Comprehensive training material for technicians

Coimbatore foundry cluster

GEF-UNIDO-BEE Project

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

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For more information

GEF-UNIDO-BEE PMU
Bureau of Energy Efficiency
4th Floor, Sewa Bhawan, Sector-1,
R.K. Puram, New Delhi-110066

Email: gubpmu@beenet.in
pmc@teri.res.in
Website: www.beeindia.gov.in
www.teriin.org

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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 'Technicians' 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, Lean Manufacturing 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	Lean Manufacturing
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.

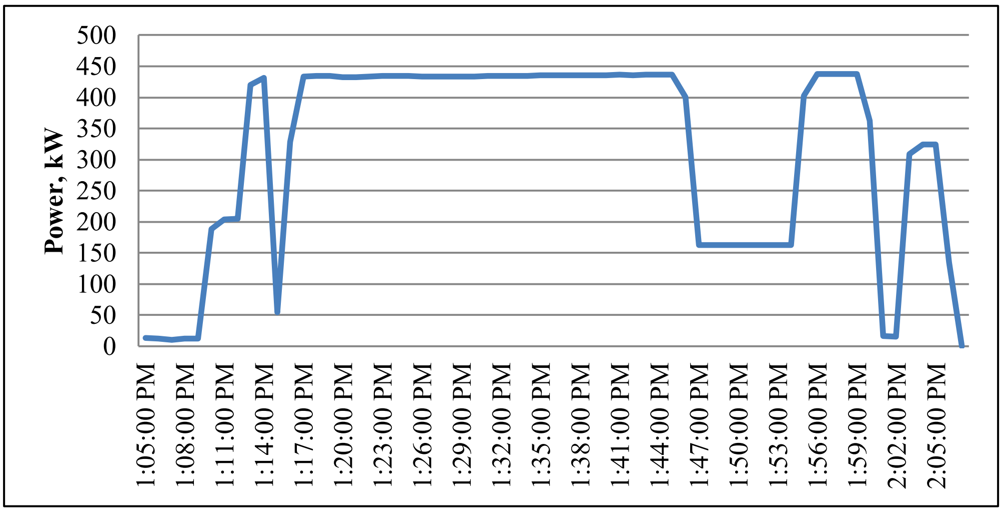


Figure 2.1.1: Power curve of a sample batch of melting in induction furnace

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.

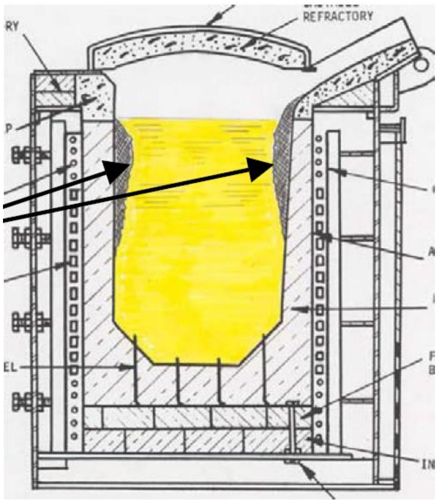


Figure 2.1.4c: Slag build-up near furnace crucible neck

- 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 ^{o}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

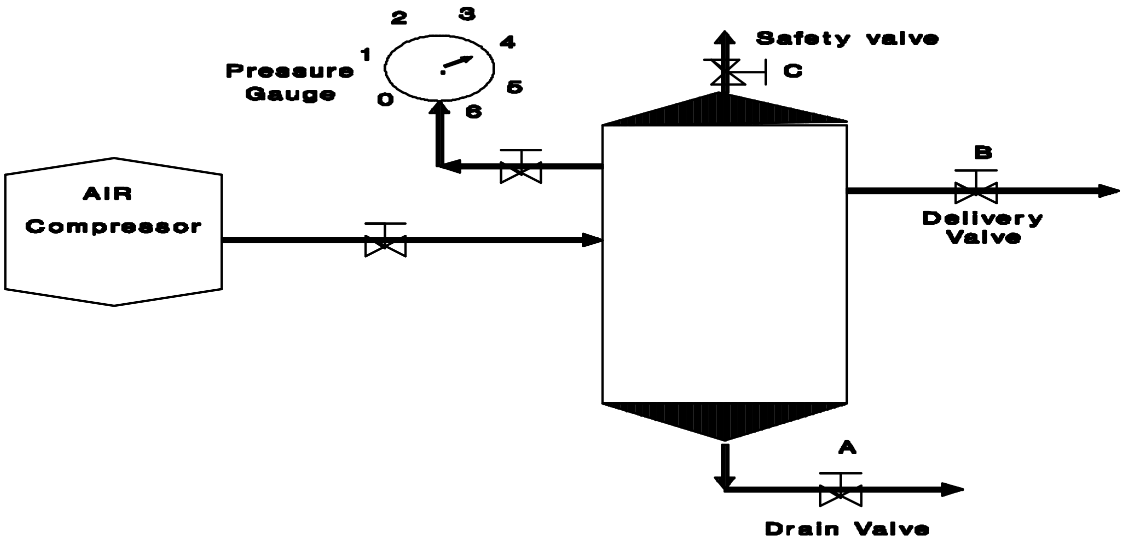


Figure 2.1.3a: Pump up test schematics

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.

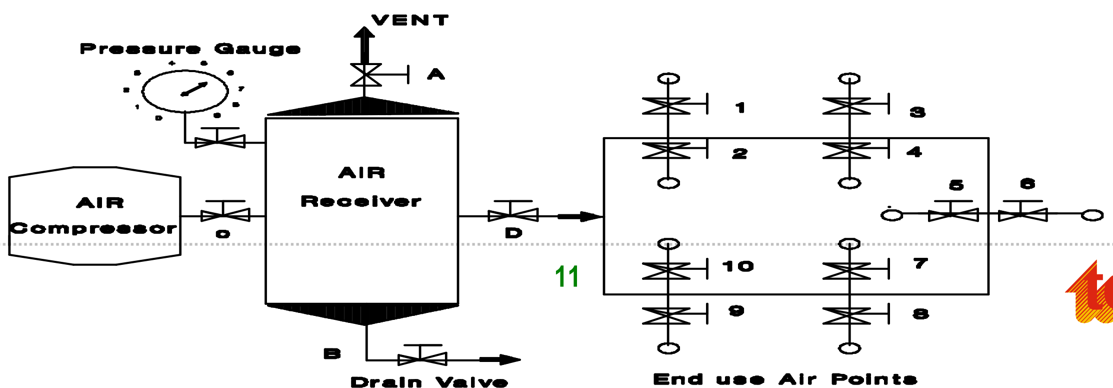


Figure 2.1.3b: Leakage test schematics

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/cm²	7.5
Unloading Pressure	kg/cm²	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/cm²	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/cm²	7.5
Power	kW	18

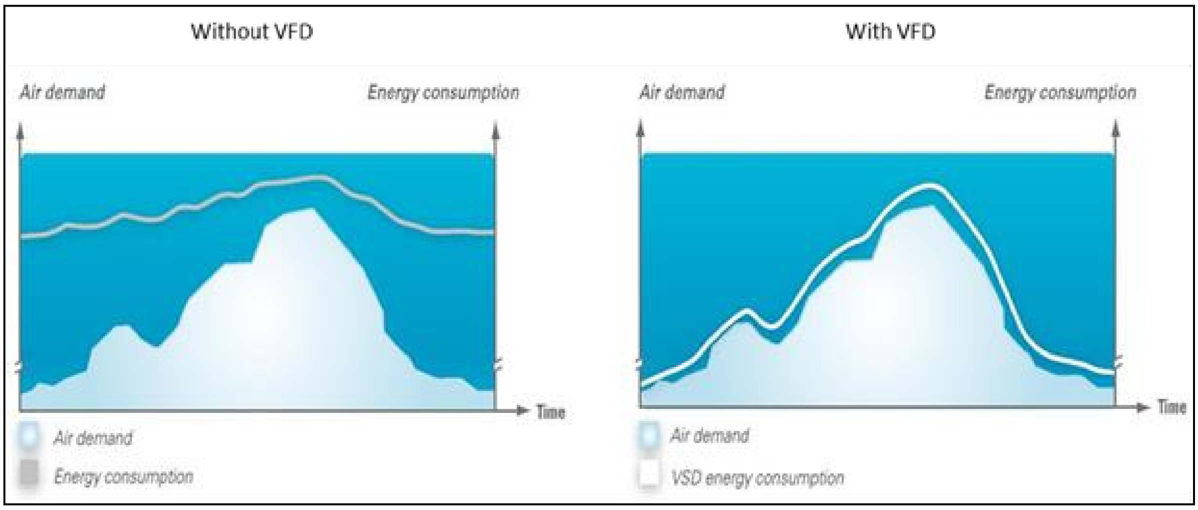


Figure 2.2.4a: Air demand and energy consumption with and without VFD

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

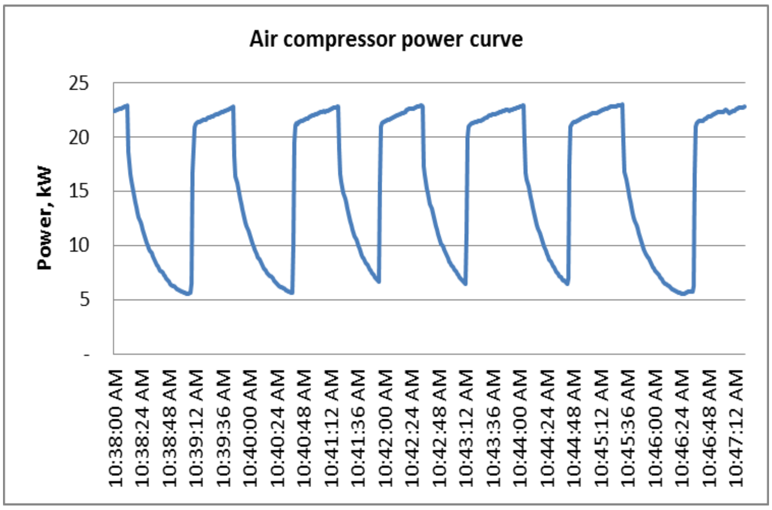


Figure 2.2.4b: Air compressor power curve after installation of VFD

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.

