

# Eco-friendly cokeless-cupola

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**Abstract :** This paper envisages the developmental work on eco-friendly cokeless cupola at the National Metallurgical Laboratory, Jamshedpur. The normal Cupolas for melting cast-iron in major parts of the World are operating with coke as fuel and the emission from such cupolas have been found to be containing Suspended Particulate Material (SPM) in the range of 700 to 2500 mg/Nm<sup>3</sup> with sulphur dioxide content of the order of 400-1000 mg/Nm<sup>3</sup>. From the pollution point of view, these figures are excessively high. The use of low sulphur gaseous/liquid fuel promises extremely low level of SPM and SO<sub>x</sub> and does not need any pollution control device and can very well be installed within any thickly populated municipal area. In view of the above, NML was entrusted by the Technology Information Forecasting and Assessment Council (TIFAC) of Department of Science & Technology (DST), Govt. of India, to design and develop a suitable eco-friendly cokeless cupola in order to provide indigenous technical know-how to the clusters of foundries located at various places in the Country.

**Key words :** *Eco-friendly cokeless cupola, Gaseous fuel, Liquid Fuel, SPM/SO<sub>x</sub>, Design & development of cokeless cupola, Technology Evaluations.*

## INTRODUCTION

There are about 6000 foundries currently operating mostly as cluster in places like Rajkot, Agra, Batala, Coimbatore, Howrah, Belgaum, etc. Almost all of these are coke fired. Coke based foundries are plagued with pollution problems. Normal stack emission from foundries ranges from 700 to 2500 mg/Nm<sup>3</sup> of SPM and SO<sub>x</sub> beyond 400 mg/Nm<sup>3</sup>. To obviate this problem, Cokeless cupola was introduced by M/s. R. T. Taft<sup>(1,2,3,4)</sup> of U. K. in 1970 and has since been used in many countries including M/s. Duker (Germany). The cokeless cupola operates either on gaseous fuel like CNG/LNG/LPG/Propane (super gas) or on liquid fuel (LDO). As per the directive of Honourable Supreme Court of India, Pollution has to be within the acceptable limits fixed by the Central Pollution Control Board (CPCB). The current limit on SPM is less than either 150 mg/Nm<sup>3</sup> for cupolas having inner dia more than 1000 mm or 400 mg/Nm<sup>3</sup> have for cupolas having inner dia. less than 1000 mm and on SO<sub>x</sub> is less than 350 mg/Nm<sup>3</sup>. As a result of such stringent limits most of the foundries are facing closure. Considering the enormity of the problem from technical, economical and social angles, the NML Jamshedpur carried out considerable Research and Development work under the sponsorship of Home ground technology of TIFAC under DST, Govt. of India during 1996-99 and finally developed the eco-friendly cokeless cupola based on gas and oil. Design consideration parameters such as water cooled grate, refractory sphere, gas/oil burners considering its heat capacity, flame length, air-gas ratio regulation etc., shell cooled refractory lining along hearth area, acceptable limit of pollution such as SPM and SO<sub>x</sub> and the melting rate.

An existing conventional cupola at NML with a capacity of 1 tonne per hour was converted to a gas/oil fired furnace in order to assess the feasibility of cokeless cupola.

After some initial teething problems, large number of successful trials were carried out over a period of 36 months using LDO oil as well as LPG gas. Based on above mentioned success by the end of 1997, M/s. Tata Korf and NML agreed to enter into a memorandum of understanding (MoU) to commercialise the process and to provide pollution free cokeless cupolas elsewhere. Subsequently M/s. Tata Korf and the Agra Iron Founders Association (AIFA) entered into an agreement in early 1998 for the transfer of the NML's developed technology involving installation, commissioning and demonstration of natural gas based cokeless cupola of 2T/hr capacity. Teething problems came up during the demonstration which helped subsequently in improving the design and process parameters. Many advantages noticed were as follows :

