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Technology options for mitigation of foundry emissions

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ABSTRACT

Foundry emissions are well defined source of air pollutants, however, only scanty information is available on actual emission characteristics of foundry units. A study on emission characterization of foundry flue gases comprising particulates, CO and SO_2 was undertaken in Agra and Ludhiana. The data on operating conditions and emission characteristics of identified Indian foundry units have been compared with that of working units in other countries. Prevailing control options, their performance and relative cost analysis have been delineated for their possible adoption with reference to variation of emission scenario of Indian foundry units. Preliminary computations on energy balance across the cupola system indicate that an appropriate flue gas heat recovery system, if devised, may reduce expenditure on fuel cost and would prove to be a cost effective solution.

INTRODUCTION

Iron foundries have been recognised as the most economical small/medium scale units for manufacturing wide range of iron castings, using pig iron, rusted iron scrap, foundry rejects etc. in a pre-determined ratio along with coke as fuel and limestone as fluxing agent. Molten metal of required assay is produced under reduced atmosphere and is poured into sand mould for desired product. Although, there are wide variation in the quality and quantity of raw materials, cupola dimensions, capacity and operating conditions depending upon desired end product, yet the basic manufacturing principle remains the same. Obviously depending upon these factors there are wide fluctuations in flue gas characteristics and emission rates. Particulate matters (dust), Sulfur dioxide (SO_2) and Carbon monoxide (CO) have been identified[1] as major air pollutants in foundry emissions. The theme of the paper is to analysize factors responsible for generation of various pollutants and to scan merits/demerits of existing control options under typical Indian conditions, before making ultimate choice of air pollution mitigation system.

Table-1 : Comparison of operating and emission characteristics of some Indian and Overseas Cupolas

Sr. No.	Cupola Data	Indian Foundry Units [2,7]				Overseas Foundty Units[3]				
		1+	2°	3+	4°	5	6	7	8	9
1.	Inside Diameter	1.22	1.22	0.91	0.91	0.94	1.22	1.07	1.52	1.6
2.	Iron: Coke Ratio	4:1	5:1	4:1	5:1	7:1	7:1	9:1	10:1	10:1
3.	Melting Rate kg/hr	5000	3000	2500	1500	3805	7627	6356	16753	1775
4.	Melt Flux kg/hr/m^2	4277	2566	3844	2306	5485	6533	7111	9184	8826
Flue Gas Details										
5.	Temperature °C	250	598	200	600	760	250	221	105	101
6.	Volumetric flow Rate, Nm^3/hr.	6368	5430	12701	2238	9379	14323	34490	35679	51820
7.	Particulate Matter (gm/Nm^3)	0.45	3.98	-	-	3.02	3.48	6.80	0.89	0.95
8.	Emission Factor (kg/MT casting)	0.83	7.28	-	-	7.45	6.54	36.91	1.91	2.76

o Ludhiana based units
+ Agra based units

Flue gas characteristics

Variations in emission characteristics and prevailing foundry practices in some of Indian cupolas[2,6] as well as overseas foundries have been compared in Table-1. Metal to coke ratio as well as melt flux ratio[3] being low in Indian foundries, the necessary quantity of coke fired and the resulting emissions are proportionately higher. Flue gas temperature in local foundries is comparatively higher than those in other countries reflecting higher energy losses.

Flue gas temperature and volumetric flow-rate vary widely from 100°C to 760°C and 2200 to 51800 Nm^3/hr respectively. Dust concentration in flue gases ranges from less than 1 gm/Nm^3 to around 7 gm/Nm^3 with corresponding dust emission factor of about 1 to 37 kg/MT of castings. Apart from particulates, other major gaseous pollutants in foundry emissions are SO_2 and CO. Observed concentration, emission rate and emission factors of these gaseous pollutants found in Indian cupola units along with results of orsat analysis are projected in Table-2. The observations depict that CO varies within 1.3-5.9% on volumetric basis. This corresponds to 16 to 68 gm/Nm^3 with corresponding emission factor range of 19-124 kg/MT of metal castings. SO_2 emission concentrations fluctuate between 0.10 and 0.77 gm/Nm^3 and emission factor varies between 0.1 and 1.1 kg/MT of iron produced. The results summarised in Tables 1 and 2 reflect that SO_2 pollution is not as alarming as CO and dust pollution. However, comprehensive approach encompassing control strategy for all foundry pollutants is discussed below.