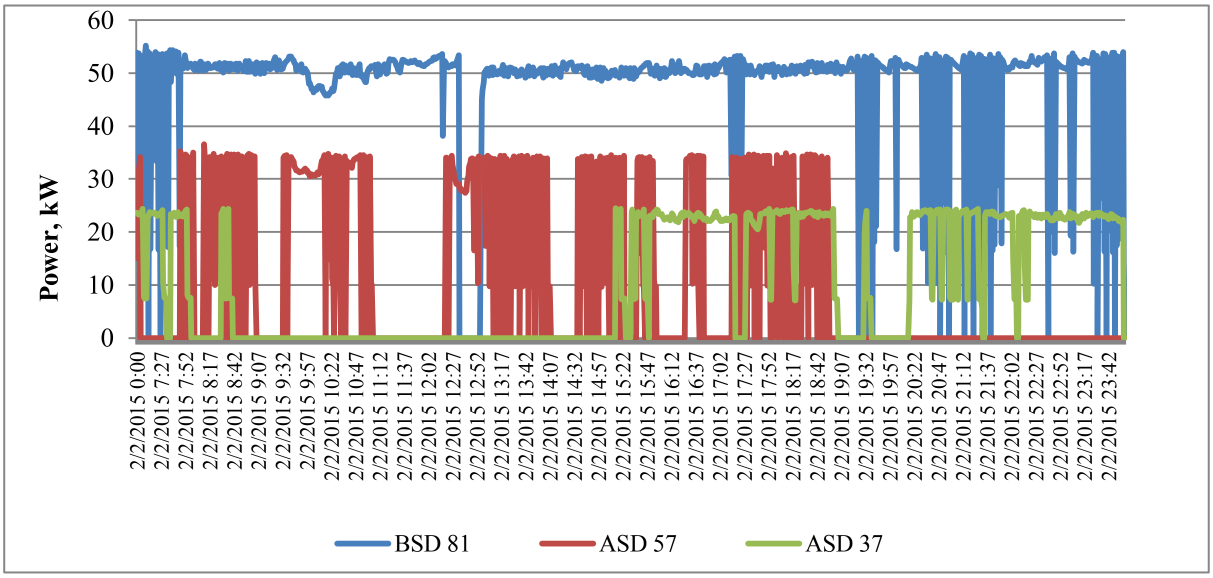


Figure 2.2.4c: Before sequence controller

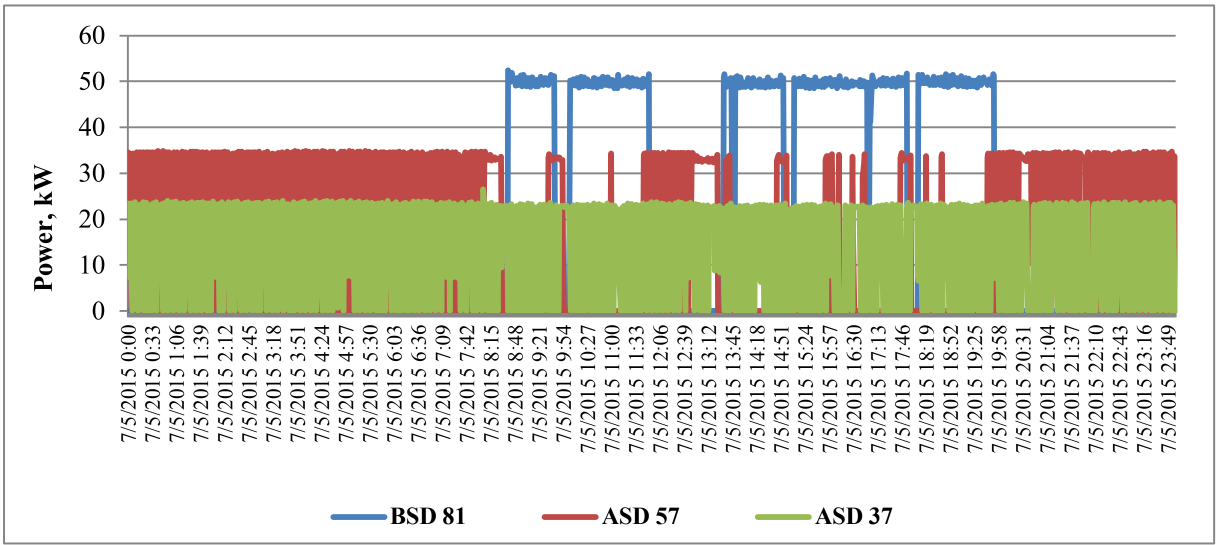


Figure 2.2.4d: After sequence controller

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.

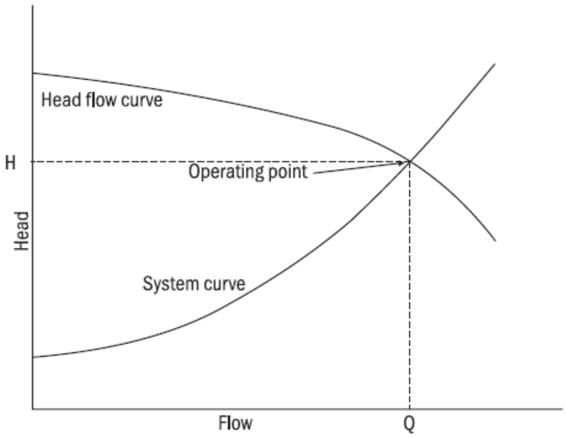


Figure 2.3.2: Operating curve of a Pump

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 – Lean manufacturing

The lean approach is primarily based on finding and removing wasteful steps that do not add value to the end product. There's no need to reduce quality with lean manufacturing – the cuts are a result of finding better, more efficient ways of accomplishing the same tasks. Lean manufacturing is not only aimed at the elimination of waste in every area of production but also focuses on the activities which will help for good customer relations/satisfaction, production machine layout, waste reduction and factory management.

3.1 Objective

The objective of a lean approach to manufacturing is to maximize the value of the product to the customer while minimizing waste. Many companies in the manufacturing industry use lean manufacturing principles (LMP) to maximize their profit, minimize their cost of production, and eliminate waste. The goal of lean manufacturing is to incorporate less human effort, less inventory, less time to manufacture products, and less space and to become highly responsive to customer demand, while at the same time producing top quality products in the most efficient and economical manner. Lean principles can be applied to nearly anything from optimizing management to developing vertical and horizontal integration that help with optimizing the flow of products.

The lean manufacturing adopts a customer-value approach that focuses on the question "What is the customer willing to pay for?" Customers want value, and they'll pay only if needs are met. They should not pay for defects, or for the extra cost of having large inventories. In other words, customer should not be made to pay for a unit’s waste. Waste is anything that doesn't add value to the end product.

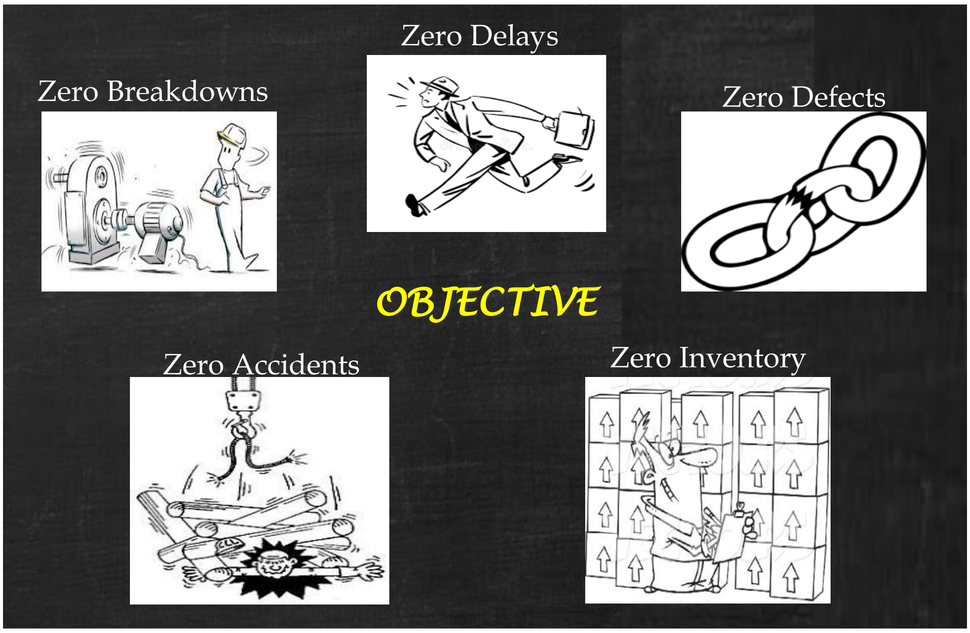


Figure 3.1: Objectives of lean manufacturing

3.2 Methodology

First recognize that there is no "one path" in lean manufacturing. Training on Lean Implementation is a multi-dimensional activity. There are number of lean tools, which could be adopted by the unit to reduce wastes, improve overall operating practises and increase productivity. It is not as simple as just creating a list of lean tools and methodologies, and learning how to use them. Every organization is different from each other. Many of the lean tools like one piece flow, Kanban, Cellular manufacturing, batch size reduction, Heijunka are not universally applicable. Managerial judgment will have to be applied to determine techniques and methods to implement which reflects business realities of the organization.

