Energy Efficiency
Best Operating Practices Guide for Foundries

Prepared by TERI

in Association with COINDIA — COIMBATORE INDUSTRIAL INFRASTRUCTURE ASSOCIATION

MSME — MICRO, SMALL & MEDIUM ENTERPRISES
सूक्ष्म, लघु एवं मध्यम उद्यम
Ministry of Micro, Small & Medium Enterprises
Govt. of India

United Nations Industrial Development Organization

GLOBAL ENVIRONMENT FACILITY
INVESTING IN OUR PLANET

Bureau of Energy Efficiency
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A GEF-UNIDO-BEE Project
'Promoting Energy Efficiency and Renewable Energy'
in Selected MSME Clusters in India
at

COIMBATORE FOUNDRY CLUSTER

Foreword

Today, more than 50% of India's Energy requirements is imported from outside the borders of the country, a reality that presents tremendous opportunities for improving Energy Efficiency. Electrical Energy constitute a significant portion of the energy bill in many Industries, and offers considerable potential for Energy savings.

At the initiative of GEF – UNIDO – BEE Project and COINDIA for meeting the requirements of Foundry members, TERI has associated with us to prepare this guide book for improving the energy efficiency and best operating practices in Foundry sector. The energy efficiency guide book have been prepared by experts with rich experience at The Energy and Resources Institute (TERI).

The crux of this guide book is the crisp and lively presentation, which facilitate easy reading and absorption for enhancing our knowledge of underlying issues.

We trust that this book,besides its intended purpose will also help in enhancing the knowledge base of Engineers and Managers in Foundries in understanding and applying Energy efficiency techniques.

With gratitude, we acknowledge the work of experts in GEF – UNIDO – BEE Project and TERI whose diligent labor and tireless commitment to Energy conservation made this possible. We sure that this guide book has further scope for improvement and hence we invite your valuable suggestions and comments, which may be mailed to info@coindia.in.

Coimbatore
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Mahendra Ramdas
President

About the Document

A foundry uses two main forms of energy: coke and/or electricity. Melting accounts for a major share of about 70-80% in a foundry unit. The other important energy consuming areas include cooling water system, compressed air system and lighting.

The melting of raw material is either done using electricity in an induction furnace or coke in a cupola (conventional or divided blast type). Compressed air is mainly used to operate molding machines, pneumatic grinders, mould cleaning and for other miscellaneous uses in a foundry. Cooling water circuit plays a vital role in operating of induction furnace.

The following equipment and/or area are selected for documentation of the best operating practices based on their energy consumption and conservation potential.

1. Cupola
2. Induction furnace
3. Compressed air system
4. Pumping system

Contents

1.0 Best Operating Practices for Cupola

1.1 Introduction

Cupola is the most common type of melting furnace used in foundry industry.Heat is released by the combustion of coke. Carbon dioxide (CO_2) and carbon monoxide (CO) is released through the following reactions through the combustion of coke.

1. $C + O_2 = CO_2$ Exothermic (heat generated)
2. $CO_2 + C = 2CO$ Endothermic (heat absorbed)

In a divided blast cupola (DBC), reaction (2) (generation of CO) is suppressed by introduction of secondary (upper) row of tuyeres, about a metre above the primary (lower) tuyeres. A properly designed and operated DBC has the following benefits:

- Lower coke consumption by 20-30%;
- Increase in tapping temperature by about 50º C; and
- Higher melting rate for the same internal diameter (ID) of the cupola.

1.2 Melting Rate of Cupola

- The melting rate of a cupola using low ash (14%) should be about 10 tonnes/hr/m^2 and for cupola using high ash coke (30%) should be about 7 tonnes/hr/m^2.
- If the melting rate is lower, check the parameters of cupola blower.

1.3 Cupola Blower

The blast rate and pressure have an important influence on cupola performance.

1.3.1 Blast Rate

- Optimum blast rate is 375 ft^3/min per square foot or 115 m^3/min per square metre.
- Blower rating should be 15%-20% more than the optimum blast rate, to account for air losses in the pipeline.
- Do not overblow the cupola. A higher blast rate increases oxidation loss of iron and other elements like silicon and manganese.
- A lower blast air leads to lower metal temperature, slower melting and higher coke consumption.

1.3.2 Blast Pressure

- Optimum blast pressure (P) = 0.005 (ID)2 - 0.0134 ID + 39.45, inch water gauge (W.G.). ID is in inches. For conversion to kPa from inch W.G. divide by 4.0146.
- Proper blast pressure is required to penetrate the coke bed. Incorrect air penetration adversely affects the temperature, carbon pick-up and the melting rate of the cupola. Incorrect and correct penetration of blast air is shown in figure 1.3.2.

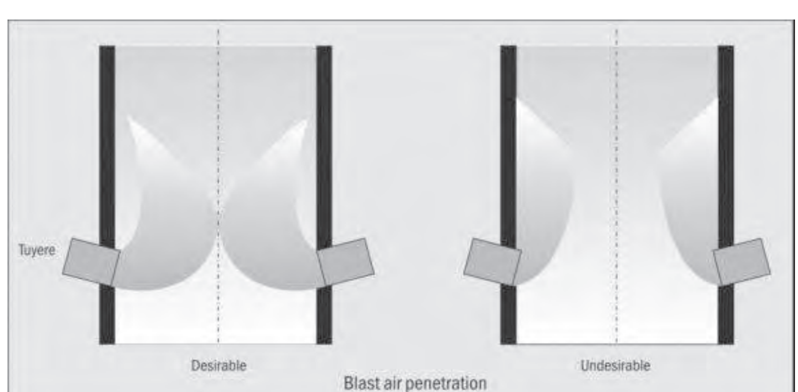


Figure 1: Incorrect and Correct penetration of blast air

1.4 Stack Height

- Consider increasing stack height of the cupola.
- A stack height between 16 ft to 22 ft (depending upon its diameter) is necessary for heat exchange. Inadequate stack height leads to lower heat exchange and higher coke consumption.

1.5 Well Capacity

- Do not increase well capacity more than what is desired
- Every inch increase in the well depth reduces molten metal temperature by 4^{o}C.
- For intermittently tapped cupola, the well capacity should match the capacity of the ladle.
- For continuously tapped cupola, a minimum well depth, ideally of 300 mm is usually sufficient

1.6 Refractory Lining

- Use IS 8 grade fire bricks for lining the cupola. For double brick lined cupola, IS 6 grade bricks can be used in the rear side towards cupola shell.
- Do not use cracked and corner chipped bricks in the melting zone.
- Store the fire bricks in a shed to keep them dry.
- Fire clay should be soaked for at least 48 hours before use. This is required to develop its plasticity and adhesive quality required for joining bricks.
- Provide proper tools, such as hammer, Trowel (or karni), mallet to operators.
- Make diameter gauge for the tap-hole.
- Provide a lighting arrangement inside the cupola during repair.
- Bricks should set 15-20 mm away from the Cupola shell. Pack this gap with dry foundry sand.
- Mortar applied on the bricks should not be of thick layer. It should be just enough so that the brick sets firmly on to the other. Excess spilled mortar to be wiped off. Excess or thick layer of mortar are weak points through which molten metal can penetrate to the shell causing hot spots on the shell.
- 20 / 25 mm thick layer of ganister over the newly lined bricks is advisable.
- Cupola must be properly lined/ repaired after each melt. Correct internal diameter (ID) needs to be maintained.
- Patching material can be used to repair the refractory lining if erosion/burn-back is less than 3 inch (75 mm). If erosion is more then use bricks for repair. To make 6 bags of patching material, mix the following:
  - ✓ 4 bags of refractory (or 3 bag of refractory + 1 bag of fireclay)
  - ✓ 1 bag of small grogs
  - ✓ 2 bags of bigger grogs (about ½ inch size)

  Mix the above materials in water (To check the consistency, the mix may be tested for stickiness on a vertical surface). Add 2 kg sodium silicate to the mix prepared and mix it again. The patching material is now ready for use.
- A wooden bat (14 inch blade length with slight convex surface on one side) may be used for ramming the patching material during cupola repair.

1.7 Bed Preparation

- Check sand-bed for correct sloping.
- Put dry fire wood on the sand-bed. Large pieces of wood should be avoided as this may prevent subsequent instalments of coke to consolidate easily. Be careful that sand bed is not damaged while placing fire-wood.

