Comprehensive training material for fabricators and maintenance operators Coimbatore foundry cluster

GEF-UNIDO-BEE Project

Promoting Energy Efficiency and Renewable Energy in selected MSME clusters in India

Prepared for:

Bureau of Energy Efficiency

The Energy and Resources Institute

...towards global
sustainable development

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GEF-UNIDO-BEE Project, Bureau of Energy Efficiency, 2018

"Capacity Building of Local Service Providers"

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Contents

About this manual

This manual provides, in a direct and simple manner, guidance on improving energy efficiency for local service providers (LSPs) in the 'Fabricators and maintenance operators' category.

The aim is to build their capacities and equip them with the necessary knowledge and skills and to provide background information and tips regards energy efficiency (EE)/renewable energy (RE) options in important foundry operation viz. Energy conservation, Pollution control system and Sand preparation, moulding and regeneration.

The manual is designed to complement the knowledge shared with the participants through a series of four one day training/capacity building programs undertaken by TERI in Coimbatore Foundry Cluster between February to April 2018 under the GEF-UNIDO-BEE Project "Capacity Building of Local Service Providers".

1.0 Introduction

1.1 Background

The overall aim of the GEF-UNIDO-BEE project is to develop and promote a market environment for introducing energy efficiency and enhancing the use of renewable energy technologies in process applications in selected energy-intensive MSME clusters in India. This would help in improving the productivity and competitiveness of the MSME units, as well as in reducing the overall carbon emissions and improving the local environment.

The following three foundry clusters are targeted under the assignment – Coimbatore, Belgaum and Indore.

This comprehensive training material for Coimbatore foundry cluster is targeted at 'EE/RE system suppliers' category. The material is structured in the following 3 modules.

Module 1	Energy conservation
Module 2	Pollution control system
Module 3	Sand preparation, moulding and regeneration

2.0 Module 1 - Energy conservation

2.1 Melting – Induction Furnace

Melting is the heart of the foundry industry. A number of options are available for melting but induction furnace is by far the most famous and used furnace for melting.

2.1.1 Performance assessment of induction furnace

The performance of induction furnace is represented by its specific energy consumption (SEC). The SEC of induction furnace is defined as the energy consumed by tonne of liquid metal. Energy consumption in melting could be noted from a dedicated energy meter installed in induction furnace panel and the charged metal could be weighed using an electronic balance and maintain a log sheet to record the weight of metal during actual operation of the induction furnace.

$$SEC = \frac{Total\ energy\ consumption\ (kWh)}{Liquid\ metal\ production\ (tonne)}$$

The deviations of efficiency or SEC levels from design values indicate the scope for energy saving potential. The assessment of induction furnace power curves helps understand where the delays in production are actually coming from, a sample power curve of induction furnace is presented in figure 2.1.1.

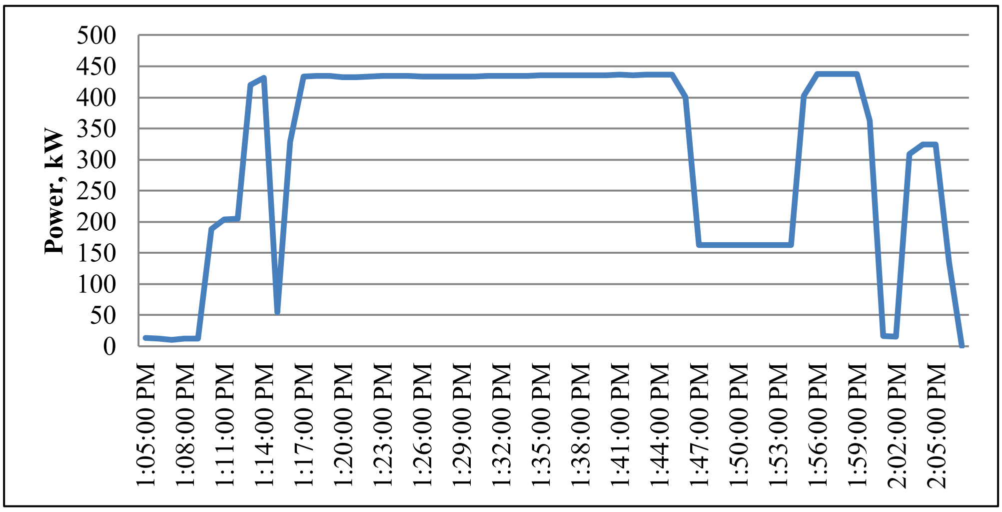


Figure 2.1.1: Power curve of a sample batch of melting in induction furnace

The starting of power curve indicates start of the heat, during initial charging the power is OFF. The furnace takes some time to stabilize to an average power level. Towards the end of heat a dip in power level shows sampling for chemistry, the second dip is for temperature measurement followed by ending of heat.

The energy conservation measures (ECM) in induction furnace can be categorized into selection & sizing and best operating practices. The parameters under selection and sizing of induction furnace affecting energy performance are as follows:

- Crucible size
    - Melt rate handling capacity
    - Moulding capacity
    - Number of crucibles in operation
- Panel capacity and type
    - Technology adopted: SCR or IGBT
    - Power density of furnace i.e. kW/kg
- Cooling water circuit
    - Pump selection: flow rate and head design
    - Type and size of sizing

The improvements in energy performance in melting can be categorized based on the investment required as follows: complete replacement of technology, retrofits and best operating practices.

2.1.2 Replacement of in-efficient induction furnace

Traditionally induction furnace uses a silicon controller rectifier (SCR) which is a 6-pulse operation with a maximum power factor at full load of about 0.95. The average energy consumption of a SCR based induction furnace in a typical small scale foundry producing cast iron is 650 kWh per tonne of liquid metal.

Insulated Gate Bipolar Transistor technology, or IGBT, is considered to be the most effective and efficient induction melting technology. IGBT technology is fairly new, with its first generation devices coming in the 1980s and early 1990s. The technology is now in its third generation which also happens to be its best generation given its speed and power. Compared to older methods, such as a traditional furnace, an induction furnace utilizing IGBT technology is not only more efficient, but is also easier to operate. Such ease of use means more time can be spent on metal melting rather than ensuring the furnace is operating correctly. Another cost-effective feature is the fact that IGBT technology coupled with the induction furnace allows for loss prevention. Some of the advantages of IGBT induction furnace are as follows:

- Higher power factor (0.95-0.98)
- Noise reduction
- Better efficiency
- Low switching losses
- Better control and
- Simpler yet stable operation

2.1.3 Retrofits in induction furnace

Lid mechanism for induction furnace

The loss of heat through radiation and convection from opening of induction furnace crucible is about 3%. Typically foundries do not have a practice of covering the opening.

Figure 2.1.3: Different options for lid mechanism for induction furnace

Low cost automation in raw material charging

Charging of raw material is one of the most important steps in induction furnace operation. Majority of small scale foundry relies on manual labour for charging. Typically the charging of raw material takes up about 50-60% of total duration of the batch, leading to lower production efficiency and higher energy consumption.

2.1.4 Best operating practices in induction furnace

Charge preparation and charging

- The raw material must be weighed and arranged on melt floor near to furnace before starting the melting.
- Charge must be free from sand, dirt and oil/grease. Rusty scrap not only takes more time to melt but also contains less metal per charging. For every 1% slag formed at 1500 °C energy loss is 10 kWh per tonne.
- The foundry return i.e. runner and risers must be tum blasted or shot blasted to remove the sand adhering to it. Typically runner and risers consists of 2 to 5 % sand by weight.
- Keeping exact weight of alloys ready, as alloys are very expensive proper handling will not only reduce wastage but also reduce time lost in alloying.
- The maximum size of single piece of metal/scrap should not be more than 1/3rd. of diameter of furnace crucible. It avoids problem of bridging. Moreover, each charge should be about 10% of crucible volume.
- There should be no or less sharp edges, particularly in case of heavy and bulky scrap, as this may damage the refractory.
- Furnace should never be charged beyond the coil level. It should be noted that as furnace lining wears out the charging may slightly increase.
- Proper charge sequence must be followed. Bigger size metal first followed by smaller size and gaps must be filled by turnings and boring.
- Limit the use of baled steel scrap and loose borings (machining chips).

- Use charge driers and pre-heaters to remove moisture and pre-heat the charge. Vibro-feeders for furnace are equipped with vibrating medium and they could be fuel fired to pre-heat charge and remove oil/grease.
- Avoid introduction of wet or damp metal in melt, this may cause explosion

Figure 2.1.4a: Vibrating feeder for induction furnace

Figure 2.1.4b: Tum blast for runner and risers

Melting and making melt ready

- Always run the furnace with full power. This not only reduces batch duration but also improves energy efficiency. E.g. 500 kg, 550 kW furnace, when run at full power melt may be ready in 35 minutes but if not at full it may take over 45 minutes.
- Use lid mechanism for furnace crucible, radiation heat loss accounts for 4 – 6 % input energy. E.g. 500 kg crucible melting at 1450 °C with no lid cover leads to radiation heat loss of up to 25 kWh per tonne.
- Avoid build-up of slag on furnace walls, as shown in figure 2.1.4. Typical slag build-up occurs near neck, above coil level where agitation effect is less. Quantity of flux used for slag removal is important. Typically flux consumption should be less than 1 kg per tonne of metal.
- Proper tools must be used for de-slagging. Use tools with flat head instead of rod or bar for de-slagging; it is more effective and takes very less time.

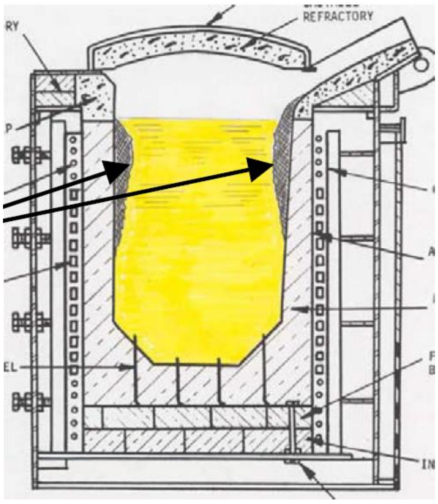


Figure 2.1.4c: Slag build-up near furnace crucible neck

- Process control through melt processor leads to less interruptions. Typically reduce interruptions by 2 to 4 minutes. Spectro-testing lab must be located near to melt shop to avoid waiting time for chemical analysis.
- Avoid un-necessary super-heating of metal. Superheating by 50 °C can increase furnace specific energy consumption by 25 kWh per tonne.

Emptying the furnace

- Plant layout plays an important role in determining distance travelled by molten metal in ladle and the temperature drop.
- Optimize of the ladle size to minimize the heat losses and empty the furnace in the shortest time.
- Plan melting according to moulding capacity. Metal should never wait for mould rather mould should be ready before metal.
- Use of ladle pre-heater. Using molten metal to pre-heat ladle expensive.
- Quantity of liquid metal returned to furnace must be as low as possible.
- Glass-wool or ceramic-wool cover for pouring ladle to minimize temperature drop.
- Minimize plant breakdown by implementing a planned maintenance schedule.

Figure 2.1.4d: Mono-rail and manual

Furnace lining

- Select the correct lining material.
- Do not increase lining thickness at bottom or sidewalls. Increase in lining means reducing capacity of furnace and increase power consumption.
- Do not allow furnace to cool very slow. Forced air cooling helps in developing cracks of lower depth, this helps in faster cold start cycle. Cold start cycle time should be ideally not more than 120% of normal cycle time.
- Coil cement should be smooth, in straight line and having thickness of 3 to 5 mm.
- While performing lining ensures that each layer is not more than 50mm. Compaction is better with smaller layer.
- Consider use of pre-formed linings.
- Monitor lining performance.

Energy monitoring and data analysis

- Separate energy meter for furnace must be installed.
- Monitor energy consumption on heat by heat basis. Analyse them in correlation with production data to arrive at specific energy consumption of furnace on daily basis.
- Any peak or valley in data must be studied and investigated in conjuncture with tapping temperature and quantity of metal tapped.
- Energy monitoring is the first step for achieving energy saving.

Others

- Effective raw material storage is important for optimum performance of the furnace. E.g. Bundled scrap is stored on mud floor, thus it will lead to dust and moisture pick-up
- Coil cooling and panel cooling water's temperature and flow rate must be monitored.
- The panel must be checked on weekly basis and cleaning must be done on monthly basis.
- Check the condition of fins in cooling tower, do cleaning of fins on monthly basis.

2.2 Compressed air system

2.2.1 Background

Compressed air is highly energy intensive as only 10 to 30% of the electrical energy consumption of an air compressor is usefully converted into compressed air and the balance is lost as unusable heat energy. A lifecycle cost assessment of compressed air system shows about 75% of total cost is towards energy. A number of studies have revealed that by proper management, energy saving in tune of 10 – 50% can be achieved in a compressed air system.

Reciprocating air compressor

Reciprocating compressors are generally best suited for medium pressure and volume applications. They are comparatively cheap, rugged in design, and have fairly high efficiencies. The disadvantages with this type, however, are the pulsating output and higher installation costs due to relatively high vibrations.

Screw air compressor

Screw compressors have several advantages over reciprocating compressors. They are inherently more reliable and require less maintenance as they have few moving parts. Further, the maximum temperature anywhere in the compressor does not exceed 100 °C, thus obviating the need for cooling the casing. In screw compressors, the suction and discharge valves are replaced by ports in the housing, and the piston is replaced by rotors. It consists of two helical rotors: an electric motor drives a rotor shaft, which in turn drives the other rotor. These compressors have less wear and tear and vibrations, and require smaller foundations. The advantages of a screw compressor are its smaller size, lighter weight, step-less capacity control, and less starting torque requirement. Also, the performance of screw compressors, unlike reciprocating and centrifugal compressors, is not affected by the presence of moisture in the suction air.

2.2.2 Performance assessment of compressed air system

Compressors are designed to deliver a fixed quantity of air at certain pressure. But, due to ageing, wear and tear or poor maintenance, compressor may not deliver the same volume of air as specified by the manufacturer in the nameplate. By performing the FAD (free air delivery) test, actual output of a compressor with reference to the inlet conditions can be assessed. The test determines the pumping capacity of the compressors in terms of FAD, i.e. air pumped at atmospheric conditions. Following tests are generally carried out for evaluating the operating capacity of compressors.

(i) Pump-up test
(ii) Suction velocity method

The pump-up test of a compressor needs isolation of the air receiver and compressor from rest of the plant, whereas the suction velocity method could be undertaken without isolating the compressor. Depending upon the operating conditions in the plant, suitable method is used to study the performance of the compressors. Apart from FAD, it is also advisable to check power consumption, the optimum pressure setting and carry out the air leak test in the air distribution network in the plant to evaluate the condition of the air distribution system. The methods of carrying these tests are explained below.

