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Modelling of a calcium carbide furnace

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Design parameters of an electric arc furnace for one ton per day calcium carbide production have been presented in this paper. Various heat losses have been identified and computed.

Key words: Calcium carbide, modelling, furnace design

INTRODUCTION

Production of calcium carbide in the arc furnace is an energy intensive process requiring careful design and operating parameters. Recently many carbide units of 1–2 T/day capacity have come up. Even a small unit to be competitive, energy requirements should be comparable to large scale plants. This could be achieved by an optimum design of the furnace with minimum losses. A systematic modelling of the smallest carbide plant is therefore felt and presented in this paper. Various design parameters and their effect on the heat flow mechanism and furnace efficiency have also been discussed.

DESIGN ASPECTS

Transformer rating, voltage and current

Calcium carbide (CaC_2) is produced according to the following reaction

$$CaO + 3C \longrightarrow CaC_2 + CO - 108\text{K.Cals.}$$

The usual practice in design calculations is to assume 130% excess and on this basis 250 K.Cals/mole of energy is required. Since a one ton furnace is to be designed, 190 KW is the energy input per hour. From the relation, KVA × power factor = KW and assuming a power factor of 0.6, the transformer rating becomes 350. i.e. A 350 KVA transformer is essential for a 1 Ton CaC_2 Unit.

The secondary voltage and current obtained from the following relations are respectively 100 volts and 3500 amperes.

$$V = 15\sqrt[3]{P} \qquad I = P/E$$

Power density (P.D.)

Selection of p.d. depends on the hearth area and affects the reaction zone temperature. The choice of a higher p.d. offers scope for a smaller hearth area but an adverse effect on the refractory lining while a smaller p.d. lowers the production rate. In CaC_2 furnaces it is the usual practice to refer to the electrode current density given by [1].

$$\text{c.d.} = 250/\sqrt{D}$$

Again designers are dictated to opt for the highest possible c.ds to keep the capital cost to a minimum. In the present design, a c.d. of 12A.cm^{-2} is suggested.

Electrode diameter (D)

In an arc furnace, current, voltage and the charge resistance have an influence on the electrode diameter. In this connection, the electrode periphery resistance concept or Rk factor developed by the early designers resulting in the best known formula [2] is highly useful.

$$Rk = E\pi D/I$$

Based on the data available, ranges of RK factors were established for different arc furnace products and an Rk value of 0.19-0.22 is reported for CaC_2 [2]. The diameter of the electrode calculated from the above equation turns out to be 0.17m.

FURNACE DIMENSIONS

Shape

Various shapes, such as circular, elliptical and rectangular furnaces have been in use. However circular furnaces are preferred owing to the following advantages [2]. (1) Heat utilisation is maximum and losses are minimum. (2) In well designed circular furnaces high power factors can be achieved. (3) They have minimum "wild" (unstable) and "dead" (glow discharge) phase effects. Hence a circular shape is best suited and recommended.

Furnace hearth diameter (Df) and inter-electrode spacing (s)

In arc furnaces the three electrodes are usually arranged in the three corners of an equilateral triangle described by the pitch diameter, (p.d.) Selection of the p.d. is related to both the electrode and hearth diameter. In addition, the electrodes are usually cooled by water cooling rings. Hence the spacing of electrode becomes highly critical. The relation [2] between the electrode spacing and furnace diameter has been brought out by

$$D_f(\text{min}) = 2.16S;\; D_f(\text{max.}) = 2.31S - D;\; D_f(\text{opt.}) = 2.3S$$

considering an optimum reaction zone and allowing a safety factor of 0.15, the furnace diameter in the present design is given by

$$D_f = 1.15 \times 2.3s = 0.88\text{m}.$$

An arrangement of the electrodes inside the furnace is shown in Fig. (1)