Depending upon the availability of material and human resources, an organization may or may not engage a consultant. The Ministry of Micro, Small and Medium Enterprises, GoI also provides support for implementation of lean manufacturing in MSMEs under Lean Manufacturing Competitiveness Scheme. There are technical associations, consultants in your area which provides services to implement lean manufacturing.

In the long run, the achievement and maintaining the results will depend on knowledge of organization's own team. Therefore the implementation of lean manufacturing should begin with a broad based capacity building plan. When a company decides to implement Lean they should start by creating a position of a Lean Leader or even better by creating a Lean Leadership organization. These leaders should be trained and become Lean Practitioners capable of teaching, coaching and mentoring the implementation of Lean. Lean Practitioners should than teach all managers and supervisors not only the knowledge of Lean tools and methodologies, but also their roles and responsibilities. All managers and supervisors must know how to manage in a Lean environment and apply this knowledge daily. All managers and supervisors must be made accountable for a success or a failure of the Lean implementation process. This is not optional – either you are in or you are out. Too many times a task of implementing Lean is assigned to an individual from manufacturing, engineering or a quality department without proper support and training in place.

The best way to learn lean principles is on-the job training. Some tools and methodologies can be presented in a classroom; some must include exercises, a practical portion of training and the others you can learn only by applying them - learning by doing. All training activities must conclude with a demonstration by participants that they have learned and understand how to use the new process.

Delivery of this training modules should be synchronized and follow a well-defined sequence. Participants are not allowed to skip any level of training. Participants advance to the next level of training only by successfully passing the course – demonstrating that they have required knowledge and skills. This can be done by writing a final exam, or by selecting and implementing a project.

Training module is grouped into three levels of advancement. Each course is designed for a specific audience. Some of this training should be mandatory; some of it could be made available to the employees who are interested in learning and advancing on their own. The three levels are:

- Level I (Basic) – Principles of Lean
- Level II (Intermediate) – Activities Based Training
- Level III (Advanced) – Sustaining and Improving

3.3 Level - I (Basic)

3.3.1 Principles of lean

Lean manufacturing is a series of applied processes and tools that eliminate waste from production. Improved efficiency, effectiveness, and even profitability are all by products of lean manufacturing. A unique feature about lean manufacturing is that it focuses more on perpetual improvement of products rather that the final output. By shifting the attention to the process in which the product is made, defaults are minimized, the right raw materials are used, people are properly organised and coordinated, and the costs of production are properly optimized. For the process to work effectively, the manufacturing industry should consider the following five principles that will help in implementing lean techniques:

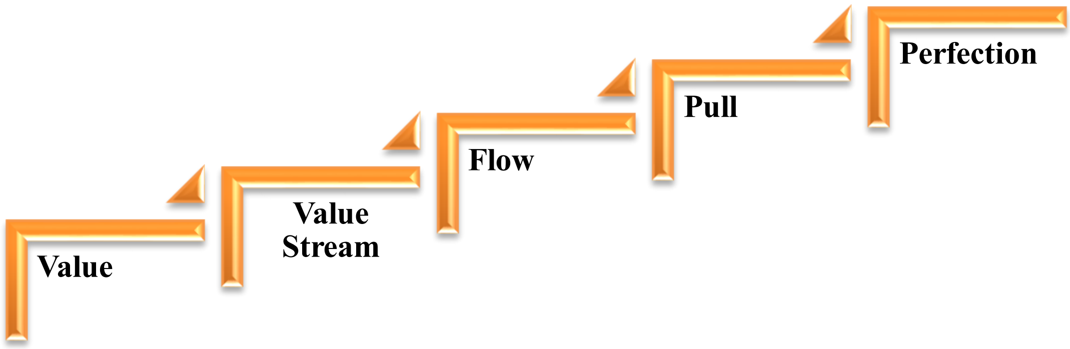


Figure 3.3.1: Five principles of lean

1. Value

The lean approach begins with a detailed understanding of what value the customer assigns to product and services. Always be sure to determine value from the customer perspective (not yours!) and by product family. Value goes hand-in-hand with what customers are willing to pay for a product. When manufacturing any product, as a manufacturer, you should consider value as what the customer needs.

At many times, manufacturers tend to think that value is created from what they think is best. However, they forget that the end user of their products is the customer. Therefore, if you want to create the highest value in your product, you have to find ways of determining customer needs. There are different ways that you can use to identify the various customer needs before manufacturing your product:

- Quality function deployment
- Brainstorming
- Identifying market gaps
- Providing different choices and identifying the most preferred choice
- Issuing out questionnaires

Engage only in activities that improve the value of your product or service to the customers to minimise or eliminate wastage. Remember, your customers are the key determinant of what value means to your products. Involving them in creating value of your products is inevitable.

2. *The value stream*

In order to create value, you will have to go through various processes. These processes involves the entire flow of a product's life-cycle from the origin of the raw materials used to make the product through to the customer's cost of using and ultimately disposing of the product.

These processes engage steps that add value and others that do not add value. In order to identify non-value added steps, there must be an accurate and complete understanding of the value stream. Any steps that don't create value should be eliminated. Flagged process steps that create no value due to technology or manufacturing limitations become opportunities for improvement.

3. *Flow*

After identifying value-adding processes, it important to ensure a smooth flow of these processes as the raw material is being processed to suit the customer needs. The lean manufacturing principle of flow is about creating a value chain with no interruption in the production process and a state where each activity is fully in step with every other.

Creating a value stream is essentially important in that the processes would continue even after reshuffling of employees. This is because there is a perfectly designed way of going through all these processes. The first visible effect of converting from departments and batches to product teams and flow is that the time required to go from concept to launch, sale to delivery, and raw material to the customer falls dramatically.

4. *Pull*

The lean principle of pull helps ensure flow by making sure that nothing is made ahead of time, building up work-in-process inventory and stopping the synchronized flow. Rather than using the traditional manufacturing approach of pushing work through, based on a forecast and schedule, the pull approach dictates that nothing is made until the customer orders it. This principle requires you to set out ways that will make the customers look for the product rather than pushing the product to them. If you did not design the product to suit your customer's needs, you would have a hard time persuading customers to purchase your product.

To achieve this requires great flexibility and very short cycle times of design, production, and delivery of the products and services. It also requires efficient communication system at each step in the value chain what is required of them today, based upon the customer's needs. Pull eliminates work-in-progress inventory and waste from incorrect production forecasts.

5. Perfection

The final lean manufacturing principle is seeking perfection. The idea of total quality management is; to remove the root causes of poor quality systematically and continuously from the production processes so that the plant and its products are moving towards perfection. The relentless pursuit of perfection is what drives users of the approach to dig deeper, measure more, and change more often than their competitors.

As organizations begin to accurately specify value, identify the entire value stream, make the value-creating steps for specific products flow continuously and let customers pull value from the enterprise, something very odd begins to happen. It dawns on those involved that there is no end in the process of reducing effort, time, space, cost and mistakes while offering a product which is ever more nearly what the customer actually wants.

4.3.2 Elimination of wastes

The identification and elimination of wastes from the value stream is the central theme of the Lean Manufacturing philosophy. Lean manufacturing is a dynamic and constantly improving process dependent on the understanding and involvement of all the company's employees. Successful implementation requires that all employees be capable of identification and elimination of wastes from their work. Waste exists in all types of work and at all levels of the organisation. Effectiveness is a result of efficient integration of Man, Material and Machines at the workplace.

There are eight categories of wastes that should be monitored in the factory:

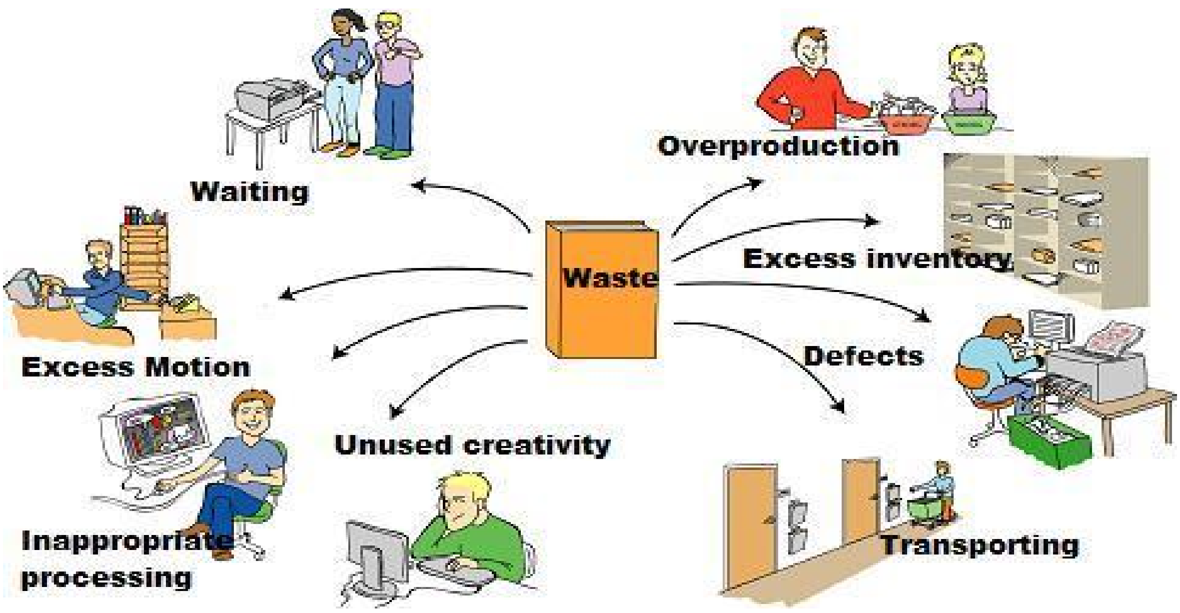


Figure 3.3.2: Eight wastes of lean

1. *Overproduction* – More production than customer demand

Characteristics:

- Batch Processing
- Building ahead
- Complicated inventory management
- Excess equipment/Oversized equipment
- Excess scrap due to obsolescence
- Excess Storage racks
- Inflated workforce
- Large lot sizes
- Large Work in Progress/Finished goods inventory
- Unbalanced Material Flow

Causes:

- Automation in the wrong places
- Cost accounting practices
- Incapable processes
- Poor planning
- Lack of communication
- Lengthy setup times
- Local optimisation
- Low uptimes

Identification:

- Are we making extra copies, more than needed?
- Are we printing, faxing, e-mailing more than what is needed?
- Are we entering repetitive information on multiple work documents or forms?
- Are we ordering more tests or services than what is required by the customer?
- Are we purchasing items just in-case they are needed?
- Are we preparing reports/products that are not used or read?
- Are we having meetings without the necessary information for action?

