FEED FORWARD CONTROL METHOD TO REDUCE SOOT FROM STEAM ASSISTED FLARES
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ABSTRACT
Flaring is an oxidation process used in process industries like oil and gas industry to burn unwanted and excess waste gases. In this process, black smoke and particulate matter results from the flare stacks. Smoke formation may vary from different gases which are flaring have different carbon components. Rich in hydrocarbon molecular weight and unsaturated hydrocarbons are more favourable for smoke generation. Smoke formation depends on distribution of combustion air mixed in the flare tip nozzles. Most of the flare stacks are assisted with steam to get complete combustion to avoid black smoke and unburnt hydrocarbons. The amount of steam is insufficient to the flare stack, leads to generate more smoke. It was estimated that, soot particles life time in the atmosphere is 1-2 weeks to disperse. Recently lot of respiratory diseases are reporting more and are caused by air borne particles such as soot in the air. The size of a particulate matter plays major role on severity of lung damage. Less than 3micron size fine particles are more prone to pass through the lung tissues. The short lived climate forcers such as black carbon particles play significant role in global warming. Reduction in methane and black carbon particles achieve reduction in global warming. The new approach of automation of steam control to the flare stack by adopting steam to hydrocarbon ratio control and feed forward action to minimize the time lag from the Gas Chromatograph result, will gives the smokeless operation of flare stacks in oil and gas industry. This paper explains the methodology of control of soot from flares by S/C ratio control and how the combustion efficiency varies with the amount of steam. The economical benefit of smokeless operation of flare stacks are energy saving in terms of minimization of excess steam and indirectly reduce the amount of CO₂ to the atmosphere.

Key Words : Automatic control, Black carbon, Poly aromatic hydrocarbons, Soot

Abbreviations
BC : Black Carbon
GC : Gas Chromatograph
HC : Hydro Carbon
PAH : Poly cyclic Aromatic Hydrocarbons
PM : Particulate Matter

INTRODUCTION
In many oil refineries, the flare is manually observed by the operator for any abnormality. Manual observation of the flare on a continuous basis is a tedious job, and is not a reliable way to detect abnormalities. In case of plant shut down/emergency or pressure relief valves pops up, sudden flaring causes smoky flare. It may take some time to operator to respond to inject steam as process operator's manual action. During this time, often flares are smoky. According to US Environmental Protection Agency, Rule 401 prohibits visible emissions in excess of Ringelmann 1 or 20 percent opacity for periods exceeding more than three aggregate minutes within any hour.40CFR 60.18 requires flares to have no visible emissions except for periods of time up to five minutes during two consecutive hours. If waste gases venting with black smoke and its opacity is above Ringelmann no. 2 and smoky flare is more than 5 minutes, it should be reported as flare incident. So during this 5 minutes crucial period of process plant upset, it is difficult to adjust steam to flare manually. Ringelmann chart method is out dated now a days and it will take 15minutes to check the correct flare opacity. This result increases number of flare incidents.

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A well designed process plant is utilize the waste gases generated in the process are used in furnaces rather than send to flare stack. But in certain emergency conditions excess vent gases cannot be fired in furnaces and diverted to flare header to control the system pressure. Oxidation of the waste hydrocarbon gases can produce emissions of methane (greenhouse gas), and flaring creates other pollutant emissions such as particulate matter (PM) in the form of soot or black carbon (BC).\(^5\) Smoke forms when C-C bonds in hydrocarbon crack and aromatic structures grow into multi ring molecules (>3 ring=primary soot particle). Other Polyaromatic hydro carbons [PAH] form a long reaction route to soot. “As of the end of 2011, 150 × 10^9 m\(^3\) of associated gas are flared annually. That is equivalent to about 25 percent of the annual natural gas consumption in the United States or about 30 per cent of the annual gas consumption in the European Union”\(^6\) The amount of flaring and burning of associated gas from oil drilling sites is a significant source of carbon dioxide (CO\(_2\)) emissions. “Some 400 × 10^6 tons of carbon dioxide are emitted annually in this way and it amounts to about 1.2 per cent of the worldwide emissions of carbon dioxide”\(^7\) Black carbon has a relatively short life span of approximately one to two weeks. Polycyclic aromatic hydrocarbons (PAH) are important components of organic particulate matter because of their carcinogenic nature. Some typical PAH compounds are: benzo alpha pyrene, Chrysene, benzofluoranthene. PAH compounds occur in urban atmospheres at levels of about 20 μg/m\(^3\). They are mostly found in the solid phase. It is known that most PAH compounds are sorbed onto soot particles. Soot itself is a highly condensed product of PAH compounds. A soot particle consists of several thousand interconnected crystallites which are made up of graphitic platelets.

