Almost all the foundries use coke-fired cupolas for melting. The voluminous production of flue gases by cast iron foundries using coke-fired cupolas damage the environment, since it contains harmful gases like $\text{SO}_2$, $\text{CO}_2$, $\text{CO}$ and $\text{H}_2\text{S}$ which are poisonous to all living beings. Sometimes, the melting practice by coke-fired cupolas does not obey the environmental regulations. Not only the environmental problems but energy consumption is also much higher. In view of diminishing natural resources of energy, consumption of oil, coal, gases etc. required to be drastically reduced. Several industrial organisations have made certain developments in cupola melting by installing pollution control devices and introducing energy saving techniques. This paper presents the details of developments in cupola melting.

**Keywords**: Cupola, Environment, Energy Consumption.

**Introduction**
Several workers have reported the developments in this area. Tewari S. N. (1) has explained the facts about Indian foundry industry. Sanyal D. (2), is very much optimistic about revival of foundry industry in Howrah. Herves S. A. et al. (3) has stressed upon the need for control of air blast in cupola. Transactions, American Foundrymen's Society (4) has described different methods of cupola operation as selection of proper methods effects the operation. Chaudhari S. P. (5) urged that selection of proper air system and control to supply blast air in appropriate volume and pressure to a foundry cupola is of utmost importance. Hegyn Gery etal. (6) laid the stress upon proper supply of oxygen along with air and fuel, using suitable equipments. Gupta V. P. (7) has advocated the use of modern divided blast cupola with proper instrumentation, while using standard grade pig iron, with low ash content coke, with alternate day cupola running for maintaining the quality of cast iron castings produced. NCTS Helpline (8) studied the case of 42” ID cupola. The silicon content of melt was very low. The solutions suggested were to use high purity limestone, use 0.5% of soda bricks along with lime and not to use rusty scrap. Lal Sohan\textsuperscript{10} concluded that divided blast cupula developed by TERI-SDC is the best option to reduce the coke consumption and increasing the melting rate. Singh S.D. (11) has urged to convert existing coke-fired cupulas into gas-fired cupulas as it fulfills all environmental regulations. Pal Prosanto, Vasudevan N. (12) stressed upon to replace existing conventional coke-fired cupulas by divided blast cupula designed by TERI for optimal utilisation of energy and reduced emission level. Bandopadhyay, Amitava etal. (15) of NML Jamshedpur presented an overview of pollution phenomenon in foundries of West Bengal and urged on using gas cleaning system. Panigrahi S.C. (14) has given the scheme of cleaning of cupola gases by using dry spark arrester and wet spark arrester, cyclones, bag filters etc. Malit B.R. (15) has suggested detection and monitoring techniques on basis of fundamental principles involved. Chaudhary S. P. (16) has suggested different efficient air systems like centrifugal type blowers, wind belt and location of tuyers. Parthasarthy T. C. etal. (17) recommended the use of ESP (electro-static precipitators), bag filters, wet collectors, cyclones etc. Singh Ranjit, Jain R. K. (18) studied the cokeless cupula in special relevance to Agra and found that cost saving is approx. 27% and energy saving is approx. 39% in cokeless cupula as compared to conventional coke-fired cupula in TTZ in Agra. Basak B. K. (19) accrued the three-fold advantages of cokeless melting furnace viz. emission levels, metal of desired temperature and composition, and reduced fuel energy consumption. Singh S. D., Vaish A. (20,21) has concluded that gas-fired cokeless cupula developed by National Metallurgical Laboratory Jamshedpur is highly eco-friendly and cost-effective furnace and urged to replace existing coke-fired cupulas by cokeless cupulas as it is efficient, eco-friendly and economical. Jain R. K. (22) surveyed various foundries in India and during his visit to European and American countries.