- o Visible emission was not seen at the top of the furnace during the melting period and the measured values of SPM,  $\text{SO}_x$  and  $\text{NO}_x$  (the constituents of the emittant) were found well below the limit set by CPCB and requires no additional investment to satisfy the environmental regulation.
- o There was no sulphur pick up by the metal during melting which enables the hot metal suitable for the production of SG iron.
- o Close control on the chemistry of the liquid metal. The addition and injection of desired constituents is feasible.
- o Due to low slag volume, cokeless cupola is more efficient than coke based cupola

## PROCESS DESCRIPTION

The cokeless cupola is very similar to a conventional coke fired cupola. The coke in coke based cupola provides following four important features :

- o Enough heat for heating and melting the pig iron and the flux to get molten cast iron and slag at desired temperatures
- o Enough permeability enabling liquid product to flow downward and gaseous flue to move upward without any hindrance.
- o Adequate bed height in order to take the entire load of raw material column without crushing
- o Carbon content of the cast iron is kept saturated.

The necessary heat for heating as well as melting is provided by oil/gas burners that are located in approximately the same position as the Tuyers. The actual location/height of burners depends on how much metal the foundry requires to hold in the well. Above the burners there is a set of water cooled grate consisting of steel tubes which may be coated with refractory for insulation purpose. The grate supports entire load of permeable bed as well as throughputs. Permeable bed is created by incorporation of specially developed high temperature resistant refractory spheres. These spheres arranged in multiple layers above the grate and acts as heat exchanger and provide heat to the throughputs.

The burners are operated with slightly excess fuel in order to ensure partially reducing conditions inside the cupola to avoid oxidation losses. During the operation the hot gases from the burners flows up through the bed and descending charge where it preheats the metallics. The metallics with flux get melt above the superheated bed and trickles through the multiple layers of spheres. The depth of the bed is the main governing factor for metal

temperature. The height of the refractory bed can be adjusted in order to obtain required temperature for the melting process. The melting rate can be controlled by the fuel rate.

The above mentioned parameters provide greater flexibility in controlling the process as well as operation of cokeless cupola. It meets strict environment standard set by any municipality. Economics of coke less cupola is also sound. Table 8 show the conversion cost (fuel + flux + ceramic) figures of melting cast iron in coke less cupola.

From the quality point of view the main advantages are that the cokeless cupola can give iron of consistent quality and temperature over the entire melting campaign. The slag generation is less which easens the problem of disposal. By suitably adjusting the fuel air ratio the combustion, conditions can suitably be adjusted to oxidising, reducing or neutral. The initial investment on cokeless cupolas are relatively more than the coke cupola because it requires special burners, grate, refractory, fuel and control system complete with safety devices.

### DESIGN & DEVELOPMENT

The line diagram of the designed coke-less melting unit is illustrated in Fig 1. The main features of this gas/oil fired melting unit includes : (i) Water-cooled Grates, (ii) Refractory Spheres and (iii) Gas/oil fired Burners.

1. Tapping Hole
2. Gas Burner
3. Water Cooled Grate
4. Combustion Air Duct
5. Charging Door
6. Refractory Balls
7. Charge Material

