Reducing Flare Emissions from Chemical Plants and Refineries Through the Application of Fuzzy Control System

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Abstract: Increasing legislative requirements on a global basis are driving the development of solutions to reduce emission. Flaring and venting of waste hydrocarbon gases is a known contributor to pollution and increasing pressure is being exerted onto operators to monitoring and minimizes emission levels. Flaring, in fact, is a specific combustion system which has a complicated mathematical model. But it can be model by means of specific combustion software. In this paper we design a fuzzy controller system to control temperature of flare flame with the injection of optimum amount of steam. Also this method supply adequate oxygen to complete combustion and reducing flare emission. To study the effect of proposed method we use STANJAN which is a combustion software. The results of simulation show that the flare efficiency has improved.

Key-word: **Flare, Combustion, Emissions, Combustion Efficiency, Steam injection, Air assist, Toxic gas, Fuzzy control, Member ship function**

1 Introduction

Commonly, waste gases are vented or flared in an uncontrolled manner polluting the atmosphere with harmful gases and toxins which have a detrimental effect on the earth's bio system. On major Oil, Gas and petrochemical assets, recent legislation has required operators to install various process controls to minimize emissions during flaring.

Flaring waste gases can cause an additional array of pollution problems over and above pollutant emissions; these include hazardous pollution, smoke and even heat radiation which can have an adverse effect on the surrounding area.

Combustion is complete if all volatile organic compounds are converted to carbon dioxide and water. Incomplete combustion results in some of the volatile organic compounds being unaltered or converted to other organic compounds. In addition to these problems conventional flares that run outside the optimum design envelope produce undesirable bi-products, such as: Sulphur Dioxide (SO_2), Nitrogen Oxides (NOx) and Carbon Monoxide (CO). The completeness of combustion in a flare is governed by flame temperature, residence time in the combustion zone, turbulent mixing of gas stream components, and the amount of oxygen available for combustion.

If oxygen deficiency occurs and if the carbon particles are cooled to below their ignition temperature smoking occurs. Therefore it is important to keep the right temperature in the combustion zone. If there is not quite enough air to burn the gas completely, combustion will still occur but it will leave some of the gas unburned. Smoking may also result from combustion depending on gas composition and the amount and distribution of air. Gas containing heavier paraffins, olefins and aromatics tends to smoke.

There are some parameters that lead to lack of adequate air for complete combustion. Some these main variable parameters are:

- Wind cross speed
- Fuel exit velocity

- Fuel composition change

If these parameters are not considered, incomplete combustion can occur, causing some of the waste gases to remain unconverted or transformed into other organic compounds such as soot, VOC, aldehydes or acids and some bi-products. The nonlinear control system designed based on operator's experiments can, to some extend, minimizes SO_2, NOx and CO pollution to acceptable levels during the incineration of waste gases, whiles minimizing heat radiation and smoke.

One key parameter for complete combustion is providing stochiometric air to burn hydrocarbon fuel at high temperature.

2 Flaring process

Flare is a combustion device that uses an open flame to burn combustible gases with combustion air provided by uncontrolled ambient air around the flame. Flares may be either continuous or intermittent and are not equipped with devices for fuel-air mix control or for temperature control.

Flaring process exhibit time varying behavior and experience indicates that mathematical model for the process became either too simple to be any practical value, or too comprehensive and needled into the specific process to possess any general applicability. However, humans can be trained and in a relatively short time become skilled operators.

It is vital to monitoring and control exhaust and flue temperature in order to maintain efficient flaring. If the operating temperature falls too low, incomplete combustion of hydrocarbon is likely to occur resulting in high emission values (for example CO, unborn hydrocarbons). If the temperature gets high, NOx may be produced. Therefore it is essential to maintain controlled operating temperatures. So in some refineries a well-controlled steam injection system is installed. This type of flare system injects steam into the combustion zone to promote turbulence for mixing, induce air into the flame, and achieve smokeless burning. The purpose of the addition of steam is to reduce smoking by hydrocarbon flames and has a multiple effect in a flare flame in its qualities for smoke suppression. Primarily, steam acts as a "heat-sink" and reduces the flame temperature long enough to reduce the amount of NOx formation. Additionally, the jet energy of the steam injection may be utilized to entrain and mix air into the flame and produce turbulence, which speeds up the combustion and minimizes the time available for formation of carbon chains.

