepared for burning, and addition to this, to foresee the negative effects that can occur if no intervention is made.

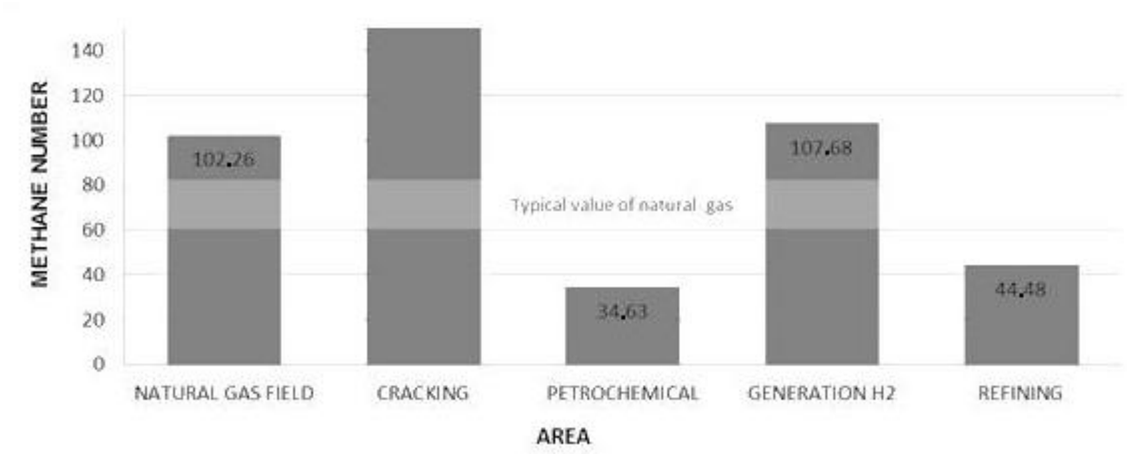

Figure 1: Average value of the number of methane by area. Source: Author.