Measurement of FAD

Pump up test method

This test determines the pumping capacity of the compressors (reciprocating and screw) in terms of air pumped at atmospheric conditions. It requires the isolation of the air receiver from the system, and only the compressor, whose pumping capacity has to be determined, must be connected to it. The receiver must be drained before switching on the compressor. The time taken by the compressor to maintain the working pressure in the air receiver (compressor on time or on load time) must be observed. A minimum of three readings are required to calculate the average value of time. The volume of the pipeline between the compressor and the receiver must then be calculated. The capacity of the compressor can be calculated using the formula

$$FAD = \frac{(P_2 - P_1) \times V \times T_1}{P_1 \times t \times T_2}$$

Where,
FAD = actual pumping capacity of the compressor (m^3/minute),
V = total volume (m^3) = V′ + v,
V′ = volume of the receiver (m^3),
v = volume of the pipe line connected from air compressor to air receiver (m^3),
P_1 = atmospheric pressure (1.013 bar absolute),
P_2 = final pressure of the receiver (bar absolute),

$t = average\ time\ taken\ (minutes)\ \frac{t_1 + t_2 + t_3}{3}$
t_1, t_2, t_3 = time taken to fill the receiver at working pressure of the system.
T_1 = inlet air temperature in K
T_2 = compressed air exit temperature in K

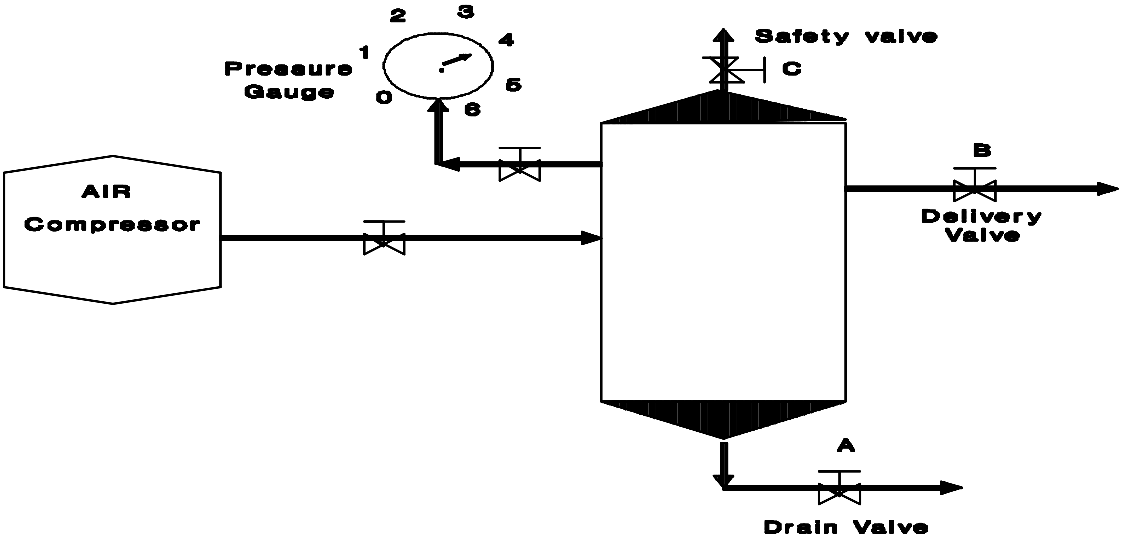


Figure 2.1.3a: Pump up test schematics

Specific power consumption

It is always better to evaluate the compressors on the basis of the specific power consumption index. This is the actual shaft power to generate 1 Nm^3/minute (normal m^3 per minute, that is, 1 m^3 per minute at 1 bar, 0 °C and 0% RH) at 7 kg/cm^2 (g) or at any common pressure, when the compressor is running at full load. This ratio can be calculated when the actual electrical power input (not the rated power of motor) and the FAD in Nm^3/min are known.

$$Specific\ power\ (kW/Nm^3/minute) = \frac{(Actual\ power\ (kW)}{FAD\ (Nm^3/minute)}$$

Pressure setting

The discharge pressure should be kept at the minimum required for the process or the operation of pneumatic equipment for a number of reasons, including minimizing the power consumption. The compressor capacity also varies inversely with discharge pressure and the power consumption increases. Another disadvantage of higher discharge pressure is the increased loading on the compressor piston rods and their subsequent failure. Maintaining a higher air pressure (generated for buffer storage) than operating pressure is a waste of energy and cost. Also, at higher pressure, air leakages from the same size of orifice increase. An increase in operating pressure by 1 kg/cm^2 can increase energy consumption by four per cent. On the other hand, lower air pressure than required reduces the productivity of pneumatic tools drastically. Most of the air tools are designed to operate at 90 psig. The performance of these tools reduces by 1–4% for every one psig drop in pressure.

Leakage test

The leakage in the compressed air system can be quantified by running the compressor with all the air-using equipment shut off. The time taken for the system to attain the desired pressure or for the compressor to unload can be noted. This pressure will fall because of leakages in the system and the compressor will come on load again. The time taken for this to happen is to be noted as well. The period for which the compressor is on or off load should be recorded at least thrice to calculate an average value. The leakages can be estimated as follows.

$$L = \frac{(FAD)\ \times\ t_1}{t_1 + t_2}$$

$$Power\ wasted\ in\ Rs/year =$$
$$1.17 \times Specific\ power\ consumption\ (kW/Nm^3/min) \times L \times operating\ hours/year \times Rs/kWh$$

Where,
L = leakages (m^3/minute)
FAD = actual free air delivery of the compressor (m^3/minute)
t_1 = average on load time of compressor (second)
t_2 = average off load time of compressor (second)

A certain amount of wastage through leakage in any compressed system is inevitable, but air leakages above 5%, certainly needs in-depth study of the system. It is difficult to detect air leakages as they cannot be seen and smelt. While large leakages are easily detected by their hissing sound or by ultrasonic generated, it is difficult to detect small leakages, which can only be identified by applying soap solution on pipelines, joints, and so on. It is recommended that the entire distribution system be tested with soap solution once in six months. The air lost due to leakages can be quite significant depending on the air pressure.

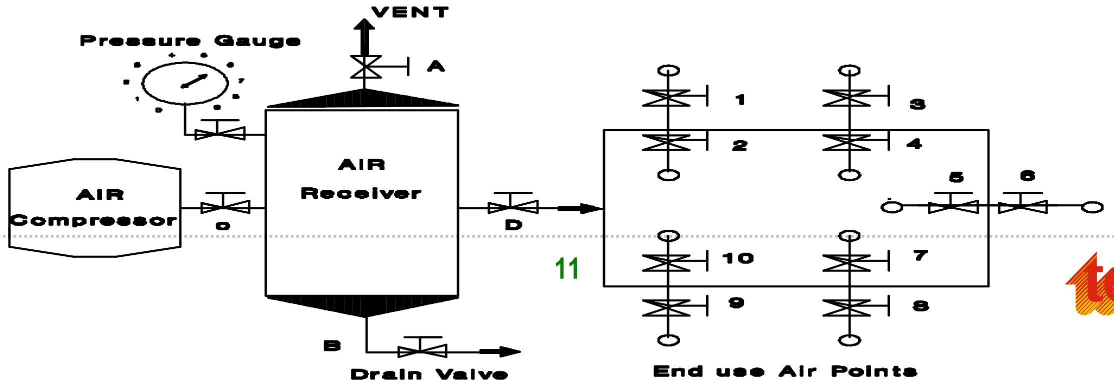


Figure 2.1.3b: Leakage test schematics

2.2.3 Replacement of in-efficient air compressor

EE compressor with VFD

Table 2.2.3a provides the detailed techno-economic analysis of a typical EE project of replacing an existing air compressor new VFD based screw compressor.

Table 2.2.3a: Details of recommended EE compressor

Actual Parameters	Unit	Value
Loading Pressure	kg/cm^2	5.9
Unloading Pressure	kg/cm^2	6.6
Specific Power Consumption	kW/cfm	0.414
Operational hours	hours/year	7,200
Base load Screw compressor		
Capacity	cfm	127.5
Pressure		7.6
Power	kW	30
Specific Power Consumption	kW/cfm	0.190
Annual energy consumption	kWh/year	1,74,420
Air compressor with VFD	**Unit**	Air Compressor
Capacity	cfm	225
Pressure	kg/cm^2	7.1
Power	kW	37
SPC	kW/cfm	0.180
Unload time per hour	Min	15.00
Saving per hour	kWh	3.13
Total Annual Energy Saving	kWh/year	1,08,930
Monetary saving	lakh INR/year	7.37
Investment cost	lakh INR	8.48
Simple payback period	Year	1.15

Replacement of reciprocating compressor by screw air compressor

A typical foundry was using an air compressor of the specifications given in table 2.2.3b.

Table 2.2.3b: Design details of existing compressor

Particular	Unit	Compressor 1
Type		Reciprocating
Operating mode		Load and unload
Capacity	cfm	34
Pressure	kg/cm^2	10

Power	kW	11

The cost benefit and saving by rreplacing the air compressor with new screw air compressor estimation is given in table 2.2.3c.

Table 2.2.3c: Details of recommended on reciprocating to screw air compressor

Actual Parameters	Unit	Air Compressor
Loading	%	47.9%
Unloading	%	52.1%
Loading Pressure	kg/cm^2	7.5
Unloading Pressure	kg/cm^2	9.0
Loading	kW	12.98
Unloading	kW	4.51
Specific Power Consumption	kW/cfm	0.434
Hours of operation	hr/year	7200
New Screw Air Compressor	**Unit**	**Air Compressor**
Make		Atlas Copco
Model		GX-11-7.5P TM
Capacity	cfm	57.2
Pressure	kg/cm^2	7.5
Power	kW	11.0
SEC	kW/cfm	0.192
Generated CFM	cfm	29.92
Annual energy consumption	kWh/year	41,431
Energy savings	kWh/year	20,227
Monetary saving	lakh INR/year	1.46
Investment cost	lakh INR	2.31
SPP	year	1.59

2.2.4 Retrofits in compressed air system

Retrofit of VFD on screw air compressor

The design specifications of existing compressors are given in table 2.2.4a.

Table 2.2.4a: Design details of existing compressors

Particular	Unit	Compressor 1
Type and make		Screw & Atlas Copco
Operating mode		Load and unload
Capacity	cfm	114
Pressure	kg/cm^2	7.5
Power	kW	18

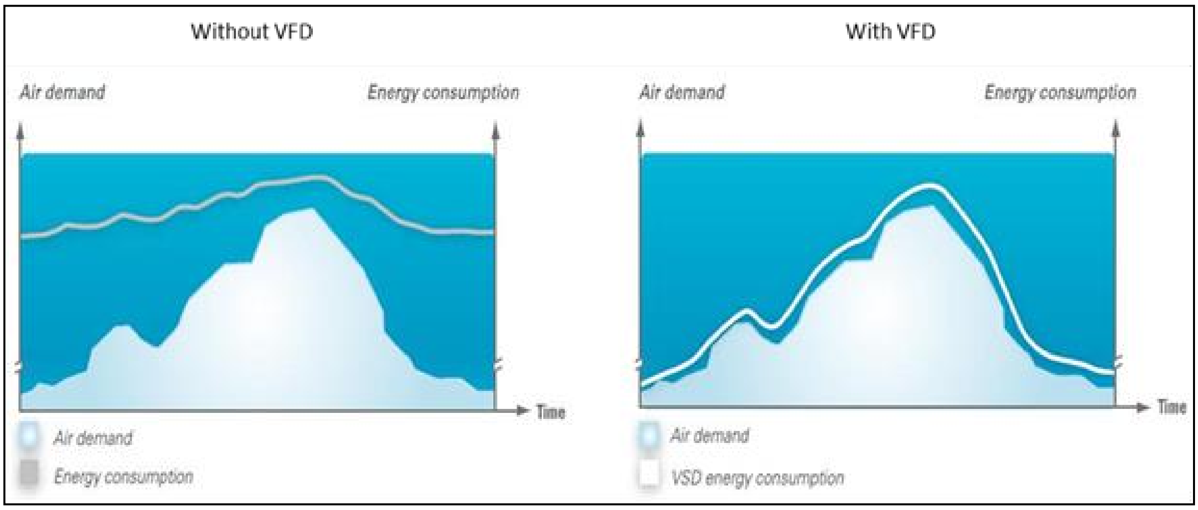


Figure 2.2.4a: Air demand and energy consumption with and without VFD

Retrofitting the air compressor with variable frequency drive (VFD) resulted in the energy savings as given in table 2.2.4b.

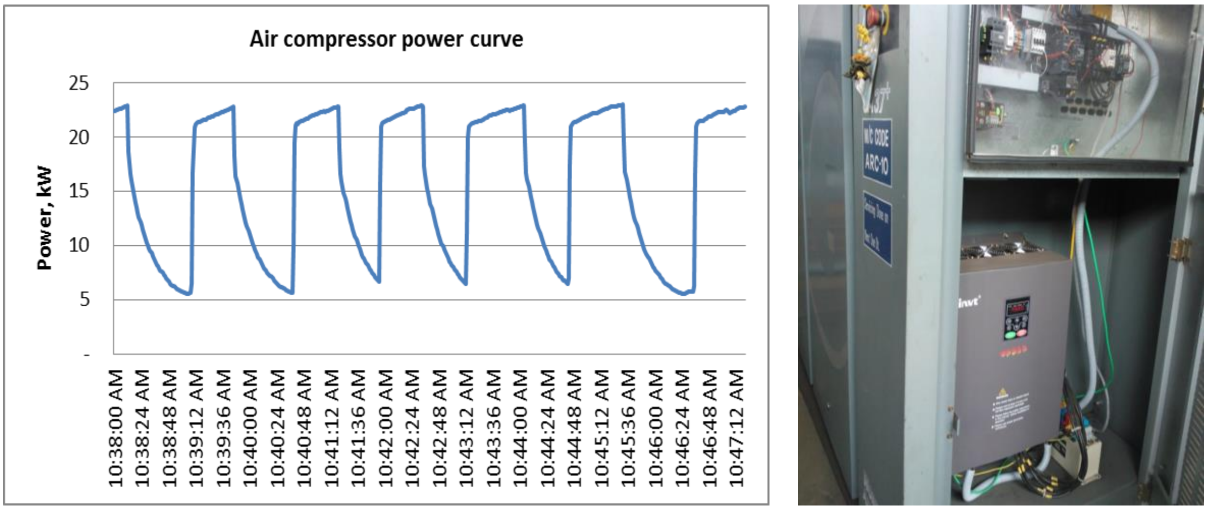


Figure 2.2.4b: Air compressor power curve after installation of VFD

Table 2.2.4b: Details of VFD retrofitting on compressor

Actual Parameters	Unit	Value
Suction Area	cm^2	50.3
Suction Velocity	m/s	10.2
FAD Generated	m^3/min	3.08
	cfm	108.6
Loading	%	41%

Unloading	%	59%
Loading pressure	bar	6.5
Unloading hours	bar	7.5
Loading	kW	21.9
Unloading	kW	7.7
Specific Power Consumption	kW/cfm	0.202
Operating hours	hour	3,600

VFD Retrofitting	Unit	Value
Unload power saving	%	15
Annual energy saving	kWh/year	10,816
	toe/year	0.93
Cost of electricity	INR/kWh	7.12
Monetary saving	lakh INR/year	0.77
Investment	lakh INR	1.24
SPP	year	1.6

Sequence controller for air compressors

A foundry was equipped with three screw type air compressors of rating 55 kW, 37 kW and 22 kW respectively. There was no control mechanism in place to insure proper meeting of the demand. The compressors were running in ad-hoc basis, leading to high energy consumption (1029 kWh per day).

It was recommended to install a sequence controller for the air compressors with closed loop feedback from a pressure transducer installed at the receiver end. This led to sequential operation of air compressor and led to improved energy performance. The daily energy consumption in compressed air system came down to 775 kWh. The switching between the air compressors with and without sequence controller for meeting foundry demand is shown in figure 2.2.4c & d.