3 Operating parameter

The waste stream routed to the flare either burns on its own or, if it has low heating value (less than 300 Btu/scf), with the assistance of a high energy (more than 1000 Btu/scf) fuel gas, like natural gas or propane, to facilitate complete combustion. Typically, operators use fuel gas, or some other purge gas, to keep slow flowing emissions moving toward the flare. With or without additional fuel, the combustion of many waste streams produces smoke, visible emissions. For smokeless combustion, operators typically inject steam or air to achieve more complete combustion. The injection of steam or air (assist gas) at the flare tip also increases the mixing of waste gas with air, as well as the residence time of the waste gas constituents into the flame zone, thereby increasing combustion efficiency. Operators must maintain a delicate, but essential, balance between smokeless and over steamed emissions. Too much assist gas (over steaming or over aerating) may reduce the overall combustion efficiency by cooling the flame to below optimum temperatures for destruction of some waste gas constituents, and in severe cases may even snuff the flame, thus significantly reducing combustion efficiency and significantly increasing flare exhaust gas emissions.

4 Control strategy

The main purpose of fuzzy controller system is to reduce formation of NOx, CO, unburn hydrocarbon and soot which is describe below.

4.1 Reduction of formation of NOx

Generation of NOx is depending on temperature. As the temperature rises, generation rate of NOx rises. So the first step is to set fuzzy control system in such a way to maintain the temperature of the flame below critical temperature in which NOx starts to form. Additionally we know that flaring occurs at the open ambient so in order to have a high speed reaction, high temperature is required. In this paper we test various temperatures with STANJAN software and the best results (minimum NOx) gets around 1200 Kelvin.

4.2 Reduction of formation of CO, unburned hydrocarbon and soot

If oxygen deficiency occurs and if the carbon particles are cooled to below their ignition temperature carbon monoxide, unburned hydrocarbon and smoking occurs. Therefore it is important to keep the right temperature in the combustion zone. If there is not quite enough air to burn the gas completely, combustion will still occur but it will leave some of the gas unburned. Smoking may also result from combustion depending on distribution of air. So injection rate of air has a great effect on the efficiency of combustion in flare.

5 Fuzzy control advantages

For many practical control problems (for example, industrial process control), it is difficult to obtain an accurate yet simple mathematical model, but there are experienced human experts who can provide heuristics and rule-of-thumb that are very useful for controlling the process. Fuzzy control is more useful for these kinds of problems. Conventional control starts with a mathematical model of the process and controls are designed for the model; fuzzy control, on the other hand, starts with heuristics and human expertise (in terms of fuzzy IF-THEN rules) and controllers are designed by synthesizing these rules.

6 Fuzzy logic controller

The fuzzy logic controller used in the model of flare combustion has two inputs: carbon monoxide concentration (CO) and flame temperature deviation $(T_F - 1200K)$, and two outputs: desired amount of air (F1) and desired amount of steam (F2). The control system itself consists of three stages: fuzzification, fuzzy inference machine and defuzzification. The fuzzification stage converts real-number (crisp) input values into fuzzy values while the fuzzy inference machine processes the input data and computes the controller outputs in cope with the rule base and data base. These outputs, which are fuzzy values, are converted into real-numbers by the defuzzification stage.

A possible choice of the membership functions for the mentioned variable of the flare system represented by a fuzzy set is shown in figure 1 to 4.

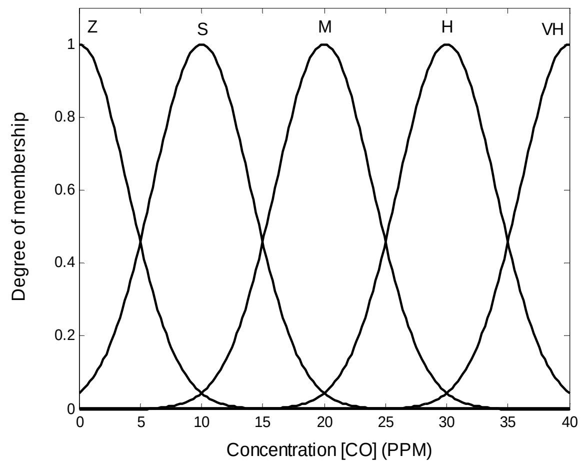

Fig.1. Membership functions for Monoxide Carbon of flare produce.