**Recent Developments in Cupola Melting**

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36” ID cupula. The silicon content of melt was very low. The solutions suggested were to use high purity limestone, use 0.5% of soda bricks along with lime and not to use rusty scrap. Lal Sohan\textsuperscript{10} concluded that divided blast cupula developed by TERI-SDC is the best option to reduce the coke consumption and increasing the melting rate. Singh S.D. (11) has urged to convert existing coke-fired cupulas into gas-fired cupulas as it fulfills all environmental regulations. Pal Prosanto, Vasudevan N. (12) stressed upon to replace existing conventional coke-fired cupulas by divided blast cupula designed by TERI for optimal utilisation of energy and reduced emission level. Bandopadhyay, Amitava etal. (15) of NML Jamshedpur presented an overview of pollution phenomenon in foundries of West Bengal and urged on using gas cleaning system. Panigrahi S.C. (14) has given the scheme of cleaning of cupola gases by using dry spark arrester and wet spark arrester, cyclones, bag filters etc. Malit B.R. (15) has suggested detection and monitoring techniques on basis of fundamental principles involved. Chaudhary S. P. (16) has suggested different efficient air systems like centrifugal type blowers, wind belt and location of tuyers. Parthasarthy T. C. etal. (17) recommended the use of ESP (electro-static precipitators), bag filters, wet collectors, cyclones etc. Singh Ranjit, Jain R. K. (18) studied the cokeless cupula in special relevance to Agra and found that cost saving is approx. 27% and energy saving is approx. 39% in cokeless cupula as compared to conventional coke-fired cupula in TTZ in Agra. Basak B. K. (19) accrued the three-fold advantages of cokeless melting furnace viz. emission levels, metal of desired temperature and composition, and reduced fuel energy consumption. Singh S. D., Vaish A. (20,21) has concluded that gas-fired cokeless cupula developed by National Metallurgical Laboratory Jamshedpur is highly eco-friendly and cost-effective furnace and urged to replace existing coke-fired cupulas by cokeless cupulas as it is efficient, eco-friendly and economical. Jain R. K. (22) surveyed various foundries in India and during his visit to European and American countries.
Recent Developments in Cupola Melting

The primary purpose of cupola is: (1) To melt cast iron with specific chemical composition; (2) To maintain the desired temperature of melt; (3) To obtain the optimal melting rate. Various improvements in cupola design have taken place to improve the cupola efficiency and to reduce the operating cost. In view of the above, the following development has taken place:

Water-cooled Cupola - To prevent the refectories losses and overheating of cupola shell in the combustion and tuyer zone, the water-cooled cupolas are used. The water cooling is of two types: (1) External spray on shell (2) Cooling with water jackets.

External Spray on Shell: A thin continuous water film is maintained on the cupola shell and additional water is sprayed. The shell is made in slope to larger diameter to get water film adhered to the shell.

Cooling with Water Jackets: In water-jacket type cupola, cold water is introduced through the bottom of water jacket and the warmer water is removed from the top. The projected tuyers made of copper are used to confine combustion to a concentrated area and to minimise the maximum temperature zone to prevent heat loss and free oxygen zone. These tuyers are water-cooled. The air is introduced at a pre-determined distances from the shell.

Hot Blast Cupola - The hot blast cupola uses the hot air blast by which, for same melt rate, temperature and carbon pickup, the amount of coke required is reduced. The hot gases are passed into counter-flow heat exchanger and air is preheated. This preheated air is supplied for combustion. The advantages are: (1) Flame temperature is increased, 2 The efficient carbon monoxide contents are reduced to desired environmental level. The flame temperature increases from 1800°C to 2300°C. Consequently, the temperature of coke bed is 1900°C and metal temperature is 1500°C. For Cupola operating at 400-500°C, hot blast temperature achieves better flame temperature within safe metallurgical limits. The superheating power of cupola is determined by the coke bed. The additional cost of heating the blast by cupola top gases is high, but the emission levels are well within the norms of CPCB limits. According to CPCB requirements, (1) Full combustion of CO is necessary to reduce emission levels (2) The efficient cleaning of combustion products is to be done before liberating them to atmosphere to reduce SPM, SO₂, CO₂, NOx etc.

Divided Blast System

In the divided blast system, the total blast is divided in the ratio of 60:40 and blown at two different zones from separate blowers with distribution of blast between two wind belts. Two rows of tuyers are provided at calculated distance and tuyer area is changed to provide the thermal balance of system.