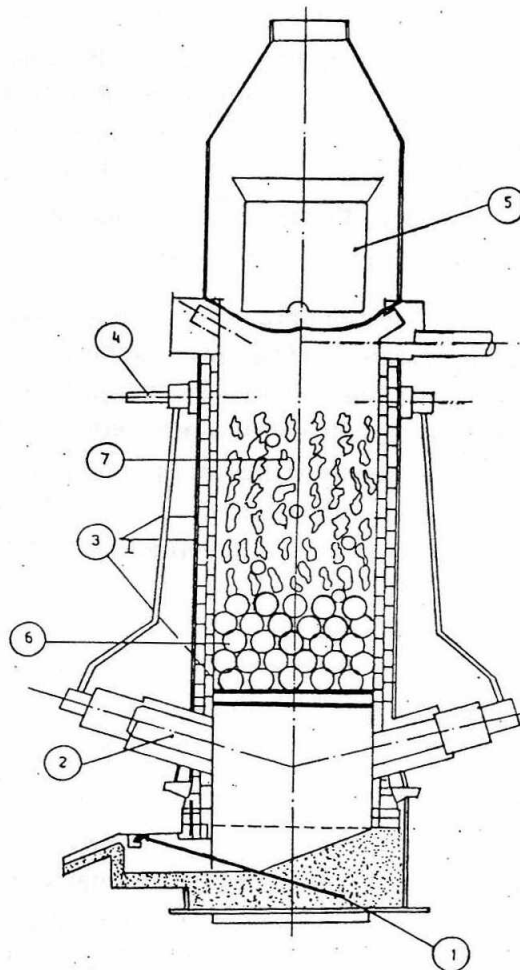


Fig. 1 : Cokeless Cupola

### **Water-cooled grates**

The water cooled grates consist of steel tubes coated with refractory material for insulation purpose. The water cooled grates support the specially developed refractory balls which form the melting bed and act as heat exchanger. The size and number of water cooled grates and refractory coating on the steel tubes depend upon the size of the cupola. The life of the refractory coating depends upon the required metal temperature and number of operations. The grate housing is such that grate can be removed easily as and when it is required. Water cooled grates normally in use are made of single wall tubular steel and provide the unidirectional flow of coolant water. Moreover, the single wall tubular steel grates provided in the furnace design have to bear the full impact of the throughputs being delivered from the charging door of the furnace which may be as high as 6-8 times the diameter of the cupola above the grate. Thus, any damage due to such impact may lead to distortion of the grate which may cause water leakage and subsequent explosion. NML's design has provided a robust design to take care of the above problem. The water consumption is 10 litres/minute to 15 lit/min. and rise in temperature of outlet water varies between 10°C to 60°C depending upon the furnace temperature. The average life of water-cooled grate assembly is several months and depends on the type of raw material to be melted, metal temperature and the mode of operation i.e., whether it is batch-type or continuous-type operation.

### **Refractory spheres**

In gas/oil fired cupola furnace coke bed is replaced by a multiple layers of refractory spheres. As the melting unit is being operated with gas/oil as fuel, bed porosity is required in order to enable the products of combustion to dissipate through the descending charge. For an easy escape of the combustion product through the descending mass, good bed permeability is desirable. For this purpose and also as a medium for heat exchange especially developed refractory balls are used and placed on the grates.

The refractory balls are required to have high strength and refractoriness to withstand the downward thrust of throughputs as well as thermal shock resulting from the passage of the liquid metal. Therefore, the refractory material for ball is most important item for the cokeless cupola operation and all development work has been completed with abundantly available raw material in India. The size of spherical balls made of refractory is decided by the requirements of the bed permeability and varies between 100 to 150 mm. The size of balls also depends upon the number of the water cooled grates which is decided according to the size of the melting unit. The bed material is, of course, consumable. Its rate of dissolution depends upon the metal temperature, melting rate and the nature of the throughputs. As these are consumed during operation, new balls are added along with throughputs in quantities equal to the rate at which they are being consumed.

### **Gas/oil fired burners**

The gas/oil fired burners are placed below the grate at a suitable distance and at an appropriate angle to heat up the refractory balls and finally melt the charge material. The metal is collected in the cupola well. The size and angle of orientation of the burners in the cupola are very important. The size of the burner depends upon the capacity of cupola. The angle of the burner should be such that the flame beyond the burner housing should form a stable flame front and entire combustion to complete below the grate. Another important

factor is fuel to air ratio. The burners are operated with a slightly excess fuel to air ratio in order to maintain a partially reducing condition so as to prevent the oxidation of the melt. For this reason the measurement and monitoring of air and fuel are essential.

Apart from these, several other factors such as the properties of the throughputs and the nature of the hot metal have been taken into consideration during the design. Pilot scale as well as commercial scale cokeless cupola have been designed and developed. NML's cokeless cupola was commissioned by converting a coke based cupola of 1 t/hr capacity. Details of the melting-unit has been reported elsewhere<sup>(5)</sup>.