The latter (platelets) consist of roughly 100 condensed aromatic rings. Soot consists (Fig. 1) of 1-3% H and 5-10% O trace metals such as Be, Cd, Cr, Mn, Ni, and V and also toxic organic such as benzo alpha pyrene adsorbed on its surface. During their lifetime, black carbon particles are coated with airborne chemicals,

![Soot particles](image)

**Fig. 1** : Soot particles\(^8\)

**Emission factors**

For a very rough order of magnitude estimate, “considering gas flared volumes of 139 billion m\(^3\)/year as estimated from satellite data”\(^9\) and estimating a single valued “soot emission factor of 0.51 kg soot/103 m\(^3\)”, flaring might produce 70.9 Gg of soot annually. This amounts to 1.6% of global black carbon emissions from energy related combustion, based on estimates of 4400 Gg for the year 2000”\(^10\). Soot in concentration values\(^11\) Non smoking flares, 0μg/L, Lightly smoking flares,
40µg/L, Average smoking flares, 177 µg/L, and Heavily smoking flares, 274µg/L.

**METHODOLOGY**

Required steam will be injected as calculated into the flame zone with the help of Steam/Carbon ratio controller by feed forward signal. (Fig. 2) Ultrasonic flow meter measures the gas flow to the flare. Different molecular weight gases having different carbon numbers. Gas chromatography measures the carbon numbers of different gases. Sum of all different carbon numbers gives total number of hydro carbon to flare. Carbon flow in kg/hr can be achieved as follows, Carbon flow (kg/hr) = hydrocarbon flow (N m³/hr) * total carbon no./22.414. Gas Chromatography takes 15-20 minutes to calculate the complete gas composition. Feed forward signal compensates this time lag. In a process unit any vent to flare header control valve output >0% and predetermined carbon number will be taken from the loop is used as a feed forward signal to ratio controller. If multiple vents to flares are operate at the same time, higher carbon number output will be taken by ratio controller. Then once FF signal taken from a loop, steam flow set point will be calculated and steam control valve will open. After getting gas Chromatograph results (approx 15-20min) actual carbon number will be calculated and it will optimize the steam to flame zone. Steam flow required to achieve smokeless flame will be calculated as follows Required Steam flow (kg/hr) = S/C * Carbon flow (kg/hr).

**Combustion efficiency**

Flare gases of different compositions and same heating value can have different stable flame operating envelopes when flared from the same flare. But with different quantities of steam to hydrocarbon ratio will change the combustion efficiency. (Fig. 3) Steam to HC ratios of 3.5 to 1 or less had 98% plus Combustion efficiency. Steam to HC ratios of 5.8 to 1 or less had 82% plus Combustion efficiency. Steam to HC ratios of 6.7 to 1 or less had 69% plus Combustion efficiency.
Limitations of Ringelmann Chart

The chart shall be used under day light conditions. Clear back ground should be there when an observer takes observations. If the weather is dusty, foggy and rainy, Ringelmann chart cannot be used. Health Effects of Soot particles in the air are a contributing factor in respiratory diseases. The fine particles of size less than 3micron can penetrate easily into air passage. Larger size than 3 micron are entrapped in the nose. But very fine particles stay for longer duration in the lungs. These are causing for cancer and bronchiole problems. Larger particles which are trapped in the nose may create breathing problems and creates irritation. Emissions of fine particulate matter i.e., black smoke from flare stacks is almost same chemical characteristics of diesel engine exhaust have been of growing community, industry and government concern. Combination of small size and chemical composition increases the likelihood that particles will carry irritants and toxic compounds into the deepest and most sensitive areas of the lungs. Pneumonia, bronchitis, and asthma can causes from these fine particles. Occupational health studies depicts lung cancer is causing from black carbon particles which are from diesel engine exhausts. Traffic studies suggest increased rates of respiratory and cardiovascular disease and risk of premature death near busy urban streets or highways and thus must be addressed by industry and government.

CONCLUSION

Ringelmann Chart is used to identify the opacity of the flare. But as it is out dated and is not a continuous method to find out the opacity, it is obsolete. So automatic control of soot by ratio controller keeps always zero soot formation from the flare stack in any emergency situation. Meet or exceed government legislation, and eliminate risk of non-compliance, as flare opacity is always less than Ringelmann index 2. Economical benefits by adopting automatic control of soot from flares are

1. Rs 20, 000/ hour saving by reducing excess steam to flares, consider that Natural gas price is Rs 267/mmbtu and Raw water price is Rs 60/ m³
2. Due to reduction of excess steam, total CO₂ reduction to atmosphere is 7.45ton/day. International Carbon Trade: 1Carbon Credit = 1ton CO₂ removed = $12 in today’s market. The above cost savings will be different from different countries due to raw materials cost is different.
3. US Environmental Protection Agency proposal would strengthen the annual health standard for harmful fine particle pollution (PM 2.5) to a level within a range of 13μg/ m³ to12μg/m³. The current annual standard is 15μg/ m³. By proposing a range, the agency will collect input from the public as well as a number of stakeholders, including industry and public health groups, to help determine the most appropriate final standard to protect public health.

REFERENCES

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