- Selected good quality coke of proper size for bed-coke. Too large and small pieces avoided.
- Weigh the bed coke and keep in a separate heap. This is to be charged into the cupola in instalments.
- Open all the tuyere covers. Put the first instalment of coke inside and light up fire wood with cotton waste soaked in kerosene oil or L.D.O. as may be available. Plastic bags must never be used in place of cotton-wastes or cotton rags. Some foundries use oil burners for ignition.
- Natural draught entering through the breast-door and moving upto the cupola shaft, helps ignition. Keep watching. As the coke gets ignited upto the tuyere level (lower) add the second lot of coke. Go on adding in splits, as ignition progresses. Keep the last lot of coke in hand. This is to be charged after the askblow off and height bed) measurement.
- Check through the tuyere to see that coke has ignited uniformly in an amper glow. With natural air ignition time should take 2 – 2 ½ hours. However to expedite ignition a small (portable) blower may be used. Normally this is necessary in rainy season when wood and coke contain more moisture.
- After coke is satisfactorily ignited, close the upper tuyere covers. Keep the lower tuyere covers open. Tap hole and slag hole should also be open. Fettling door also to be kept open. Place guards in front of tap hole and slag hole to arrest shooting spark and coke pieces causing injury to people. Start the blower and blow off the ash for ½ minute strictly. This exercise cleans the furnace as well helps coke consolidation. After blow-off, open the tuyere covers. Close the breast door securely. Keeping lower tuyeres (air flow) open blow for another 2 minutes to ignite the coke fully. Shut blower, open tuyeres.
- Measure the bed height using a height gauge. The guage is inserted from the top (charge door).
- The remaining last split of coke (kept for bed) has to be put in before measuring the bed-height.

1.8 Bed Top Flux

- Before start of metallic charges bed flux has to be changed on the bed.
- The flux (lime stone in most case) size should be ¾ – 2 inch for small cupolas.

1.9 Melting

1.9.1 Implements and Safety Gear for Operators

Furnace operators should be in constant attendance.

They must have proper implements and safety gear, such as the following:

- Goggles (Blue)
- Hard Gloves (Leather)
- Poker for tap-hole)
- Crow bar
    - Small hammer
    - Bucker of water
    - Oxygen lancing gear (stand by)

1.9.2 Charge Material

- Charge material should be clean as far as possible. Excess rust or dirt clinging to charge metallics will require more flux material and coke and also lead to greater erosion of cupola lining.
- Heavy (thick) sections of scrap should be avoided in first 5 charges.
- No dimension of the charge material should be larger than 1/3 of the cupola ID.
- Correct weighing of charges is very important for proper and stable chemistry of the molten metal.

1.10 Cupola Operation

- Close tuyere covers, plug tap hole and slag hole. Allow some time for metallics to absorb heat. This is called soaking time. Generally 10 minutes is sufficient.
- Switch on blower and note time.
- Look for droplets of molten metal through the tuyere peep-hole and note time. Droplets should be visible approximately after 7 – 10 minutes of starting the blower.
- After blow on, first tapping can be made approximately within 15 – 20 minutes.
- If the tap – hole gets jammed due to cold metal or any other reason, do not attempt to open it by hammer. Put some lighted cotton waste and charcoal at the tap-hole and apply oxygen with a lancing tube (M.S. pipe of 2 mm bore diameter) at regulated pressure.
- Oxygen cylinder (kept for lancing) must have a regulator fitted on. Pneumatic pipe used for this purpose must match (bore) with the lancing pipe. No leak should be there.
- The oxygen will melt the solidified metal at the tap-hole.
- In intermittent tapped cupolas, the slag hole should be opened after 2/3 tapping.
- Note down slag conditions i.e. fluidity/viscous or fluid. Ideal colour should be bottle green.
- Constant vigil should be kept to ensure that at no time charge stack level falls. If due to any reason this happens. Shut off the blower, open tuyere covers, fill up the stack, close tuyere covers and start blower.
- Maintain proper sequence of charging.
- Bridging or hanging inside the cupola should be taken care of immediately. Fall in stack level, bridging or hanging affects quality and chemistry of molten metal.
- Maintain a log-book recording every detail for every heat. Some of the important parameters (apart from the weight of each charge) that must be recorded in the sheet are bed height, weight of bed coke (this may vary with the bulk density), bed light-up time, time taken for coke ignition, time taken and number of charges to fill up the stack at the beginning, blower on time, any interruption during melting, its cause, end time of melt i.e. blower off, last tapping, drain out, bottom door opened and bed dropped. All timings must be maliciously recorded

1.11 Closing Operation

- If the cupola has two levels of tuyeres – after the last charge air from the top tuyeres to be reduced and increased in the lower level. This can be done by use of blast control valves.
- After the last tap shut off the blower. Drain out the last metal and open all the tuyeres.
- Remove bottom door props so that bottom – drop doors fall op\en.
- Before the pros (door support) are removed be sure that no water is under the drop-door floor.
- Area around should also be clear so that the operator removing the props can get away.
- After dropping check for a clean drop through the tuyeres. Remove by poking tuyeres coke or slag.
- Water cool drop – off to salvage coke.

2.0 Best Operating Practices for Induction Furnace

2.1 Introduction and Working Principle

The electric induction furnace is a type of melting furnace that uses electric currents to melt metal. The principle of induction melting is that a high voltage electrical source from a primary coil induces a low voltage, high current in the metal or secondary coil. Induction heating is simply a method of transferring heat energy. Two laws that govern induction heating are: Electromagnetic induction and the joule effect.

The high frequency induction furnaces use the heat produced by eddy currents generated by a high frequency alternating field. The inductor is usually made of copper in order to limit the electric losses. The inductor is in almost all cases internally watercooled. The furnace consists of a crucible made of a suitable refractory material surrounded by a water cooled copper coil. In this furnace type, the charge is melted by heat generated from an electric arc. The coil carries the high frequency current of 500 to 2000 Hz. The alternating magnetic field produced by the high frequency current induces powerful eddy currents in the charge resulting in very fast heating. Typical schematic of induction furnace crucible is given in figure 2.1.

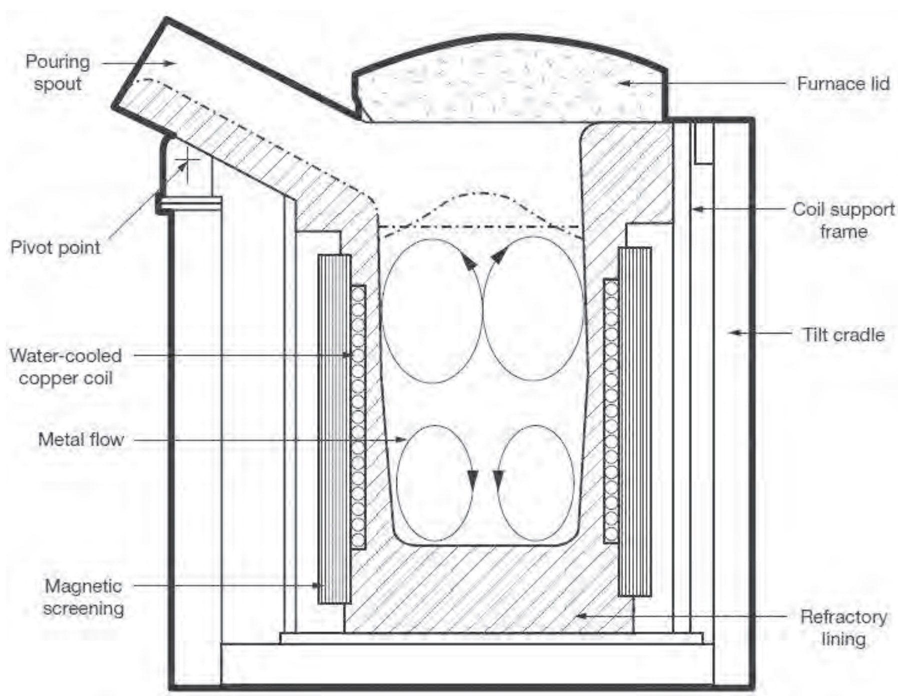


Figure 2.1: Schematic of induction furnace crucible

There are two main types of induction furnace: http://www.atlasfdry.com/inductionfurnaces.htm - coreless ***Coreless*** http://www.atlasfdry.com/inductionfurnaces.htm - corelessandhttp://www.atlasfdry.com/inductionfurnaces.htm - channel ***Channel.*** The coreless induction furnace has essentially replaced the crucible furnace, especially for melting of high melting point alloys. The coreless induction furnace is commonly used to melt all grades of steels and irons as well as many non-ferrous alloys.

A modern coreless induction furnace can melt a tonne of iron and raise the temperature of the liquid metal to 1450 °C using less than 600 kWh of electricity. Typically, specific energy consumption of coreless induction furnace varies from 500 to 800 kWh per tonne depending on type and grade of casting. The overall efficiency of induction furnace depends on many factors, such as: scrap charging system, furnace design, furnace cover, harmonics control, multiple-output power supply and refractory.

2.2 Losses in Induction Furnace

Electrical energy required for heating one tone of iron to 1500 °C is 396 kWh. In furnace numerous losses takes place which increases the specific energy consumption to above 500 kWh. The losses are: thermal furnace losses, furnace coil losses, capacitor bank losses, convertor losses and losses on main side transformer. The losses are represented in figure 2.2.