The Advantages are

- The temperature is improved by 35-40°C.
- Melting rate is improved by 10-15% at same coke consumption rate.
- Lower emission level.
- Lower energy consumption.

The Disadvantages are

- The wearing out of the refractory lining along the tuyer level. It was found to be approx. 50% more than that of balanced blast system.

The Factors affecting Operation are:

- The optimal distance between two rows of tuyers is to be maintained for optimum result;
- Quality of coke influences the efficiency. It is better to use low ash containing.
- The balance should be made in blast distribution in two tuyers for optimum results.
- The fettling cost is high.
- The wearing of refractory lining depends upon blast distribution.

The extra cost for Hot Blast Cupola is not substantial as it is recovered by reduction in operating cost. The operating cost can further be reduced by using lamellar/sponge iron due to its low carbon content.

The comparison of hot blast and cold blast cupolas are shown in Table-1.

Table-1: Comparison of Hot Blast and Cold Blast Cupola

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Particulars</th>
<th>Hot Blast</th>
<th>Cold Blast</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>CO Emission</td>
<td>16%</td>
<td>20%</td>
</tr>
<tr>
<td>2</td>
<td>Melt Temperature</td>
<td>2200°C</td>
<td>1970°C</td>
</tr>
<tr>
<td>3</td>
<td>Pre-heated Air Temperature</td>
<td>500°C</td>
<td>40°C</td>
</tr>
</tbody>
</table>

Hot Blast-Oxygen Injected Cupola

The hot blast-oxygen injected cupola with water-cooled lances below or at tuyer level is used with 85% steel scrap charged along with 1-2% oxygen. The melting rate is controlled by varying amounts of oxygen. At higher oxygen rate, the flame temperature is extremely high, approx. equal to plasma superheat blast. Lower grade of scrap can be used by providing higher reducing atmosphere. The extensive use of oxygen depends upon its availability at reasonable cost. The operational cost of oxygen is approx. equal to cost of 0.7 kWh/m³. Continuous use of oxygen is made to control the cupola operation within very close limits. As soon as CO content of cupula stack gases increases, due to cupola
bed height, the oxygen rate is reduced to adjust the bed height and reduce the CO content of top gases.

Advantages: The oxygen enrichment cupola has the following advantages:

- The metal temperature is increased as shown in Table-2.
- The melting rate is also increased which is shown in Table-3.
- The refractory consumption is decreased.
- The fettling cost is decreased.
- High productivity is achieved resulting into cost reduction.
- Sulphur pickup can be reduced by adding soda ash.

Table-2: Effect of Oxygen Enrichment on Metal Temperature

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Oxygen Enrichment</th>
<th>Metal Temperature</th>
<th>Coke Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1%</td>
<td>1420°C</td>
<td>1:4</td>
</tr>
<tr>
<td>2</td>
<td>2%</td>
<td>1450°C</td>
<td>1:4</td>
</tr>
<tr>
<td>3</td>
<td>2.7%</td>
<td>1470°C</td>
<td>1:4</td>
</tr>
<tr>
<td>4</td>
<td>3.2%</td>
<td>1490°C</td>
<td>1:4</td>
</tr>
<tr>
<td>5</td>
<td>1%</td>
<td>1360°C</td>
<td>1:8</td>
</tr>
<tr>
<td>6</td>
<td>2%</td>
<td>1380°C</td>
<td>1:8</td>
</tr>
<tr>
<td>7</td>
<td>2.7%</td>
<td>1400°C</td>
<td>1:8</td>
</tr>
</tbody>
</table>

Table-3: Effect of Oxygen Enrichment on Melting Rate

<table>
<thead>
<tr>
<th>S.N.</th>
<th>Oxygen Enrichment</th>
<th>Metal Temperature</th>
<th>Coke Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1%</td>
<td>21.0</td>
<td>1:8</td>
</tr>
<tr>
<td>2</td>
<td>1.6%</td>
<td>22.5</td>
<td>1:8</td>
</tr>
<tr>
<td>3</td>
<td>1.8%</td>
<td>24.0</td>
<td>1:8</td>
</tr>
<tr>
<td>4</td>
<td>2.0%</td>
<td>26.0</td>
<td>1:8</td>
</tr>
</tbody>
</table>

