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Simulation Study to Minimize Soot and Unburnt Hydro Carbons from Steam Assisted Flares and Health Effects of Soot

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Abstract: ***Soot is a black powdery substance that consists mainly of carbon and is formed through the incomplete combustion of wood, coal, diesel oil or other materials. Flaring is a high-temperature oxidation process used to burn waste gases from industrial operations. Flare stacks used in industries are often assisted with steam to ensure complete combustion and to avoid any UBHCs. In this process, flares are often sooty due to insufficient steam. This results in black carbon from flares. The purpose of steam injection into flame zone is to reduce the amount of smoke from the flare, otherwise be created by combustion. Flare can achieve 98% combustion efficiency during turn down operation with well controlled and proper designed steam supply system. US EPA rule 401 prohibits visible emissions in excess of Ringlemann 1 or 20% opacity for periods exceeding more than three aggregate minutes within any hour. IR cameras cannot be used to keep a flare near the incipient smoke point at low flow rates. When wind direction changes, detecting smoke from flare tip is difficult with IR cameras. Adverse weather conditions like foggy weather will influence the performance of IR camera. Ultrasonic flow meters are the best suit for flow measurement in vent gas header. Ultrasonic flow meters are effectively employed at high turndown ratios. This paper explains the method of automatic control of soot from flares by using advanced control system with feed forward signal. Soot particles in the air are contributing factor in respiratory diseases. The fine particles (<3μ) are the worst causes of lung damage due to their ability to penetrate into the deep air passage. Automatic control of steam injection into flame zone by steam to carbon ratio control helps in reduction of excess steam and optimizes the flare operation, and reduces CO2 generation to the atmosphere.***

Keywords: Black Carbon, Green House Gases, Poly Aromatic Hydrocarbons, Soot

1. 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. If waste gases venting with black smoke and its opacity is above Ringlemann 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. Ringlemann chart method is out dated now a days and it will take 15minutes to check the correct flare opacity. This results increases number of flare incidents. This paper explains the automatic control system to minimize soot and unburnt hydro carbons from flares. To achieve quick action of S/C ratio control system with reliable ultrasonic flow measurement and feed forward signal introduced by calculated hydro carbon number. Simulation study results depicts that soot minimization can be achievable within 5 minutes by adopting feed forward control system.

2. Literature

Flaring is a high-temperature oxidation process used to burn combustible components, mostly hydrocarbons, of waste gases from industrial operations. Oxidation of the gas can preclude emissions of methane (a potent greenhouse gas); however flaring creates other pollutant emissions such as particulate matter (PM) in the form of soot or black carbon (BC) [2]. Smoke forms when C-C bonds in hydrocarbon crack and aromatic structures grow in to multi ring molecules [>3 ring=primary soot particle]. Other Polyaromatic hydrocarbons [PAH] form a long reaction route to soot. As of the end of 2011, $150 \times 10^9 m^3$ of associated gas are flared annually. That is equivalent to about 25 per cent of the annual natural gas consumption in the United States or about 30 per cent of the annual gas consumption in the European Union [3].

As of 2010, 10 countries accounted for 70% of the flaring, and twenty for 85%. The top ten leading contributors to world gas flaring in 2010, were (in declining order): Russia (26%), Nigeria (11%), Iran (8%), Iraq (7%), Algeria (4%), Angola (3%), Kazakhstan (3%), Libya (3%), Saudi Arabia (3%) and Venezuela (2%) [4].

The amount of flaring and burning of associated gas from oil drilling sites is a significant source of carbon dioxide (CO2) 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 [5].

Black carbon is part of a group of pollution sources known as Short-Lived Climate Forcers (SLCFs), including methane gas and ozone, which are produced on earth. 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.