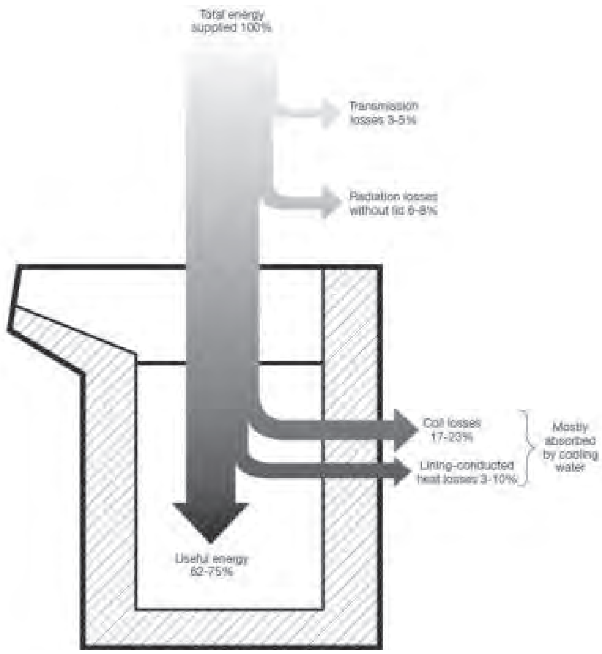


Figure 2.2: Sankey diagram of energy flow in induction furnace

In a typical induction furnace the energy loss in equipment is between 100 to 130 kWh per tonne. The furnace efficiency is around 65 to 75%. With new development in energy efficient coils, new refractory material, reduction of converter losses and reduction in transformer losses the state of art furnace equipment energy loss is reduced to 60 to 90 kWh per tonne. The new furnaces have efficiency 81 to 87%.

2.3 Best Operating Practices

Efficient operation of coreless induction furnace depends primarily on implementation of good/best operating practices. The steps involved in operation of induction furnace are shown in figure 2.3. Best operating practices under each of stages are elaborated in following section.

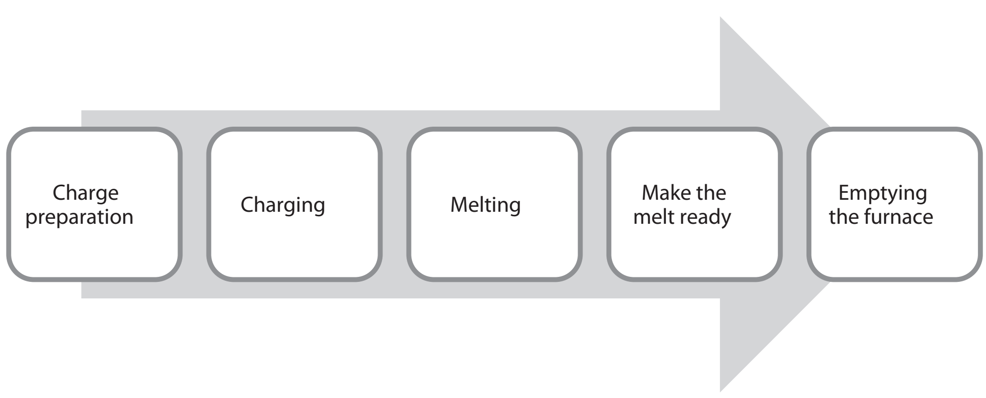


Figure 2.3: Stages of operation in induction furnace melting

2.3.1 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 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, i.e. charging the furnace to its capacity. 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 equiped with vibrating medium and they could be fuel fired to pre-heat charge and remove oil/grease. This is shown in figure 2.3.1.
- Avoid introduction of wet or damp metal in melt, this may cause explosion.

Figure 2.3.1: Vibrating feeder for induction furnace

2.3.2 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 2.3.2. 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.

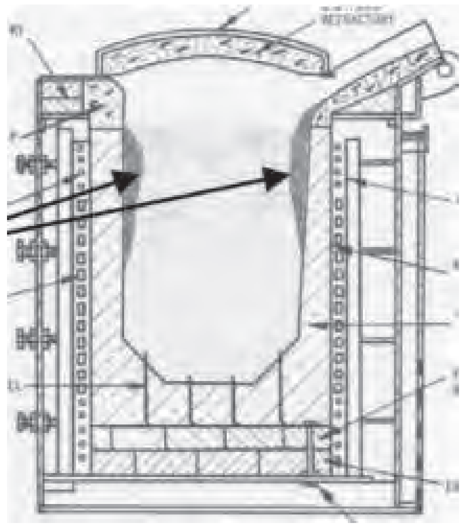


Figure 2.3.2: Slag build-up near furnace crucible neck

- 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.
- 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.

2.3.3 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 is quite energy intensive and 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.

2.3.4 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. The effect of increasing or decreasing lining thickness on power consumption rate is shown in figure 2.3.4.
- Do not allow furnace to cool very slow. Forced air cooling helps in developing cracks of lower depth, this helps in faster

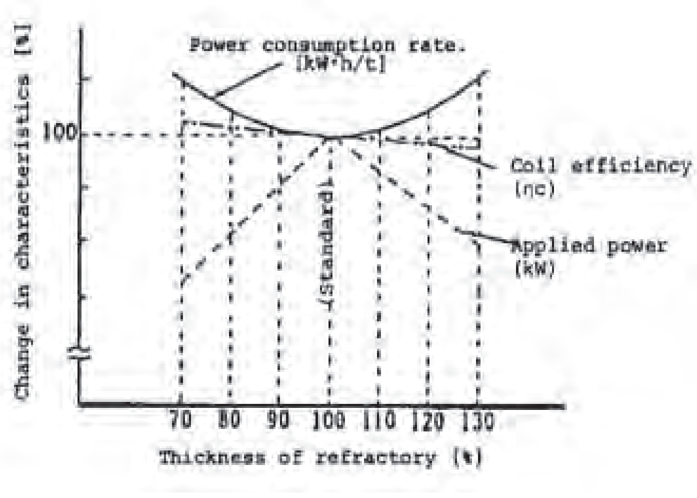


Figure 2.3.4: Lining thicknesss vs. power consumption rate

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.

2.3.5 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.

2.3.6 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, see figure - 2.3.5.
- 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.

Figure 2.3.5: Raw material storage

2.4 Harmonics Analysis

The induction furnace is major electrical load in foundry. It has coil fed by medium frequency AC current supplied by an inverter which is fed by a DC current converter connected to AC distribution network supply. The magnitude of distortion by induction furnace is very high and affects the voltage supplied.

Presence of harmonics will give rise to variety of problems including equipment overheating, reduced power factor, deteriorating performance of electrical equipment, incorrect operation of protective relays, interference with communication devices and in some cases, circuit resonance to cause electrical apparatus dielectric failure and other types of severe damage.

The voltage and current harmonics as per the CEA Regulations are as follows:

1) The total harmonic distortion for voltage at the connection point shall not exceed 5% with no individual harmonic higher than 3%
2) The total harmonic distortion for current drawn from the transmission system at the connection point shall not exceed 8%

Maximum Harmonic Current Distortion in Percent of IL						
Individual Harmon ic Order (Odd Harmonics)						
ISC/IL	<11	11≤h<17	17≤h<23	23≤h<35	35≤h	TDD
<20*	4.0	2.0	1.5	0.6	0.3	5.0
20<50	7.0	3.5	2.5	1.0	0.5	8.0
50<100	10.0	4.5	4.0	1.5	0.7	12.0
100<1000	12.0	5.5	5.0	2.0	1.0	15.0
>1000	15.0	7.0	6.0	2.5	1.4	20.0

Induction furnace with SCR technology is typically a 6-pulse converter, which generates mainly 5th and 7th harmonics. Overall THD in voltage and current is around 8% and 24% respectively. In 12-pulse converter 11th and 13th harmonics are predominant; overall THD in voltage and current is around 7% and 10% respectively. Typical distorted current waveform in case of 6, 12 or 24 pulse rectifier is given in figure 2.4a. Figure 2.4b-d shows typical harmonics level in induction furnace and voltage unbalance.