2. *Waiting* – Ideal time that occurs when co-dependent events are not fully synchronised

Characteristics:

- Ideal operators waiting for equipment
- Lack of operator concern for equipment breakdowns
- Production bottlenecks
- Production waiting for operators
- Unplanned equipment downtimes

Causes:

- Inconsistent work methods
- Lack of proper equipment/materials
- Long setup times
- Low man/machine effectiveness
- Poor equipment maintenance
- Skills monopolies

Identification:

- Are there excessive signatures or approvals required?
- Is there too much dependency on others to complete a task?
- Are there delays in receiving information?
- Are there any technical problems causing delays?
- Equipment downtime or response time causing delays?
- Are there cross-departmental resource commitment issues?

3. Inventory (work in progress) – High supply levels and work in progress inventories

Characteristics:

- Additional Material handling resources (Men, equipment, racks, storage space)
- Extensive rework of finished goods
- Extra space for receiving docks
- Long lead times for design changes
- Storage space congestion

Causes:

- Inaccurate forecasting system
- Incapable processes
- Incapable suppliers
- Local Optimisation
- Long changeover times
- Poor inventory planning
- Poor inventory tracking
- Unbalanced production processes

Identification:

- Do we have any obsolete dies in the area?
- Do we have obsolete equipment in the area?
- Is there batch processing of the product?
- Are files awaiting task completion by other?
- Are there delays in receiving information?
- Are we purchasing excessive supplies of any kind?

4. Transportation – Any material movement that does not directly support immediate production

Characteristics:

- Complex inventory management
- Difficult & inaccurate inventory counts
- Excessive transportation equipment and shortage of associated parking spaces
- Excessive material racks
- Poor storage to production floor space ratio
- High rate of material transport damage
- Multiple material storage locations

Causes:

- Improper facility layout
- Large buffers and in process Kanbans
- Large lot processing
- Poor scheduling
- Large lot purchasing
- Poor production planning
- Poor workplace organisation

Identification:

- Are we delivering material/tools/documents that are not required?
- Are we doing excessive filing of work documents or filing documents that will never be used again?
- Are we requiring multiple approvals?
- Are we hand delivering items manually that can be sent on forklift?

5. Over-processing – Redundant work which adds no value to the product

Characteristics:

- Endless product/Process Refinement
- Excessive copies/Excessive Information
- Redundant reviews & approvals
- Unclear customer specifications
- Process Bottlenecks

Causes:

- Decision making at inappropriate levels
- Inefficient policies and procedures
- Spurious Quality control
- Lack of customer input concerning requirements
- Poor configuration control

Identification:

- Is there a lack of visual controls?
- Are we doing more work than is required for that process?
- Are we producing repetitive documents from scratch?
- Do we have a poor recording system?
- Are we too many approvals required for action?
- Are we entering repetitive information?

6. Motion – Any movement of people which does not contribute added value to the product

Characteristics:

- Excess moving equipment
- Excessive reaching or bending
- Excessive tool gathering
- Unnecessary complicated procedure
- Widely dispersed materials/tools/ equipment

Causes:

- Ineffective equipment/plant layout
- Lack of visual controls
- Poor process documentation
- Poor workplace organisation

Identification:

- Are we making multiple trips to the tool crib at the beginning of job work?
- Are we searching for required dies in storage areas?
- Are we misplacing equipment/accessories?
- Are we reaching for commonly used tools?
- Are we constantly reviewing the same manuals for information?
- Are we hand carrying paper work to another process or department regularly?

7. *Defects/rework* – Time spent in finding and fixing production mistakes

Characteristics:

- Complex material flows
- Excess finished goods inventory
- Excessive manpower to inspect/ rework/repair
- Questionable quality
- High customer complaints /returns
- High scrap rates
- Poor production schedule performance
- Reactive organisation

Causes:

- Excessive variation
- High inventory levels
- Inadequate tools/equipment
- Incapable/Incompatible processes
- Insufficient training
- Poor layouts/Unnecessary handling

Identification:

- Do we have any product errors?
- Is there a lack of standardized procedures?
- Do we ever lose tools/accessories?
- Do we ever encounter incorrect information on a document?
- Do we have pricing, quoting, billing, or coding errors?

8. *Skills* – Under-utilizing capabilities, delegating tasks with inadequate training

Characteristics:

- Poor team building
- Inefficient time management
- Slower Improvements
- Ineffective communication
- Unskilled manpower
- Poor coordination

Causes:

- Insufficient training
- Lack of employee reward/ recognition system
- Improper delegation of tasks
- Poor leadership
- No employee suggestion scheme

Identification:

- Are we spending time on correcting errors and defects?
- Are we not involving employees in process improvement?
- Are we in positions we were trained to do?
- Can we assist other areas when work is slow in an area?

- Can we be trained to do more within the organization?
- Are you restricting or not offering training on technical resources?

3.4 Level II (Intermediate) – Activities based training

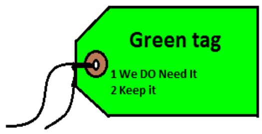
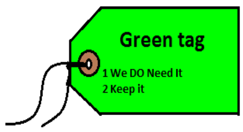
3.4.1 5 S – Workplace organization

5S is a technique originated from Japan and it was first developed by Hiroyuki Hirano in 1980s. The 5S philosophy focuses on simplification of the work environment, effective workplace organization, and reduction of waste while improving safety and quality. It allows the enhancement of efficiency and productivity. The 5S technique is a structured program to systematically achieve total organization cleanliness and standardization in the workplace. The benefit of 5S technique is improvement in productivity, quality, health and safety. Through 5S methodology, the management can create an environment where quality work is comfortable, clean and safe in the organization and it can ensure the compliance to standards and will further foster continuous improvement. The term "5S" is derived from five Japanese words Seiri (Sort), Seiton (Set in order), Seiso (Shine), Seiketsu (Standardize) and Shitsuke (Sustain).

Sorting – Separating the needed from the unneeded. Sorting activities aim to eliminate unneeded items from the work area and to perform an initial cleaning. Sorting clears the deck for the remaining activities. The steps of sorting are:

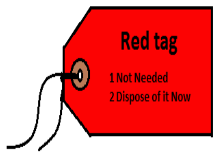
- Establish criteria for what is not needed. For example, if something hasn't been used for a year, it may be a candidate for disposal
- Identify the unneeded items and move to a holding area
- Dispose of the not needed items, either by transferring to a department that needs them, selling them, or discarding them
- Conduct an initial cleaning

Table 3.4.1: Tagging criteria & recommended action.

<table>
<tr><th>Priority</th><th>Frequency of use</th><th>Action Required</th><th>Tag</th></tr>
<tr><td>High</td><td>Daily</td><td>Store at the workplace, where it is needed and is easily assessable</td><td>
</td></tr>
<tr><td>Medium</td><td>Once per week, once per month</td><td>Store together, near the workplace</td><td>

OR

</td></tr>
<tr><td>Low</td><td>Less than once per year</td><td>Throw away, or store away from the workplace</td><td>

OR

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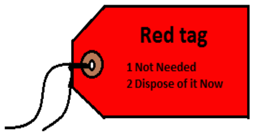
No	Unusable items	Throw away	

Before	*After*
	

Setting in order – Once the initial sorting is completed, the natural sequence is to get the work area organized. After initial sorting the unit will be benefitted with approximately 20% of space saving. The disposable items should be tagged red. The setting in order of things will most efficiently be stored as required. Frequently-used items must be as close to where they are used as possible. The steps of simplifying are:

- Determine a location for each item based on frequency of use and proper safety zone (decreasing the likelihood of strain injuries, for example)
- Develop shadow boards and label items - a home for everything
- Determine how to replenish supplies
- Document layout, equipment, supplies, and agreements for returning items to their homes

Before	*After*
	

Shine – The third step in the 5S process initiates a work ethic of keeping everything clean and in order at all times. Examples of shine include wiping machinery, sweeping, tightening loose belts or bolts, cleaning gauges and indicators, tracking the source of leaks, overheating or undue noise, and organizing papers and books on office desks and shelves. Systematic cleaning provides a way to inspect, by doing a clean sweep around a work area. This means visually as well as with a broom or rags. The idea is make the job of doing daily cleaning and inspections easier.