Foundry Emissions Mitigation - A Comprehensive Approach

Mitigation of cupola emissions may be effectively achieved by adopting a three tier approach, namely short term, medium term and long term. Short term approach includes modifications/alterations in cupola design and operating practices, while medium term approach would comprise flue gas treatment and long term approach would aim at adoption of cleaner technologies. Since short term approach (alteration in cupola design and operating practice) would achieve target only to a limited extent, and long term approach of adopting cleaner technologies need policy decisions at governmental levels, major emphasis in this paper is directed towards medium term approach of flue gas treatment with respect to identified pollutants.

Sulfur Dioxide Control

Sulfur oxides emissions evolve as a result of sulfur content in the coke[4] (around 0.4%) as well as in the charged metal (<0.12%)[5]. Molten metal has good affinity for 'S' and dissolves about 0.05% 'S' of total input i.e. 0.5 kg/MT of casting.

Table-2 : Emission status of gaseous pollutants from some Indian cupolas

Sr. No.	Flue Gas Details	Agra(2) 1	Ludhiana(7) 2	3	Agra(2) 4	Ludhiana(7) 5	6
1.	Temperaturue °C	200	250	598	250	200	600
2.	Volumetric flow Rate, Nm^3/hr.	5055	6368	5430	4857	12701	223
3.	F.G.Composition-Orsat Analysis						
	Carbon dioxide %	3.6	4.4	15.1	1.4	-	14.2
	Oxygen %	15.1	14.5	2.7	16.5	-	3.0
	Carbon monoxide %	1.3	2.0	5.9*	2.5	-	5.7
	Nitrogen, %	80.0	79.6	76.3	79.6	-	77.1
4.	Sulfur dioxide						
	Concentration, gm/Nm^3	0.46	0.10	0.60	0.77	0.23	-
	Emission Rate kg/hr.	2.32	0.62	3.20	3.73	2.92	
	Emission Factor, kg/MT casting	0.77	0.12	1.09	0.93	1.17	-
5.	Particulate Matter gm/Nm^3	15.9	23.21	68.48	29.02	-	66.16
	Emission Rate, kg/hr.	76.38	143.83	371.86	140.76	-	146.5
	Emission Factor kg/MT casting	19.07	29.57	123.95	35.19	97.03	-

* Sample collected well below charging door

In Indian cupolas with low metal: coke ratio (4:1), only about 60-70% 'S' input is retained in molten metal and slag as compared to 90% reported[3], for similar foundry practices in other countries having higher metal: coke ratio. Remaining sulfur is emitted as SO_x in flue gas which has been confirmed from observed SO_x emissions of some Indian foundry units. However , SO_x concentration encountered in foundry emissions are still lower as compared to other industrial processes to warrant any top priority preference except in certain industrial pockets having agglomeration of foundry units. SO_x control may be affected through high stack height approach based on thumb rule of stack height, which is taken as 2.5 times of the nearest building height[4] or adopting empirical correlation (whichever is more) :

$$H = 14\,Q^{0.3}$$

Where H is stack height in metres,
Q is SO_2 emission rate in kg/hr.

Carbon monoxide (CO) Control

Reducing atmosphere of cupola leading to high CO formation, is imperative in such foundry operations. In some of the Indian cupolas, the emissions varied from 1 to 6% as projected in Table-2, depending upon operating conditions as well as sampling location, whether above or below the charging door. In existing old cupolas with open top, air infiltrates through charge door and partially burns CO thereby reducing CO pollution only marginally. Besides, it is further revealed in recent findings[6] that potential heat (up to 20% of the total input) is released to atmosphere through this source alone. It is, therefore, highly desirable to combust excess CO effectively using afterburner with controlled injection of secondary air.

