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Design of an Electric Arc Furnace for Fused Quartz Industry

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Abstract— The electric arc furnace used for the manufacture of fused silica in industries has been quite an old one and no such innovations have been performed in its design area in order to yield high product output for large scale operations. Here, we present a design of this electric arc furnace which can be used to operate for a feed of about 2-2.5 tons and thus can yield about 80% of the feed as product (fused quartz) quantity wise. The furnace is considered to be a combination of 3 coaxial vertical cylinders, where the impure silica rock is itself used as a refractory in the furnace. For detailed explanation we have taken the chemical design along with heat transfer parameters into consideration. In comparison to the literature study, a detailed study was done on the variation of different dimensionless parameters associated with the furnace operation and also on the usage of impure silica rocks as the refractory in the outermost cylindrical chamber of the furnace was found effective along with the usage of a torispherical head arrangement.

Keywords— Cylinder, Design, Electric Arc Furnace, Fused quartz, Nusselt Number ,Pressure, Torrispherical Head

1.INTRODUCTION

Silicon dioxide occurs naturally as sand or rock, and when melted, the resulting product is called Fused Quartz. Fused Quartz is very pure, has a high chemical resistance, good thermal shock resistance and is very strong in compression. Quartz is the most stable crystal modification at normal temperature and pressure conditions. The mineral is a widely spread mineral in the earth's crust. Fused quartz has nearly ideal properties for fabricating first surface mirrors such as those used in telescopes. The material behaves in a predictable way and allows the optical fabricator to put a very smooth polish onto the surface and produce the desired figure with fewer testing iterations. In some instances, a high-purity UV grade of fused quartz has been used to make several of the individual uncoated lens elements of special purpose lenses. These lenses are used for UV photography, as the quartz glass has a lower extinction rate than lens made with more common flint.

2.MATERIALS AND METHODS

The Electric Arc Furnace Method and Silicon Tetrachloride Process are used today for the manufacture of fused quartz in industries now a days. But Electric Arc Furnace Method is mainly preferred as :

- Higher efficiency in electric arc furnace process than $SiCl_4$ process as we get higher quantity of pure product.
- Corrosion due to HCl presence in the $SiCl_4$process reduces the lifetime of the process, which is not produced in Electric Furnace Method.

The Electric Arc Furnace Method mainly involves crushing the obtained fused rocks from mines and heating it at a very high temperature of about 1700 deg C in an electric arc by supplying a voltage of about 1400 KW. As a result, a fused form of the silica is obtained, which is allowed to get dried in air and later impurities are chipped off.

For better performance, it is better to use the waste scrapped off silica with impurities as the main refractory lining for furnace. The advantages of doing so are:

- The expenditure behind buying refractory's will be minimised.
- Less maintenance will be required for the furnace as silica with impurities have huge temperature withstanding ability.
- Wastage from the industry overall will be minimised.

3. RESULTS AND DISCUSSIONS

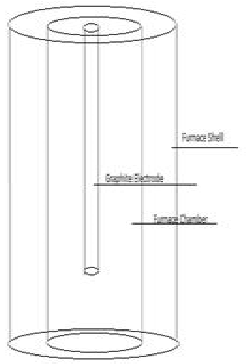

Figure 1. Side view of the furnace

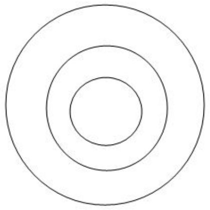

Figure 2. Top View of the furnace

The designed furnace consists of three coaxial cylinders placed vertically.

The inner most cylinder is the graphite electrode with radius r. It is surrounded by another cylinder which is the furnace chamber with radius R_1 and the last surrounding cylinder is the furnace shell with radius R_2 ,which will be filled with refractory.

3.1 Effect of feed on furnace chamber diameter and furnace shell diameter

It was observed that with increase in the feed content of the furnace, the furnace shell diameter and the furnace chamber diameter also increased. The variation is linear. (Figure 3)

3.2 Effect of feed on furnace shell volume and furnace chamber volume

It was observed that with increase in the feed content of the furnace, the furnace shell volume and the furnace chamber volume also increased. (Figure 4).