The steps of systematic cleaning are:

- Identify points to check for performance
- Determine acceptable performance
- Mark equipment and controls with visual indicators (e.g., gauges show the correct range)
- Conduct daily cleaning and visual checks

Before	*After*
	

Standardize – The first three steps will slip unless standardized procedures, schedules and expectations are clearly identified and regularly measured. Standardizing assures that everyone knows what is expected. Since the workplace team establishes the standards, everyone should have had some involvement in establishing the 5S in their work area. Still, it is important to make these standards very clear. The steps in standardizing are:

- Establish a routine check sheet for each work area. The check sheet is like a pilot's pre-flight check list. It shows what the team should check during self-audits
- Establish a multi-level audit system where each level in the organization has a role to play in ensuring that 5S is sustained in the work areas and that the 5S system evolves and strengthens
- Establish and document standard methods across similar work areas
- Document any new standard methods for doing the work

Sustain – In order to sustain improvements made during deployment of the first 4S's, old inefficient habits will have to be removed. Changing the culture and instituting new habits will demand time and attention. It would not happen by itself. Sustaining is usually thought of as the toughest "S." However, the trick is to let the 5S system work, engage everyone in the work area during 5S activities and have a "tell at a glance" visual workplace to sustain easily. That is important, but not sufficient. A more systematic way to prevent backsliding and to foster continuous improvement is needed. The steps of sustaining are:

- Determine the 5S level of achievement - the overall grade
- Perform worker-led routine 5S checks using the 5S check list
- Address backsliding and new opportunities found during routine checks
- Conduct scheduled, routine checks by team leads or supervisors or by people from outside of the workgroup

Perform higher-level audits to evaluate how well the 5S system is working overall. For example, are there systemic issues with sustaining 5S? Often, the company's safety committee is an excellent body for conducting these audits.

3.4.2 Value Stream Mapping (VSM)

Value Stream mapping is a first key practical step towards learning and implementing Lean. The purpose of Value Stream mapping is not to produce a "map" of a value stream. The purpose of VSM is to open our eyes to existing problems and issues, to identify shortfalls and process breakdowns and to identify opportunities for improvement.

Value stream mapping is a flowchart method to illustrate, analyse and improve the steps required to deliver a product or service. A key part of lean methodology, VSM reviews the flow of process steps and information from origin to delivery to the customer. As with other types of flowcharts, it uses a system of symbols to depict various work activities and information flows. In this respect, Value stream mapping helps an organization to identify the non-value-adding elements in a targeted process and brings a product or a group of products that use the same resources through the main flows, from raw material to the arms of customers.

Objectives:

Value stream mapping is a powerful method to ferret out waste in any process, not just manufacturing. Detail each significant process step and evaluate how it's adding value—or not adding value—from the customer's standpoint. Focus on value keeps the analysis targeted to what really matters, allowing the company to compete most effectively in the market. Foreseeing or facing any competitive threat, lean practitioners can make good use of VSM to produce the most value for the customer in the most efficient way possible. It can and should be used on an on-going basis for continuous improvement, bringing better and better process steps on line. VSM allows you to see not only the waste, but the source or cause of the waste.

- Visualization of material and information flows
- Facilitate the identification and elimination of wastes and sources of wastes
- Support the prioritization of continuous improvement activities at the value stream
- Support constraint analysis

- Provide common platform for process evaluation

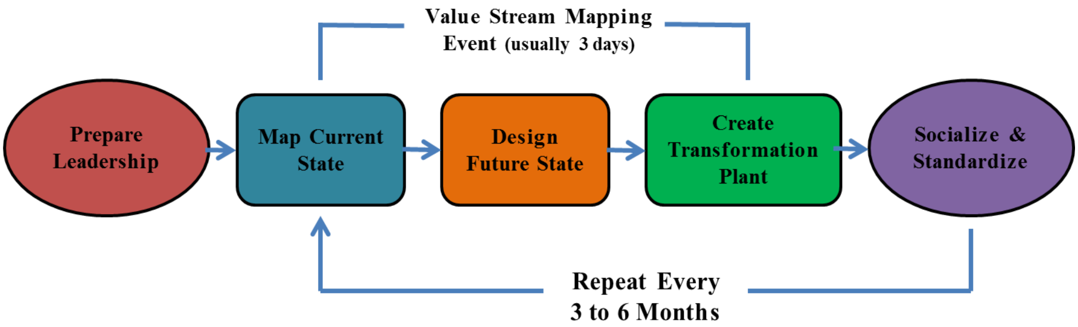


Figure 3.4.2: Value stream mapping

Methodology

While Value Stream Mapping is core to lean methods, it often requires a substantial investment of people and time to do it, and if not applied wisely, it can be wasteful in itself. It requires team members skilled in carrying out advanced VSM, and it may take days, weeks or even months to carry out some involved mapping projects. Think of it as a powerful tool central to lean methods, but not every circumstance lends itself to value stream mapping. You need to balance potential value with the work necessary to conduct the VSM.

You might choose to start small, with a limited focus and a limited budget, get the win and then move on to something more complex and potentially rewarding.

1. **Identify the product** or product family to be studied and improved. You typically put together a team to do the mapping and analysis, depending on the size of the initiative. If inexperienced, the team will need training in VSM.
2. **Get leadership's buy-in** for the value stream mapping project, given the potential costs involved. It's possible you might use a smaller VSM, showing potential improvement, to help gain leadership's buy-in for a fuller look.
3. **Determine the problem for the value stream** for this product, from the customer's standpoint. Make sure the customers' concerns are clearly understood, since they are the ones defining value. It's possible that customers might be demanding a price reduction based on competitors, or that quality control problems are reducing value, or that production delays are causing customers to look elsewhere.
4. **Bound the process**, which means determining the limits or scope of your map. For example, if you're doing lean manufacturing, are you going from raw materials to final product delivered to the customer? Or are you starting with one problematic part of the value stream?
5. **Now, do the VSM walk, as outlined in upcoming steps 6-11**. Walk (or directly experience) the process steps and information flow required for processing of product. Some VSM practitioners do the walk in reverse, starting with the customer. You might do the walk multiple times to gather more information, filling in any gaps.

6. **Define the process steps**, keeping within the boundaries you've just defined as you do your walk. In lean manufacturing, all of the steps might take place in a single location that inventory enters and then leaves. You aren't listing out every specific task that could be done by process mapping. You are studying work activities and information flows that produce customer value or don't. It's vital to record the reality of your observations, and not rely on information from employees who may have a vested interest in explaining away a problem. The purpose is to document each significant step required to create the product's value.
7. **Collect process data on your walk**. This is where you start evaluating the performance of each step of the process. Examples are inventory type and size, cycle time, change-over time, machinery or process uptime and downtime, number of workers, shifts worked, available working hours and batch size. All of these could result in finding efficiencies and cutting waste. Add that process data to the data boxes of your Value Stream Map.
8. **Evaluate the process steps**. You also use data boxes for this information. We want to know whether the process step is:
   a) **Valuable,** meaning it creates value from the customer's standpoint. You might just ask the customer if he cares whether a step is left out.
   b) **Capable**, the degree to which there's a high-quality result every time.
   c) **Available**, the degree to which the process step is available when needed.
   d) **Adequate**, the degree to which capacity exists to meet customer demands. This often ties in with analysis of constraints, bottlenecks, excess capacity and excess inventory.
   e) **Flexible**, the degree to which a process step can switch over quickly and inexpensively from one member of a product family to another.
9. **Map the movement of the product and information flows**. Look for three key things:
   a) **Flow vs. Stagnation**. The ideal is for the product to never stop moving. This can be measured by inventory levels.
   b) **Push vs. Pull**. This shows how production information is handled. In the ideal value stream, no information is required except for a signal at the top of the stream to make the next product. In reality, however, there are disconnects between parts of the stream. This is dealt with by having the steps able to signal each other as to upcoming needs.
   c) **Level vs. Erratic**. This shows the degree to which the process has been smoothed out for efficiency. This addresses the lean manufacturing concepts of **mura** (unevenness), **muri** (overburdening of the value stream to keep up) and **muda** (waste.) It's also vital to understand the overall flow of information and communication in the value stream. Producing a product or service of value to the customer means we need to understand the communication touch points. Examples include how customers order the product, how suppliers are contacted, and how we ensure that customers get what they want.
10. **Count the inventory**. Inventory and overproduction can be an extensive cause of waste. Take special note that inventory may be scattered in a makeshift manner.

11. **Create a timeline**. Map out process times and lead times for inventory through our process steps. By monitoring inventory levels at each step, we can find inefficiencies and non-value-adding items in our production.
12. **Now, reflect on the Value Stream Map** to see things that might not have been entirely apparent at first. Use the information you've collected in the data boxes and timeline to find the waste. This could be problems such as excess inventory, too much downtime, long process times or setup times, or quality problems resulting in rework.
13. **Then, create a future state Value Stream Map and/or ideal state Value Stream Map**. Instead of just attacking each problem point individually, now sketch out an ideal state VSM, illustrating goals for the items that lead to a leaner, more effective process. This vision needs to be agreed upon by the leadership and becomes the ultimate goal of the VSM project. The Value Stream Maps are used to communicate and guide the work. Sometimes a series of future state Value Stream Maps are drafted before reaching the ideal state Value Stream Map.
14. **Using the Value Streams Maps as your basis, create an implementation plan and carry it out**. Consistently monitor the results in key metrics, and implement further adjustments as necessary. You are on the path to continuous improvement.

3.4.3 Visual Management (Andon)

Visual Management is defined as a set of techniques for creating a visual workplace, embracing visual communication and control throughout the work environment. Visual management is a way to visually communicate expectations, performance, standards or warnings in a way that requires little or no prior training to interpret.