## OPERATING DETAILS

One-tonne/hr. capacity coke cupola was first converted to cokeless operation by using LDO as fuel. The conceptual plant and conversion design began from April '96 and final conversion got completed in December '96. The combustion rate at burners was always maintained near to stoichiometric level during the trials. First four trials ended up with problems such as chocking of bed, metal temperature and melting rate. The initial process parameters were then changed and cupola was preheated for about 75 mts. before charging. Successful melting started from February '97 and 30 nos. of trials were carried out upto May '97. Liquid iron of satisfactory temperature and composition was obtained. The conventional drop-bottom with intermittent tapping and slagging was practiced. The desired water flow for the cooling of grate was designed to maintain from either from tap water supply or by putting an overhead tank. The continuous operation of 3 hrs. without any hindrance and closer control over the melting process was achieved. The effluent emitted was found well below the norms specified by CPCB. The typical composition of the pig iron and the slagging agent used for the mentioned trial are given in tables 1 & 2. The chemical composition of the metal and slag so produced are given in tables 3 & 4.

After achieving desired results with LDO-based Cokeless operation, action was taken to convert the same cupola to gas based cupola operation using LPG as fuel (Photo 1-3). The LPG based pilot plant was ready for trial in mid August 97. Twenty no. of successful experimental trials conducted within November '97. Each operation conducted for melting to the extent of 3 tons @ 1 ton/hr. Higher melting amounts were not attempted as there were no down line casting facilities. The chemical composition of metal so produced are given in table 5. Raw material and slagging agent used were same as that used for LDO based operation. Chemical composition of the slag was also similar.

*Table 1 : Pig Iron composition (wt%)*

| C      | Si      | Mn      | S         | P       |
|--------|---------|---------|-----------|---------|
| 3~3.35 | 1.2~1.5 | 0.3~0.4 | 0.05~0.06 | 0.2~0.3 |

*Table 2 : Chemical Composition of slagging agent (wt%)*

| CaO  | SiO <sub>2</sub> | MgO | Al <sub>2</sub> O <sub>3</sub> | S     | P     | LOI  |
|------|------------------|-----|--------------------------------|-------|-------|------|
| 55.1 | 0.52             | 0.5 | 0.05                           | Trace | Trace | 43.5 |

Table 3 : Chemical analysis of the product (cast iron) using LDO

| Sl. No. | C     | Si   | Mn   | S    | P    | Remarks                                                       |
|---------|-------|------|------|------|------|---------------------------------------------------------------|
| 1.      | 3.241 | 1.10 | 0.30 | 0.05 | 0.05 | 0.19 Without any addition                                     |
|         | 3.250 | 1.10 | 0.25 | 0.05 | 0.10 |                                                               |
| 2.      | 3.32  | 2.35 | 0.31 | 0.05 | 0.25 | Fe-Si was aiming 3% Si in Metal                               |
|         | 3.27  | 2.34 | 0.33 | 0.05 | 0.21 |                                                               |
| 3.      | 3.25  | 2.90 | 0.27 | 0.06 | 0.19 | Fe-Si was added aiming at 3% Si in Metal                      |
|         | 3.23  | 2.90 | 0.27 | 0.06 | 0.19 |                                                               |
| 4.      | 3.26  | 2.88 | 0.61 | 0.06 | 0.20 | Fe-Si & Mn were added aiming at 3.0% of SC & 0.7% Mn in Metal |
|         | 3.25  | 2.90 | 0.63 | 0.06 | 0.20 |                                                               |

