International Journal of ChemTech Research
CODEN(USA): IJCRGG ISSN : 0974-4290
Vol. 3, No.3, pp 1704-1707, July-Sept 2011

Thermal Treatment of Refractory Materials

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Abstract: Solar concentrator of 2kw was used for melting and thermal decomposition of some refractory oxides (Fe_3O_4, Mn_3O_4), at very high temperature more than 2000°k, either on a water cooled support or in a black body cavity. The influence of temperature, quenching speed and exposure time at the focus on the residue of decomposition is presented. Melting, cracking, and thermal decomposition have been discussed. The experimental results can be used to determine the type of reactor to be used for the 1000kw solar furnace.

Key words: Solar concentrator, Refractory oxide, Melting-point, Thermal, Decomposition, Conversion rate, Cracking.

Introduction

Many utilization of both the energetic and chemical reaction type have been developed, the main object of many studies is the cracking, melting, and thermal decomposition of refractory material in the focus of a solar concentrator [1-2], particularly involving alumina used to produce corundum and quartz to give vitreous silica. The melting of refractory products is the simplest operation that can be carried out in a solar furnace. Unlike what happens with electric ovens, here, it is treatment in oxidizing atmosphere that is easiest to test. The fluidized bed may be an efficient solar receiver to process gas-solid reactions [3-4]. Nakamura in 1976, proposed a scheme to treat magnetic by gravitational circulation of powder through the focal zone of a solar furnace. Such a technique is not likely to succeed. Indeed a powder with a similar absorption coefficient cannot be heated in a fluidized bed to more than 1650°k on the other hand, the average highly concentrated energy [5]. The aim of this work is to show the used of a 2kw solar concentrator (horizontal and vertical axis) for thermal treatment of refractory materials. The thermal decomposition of some oxides (Fe_3O_4, Mn_3O_4), above 2000k was also studied .

$2\,Fe_3O_4\,(S) = 6\,FeO\,(l) + O_2\,(g)$ Endothermic (ΔG 2500°k = 0)

$2\,Mn_3O_4\,(S) = 6\,MnO\,(l) + O_2\,(g)$ Endothermic (ΔG 2300°k = 0)

The nature of the decomposition residue is a function of different kinetic and thermodynamic parameters i.e. temperature quenching speed, residence time (in the focus), and partial pressure of oxygen [6].

Instrumentation Set up

The 2kw solar concentrator (vertical axis), fig.1, consisted of a fixed parabolic mirror of 2m diameter, with an open angle of 122°, and focal distance 85cm from the vertical axis and parallel to its optical axis. It received the solar radiation reflected by a heliostat about 25m subjected to the apparent movement of the sun the energy density variables curve in the focal plane was showed in fig.2. The experiment arrangement consists of 1) sample, 2) Refrigerated sland, 3) solar radiation, 4) reaction vessel, 5) CaF_2 scuttle with a ι=94% transmission, 6) IR Pyrometer, 7) gas out, and 8) vacuum. The cylindrical sample with 8mm diameter, height of 4mm was placed on a cone-shaped (120°) water cooled support. The temperature of the melting sample was measured by a monochromatic IR Pyrometer with wave length of λ=2.9μ, are shown in fig.3. Thermal analyzer shows that in the focus, temperature of magnetite can reach 2200°k (350°C above the solidification temperature), a decomposition rate of about 40% can be taken place.

Fig.4, shows that it is possible to obtain 100 mol percent FeO with splat cooling (inert atmosphere) at 2173°k, after 2 min exposure in the focus. A solar concentrator of the same power with a horizontal axis, was use to work out the centrifugal force of the products (black body) and determine the precise temperature of the sample. The observations and indicates that overheating of the liquid phase is more significant on a refrigerated stand than treatment in a melting – pot for these materials. The iron oxide example can be used for thermal treatment of other types of materials with the same thermo physical characteristics. Concerning Mn_3O_4, the data on the stability of the oxides of manganese and the temperature of their decomposition under standard conditions from the thermodynamic tables, shows that in air, MnO_2 is stable to 770k, Mn_2O_3 to 1250k, Mn_3O_4 to 1775°k, and MnO stable to 3270k. In this work at 2173°k, in air and with a cooling speed of 100°C S^{-1}, the conversion rate rapidly reached 80% after less than one min of exposure time.