Particulate Emission Control

Ultimate choice of particulate emission control system is primarily governed by the desired dust collection efficiency to satisfy the statutory norms of concerned regulatory agencies. Higher collection efficiency shall proportionately reflect on the capital as well as operational costs. Status comparison of various control technologies[7] , as projected in Table-3, reveals that operational costs as well as capital investment on Irrigated Cyclones, Self Induced Spray (SIS) Deduster and Wet Impringnant (WI) scrubber are around 22-22%, 35-37% and 62-69% respectively more than that of High Efficiency Cyclone (HEC). The corresponding costs for ventury scrubber are 5 and 2 times higher, 0.6 to 0.8 and 5 to 6 times respectively more for Dry and Irrigated ESPs and 2 to 4 and 3 to 5 times respectively more for "Shaker type" and "Reverse Jet type" Fabric Filters than that of HEC. The proportionate component of capital cost when combined with operating cost is termed as

Table-3 : Relative investment pressure drop and space requirement data of various dust emission control systems

Sr. No	Equipment	Efficiency (%)	Relative Investment			Overall equivalent Pressure Drop, mbar	Specific Volume of Plant	
			Capital	Total Operating	Annualised		1000m³/hr	in terms of HEC
1.	High Efficiency Cyclone	84.2	100.0	100.0	100.0	22.3	3.40	1.000
2.	Irrigated Cyclone	91.0	121.9	122.4	121.1	27.3	2.55	0.750
3.	Self Induced Spray (SIS) Deduster	93.5	137.2	135.3	136.5	30.4	2.55	0.750
4.	Wet Impingent (WI) Scrubber	97.9	169.4	162.5	165.4	37.4	1.70	0.500
5.	Ventury Scrubber	99.8	221.9	471.6	360.0	80.6	5.67	1.868
6.	Electrostatic Precipitator (ESP)	98.5	482.5	60.3	246.1	55.0	14.20	4.176
7.	Irrigated Electrostatic Precipitator (ESP)	99.0	619.7	84.9	319.2	71.6	10.20	3.000
8.	Shaker type Fabric Filter	99.9	339.3	218.5	271.2	60.6	17.00	5.000
9.	Reverse Jet FabricFilter	99.9	476.0	429.3	448.1	100.4	28.90	8.500

annualised costs. The relative cost (Table-3) reflect that with the marginal increase of 21%, 36% and 65% in annualised costs of HEC, incremental rise in dust collection efficiencies is of the order of 91%, 94% and 98% respectively could be achieved for Irrigated Cyclones, SIS Deduster, and WI Scrubber. Whereas, for attaining more than 99% collection efficiencies, the deployment of ESPs, Ventury Scrubber (VS) or Bag Filters (BF) would increase annualised cost by 250% to 450% of the HEC. Thus marginal improvement in collection efficiency results in huge financial burden, when advanced system of highly efficient dust collector (ESPs Ventury Scrubber or Bag Filter) are preferred unless otherwise justified.

Since these relative costs vs performance comparisons date back to the base year 1969, the existing gap in annualised cost between HEC and other highly efficient dust collection equipments must still be more due to various other factors. Besides these factors, the cost comparisons were proportionately scaled down from 1,00,000 Nm^3/hr capacity treatment system (at 20°C) to 2000 to 13000 Nm^3/hr flow-rate encountered in Indian cupolas, the cost difference will be further widened imposing more financial constraints for application of highly efficient dust control technology options (Ventury scrubber/bag filter/ESP).

Particle size

Another important factor for dust control equipment choice is particle size distribution pattern. Cupola dust emissions exhibit wide range of size distribution[8] as depicted in Figure-1. The results indicated that there were 85% particles larger than 10 μm size which can be effectively arrested by HEC or Wet Scrubber units.

Pressure Drop

Total effective pressure drop for the enlisted equipments (Table-3) followed the same pattern as that of annualised cost, the least being 22 m bar in case of HEC and the highest 100 m bar for reverse Jet high ratio BF. The pressure drops for irrigated Cyclones, SIS Deduster, and WI Scrubber were 21%, 36% and 65% respectively more, whereas for ESP and Fabric Filter it was 2.5 to 4.5 times more than that of HEC.