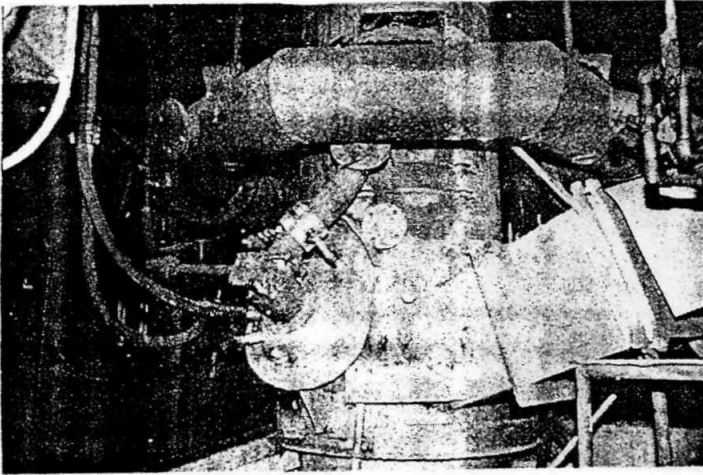
Table 4 : Chemical analysis of slag (wt%)

| CaO  | SiO <sub>2</sub> | Al <sub>2</sub> O <sub>3</sub> | FeO   | MnO | MgO        |
|------|------------------|--------------------------------|-------|-----|------------|
| 5-19 | 26-45            | 14-19                          | 25-38 | 1-2 | 0.8 to 1.0 |

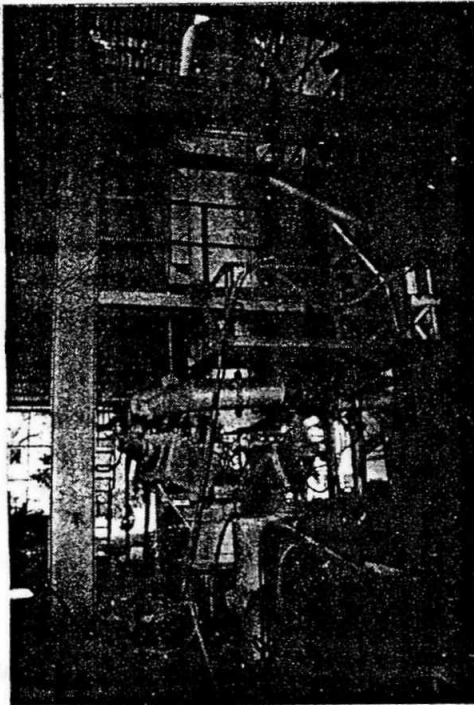
Table 5 : Chemical composition of the product using L.P.G.

| Sl. No. | C    | Si   | Mn   | S     | P    | Remarks                                                                                                                                                       |
|---------|------|------|------|-------|------|---------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1.      | 3.27 | 1.08 | 0.23 | 0.05  | 0.19 | Without any addition                                                                                                                                          |
|         | 3.26 | 1.1  | 0.25 | 0.05  | 0.19 |                                                                                                                                                               |
| 2.      | 3.60 | 2.71 | 0.22 | 0.02  | 0.19 | Chemistry of the hot metal was adjusted inside the cupola with coke fine injection and Mg bullets were impinged in the ladle aiming the production of SG iron |
|         | 3.69 | 2.78 | 0.25 | 0.02  | 0.19 |                                                                                                                                                               |
| 3.      | 3.51 | 1.10 | 0.23 | 0.065 | 0.20 |                                                                                                                                                               |
|         | 3.69 | 1.10 | 0.25 | 0.069 | 0.20 |                                                                                                                                                               |
| 4.      | 3.30 | 2.20 | 0.34 | 0.06  | 0.19 | Fe-Si was added aiming at 2.5% Si in metal                                                                                                                    |
|         | 3.28 | 2.42 | 0.28 | 0.06  | 0.19 |                                                                                                                                                               |