Calculation

Even so one can predict that the maximum fraction of incident energy (E) which is stored in an amount of product FeO equivalent to a complete transformation will be low

$E < (0.4)\,(0.8)\,(0.8)\,\eta$

Where

0.4 = maximum transformation rate under air,

(0.8) (0.8) = efficiency of a two reflection solar device,

η = efficiency of the receiver.

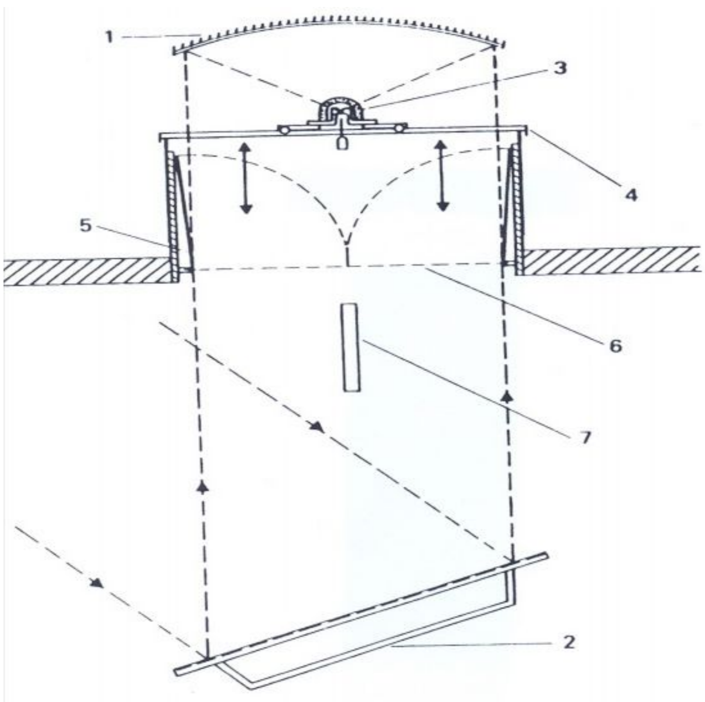

Fig.1. Solar concentrator (vertical axis.