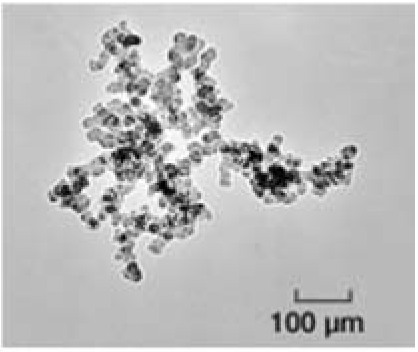

Figure 1: TEM graph of soot particles. [8]

Soot consists 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. For a very rough order of magnitude estimate, considering gas flared volumes of 139 billion m3/year as estimated from satellite data [6] and estimating a single valued soot emission factor of 0.51 kg soot/103 m3, 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[7].

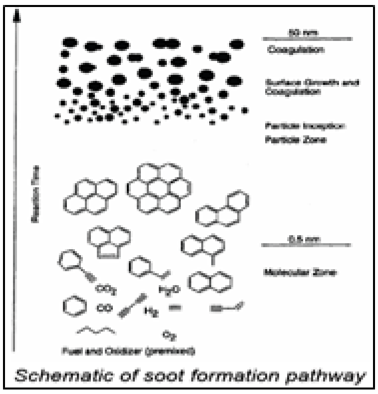

Figure 2: Soot formation

3. Methodology

Required steam will be injected as calculated into the flame zone with the help of Steam/Carbon ratio controller by feed forward signal. Ultrasonic flow meter measures the gas flow to the flare.

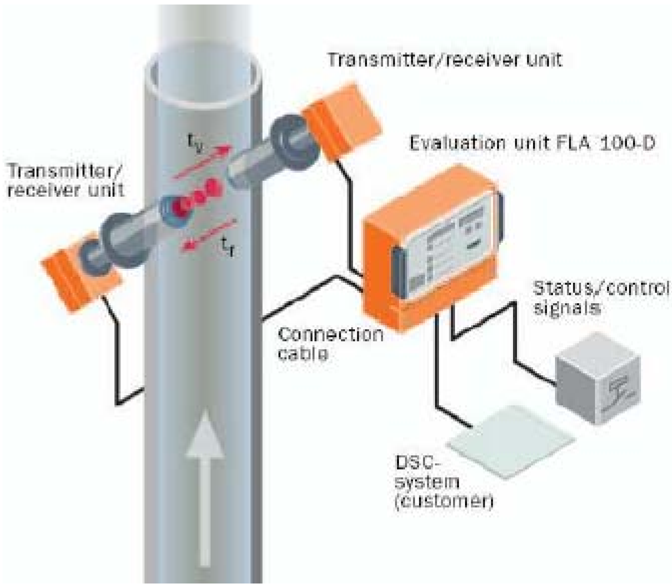

Figure 3: Ultrasonic Flow meter

Different molecular weight gases having different carbon numbers. Gaschromatography 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 m^3/hr) total carbon no./22.414*

Gas Chromatography takes 15-20minutes to calculate the complete gas composition. Feed forward signal compensates this time lag. Steam flow required to achieve smokeless flame will be calculated as follows [9]