3.3 Effect of temperature on Nusselt and Grashof Numbers

It was observed that with increase in the operating temperature of the furnace, the value of Nu and Gr also increased. The variation observed was also linear. (Figure 6)

3.4 Effect of increase in temperature on the product of Grashof and Prandtl Number

It was observed that with increase in the operating temperature of the furnace, the value of GrPr also increased and varied linearly. (Figure 7).

A sample calculation for a feed of 2000 Kg for to the furnace has been shown

Input feed to the furnace = 2000Kg
Density of the quartz = $2800 Kg/m^3$
$V_1 = 2000/2800 = 0.7148\ m^3$
Now, $V_1 = 0.0968 * D_{,\text{furnace chamber}}{}^3$ [1]
$D_{,\text{furnace chamber}} = 1.9468$ m.
In this design, the height of the furnace chamber and the furnace shell are same. As a result the overall volume of the furnace chamber is more and thus more space is available for the reactions to take place inside the furnace.
$D_{,\text{furnace shell}} = 0.2+1.9468 = 2.1468$m
$H_1 = 1.5 * D_{,\text{furnace shell}}$
$= 1.5*2.1468 = 3.202$ m
$H_2 = 3.202$m
Amount of power supplied = 1400 KW
Due to slag formation, the rough power supplied is 80% of the original
$P_{\text{actual}} = 0.8*1400 = 1120$ KW
$P = V*I$
$1120 * 1000 = 440 * I$
$I = 2545.45$ A
$d = ((0.406 *I *I *\delta)/ k)^{(1/3)}$ [1]
$\delta = 2.633 * 10^{-6}$ ohm m ,[1] $k= 20193.51\ kg/sec^3$
$d= (0.406*2545.452* 2.633*10^{-6} /20193.51)^{1/3}) = 0.07$m ;
r=0.035m
$h = 0.7*H_1 = 2.25414$m.
Volume of furnace shell $= \pi/4* D_{,\text{furnace shell}}{}^2 * H_1$
$= 11.5844\ m^3$
Volume of furnace chamber $= \pi/4* D_{,\text{fumace chamber}}{}^2 *H_2$
$= 9.526\ m^3$
Volume of electrode $= \pi/4* 0.07 * 0.07* 2.25414$
$= 0.008670\ m^3$

4. TABLES AND GRAPHS

4.1 Study of volume and diameter

The above shown were just a standard calculation done for a feed of two tons. For various feed inputs calculations were done and the variation in the diameters and the volumes with respect to the feed were noted down in a table and were studied graphically.

TABLE 1
Collective data of the feed , volume of the furnace chamber and shell as well the diameter of the furnace shell and volume.

Feed (Kg)	**Diameter Of Furnace Chamber(m)**	**Diameter of Furnace Shell(m)**	**Volume of Furnace chamber(m^3)**	**Volume of Furnace shell(m^3)**
1000	1.5452	1.7452	4.906	6.258
1500	1.7688	1.9688	7.253	8.985
2000	1.9468	2.1468	9.580	11.65
2500	2.0971	2.2971	11.895	14.272

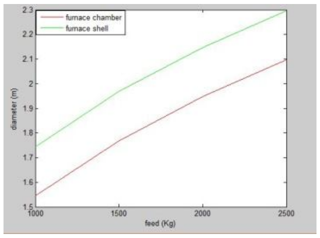

Figure 3.Variation of the diameter of furnace chambers with feed

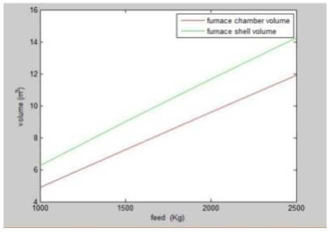

Figure 4. Variation of the volumes of the furnace chamber with feed

From the above calculations we have a clear picture of how the shell, reaction chamber diameter and volume vary with feed.