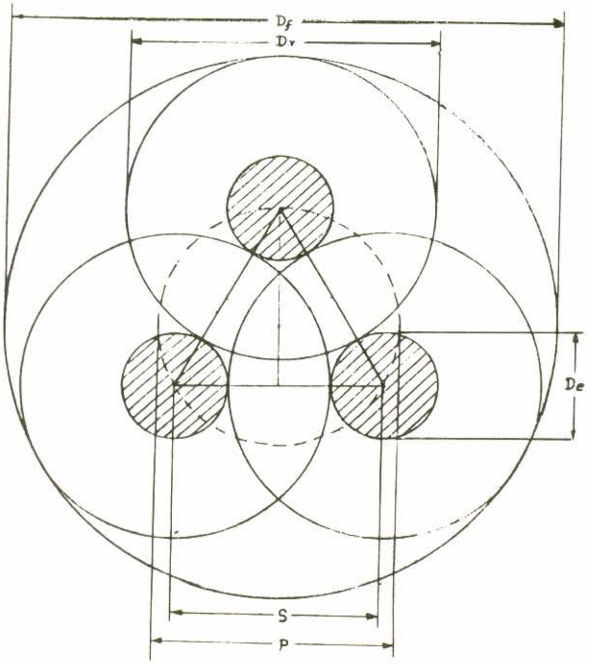

Fig. 1: Optimum arrangement of electrodes inside the furnace
D_e = Diameter of electrode = 7″ = 0.1778m;
S = Centre to centre distance of electrodes = 14″ = 0.3556m;
P = Pitch circle diameter = 16.14″ = 0.41m;
D_r = Diameter of reaction zone = 21″ = 0.535m;
D_f = Diameter of bath or hearth = 37.2″ = 0.945m

Furnace height (H)

The following relation [4] may be useful in finding the height of the furnace hearth:

$$H = P\rho D_f/3E^2D$$

Assuming that 60% power (P) is utilised in the resistance heating and substituting a value of 69.4 ohm-m for ρ sp.resistance as found in a separate experiment in the above relation, the hearth height becomes 1.44m. Having fixed all the important parameters, it only remains to propose a suitable refractory lining as suggested in Fig. (2).

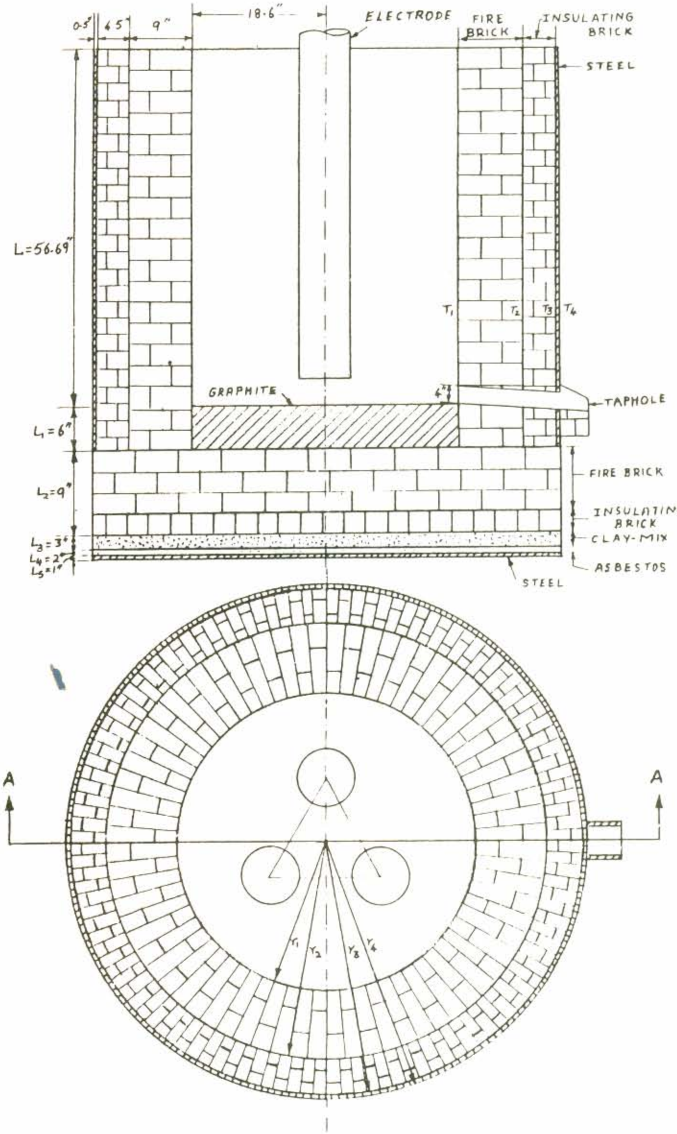

Fig. 2: (a) Section at AA
(b) Cross sectional top view of arc furnace

Heat transfer studies

There are three thermal considerations in an arc furnace viz. heat generation, heat transmission and heat losses. Heat generation takes place in the electrode column, in the charge and across the arcing zones. Heat transmission is mainly by radiation and conduction and less by convection.

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Losses occur mainly through the roof, side walls, water cooling of the electrodes. A greater part of the heat loss is due to the sensible heat of the molten carbide. Electrical losses also add to the above total. Thus only 40-50% of the power supplied alone is useful in melting and refining. A detailed picture of the thermal effects occurring in an arc furnace is well discussed in the following.