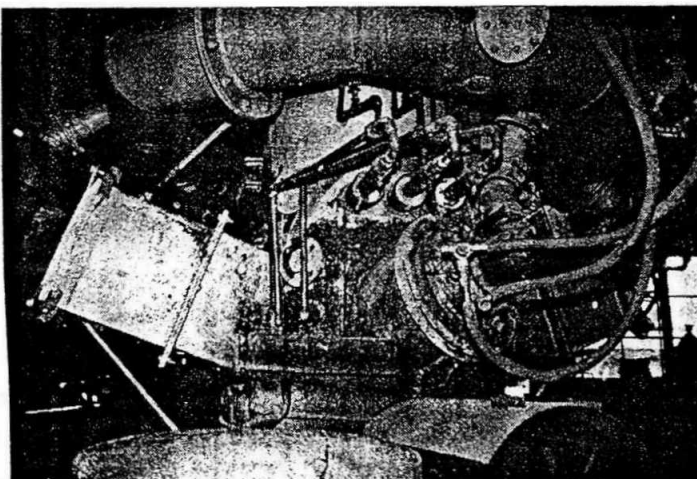
It has been found that hot metal produced from the oil/gas cupola was more consistent than that of the conventional coke-fired cupola. The temperature of the hot metal was found to be constant over long periods, provided hot metal is tapped regularly. The hot metal (photo 4) was also cleaner as it was not in contact with the fuel. It was also found that melting is required under partially reducing conditions. To create partially reducing condition, the slightly excess fuel to air ratio was maintained. Combustion of the excess fuel was found to be complete within charging area of the stack and there was no sign of flame near the top of the furnace. This was the most likely reasons why there was no any visible emission during the melting operation.



*Photo 1 : Coke-less cupola  
1 tonne/h at NML*



*Photo 2 : Coke-less cupola  
with gas/oil burner*



*Photo 3 : Coke-less cupola  
showing a set of water  
cooling grate*



*Photo 4 : Tapping of metals  
from coke-less cupola at NML*

### **Effect of gas/oil melting on sulphur and phosphorus content of metal**

A significant advantage of the cokeless cupola over conventional coke-fired cupola is that no sulphur pick-up takes place by the metal during melting, making hot metal suitable for SG iron production, (Table 5). The degree of De-S increases with the increase in the amount of limestone in the charge mix. With every trial, it was found that the phosphorus content of the product is slightly lower than the initial phosphorus content of the charge although, throughout the melting operation reducing conditions were maintained.

### **Effect of gas/oil melting on carbon and silicon of metal**

Some losses of carbon and silicon took place during melting. Trial and reported tables indicates the maximum loss of carbon and silicon were 3.1% and 8.5% respectively. In order to obtain the required carbon and silicon in the hot metal a carburizing agent was injected and ferro-silicon was added to the charge mix.

### **Effect of gas/oil melting on the temperature of metal and refractory consumption**

The metal was tapped in set intervals and the tapping temperature was measured in the range of 1350°-1380°C. It was found that the metal temperature is a function of bed height and the refractory consumption was a function of metal temperature. It was observed that the temperature increases with increase in the bed height of the refractory spheres to a depth of 400 mm and beyond this temperature drops. In the first phase of operation, due to different orientation of the burners angle, the ceramic ball consumption in case of LDO melting was more than 2% while in the second phase with changed orientation of burners, the ceramic ball consumption per tonne of hot metal was drastically reduced to even less than 1% of the charge mix.

### **Environmental evaluation with gas/oil melting**

A remarkable feature of the coke-less cupola in operation was the very low SPM content of the effluent gas, making the exhaust gas virtually invisible. The SPM and SO<sub>2</sub> content of effluents are given in Table 6. It can be seen from Table 6 that SPM and SO<sub>2</sub> content of effluent in the case of coke-less cupola are well below the norms specified by CPCB and require no additional investment to satisfy the environmental regulation. Comparative evaluation of economic performance i.e. cokeless vs. coke-fired is given in Table 7.