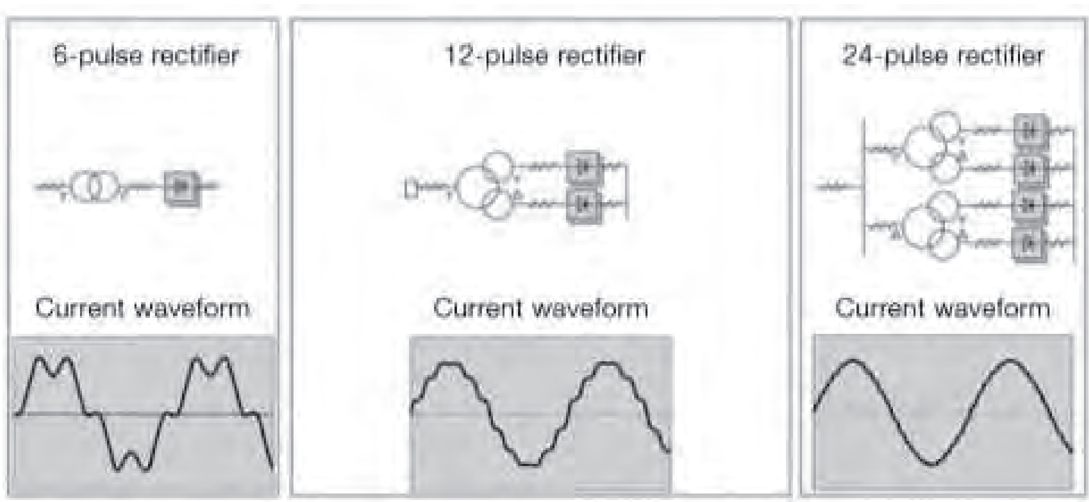


Figure 2.4a: Current waveform output in 6, 12 or 24 pulse rectifier

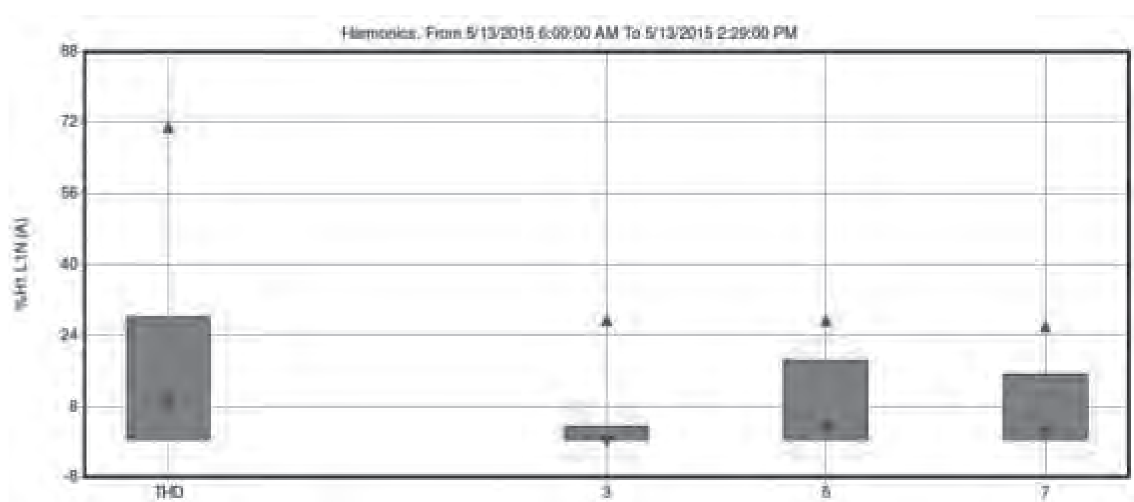


Figure 2.4b: Typical current THD in induction furnace

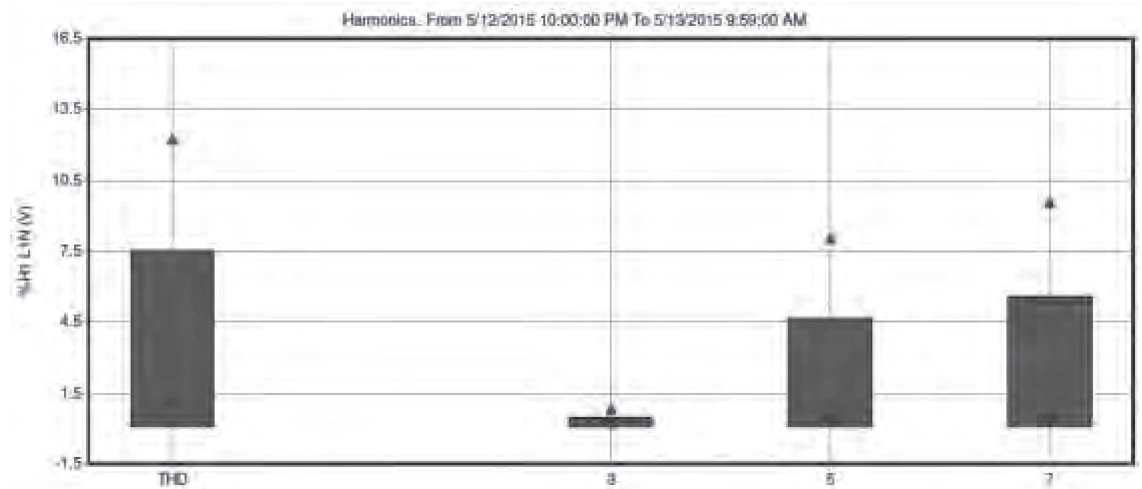


Figure 2.4c: Typical voltage THD in induction furnace

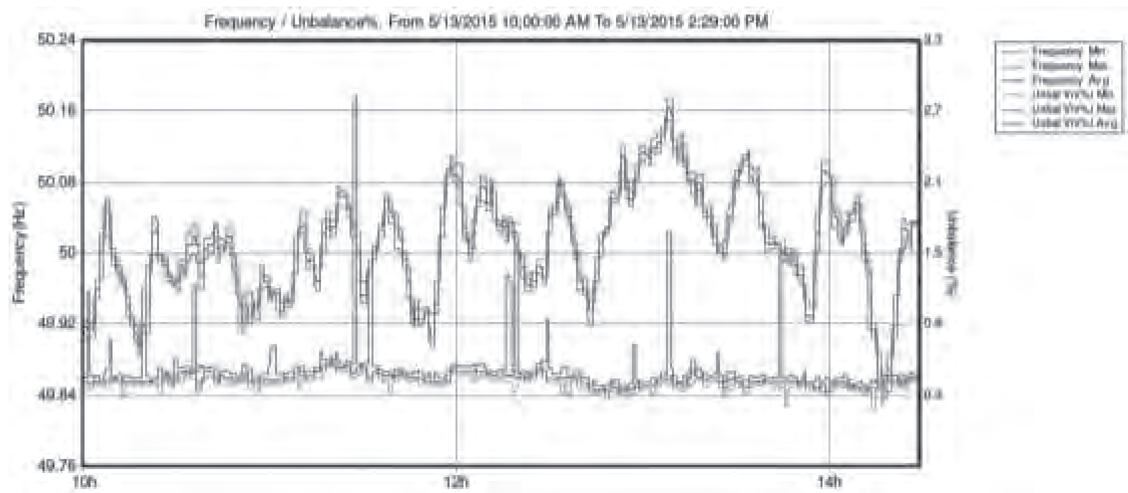


Figure 2.4d: Frequency variation and voltage unbalance

The solution for harmonics problem:

- Replace induction furnace with new IGBT based 24-pulse converter furnace
- Install active filters for existing furnace
- Multi-pulse rectifiers

It is to be noted that **TANGEDCO has already announced 15% penalty** (of energy charge) on not maintaining harmonics level in control. Most existing induction furnaces are 6-pulse converter based and harmonics can be mitigated by installing active filters.

Other benefits of harmonics filters:

- Improvement in power factor (6 or 12-pulse max. 0.95, in 24-pulse 0.975)
- Reduction in the kVA demand
- Reduction in distribution losses (I2R)
- Reduction in energy (kWh) consumption

3.0 Best Operating Practices for Compressed Air System

3.1 Rational

Compressed air is the fourth utility of any type of industry/SME, after electricity, gas and water since it is extensively used as a source of power for tools, equipment and industrial processes. In general, compressed air systems are not well managed resulting in high-energy losses. 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.

It has been observed that the there is still gap between the how to keep high reliability of compressed air system through maintenance activities and how to reduce energy consumption through adoption of best operating practices for using compressed air system.

3.2 Best Operating Practices

The following practices can be adopted by industries/SMEs for operating their compressed air system efficiently:

3.2.1 Basic Understanding

- The air compressors motor consumes about 20-40% of the total energy of the motors in the plant in many industries.
- For air compressors life cycle, the operating cost on energy is ~84%, ~7% for initial investment and ~9% for maintenance of the air compressor.
- There are three ways for using air compressor efficiently – Reduce the consumption of air, reduce the air pressure and optimize the air compressor.

3.2.2 Reduce the consumption of air, this is the most important measure for efficient operation like

- There are always air leakages exists in the shop floor and which could be near to the equipment/application point and/or in the air piping distribution system

  Leakage test

  ✓ Operate compressor at night, or holiday, and shut it down when achieving a predetermined pressure value.

  ✓ When the compressor is shut down, due to the leakage, the pressure will automatically decrease. The amount of leakage can be known by measuring the time (T) taken to decrease the pressure by 1 bar.