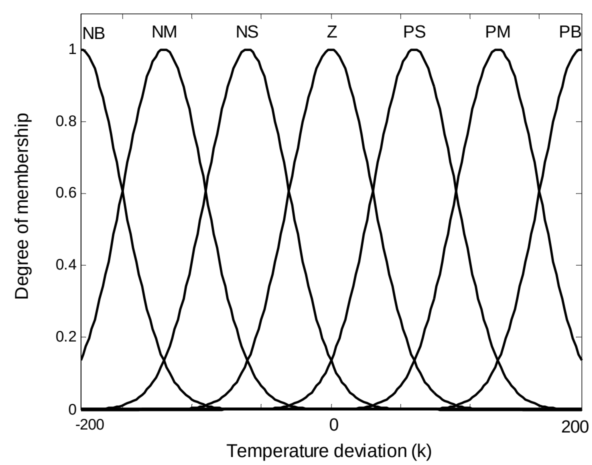

Fig.2. Membership function for Temperature deviation of flame.

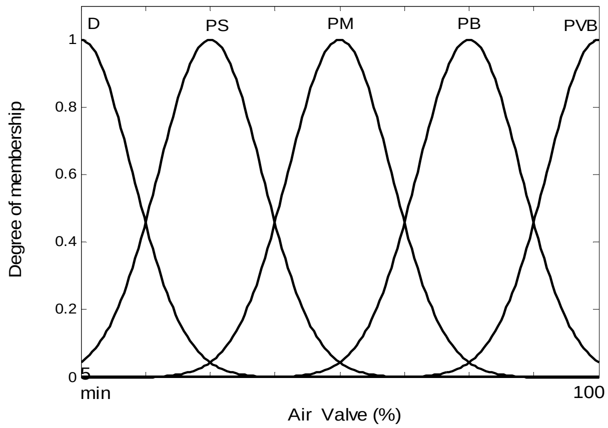

Fig.3. Membership functions for desire assist air

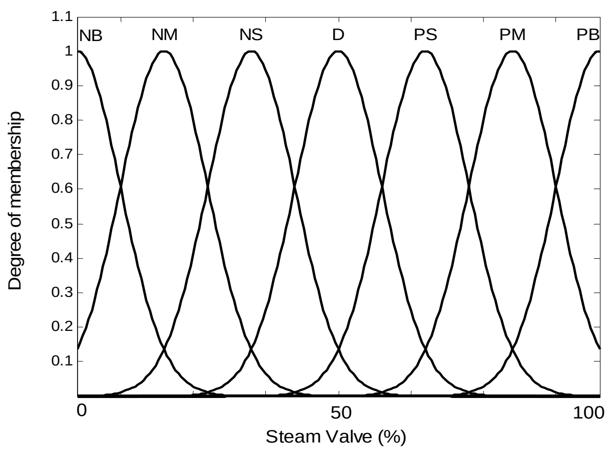

Fig.4. Membership function fordesire assist steam

The abbreviations used correspond to:

- Z Zero
- S Small
- M Medium
- H High
- VH Very High
- NB Negative Big
- NM Negative Medium
- NS Negative Small
- D Desire
- PB Positive Big
- PM Positive Medium
- PS Positive Small
- PVB Positive Very Big

Table 1 shows the rule base used in the model of flare combustion system with fuzzy terms which derived by designer's knowledge and experience.

Table 1: Fuzzy rules defined for control system

Rule No.	CO	F1	Rule No.	dT=T_F-1200	F2
1	Z	D	6	NB	NB
2	S	PS	7	NM	NM
3	M	PM	8	NS	NS
4	H	PB	9	Z	D
5	VH	PVB	10	PS	PS
			11	PM	PM
			12	PB	PB

The linguistic control rules of the fuzzy logic controller obtained from the Table I used in such case are as follows:

R1: IF (CO is z) THEN (F1 = D)

R6: IF (CO is NB) THEN (F2=NB)

And so on …

The output of the fuzzy controller is a fuzzy set of control. As a process usually requires a non-fuzzy value of control, a method of defuzzification called "center of gravity method" is used here:

$$F = \frac{\int f^{*} \mu_D(f)df}{\int \mu_D(f)df}$$

Where $\mu_D(f)$ is corresponding membership function.