Table 6 : Environmental evaluation

| Factors                               | LDO-based | Gas based | CPCB Recommended value                                                                                                                |
|---------------------------------------|-----------|-----------|---------------------------------------------------------------------------------------------------------------------------------------|
| SO <sub>2</sub> (mg/Nm <sup>3</sup> ) | 88-98     | 135-150   | 350 mg/Nm <sup>3</sup>                                                                                                                |
| SPM (mg/Nm <sup>3</sup> )             | 30-35     | 9-10      | (i) 150 mg/Nm <sup>3</sup> for cupolas having dia. more than 1000 mm<br>(ii) 400 mg/Nm <sup>3</sup> for cupolas dia less than 1000 mm |

Table 7 : Environmental performance

| Sl. No. | Factors                                                                | Coke-less Cupola                             |
|---------|------------------------------------------------------------------------|----------------------------------------------|
| 1.      | Visible Emission                                                       | No.                                          |
| 2.      | Requires additional investment to satisfy the environmental regulation | No.                                          |
| 3.      | 'S' Pick-up                                                            | No                                           |
| 4.      | Need of external De-S                                                  | No                                           |
| 5.      | Energy consumption                                                     | Low                                          |
| 6.      | Manpower required                                                      | Less                                         |
| 7.      | Slag volume                                                            | Low                                          |
| 8.      | Efficiency                                                             | Higher<br>(better than conventional furnace) |

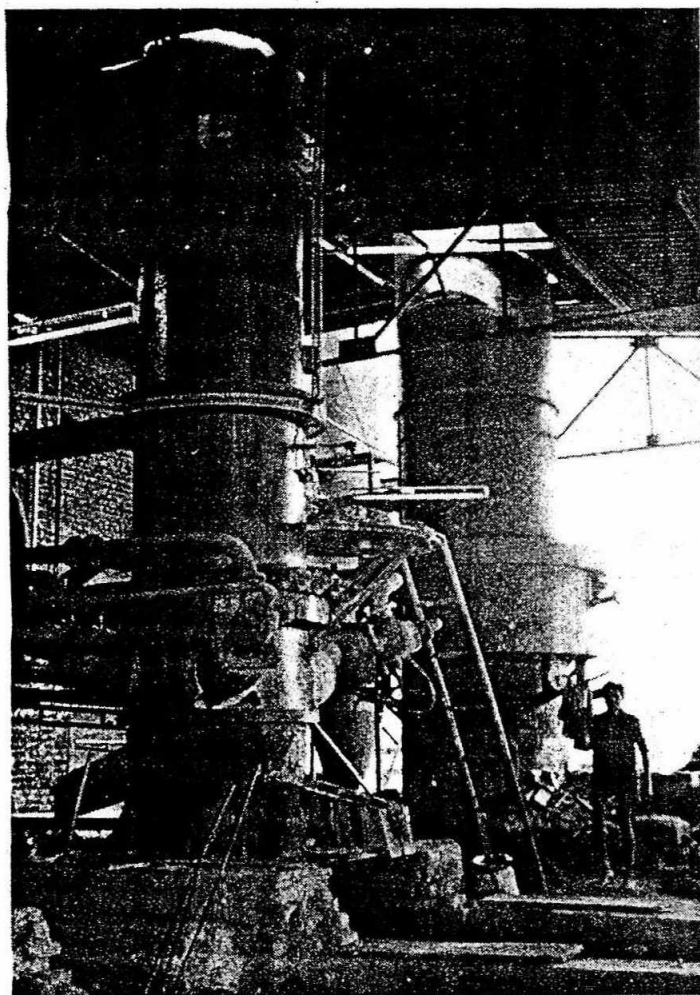
Based on the achievement, agreements were reached between NML and M/s. Tata Korf Engg. Services on one hand and between M/s. Tata Korf Engg. Services and Agra Iron Founder's Association on the other hand for the transfer of the technology involving installation, commissioning, demonstration of cokeless cupola in the Agra region in March '98. Photo 5 shows the general view of the erected and commissioned cokeless cupola at Agra.

The cupola campaign at Agra began on 14.05.98 and continued till 9th campaign i.e. upto 21.11.98 without any system modification. The meltings were not satisfactory as were more slag generation and development of back pressure in the burners. Moreover the following undesirable defects were noticed in the melting unit and its accessories.