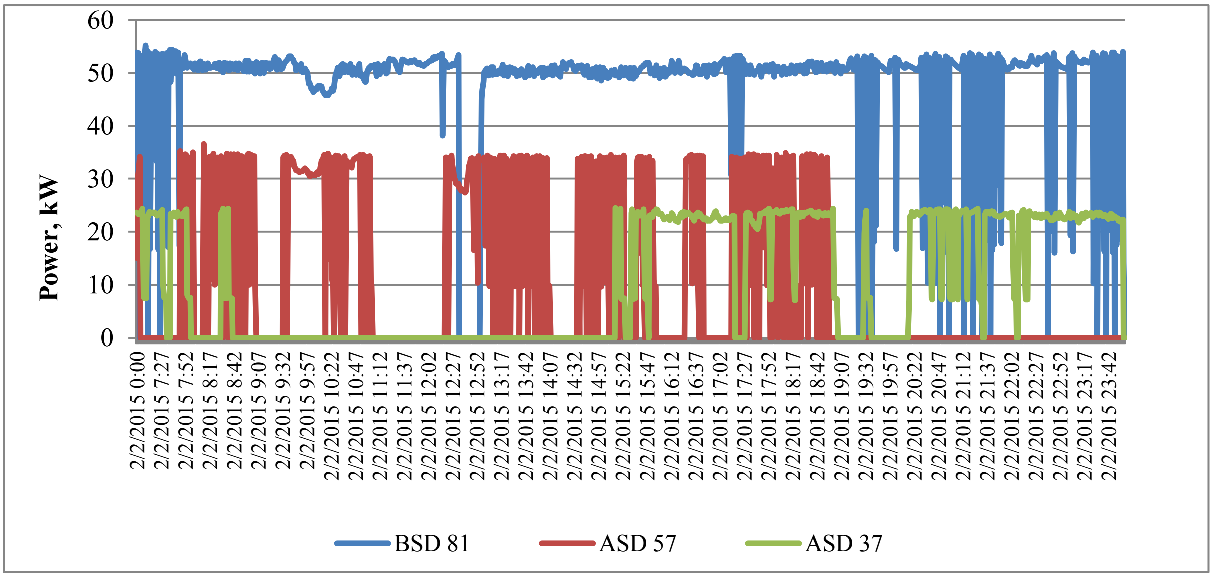


Figure 2.2.4c: Before sequence controller

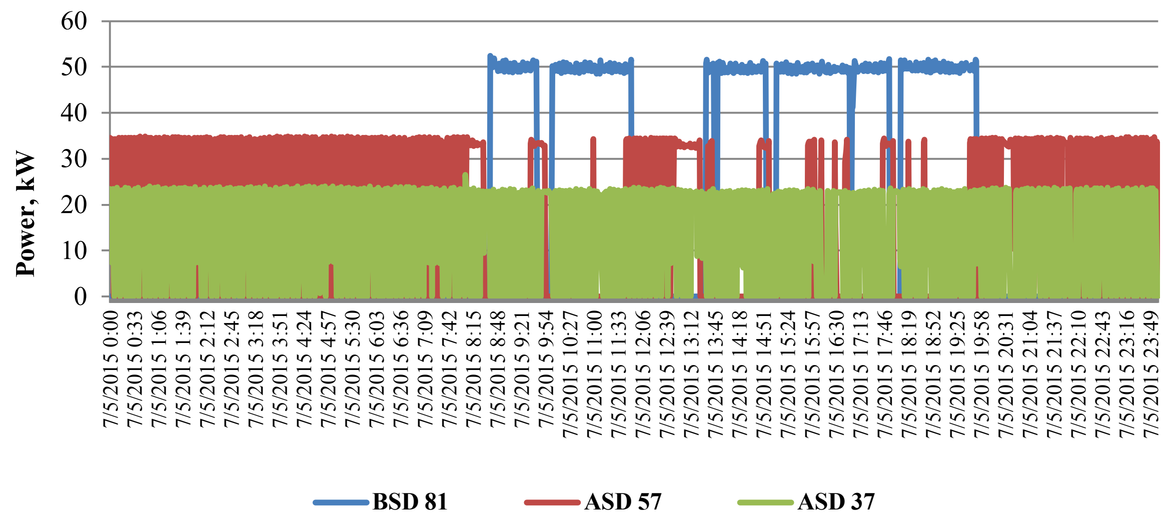


Figure 2.2.4d: After sequence controller

2.3 Cooling water system

2.3.1 Background

The foundry using induction furnace for melting have a dedicated cooling water circuit for meeting cooling demand of the coil and the also the power panel. The panel cooling and coil cooling is done using soft water i.e. demineralised water. A plate heat exchanger exchanges the heat from soft water to industrial raw water, which is circulated using another pump. Some foundry use this raw water pump to directly cool the water in a cooling tower, on the other hand a few units have hot well and cold well system, where another pump is incorporated for cooling tower water circulation.

2.3.2 Performance assessment

Performance assessment of pumps

In metal casting industries, the pumps are mainly used to transfer water from reserve source point to user end as employed in the process and connected with the utilities to circulate the cooling water. The condition of an operating pump can be understood by calculating operating efficiency of the individual pump and comparing with design value. Efficiency of a pump can be estimated by the following relation.

$$Hydraulic\ power = \frac{Q\ (m^3/s)\ \{total\ head\ (hd - hs)\}\ (m)\ \times\ \rho\ (kg/m^3) \times g\ (m/sec^2)}{1000}$$

Where,

$$h_1 - discharg\ head\ in\ metre, h_s - suction\ head\ in\ metre, \rho - density\ of\ the\ fluid\ in\ (kg/m^3, g - acceleration\ due\ to\ gravity.$$

$$Pump\ shaft\ power, P_s(kW) = Electrical\ input\ power\ (kW) \times motor\ efficiency$$

$$Pump\ Efficiency\ (\%) = \frac{Hydraulic\ power, Pd \times 100}{Pump\ shaft\ power, Ps}$$

Best performance from a pump can be observed when a pump is operated at point where its operating curve intersects with system curve without any throttling at either stream of flow as shown in the figure 2.3.2.

The pump performance will vary depending upon the operating parameters like RPM (N), input power (kW), head (H) and flow rate (Q). These operating parameters are linked with the following relationship.

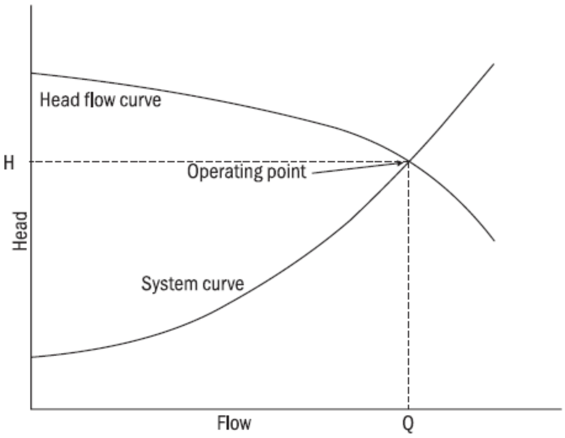


Figure 2.3.2: Operating curve of a Pump

Flow: Flow is proportional to speed; $\frac{Q_1}{Q_2} = \frac{N_1}{N_2}$

Where, Q_1 is flow corresponding to speed N_1 and Q_2 is the flow corresponding to speed N_2

Head: Head is proportional to the square of speed; $\frac{H_1}{H_2} = \frac{(N_1)^2}{(N_2)^2}$

Power (kW): Power is proportional to the cube of speed; $\frac{kW_1}{kW_2} = \frac{(N_1)^3}{(N_2)^3}$

As can be seen from the above laws, doubling the speed of the centrifugal pump will increase the power consumption by eight times. Conversely a small reduction in speed will result in drastic reduction in power consumption. This forms the basis for energy conservation in centrifugal pumps with varying flow requirements. The table 2.3.2 provides the list of data that are required for calculating above mentioned performance indicators of a cooling tower.

Table 2.3.2: List of operating parameters of pump

S No	Parameter
1	Power consumption (kW)
2	Suction head (metre)
3	Delivery head (metre)

4	Pump flow rate (kg/second)
5	Fluid temperature (°C)

2.3.3 Energy efficiency in pumps

The performance of an induction furnace is directly linked with the performance of its cooling water circuit. Therefore, it is recommended to replace inefficient coil cooling pump with an energy efficient pump. The cost benefit analysis of the EE pump is shown in table 2.3.3.

Table 2.3.3: Replacement of inefficient coil cooling pump with energy efficient pumps

Recommended Pump Specification	Units	Coil cooling pump for Furnace
Flow rate	m^3/hour	14.4
Differential Head	m	40.0
Efficiency	%	51.1%
Power proposed pump	kW	3.07
Power saving	kW	1.43
Operating period	hour	4,800
Annual Energy saving	kWh/year	6,856
Cost saving		
Annual Monetary Saving	Rs lakh / year	0.42
Investment	Rs lakh	0.55
Simple Payback Period	years	1.3

List of references

Bureau of Energy Efficiency Guide Books on the following topics – Compressed air system, Pumps and pumping system, Cooling tower and Furnace

TERI – Past studies on foundries

3.0 Module 2 – Pollution control system

3.1 Foundry process

The foundries generate significant amount of particulates and volatile organic compounds (VOCs) during the production process. These pollutants cause enormous damage to the environment and health of plants and animals over prolonged exposure. While particulate emissions lead to respiratory and other diseases in human and animals, it reduces the rate of photosynthesis in plants by depositing on the leaves of the plants. Besides, dust deposition causes soiling of the buildings and damage to building fabrics. The finer the particles are, higher is the extent of damage, as finer particles can penetrate into the deepest part of the lungs where gases are exchanged with the blood stream.

VOC causes formation of ozone at ground level. Ozone, an aggressive ground level pollutant, is formed by reaction between VOCs and nitrogen oxides in the presence of sunlight, includes respiratory distress and also damages crops and building materials, besides causing odor nuisance. Amines used to catalyze phenolic urethane cores are mainly responsible for generation of VOCs. Breakdown products from the casting of moulds with phenol-based chemical binders have also implicated in some cases. Table presents various emissions from different processes of the foundry.

Table 3.1: Emissions from different processes of the foundry

Process	**Particulate emissions**	**Volatile organic compound emissions**
Patternmaking	Wood dust, resin dust	Solvents from paints and adhesives
Mould and core making	Sand dusts (silica, zircon or chromite)	Phenol, formaldehyde, furfuryl alcohol, toluene, benzene, isocyanates, esters, amines, methyl formate, etc*
Investment shelling	Shell material dusts	Solvents (where used)
Mould coating and burn-off	Soot	Isopropyl alcohol
Melting	Metal dust and fume, dirt from scrap, dusts from metal treatments, fluxing and refractories Cupolas only : coke dust	Organic compounds from the burn-off of oil, grease, paints and plastic contaminants, if present
Casting and knock-out of sand moulds	Silica dust, resin dust, metal fume	Phenol, cresols, xylenols, anilines, naphthalene, aromatics, formaldehyde, toluene, benzene, xylene, butadiene, acrolein, etc.*
Shotblasting and fetting	Silica dust, metal dust	N/A
Casting painting	Paint particles	Solvents, e.g. xylene

* The actual compounds emitted vary according to the chemical binder system used. Not all substances shown will be emitted from all mould and core-making processes.

3.2 Present environmental standards

Existing emission standards for foundries prescribed by Central Pollution Control Board (CPCB) are given in table 3.2a below.

Table 3.2a: Existing emission standards for foundries prescribed by CPCB

Type	Pollutant	Concentration (mg//Nm³)
i. Cupola capacity (melting rate) :		
less than 3 Mt/hr	Particulate matter	450
3 Mt and above	Particulate matter	150
ii. Arc furnaces capacity : all sizes	Particulate matter	150
iii. Induction furnaces capacity : all sizes	Particulate matter	150

Note:

1. It is essential that stack is constructed over the cupola beyond the charging door and the emissions are directed through the stack which should be at least six times the dia of cupola.
2. In respect of arc furnaces and induction furnaces provision has to be made for collecting the fumes before discharging the emissions through stack.

Source: EPA Notification, G.S.R. 742 (E), dt. 30 th August, 1990

Emission standard for SO_2 from cupola furnace is prescribed to be 300 mg/Nm³ at 12% CO_2 correction as referred in MOEF notification dated 2nd April, 1996, New Delhi. To achieve the standard, foundries may intake scrubber, followed by a stack of height six times the diameter of cupola beyond charging door. In case due to some technical reasons, installation of scrubber is not possible, the value of SO_2 to the ambient air has to be effected through the stack height. The rule to be called the Environmental (Protection) Act, 1996.

Standards in other countries

Emission standards for hot and cold blast cupola prescribed by EPA, UK are given in table 3.2b below. The existing standard promulgated only for particulate matter but no standards for gaseous pollutants.

Table 3.2b: Emission standard for foundry prescribed by EPA, UK

Type	Pollutant	Concentration (mg//Nm³)
New cupola (Oct,1991): Hot and cold blast	Particulate matter	100
New cupola (April,1997): Hot and cold blast		20
Existing hot blast cupola (1991)	Particulate matter	115
Existing hot blast cupola (1997)		100

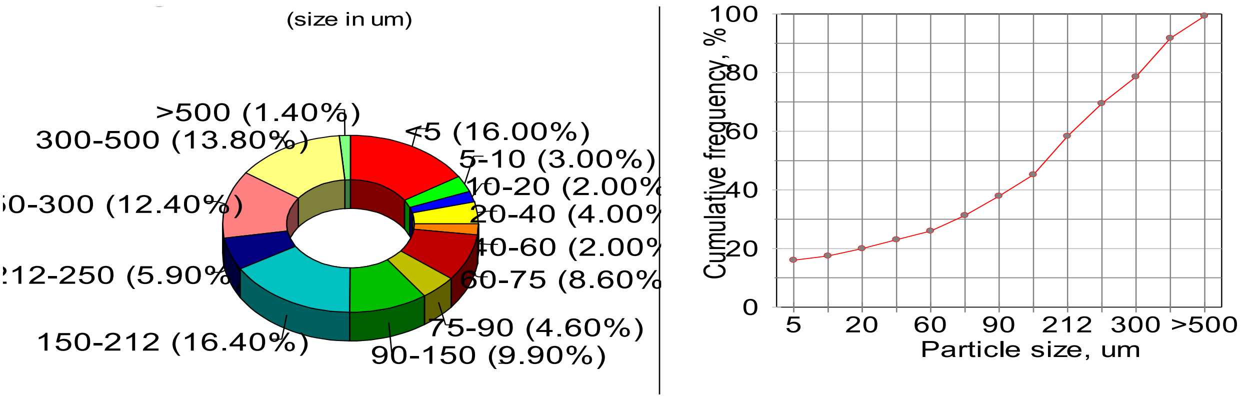
Type	Pollutant	Concentration (mg//Nm³)
Existing cold blast cupola	Particulate matter	
Capacity :		
less than 4 tonne/hr		No standard
4 tonne/hr and more (1991)		115
4 tonne/hr and more (1997)		100

3.3 Measurements

Typical emission levels from cupola are presented in table 3.3. The particle size distribution of the flue gas analysed by centrifugal dust classifier are given in figure below.

Table 3.3: Emission measurements at two units

Unit	Location	Particulate matter emission, g/Nm³
Foundry 1	Below scrubber, charging door open	1.17
	Below scrubber, charging door open	2.20
	Below scrubber, charging door closed	5.66
	Above scrubber, charging door open	0.56
	Above scrubber, charging door open	2.44
Foundry 2	Sampling port, charging door open	1.38
	Sampling port, charging door closed	2.77
	Sampling port, charging door open	3.94



The particle size distribution of the flue gas analysed by centrifugal dust classifier

3.4 PCS design vis-à-vis standards

The emissions from cupola consist mainly of particulate matter, sulphur dioxide, oxides of nitrogen and carbon monoxide. The emission level of particulate matter depends on a number of variables such as the size and design of cupola, size and composition of raw materials, specifically the ash content of coke, volume and velocity of the air blast, blast temperature, melting practice. etc. Sulphur dioxide mainly arises out of the sulphur in the coke. Approximately, 50% of sulphur in coke is usually absorbed in the metal and slag, and the rest gets discharged as sulphur dioxide through the stack along with the exhaust gases. Nitrogen oxide is emitted due to the intense combustion conditions prevailing near the tuyers. There is high presence of carbon monoxide in the exhaust gases which is to be expected considering the design of a cupola to ensure that the melt is not exposed to oxidising atmosphere which will adversely affect the melt quality.

Depending upon the sizes of the particulates and their distribution in the exhaust gas and presence of gaseous pollutants, a controlling device or combination of device may be selected for use. The different pollution control options for cupola furnace are given in Table 3.4.

Initial separators namely settling chamber, baffle chamber etc. can remove upto 90% of the higher size particles but overall collection efficiency would be of the order of 30 - 40%. Centrifugal separators namely cyclone, multiple cyclone can remove effectively upto 90% of the particles more than 10 µm size and with overall collection efficiency of 70%. The low energy scrubber like spray tower, centrifugal wet cyclone is very effective to remove the particle size greater than 5 µm with the overall efficiency of 90%. These units have an added advantage of removing gaseous pollutants like NOx, SO_2. Installation of a well-designed after burner above the charging door will reduce CO emissions by 80-90% and raise flue gas heat content.

