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Control of pollution created by suspended particulate matters (SPM) from small and medium scale iron and steel and refractory industries – The dry and wet options

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ABSTRACT

In the design of pollution control systems, the designer is often faced with the crucial decision to choose between either a dry or a wet system. The choice is not often easy as factors such as cost, availability of process water, implications of causing secondary pollution due to the discharge from the scrubbers conflict with each other. Some of these issues have been critically analyzed in this paper with specific examples from pollution control in metallurgical industries.

INTRODUCTION

A clean environment is a goal to which we all strive. However, we have been the victims of severe environmental damages as a result of industrial growth and defence related activities. The resulting damage to our environment is substantially affecting our overall health and welfare. In fact, environment has now become the most important global issue of all times. It is a credit to our human spirit that we remain optimistic and share an enthusiasm about environmental issues. In India also the rapid economic growth, rapid urbanization and industrialization are increasingly affecting the natural environment. There is now increased pressure of society on industries to reduce and if possible eliminate pollution and waste generation. Amongst the various industries of our country, the metallurgical industry especially the steel industry to reduce and if possible eliminate pollution and waste generation. Amongst the various industries of our country, the metallurgical industry especially the steel industry happens to be one of the most polluting. Due to the sheer volume of metallurgical industries and the amount of raw materials it processes, this industry creates severe environmental pollution and generates huge amount of waste materials. Although industries install pollution control equipments, they do not use them as the cost of compliance is much higher than the cost of noncompliance. Thus installation of pollution control system is not the only solution to achieve environment friendly industrial operations. It may also be noted that presently we produce about 21 million tonnes of steel per year and by the end of this century the steel production capacity of India is likely to cross 30 million tonnes. As a result, the contribution of pollution and waste generation from the steel industries in our country would go up considerably and thus with time the situation will go from bad to worse.

In such a situation the worst problems are being faced by the small and medium scale iron and steel industries which also include the refractory industries. It may also be noted that the refractory industries generate lot of dust during raw material crushing and grinding operations. These small and medium scale industries have some unique problems such as limited availability of funds, extremely limited availability of technologists who can design and implement a cost effective and compatible pollution control system, very limited availability of process water, lack of availability of additional electric power to operate the pollution control systems and often the lack of attitude to install and operate the pollution control systems. Even when these industries decide to install a system, clear guidelines are not available regarding selection of equipments mainly whether to got for a dry gas cleaning system or a wet system. The wet system, even though very effective, often have the disadvantage of creating secondary pollution caused by the effluents from the gas cleaning plant. Some of these critical issues are presented and discussed in this paper.

FACTORS FOR SELECTING POLLUTION CONTROL SYSTEMS

The proper choice of gas cleaning equipment for any particular case depends on a number of variables. These can be broadly grouped into four general categories [1] :

(i) Process and effluent characteristics

(ii) Required degree of reduction of emissions to meet the pollution control norms

(iii) Equipment capacities and limitations

(iv) Capital investment and operating costs

Each manufacturing operation/process has different pollution problems and can be solved in several ways. An understanding and appreciation of various factors mentioned above greatly helps in identifying the most cost effective solution. Considering that the solid particulates, carried in the flue gas, are the main source of air pollution, the classification of gas cleaning system (dry and wet) can be decided based on the mode of removal of these particulates. Dry process refers to the recovery of the solid in dry form while wet process indicates the dust recovery in wet/slurry form.

There are basically four different types of gas cleaning devices used in the industry :

- Cyclone or inertial collectors
- Fabric filters
- Electrostatic precipitators
- Scrubbers

Table - 1 illustrates the average collection efficiencies of commonly used air pollution control equipments [2]. The choice of one suitable control device over another is primarily determined by the degree of emission reduction required. Each equipment will have a specific cost associated with it. Those alternatives that meet the efficiency as well as process and plant facility requirements can then be evaluated in terms of costs. On this basis, the gas cleaning system may be selected.

In general, flue gas from different process equipment carries alongwith it dust varying in size from a few millimeters, to submicron particles. The cyclones have been widely used throughout for removing medium to large sized (upto about 10 μ size) particles from gas stream. The cyclones have found wide applications in the past because they are relatively inexpensive. However, with the present stringent regulations, it has become necessary to employ devices to remove submicron particles as well as to obtain optically clean stack discharges. This has relegated cyclones and inertial collectors to the role of precleaners upstream of more efficient gas cleaning devices. For separation of fine dust particles, both dry and wet methods such as bag filters, electrostatic precipitators (dry or wet) and venturi scrubbers are used.