7 Definition of Flare Efficiency

In characterizing the performance of a flare, it is convenient to define a term called the "Efficiency" of the flare. Several similar but different definitions of efficiency have been proposed and used in the past. The most rigorous and useful definition of these is properly termed a "conversion efficiency" which quantifies the effectiveness of a flare to fully oxidize fuel. For a flare burning a mixture of hydrocarbon fuels, the relevant parameter is the "carbon conversion efficiency" which is defined in terms of a rate as follows:

$$\eta = \frac{[CO_2]}{[CO_2] + [CO] + [THC] + [soot]}$$

where:
[CO2] is the CO_2 concentration produced by the flare,
[CO] the CO concentration exiting the flare,
[THC] the concentration of total hydrocarbons exiting the flare, and
[soot] is the concentration of any soot present exiting the flare.

This mass-based definition is indicative of the mass conservation equations. Though properly called the “carbon conversion efficiency”, this term is often referred to as the “combustion efficiency”, “efficiency”, “flare efficiency” .Sometime the performance of a flare is presented by means of “inefficiency” that is defined by $1-\eta$.

8 Case study

To apply this method on an experimental case we use information of sampled waste gas which directed to flaring unit in Karoon Oil and Gas Company in Ahvaz-Iran. Table II shows the composition of the flaring gas in this area.

According to the examinations are done in laboratory, flaring gas in this area has heating value around 1111.488 Btu/scf.

Table 2: Real sample compositions

Composition	Mole fraction
Carbon Dioxide (CO)	2.63
Hydrogen Sulphide (H_2S)	1.00
Nitrogen (N_2)	6.70
Methane (CH_4)	65.38
Ethane (C_2H_6)	13.44
Propane (C_3H_8)	7.18
i-Butane (IC_4H_{10})	0.87
n-Butane (NC_4H_{10})	1.42
i-Pantane (IC_5H_{12})	0.33
n-Pantane (NC_5H_{12})	0.36
Hexane (C_6H_{14})	0.30
C_7H_{16}	0.39
Total	100

We proposed that, the fuzzy temperature controller maintain the temperature of the flare flame at the 1200 Kelvin.

By applying operating flare condition to the STANJAN software in 1 atmosphere pressure and 1200 Kelvin temperature to the flaring gas component of this area the efficiency are shown in figure 5 for of with and without control system. The reason of why we consider 1200 Kelvin is that NOx is produced for temperature above 1200 Kevin; also for complete combustion of hydrocarbons the temperature of the flare flame should be 1200 Kelvin.

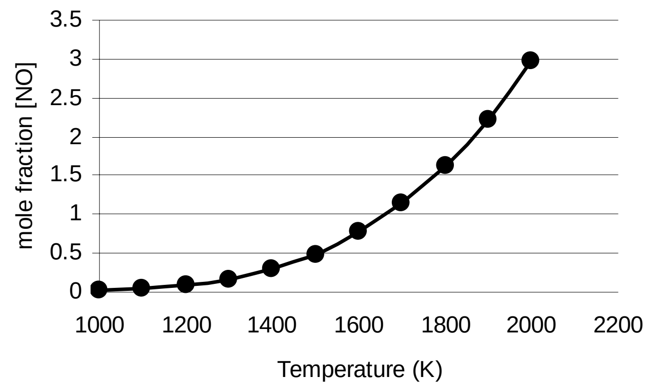

Fig.5. Effect of temperature on generating NO.

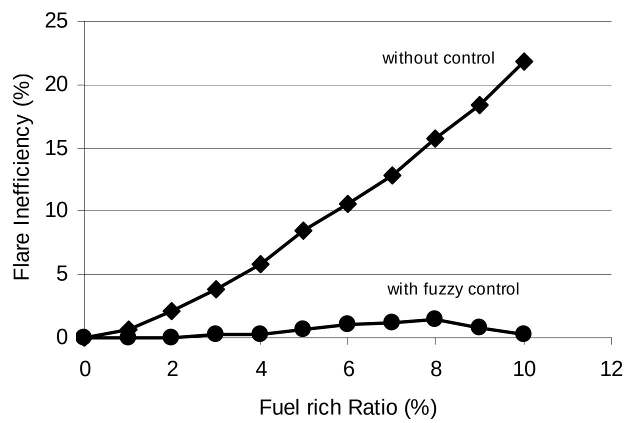

Fig.6. Flare inefficiency in fuel-rich condition, with and without control.

9 Conclusion

In this paper we have shown that the optimum temperature for flare operating is about 1200 Kelvin in which no NOx is produced and speeds up the combustion and minimizes the time available for formation of carbon chains.

Also we have shown that with a fuzzy controller which consists of a simple structure, the flare will be achieved to high efficiency.

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