Table 3.4: Various pollution control options for cupola foundries

Equipment	Minimum particle size, microns	Overall collection efficiency, %
Dry Inertial Collection		
Settling Chamber	> 50	< 50
Baffle Chamber	> 50	< 50
Cyclone	> 10	< 85
Multiple Cyclone	> 5	< 95
Impingement	> 10	< 90
Wet Scrubber		
Centrifugal	> 5	< 90
Impingement	> 5	< 95
Packed bed	> 5	< 90
Jet	0.5 - 5	< 90
Venturi	> 0.5	< 99
Fabric Filter	> 0.2	< 99
Electrostatic Precipitators	> 2	< 99

3.5 Commonly used PCS

Cyclone

- Not effective for controlling finer size particles (< 10 µm)
- Very difficult to meet emission standard of 450 mg/m^3 when ash content in coke fluctuates so widely between 20 to 40 %
- Dry process does not control SO_2 emission

Wet arrester or cap

- Can capture a large amount of dust particles an also dissolve a part of SO_2 emitted
- Water is recycled if proper provision for settling can be provided
- Suitable for meeting 450 mg/m^3 standard but not for 150 mg/m^3 prescribed for cupola above 3 Mt/hr
- Not effective for particles less than 5 µm

Multicyclone

- Pressure loss of around 150mm Hg across collector
- Induced draft fan is needed
- Not effective for 150 mg/m^3 prescribed for cupola above 3 Mt/hr
- Cannot control sulphur dioxide emissions

Venturi Scrubber

- Highly efficient for meeting stringent PCB norms of both SPM and SO_2
- Pressure loss of around 1000mm Hg
- Hence, induced draft fan is required
- Particles upto 0.5 µm can be collected with an efficiency of 99%
- Suitable for cupola of all sizes

Fabric Filter

- Most efficient type suited for cupola furnace
- Needs fan for cooling of exhaust gas
- Can remove 0.2 µm size particles with 99% efficiency
- Costly but cannot remove SO_2

More details of these PCS are given below:-

Cyclone

The major drawback of cyclone is that it is not effective for controlling the finer size (<10 µm) particulate matter whereas overall control efficiency can be achieved upto maximum 85% which is considered as low. It is very difficult to meet the emission standard of 450 mg/m^3 by cyclone particularly when ash content in coke fluctuates so widely between 20 to 40%. So there would be always uncertainty to meet the prescribed CPCB standard by dry cyclone.

Moreover, emission standard for SO_2 for cupola furnace has also been prescribed by CPCB which is not possible to control by dry cyclone.

Wet arrester or cap

Wet arrester can capture a large amount of dust particles and also dissolve a part of sulphur dioxide emitted. Water is sluiced back into settling tank and can be recycled by providing a proper provision for settling. It may be suitable for meeting 450 mg/m^3 standard but difficult to achieve the standard of 150 mg/m^3 prescribed for cupola capacity of above 3 t/hr. Its overall efficiency is of the order of 90%. It is not very effective for particulate matter less than 5 µm size. Coke containing higher percentage of finer particulate (say for instance more than 20%of size below less than 5Φm) may lead problems of meeting even 450 mg/m^3 emission standard.

Multicyclone

Induced draught fan is needed. Moderate pressure loss (app. 150 mm Hg) across the collector and hence more energy consuming than simple wet arrester. This is sensitive to particle size changes. It can meet the emission standard of 450 mg/m^3 with greater degree of certainly as it overall efficiency goes upto 95%. Since it is not effective for less than 5um size particulate, it is difficult to meet the standard of 150 mg/m^3 prescribed for above 3 t/hr capacity cupola. This cannot control sulphur dioxide emission.

Venturi scrubber

Highly efficient for meeting the stringent standard of SPM and SO_2. Fan is required to overcome the high pressure loss (as high as 1000 mm Hg). With the development of high energy venturi type collector, it has become to collect sub-micron particulates, fumes and smoke (upto 0.5 micron) with high efficiency of 99%. In general high efficiency collection of fine particles require increased energy inputs, which will be reflected in higher collection pressure loss. It can meet the emission standard of 150 mg/m^3 prescribed for above 3 t/hr capacity cupola with certainly.

Fabric filter

This is one of the most efficient type of particulate collector for cupola emission control. More energy intensive, needs cooling of exhaust gas (<140 C) before entering the bag filter. It can even remove the finer particulates upto 0.2 µm with 99% efficiency. It is used for even more stringent standards. It is very costly pollution control device but it cannot remove SO_2 in the flue gas.

Table 3.5: Comparison of Collection Methods

Method	Ability to give invisibl emission	Typical weight of Dust	Cost Index	Power Index	Water Pollution	Comment

Method	Ability to give invisibl emission	Typical weight of Dust	Cost Index	Power Index	Water Pollution	Comment
Simple Wet Collector	No	4	1	1	Yes	Simple, Cheap. Remove 50-60% dust
Multicyclones	No	2	5	10	No	Simplest of Power collectors. Meets some regulations
Medium/low intensity scrubber	No	0.4-2	5	12	Yes	Some designs can be updated to high efficiency
High intensity scrubber	Yes	0.4 or less	8	49	Yes	Simplest collector capable of cleaning gases to invisibility. Cheapest of high efficiency units but uses most power
Wet Electrostatic precipitator	Yes	0.4 or less	15	10	Yes	Complex. Sensitive to gas conditions. Potential explosion hazard
Dry Electrostatic Precipitator	Yes	0.4 or less	15	10	No	Complex. Sensitive to gas conditions. Potential explosion Hazard.
Fabric Filter	Yes	0.02	12	15	No	Needs good maintenance. Collected dust may need treatment to prevent dust nuisance.

It is clear from the above discussion that venturi scrubber and bag filter can meet the standard of 150 mg/Nm^3 prescribed for particulate matter with greater degree of certainty. Bag filter cannot remove SO_2 whereas, venturi scrubber is very effective for controlling SO_2 emission. Multi cyclone can meet the emission standard of 450 mg/Nm^3 prescribed for particulate matter with certainty. It cannot control SO_2 emission. Wet cap can be suitable for meeting 450 mg/Nm^3 standard but presence of higher percentage of finer particulates might be difficult for meeting the said standard with certainty. Many units have installed dry cyclone after intervention of Supreme Court in Howrah cluster. A very clear direction needs to come from PCB towards installation of pollution control system for different capacity cupola.

3.6 Technologies used in different foundry clusters

3.6.1 Pollution control system used in Howrah foundry cluster

The Howrah Foundry Association (HFA) and The Industry-Institute Partnership Cell (IIPC) at Jadavpur University devised a low-cost pollution control device using conventional dry cyclone and a new type of wet scrubber, a patented item, in tandem for the treatment of the stack emission.

The existing cyclone's collector efficiency was assessed before the new design and was rated satisfactory. However, the residual SPM had a high percentage of medium and small particles. A high efficiency cyclone has therefore been incorporated after the existing one for arresting medium-size particles and a submerged wet scrubber separator (figure.3.6.1), based on a new technology, was designed for arresting smaller ones. The flue gases would pass through the devices in series before release to the atmosphere.

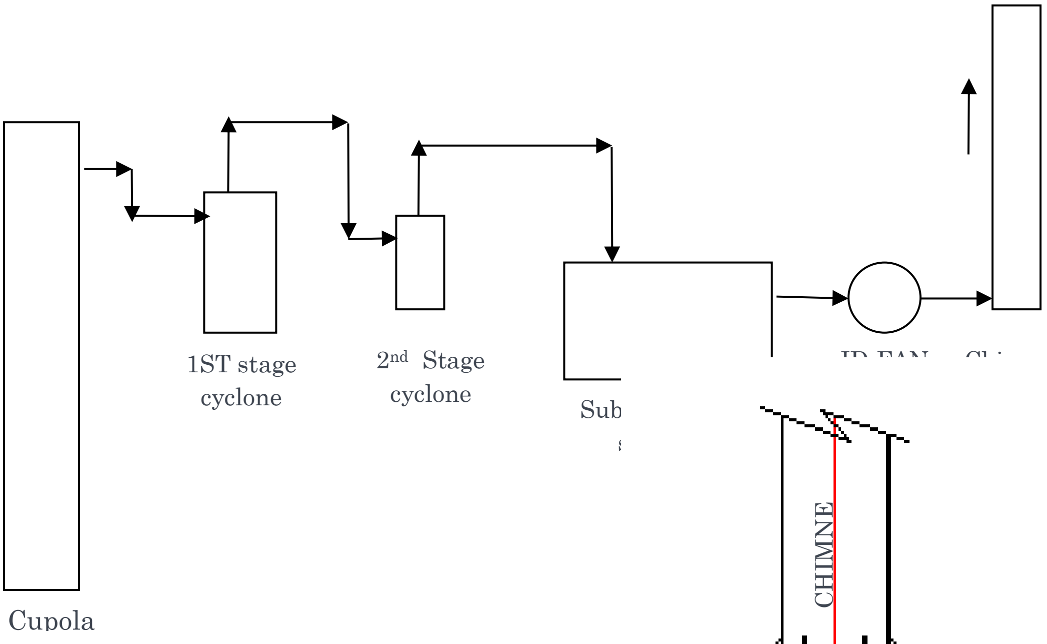
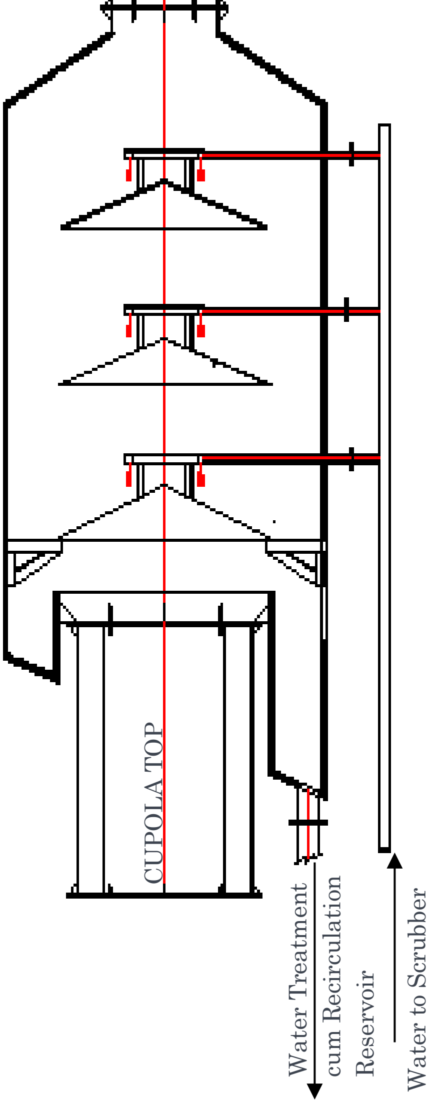


Figure. 3.6.1: The schematic flow diagram of the flue gas path through the control devices

3.6.2Cupola wet cap (3-stage scrubber)

The 3-stage scrubber called Cupola Wet Cap is positioned just above the Cupola top shell and just before the Chimney (figure 3.6.2). scrubber apparatus is provided for recovering or removing entrained particulate matter from gases comprising a settling basin, a wet scrubber mounted over the settling basin, the scrubber having a tower free of a bottom wall so as to be completely open at the bottom to said settling basin and open at the top to exhaust and open adjacent to its bottom to a source of said gases. Liquid spray means are mounted in the tower for spraying liquid counter current into contact with the gases rising in the tower to remove the particulate matter by gravity directly to the settling basin. The tower has an outer shell and an elastic liner. Means are provided for



introducing a pressurized medium between the liner and the shell to distort the liner to loosen accumulated matter therefrom for discharge by gravity directly to the basin. The elastic liner is porous to permit discharge of at least some of the pressurized medium through the liner to aid in removal of the accumulated matter from the liner. The liquid spray means also includes a plurality of circular conduits located adjacent to the inner surface of the liner, the conduits containing apertures for discharging spray liquid into the gases and also tangentially along the surface of the liner to aid in removal of the accumulated matter from the liner. .

Figure 3.6.2: Cupola wet cap

3.6.3 Twin cyclone separator

This is a type of multi-cyclone separator with two cyclones placed parallel to one another (figure 3.6.3). Collection of dust in a cyclone separator is the outcome of action of inertial (centrifugal) forces upon dust particles. The primary roles of cyclone separators are the collection of coarse dust particles. This equipment is also used for control high concentration and it has long life. The dust particles are separated due to the whirling action and vertex formation and are collected in the hopper. There is a pressure loss of around 150µmm Hg across the pollution control system. Hence induced draft fan is needed. It is not effective for prescribed standards of cupola above 3 Mt/hr. It also cannot control sulphur dioxide emissions.

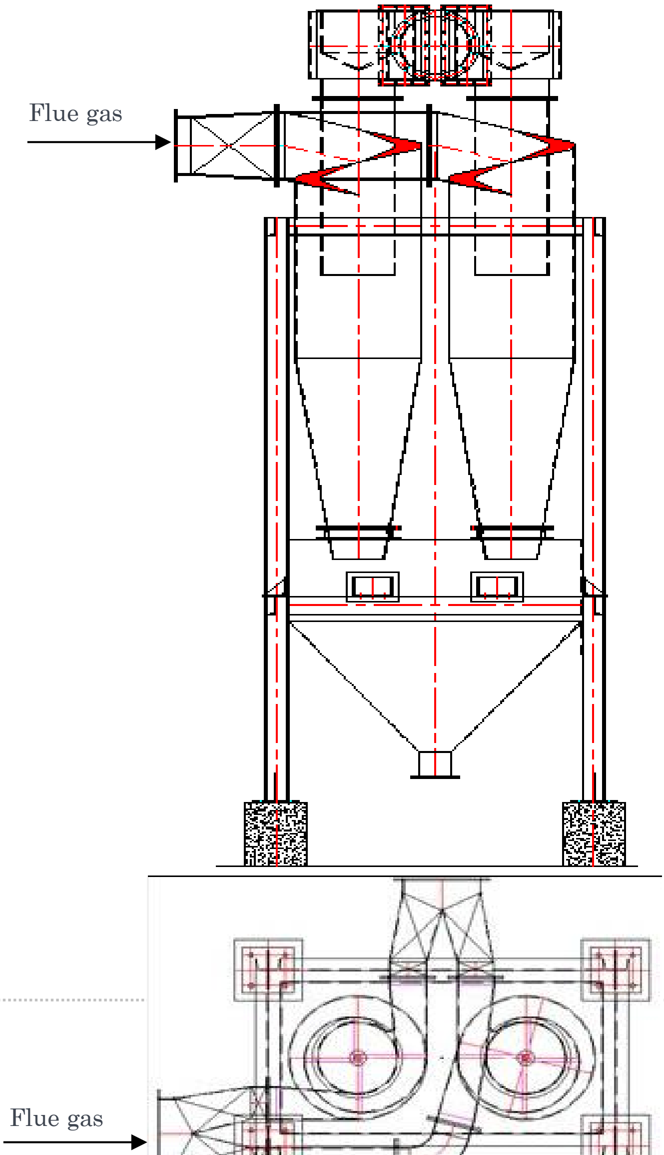


Figure 3.6.3: Twin cyclone separator

3.6.4 Pollution control system used in Punjab foundry cluster

The Air Pollution Control & Energy Conservation Cell of The Punjab State Council For Science & Technology (PSCST), Chandigarh has developed and commissioned cross current scrubbing technology (figure 3.6.4) for controlling particulate emissions from cupolas with molten capacity more than 3T/hr. The flue gas from the cupola is passed on to the deflector held at the top. There is a stream of cool water re-circulated from a tank. The cool water comes in contact with the flue gas from the deflector. Water and the entrapped dust particles are collected at the bottom and treated.