GAS CONDITIONING

The gas cleaning systems, both dry and wet type, sometimes requires conditioning of inlet gas for effective gas cleaning operation. When operating temperature exceeds the limit imposed by material of construction of gas cleaning device, it becomes necessary to reduce it to an optimum value from the viewpoint of cleaning efficiency and of capital and operating costs.

Gas having temperature of the order of 1500°C and above (such as gas from LD furnace) is generally cooled by indirect heat extraction e.g., through closed loop pressurised hot water cooling system or waste heat boiler to about 900-1000°C. The amount of further cooling by water sprays depends on the type of gas cleaning equipment under consideration. Venturi scrubber is generally preceded by a quencher to cool and saturate the gas to a temperature of about 50-70°C. The temperature to which the gas can be cooled, by direct contact between water and gas, is governed by initial gas temperature and moisture content. Wet type ESP is

Table - 1 : Equipment applications[2]

Types of Dust Collecting equipment	Particle Size Microns	Loading Grains/ Cu. Ft.	Collection Efficiency Weight %	Pressure Loss Gas In. W.G.	Pressure Loss Liquid Psi.	Utilities Per 1000 Cfm.	Gas Velocity Fpm.	Size Range limits (1000 cfm)	Space Reqd. (Relative)
Dry inertial collectors									
Settling chamber	>50	>5	<50	<0.2	—	—	300-600	None	Large
Baffle chamber	>50	>5	<50	0.1-0.5	—	—	1000-2000	None	Medium
Skimming chamber	>20	>1	<70	<1	—	—	2000-4000	50	Small
Louver	>20	>1	<80	0.5-2	—	—	2000-4000	30	Medium
Cyclone	>10	>1	<85	0.5-3	—	—	2000-4000	50	Medium
Multiple cyclone	>5	>1	<95	2-6	—	—	2000-4000	200	Small
Impingement	>10	>1	<90	1-2	—	—	3000-6000	None	Small
Dynamic	>10	>1	<90	Provides head	—	1-2 hp.	——	50	
Wet scrubbers									
Gravity spray	>10	>1	<70	<1	20-100	0.5-2 gpm	100-200	100	Medium
Centrifugal	>5	>1	<90	2-6	20-100	1-10 gpm.	2000-4000	100	Medium
Impingement	>5	>1	<95	2-8	20-100	1-5 gpm.	3000-6000	100	Medium
Packed bed	>5	>0.1	<90	1-10	5-30	5-15 gpm.	100-300	50	Medium
Dynamic	>1	>1	<95	Provides head	5-30	1-5 gpm. 3-20	3000-4000	50	Small
Submerged nozzle	>2	>0.1	<90	2-6	None	No pumping	3000	50	Medium
Jet	0.5-5	>0.1	<90	Provides head	50-100	50-100 gpm.	2000-20000	100	Small
Venturi	>0.5	>0.1	<99	10-30	5-30	3-10 gpm.	12000-42000	100	Small
Fabric Filters	>0.2	>0.1	<99	2-6	—	—	1-20	200	Large
Electrostatic precipitators	<2	>0.1	<99	0.2-1	—	0.1-0.6 kw.	100-600	10-2000	Large

Note : The terms expressing concentration, or loading, can be defined as light - 1/2-2; moderate = 2-5; and heavy = 5+ Grains/cu. ft. Particle size : fine, 50% in 1/2-7 micron size range; medium 50% in 7-15 micron size range; coarse 50%; over 15 microns.

generally used in combination with venturi scrubber for final cleaning of flue gas.

Dry type precipitators and bag filters also need the inlet gas to be cooled down to a temperature of about 200°C, either by injecting atomised water or dilution with air. The final temperature is selected depending on the material of construction of gas cleaning equipment, dew point of the gas and in the case of ESP, the resistivity of the dust. In some cases, chemicals such as sulphur trioxide are also injected to improve resistivity.

It can be summarised that gas cooling, if required, can be achieved by the following methods :

- dilution with atmospheric air
- injecting atomised water, which causes gas cooling through evaporation of water
- indirect heat extraction e.g., through closed loop pressurised hot water cooling system or waste heat boilers. Overall economics for the gas cleaning device, including controlled gas cooling must be worked out before taking the final decision.

