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IMPROVEMENT OF THE CUPOLA & THE RECUPERATOR

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1.0 Introduction.

Today within the foundry industry, the Cupola is the most widely used of melting furnaces. Melting in the Cupola is generally considered the cheapest method for converting cold ferrous scrap metal or pig iron to usable molten iron. Fuel for the Cupola is preferably a good grade, low sulphur coke. A Cupola is essentially a refractory lined vertical cylinder, open at both its top and bottom. An outer shell or casing of relatively thin steel plate gives support and protection to the refractory lining. Air from a suitable blower, comes through the blast pipe and enters a chamber called the 'wind box.' The wind box completely encircles the Cupola, and its purpose is to supply air evenly to all of the tuyeres. From the wind box, opening called 'tuyeres' extend through the steel shell and refractory wall to the combustion zone. The furnance is charged at frequent intervals with proportioned amounts of coke, limestone and metal (pig iron, scrap steel or scrap iron) and melting can be continuous over long periods of time, or intermittent as required.

2.0 Developments

In recent years there have been several developments in Cupola practice. They have come into use primarily because of increased labour and material costs. Some of the developments are detailed below.

2.1 *Water Cupolas*

In this type the melting zone is water jacketed or the steel shell in this zone is water sprayed. Water cooling saves both refractory and maintenance costs, On large cupolas, say over 90 cm inside diameter, savings are worthwhile.

2.2 *Cupolas Using Auxiliary Tuveres*

In this Cupla, there are, in addition to the main tuyeres, auxiliary tuyeres disposed spirally up the stack.

In this design, incomplete combustion in the lower part of the Cupola was deliberately aimed at, with intent to avoid oxidation. The arrangement of the auxiliary tuyeres was considered to promote fractional combustion of the CO higher up stack, so as to impart extra heat to the descending charges, for promoting a higher top temperature and a greater fuel economy. It was claimed that success or failure of regenerative tuyeres was entirely a question of position and arrangement.

2.3 *Cupolas Using Oxygen Enriched Blast*

Air contains 80% by volume of N_2, which is no use in the combustion of coke and also exerts a cooling effect in melting. The addition of 1% of 0_2 to the blast is thus equivalent to an increase of 5% in the volume of air delivered to the Cupola. There is however a limitation in that lining wear is increased, due chiefly to the increase in temperature.

Applications

2.3.1 Continous use of 0_2 enriched blast appears not to be economical in its present stage of development. But, it can usefully be employed as a BOOSTER for the first tap of the day's operation.

2.3.2 When the Cupola is operating irregulary and the metal tapped is below normal temperature, the introduction of 0_2 into the blast will rapidly restore the Cupola to normal operation. For this purpose, a battery of cylinders, with regulating valves should be employed.

2.3.3 Intermittent injection of 0_2 helps to prevent bridging but does'nt remove it once it has started. 0_2 enrichment is more effective with a positive displacement blower than with a fan.

2.3.4 0_2 is sometime injected into the molten metal held in the receiver for the purpose of superheating. Use of 5–6m^3 of 0_2/T of iron is said to raise the bath temperature by 80^0–100^0C. 8–10m^3/T bring the metal temperature to 1500^0–1520^0 C, when Carbon begins to burn vigorously.

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2.4 *Hot Blast Cupolas*

The adoption of hot blast has been increasing steadily for economy in coke and to permit of a higher proportion of steel scrap being used in Cupola charges. Today the price of Coke is 13,000 Rs./T. Hot blast enables,

(*a*) Poorer quality cokes to be used.

(*b*) Reduces the loss of Silicon in the Cupola.

(*c*) Increases Carbon pick up.

(*d*) The production of better grade of C.I.

3.0 Systems of Preheating

3.1 *Air Preheating System*

A specially fixed air preheater heated by oil, gas or other fuel is used. It is normally a tubular type heat exchanger in which fuel is burnt in a combustion chamber and the products pass over either the outside or inside of the tubes, the air blast passing over the other surface.

3.2 *System of Utilising The Waste Gases*

Gases drawn off the Cupola through an off-take just above the melting zone and their sensible heat used for preheating the blast by a RECUPERATOR.