There are six categories of visual management that allow increasing control of standards, performance and quality. It starts out at simple communication of facts and works up to using visual controls to prevent errors occurring. The categories are:

1. Share information
2. Share Standards
3. Build Standards
4. Warn about abnormalities
5. Stop abnormalities
6. Prevent abnormalities

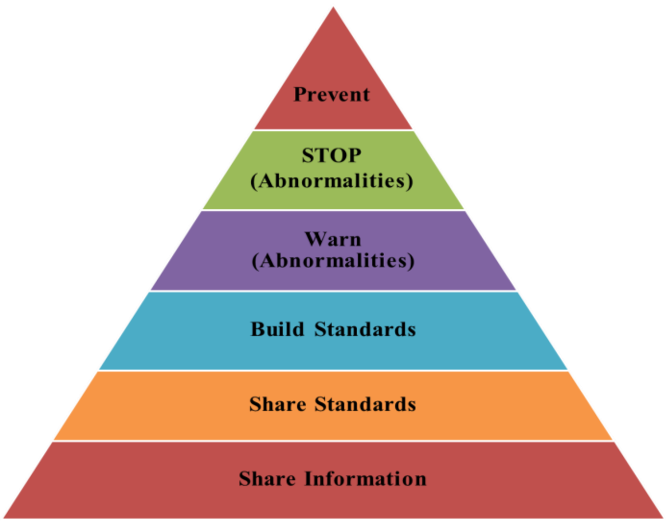


Figure 3.4.3: Pyramid of Visual management

Visual display

Visual display serves as a method for improving communication between members of a work group. Visual display, as indicated in the graphic above includes sharing of information and standards for the group.

Ideally, team members themselves should maintain a display of area performance metrics, schedules, improvement actions, cross-shift management issues training matrices and other useful group. For example visual displays could include:

- Standard Work Instructions
- Performance information
- Status of current issues/actions lists
- Schedules of Maintenance, Calibration & other support activities
- Product and process information
- Customer requirements information
- Site level display board
- Safety Instruction
- Details of Team leaders & members
- Manpower tracking boards
- Designated and clearly marked parts storage locations
- Posting Maintenance schedules
- Inventory record board
- Pictures and information about final products

Visual controls

The objective of the use of visual controls is to actually guide or control the actions of the team by visual means. Visual control is often achieved through the use of notice boards prominently displayed in the workplace. These boards are updated frequently and used to control production or specific products. The board below is used to highlight where issues exist on specific tasks and display an imbalance in the allocation of work to manpower.

Visual control is also referred to as "management by sight", in basic terms it means:

- Anything that doesn't belong is obvious
- Anything that is in the wrong place is obvious
- Anything that is unsafe is obvious
- Anything that is out of sequence is obvious
- Too many or too few is obvious

Benefits

The most immediate benefit of the introduction of visual management is that it exposes abnormalities i.e. situations where standards are not being met. In addition, the following benefits are associated with the practical use of visual management.

- Facilitates employee autonomy – clearly sets expectations, empowering employees by giving them responsibility for their own work areas
- Serves to eliminate wastes such as searching and errors due to miscommunication or lack of communication of organisational targets
- Promotes prevention because it's easier to see when the work situation is not in control

- Fosters continuous improvement through regular monitoring of performance, detection of issues and associated problem solving
- Leads to information sharing automatically once the visual displays are kept up-to-date

3.4.4 Total productive maintenance

Total Productive Maintenance is a systematic well defined methodology to not only eliminate equipment breakdowns but also to eliminate any quality defects. TPM is often defined as productive maintenance involving total employee participation and it must be carried out on a company wide basis. Unfortunately many companies confuse TPM with Preventive Maintenance (PM) and leave the repairs and improvements to equipment and processes to a specialized group of engineers and maintenance personnel.

The purpose of a TPM program is to aim at maximizing equipment efficiency not only from the profitability point of view but also from the operator point of view. It establishes a thorough system of preventive maintenance plans and procedures for the equipment's life span. Once these plans are developed it identifies all levels of responsibilities for operators, engineers, maintenance and supervisors. Operators in the area are responsible for conducting TPM and supervisors are responsible for following and maintaining this process.

The eight pillars of TPM are mostly focused on proactive and preventative techniques for improving equipment reliability.

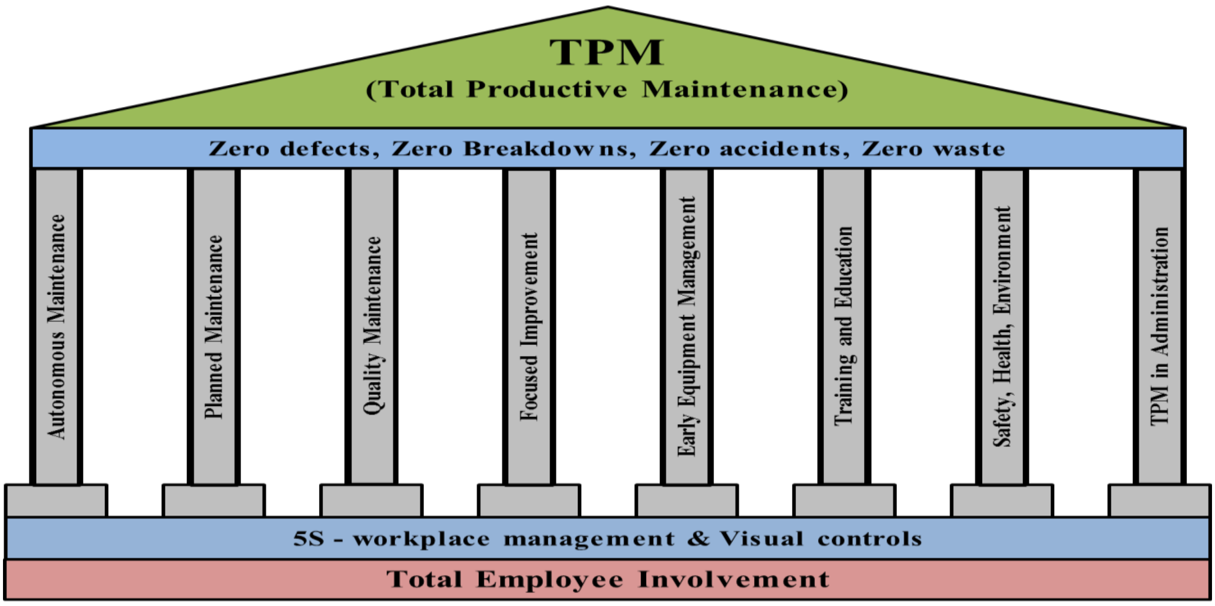


Figure 3.4.4: House of TPM

Table 3.4.4: Description & benefits of TPM

Pillar	Description	Benefits

Pillar	Description	Benefits
Autonomous maintenance	Places responsibility for routine maintenance, such as cleaning, lubricating, and inspection, in the hands of operators	• Gives operators greater "ownership" of their equipment • Increases operators' knowledge of their equipment • Ensures equipment is well-cleaned and lubricated • Identifies emergent issues before they become failures • Frees maintenance personnel for higher-level tasks
Planned maintenance	Schedules maintenance tasks based on predicted and/or measured failure rates	• Significantly reduces instances of unplanned stop time • Enables most maintenance to be planned for times when equipment is not scheduled for production • Reduces inventory through better control of wear-prone and failure-prone parts
Quality maintenance	Design error detection and prevention into production processes. Apply Root Cause Analysis to eliminate recurring sources of quality defects	• Specifically targets quality issues with improvement projects focused on removing root sources of defects • Reduces number of defects • Reduces cost by catching defects early (it is expensive and unreliable to find defects through inspection)
Focused improvement	Have small groups of employees work together proactively to achieve regular, incremental improvements in equipment operation	• Recurring problems are identified and resolved by cross-functional teams • Combines the collective talents of a company to create an engine for continuous improvement
Early equipment management	Directs practical knowledge and understanding of manufacturing equipment gained through TPM towards improving the design of new equipment	• New equipment reaches planned performance levels much faster due to fewer start-up issues • Maintenance is simpler and more robust due to practical review and employee involvement prior to installation
Training and education	Fill in knowledge gaps necessary to achieve TPM goals. Applies to operators, maintenance personnel and managers.	• Operators develop skills to routinely maintain equipment and identify emerging problems • Maintenance personnel learn techniques for proactive and preventative maintenance • Managers are trained on TPM principles as well as on employee coaching and

Pillar	Description	Benefits
		development
Safety, Health, Environment	Maintain a safe and healthy working environment.	• Eliminates potential health and safety risks, resulting in a safer workplace • Specifically targets the goal of an accident-free workplace
TPM in Administration	Apply TPM techniques to administrative functions	• Extends TPM benefits beyond the plant floor by addressing waste in administrative functions • Supports production through improved administrative operations (e.g. order processing, procurement, and scheduling)

3.4.5 SMED/quick changeover

Machine capacity utilization is a key goal in achieving minimum time consumption. Changeover procedure during casting process is recognized as possible area for reducing time consumption. SMED - single minute exchange of dies is a lean tool to reduce changeover or set-up time to less than 10 minutes.

Changeover time is defined as the time elapsed between the last good piece of product being produced and the first good piece of next product being produced. The SMED method has been improved by additional procedures simultaneously applying the 5S method. Their contribution is evident in recognition of internal and external activities, particularly while transferring internal activities into external ones in as many numbers as possible, by minimizing at the same moment the internal ones.

The most basic cornerstone of any setup reduction is to first understand the difference between external and internal activities:

- **Internal elements:** operations that must be performed while the machine/process is stopped
- **External elements:** operations that can be performed while the machine/process is still running

The implementation must be started by closely observing the changeover process so that the distinctions between internal and external elements are made clear. Once the difference is understood, the process of converting internal to external can be initiated. The key is to complete all preparatory work before starting the changeover, eliminate search-and-find work and have tools & materials arranged beforehand.