CRITICAL ISSUES IN SELECTION OF DRY AND WET GAS CLEANING OPTIONS

The designer faced with a dust collection problem must make a thorough evaluation of the situation. If a shortcut is tried with an equipment design, it may lead to a costly and inadequate installation. A few questions need to be answered : What data are needed ? What type of equipment might be suitable ? Table - 2 lists the type of data needed for selection/design of pollution control systems. For example, when choosing a pump or heat exchanger there are well established routes to answering the usual questions. By contrast, the nature of particulates in gas streams has led to a wide variety of separation devices, for which engineering principles are either lacking or not readily available. Equipment manufacturers must be relied upon for proprietary designs and performance guarantees.

However, when designing a tailor made system suiting a particular condition, it is preferable to design the system from basic principles. This also allows an opportunity to look at gas cleaning from the point of view of its need, how it is going to be integrated into the rest of the plant equipment/systems and the secondary pollution problems the gas cleaning operation may create.

The need for gas cleaning may be for process operation, protection or profit. A collector may be an integral part of a process such as spray-drying or an auxiliary to recover valuable by-products. The main aim may be safety, as in reducing toxic

Table 2 : Data required for equipment selection

Particulate Characteristics	Gas Characteristics
*1. Particle size distribution	*1. Flow rate-average and extreme values
*2. Concentration-average and extreme values	2. Pressure
3. Particle density (and viscosity)	3. Temperature
4. Bulk density	4. Moisture content, condensable vapours
5. Moisture content	5. Composition and reactivity
6. Electrical resistivity and sonic properties	6. Corrosive properties
7. Handling characteristics – erosion, abrasion, flocculent, adhesive, sticky, linty, bridging	
8. Composition	
9. Recovery value	**Effluent**
10. Flammability or explosive limits	*1. Desired emission of contaminant in clean gas
11. Toxicity limits	2. Method of disposal or recovery of collected contaminant
12. Solubility	

*Required for preliminary equipment selection

or combustible dust. People and property in the plant or neighborhood may need to be protected by a good dust collection system, or the requirement may be to meet air pollution laws and to clean up an unsightly stack plume. The many different dust collectors available today are already summarized in Table - 1, which is a simplified review of the whole collector field. Ranges and limits tabulated are typical values but naturally may vary widely for unusual applications.

A dry collector has certain advantages compared to a wet collector. If the dust is a useful product, dry collection saves the cost of reprocessing. Handling the collected material can give rise to additional dust problems. Dry dusty material has the disadvantage of requiring ventilation and if hygroscopic, caking can be a problem. The cleaned gas will not be cooled or completely free of fines. Without cooling, the temperature limits of equipment will have to be considered. Corrosion will be minimum unless the fumes contain corrosive mists. Equipment in such cases is generally bulky.

Intertial or mechanical collectors are best suited for medium or coarse particulates. High dust-loadings can be handled at moderate pressure drops and power consumption. Simple construction of this type of collectors results in lower cost and maintenance then other types. Efficiency is not very high; hence, for a really clean effluent, some other type of collection device must by used in combination with or in place of the inertial collector.

For example, Table 3 presents the various gas cleaning devices used in foundries. For heavily dust laden gases a high pressure venturi type wet scrubber is recommended. The venturi scrubber is often used as they have a typical operating efficiency of 99% and can be put up with moderate capital expenditure. One of the greatest advantage of venturi scrubber is that change in particle size has very little effect on its operational efficiency. Thus the SPM concentration in the exit gas is not likely to change with changes in the input material characteristics which are very common in such foundries [3]. Foam bed scrubbers are also used. They have the advantages of operating at very high efficiency with a low pressure drop (40-60 mm water column) even for fine particles. However, where water supply is a problem an appropriate dry gas cleaning system with specially designed cyclones has to be employed. The recommended process flow sheet for the dry gas cleaning system designed by NML is presented in Fig. 1.

Table 3 : Typical pollution control devices used to control SPM from cupolas in foundries

Melting Capacity (MT/hr)	*Possible collector required to meet SPM limit*
1-4	Simple Dry/Wet Arresters
5-10	Simple/Multi cyclones or medium intensity scrubbers
11-14	High intensity scrubbers/fabric filters/electrostatic precipitators

Pollution level is also controlled through design changes. It may be noted that incorporation of divided blast design in existing cupolas reduces coke consumption thus indirectly reducing SPM and other pollutant load in the exit gases from the cupolas. Our measurements indicate that finer particles agglomerate to form large particles presumably due to the presence of higher temperatures due to the combustion of majority of carbon monoxide to carbon dioxide. It has also been observed that in divided blast cupolas the average particle size is around 400 μ whereas in other cupolas in most cases the +10 μ fraction amounts to 50%. In view of the presence of particles of larger size in divided blast cupolas it is even possible to clean the gases to the desired limits just by employing dry arresters and cyclones