4.0 Theory and Design of the Recuperator

4.1 *Chemical Reactions*

As the Cupola is operated, the 0_2 in the blast is consumed by the combustion, which is completed at the upper limit of the combustion zone. The chemical reaction which takes place there is,

$$C + 0_2 \text{ (from air)} \longrightarrow CO_2 + 14{,}544 \text{ BTU/Lbs of C}$$

4.1.1 *Reduction of CO_2*

Hot gases consisting principally of N_2 and CO_2 move upward from the combustion zone. The portion of the coke bed above the combustion zone is known as the REDUCING ZONE. It is a protective zone to prevent oxidation of the metal charge above. As hot CO_2 gas moves upward through hot coke, some of it is reduced by the reaction,

$$CO_2 + C \text{ (Coke)} \longrightarrow 200 - 10{,}090 \text{ BTU/Lbs of C}$$

After the hot gases pass upward through the reducing zone, the stack gases contain 12 % CO_2, 12% CO, 76% N_2.

By adding above two equations,

$$C \text{ (Coke)} + \tfrac{1}{2}0_2 \longrightarrow CO + 4454 \text{ BTU/Lbs of C}$$

4.1.2 *Deduction*

The C which goes into the CO passing out of the stack will in the final result contribute only 4454 BTU/Lbs of C. It is desirable, therefore, to have as HIGH A PERCENTAGE OF CO_2 gas in the Cupola as possible in order to get the MOST HEAT from the coke. (*See Fig.* 1).

4.2 *Mechanism of the Recuperator*

Fig. I shows arrangement of convection recuperator in conjunction with Cupola. This has no dust arrestor which may be in the form of a Cyclone. The hot gases usually pass through a dust arrestor to remove dust. Generally recuperator elements accumulate dust. To avoid impairing the efficiency of heat transfer, means for cleaning out the dust at intervals are provided.

The gases are drawn from the side of the Cupola in the preheating zone, and passing these gases through a stove. Enough air is admitted to the stove to burn the CO in the gas.

The air for the Cupola is blown through a set of heating pipes in the stove on its way from the blower to the Cupola.

Arrows indicate the direction of the blast in its passage from the blower to the Cupola. An exhaust fan pulls the heated gas from the Cupola through a chamber provided with a great number of pipes.

4.3 *Design of the Recuperator*

For the purpose of this calculation the following actual readings taken are made use of.