Cold Divided Blast Cupola

In cold divided blast cupola, the tuyers are made into rows and coke consumption is reduced while melt rate is increased. 50% of the air enters through the upper tuyers. The upper blast is cold blast whereas the lower blast can either be hot or cold. The CO formed at lower tuyer gets converted into CO₂ at upper tuyer level and reaction is exothermic. The cold and divided blast cupola is operated on long campaign basis having projecting-water-cool tuyer and gas extraction below the charge level. The capital cost is slightly lower than hot blast cupola, but operating cost are higher because they have lower superheating capacity.

Cold Blast-Oxygen Injected Cupola

In cold blast cupola with oxygen injection by addition of 4% oxygen, the coke bed temperature is increased from 1550°C to 1800°C. The same metal temperature and degree of carburisation is achieved by using lower coke bed height than in conventional cold blast cupola. The additional cost of oxygen is slightly more than reduction in cost of coke.

Cold Blast-Triple-Fired Cupola (O₂ and Gas Injected)

The cold blast cupula triple-fired utilises coke, oxygen and natural gas by using auxiliary gas burners. The part of coke energy is substituted by natural gas. Consequently, the sulphur content of metal is reduced. It has been found that reduced coke consumption is not due to supplementary gas addition, but because of post-combustion of CO generated in cupula by excess air being introduced into the upper tuyer. The auxiliary gas burners are installed high enough to-

- Avoid reaction between coke and combustion products.
- To provide efficient preheating of metallic charge by products of combustion.

Cold Blast Cupula- FAR Type Melter

The cold blast cupula with FAR type melter has been installed at TUPY foundry in Joinville in Brazil. The scrap is charged into central shaft of furnace. Coke is added through six separate entries directly into the hearth of the furnace. The cupula is operated as a cold blast cupula and is fitted with high velocity silicon carbide pipe tuyers. These high velocity tuyers achieve blast penetration, deep into the cupula bed. The CO rich gases in the cupula bed section are completely burnt to CO₂ before entering the central scrap shaft. The auxiliary gas burners are installed high enough to-
to 380 m³/tonne. Highly reducing atmosphere is provided, to protect thin-wall loose borings from oxidation.

**The Advantages are**
- Lower cost (cheap borings in the metallic charge can be used).
- The silicon is gained out of the process.

**The Disadvantages are**
- The power consumption is very high leading to high operational cost.
- The initial cost is very high.

**Natural Gas-Fired Hot Blast Cupola-Cokeless Melter**

The natural gas-fired hot blast cupola is installed in Keulahutte in East Germany. The stack gases leave the cupola at approx. 800°C. The residual CO and most of the hydrocarbons burn at this temperature. The products of combustion are used to preheat the blast upto 500°C. This increases the flame temperature of the natural gas upto 2050°C due to recycled energy.

**The Advantage is**
The operation of gas-fired cupola with hot blast is more economical and smooth than of cold blast cupola where oxygen is used to increase flame temperature.

**The Disadvantages are**
- The heat losses are increased due to higher top flue gas temperature.
- The cost is increased.

**The Basic Lined Cupola**
The basic slag produces molten metal with higher carbon and lower sulphur content with a possibility of using more economical metallic charge such as steel scrap. Basic slag consists mainly of CaO, MgO, Al₂O₃ and SiO₂. Due to additional fluxing, the volume of slag is more in basic slag practice than in acid slag practice.

**The Lining-less Cupola**
In lining-less cupola, water cooling is done externally and basic slag melting is possible. The heat going out in form of flue gases is approx. 50-60% of theoretical heat produced in cupola. This heat can be utilised for preheating the blast upto 500°C. The cupola can run for longer period upto 16 hours having diameter of 900 mm for better melting rate and controlled heat losses.