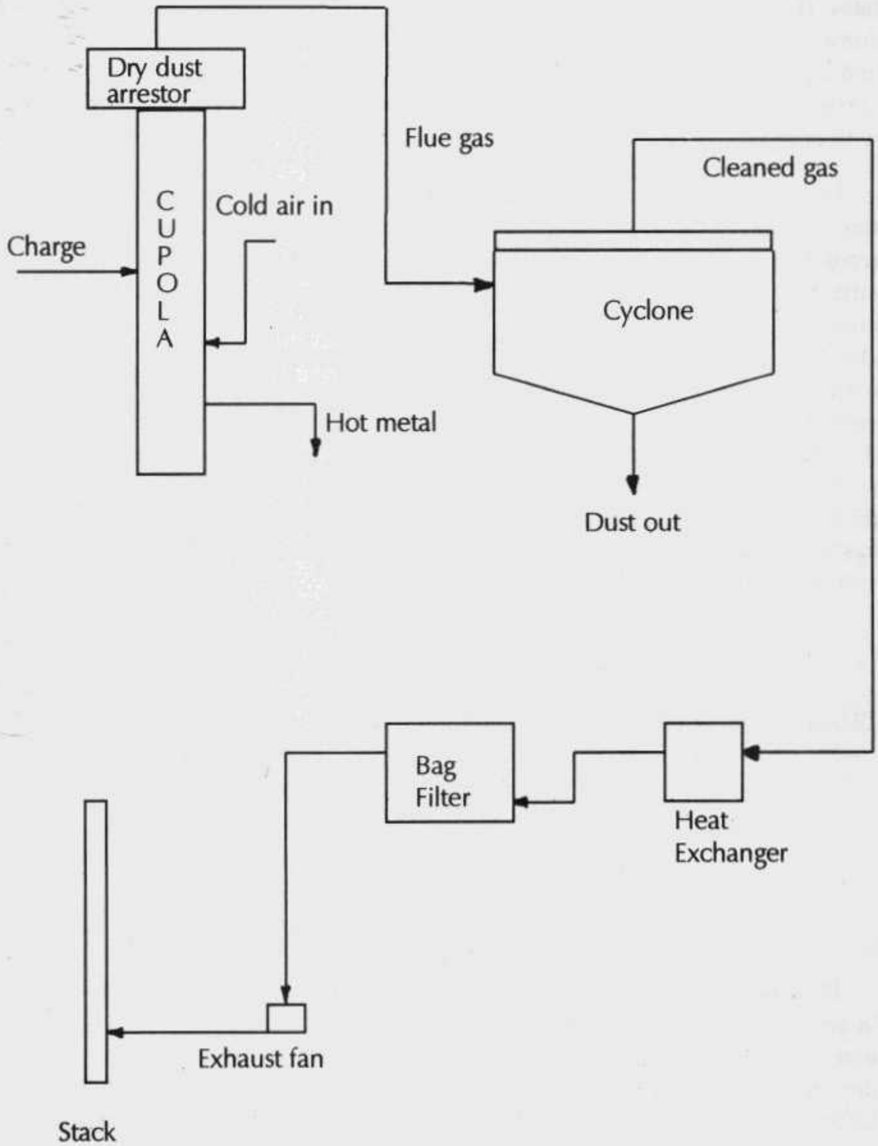

Fig. 1 : Schematic diagram of a dry gas cleaning system for cupola exhaust gases developed by NML

thereby avoiding expensive bag filters. In cases where the nature of dust is fairly fine, employment of specially designed cyclones such as Stairmand Cyclones or Multi-Cyclones may be needed. They, however, need totally sealed dust chambers.

With higher gas volumes, however, the dimensions of such a cyclone become so great as to cause a progressive reduction of efficiency. To obtain an acceptable efficiency, it is necessary to use intermediate diameter cyclones. But they cause higher pressure drop (above 100 mm water column) and will result in greater abrasion and energy needs. For these reasons, the designer, noting that a smaller-diameter cyclone achieves a higher collection efficiency, may elect to arrange a number of smaller-diameter cyclones in parallel. Since it is not practical to provide each of these small cyclones with its own sealed dust-chamber, the dust outlets of all cyclones are connected to a common dust hopper. In foundries, the characteristics of dust varies a lot. Typically for example, the average particle size distribution in cast iron foundries can be given as :

$+ 10\ \mu = 50\%$
$5\text{-}10\ \mu = 25\%$
$- 5\ \mu = 25\%$

For a 5T/hr cupola, if the gas is cleaned using a single cyclone, it requires a cyclone of diameter about 1500 mm and achieves an efficiency of only 40% for the above particle size distribution. However if, the same gas is cleaned using three smaller diameter (ϕ 900 mm) cyclones of Stairmand design operating in parallel, the efficiency can be increased to 80%.