*Required Steam flow (kg/hr) = S/C * Carbon flow (kg/hr)*

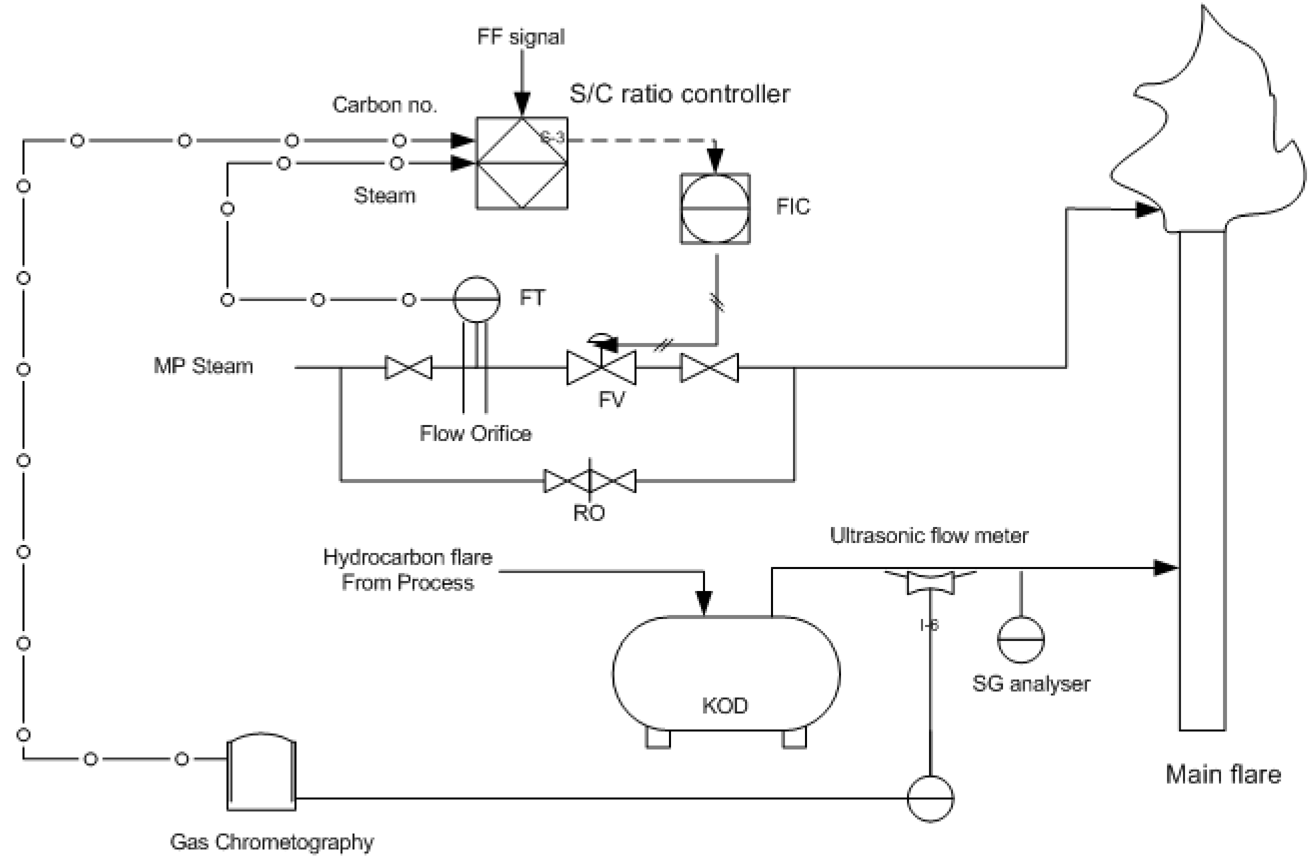

Figure 4: Automatic S/C ratio control loop with feed forward

3.1 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.

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.