- o Combustion of gas was not taking place at the desired location,
- o Instruments provided like ratio control & pressure regulating valve were malfunctioning,
- o Quality of refractory used for lining of the furnace was found to be inadequate.

The following actions were taken between 9th to 13th trial to resolve the above problems.

(1) Long flame burners were replaced by short flame high velocity burners to provide complete combustion below the grate and within cupola well. The burner were housed at equal spacing at the same level in the hearth, (2) Resetting of pressure reducing valve for gas was carried out, (3) Gas and air lines were provided with measuring device using orifice plates with local panel mounted metering facility, (4) The refractory lining in the well portion of the furnace were replaced with the much improved quality of refractory, (5) Development work was done to make suitable flux concerning slagging, and the establishment of the proper operating procedures.



*Photo 5 : Coke-less cupola at Agra*

## EVALUATION

The economies of any melting unit is of crucial importance. At present the conventional coke based cupola requires capital for the insallation, maintenance and running of intricated pollution control devices and this make conversion cost of coke-less cupola comparable with that of coke-based cupola. Cost break-up of the main items required for melting with cokeless cupola is provided in table 8. The points for consideration are the consumption of gas/oil, ceramic balls, refractory of cupola wall and flux for making slag. The consumption of propane gas has been estimated on the basis of its calorific value.

Table 8 : Conversion cost of melting includes : fuel, flux and ceramics

| Consumption<br>of fuel         | Unit           | Rs/Unit      | Consumption<br>MT | Conversion/<br>cost in Rupees |
|--------------------------------|----------------|--------------|-------------------|-------------------------------|
| I) LDO                         |                |              |                   |                               |
| a) Fuel                        | Lit            | 10           | 60                | 600.00                        |
| b) Ceramic ball                | Kg.            | 45           | 12.50             | 565.00                        |
| c) Flux+repair                 | Kg.            | 3            | 55                | 165.00                        |
| d) Pollution control<br>device |                | Not required |                   | —                             |
|                                |                |              |                   | 1330                          |
| II) LPG                        |                |              |                   |                               |
| a) Fuel                        | Kg.            | 15           | 45                | 675.00                        |
| b) Ceramic ball                | Kg.            | 45           | 10                | 450.00                        |
| c) Flux+repair                 | Kg.            | 3            | 55                | 165.00                        |
| d) Pollution control<br>device |                | Not required |                   | —                             |
|                                |                |              |                   | 1290                          |
| III) Natural Gas (N.G.)        |                |              |                   |                               |
| a) Fuel                        | M <sup>3</sup> | 5.1          | 80                | 410.00                        |
| b) Ceramic ball                | Kg.            | 45           | 10                | 450.00                        |
| c) Flux+repair                 | Kg.            | 3            | 55                | 165.00                        |
| d) Pollution control<br>device |                | Not required |                   | —                             |
|                                |                |              |                   | 1025                          |
| IV) Propane/Super Gas          |                |              |                   |                               |
| a) Fuel                        | Kg.            | 13.0         | 48                | 624.00                        |
| b) Ceramic ball                | Kg.            | 45.0         | 10                | 450.00                        |
| c) Flux+repair                 | Kg.            | 3.0          | 55                | 165.00                        |
| d) Pollution control<br>device |                | Not required |                   | —                             |
|                                |                |              |                   | 1239                          |

## CONCLUSION

There is no visible emission and SPM, SO<sub>x</sub> and NO<sub>x</sub> content of effluents are well below the norms specified by the Central Pollution Control Board of India (CPCB) and require no additional investment to satisfy the environmental regulations. There is no sulphur pick-up by the metal during melting and requires no external desulphurising. It provides a ecofriendly environment. The foundries operating as SSI units also can upgrade their product quantum of production and profitability. It will open enormous scope for the export of the castings.

## ACKNOWLEDGEMENT

Financial support for this work from Technology Information, Forecasting and Assessment Council (TIFAC), Dept. of Science & Technology (DST) Govt. of India is greatly acknowledged.

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