If the gas pressure at cyclone dust outlet is not identical for each cyclone, secondary circulation will develop through the dust hopper from one cyclone to another. Those cyclones that take in gas through their dust outlet perform at lower collection efficiency and may cease to collect any dust at all. To obtain the same pressure conditions in each of the parallel cyclones, it is necessary to provide exactly same dimensions in each, and the same pressure at all inlets and behind all outlets. In addition, the dust concentration and size distribution for each cyclone would have to be the same. However, since none of these stipulations can be met in practice, it is not surprising that we can find multicyclones operating with efficiencies lower than if only one cyclone had been used. By modifying the dust discharge of the cyclone, the above mentioned disadvantages can be reduced. Table - 4 presents the fractional efficiencies of conventional and Stairmand cyclones for typical foundry dust. Summarising the above discussion it can be stated that for foundries and other medium scale metallurgical industries (including related industries such as refractory industries) it is preferable to clean the exit gases through dry options preferably high efficiency cyclones after incorporating

Table 5 : Comparison of dry and wet processes of gas cleaning

Parameters	Dry Type	Wet Type
Capital Cost	Higher	Low
Operating Cost	Low because of lower power and utilities consumption	Higher due to more pressure drop and loss of water
Pollutant Characteristics	Suitable only for dry and free flowing dusty gases. Not suitable for hygroscopic or tarry materials	No limitations
Pollution Control	Only dust is removed. No water pollution is created	Besides dust, SO_2 and NO_x are also removed considerably. Adds to water pollution
Dust collection and disposal	Dust collection in dry state. Disposal simple with very low operational and maintenance cost and no requirement of sludge treatment plant	Dust collection in slurry form. Disposal cumbersome with high operational and maintenance costs on sludge treatment plant
Corrosion and Rusting of Equipments	Usually free from this problem	Problems encountered in the presence of corrosive gases
Plant Availability	Reduced in case of choking of filter bags (for bag filters) and breakage of electrodes (for ESPs)	System clogging reduces plant availability
Dispersion of Discharged Gases	Improves dispersion characteristics	Loss of plume buoyancy due to low temperature
Safety of Operation	Explosion hazards while operating with gases containing explosive components	Limited explosion hazards
Installation space	Large	Relatively less

process optimization measures which automatically reduces the SPM load at source. This also eliminates the complex steps of treating the effluents from the wet scrubbers thereby eliminating the scope of secondary pollution.

Table 4 : Collection efficiencies of various cyclone configurations

Size Range (μ)	Size Dist. (Mass Pct.)	Single 1500 mm Diameter Cyclone	Three 900 mm Diameter Cyclones operating in parallel
+10	50	0.07	0.58
5-10	25	0.42	0.82
-5	25	0.56	0.88

A general comparison of dry and wet gas cleaning processes are given in Table - 5 [1]. In the case of gases containing extremely fine particles, bag filters can be used. However, the expenses of installation of bag filters are about 7-8 times more than the option of using high efficiency cyclones. Hence efforts should be made to convert fine particles to coarse particles during the course of operation by manipulating the furnace operational parameters. More details in this regard are given by Bandopadhyay et. al. [3]. Amongst the wet options, a few of the foundries are using natural drought wet scrubbers. However, for typical particle size distributions as mentioned earlier, it can not achieve the existing norms of 150 mg./Nm^3 of dust in the exit gas. However, for smaller foundries where the norm is 450 mg/Nm^3, this option can be used. Venturi scrubbers on the whole are very efficient. But their power consumption is very high and requires substantial amount of water. Hence it is a difficult proposition for small and medium scale metallurgical industries to opt for venturi scrubber.

CONCLUSIONS

1. The various pollution control options available to small and medium scale metallurgical industries have been critically assessed keeping in view of their incorporation in Indian industries. The advantages of dry and wet methods of gas cleaning with respect to their costs, possibilities of creating secondary pollution, achievability of existing pollution control norms etc., have been analysed.

2. The critical factors of obtaining high efficiencies in cyclone separators have been discussed including the problems created by air ingress into the cyclones from the dust discharge pipes.

3. Alternate designs have been discussed for pollution control systems in cast iron foundries and their comparative efficiencies have been indicated.

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