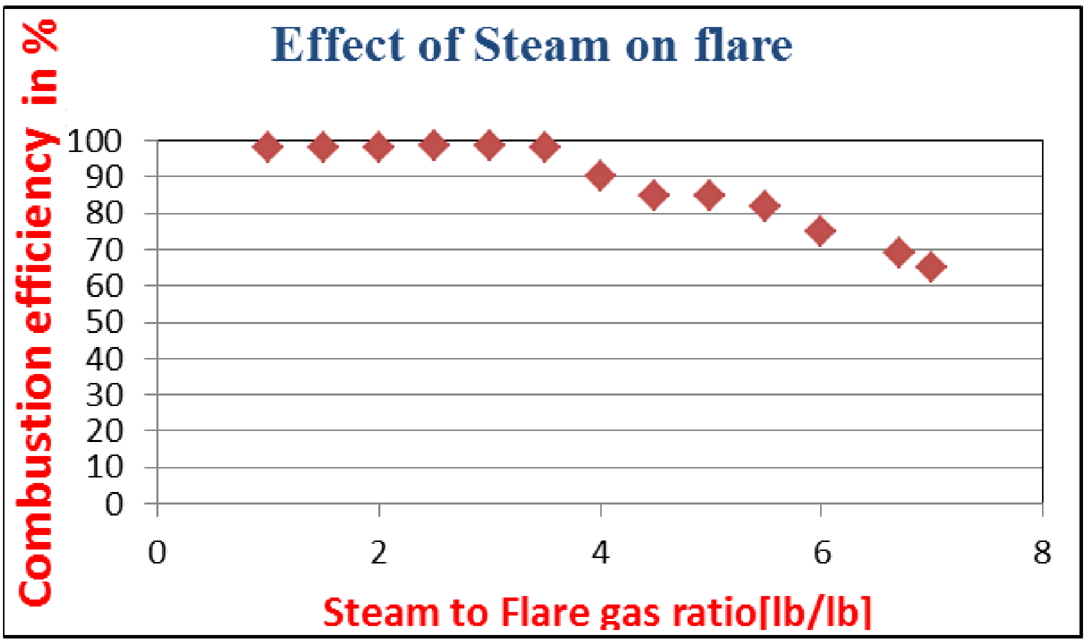

Figure 5: Impact of steam injection and combustion Efficiency

4. Simulation Results

In a typical refinery process, each unit vent gases connected to a common flare header and finally burn at flare stack tip. Here for simulation purpose each unit vent taken as 1, 2, 3…8. Each unit is having different carbon number according to process design. In simulation model any unit vent open above 0%, algorithm checks the design carbon number versus actual carbon number calculated from gas chromatography, then higher value is taken for feed forward signal for S/C ratio controller. As a normal feedback control valve, steam flow control valve will operate to maintain the desired steam flow to flame zone according to S/C ratio set point. But due to time lag from gas chromatography, feed forward signal is calculated from algorithm is directly multiply the S/C ratio set point to control quickly. Once GC gives actual carbon number steam flow will be optimized. Simulation models depict that smoke less flaring operation is possible by adopting S/C ratio control with feed forward action.