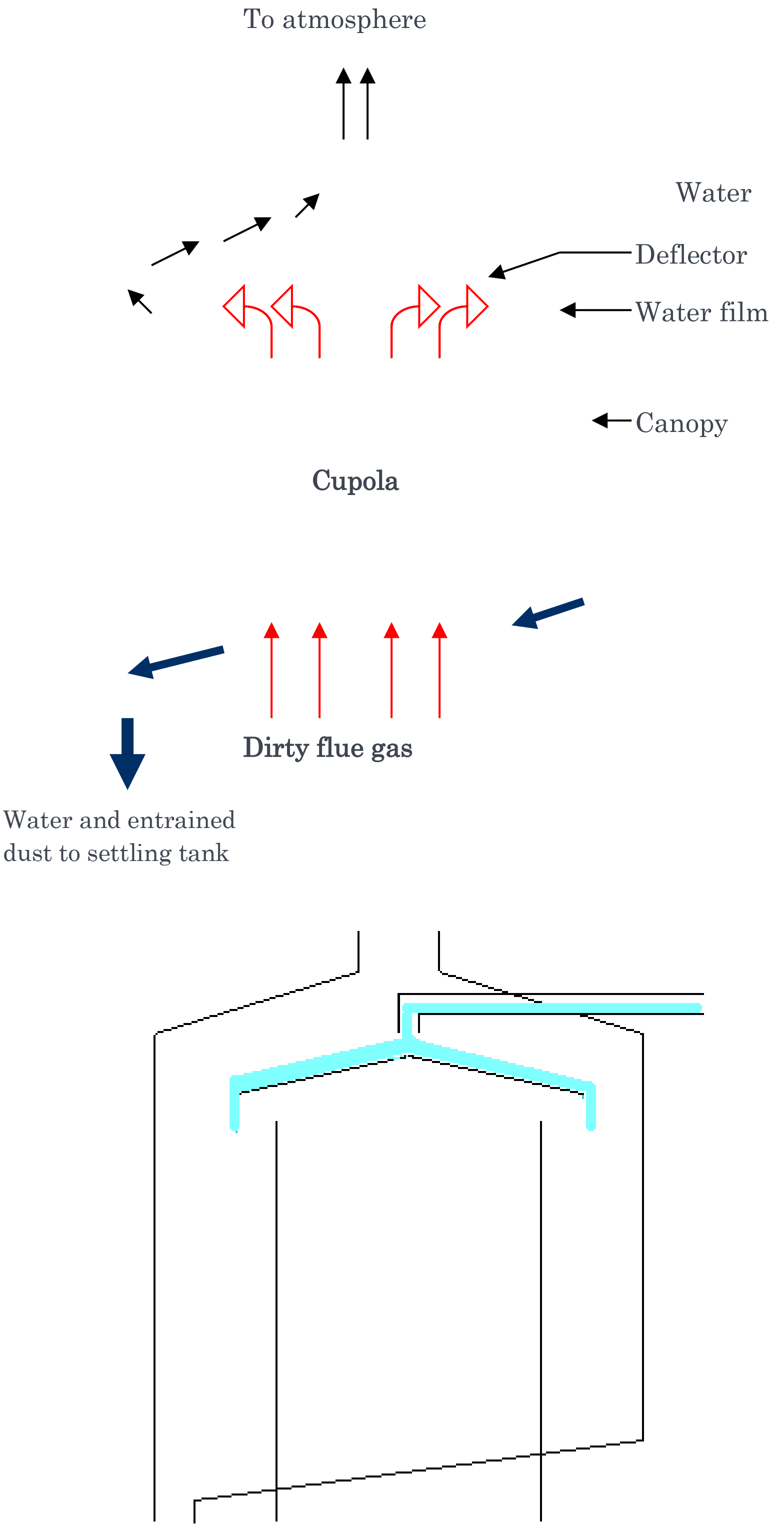


Figure 3.6.4: Cross current scrubber technology

The flue gas from the cupola is passed on to the deflector held at the top. There is a stream of cool water re-circulated from a tank. The cool water comes in contact with the flue gas from the deflector. Water and the entrapped dust particles are collected at the bottom and treated.

3.6.5 Coimbatore Foundry Cluster

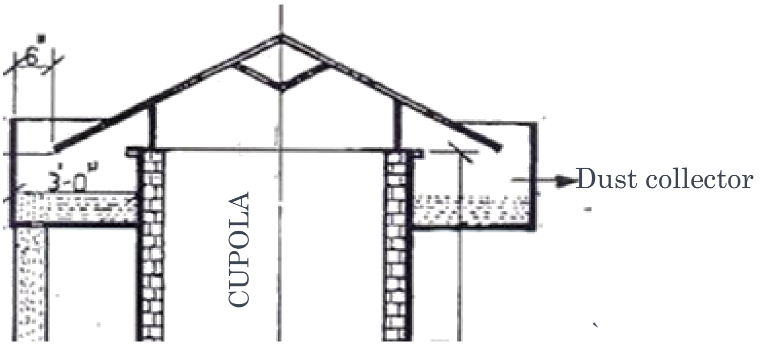


Figure 2.6.5: Dry Scrubber

Total number of Foundries in the cluster: 400
Number of Cupola Furnace using Foundries: 225
Type of PCS used:

1. Dry Scrubber (Chinese Hat Type) figure 3.6.5, Cost of Dry Scrubber : Rs. 50,000 to 75,000
2. Wet Scrubber, Cost of Wet Scrubber : Rs. 1.5 lakhs to 2 lakhs

3.6.6 TERI venturi scrubber design

The analysis by TERI reveals that cupola stack gases contain a significant percentage of fine particulates. The most effective pollution control device to bring down these particulate emissions to below 150 mg/Nm^3 is the venturi scrubber (Figure 3.6.6a). Figure 3.6.5b shows a schematic of the venturi scrubber system. Salient features of the venturi scrubber design are listed below.

Hot gas from the cupola is sucked into the venturi through an ID (Induced Draft) fan. Water is injected into the Venturi throat. Water mixes with the hot, high-velocity gas, it mixes with the gas to form a very fine, fast-moving 'mist'. The mist then passes through a 'dewatering cyclone'; which removes the water droplets along with particles adhering to them. The remaining gas, now dry and cleaned of almost all particle matter, is allowed to escape through the chimney.

- Variable venturi throat to clean the gas by binding the particles to water droplets
- Optimum gas velocity at the throat, liquid/gas ratio, and throat geometry for maximum efficiency

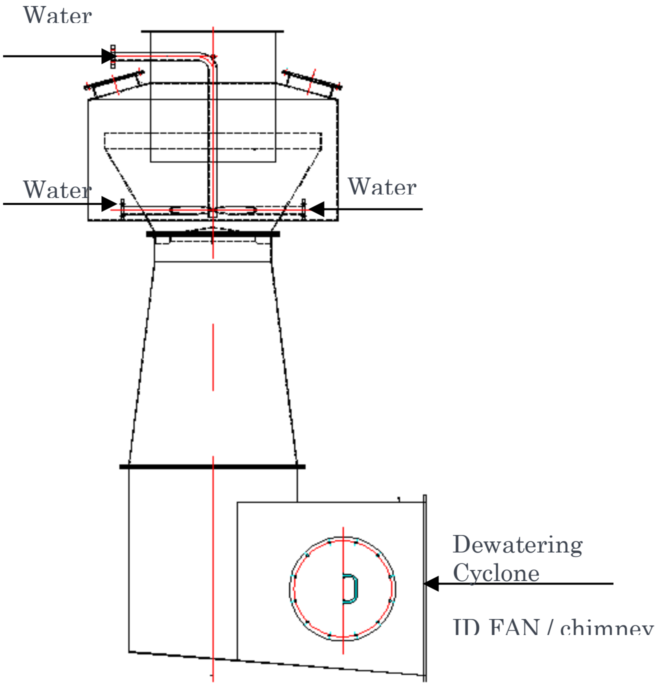


Figure 3.6.6a: TERI venturi scrubber design

- Dewatering cyclone after the venturi to retain water droplets in the gas stream
- ID (induced draft) fan to ensure sufficient pressure drop
- Stainless steel construction to prevent corrosion
- Closed-circuit recirculation to minimize water requirement
- Lime dosing to maintain the pH of the recirculating water
- Explosion-proof doors and gas-tight construction

TERI installed a venturi scrubber system at Bharat Engineering Works, Howrah—the site where the DBC was first demonstrated. Analysis revealed that the system reduced SPM emissions to a mere 50 mg/Nm^3; well below the most stringent emission norm of 150 mg/Nm^3. Figure 3.6.6c shows a comparison of particulate emission levels of (a) cupola without PCS (2000 mg/Nm^3); (b) with commonly used PCS (500 mg/Nm^3); and (c) with demonstration venturi scrubber (50 mg/Nm^3).

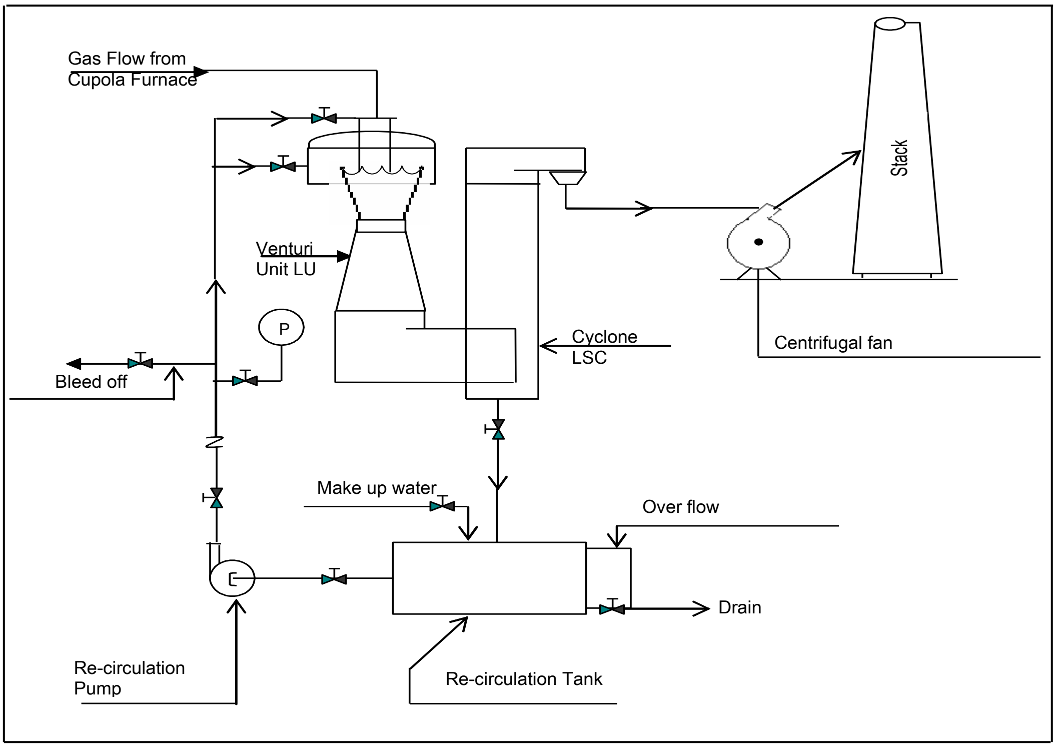


Figure 3.6.6b: Schematic of the venturi scrubber system

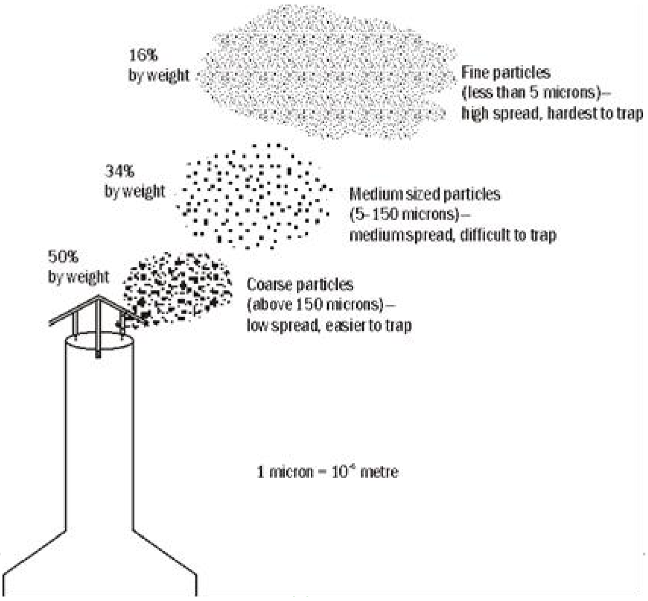


Figure 3.6.6c: Comparison of particulate emission levels

3.7 Legal framework

Central Pollution Control Board has responsibility to lay down standards for a stream or well and for air quality, planning and execution of nationwide programmes for the prevention, control or abatement of water and air pollution, and ensure compliance with the provisions of to Environment (Protection) Act, 1986. State pollution control boards has responsibility to ensure compliance with the provisions of the relevant Acts, lay down or modify effluent and emission standards and ensure legal action against defaulters.

Where it is apprehended by the Board that emission of any air pollutant, in excess of the standards laid down by the State Board under clause (g) of section 17, is likely to occur by reason of any person operating an industrial plant or otherwise in any air pollution control area, the Board may make an application to a court, not inferior to that of a Metropolitan Magistrate or a Judicial Magistrate of the first class for restraining such person from emitting such air pollutant. On receipt of the application, the court may make such order as it deems fit. Where under section (2), the court makes an order restraining any person from discharging or causing or permitting to be discharged the emission of any air pollutant, it may, in that order, I) direct such person to desist from taking such action as is likely to cause emission, ii) authorize the Board to implement the direction in such manner as may be specified by the court.

Any person aggrieved by an order made by the State Board under the act may, within thirty day from the date on which the order is communicated to him, prefer an appeal to Appellate Authority as the State Government may think fit to constitute: provided that the Appellate Authority may entertain the appeal after the expiry of the said period of thirty days if such authority is satisfied that the appellant was prevented by sufficient cause from the filing the appeal in time.
(Note: Appellant authority means an Appellate Authority constituted by the Central Government under sub-section (l) of section 31 of the act. Appellant means any person aggrieved by and appealing against an order made by the Board).

The Appellant Authority shall consist of a single person or three persons as the State Government may think fit to appoint. The form and manner in which an appeal may be preferred under sub section (l), the fees payable for such appeal and the procedure to be followed by the Appellate Authority shall be such as may be prescribed. On receipt of an appeal, the Appellant Authority shall, after giving an appellant and State Board an opportunity of being heard, dispose of the appeal as expeditiously as possible. No court shall take cognizance of any offence under this Act except on a complaint made by: I) the Central Government or any authority or officer authorized in this behalf by that Government, or ii) any person who has given notice of not less than sixty days in the manner prescribed, of the alleged offence and of his intention to make complaint, to the Central Government or the authority or officer authorized as aforesaid.

3.8 Solutions/action plan

One of the major reasons for general reluctance to foundries to adopt pollution control is the high pollution control costs. Since pollution control costs do not increase at the same rate as plant output the additional cost per ton of castings due to installation of pollution device for a small foundry is be very high. This calls for some policy changes, so that small foundries are self-motivated to adopt pollution control.

Some of the possible measures to help adoption of pollution control systems in foundry industry could be:

a) **Institutional development of foundry associations**

Technical and financial help should be given to foundry associations so that they are geared to conduct environmental measurements, design pollution control equipment, and provide all technical advice in matters of design, fabrication, procurement and installation, so that individual foundries do not have to experiment with different designs.

b) **Concessions in sales tax on pollution control equipment**

To reduce the cost of pollution control equipment, sales tax exemption on materials and equipment's required for pollution control device could be granted.

c) **Facility of loans on easy terms**

To partially meet the financing of expensive pollution control devices, an environment service company exclusively for small scale foundry could be established. This has been discussed in more detail below in financing of PCS.

Acceptable accuracy for emission value

Since foundries have to meet the emission standards prescribed for particulate matter and sulphur dioxide by CPCB, it is extremely important to carry out the systematic and accurate measurement of flue gases emanating from the stack. Since sampling has to be carried out iso-kinetically (velocity of flue gas would be the same as suction velocity of the measuring instrument), erroneous measurement of velocity or not maintaining the accurate velocity during isokinetic sampling might lead to erroneous emission value. Therefore, it is rational to have some minimum acceptable accuracy level for described method of measurement. The British Standard describes a method for measuring, with an accuracy of ∀25% under defined conditions, the concentration of particulate matter including girt and dust in the gases and total mass of these solids carried in unit time by gases passing through a flue or discharging from the chimney. The other alternative would be the measurement of emission level directly using instrument based on light extinction principle. The laser light source has become popular due to its compact beam size, good stability and high intensity with specific wave length.