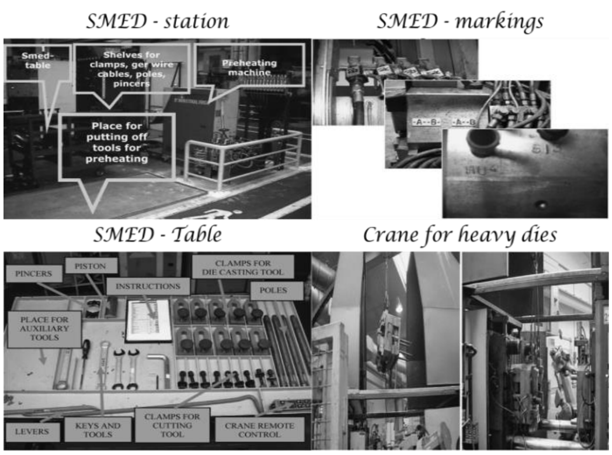


Figure 3.4.5: SMED implementation

Machine settings should be standardised, machine stops or visual marks should be put in place to eliminate the time wasted due to "trial-and-error" adjustments to get the settings correct. On large machines is may be possible to establish "Parallel" steps, which are completed at the same time by two people, one at the front and one behind the machine. For example,

- Functional fixtures and jigs should be used, such as motion fasteners, levered or one-turn fasteners or interlocking wedges or slots
- Eliminate adjustments by using pre-set pins, guides, notches etc.
- Eliminate the need to leave the machine by delivering material to the point-of-use via external suppliers or dedicated material allocators

3.5 Level III (Advanced) – Sustaining and Improving

3.5.1 Kaizen - continuous improvement

The Japanese word KAIZEN simply means "change for better". It is a Japanese business philosophy of continuous improvement of working practices, personal efficiency. This is where all the knowledge of Lean methodologies, tools and process is put to an ultimate test of generating cost reductions and improvements to quality, efficiency and performance.

The purpose of Kaizen training is to identify problems and opportunities and to implement changes needed to achieve very specific management objectives. The objective is not only to learn how to identify and implement improvements, but is also to develop the processes and procedures necessary to sustain the new methodology.

Two kaizen approaches have been distinguished:

- Flow Kaizen: Oriented towards the flow of materials and information, and is often identified with the re-organization of an entire production area
- Process Kaizen: The improvement of individual work stands

Kaizen is a strategy where employees at all levels of a company work together proactively to achieve regular, incremental improvements to the manufacturing process. In a sense, it combines the collective talents within a company to create a powerful engine for improvement.

Kaizen is part action plan and part philosophy.

- As an action plan, Kaizen is about organizing events focused on improving specific areas within the company. These events involve teams of employees at all levels, with an especially strong emphasis on involving plant floor employees
- As a philosophy, Kaizen is about building a culture where all employees are actively engaged in suggesting and implementing improvements to the company. In truly lean companies, it becomes a natural way of thinking for both managers and plant floor employees.

Kaizen events

A typical Kaizen event goes something like this:

1. Set goals and provide any necessary background.
2. Review the current state and develop a plan for improvements.
3. Implement improvements.
4. Review and fix what doesn't work.
5. Report results and determine any follow-up items.

This type of cycle is frequently referred to as PDCA (Plan, Do, Check, and Act). PDCA brings a scientific approach to making improvements:

- Plan (develop a hypothesis)
- Do (run experiment)
- Check (evaluate results)
- Act (refine your experiment; then start a new cycle)

Kaizen philosophy

Kaizen as an action plan is exactly what develops Kaizen as a philosophy. When Kaizen is applied as an action plan through a consistent and sustained program of successful Kaizen events, it teaches employees to think differently about their work. In other words, consistent application of Kaizen as an action plan creates tremendous long-term value by developing the culture that is needed for truly effective continuous improvement.

3.6 Case study

A case study in xyz foundry for waste reduction with process activity mapping is carried out to identify the process flow and non-value adding activities. The study is focused only on foundry production line (Line 1 namely KOYO production line) which contributes to 98% of the castings of the foundry. The value stream mapping tool is used to analyse both the flow of materials and the flow of information. The line is semi-automated and the casting goes through various processes drums, conveyors, sand separation, sand preparation, knock out, shot blasting etc. Mapping the value stream activities of other products would give similar results with small differences in numerical values as some castings are simple, requires hot/cold box process while some are complex requiring cold/hot box process. However the bottleneck product is selected for the study. This study is a case study applied for the foundry processes which are continuous processes as production lines are semi-automated and the analysis uses the process activity mapping tool. This tool is selected with questionnaires, interviews and brainstorming sessions with manager and operators on the shop floor. Marketing, production planning & control department, pattern shop has helped us to give past record values of foundry production line for e.g. marketing dept. has given monthly customer order, production planning dept. has given the total foundry layout, pattern shop has given classification of simple and complicated jobs depending upon their work experience etc. The process flow is shown in figure 3.6a.

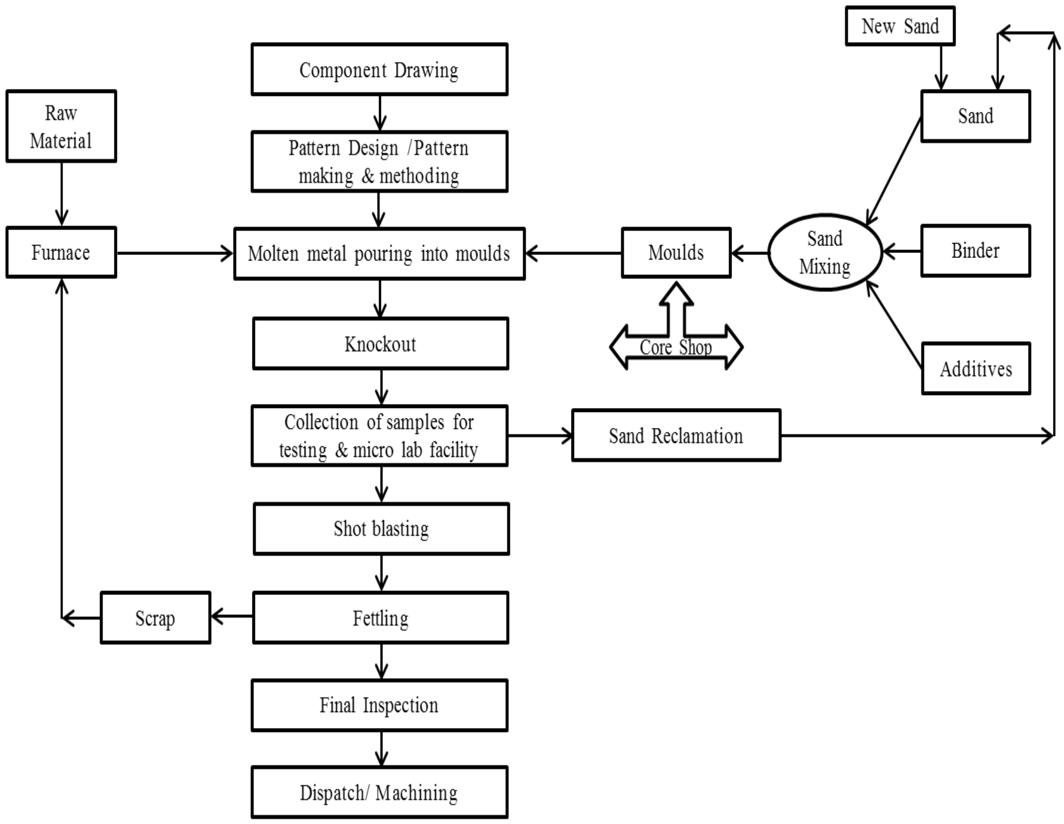


Figure 3.6a: Foundry process flow chart

The time study is carried out by the stopwatch for 45 days on the shop floor of the foundry. The study have gone through each and every process on the production line-1 by recording the travelling distances of men, materials, time taken by each activity, number of operators and workers right from raw material to final product dispatch.

Current state map is prepared keeping in view of the lean manufacturing principles. A few assumptions are also made for preparation of current state map. From past sales data at the industry under study, it is known that maximum demand of product 2,884 may reach up to 3,300 per month. The current state map captures information at a particular instance, which may vary from shift to shift. For the sake of analysis, the shift and operator-wise variation (which may be there) is not considered. Effective numbers of working days are 26 per month, number of shifts per day is three and working hours per shift are eight. Available working time per day is 86,400 seconds. Takt time can be calculated as;

Takt time = {(Available working time per day (seconds)/customer demand per day (units)}
= {(86,400/ (3,300/26)} = 681 seconds

From current state map, Value added time as a % of total time in plant = {(13497.54/ (15 Day X 24 hrs./day X 60 min/hr.)} = 0.62 %.