Useful heat

It is the heat utilized in the reaction leading to the formation of CaC_2 and equal to the sum of the enthalpy of formation and energy needed to raise the charge from ambient to the temperature of formation of the product. Based on the reaction and considering the specific heat of raw materials and their respective masses, the useful heat in the formation of CaC_2 is equal to 70,875 K.Cals/hr.

Heat losses

Computation of heat losses occurring in the arc furnace can be well understood by a reference to Fig. (2).

Conduction losses

Conduction through the side walls [3] reckoned from the equation is given as:

$$q_1 = \frac{2\pi H(T_m - T_s)}{1/k_1 \log_e r_2/r_1 + 1/k_2 \log_e r_3/r_2 + 1/k_3 \log_e r_4/r_3}$$

Similarly conduction losses through the bottom of the furnace is given by

$$q_2 = \frac{A(T_b - T_a)}{1/h + L_1/K_1 + L_2/K_2 + L_3/K_3 + L_4/K_4 + L_5/K_5 + L_6/K_6 + 1/h_O}$$

Roof losses

From the Fig. (2), the area of the radiating surface is $A = \pi D_f^2/4 - 3\pi D^2/4$. Heat loss from the radiating surface is computed from

$$q_3 = \sigma A \xi (T_s^4 - T_a^4)$$

Taphole losses

Molten CaC_2 is removed from the furnace by opening the tap doors and this results in losses given by the following [4]

$$q_4 = 0.252(T_b - T_a) t F_r C_c A$$

The tap hole loss is found to be only 0.38% and is reasonable as the tap doors are opened only for a short time and closed immediately.

Combined radiation and convection losses

This form of heat loss arises from the electrodes and may be evaluated [4] from

$$q_5 = 3[\sigma A \xi (T_m^4 - T_a^4) + h_O A (T_m - T_a)]$$

Heat loss in off gases

This forms the major part of the heat losses and is mainly due to carbon monoxide formed as a coproduct of the reaction. It can be shown by a simple calculation that 350 M^3 of the CO gas is evolved for every ton of CaC_2 produced. Assuming that the CO leaves the furnace top at around 773K, heat losses in the off gases turn out to be 26.14%.

Water cooling losses

Electrical connections to the electrodes are provided very close to the surface of the charge to avoid voltage drop. Since the surface is at 773K and in addition the electrodes are heated through the current passing and also by conduction of heat from the molten bath, the electrical contact points are usually water cooled. For this

	K.Cals/hr	Kwh	Percentage
INPUT			
Power into Transformer	164052.00	190.75	100.00
OUTPUT			
1. Heat utilised in the reaction	70875.00	82.41	43.20
2. Heat through side walls	5718.34	6.65	3.48
3. Heat through bottom	1148.69	1.34	0.70
4. Radiation from the top surface	1920.18	2.23	1.17
5. Radiation through tap hole	628.25	0.73	0.38
6. Combined convection and radiation	5458.47	6.34	3.33
7. Heat content of fumes and dusts	42840.00	49.81	26.14
8. Heat into cooling water	7500.04	8.72	4.57
9. Sensible heat of molten CaC_2	25075.05	29.16	15.28
10. Electrical losses etc	2887.98	3.36	1.75
Total output	164052.00	190.75	100.00

purpose, water cooling rings are provided which also serve as the electrical contact points and considerable heat loss of around 4.5% is encountered as a result of water cooling the electrodes.

Sensible heat of molten carbide

CaC_2 tapped out of the furnace at a temperature of around 2073K into cast iron ladles cools down to ambient temperature. This sensible heat also forms a sizable loss amounting to 15.28%.

Heat balance chart

The following heat balance chart is borne out of the preceding thermal considerations occurring in the electric arc furnace of the designed capacity.

CONCLUSION

The furnace designed is a small type and hence only about 43% efficiency is obtained. Thermal efficiency can be increased by (1) implementing the off gas utilization (2) incorporating computer or microprocessor controlled operating mechanism (3) employing improved refractories and (4) adopting strict raw materials control and better operating procedures.

Nomenclature

T_m, T_s, T_h, T_a — Mean, surface, bath & ambient temperature
t — Temperature function
$k_1 \cdots k_4$ — Thermal conductivities, K.Cal/m^{2}hr °C
$r_1 \cdots r_4$ — radii, m
$L_1 \cdots L_6$ — Length, m
h_1, h_0 — Heat transfer, co-efficients K.Cal/m^{2}hr °C
A — Area of the radiating surface–m^2
σ — Boltzman constant
ξ — Emissivity, K.Cals/m^2 hr °C
F_r — Total radiation factor
C_c — Correction factor
$q_1 \cdots q_5$ — Heat losses K.Cal/hr

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