Velocity and temperature measurement of flue gas

Since different instruments are used for measuring the velocity and temperature, it needs to have the acceptable accuracy of the measurement. Velocity is an important parameter as it has to be set iso-kinetically to carry out the emission measurement. If there is some error in velocity measurement, it bound to have some effect on measured emission value. Things are more critical for measurement of low velocity flue gas.

As per BS standard, the gas velocity at any sampling point shall be positive and the pitot-static difference shall not be less than 5 Pa. This is the lowest pressure difference that can practically be measured under field conditions and is equivalent to a gas velocity of about 3 m/s at 200 C. If the ratio of the highest to lowest pitot-static readings exceeds 9:1 or if the ration of highest to lowest gas velocities exceeds 3:1, another sampling position shall be sought. A gas flow rate measuring device capable of determining the rate of flow of the gas sample with an accuracy of +/– 5%.A temperature measuring device capable of measuring the temperature of the flue gases with an accuracy of +/-5%C.

At each sampling point repeat the readings of gas velocity and temperature as soon as sampling points has been completed. If the sum of the pitot static readings differ by more than +/- 10% (or the sum of the gas velocity readings by more than +/- 5%) from the original readings, the test result shall not be regarded as having the required accuracy (BS standard).

Maximum stack height

CPCB recommends that the stack is constructed over the cupola beyond the charging door and emission is directed through the stack which should be at least 6 times the diameter of the cupola. WBPCB has suggested the chimney height of 15 m for hard coke fired hot/room/core stove and raise the height of the cupola stack to 6 times the cupola diameter from charging door. For cupola capacity of above 3 t/hr, fumes collected from the top of the cupola should pass through heat exchanger and packed bed wet scrubber or bag filter by using suction fan and finally discharge through stack height of 15 m from ground level. From the dispersion equation it was found that the stack height of 15 m would be sufficient for keeping the particulate concentration level below 200 mg/m^3 as prescribed by CPCB for residential area contributed by single foundry. It was calculated by using the dispersion equation under various stability conditions that to keep the sulphur dioxide level within 80 mg/m^3 as prescribed for residential area by CPCB, it is preferred to have stack height of 20 m.

The height of the chimneys from process and arrestment plant should be assessed on the basis of estimated ground level concentration of the emitted residual pollutants. The chimney height so obtained should be adjusted to take into account local meteorological data, local topography, nearby emission and the influence of plant structure. The assessment should take into account the relevant air quality standards and criteria that apply for the emitted polutants. The minimum chimney height should be 6 m above the roof ridge height of any building within the distance of 5 times the uncorrected chimney height and in no circumstances should be less than 20 m above ground level (EPA 1990, Part I, UK).

Sharing of PCS

Multi cyclone/wet cap can meet the standard of 450 mg/m^3 whereas venturi scrubber/bag filter can meet the standard of 150 mg/m^3 as prescribed for cupola with greater degree of certainty. Since all these pollution control systems are very costly, it may be difficult for single unit to install the system. It is very important to have some policy where a group of foundries situated adjacent might be allowed to share their pollution control system. The stack height would be adjusted accordingly based on number of units are using the system and the maximum ground level concentration.

Measurement condition

There are no clear guidelines about the suitable conditions of measurement either by CPCB or SPCB. The different options available are during charging time, operating time and blowdown period. Measurement during blowdown period would not be truely representative since duration is much shorter in comparison to total melting campaign. The extremely high temperature of the top gas during blowdown which might ruin the PCS. Besides, the unstable conditions during blowdown making it impossible to make isokinetic measurement. There needs to have a clear direction whether the charging door would remain open or close during measurement. The suitable measurement time would be during operation.

Measurement time

It is always preferable to have online monitoring system which would facilitate to obtain emission level continuously over the duration of operation. Since it is very costly instrument, normally non continuous monitoring is followed for measurement of foundry flue gas in India. Therefore, it is important to prescribe the measurement time as representative for the operation duration and the frequency of measurement.

Measurement port/stand

In no conditions, there should be any negative pressure at the point of sampling port. It may prove to be dangerous for person carrying out sampling or workers around because of outlet of CO.

Particle size analysis

Particle size distribution of the flue gases is the most important guiding factor for selection of pollution control devices. It is the recognised fact that the correct determination of particle size distribution of the stack flue gases is the difficult task. Normally >u shaped= thimble or other glass fibre filter papers are used during sampling of stack particulate emission. Different particulate size analyzer namely centrifugal dust classifier, image analyzer, lazer based Melvern master particle sizer, etc. are commonly used for determination of particle size distribution. Since finer particulates get deposited on the filter paper, due to having fibre on filter paper, it is very difficult to remove particulates from filter paper which would lead to eronous results. Image analyzer would be better choice for particle size analysis of flue gas in comparison to other analyzer.

Financing of PCS

There is a general reluctance of foundries to borrow money from financial institutions and banks. Lack of professional manpower, proper accounting practices and tedoius documentation required, inhibit foundry owners in approaching banks for loan. To partially meet the financing of expensive pollution control devices, an environment service company exclusively for small scale foundry could be established. The company could be set-up with initial financial assistance from foundry associations, bilateral or multilateral organisations. The bottlenecks for borrowing money could be eliminated by making loan disbursement easier and providing guidance through the foundry associations.

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4.0 Module 3 – Sand preparation, moulding and regeneration

4.1 Introduction

Green sand moulding is the most widely used process for casting production. Approximately 70-80 % of the Grey/SG Iron castings are produced by green sand moulding process. Sand preparation and moulding is also very energy intensive. It is estimated that sand preparation alone account for up to 20% of the energy use in a mechanised foundry. Energy is typically used in sand conveying, preparation, moulding, mould handling, shakeout, reclamation, reconditioning and more conveying. Training on understanding the basic principles in green sand preparation and controls is hence important for a foundry.

The different types of sand mixing equipment, moulding processes, casting defects and ways to improve casting quality are outlined here.

4.2 Sand mixing equipment

4.2.1 Different types of sand mixers

Sand preparation plant must be equipped with the appropriate type of mixing units to ensure proper treatment of sand with the binders, other ingredients and moisture to obtain workable sand mixtures with optimum properties. There is a difference between mixing and mulling a sand batch.

Mixing is done to distribute various additives in a uniform manner throughout the synthetic sand mixtures. Intensive rubbing and kneading action is not required in this mixing procedure. Most of the core sands are prepared in a batch type mixer of various capacities. The mixing action is done with the aid of specially designed, slow revolving scraper arms, placed over the bottom pan of the sand mixer. Hard faced, easily replaceable scrapers are fitted at the tip of the scraper arms. During the slow revolution, the scraper arms force the sand upwards round the periphery of the sand mixer walls fixed with rubbing strips. These rubbing strips increase the mixing action. Continuous slow upward and downward churning coats the sand grains with the binder and other ingredients evenly and uniformly, without abrasive action.

The term mulling generally applies to moulding sand mixes which require high working strength in comparison to core sand mixes. Mulling is to apply a strong work force to a mixture of clay, carbonaceous additives and other ingredients to develop the strength and plasticity to the sand mix, by coating the sand grains with the clay bond uniformly with a thin film of clay-carbonaceous additives-water. Mixing alone cannot develop the required strength has some of the ingredients in the moulding sand mix cannot be easily dispersed in view of their high viscosity or strong cohesive nature. For developing maximum plasticity and green strength, it is necessary to apply a smearing, kneading or rubbing and shearing action in the mulling process, causing the materials to flow under pressure.

In green sand mulling, first the dry bentonite absorbs added water and then the rate of development of deformation will vary in the sand mix, with type and quantity of bentonite, base sand grain size, shape and distribution and water content.

For mulling green sand, batch type Simpson mixer or speed mullor can be used. For high pressure moulding lines, where higher green compression strength is required than conventional moulding lines, intensive mulling action is required**.** Newly developed Friction Mixer, Contra Mixer and Rotary Mixers with single and double rotors, from 500 kg upwards to 3000 kg batch capacity are available. Many foundries have switched over to these intensive mixers.

Simpson type mixer

A continuous Simpson Mixer is suitable when a steady supply of sand with the same properties is required throughout the day**.** Automatic measurement of the ingredients and water addition can be incorporated in the sand mills. In this type of sand mixer, two spring loaded mulling wheels roll in a circular path over the sand batch at about 40 rpm. The wheels are set slightly off the true radius to produce a smearing and kneading action as they rotate over the sand bed. They are mounted on rocker arms to permit them to move up and down, depending on the amount of sand being mulled, but the lowest position is restricted to ¼ inch (i.e. 6 mm) above the base pan, to prevent the crushing of the sand grains. A plow preceding each wheel loosens the packed sand from the bottom and directs it into the path of the rotating wheels. One of the plows scrapes all the loose sand from the outer periphery of the wall and the other plow performs the same function on the sand at the centre of the mullor. After mulling is completed the sand is discharged through a door provided in the pan of the mixer. **Mulling cycle duration varies from 6 to 8 minutes in the older models and about 2 minutes in the newer ones.**

Simpson continuous multi-mill

This consists of 2 Simpson mixers joined together. The sand traverses in a figure 'eight' (i.e. 8) pattern between the two separate rotating mullor heads. Production rate and uniformity in mulling action increases, if the feed rate of the sand is correctly adjusted to equal the discharge of the batch. The sand batch prepared in the mixer needs to be aerated before reaching moulders' hoppers.

Speed mullor

In Speed Mullors, rubber tired wheels roll along the side walls of the sand mixer, which are also rubber lined. The mulling wheels are mounted eccentrically and horizontally on a cross-head, connected to the central driving shaft driven by a powerful motor mounted at the bottom base. The cross head rotates at 90 rpm and the mulling plows are fitted on holders on the periphery of the cross head inside the mullors.

There are two rubber tired wheels, one a lower level and another at a higher level, with the lower plough inclined at a low angle to the bottom pan, preceding the lower wheel and the high plow inclined at a slightly higher angle and preceding the high wheel. In bigger capacity mullors, 3 wheels at low, medium and higher levels are mounted and with 3 plows preceding each wheel at different inclinations. The plows mounted wheels are designed to throw the sand up into the path of the wheels and into the adjustable gap space between the wheels and the fixed rubber liner at the periphery. Sand is mulled efficiently between the two rubber surfaces i.e. mulling wheels and the side walls. Eccentrically mounted wheels rotating by centrifugal forces produce the necessary friction, smearing and kneading action, which is essential for intensive mixing and to get workable strength. Mixing cycle time can be adjusted between 90 to 120 seconds or even more depending on the road.

Contra mixer

Contra Mixer is based on 3 dimensional mixing principle employing horizontal and vertical flow. The mixing plate remains stationary whereas the mixing tools rotate in opposite directions to each other, one located at the outer periphery of the mixer, the second and third ones at specified gap with each other and towards the central driving shaft of the mixer. Each mixing tool rotating in opposite directions is developing a phenomenon popularly known as “three dimensional mixing mechanism”. Low energy consumption, shorter mixing cycle time, mixed sand output of consistent quality, less wear and tear of the mixing tools due to low rotating speed of the mixing tools, low noise level during operation are the salient features of this type of mixer.

Rotary mixer

These intensive Rotary Mixers are available in various capacities, ranging from 50 to 150 tones output per hour, and batch charge size from 500 to 3,000 kg with mixing cycle time 90 to 120 seconds per batch. The mixing consists of dry mixing, wet mixing, homogenising and coating.

The mixer operates cyclically with the mixer tools in continuous motion. The loading of the mixer with new sand, used return sand and other additives is usually carried out with automatic load cell weighing arrangements for highly automatic moulding lines, where the consumption of san dis very high. Also, volumetric metering of the additives, new sand etc. can be done by means of discharge conveyor belts or screw conveyors. Nozzles spray the required amount of water into the sand mix. Automatic moisture controllers can be incorporated or water addition is controlled through a water metre. After completion of the mixing time, the sand is discharged through one or two pneumatically operated discharge gates.

Function of the rotor

The rotor consists of a body with rotor blades. It is directly coupled with the drive motor and is stationary suspended in the housing of the mixer. The three armed mixing tools operating on the mixer bottom pan are continuously feeding the sand to the rotor. The rotor is able to transmit a high amount of energy into the sand. The installation of two rotors enables higher throughputs. The intensity of preparation grows in proportion to the increasing speed and diameter of the rotor, until it is no longer possible to supply enough sand to the rotor. The mixing efficiency improves with two rotors. When the sand feeding to the rotor is optimally ensured, maximum wet tensile strength is obtained within the shortest cycle time.

Wet Tensile Strength not only indicates the mixing efficiency of the sand batch, but also helps to prevent scabbing defects on the castings. Aeration of the sand batch after mixing in the intensive Rotary Mixer will not be required, provided the prepared sand batch is fed to the moulders' hoppers without travelling on the conveyor belt for a longer distance.

Vacuum-cum-cooling mixers

Of late, High Intensity Vacuum-cum-cooling Sand Mixers are used in Canada and Europe to get a much better quality of prepared sand and completely cooled below 40 ^{O}C within the mulling cycle time. When compared to High Intensive Sand Mixers even with two Rotors, mixing efficiency is superior in Vacuum-cum-cooling mixers.

In Vacuum-cum-cooling Sand Mixers, water added to temper the sand vapourises within the stipulated mixing cycle time, thereby allowing the water vapour to penetrate through the entire depth of the bentonite platelets fully and completely. Whereas in all other types of sand mixers, it takes a few cycles for the entire water to penetrate through the bentonite platelets, before being fully absorbed. This means some amount of free water is clinging to the clay-water coated sand grains, in spite of allowing optimum mixing cycle time in the Intensive or Simpson type of Mixers. These new development Mixers are very much expensive, occupies less space when compared to other types of Cooling Unit Installations in the market. Mixed sand gets homogenized thoroughly within the cycle time.

4.2.2 Mixing procedures

Water Addition in the mullor

Theoretically, all the dry materials and additives should be fed into the mullor, dry mixed for a very short time, and then water addition to be done quickly, at least within less than half the specified mixing cycle time for the sand batch. This means sufficient mixing time should be allowed for the sand to develop its optimum properties after water addition is completed. Then only the batch of sand will be mulled to the correct temper water. Otherwise, the sand grains will carry more free water, which will cause Water pin holes etc. on the castings.

Water can be added before clay addition, mulling time has little effect on dry strength. When water is added after clay addition, mulling time improves dry strength.

Depending on the lay-out of the sand plant, it is not always possible to do dry mixing of all the ingredients first and then start water addition. As most of the modern sand mixers are of intensive mixing types, water addition is started within a few seconds of the ingredients being fed into the sand mixer and completed within 40 to 50 seconds and then allowed to wet mull for the specified mixing time of 120 seconds or so. If water addition is done manually then the operator gets some time to feel the sand and add little extra water at least 25 to 30 seconds before discharge of the sand batch, so that all the water which is added gets homogenised, leaving very little free water on the sand grains.

In case of Speed Mullors, manufacturers have specified to add at least 1/3rd portion of the specified total quantity of water into the mullor initially. This enables to flush the bottom bowl and side walls of the mullor of the sand sticking from the previous batch. Also, this enables to prolong the life of the mixing plows and at the same disintegrating any lumpy sand from the previous batch in the form of slurry. As the mullor cross-head rotates at a very fast rate, as soon as the ingredients are fed inside, intensive mixing takes place without lump formation. In case of slow revolving and less intensive mixing type machines, the chances of balling and lumping are more, when water is added first.

It is better to add water under pressure and by means of larger diameter pipes, so that the addition is completed within 50 seconds or so initially. The water is to be added through a water meter, which will enable the operator to quantity the amount in liters and to adjust the quantity from batch to batch from his experience. Even in case of automatic water addition, metering through a meter will give sufficient indication to the operator about the quantity going in each batch in case of failure of the automatic system.

Instead of adding water through one entry, double entries can be made and also sprinkled via circular pipe with multiple holes.

Water sensitivity of moulding sand

Water Sensitivity (WS) expresses how large a variation of moisture content the sand can bear, without a major change in its consistency. Water Sensitivity is expressed as a percentage change in Compactability per percentage change of water content.

Measuring Procedure: Take representative sand sample of optimum cycle time mulled sand batch from the mullor.

Determine its Compactability (C1) and water content (W1) Add a little water to the originally collected prepared sand sample and mix for a shorter duration in a laboratory sand mixer.