Space for retrofitting

Relative space requirements for Irrigated Cyclones and SIS Deduster are 75% of HEC, while that for WI scrubber it is just 50% of HEC. Ventury Scrubber requires around 87% more space than that of HEC. For ESP and Irrigated ESP it is 3 to 4.2 times more while that for BF and Reverse Jet (high ratio) BF it is 5 to 8.5 times respectively more than that of HEC.

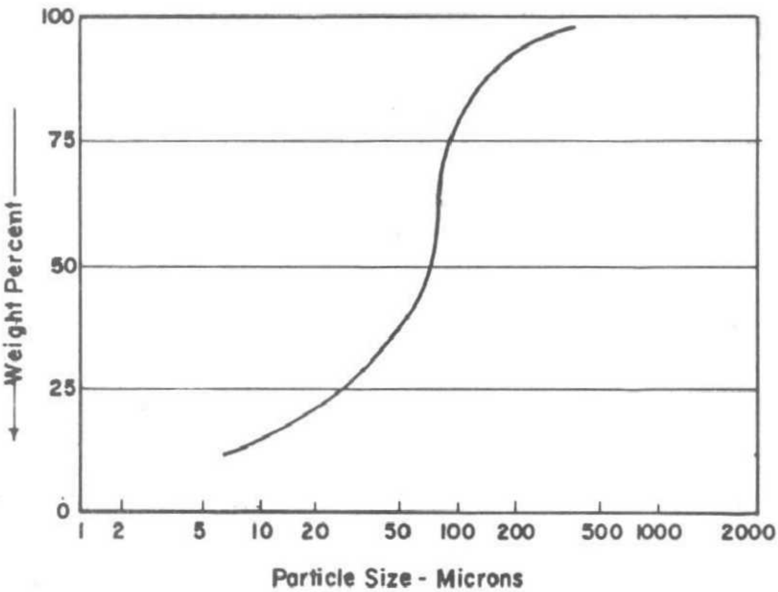

Fig.1: Particle size distribution by weight percent

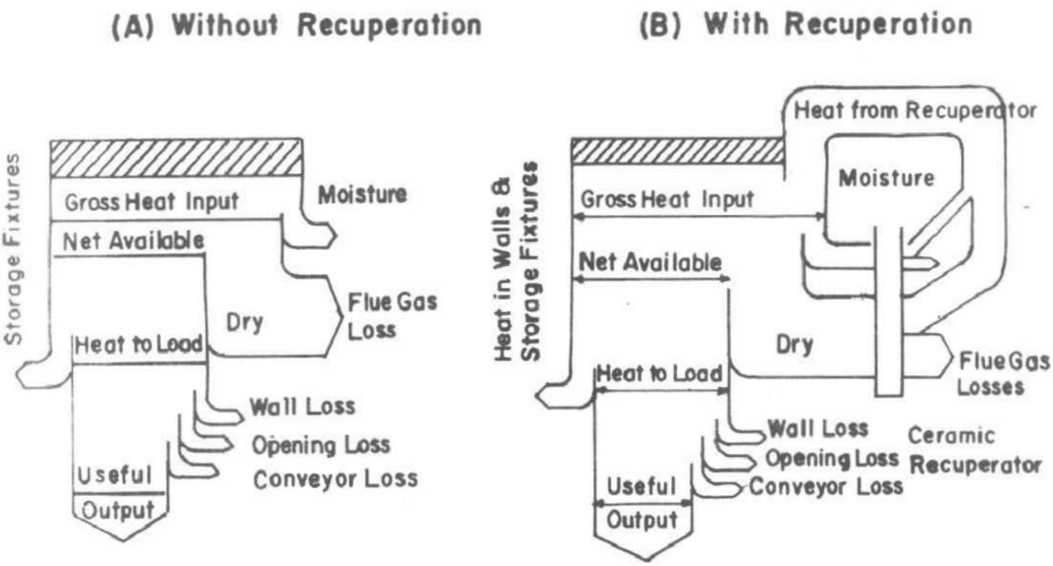

Fig.2 : Sankey Diagram

Although, cost is the prime consideration in technology decision making process, other factors namely: flue gas characteristics, temperature, humidity, concentration of SO_x, CO, volumetric flow rate, nature, size and fluid dynamic properties of particles, pressure drop and space constraints etc. play an important role in ultimate technology selection. High flue gas temperature as observed in Indian units necessitates pre gas treatment or use of special heat resistant material for BF as well as ESPs and as such, choice of these treatment systems shall not be cost effective for small/medium scale Indian foundry units. Besides, higher CO percentage at high temperature may pose explosion hazards in case of BF/ESP alternatives. The careful analysis of the foregoing discussion imply that HEC or wet scrubbers, may be preferred to highly efficient but costly ESP and BF systems under Indian operational conditions.