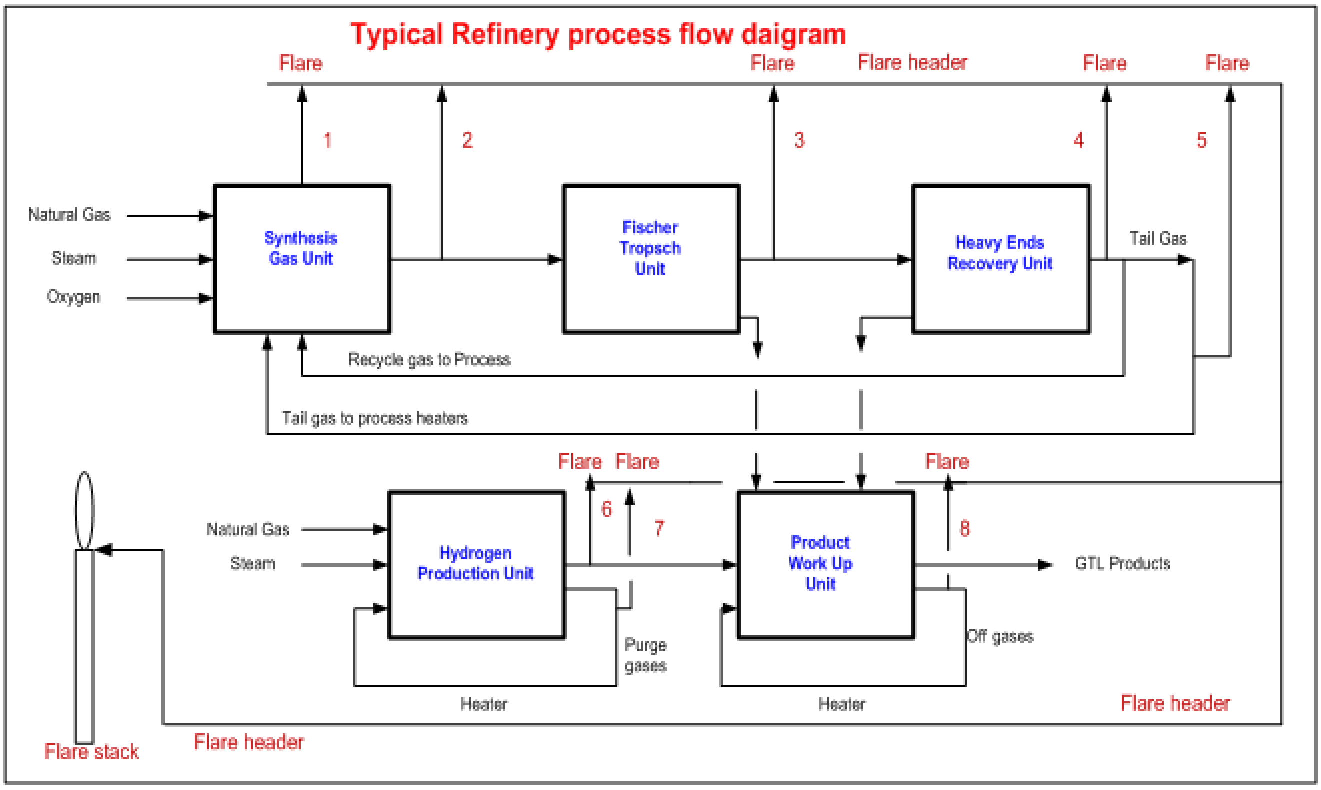

Figure 6: Typical refinery process with flare header

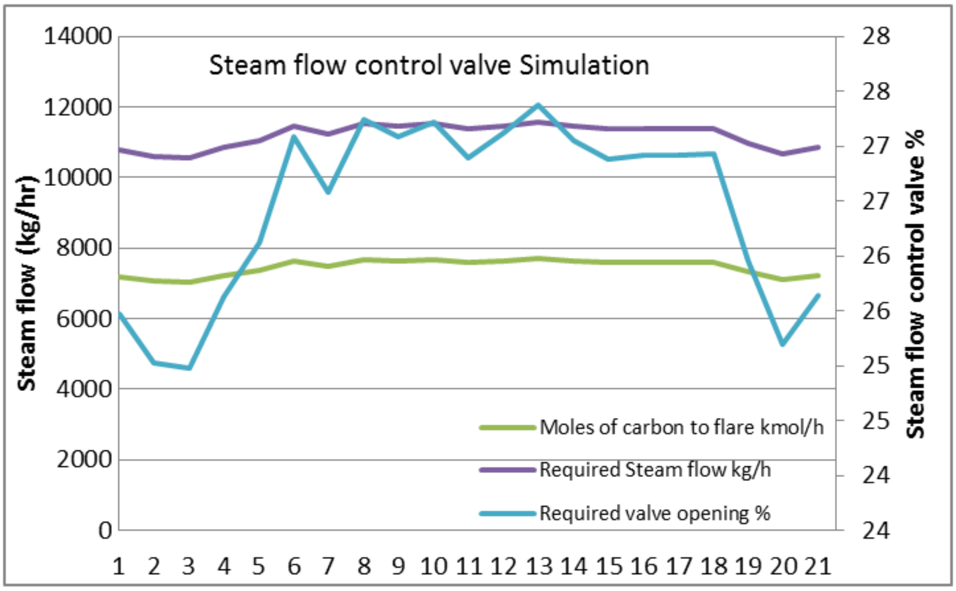

Figure 7: Steam flow control valve output vs. steam Demand [1]