Determine again the Compactability (C2) and water content (W2) of the sample.

Water Sensitivity (C2) - (C1)/ (W2) - (W1)

From the above, Water Sensitivity (WS) between 35 to 55 is highly sensitive, and between 15 to 20 is less sensitive.

Mulling cycle time calibration

Many foundries are arbitrarily fixing the mulling cycle time between 100 and 120 seconds, when intensive mixers are in use, somehow to maintain un-interrupted supply of sand to the moulding line. This results in under-or over-mulled sand without optimum properties being developed in the prepared sand batch. Further, by under mulling, and with arbitrarily fixed cycle time, chances of adding more bentonite to the batch are more, which harms the properties of the sand, resulting in increased scrapped castings. To correct this situation, it is a MUST to calibrate the Mulling Time Vs. Wet Tensile Strength relationship.

Depending on the type of mixer and the composition of the sand mixture, optimum mulling cycle time will vary.

To determine the correct mulling cycle time, New Sand, Return shake-out sand Bentonite, Carbonaceous additives etc. should be weighed accurately as per the batch size of the sand mixer, and fed into the mullor. Preferably, temperature of the return shake-out sand should not exceed ambient temperature i.e. not more than 40°C. Start adding water feed the usual quantity through the water meter and finish adding the total quantity within 50 seconds. As the mulling is in progress, collect samples at 70, 90, 110 and 130 seconds from that batch and test in the laboratory for Green Compression Strength and Compactability and wet tensile strength. Moisture also can be tested. This will stabilise around 110th second or so. Plot a graph "Mulling Time Vs. WET TENSILE STRENGTH" and "Compactability". The curves will indicate peak strength development time and Compactability. Accordingly, the minimum mulling cycle time for getting optimum properties should be followed for the routine production. It is suggested to do this calibration once every week and accordingly follow the cycle time.

In foundries, where they have **Wet Tensile Strength,** or **Green Tensile Strength Splitting/Spalling Strength** testing facilities, the same should be included in the calibration test. In the highly automated lines, these additional tests will reveal the true characteristics of the UNIT sand prepared, and to a very great extent the proper functioning of the bentonite in developing bonding quality.

At the end of the mulling cycle, take a sand sample. Riddle the sand through a 12 or 20 mesh U. S. Sieve. Take the moisture content of the riddled sand passing through the sieve and also after crushing the lumps retained on the sieve. The difference in moisture content in the lumped sand and riddle sand should not be more than 0.1%. If so, we can conclude the mullor is functioning efficiently.

At least once or twice in each shift, take 100 grams of prepared sand from the mullor. Riddle the sand through 20 mesh U. S. Sieve. Calculate the percentage weight of the lumpy sand retained on the sieve. Besides, find out the moisture content, green compression strength, splitting strength and compactability of the sand sample and maintained daily record. Apart from knowing the Mullor Efficiency, this nonstandard test will help to adjust bentonite and new sand addition in the batch in case the lump percentage retention on the sieve increases than the average retention experienced by the foundry. After several readings, this standard should be fixed by individual foundry.

Maintenance of the mullor

First of all, cleanliness of the mullor is a must, either at the end of each shift or at the end of days work. This will reveal any abnormal wear and tear of the moving parts viz. scrapers, plow holders etc. so that timely replacement can be done.

Clearance between the scrapers with respect to bottom pan and the side walls of the mixer should be kept as low as possible, preferably 1/16 inch. If this adjustment is maintained, then, at the end of discharge of sand from the mullor, the bottom pan will be found shining and there will be no built-up of sand lumps at the radius of curvature of the circular periphery of the bottom pan.

For prolonging the life of scrapers and other moving parts, hard facing of the tips with welding electrodes can be done. Duriod 3 B or Citorail III, or any other wear resistant electrodes can be used.

Overloading of the mullor should be avoided. This not only affects the mulling efficiency but also damages he driving motor life. An Ampere Meter fixed in the panel board will help the operator to detect excess current consumption and report to maintenance department.

During week end off day, advance preventive maintenance schedule to be planned and executed after thorough cleaning of the mullor, hoods, air chamber below bottom pan, ducting exhaust from the mullor top etc.

Manual addition of bentonite, coal dust or any other additive to be replaced by simple mechanisation and with timer controls. This will eliminate human error and consistent addition can be maintained. Periodic checking system should be introduced for proper functioning of these items.

Manufacturer's recommendations for the proper up keep of the equipment should be strictly observed. Cleanliness should be maintained on daily basis. Timely replacement of moving wear parts should be undertaken.

Functioning of Magnetic Separators should be frequently checked. Otherwise, iron pieces with sharp edges and of big size, may cause heavy damage to the conveyor belts and when gets entangled inside the mullor, may twist or break some parts.

MULLING TIME Vs. WET TENSILE Strength and Compactability calibration should be done every week. When optimum mulling cycle time is fixed, then unnecessary extra addition of bentonite can be avoided. Apart from cost savings, this will improve the quality of the prepared sand batches.

Installation of Magnetised Head Drive Pulley after the sand comes out of the screen before entering main storage hopper will greatly help to remove the tiny iron globule formed at the time of pouring the moulds, which are difficult to remove at the main shake-out magnetic separators as the sand bed height will be high.

The key points to remember in sand mixing are summarised in the box below:

Points to remember in sand mixing

1. Return sand fed into the Sand Mixer should be well below 40 °C. Excessive hot sand will not bind properly and will cause heavy scrap of castings
2. Magnetic separators to be located at such vantage points for effective removal of iron pieces and metallic globules
3. Additives to the sand mixes to be weighed accurately or automatic feeding devices to be incorporated for correct addition.
4. Manufacturers recommendation for the proper upkeep of the sand mixer, adjustments of the various moving parts with minimum clearance between side walls and bottom pan of the mixer to be maintained. This will improve mixing efficiency and build-up of lumps can be avoided
5. Water addition to be done within the first 45 to 50 seconds of the mixing cycle time and initial flush water is preferable to disintegrate lumps sticking to the moving arms from the previous batch.
6. Shift wise cleanliness of the mixer to be maintained
7. Worn out blades, scrapers etc. to be replaced then and there instead of waiting for week end OFF day.
8. Mixing Time Vs. Wet Tensile Strength development calibration to be regularly done every week.

4.3 Moulding equipment

Principally the moulding process can be divided into three major categories from the perspective of energy efficiency:

- Simultaneous Jolt Squeeze Moulding Technology working on Compressed Air
- High Pressure Moulding Technology working on combination of Compressed Air and Hydraulic Energy
- High Pressure Moulding Technology working on Hydraulic

In terms of basic mechanical engineering, the efficiency of power transmission through Compressed Air has been considered the poorest – even if very popular and useful – to as low as 30%, which some manufacturers have been able to improve to a bit more.

When comparing with Jolt Squeeze Technology the High Pressure routes have also a distinct advantage of weight saving as a result of the 5 to 6 times higher squeezing force applied with the right pre-compaction.

The energy consumed per hour for a 600 x 600 mm box size in Hydraulic was 0.19 kWh/mould while that for Jolt Squeeze Technology Pneumatic machine was about 0.3 kWh/mould (we have not factored the compressor efficiency here).

This would impact a metal saving of about 2% from weight saving, about 0.5% from rejection and the contribution from 2.5% of additional saleable castings.

Advantage of Hydraulic Moulding vs Jolt Squeeze Machines

Jolt Squeeze Machines		**High Pressure Moulding**
Specific Squeeze Force 1.5Kg/CM²	**Reduces Weight Improves Dimensional Accuracy** Improves global Competitiveness	Specific Squeeze Force 10Kg/cm² (6 times)
Safety: Low	**Energy Saving** 30% in Machine 50% in Machining 2% in Material	Safety: Improved
Noise: High (>100 dB)	Safe Working Conditions **Safety as per International Standards** **Adheres to Pollution Norms**	Noise: Low (<85 dB)
Power consumption:- 30HP		Power consumption:- 12.5 HP

4.4 Casting defects, causes and remedies

During the processing of Green sand moulds and pouring liquid metal into the acted moulds, there are lots of variations at each processing stage. Stating from Pattern making with accurate dimensions, smooth finishing of the pattern surface application of release agents over the pattern for smooth stripping, properly tempered prepared sand for getting good compacted moulds, correct jolting and squeeze pressures while making moulds, cleaning of the moulds free from loose sand particles before closing the moulds, melting practice, temperature of the metal and mode of pouring the metal into the closed boxes, time taken to fill the moulds with liquid metal-all these factors will play some role in the contribution of rejection of castings at the final stage. Besides the quality of the raw materials used at different stages of processing and mode of processing are to be monitored systematically.

Once the core group of personnel including the Sand Technologist, understand the basic reasons attributable for various types of defects and are in a position to analyse the causes, many of the rejections can be avoided/minimised with anticipatory corrective measures.
In this section each casting defect is defined, causes for the defects and probable remedial measures are suggested.

Sand inclusions

Weakly bonded, poorly tempered during mixing. low moisture and poorly compacted moulds during mould making will not be able to resist the impact of metal stream flow, and as a result will erode and wash out the sand grains and deposit these sand grains at any place on the surface of the casting. Broken moulds at the time of closing or weak thin sand sections may also get washed out and cause Sand Inclusion defects.

Causes: Low moisture, high or Low Methylene Blue Active clay, Gating system which causes high turbulence at the time of pouring metal, Poorly mixed sand with incorrect additions in the sand mixer, Contaminated sand with foreign particles, hot sand, excessive release agent spray on the pattern and poorly Compacted moulds. Once the above causes are corrected, Sand Inclusion defects will be minimized.

Scabs

Two types of Scabs, one is Expansion Scab and the other is Erosion Scab. Expansion Scabbing and Spalling are a result of failure of the surface of the mould or core during pouring. An Expansion Scab consists of a protruding thin plate of metal lightly attached with the casting and containing the "failed" sand layer between the casting surface and metal. Prising away the scab reveals the sand layer and a depression in the surface of the casting. In extreme cases, expansion scabbing is extensive and larger upper surface of the moulds will fail, whereas in others, e.g. on runners and ingates the scabs are smaller in size. On the casting the scabbed area need rectification, but then there is always danger, particularly on and around the running system , that portion of the failed" sand layer will be washed by the flowing metal and deposited elsewhere in the casting as large sand inclusions.

With curtain type of bonded sand or painted moulds, and where heat radiation is prolonged, failure of the sand surface may occur and flakes or grains of sand or paint will fall on to the Rising or flowing metal and remain as internal or sub-surface inclusions.
Probable Mechanism of Expansion Scabbing are the following:

a) Molten metal entering the mould rad ate heat on to the upper sand surfaces, which rapidly dry out. The removed water, as steam passes through the mould and condenses in the cold sand away from the heated surface. This condensing steam produces a layer of very moist, weak sand immediately behind the thin dry layer.

b) The dry surface layer expands as its temperature is raised further by radiation from the rising molten metal. With Silica sands, at 575 °C, a sudden large expansion occurs when Alpha Quartz changes to Beta Quartz. If this expansion cannot be accommodated by movement, i.e. deformation of the sand, the expanding dry surface layer buckles and cracks.

This weak, very wet condensation zone beneath allows easy separation of the expanding surface layer.

c) Metal flows through the crack and behind the buckled layer of sand causing Expansion

Causes : High Moisture, Very Hard Moulds or Cores, Low Moisture, Low Methylene Blue Active clay, Mould Spray and viscosity of Application, excess pattern Spray, High pouring temperature, Incorrect Gating, Low addition of carbonaceous additives with low LOI value in the sand mix, Non-uniform Mould Hardness, Incorrect sand composition formulation, and Mould wall Movement.

If these factors are corrected Expansion Scabbing can be controlled.

Erosion scabs

An Erosion Scab occurs where the molten metal has been agitated, boiled, or has partially eroded away the sand, leaving a solid mass of sand and metal at the particular spot. Some of the sand that was eroded away, generally finds its way to the cope of the casting as Dirt Inclusions. This erosion is due to high moisture in the sand mix, too high fines in the sand system which calls for high moisture at the time of tempering, too high additions of carbonaceous additives which calls for high moisture for tempering the sand mix, too low Hot Strength of the sand mix, and insufficient mixing time in the mullor and insufficient moisture to temper the binders to get optimum properties.

Rat tails

A Rat-Tail is a minor buckle, occurring as a small irregular line or lines. A thin irregular layer of metal separated by a thin layer of sand rests on a depression.

Causes: Low addition of carbonaceous additives, High moisture, Uneven mould hardness, Low moisture, Low methylene Blue Active clay, Wrong sand composition, Insufficient mould vents, contaminated sand, Hard mould or core, Excessive metal temperature. These are to be corrected.

Buckles

Buckle as grooves occur on the surface without the thin layer of metal. Rat tails as extensive groove.

Causes: Low addition of carbonaceous additives, High moisture, Uneven mould hardness, Low moisture, Low methylene blue Active clay, Pattern Problems, Lack of mould vents, Mould Wall Movement, Hard mould or core, High pouring temperatures.

Metal penetration

Chief cause of casting surface roughness and adhering sand is penetration of liquid metal into the pores (voids) between sand grains. In mild cases, metal penetrates only the surface layer of the sand grains in the mould or cores, but results nevertheless in a rough surface finish with some adhering sand. In severe cases, the metal may completely ill the pores or penetrate to some depth of the compacted sand grains, leading to excessive cleaning times and in particular bad cases resulting in scrapped castings. Large castings with high metallostatic pressures and which undergo more severe pouring conditions are more prone for penetration defects.

Causes: Use of Coarse grade sand and or badly compacted moulds and cores, Insufficient venting, High pouring temperature with High Ferrostatic head, High moisture, Low methylene Blue Active Clay, Poor ramming and squeezing, Insufficient New sand in the moulding sand mix, Hot sand, Explosions of gases in the mould cavity, Low Sintering point additives in the sand mix.

Once these are rectified and corrected, metal penetration will be low.

To a great extent, a sand with sieve analysis distribution pattern, with 4 adjacent sieve retention and with AFS No. around 55 to 60, with minimum Voids (pores), and with good compacted moulds, will resist metal penetration effectively.

Burn-on

This is a type of Chemical penetration, which is caused by the reaction between Iron Oxide (FeO) and Silicon Dioxide (SiO_2). Known as Burn-On, and Burn-In, Iron Oxide and Silicon Dioxide combine to form a fluid slag which easily penetrates the moulding surface, resulting in an iron oxide/iron silicate phase called Fayalite formation. This is a liquid at metal pouring temperature that easily wets the surface of silica sand grains, gluing the sand on to the surface of the casting. Burn-on defects can be corrected by shot blasting the castings. If the casting cools slowly, a layer of crystalline fayalite forms, which is known as BURN-ON. Whereas, BURN-IN defect, is caused by a rapid cooling rate at the casting surface that results in a non-crystalline iron silicate glass. Burn-In defects are more difficult to remove from the casting surface. It may be necessary to grind the area to remove the defect.

Causes: High moisture in the sand, Low Methylene Blue Clay, Hot prepared sand supply, Poorly compacted moulds, Mould spray not dried properly, Excessive pattern Spray, New sand addition not properly formulated, Uneven mould hardness, Very High pouring temperature, High ferrostatic head while pouring metal into moulds.

By adding optimum amount of carbonaceous additives in the sand mix, a reducing atmosphere (Oxygen-free) can be created inside the mould cavity, and this will lower the chances of fayalite formation. The hydrocarbon gases released by the carbonaceous additives, coat the mould cavity with a thin layer of lustrous carbon layer, and the defects will be minimised. This will greatly help to prevent both Burn-on and Burn-in defects and also mechanical penetration to considerable extent.

Blow holes

Larger holes, open or sub-surface, regular or irregular, dull or bright, grey or blue grey lining, may curtain exuded metal beads pellet. Generally caused by the generation or accumulation of gas entrapped air.