4.2 Study of dimensionless numbers due to heat transfer

The further design prospects are shown by the heat transfer correlations.
$Gr = =g\beta\Delta TL^3/v^2$ [2]
A sample calculation was done for 1700^oC with outside temperature as 25^oC
Gr= 41.055
$Pr = \mu Cp/k = 143994.506$
$Gr.Pr = 5.911x10^6$
Nu = 29.091

Local Nusselt Number = 13.566

TABLE 2
Collective data of dimensionless numbers at different operating temperatures

Operating Temperature (°C)	**ΔT (°C)**	**Gr**	**GrPr($x10^6$)**	**Nu**
1500	1475	36.1817	5.209	28.18
1600	1575	38.634	5.563	28.563
1700	1675	41.055	5.916	29.09
1800	1775	43.54	6.269	29.52

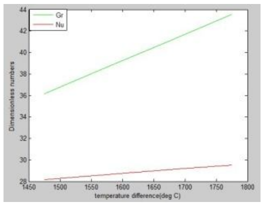

Figure 6.Variation of dimensionless numbers with temperature

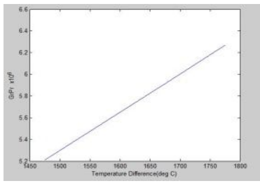

Figure 7. Variation of GrPr with temperature

4.3 Study of pressure

Total pressure acting at the top of the furnace = 101325Pa [3]

It is important to calculate the static pressure acting inside the pressure vessel, so that material of construction can be chosen as well as the type of head required to support the pressure vessel can also be figured out.

Pressure inside the vessel = pressure developed due to the body of the furnace + pressure due to impure silica used as refractory.

On analysis it has been found that the silica rock obtained from nature has the following specifications:

TABLE 3
Percentage composition and component density of fused silica rock

Components	**Percentage quantity**	**Density (Kg/m^3)**	**Component density (Kg/m^3)**
SiO_2	98	2800	2744
Al_2O_3	1.5	3980	59.25
Fe_2O_3	0.5	5240	26.2
Phosphorous pent-oxide	0.1	2390	2.39

Static pressure acting = 1.72 atm = 1.746x105 Pa [3].
Thus for resisting such high pressure the type of head that should be used is torispherical head.

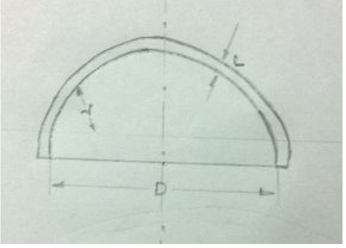

Fig 8. A section of torispherical head

CR= $D_{,fumace\ shell} = L_1$ = 2.1468m
KR= 0.1 $D_{,furnace\ shell}$ = 0.21468m
P = 174694.32 Pa
S= 139755.456 Pa
E=1
Tr= 2.622m

Thus thickness required for resisting such pressure is 2.622m.

5. CONCLUSION

The variation in Gr was found to be greater than Nu with increase in the furnace operating temperature (Figure 6).As a result the variation in the buoyant force with respect to the viscous force was more as the temperature increased and also the heat contributed inside the furnace was mainly due to conduction. The presence of impure silica rocks at the outer boundary of the furnace and being used as a refractory were meaningful as the presence of a torispherical head would certainly help in resisting high pressure that had developed inside the furnace during operation(Figure 8).

6. ABBREVIATIONS

Symbol	**Full form**	**Unit**
V_1	Volume of entering quartz	m^3
H_1	Height of furnace shell	m
H_2	Height of furnace chamber	m
V	Voltage	V
I	Current	A
d	Electrode diameter	m
δ	Resistivity	Ohm m
K	Power per unit area	Kg/sec^3
r	Radius of electrode	m
h	Height of electrode	m
Gr	Grashof Number	-
g	Acceleration due to gravity	m/sec^2
β	Volumetric thermal expansion coefficient	K^{-1}
ΔT	Temperature Difference	°C
L	Length of furnace	m

ν	Kinematic Viscosity	m^2/sec
Pr	Prandtl Number	-
Nu	Nusselt Number	-
μ	Viscosity	Kg/m sec
Cp	Specific Heat Capacity	J/Kg K
k	Thermal conductivity	W/mK
P	Acting Pressure inside furnace	Pa
S	Allowable Stress	Pa
E	Effectiveness Factor	-
Tr	Thickness of head	m

7. ACKNOWLEDGEMENT

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REFERENCES

[1] F.A. Oyawale,D.O Oyawale, Design and Prototype Development of a Mini-Electric Arc Furnace, 12-16,vol.8 no.1,May 2007.

[2] Review of fundamentals: Heat and Mass transfer,7.26-7.32,ME,IIT Kharagpur.

[3] Warren L.McCabe, Julian C.Cmith, Peter Harriott, Unit Operations of Chemical Engineering,9,7th Edition 2005.