  ✓ Formula $\boxed{Q = \frac{(P1 - P2) \times V}{Po(1.033) \times T}}$

  ✓ Q=Volume of leakage (M^3/min)

  ✓ P1= Predetermined pressure (kg/cm^2) (gauge pressure + 1.033kg/cm^2)

  ✓ P2= Pressure after leakage (kg/cm^2) (gauge pressure + 1.033kg/cm^2)

  ✓ T=Time taken to reduce pressure from P1 to P2 (min)

  ✓ Po= Atmospheric air pressure(kg/cm^2)

  ✓ V= Piping capacity (Mm^3) (In case of your company; 72.31m^3)

- There is a report that as much as 20% of leakage exists in a plant on average
- Since leakage directly leads to energy loss, it is the highest priority issue for air systems
- Be aware that leakage may occur anywhere.
  - ✓ Leakage from coupler
  - ✓ Leakage from pipe
  - ✓ Leakage from internal component of equipment
- For example, use of proper air nozzles for blowing will reduce the air consumption.
- So, reducing leakage is top-priority issue in air system.
- Recognizing that a leakage occurs from all places is required.
- The leakage with a sound is detected by using, Leak Detector e.g. Model-AAM-PWLEAK02
- However, cautions are required, since there is also the leakage with no sound (silence loss).
- Leakage test can be carried out frequently to check the quantity of air leakages in the plant. The physical verification at joints of hoses, couplers will help to identify the air leakages, even soap solution can be poured at the joints for checking the air leakages.

  Leakage check test
  - ✓ Leakage check is performed at the night time or on holidays when the plant is not in operation.
  - ✓ Once the compressor is operated and raised up to predetermined pressure, then stop the compressor and measure the time required for pressure reduction of 1bar from the predetermined pressure.
  - ✓ Since all of this leads to waste of energy, there is a necessity for quick measures.
  - ✓ If in the above investigation, it is possible to calculate the amount of leakage, then leakage locations need to be identified in the next step.
  - ✓ As the amount of leakage can be calculated by the pressure drop calculation, after confirming the same the leakage areas can be identified and effective leakage reduction can be achieved.
  - ✓ Target reduction is half of the total ratio.
- Keeping that in mind, take measures from the most leakage prone areas.
- Leakage cannot be completely stopped with the one-time measures.
- Continuous monitoring is required.

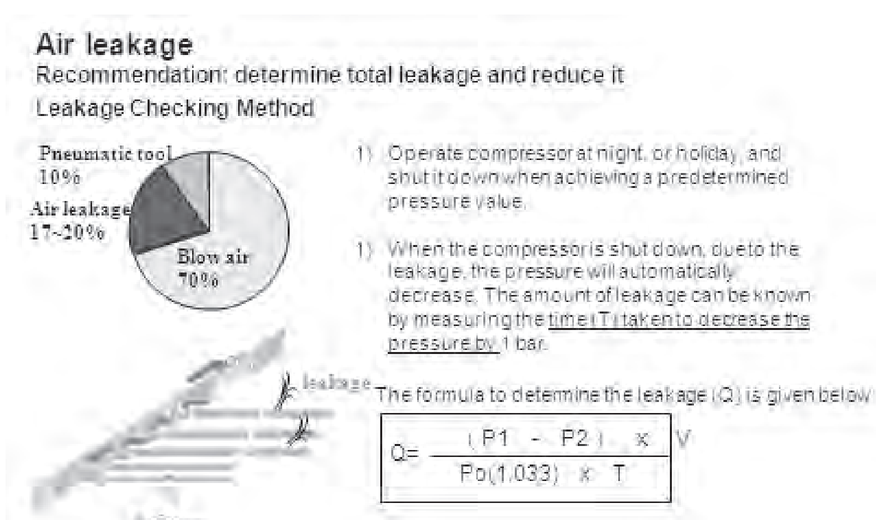


Figure 3.2.2: Air leakage

3.2.3 Reduce Air Pressure and Good Air Piping Work

- There should be always pressure gauges installed in the air piping system for regular check of design and operating pressure of pressure gauges, if there is any fall in pressure for the existing set point of air compressor then there are huge leakages exists in the system and needs to identify the points

Example of pipes having many valves or bends, generate resistance and pressure loss.
Change the type of the valves (to the one with low resistance) or reduce bends as much as possible.

A pipe narrowed immediately after the air dryer. Generates resistance and pressure loss.
A riser pipe. Causes a backward flow of condensate, leading to an increasing number of mechanical troubles.

Figure 3.2.3a: Contents of Improvement Measures – Examination of Piping Work

- Increase pipe size to reduce pressure loss and important air piping work
  - ✓ Piping system
    How pressure loss changes if size changed?
    How pressure loss changes if valve structure differs?
  - ✓ Be sure to provide a drain connection for a riser pipe.
  - ✓ Installation to a collecting pipe must be made from above to prevent backflow. (Similarly, branch pipes must be installed from above.)
  - ✓ For a collecting pipe, give an inclination (1/100) from the upstream to the downstream. Attach a drain plug at the end of each pipe.
  - ✓ Buried piping makes it difficult not only to detect air leakage but also to repair
- If there is need for higher pressure for particular application or process or shop then increase pressure by use of booster compressor instead of increasing set pressure of the entire air compressor system
- Pipe size - for reduced pressure loss without large no. of bends with 4 – 5 m/s of velocity, helps is load/unload of air compressor, running hours, leakages etc. Types of valves ball valves and globe valves, in globe valves there are 60% more losses than gate valves.
- Use of hosepipes increases the pressure drop. Piping should not be underground and drain valves should be placed at lower position in pipelines. The filter size should be adequate so, that there is no pressure drop. Higher resistance causes pressure drops and also there is overloading of the air compressors resulting in frequent breakdowns. Piping should be used in looping for reduced pressure drops.

Figure 3.2.3b: Examples of recommended piping

- If adequate and large receiver size is used, there is energy saving about 3%. Proper ventilation of air compressor decreases the surrounding temperature resulting in less stoppage due to over temperature and energy saving with less inlet temperature. For indirect ventilations large size fans are required. Proper layout of air duct is required for ventilation. For various air pressure requirements in the plant, pressure boosters or booster air compressors can be used, which will eliminate the high-pressure generation at main air compressor.

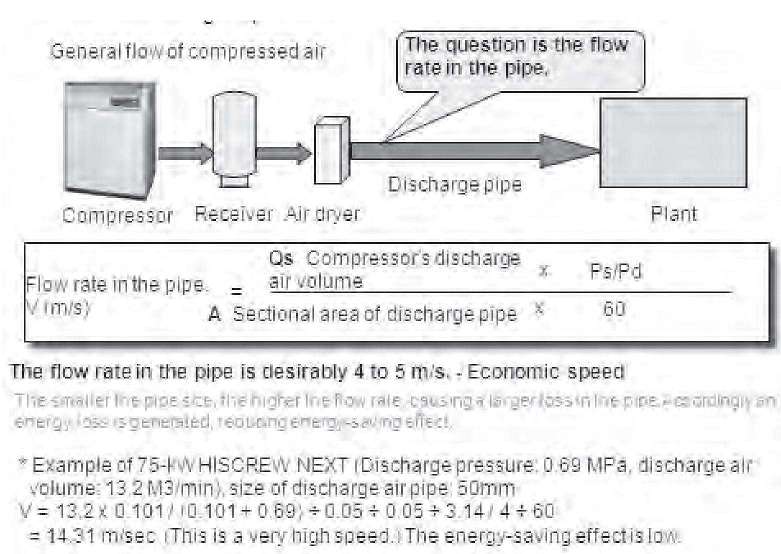


Figure 3.2.3c: Pressure loss through pipe and internal flow rate

3.2.4 Optimize the Air Compressor

- Pressure reduction by 1 bar will give energy saving of 6-8%.
- Air intake into the compressor room and better ventilation. (Pay attention to the gallery design - effective area)
  - ✓ Install the compressor in the direction so that a hermetically closed room or intake of contaminated air (oil, gas, etc.) is avoided.
  - ✓ Prevent the air discharged from the compressor room from being sent back into the room and circulating.

- ✓ Discharge air in compressor room
- ✓ Install the fan high on the wall of the compressor room.
- ✓ When using a rain hood, take resistance into consideration when selecting a ventilating fan.

- Use of inverter type air compressors is important, as industry though are using inverter compressor are not getting desired energy savings. The continuous air compressor should be used at base load and inverter compressor should be used for variable load with proper pressure setting.
- Multiunit control can be used at the air compressor installations having more than 2 air compressors. Etc. He explained advantages/disadvantages of centralised and de-centralised air compressor systems.
- Plan/do/check/act is continuously required for energy efficiency requirement in compressed air system.