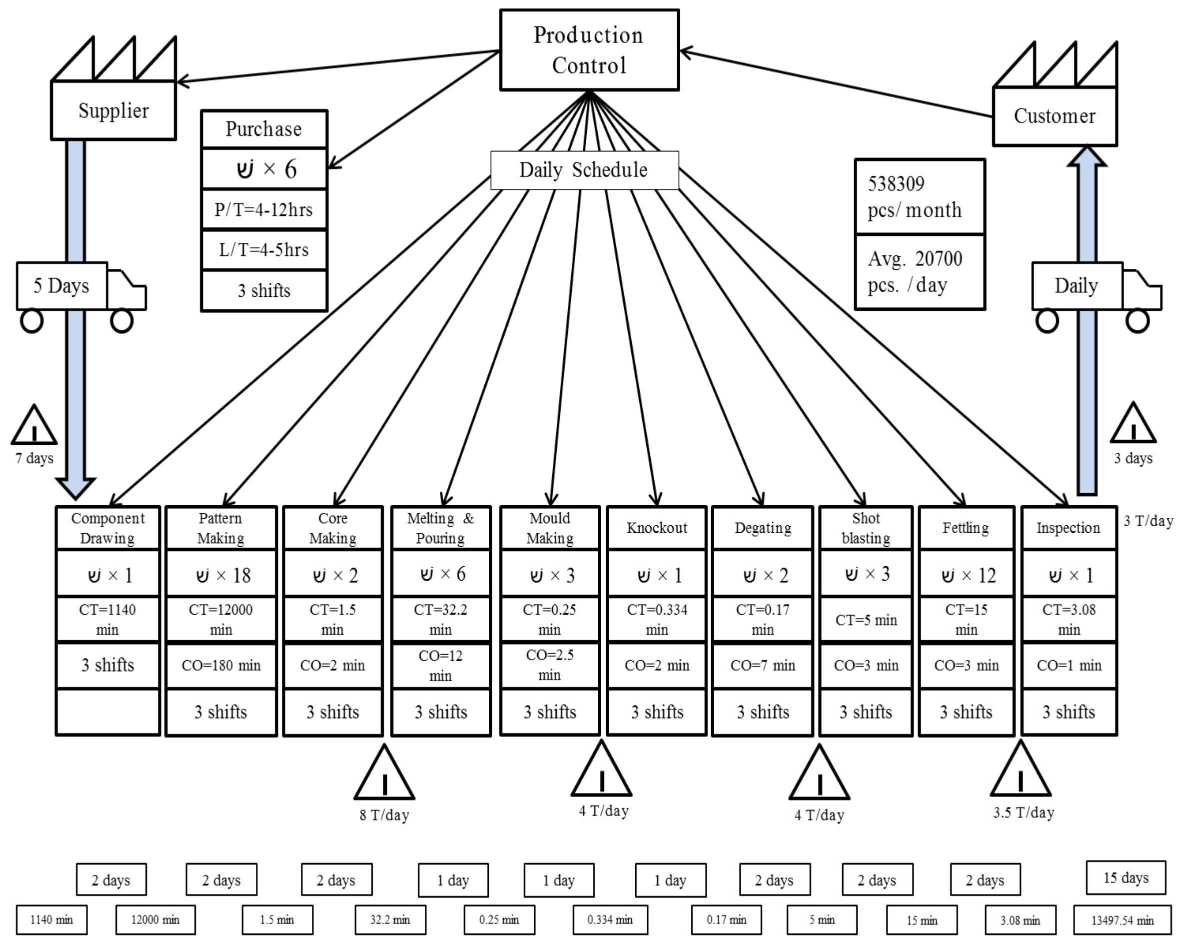


Figure 3.6b: Current state map

For future state map the following areas in which wastes like work in progress (WIP), Inappropriate processing, bad layout etc. are identified and presented separately in corresponding process. After that the wastes are converted into standard wastes and techniques of waste elimination are described in latter part. First the processes in which the identified wastes exists are,

Identification of Wastes in the above foundry processes:

(i) Pattern Making:

a. Patterns must be finished, edges, burrs should be removed

(ii) Core making:

a. Three cavity core boxes for component-1 were not enough to complete production requirement

b. Core Box of two cavities & core for component-2 was solid creating gasses problem in castings and not enough to complete production requirement

c. One cavity core boxes for component-3 was not enough to complete the production requirement

(iii) Moulding:

a. Spill over of dust in turn affecting the environment in mould sand plant

b. Moulding sand hopper was damaged so that sand leakage was more in the mould making section

(iv) Shot Blasting:

a. Due to machine breakdown of 3-4 days, work in process (WIP) is more in this section

(v) Fettling:

a. Mixing up of different parts due to bad layout
b. Poor housekeeping leads to low productivity
c. High transportation of parts

Classification of wastes into standard forms and techniques of elimination adopted is provided in table 3.6.

Table 3.6: Classification of wastes and techniques of elimination

Operations	Waste	Type	Technique of Elimination
Pattern Making	Patterns must be finished, edges, burrs should be removed	Inappropriate Processing	• Abrasive grinding brush introduced
Core Making	Three cavity core boxes for component-1 were not enough	Machine Error	• Design and Process Review • Core Box with ten cavities is made
	Box of two cavities and core for component-2 was solid creating gasses problem in castings	Machine Error	• Design and Process Review • Core Box with six cavities is made
	One cavity core box for component-3 was not enough	Machine Error	• Design and Process Review • Core Box with Two cavities is made
Moulding	Spill over of dust in environment	Machine Error	• Design and Process Review • Containers were provided for collecting the dust
	Moulding sand hopper was damaged causing sand leakage	Machine Error	• Design and Process Review • Hopper welding with proper direction was done
Shot Blasting	Machine breakdown caused more work in process (WIP)	Waiting	• Total productive Maintenance (TPM) or Preventive Maintenance
Fettling	Mix up of different parts due to poor layout	Waiting	• Part Specific self-concept was adopted, 5S was used
	Low productivity due to bad poor housekeeping	Waiting	• Part Specific self-concept, 5S was used
	High transportation of parts	Transportation	• Cellular Manufacturing or Group technology

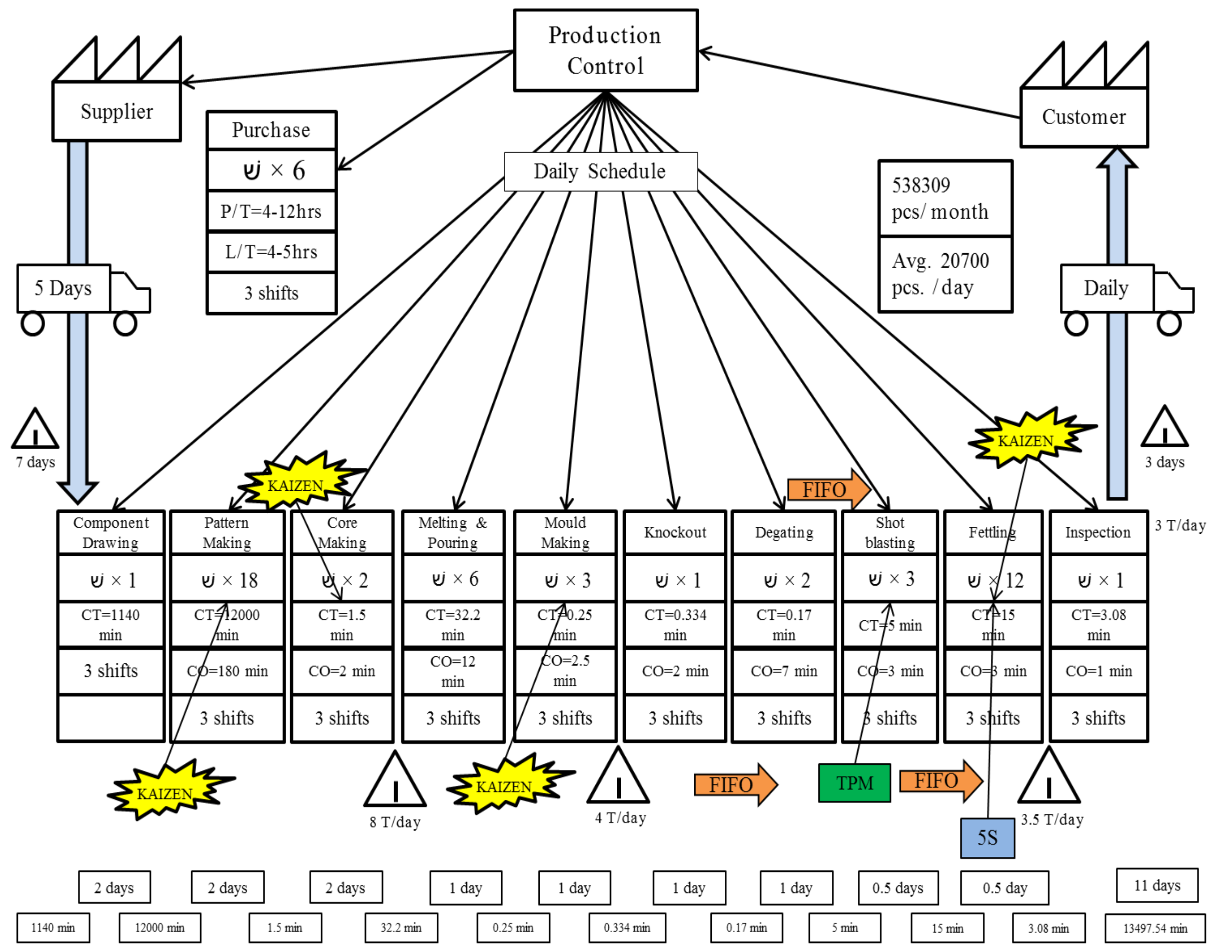


Figure 3.6c: Future state map

From future state map, value added time as a % of total time in plant = {(13497.54 / (11 Day × 24 hrs/day × 60 min/hr)} = 0.85 %.

The future state map indicates average 23% waste reduction in the critical areas of unnecessary inventory, transportation and waiting with implementation of waste elimination techniques identified for improvement.

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, homogenizing 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 homogenized, 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 stabilize 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 ^{o}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/CM^2	**Reduces Weight Improves Dimensional Accuracy** Improves global Competitiveness	Specific Squeeze Force 10Kg/cm^2 (6 times)
Safety: Low		Safety: Improved
Noise: High (>100 dB)	**Energy Saving** 30% in Machine 50% in Machining 2% in Material	Noise: Low (<85 dB)
Power consumption:- 30HP	Safe Working Conditions **Safety as per International Standards** **Adheres to Pollution Norms**	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 ^{O}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^{o}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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