Causes: High moisture in the sand mix, High or Low Methylene Blue Clay, Excessive pattern spray, Hot sand, Too much inert fines in the sand system allowed to accumulate and not introducing sufficient now sand to compensate the accumulated fines, High addition of carbonaceous additives, Insufficient venting of moulds and cores for free escape of built up gas inside the moulds, hard rammed moulds and cores, Excessive high manganese and sulphur content in the iron (Manganese Sulphide Inclusion.), Cold metal, Rusty or damp chills and chaplets placed in the mould, Incomplete baking of cores and moulds (in dry sand practice), Damp pouring ladles with poor refractory lining.

Pin holes

A portion of the casting or sometimes the entire surface may be pitted with small holes about the size of a pin point. A pin-hole may be a surface indicator or a sub-surface pin hole.

a) Spherical cavities with a shiny surface lining, small hole up to 3 mm in dia, containing no non-metallic inclusion. This is a hydrogen pin hole. Hydrogen pin holes may be elongated or fissured also, it there is a continuous graphite lining
   Causes: High moisture in sand, Contamination of molten metal with aluminium, Trace amounts of aluminium (0.005 to 0.02%) are sufficient to have a harmful effect, Excessive mould spray and Incomplete drying, Long running system which increases the time the molten metal is in contact with green sand mould face.
b) Elongated or fissured type pin hole duo to Nitrogen with discontinuous graphite film lining.
   Causes: High steel scrap in the charge, Excess addition of nitrogenous compound containing recarburiser, Use of resins with high nitrogen of unit sand system which arises out of nitrogen containing binder system.
c) Other types of pin holes due to Mn Oxides etc. Causes: Higher percentage of manganese in the meal, Mould atmosphere oxidizing

Both Blow holes and Pin holes are Gas defects. These could be due to entrapped gas or soluble gas. Entrapped gas generated from the burn out of mould and core additives are free gases which float to the top of the metal as the casting solidifies. If the permeability of sand mix is good and sufficient venting is done, these gases will escape easily.

If the skit formation takes place faster and quicker, then the gases cannot escape and defects will occur.

Soluble gas

That which dissolve in liquid metal, during melting, pouring and filling will be expelled from the metal when the metal solidifies. During solidification the dissolved gases will precipitate into tiny bubbles of gas forming pinholes in the casting. All these gaseous defects can be controlled, by tempering sand mix to minimum workable compactability, optimum addition of carbonaceous additives, correct pouring temperature, profuse venting of cores and moulds with free escape passage for the gases.

Crushes

Irregular shaped Holes or Projections on Castings.

Causes: Low moisture in sand mix, High Methylene Blue content, Badly fitting or warped moulding boxes, Pattern problems, Wear and tear of Pins and Bushes in the box, Improper Core setting, Hard moulds and cores.

Sand drop

One or more holes in a casting.

Causes: A piece of the ceiling or overhanging section of the mould dropping in the mould cavity, Cracking of cope mould, Bad moulding practice, Poorly compacted moulds, A Piece of mould face failing to strip from the pattern.

Ensure pattern is in good condition with adequate taper, and a clean strip to the cracking of cope mould, Avoid rough handling of the mould and uneven placing of weights.

Avoid High moisture and Low methylene blue clay, Low moisture and High methylene blue clay, to avoid sand drops.

Microporosity

Inadequate feeding distance of the risers employed, High phosphorous content in the metal, Mould dilation, wrong composition of metal, Lack of Mould vents, High moisture and Low methylene blue clay, Improper drying of mould sprays.

By providing open feed channels from risers, keeping phosphorous below 0.10%, Reducing carbon or silicon in the metal, Producing rigid moulds well compacted, using properly tempered sand mix this defect can be minimised.

Swell

Enlarged Cross-section anywhere in a casting. Oversized casting when the mould wall is not capable of holding the casting's shape, when the mould is filled with metal. Mainly due to Mould wall movement, Lack of Mould rigidity, and Mould Crack.

Causes: Poorly compacted moulds, High moisture in sand mix, Inadequately clamped or weighted moulds, Not firmly bedded, Mould wall movement, Low Methylene Blue clay, Not properly tempered and formulated sand mix., Uneven mould hardness.

4.5 Improving surface finish of iron castings produced in Green sand Moulds

It is possible to improve the surface finish of iron castings to a considerable extent provided the foundry is willing to incorporate certain changes in their existing sand system processing methods. These may involve some changes in the specifications of the raw materials used in green sand preparation, sand processing method, metal pouring and shake-out mode, changes in plant lay-out etc. In this section, improving the parameters in green sand processing is stressed rather than recommending specially formulated facing sand application and/ or spraying the compacted moulds with special refractory paint, torch drying and then closing and pouring the moulds, which will also give improved surface finish.

Factors effecting surface finish of iron castings

1. Low grade base silica sand with high clay, alkaline impurities and narrow sieve analysis distribution in 3 adjacent sieve retention. AFS Grain fineness number not being maintained uniformly, around 55 to 60.
2. Hot return shake-out sand having temperature above 40°C fed into the sand mixer.
3. Shaking-out solidified, hot castings earlier and quickly, without allowing enough retention time inside the moulds.
4. Failure to us Na grade Kutch bentonite.
5. Excess new sand addition in the sand mixer, not taking into account core sand influx Into the sand system and the type of processed cores used in moulding Iine.
6. Failure to maintain optimum Loss on Ignition (LOI) value with proven quality of carbonaceous additives.
7. Failure to keep optimum mixing cycle time in the sand mixer.
8. Delayed metal pouring, after mould-making, thereby causing more friability on the compacted mould surface.
9. Hesitation to introduce wet tensile strength (WTS) test and friability Index test in daily sand control.
10. Above all, sand plant personnel not exposed to Training to update their analytical approach and thinking for further improvement in their domain.

Methods of solving these problems to improve casting surface finish are described below.

Base silica sand

Select high grade silica sand with SiO2 content 97% or higher, with minimum clay content (less than 0.5% and preferably washed sand, with preferred sieve analysis as given in table below.

Preferred sieve analysis of base silica sand

US Sieve No.	Sieve Opening (micron)	Retained (%)
30 mesh	590	Nil
40 mesh	420	4.0 max.
50 mesh	297	50, 70, 100 Mesh put together 80.0
70 mesh	210	
100 mesh	149	
140	105	10.0 o 12.0
200	7	200, 270, PAN together 5.0 to 6.0
270	53	
PAN	-	

If a single grade of silica sand is used for both core-making and moulding, the above grain size distribution pattern will be beneficial. Sand being a mineral, it may not be possible to get the sand conforming to the above specification, as our suppliers do not wash and grade the sand and then blend to the customer's requirement.

Many foundries use medium fineness sand for core-making to economies on binder consumption, and finer sand for moulding, both grades having different AFS grain fineness numbers. Then how to stick to the above specification? For better surface finish, retention on 140 mesh sieve should be more than 10%.

After regular sieve analysis of prepared moulding sand, find out the percentage retention on 40, 50, 70, 100 and 140 mesh sieves. Once the trend is known, then much more finer sand (i.e. sieved either at the supplier's end or at the foundry) should be procured and added in the moulding sand. This can be achieved by trails made in the sand laboratory and also regular sieve analysis of prepared moulding sand on daily basis. Most foundries do not give importance for this test in their routine control.

Hot shake-out sand/earlier shake-out

Many foundries do not allow minimum retention time of 2.0 to 2.5 hours inside the moulds after pouring the castings. For faster production, without increasing the number of moulding boxes in the moulding line, casting are shaken out red hot, within half an hour after pouring. This practice must be stopped. As the castings are shaken out red hot, due to sudden on-rush of oxygen over the sand sticking to the hot castings, fayalite formation takes place, which creates rough surface.

Also after allowing minimum retention time inside the poured moulds, when the castings are shaken cut, moisture percentage in the shake-out sand should more than 1.0% and the sand should not be bone dry, as this will require extra mulling cycle time in the sand mixer for proper tempering.

In any case, the temperature of the return shake-out sand which is fed into the sand mixer must be maintained below 40 °C in our hot weather condition which is prevalent for most of the period in a year, except 3 months of winter. Here again, foundries which cannot afford to invest for proper cooling system in the lay-out must work out methods to transport hot shake out sand outside the moulding bay, spread the sand on the floor and do water spray, turn over, cool below 40°C and then re-transport to return storage sand hopper. Possibility of introducing pre-mixer (before the mixer) concept in the layout must be explored by all foundries. This will enhance the properties of tempered sand in the shop floor sand mixers.

Using na-grade kutch bentonite

While procuring bentonite from Kutch region, we have been giving importance to swelling property and minimum green compression strength on a standard laboratory mix recommended by Bureau of Indian Standards. All the suppliers are activating with soda addition. In this process even a Ca-grade bentonite could be boosted to exhibit high swelling value, but on repeated cycling in the unit sand system, durability of this bentonite is poor when compared to that of a Na grade, and also consumption will be higher.

Further, we have not given importance to Wet Tensile Strength test while procuring the bentonite. Here again, a Ca-grade can be boosted to higher wet tensile strength value with soda activation. But this is not desirable. Our aim should be to procure Na-grade bentonite.

So, before ordering for bentonite, the user foundry must obtain powdered sample of bentonite, without soda activation, and test in their own laboratory for the following properties. It can be done at supplier's end also.

a) Free swelling value. If it is Na grade, it will be above 16 ml and may approach even 20 ml. If it is Ca grade, it will be somewhere between 10 to 14 ml.
b) Both Na and Ca grades, when tempered to 40 and/or 45 compactability, will give GCS above 10.0 psi (700 grams/cm^2)
c) Wet Tensile Strength (WTS): In case of Na grade, WTS will be nearing 20 grams/cm^2.
d) On this non-activated samples, activation can be done with 1.0, 2.0 and 3.0% soda addition based on bentonite weight and accordingly the user can fix the percentage of soda addition to be complied by the supplier.

This change of concept should be realized by both the User and the Supplier, and accordingly both should work in unison to improve the bentonite processing at source.

New sand addition in the sand system

Many foundries add fixed percentage of new sand at the sand mullor, irrespective of the fact whether casting being poured are heavy, medium or light in weight, and are cored or non-cored. On each of the cored item, some amount of burnt, semi-burnt and un-burnt core sand enters into the sand system through shake-out, depending on the configuration of the casting and the mode of shaking out of that particular item. This means the amount of core sand influx into the system will vary item wise. While fixing the percentage addition of new sand at the mullor, core sand influx should be taken into account, and accordingly new sand addition will vary item-wise.

How to formulate New sand addition in the mullor item-wise?

Collect representative quantity of return shake out sand samples item-wise, measure temperature, sieve through 30 mesh U.S. Sieve, label property and start lab trials.

Firstly, make a batch in the lab Simpson type mixer and temper the sand to the specified compactability maintained at production line, without any addition, and to optimum mulling cycle time. Test all the properties including Wet Tensile Strength at 320°C for a duration of 20 seconds. Depending on the quality of the bentonite and the burn-out pattern of moulding and core sand item-wise, this WTS value will vary. But it will be definitely low than that value maintained at the Sand mullor for that item. GCS also will be somewhat lower due to the degree of burn out.

Firstly, make a batch in the lab Simpson type mixer and temper the sand to the specified compactability maintained at production line, without any addition, and to optimum mulling cycle time. Test all the properties including Wet Tensile Strength at 320°C for a duration of 20 seconds. Depending on the quality of the bentonite and the burn-out pattern of moulding and core sand itemwise, this WTS value will vary. But it will be definitely low than that value maintained at the Sand mullor for that item. GCS also will be somewhat lower due to the degree of burn out.

Secondly, make a trial batch with bentonite addition only to get the desired GCS which is maintained at mullor and to the same compactability. It the WTS reaches to the value maintained at the mullor then no need of adding any new sand for that item.

Thirdly, if WTS value is not as per the value maintained at the mullor, start new sand addition with 0.5, 1.0 and 1.5% till you get optimum wet tensile value. Proportionate increase in bentonite addition and carbonaceous additive to be adjusted.

In this method, new sand addition will be to the nearest accuracy and excess addition will be eliminated. Excess new sand addition will increase Friability index. By trails, we have to strike a balance between WTS and Friability Index.

This mode of collecting representative shake cut samples and making trial batches in the lab should be a continuous process by which the Sand Technologist can predict the trend well in advance and take corrective action in most of the cases.

Addition carbonaceous additives

To obtain better surface finish on iron castings, Coal Dust or Substitute of Coal Dust with pitch powder as one of the main ingredients (proprietary item), is added. When we add coal dust, of either high or low ash content, controlling the Unit sand composition becomes easier. Whereas when proprietary carbonaceous additive (with pitch powder and some other ingredients in the formulation) is added utmost caution is necessary. Proprietary item must be selected after thorough investigation and several trials. In Coal Dust of Indian origin, Volatile Matter component in the composition is satisfactory, around 35%, but the Ash content varies somewhere between 14% to even 30%.

On imported coal, ash content is well below 10% and is now available from Indian suppliers. In both Indian and imported coal. Sulphur content should be kept below 1%. Depending on the customer's need, pulverized coal dust powder to the requisite fineness can be obtained. Coal Dust powder can catch fire easily during storage and various pulverizing processes, and should be handled with utmost safety precautions.
Compared to coal dust, the pitch powder based proprietary additive gives better surface finish. Hence it is worth trying after trials. Pitch powder is more corrosive and poses health hazards and should be handled accordingly.

In our foundries LOI and VM are the two main control tests to regulate the percentage addition of the carbonaceous additives. LOl is being maintained around 4 to 4.5%, and in some cases upto 5%. VM will be lower by around 1 %. This control specification has to be established by each foundry to suit to their need after conducting trials. Excess addition of carbonaceous additive, coupled with high moisture in the tempered sand, will cause blow hole and pin hole problems. While using pitch powder based material, chances of sub surface pin holes after machining can occur and needs vigilant control.

Mixing cycle time at sand mixer

In spite of formulating proper unit sand composition with optimum percentage of new sand, bentonite and carbonaceous additives, at the time of tempering the prepared sand to get the specified compactability, sufficient mulling time should be provided to homogenize the various ingredients added into the mixer and allow water to perculate throughout the binder-coated sand grains. Even though many foundries are using Indian made High Intensive mixers, most of them keep a mulling cycle time of 110 to 120 seconds. In some formulations this could be sufficient, but as a regular practice Mulling Cycle Time Vs. Wet Tensile Strength Development should be standardised once every week. In many cases, even an increase of 10 seconds mulling, improves wet tensile strength considerably. Under mulled sand increases Friability. In Vacuum-cum-cooling type sand mixers homogenous mixing of the various ingredients within the optimum mulling cycle time is superior in comparison to other types of Intensive mixers available in the market.

Here, due to the vapourisation effect created under vacuum, inside the mixer, moisture penetrates to the entire depth of the bentonite platelets, producing consistent quality of tempered sand.

In Europe, foundries are using these mixers, and to the best of my knowledge none in India have gone for this mixer. If sufficient mulling cycle time is not provided, to develop optimum wet tensile strength, unnecessarily binder consumption will increase, with associated increase in moisture requirement and casting defects.

Delay in metal pouring after mould closing

If the moulds are waiting for molten metal after being closed for a very long time, then friability of compacted mould surface increases and this should be avoided.

WTS friability index tests in sand control

In Europe, Wet Tensile Strength (WTS) test is regularly performed for improved sand control. This sensitive test helps to check the incoming quality of bentonite and also to exercise rigid control for new sand addition at the sand mixers, item wise. Regular routine tests viz. GCS, GSS. Green Splitting Strength etc. are not sufficient to indicate the hidden characteristics of the circulating sand system.

Further, WTS machine is available indigenously, at much lower price than imported instrument. With this sensitive test, sand technologist can confidently tackle trouble shooting in sand system.

Besides, Cone Jolt Toughness test, which measures the total brittleness of the prepared sand, is preferable in comparison to Friability Index test, which measures surface friability of sand. Though the former machine is preferable, it has to be imported, hence let us be satisfied with the indigenously available Friability Index tester.

Hence, coupled with WTS and Friability Index machines, investigation studies can be undertaken by any foundry for improvement in sand processing and controls. WTS value approaching 20.0 grams/cm2 and more, and Friability index less than 10.0%, should be aimed in daily control. Of course, each foundry must work out its norms which will give optimum results. (About these sensitive tests, readers are advised to go through the chapter-10 on Sand Testing & Control.)

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