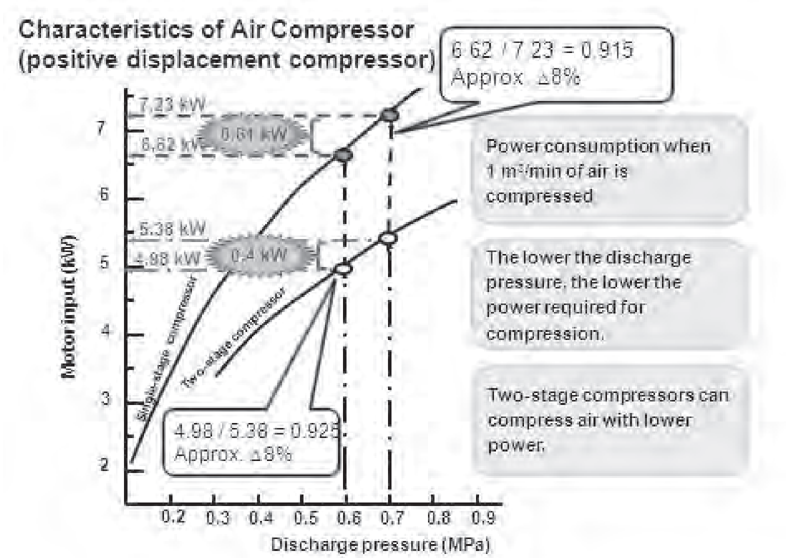


Figure 3.2.3d: Characteristics of air compressor

3.3. Some Important Points

- Life of air compressor in its life cycle is considered about 12 years life
- About pressure reduction ~6% saving is possible
- About centralized system, centralized system can be selected/ designed based on various factors like size, pressure and plant layout etc.
- About use of inverter type air compressor with percentage loading 50% to 90%, energy consumption cost savings of minimum 20% is possible even though there is less fluctuations in the compressor loading/unloading.
- About air receiver for high capacity air compressors, high capacity receiver could be used for Centrifugal air compressors which will give saving of 3 %.

3.4. Environment Point in Compressed Air System

- Replacement of reciprocating air compressor and install low vibration, low noise level air compressors.
- Drain discharge according to the actual drain amount is required in order to efficiently avoid unnecessary damage to the environment and cost associated with generating process of compressed air.
- Intelligent electronic control system keeps the loss of compressed air and energy consumption to a minimum by BEKOMAT drain discharge equipped with capacity levelling sensor can be used for drain discharge.

4.0 Best Operating Practices in Pumping Systems

4.1 Pumping System Description

Most of the pumps in foundry industries are centrifugal type. The main function of the pump is to convert energy of a prime mover into velocity or kinetic energy and then into pressure energy of a fluid that is being pumped. The pump has two main parts such as impeller and diffuser or volute. The impeller is the rotating part that converts pressure energy into the kinetic energy. This kinetic energy of a liquid coming out of an impeller is harnessed by creating a resistance to the flow.

The output power of the pump sometimes called the water horsepower, which is equal to the rate of work done on the fluid, namely

P_{out} = Y x Q x h_p

Where, Y is the specific weight of the fluid Q is the volumetric flow rate
h_p is the energy increase per unit weight, or pump head

4.2 Pump System Curves

The pressure (head) that a pump will develop is in direct relationship to the impeller diameter, the number of impellers, the size of impeller eye, and shaft speed. Capacity is determined by the exit width of the impeller. The head and capacity are the main factors, which affect the horsepower size of the motor to be used. The more the quantity of water to be pumped, the more energy is required.

A centrifugal pump is not positive acting; it will not pump the same volume always. The greater the depth of the water, the lesser is the flow from the pump. Also, when it pumps against increasing pressure, the less it will pump. For these reasons it is important to select a centrifugal pump that is designed to do a particular job. Pump performance curves are shown in figure 4.2.

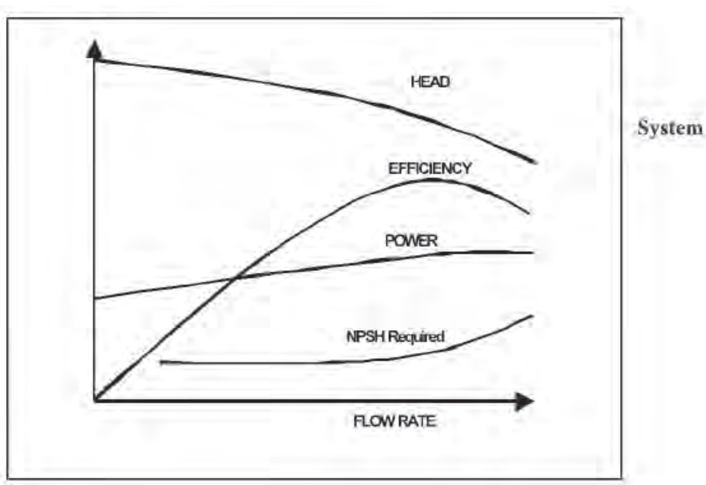


Figure 4.2: Pump performance curves

Hydraulic power, pump shaft power and electrical input power

Hydraulic power Ph = Q (m^3/s) X Total head, hd-hs (m) X ρ (kg/m^3)X g (m/s2)/1000

Where hd- discharge head, hs- suction head, ρ- density of the fluid, g- acceleration due to gravity

Pump shaft power Ps = Hydraulic power, P_h/ pump efficiency, η_{pump}

Electrical input power = Pump shaft power P_s/ η_{pump}

4.2.1 Pump Curves and Pump Operating Point

The performance of a pump can be expressed graphically as head against flow rate. The centrifugal pump has a curve where the head falls gradually with increasing flow. The figure 4.2.1 is pump characteristic curve (Head - Flow curve).

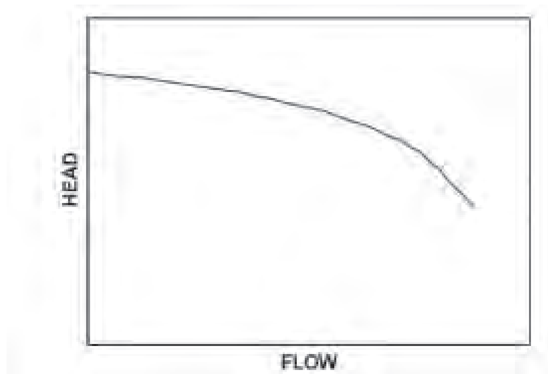


Figure 4.2.1: Pump curve

4.2.2 Pump Operating Point

When a pump is installed in a system the effect can be illustrated graphically by superimposing pump and system curves. The operating point will always be where two curves intersect. Each centrifugal pump has a BEP at which its operating efficiency is highest and its radial bearing loads are lowest. At or near its BEP, a pump operates most cost effectively in terms of both energy efficiency and maintenance. In practical applications, operating a pump continuously at its BEP is not likely, because pumping systems usually have changing flow rate and system head requirements and demands. Selecting a pump with a BEP that is close to the system's normal operating range can result in significant operating cost savings.

The performance of a pump is typically described by a graph plotting the pressure generated by the pump (measured in terms of head) against flow rate. A performance curve for a typical centrifugal pump is shown in Figure 4.2.2.

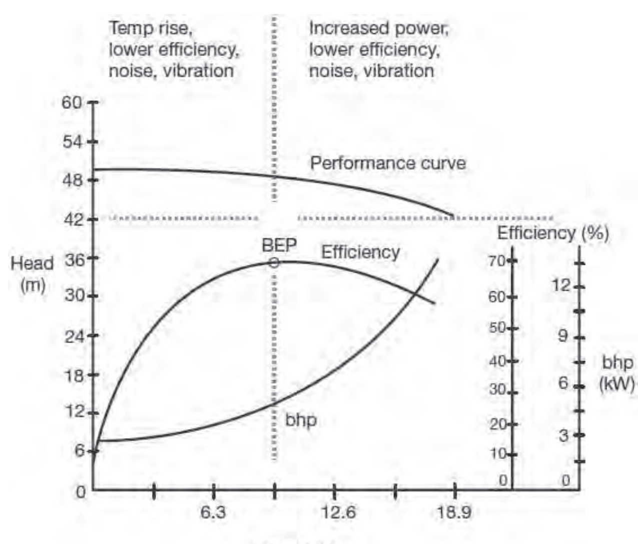


Figure 4.2.2: Pump operating point

If the actual system curve is different in reality to that calculated, the pump will operate at a flow and head different to that expected.

4.3 System Characteristics

In a pumping system, the objective, in most cases, is either to transfer a liquid from a required destination, e.g. Filling a high level reservoir, or to circulate liquid around a e.g. As a means of heat transfer in heat exchanger

A pressure needed to make the liquid flow at the required rate and this must overcome head losses in the system. Losses are of two types: static and friction head.

Static head is simply the difference in height of the supply and destination reservoirs as shown in figure. Static head is independent of flow. Friction head (sometimes called dynamic head loss) is the friction loss, on the liquid being moved, in pipes, valves and equipment in the system. Most systems have a combination of static and friction head and the system curves for two cases are shown in Figures 4.3a and 4.3b.