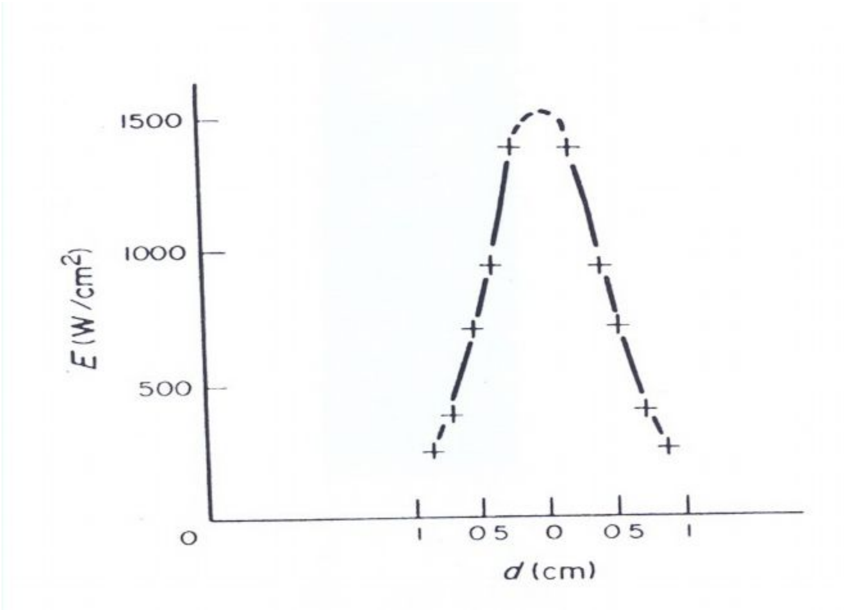

Fig.2. Energy density (E) VS distance

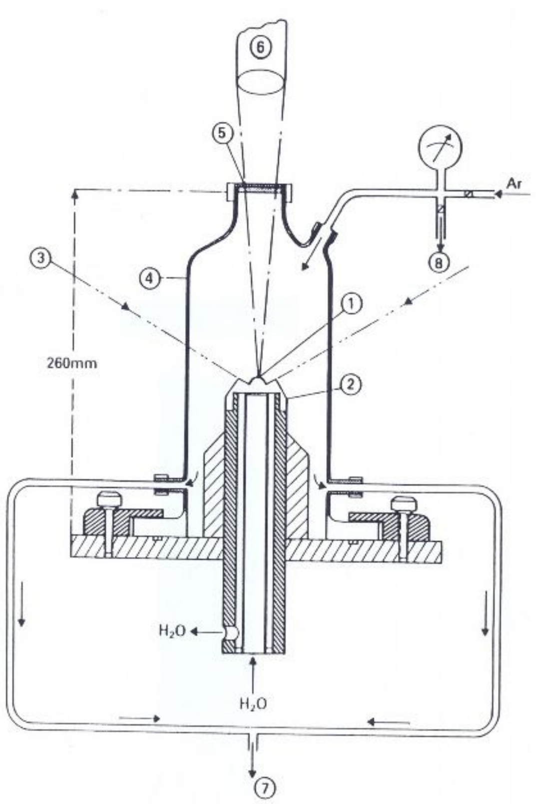

Fig.3. Solar apparatus.

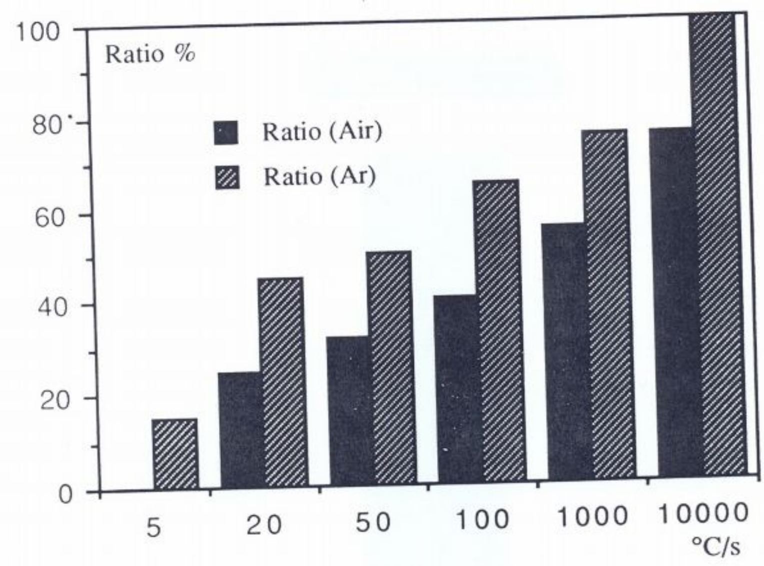

Fig.4. Conversion rate of FeO VS quenching speed.

Results & Discussion

The observation shows that the overheating of the liquid phase is more significant on a refrigerated stand, the maximum temperature reached by the sample in the focus depend on the intensity of the solar radiation, the centering of the sample in the focus, flow and temperature of the cooling water, and the thermo physical characteristics of the materials. It is important to note that, overheating unavoidably causes vaporization of a non-negligible fraction of the material about 15 weight %, after 5 min at 2200k. This vaporized part would have to be recycled after being collected to avoid too much consumption of raw material. It is evidence that the thermal decomposition of iron and manganese oxides in a solar concentrator at very high temperature in liquid state very difficult in practice.

Conclusion

The performance of solar concentrators depends on the capricious nature of solar energy i.e, dilution, intermittence, irregularity & storage. The maximum fraction of incident energy is to be less than 0.256 of η which is a function of the apparent optical properties (adsorptivity & emissivity) of the cavity. At high temperature, the theoretical value for efficiency of receiver will be below 0.8.

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