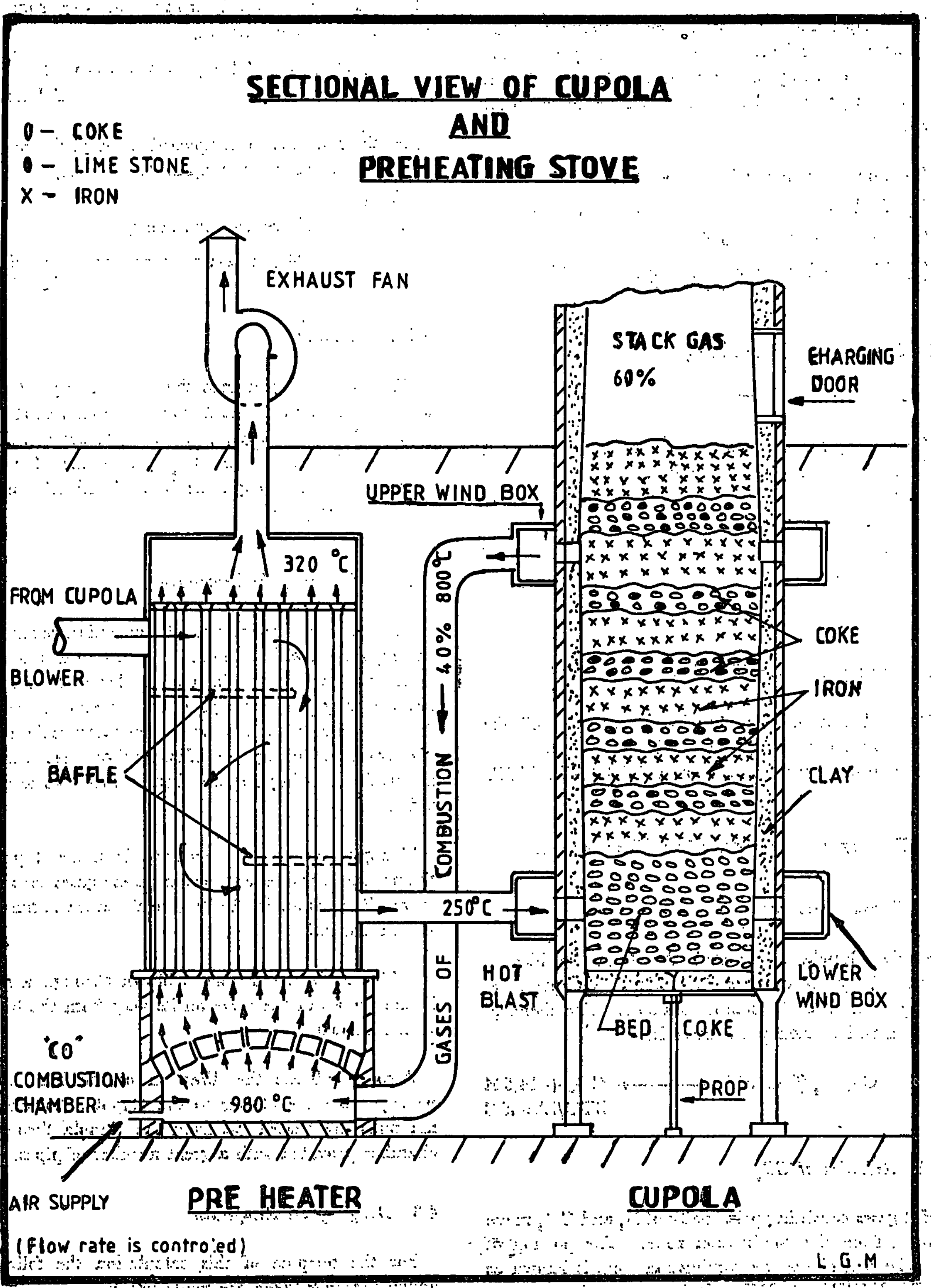


Fig. 1. Sectional View of Cupola and Preheating Stove

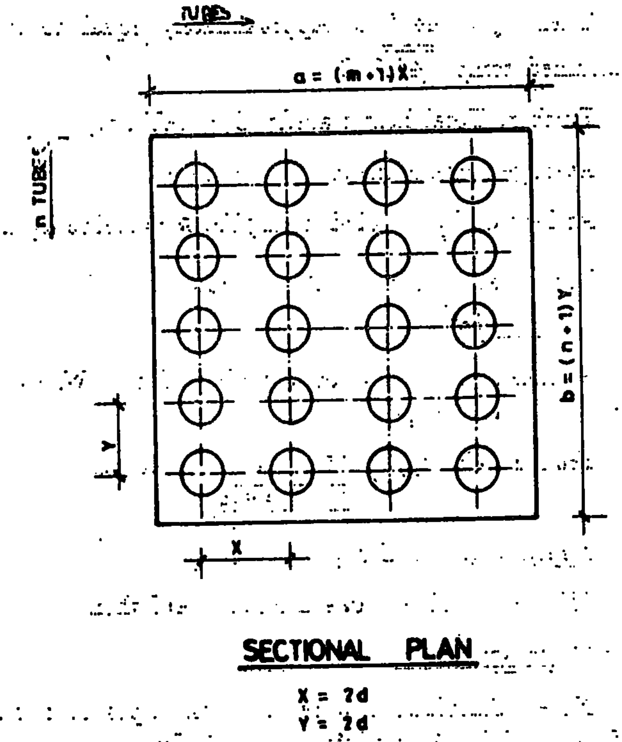
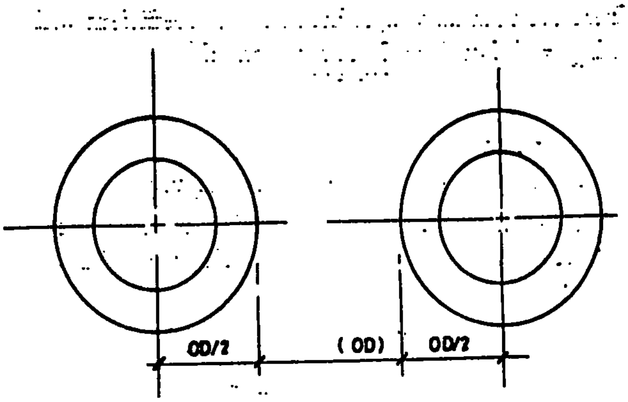
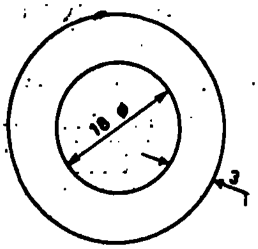


Fig. 2



PIPE PITCH



PIPE DIMENSION

Blower outlet pipe Dia = 7 in.