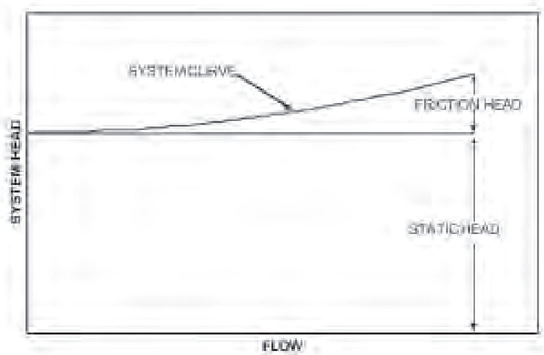


Figure 4.3a: System with high static head

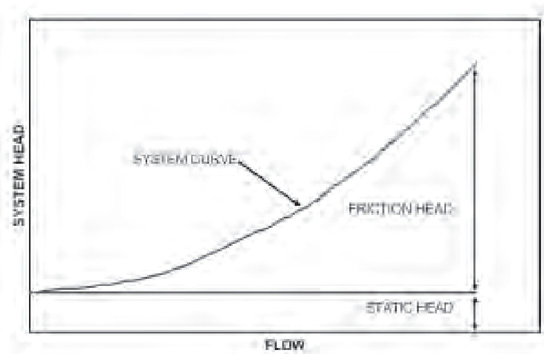


Figure 4.3b: System with low static head

Static head is a characteristic of the specific installation and reducing this head where this is possible, generally helps both the cost of the installation and the cost of pumping the liquid. Friction head losses must be minimized to reduce pumping cost, but after eliminating unnecessary pipefittings and length, further reduction in friction head will require larger diameter pipe, which adds to installation cost.

4.4 Indication that Pumps is Oversized

Following table enlists the characteristics of an oversized pump and its reasoning;

Characteristics of an Oversized Pump	Description
Excessive flow noise	Oversized pumps cause flow-induced pipe vibrations, resulting in excessive noise and increased damage to pipework (including flanged connections, welds and piping supports)
Highly throttled flow control valves	Pumps tend to remain in more restrictive positions in systems with oversized pumps; this increases backpressure, further decreasing efficiency
Frequent replacement of bearings and seals	Increased backpressures from increased flow rates creates high radial and thrust bearing loads as well as high pressures on packing glands and mechanical seals
Heavy use of bypass lines	A system that heavily uses bypass lines indicates that the system has either Oversized pumps, is not balancing properly, or both
Intermittent pump operation	Pumps being used for purposes such as filling or emptying tanks that run very intermittently indicate oversizing and hence suffer increased start/stop inefficiencies and wear, as well as increased piping friction.

4.5 Pump Wear and Maintenance

Effective, regular pump maintenance keeps pumps operating efficiently and allows for early detection of problems in time to schedule repairs and to avoid early pump failures. Regular maintenance avoids losses in efficiency and capacity, which can occur long before a pump fails.

The main cause of wear and corrosion is high concentrations of particulates and low pH values. Wear can create a drop in wire to water efficiency of unmaintained pumps by around 10–12.5%. Much of the wear occurs in the first few years, until clearances become similar in magnitude to the abrading particulates. Referring to Figure 5, it can be seen that it tends to level out after 10 years. Catastrophic failure can occu

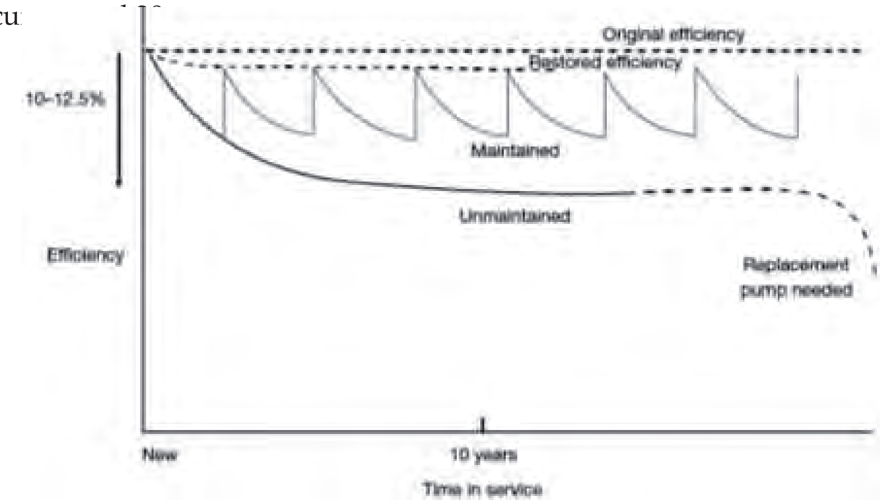


Figure 4.5: Average wear trends for maintained and unmaintained pumps

4.6 Common Problems and Measures to Improve Efficiency

Studies indicate that the average pumping efficiency in manufacturing plants can be less than 40%, with 10% of pumps operating below 10% efficiency. Oversized pumps and the use of throttled valves were identified as the two major contributors to the loss of efficiency. Energy savings in pumping systems of between 30% and 50% could be realized through equipment or control system changes. A pump's efficiency can also degrade during normal operation due to wear by as much as 10% to 25% before it is replaced.

Common Problem	Potential Measures to Improve Efficiency
Unnecessary demand on pumping system	Reduce demand on system
Oversized pumps	Select pump that operates near to BEP Change impeller Trim impeller
	Fit multiple-speed pump Use multiple-pump arrangements Fit lower speed pump/motor
Pump wear	Pump maintenance
Less efficient impeller	Change impeller
Inefficient pump throttling controls	As for oversized pumps Fit adjustable or variable-speed drive
Inefficient piping configuration	Change piping inefficiencies
Oversized motor	Change motor
Inefficient motor	Change to high-efficiency motor
Lack of monitoring and/or documentation	Install monitoring and conduct survey

4.7 Best Operating Practises Summary

- Ensure adequate NPSH at site of installation.
- Ensure availability of basic instruments at pumps like pressure gauges, flow meters.
- Operate pumps near best efficiency point.
- Modify pumping system and pumps losses to minimize throttling.
- Adapt to wide load variation with variable speed drives or sequence control of multiple units.
- Stop running multiple pumps -add an auto-start for an on-line spare or add a booster pump in the problem area.
- Use booster pumps for small loads requiring higher pressures.
- Increase fluid temperature to reduce pumping rates in case of heat exchangers.
- Repair seals and packing to minimize water loss by dripping
- Balance the system flows and reduce pump power requirements
- Avoid pumping head with a free return (gravity): Use siphone effect to advantage
- Conduct water balance consumption
- Avoid cooling water re-circulation in DG sets , air compressors, refrigeration systems, cooling towers feed water pumps, condenser pumps and process pumps.
- In multiple pump operations, carefully the operation of pumps to avoid throttling
- Provide booster pumps for few areas of higher head
- Replace od pumps by energy efficient pumps
- In case of over designed pump, provide variable speed drive, or downsize/replace impeller or replace with correct sized pump for efficient operation
- Optimize number of stages in multi-stage pump in case of head margins
- Reduce system resistance by pressure drop assessment and pipe size optimization

5.0 Best Operating Practices for Lighting

5.1. Categorization

Lighting system provides light for practical use and to make things visible and clear enough inside and outside factories. In industries/SMEs, lighting includes both daylighting and artificial light source. Proper lighting fixture selection, layout and control not only enhance lighting effect but also save energy consumption by lighting fixtures.

Based on construction and operating characteristics, lights are basically categorized into 3 types: incandescent, florescent and high intensity discharge lamps (HID). Further, depending on the place of use, lights can be broadly classified for indoor and outdoor use.

5.1.1 Indoor Lighting

- Most common types are incandescent lamp, fluorescent tube light (FTL), compact fluorescent lamp (CFL), high pressure mercury/sodium vapour lamp (HPMV/HPSV) and metal halide lamps, and now a days light emitting diode lamp (LED) are also being used and gainng popularity however light/ brightness is an issue with LED as it may create glare and negative on occupant/user.
- Uniformity of illuminance is one of the important factors that must be considered during the initial planning stage and/or for modifying existing lighting scheme. Uniformity of illuminance is achieved by proper spacing between the centres of each luminaire/fixture of particular type, size and lux levels.

5.1.2 Outdoor Lighting

- Commonly HID lamps are high pressure mercury/sodium vapour lamp (HPMV/HPSV), low pressure sodium vapour lamp (LPSV), halogen lamps and metal halide lamps
- Recently light emitting diode lamp (LED) and magnetic induction lamps are gaining popularity due to long life and higher energy efficiency

5.2. Fixture Selection and Sizing

5.2.1 High Bay Lights Fixtures

- Fixtures made up of compact high pressure die-cast aluminum housing powder coated in black. Aluminum reflector is electrochemically brightened and anodized for better optics and longer life, giving a very good distribution.
- Separate reflectors are available for narrow beam and wide beam reflector.
- For dusty environment, it is provided with heat resistant toughened glass with EPR gasket.