Table 1: Steam requirement calculation

Start	Ratio of steam to C kg/kmol 1.5							
11/14/2013 7:00								
End								
11/14/2013 11:00								
	Steam requirement calculation				Actual valve and steam			
	Steam flow control valve				181HIC0003.OP			
	Maximum carbon number	Moles of carbon to flare	Required Steam flow	Required valve opening	MP Steam to 181-Rf-001	Estimated steam flow	Excess steam being wasted	Steam deficit
Timestamp	-	kmol/h	kg/h	%	%	kg/h	kg/h	kg/h
14/11/2013 07:00:00	3.10	7182	10773	25	15	6344	0	4430
14/11/2013 07:00:30	3.10	7057	10586	25	15	6344	0	4242
14/11/2013 07:01:00	3.10	7043	10564	25	15	6344	0	4220
14/11/2013 07:01:30	3.10	7225	10837	26	15	6344	0	4494
14/11/2013 07:02:00	3.10	7365	11048	26	15	6344	0	4704
14/11/2013 07:02:30	3.10	7636	11453	27	15	6344	0	5110
14/11/2013 07:03:00	3.10	7495	11242	27	15	6344	0	4898
14/11/2013 07:03:30	3.10	7681	11522	27	15	6344	0	5178
14/11/2013 07:04:00	3.10	7636	11454	27	15	6344	0	5110
14/11/2013 07:04:30	3.10	7675	11512	27	15	6344	0	5169
14/11/2013 07:05:00	3.10	7584	11376	27	15	6344	0	5032
14/11/2013 07:05:30	3.10	7648	11471	27	15	6344	0	5128
14/11/2013 07:06:00	3.10	7718	11578	27	15	6344	0	5234
14/11/2013 07:06:30	3.10	7626	11439	27	15	6344	0	5096
14/11/2013 07:07:00	3.10	7579	11369	27	15	6344	0	5025
14/11/2013 07:07:30	3.10	7589	11383	27	15	6344	0	5039
14/11/2013 07:08:00	3.10	7588	11382	27	15	6344	0	5038
14/11/2013 07:08:30	3.10	7594	11391	27	15	6344	0	5047
14/11/2013 07:09:00	3.10	7316	10974	26	15	6344	0	4631
14/11/2013 07:09:30	3.10	7104	10656	25	15	6344	0	4312
14/11/2013 07:10:00	3.10	7230	10844	26	15	6344	0	4501
14/11/2013 07:10:30	3.10	7209	10814	26	15	6344	0	4470
14/11/2013 07:11:00	3.10	7023	10534	25	15	6344	0	4190
14/11/2013 07:11:30	3.10	6883	10324	24	15	6344	0	3981
14/11/2013 07:12:00	3.10	6948	10422	25	15	6344	0	4078
14/11/2013 07:12:30	3.10	7177	10766	25	15	6344	0	4422
14/11/2013 07:13:00	3.10	7283	10925	26	15	6344	0	4581
14/11/2013 07:13:30	3.10	7252	10878	26	15	6344	0	4534
14/11/2013 07:14:00	3.10	7322	10983	26	15	6344	0	4639
14/11/2013 07:14:30	3.10	7673	11510	27	15	6344	0	5166
14/11/2013 07:15:00	3.10	7885	11827	28	15	6344	0	5483

5. Conclusions

Zero soot formation from the flare stack in any emergency situation by adopting automatic control with feed forward control technic. Meet or exceed government legislation, and eliminate risk of non-compliance, as flare opacity is always less than Ringlemann index#2.

Economical benefits by adopting automatic control of soot from flares are, $70/ hour saving by reducing excess steam to flares, consider that Natural gas price is $1/mmbtu and raw water price is $5/m3. International Carbon Trade: 1Carbon Credit = 1ton CO_2 removed = $12 in today's market. Due to reduction of excess steam, total CO_2 reduction to atmosphere is 7.45ton/day. US Environmental

Protection Agency proposal would strengthen the annual health standard for harmful fine particle pollution (PM2.5) to a level within a range of 13µg/ m3 to 12µg/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.

6. Future Scope

Ultrasonic flow meters are very expensive and these meters are very sensitive for hydrogen gas. When there is a CO2 gas and propane gases are in the vent gas, Gas Chromatography may not gives the proper gas composition as both gases molecular weights are same. In future cost reduction on ultrasonic flow meters installation and GC accuracy needs to consider for further research work.

7. Acknowledgment

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Author Profile

Rekhapalli Srinivasarao received his AMIIChE from Kolkata University, M.Sc., (Environment & Ecology) from Sikkim Manipal University of Health Sciences and M.Phil., from Global Open University. He is having 18years of industrial experience in fertilizers and refinery industries with various positions. At present joined as a research scholar in Jawaharlal Nehru Technological University Kakinada, Andhra Pradesh, India.