Air velocity in the pipe = 9767 ft/min (Measured using a Animometer)

Preheating zone temp = 800° C (Using a Pyrometer)

Inlet air temp. = 30°C

Air flow rate = $\frac{\pi (7/12)^2}{4} \times 9767 = 2610.26$ cfm = 1.232 m^3/s.

The exhaust fan is selected to handle 40% of the input air from the blower. Assuming the waste gas has same characteristic as air.

For air, C_P = 1.0049 (30°C), C_P = 1.1502 (800°C).

Heat balance, $(\theta - 30)\ 1.0049 = 1.1502 \times 0.4\ (800 - \propto)$. Assuming θ = 250°C, then $\propto$ 319° C Fig. 3 shows the temperature variations.

The average flue gas temp. = $\frac{800 + 319}{2}$ = 559° C

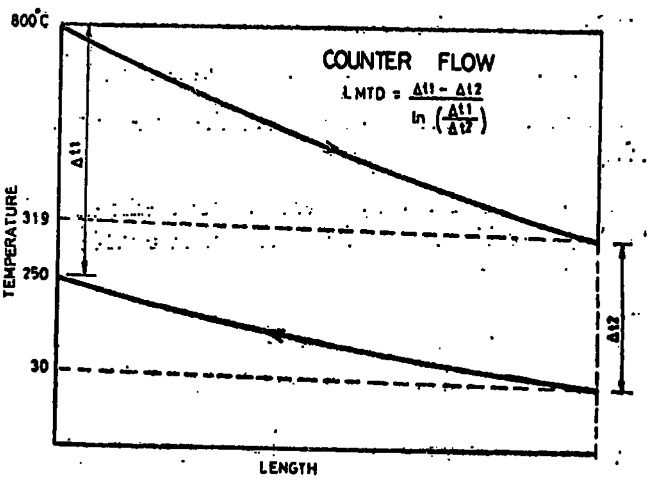


Fig. 3

The average air temp. = $\frac{250 + 30}{2}$ = 140° C

Selecting 100 No. of pipes of ¾ in. dia., velocity of gas will be 1.232 X 0.4 = π $(0.018)^2$ V 100 then, V = 19.36 m/s.

At 559°C, $\nu = 8.749 \times 10^{-5}\ m^2/s$, $k = 5.937 \times 10^{-5}$ Kw/mK°, Pr = 0.693 Re. = UD/ν = 3984.2(Turbulant flow).

For cooling process, $Nu = 0.023 \cdot Re.^{0.8}$ $Pr^{0.3} = 15.64$.

Therefore boundary layer heat transfer coefficient will be $h_{12} = k\ Nu/D = 0.0516$ kw/ $m^2 K^0$.

Calculation of h_{34}

Fig. 2 shows the arrangement of the piping.

100 tubes are arranged as 10 x 10 (ie, m = 10, n = 10), Then, a = 11 x = 11 x 2D, b = 11Y = 11 x 2D.

Pipe outside dia. = 0.224 m.

For space between pipes and square,—

Equivalent Diameter = 4 (Cross section area)/ Wetted perimeter

$$4 = \left[\frac{11 \times 11\ (2 \times 0.024)^2 - \pi/4\ (0.024)^2\ 100}{2 \times 0.024\ (11 + 11) + 100\ \pi\ (0.024)} \right]$$

$$= \frac{4 \times 0.233}{8.596} = 0.108m$$

Air velocity $= 1.232/0.233 = 5.29$ m/s

Assuming outside surface temp. as 450^0 C, then Mean boundry film temp. $= \frac{450 + 140}{2} = 295^0$ C.

At 295^0 C, $\nu = 4.687 \times 10^{-5}\ m^2/s$, $k = 4.466 \times 10^{-5}$ kW/mK^0, Pr = 0.68.

Then, $Re = UD/\nu = 12{,}012$ (Turbulant flow).