5.2.2 Flood Light Fixtures

- Floodlights fixtures with reflectors are used to illuminate a wide area like roads, car parking, playground etc
- Parabolic aluminized reflector lights fixtures are used when a substantial amount of flat lighting is required for a scene.
- Low bay light fixture is typically used with ceiling heights 20◎ or less. High bay light fixtures are typically used for heights between 20-45◎ high.
- Low bay light usually features some type of diffuser on the bottom of the light to spread the light in a manner reflective of the lower ceiling height. High bay lights typically have an aluminum reflector which allows a beam of light to reflect downwards to the floor area. Other types of high bay lights have a prismatic reflector which illuminates shelving, etc. from the floor to the ceiling.

- Whether you are using low bay lights or high bay lights, metal halide type lighting overwhelming allows users to illuminate large areas with very few lights, making it the energy savings choice for buildings of all sizes.

5.2.3 Luminaire Efficiency

- The efficiency of a luminaire is the ratio of luminaire lumen output to the lamp lumen output. Mirror optics of a luminaire and louvers decides the luminaire efficiency along with the improved visual comfort and glare control.
- Lighting simulation tools can be used to choose which luminaire will suit best the required application by analyzing the lighting distribution and glare index.

5.3. Layout

- In order to design a luminaire layout that best meets the illuminance level and uniformity requirements of the job, two types of information are generally needed: average illuminance level and illuminance level at given point.
- Every luminaire/fixture will have recommended space to height ratio (SHR), it is better to choose luminaires with larger SHR, this can reduce the number of fittings and connected lighting load.
- Lighting layout at corners of room is undesirable hence lights layout at distance from all four corners is desirable in a room.

Area	Recommended Lux level	Average lux level in foundry
Corridors and walkway	40	5 – 20
Change rooms, storage	80	25 – 55
Mould and core preparation	160	45 – 85
Melting shop floor	240	105 – 165
Office work space	250	185 – 305
Laboratory	500	215 – 245
Inspection area	1500	255 – 365

5.4. Maintenance of Fixtures

- Light levels decrease over time because of aging lamps and dirt on fixtures, lamps and room surfaces. Together, these factors can reduce illumination by 50 percent or more, while lights continue drawing full power.
- Regular maintenance is essential to ensure that facilities receive the desired quantity and quality of light, as well as energy efficiency, from their lighting systems. Periodic maintenance can produce a range of benefits, including a brighter and cleaner workplace, a higher level of security, and enhanced productivity.
- The basic maintenance includes cleaning of lamps and fixtures, cleaning and repainting interiors and re-lamping. Keep light-reflecting surfaces and lenses clean in order to maintain designed light levels.
- Workers should take care not to touch the envelope of halogen bulbs because doing so leaves skin oils on the glass surface. As these bulbs heat and cool, the oils cause uneven stress, leading to glass cracking and shorter lamp life.
- Tips for cleaning fixtures:
  - o Clean lighting fixtures whenever lamps are replaced. In areas where doors allow outside air or filtering is not adequate, clean at least twice a year.
  - o Wipe plastic lenses with damp, not dry cloth (a mild detergent may be needed). Small cell louver panels, including parabolic wedge louvers, should be removed and dipped in mild detergent solution, then air-dried.
  - o Do not wipe luminaire or lamps while fixture is energized.
- Line voltage should be checked at the fixture and compared with the ballast rating to be sure it is within the prescribed limits, so as to prevent lamps premature failure due to flickering caused by voltage fluctuation, hence if voltage controllers/stabilizers are present then its maintenance should also be done periodically.

- Replacement of old conventional magnetic ballast with new electronic ballast also reduces maintenance part of ballast repairing.
- To avoid damage to ballasts, lamps are replaced when it ceases operation unexpectedly, failed to light up after turning it on.
- Lamps should be replaced when they reach 70%-80% of their rated life. Your lamp supplier has additional information available regarding lamp maintenance procedures.
- Bulbs should be replaced not only when they break, but on a schedule according to how the brightness of the lamp decays over time. Some bulbs lose over a third of their initial brightness over a few years.

5.5. Control Strategies

5.5.1 Localised Switching

Localised switching is preferred in large spaces. Local switches give individual occupants control over their visual environment and also facilitate energy savings, by using localized switching it is possible to turn off artificial lighting in specific areas, while still operating it in other areas where it is required, a situation which is impossible if the lighting for an entire space is controlled from a single switch.

5.5.2 Occupancy Sensors

Occupancy–linked control can be achieved using infra-red, acoustic, ultrasonic /microwave sensors, which detect either movement/noise in room spaces. These sensors switch lighting on when occupancy is detected, and off again after a set time period, when no occupancy movement detected. They are designed to override manual switches and to prevent a situation where lighting is left on in unoccupied Spaces with this type of system it is important to incorporate a built–in time delay, since occupants often remain still or quiet for short periods and do not appreciate being plunged into darkness if not constantly moving around.

5.5.3 Photocells

These measure the amount of natural light available and suitable for both indoor and outdoor (Street lights) applications. When the available light falls below a specified level, a control unit switches the lights on (or adjusts a driver to provide more light). Photocells can be programmed so that lights do not flip on and off on partially cloudy days.

5.5.4 Time Based Control

Timed–turnoff switches are the least expensive type of automatic lighting control, Electronic timer switches provides a choice of time intervals, which you select by adjusting knob located behind the faceplate. Most timer models allow occupants to turn off lights manually; some models allow occupants to keep on, overriding the timer. Timed-turnoff switches are available with a wide range of time spans. The choice of time span is a compromise. Shorter time spans waste less energy but increases the probability that the lights will turn off while someone is in the space.

5.5.5 Dimming Technologies

It include common manual dimming switches as well as more sophisticated technology that automatically reduce light output according to the availability of daylight or other ambient light. While dimming of incandescent lamps is common, dimming of fluorescent fixtures can only be accomplished if they have ballasts designed especially for dimming applications.

5.5.6 Day Lighting Controls

It adjusts light output levels from fixtures in perimeter areas next to windows or under skylights in response to natural outdoor light entering the building. Day lighting controls are available in continuous dimming and stepped reduction models.

5.5.7 Automated Lighting Management Systems

It provides centralized computer control of lighting systems.

5.6. Efficiency improvement

5.6.1 Use Of Daylights

Glass strips, running continuously across the breadth of the roof at regular intervals, can provide uniform lighting on industrial shop floors and storage bays, also maximum usage of daylights should be done in industries/factories by using transparent/translucent roofing sheets so as to minimise usage of electrical lighting in daytime.

5.6.2 Lighting Voltage Transformer/Controller

Higher and frequent voltage variation leads to increased energy consumption by lighting loads, lamp lumen depreciation and also reduces the life of lamps.

It is always recommended to maintain single phase voltage between 210 – 215 V exclusively for lighting circuit for better and optimum performance of luminaries.

It is recommended that the plant should install lighting transformers to separate the lighting load from other plant load and process load. In areas where lighting transformers may not be feasible, energy savers or voltage reduction devices may be installed in the outgoing circuit. This is likely to improve the power factor as well as increase the reliability of the lighting infrastructure.

Lighting voltage controller

The reduction of voltage to these levels does not impair the ability of discharge lamps to strike, though an insignificant reduction in lumen output takes place. Usage of lower voltage leads to an increase in the operating power factor as well as the life of luminaries, which is confirmed by lower failure rates.

5.6.3 Occupancy Sensors Based Control

In most of the offices and factories it is observed that the lighting in the most of the areas is ON during the non-use period as well.

There are various areas/offices found in which manpower movement is limited but lights are illuminated. To avoid the idle running of the lighting system, it is recommended to retrofit the occupancy sensors, hence it is necessary for plant personnel to identify such areas and retrofit occupancy sensors as early as possible to save energy.

Occupancy Sensors

5.6.4 Lighting Dimmer Control

Use of dimmer control in parking areas will reduce the substantial energy consumption as most of the time parking area is non-occupied space once shifts in the evening starts.

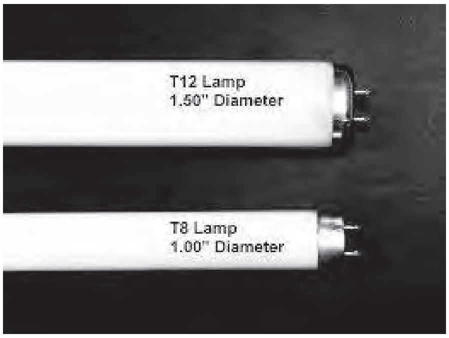
5.6.5 Replacement of Existing Lights with Energy Efficient Lighting

- Replace T12 (52 watts)/T8 (40 watts) with FTL T5 (30 watts) or LED tube light(20 watts)
- Replace CFLs with LED lamps with good lumens
- Replace of metal halide lamps of (250W) with magnetic induction flood lamp of (150 W)
- Replace of HPMV lamps of (400W) with high bay magnetic induction lamp of (250W)

Lighting Dimmer control

Photographs of these replacements are provided below:

Existing | **Replacementv**



T12 and T8 FTL

T5 FTL

CFL

LED

Metal Halide flood lamp

Magnetic Induction Flood Lamp

High bay HPMV lamp

High bay Magnetic induction lamp

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