**Apcos Technique Cupola**
The Apcos technology-based cupola has been installed in a foundry in Brazil. Once oxygen/fuel firing is established, the burners can also be used to inject fines by a pneumatic injection machine directly into the coke bed through the tuyers. In normal cupola, most materials if injected in any quantity would cause cooling of the melt zone with consequences for metallurgy and reduced temperature and even blockage of tuyers. But by introducing fines through centre of an oxy/fuel flame at 2000°C, the material is rapidly heated preventing any cooling or metallurgical problems and even tuyers blockage. The material injected is foundry waste products such as fines, fettling shop waste. Approximately, 80 Kg of materials can be injected for every tonne of iron metal.

**Advantages**
- High Energy Efficiency.
- Melt rate increased.
- The temperature of the melt along with its carbon and silicon content is improved.
- The emissions of SO₂, NOₓ, CO₂, CO etc. are reduced.
- The most of the foundry waste is recycled.
- The lower cost charge material may be used.

Alternatively, the useful alloying materials such as ferrosilicon or ferromanganese can also be injected. The ferrosilicon injections into the tuyers have the following advantages:
- Raw material cost savings (FeS fines are much cheaper than FeS briquettes).
- The overall silicon losses are reduced.
- The silicon level can be easily controlled.

**The Cokeless Cupola**
As conventional coke-fired cupola, the cokeless cupola is also a vertical type shaft furnace with air blast. The designed parameter is entirely different from conventional coke-fired cupola.

The main features of Gas/ Oil-fired unit are:
- Water-cooled Grates.
- Refractory Spheres.
- Gas/Oil- Fired Burners.
- Super-Heater.
- Gas/Air Exchanger.

**Water-cooled Grates**- The grates support the specially developed refractory balls which form the melting bed and acts as heat exchanger.

**Refractory Spheres** - For an easy escape of the combustion products and medium of heat exchange, especially developed refractory balls are used and placed on grates.

**Gas/Oil-Fired Burners** - The Gas/Oil-fired burners are placed at an appropriate angle to heat up the refractory balls and finally melt the charge material.

**Super-Heater** - The electrically heated super-heater is installed where the desired iron temperature is regulated electrically and composition is adjusted by adding the proper mix of alloying elements.
**Gas/Air Exchanger** - The gas/air exchanger is used to cool the exhaust gases which are further cleaned by using dry filters.

**Advantages**

- **Pollution level**
  - No air pollution as SPM, SO₂, CO₂, CO, NOₓ are far below the standards laid down by CPCB.
  - Volume of Flue Gases is much smaller.
  - Low dust content in exhaust gas.

- **Energy Consumption**
  - The energy consumption
  - of Natural Gas-fired is 962.00 kWh/tonne
  - of LDO-fired is 716.00 kWh/tonne

- **Quality of Molten Metal:** Quality of molten metal is better due to following reasons:
  - Refining and cleaning of molten metal is done in furnace itself due to droplet phases.
  - Desired temperature and chemical composition is maintained.
  - Continuous and consistent supply is available.
  - Phosphorus levels below 0.2%. Sulphur pickup is nil. No microporosity and leakage in machined components.
  - Mechanical Properties- Percentage rejection due to hardness is very low; tensile strength is better.

- **Cost**
  - Total cost, capital cost and installation cost varies from 28.00 lakhs to 44.00 lakhs depending upon capacity from 1.00 to 3.00 tonnes/hr.
  - Operating Cost: (i) Rs.30210.00 /tonne of metal produced for LDO-fired (ii) Rs.28407.00 /tonne of metal produced for natural gas-fired.

**Disadvantages:**

- Refractory spheres are not easily available in India. They have to be imported from European countries.
- Technical staff and skilled workers are not easily available.
- GAIL (Gas Authority of India Ltd.) is not supplying natural gas to foundries being set up after 2000.

**Conclusion**

Several developments have been made in cupola melting. Some of them have been successful in Indian environment and others in European and American countries. The problem is to be dealt from grassroots level. Thus, there is need of new melting techniques which are economically viable, ecofriendly and energy-efficient. In fact an “Ecofriendly and Energy-efficient Furnace” is urgently needed for ferrous foundries.

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