For heating process, $Nu = 0.023\ Re^{0.8}\ Pr^{0.4} = 36.18$.

Therefore boundary layer heat transfer coefficient wil be, $h_{34} = k\ Nu/D = 4.466 \times 10^{-5} \times 36.6/0.108 = 0.0151$ kw/m^2K^0

For steel tubes, k = 0.076 kw/mK^0.

Overall heat transfer coefficient = U.

$$U = \frac{1}{\left(\frac{r_3}{r_2}\right)\frac{1}{h_{12}} + \frac{r_3}{K}\ ln\left(\frac{r_3}{r_2}\right) + \frac{1}{h_{34}}}$$

$$U = \frac{1}{\frac{24}{18} \times \frac{1}{0.0516} + \frac{0.024}{2 \times 0.076}\ In\ (24/18) + \frac{1}{0.0151}}$$

$$= 0.011\ Kw/m^2 K^0$$

Considering toatal heat transfer, $U (t_1 - t_4) = h_{34} (t_3 - t_4)$ 0.011 (559 − 140) = 0.0151 (t_3 − 140).

Then, $t_3 = 447^0$ C Approximately equal to the assumed temp. (450^0 C).

Further, Total heat transfer $Q = AU\ \Delta t_m$.

Average temp. of the input air = 140^0 C.

At 140^0 C, $C_p = 1.0135$ kJ/Kg K^0, $\rho = 0.8565$ kg/m^3

Total heat transfer = 1.232 × 0.8565 × 1.0135 (250 − 30) = 235.279 kw.

Surface area = A = 100π 0.024 × L m^2, Where L =Length of the pipe.

From Fig. 3, $\Delta t_m = \frac{550 \quad 289}{In\ (550/289)} = 405^0C$

Applying $Q = AU\ \Delta t_m$.

235.279 = 100 × 0.024 L 0.011 × 405 then /

L = 7m (23 ft.)

Note : Calculations were done for pipes of 3"dia 2" dia, 1" dia, ½" dia but for all, L > 7m.

Therefore, required length of the each pipe is 23 ft. Hence, BY USING 100 NO. OF PIPES OF ¾ in dia, AND 23ft. LENGTH, SUPPLY AIR CAN BE HEATED TO 250^0 C. Further, since the length of the pipes are 23ft, height of the recuperator will be more than 23ft. If the height is critical, the pipe length can be shortened by increasing the number of passes. Supposing 3 pass system is used, Length/Pass = 23/3 = 7.7 ft., In this case, the exhaust fan must be selected to resist additional drag due to 3 pass.

5.0 Saving

5.1 Calerific value of the coke = 13000 BTU/Lbs = 30.239 kJ/Kg.

At 140^0 C, C_p = 1.0173 kJ/Kg K^0 and at 30^0 C, ρ = 1.177 Kg/m^3.

Amount of air handled by the blower = 1.232 m^3/s = 1.232 × 1.177 Kg/s.

Additional sensible heat of the hot blast = 1.232 × 1.177 × 1+0173 (250–30) = 324.54 kJ/s.

If M be the equivalent amount of coke saved per sec., then, M × 30,239 = 324.54, therefore M = 1.07×10^{-2} Kg/s.

FOR 7 hrs. CONTINUOUS OPERATION, AMOUNT OF COKE SAVED = 7 × 3600 × M = 270.5 Kg/Cast.

5.2 Dia. of the Cupola	=	30 in.
Capacity of the Cupola	=	2 T/hr.
Amount of coke/charge	=	84 Lbs (2 bags)
Scrap mixture/charge	=	(4.5 CI + 1.5 PI) cwt
Number of charges	=	40 (Minimum)
Total amount of coke	=	$84 \times 40 = 3360$ lbs = 1.5 Ton.
Percentage of saving	=	270.5/1500 — 18%
Price of coke	=	13,000 Rs/T
18% MINIMUM SAVING/CAST	=	3510 Rs/Cast

THEREFORE, FOR CONTINUOUS CASTING OPERATIONS THE SAVING IS WORTHWHILE.

6.0 Acknowledgements

Author wishes to thank in particular Mr. Hemantha Wijesekara—Assistant Lecturer in Mechanical Engineering of University of Moratuwa for the assistance given by scrutinizing and checking the calculations.

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