Energy Conservation: Flue Gas Heat Recovery

Considerable extent of effective energy losses occur as substantial quantum of heat input escapes through coke fired cupola furnaces, resulting in very low thermal efficiency as depicted in Sankey[9] diagram (Fig.2). The thermal efficiency of the furnaces can be improved by exchanging waste heat in flue gases through primary combustion air, thereby saving gross (heat) energy input to cupola furnaces. The computations based on field studies[6] conducted to evolve air pollution control system for coke fired cupola emissions, revealed that an appropriate design of flue gas heat recovery system may provide following three fold advantages.

- o CO combustion (with or without after burner) would transform potential heat in flue gas in to recoverable sensible heat and reduce CO pollution as well.
- o Primary combustion air would recover in recuperator/regenerator around 50% of the flue gas heat, thereby substantial saving (20-25%) on fuel cost and in turn fairly reduced pay back period.
- o Reduced flue gas exit temperature (after heat recovery) would proportionately reduce flue gas volume, resulting in size and cost reduction of the air pollution control system.

Table-4 provides tentative project investment for tail gas treatment coupled with heat recovery system and cost benefit analysis for a typical Indian Cupola. The projected summary indicates that the total investment on the project could be recovered by saving on fuel cost within a fairly short pay back period, if a proper flue gas heat recovery system could be devised to recover waste heat from foundry flue gases.

Table-4 : Project Investment for air pollution mitigation system for foundry emissions and cost benefit analysis

Investment and other costs		Amount (Rs.)
A.	Capital Investment	
1.	Material cost including fabrication	45,000
2.	I.D. Fan (5000 cfm, 7.5 MP)	30,000
3.	Air Preheater (HT area 786 m^2)	250,000
4.	Equipment Investment (1+2+3)	325,000
5.	Erection and Installation including civil work	48,750
6.	Overhead Expenditure	16,250
	Total Capital Investment (4+5+6)	390,000
B.	Annual Operating Cost	
7.	Supervisor-cum-operator	18,000
8.	Electricity	12,000
9.	Electrical and Mechanical Maintenance	6,000
	Total Annual Operating cost (7+8+9)	36,000
Cost Benefit Analysis		
A.	Total Capital Investment	390,000
B.	Interest on Capital Investment	77,700
C.	Annual Operating Cost	36,000
D.	Annualised Project Cost (B+C)	113,700
E.	Annual Depreciation (10% of A) on Fixed Investment	39,000
F.	Profit due to reduction in fuel cost	140,000
G.	Gross Profit (E+F)	179,000
H.	Net Profit (G-D)	65,300
I.	Pay-back Period (A/H)	6 years

Although, off the shelf high temperature flue gas heat recovery system[10] such as recuperators or regenerators for low heat duty (< 10 MMBTU/hr) are commercially available, it is much more economical to indigenously develop tailor made cost effective flue gas heat recovery system which would be within the reach of small/ medium scale foundry units to conserve precious fuel and simultaneously control CO pollution as well.

CONCLUSION

In order to select optimal air pollution mitigation system in Indian foundries following aspects should be critically studied.

1. Carbon monoxide (CO) and particulate matters (dust) are major air pollutants emanating from iron foundries rather than sulfur dioxide (SO_2)

2. Existing open top cupolas should be converted in to close loop system. CO may be combusted using after burner by injecting requisite secondary air.

3. Sensible heat in flue gas may be recovered by preheating primary combustion air through indigenously developed cost-effective heat recovery system to cut down fuel cost substantially in addition to controlling CO pollution.

4. Tail gases after waste heat recovery may be treated in HEC or wet scrubber for efficient particulate emission control and discharged through high stack to reduce ground level built up of dust and SO_x.

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