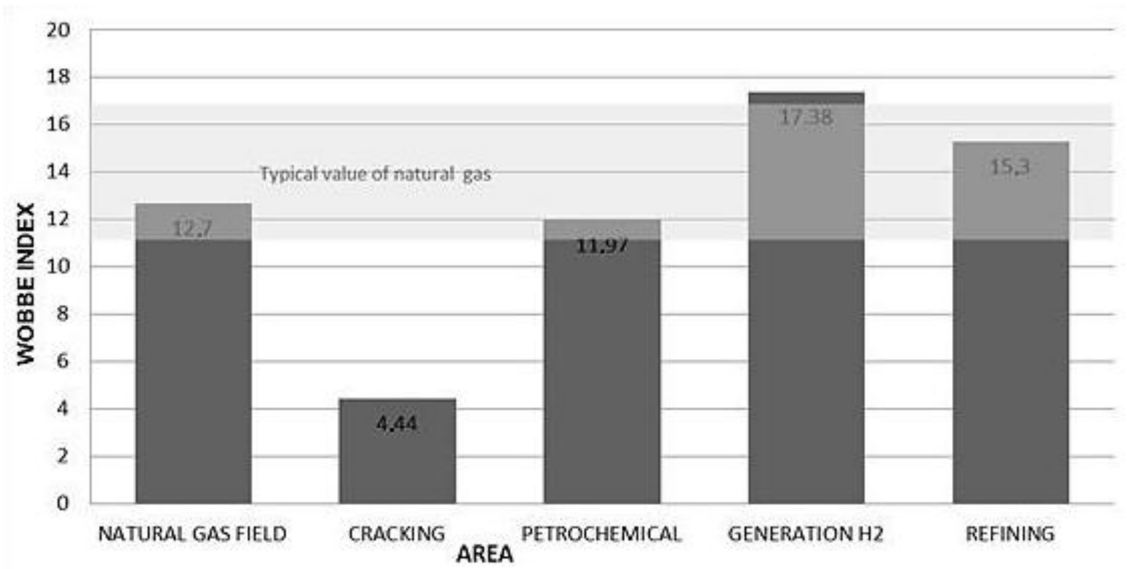

Figure 2: Average value of the number of Wobbe index by area. Source: Author

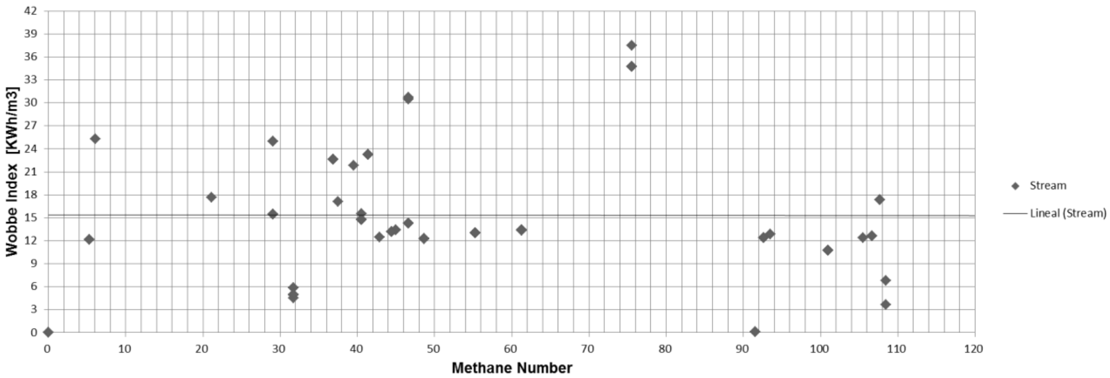

Figure 3: The Methane Number in relation with Wobbe Index. Source: Author

4. Discussion of Results

The methane's number variation in results is high, mainly in the cracking area ranging from a 77,690. 38, until a value of 31.757, It shows the heterogeneity of the mixtures within the same areas. If different areas are compared, the result is similar and there is also variability in the results for this parameter. Considering 77,690.38 values are presented as necessary to explain that for higher values of the combustible 100 reference, It would for example for a number of methane of 145, the fuel gas reference contain a molar fraction of 55 % hydrogen and 45 % mole fraction of methane. For even higher values, as presented in cracking area, an assessment of the composition of flows is needed to directly assess these particular values, in order to perform a more thorough evaluation of the components that could affect the mixture erratically in the burning. For number 77,690.38 methane, fuel gas mixture reference contains a molar fraction of 10% hydrogen and 90 % mole fraction of methane.

If we use the values representing the number of methane as a guide and compare the Wobbe index for each stream, it will be corroborated the heterogeneity and in rank, we can determine the range of representative interchangeability for this set of streams. Thus, thanks to the values obtained and the integration of the two parameters, which is presented in a linear form, we can separate the streams in different ranges or areas so that the characteristics of the process are kept during the burning time, and with the rules of the integrated management system defined.

The segmentation of the gases can be as follows:

- Optimal: gas or natural gas streams.
- Goal: gas or fuel gas streams that have the same characteristics of natural gas, and therefore needed no addition of other streams when burning, this in order to stabilize them.
- Variables: Gas or fuel gas streams that require the addition of one or more streams to be included in the target range.
- Regular: gas or fuel gas streams that require the addition of optimal fuel gas streams or goal to be burned uneventful.
- Discarded: gas or fuel gas streams that need a pre-treatment before they can be considered again for the burning process.

5. Conclusions

- Based on the results, the data collected serves as a guide for creating an integrated management system, for implementing, maintaining and making continuous improvements based on ISO 14001:2004 and ISO 50001 standards , which extend staff that is associated with the process, and in addition, create campaigns of conscientization within the company assessed, searching for that each person who is involved in the process have the opportunity to perform preventive actions or corrective actions, as applicable .
- Was determined a range in which the majority of streams works in an efficiency process, constant over the time. Based on the aspects evaluated was determined as a possible answer the design of a fuel gas network to control the principal problems that affecting the burning process.

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