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Modeling of Limestone Calcination Using Joule Heating

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Abstract—The limestone calcination reaction is endothermic ($CaCO_3$==>CaO + CO_2 ΔH = 1660 kJ /kg) which means that higher temperatures favor the forward reaction. The reaction will proceed only if the partial pressure of CO_2 in the gas above the solid surface is less than the decomposition pressure of the $CaCO_3$. All researchers found that the presence of CO_2 inhibited the calcination reaction, but the form of dependence is uncertain. As the reaction is endothermic, the conventional process for calcinations uses coal firing in rotary kiln with limestone feed to get the desired temperatures. This generates CO_2 in the process leading to inhibition of calcination reaction.
Microwave heating of limestone is proposed to increase the temperature of the limestone to the desired levels. Microwave heating is an emerging but underutilized phenomenon in modern industrial applications having the advantages such as: time and energy saving, very rapid heating rates, improved mechanical properties, considerably reduced processing time etc. In the current work, 3D model was created with joule heating (to mimic microwave heating) of 15*15*1 mm limestone block due to lack of RF module at author. Temperature and CO_2 concentration profiles were obtained from COMSOL model & were studied with respect to the time. Results from the theoretical model were analyzed and compared with the published data on calcination temperatures and CO_2 dependency.

Keywords—Calcination, rapid heating, CO2 concentration.

I. INTRODUCTION

RAPID heating of lime stone is one of the recent research interest evaluated by Fall recently [1]. Similar study was performed for Alumina heating by Suryanarayana Murthy et.al. [2] using the COMSOL software. This will enable to reduce CO2 concentrations and hence the calcination temperatures in cement production. COMSOL capabilities were demonstrated to model this problem.

II. MODEL & GOVERNING EQUATIONS

A. Joule Heating

15*15*1 mm limestone block was subjected to joule heating (to mimic the microwave heating) for 0-20 minute duration with the governing equation:

$$\rho C_p \frac{\partial T}{\partial t} + \rho C_p \mathbf{u}_{trans} \cdot \nabla T = \nabla \cdot (k \nabla T) + Q + W_p$$

$$\nabla \cdot \mathbf{J} = Q_j$$

$$\mathbf{J} = \sigma \mathbf{E} + \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J}_e$$

$$\mathbf{E} = -\nabla V$$

All surfaces are assumed to be available for heating with the consideration that it is free falling particle. Initial condition was T=303.15K and V=220 Volts. Relative permittivity was taken as 7.2 and electrical conductivity was taken as 0.02 S/m for limestone [3].

B. Transport of diluted species

Calcination reaction of limestone with following reaction was considered:

$CaCO_3$==>CaO + CO_2 ΔH = 1660 kJ /kg

Parameters for Reaction Rate Constant was taken from Boateng [4], k= A*exp(−E/RT)

Where Frequency factor, A=9.67*10^{24} hr^{-1}

Activation Energy, E= 1092.947 KJ/mol

Rate expression: Rj=k*Cj

Diffusion of CO_2 was considered from within the block to the surface with D_{CO2} = 1.39e-8 m^2/s.

Governing equation:

$$\frac{\partial c_i}{\partial t} + \nabla \cdot (-D_i \nabla c_i) = R_i$$

$$\mathbf{N}_i = -D_i \nabla c_i$$

Convective flux was considered with the following specification:

Inward flux= 0.1 mol/m^2.s

Mass transfer coefficient= 0.0833 m/s

CO_2 concentration in bulk phase = 0.002 mol/m^3

Some of the conditions / properties are assumed due to lack of data & this model should be used for demonstration purpose only.

Physics controlled mesh with fine element size was used for simulation.

III. RESULTS & DISCUSSION

Heating time required for calcinations was studied for various Inflow heat flux values ranging from 500000 (rapid heating) - 500 W/m^2 (slow heating) and the results were shown in Figure 1.

$5*10^5$ W/m^2

$5*10^4$ W/m^2

$5*10^3$ W/m^2

$5*10^2$ W/m^2

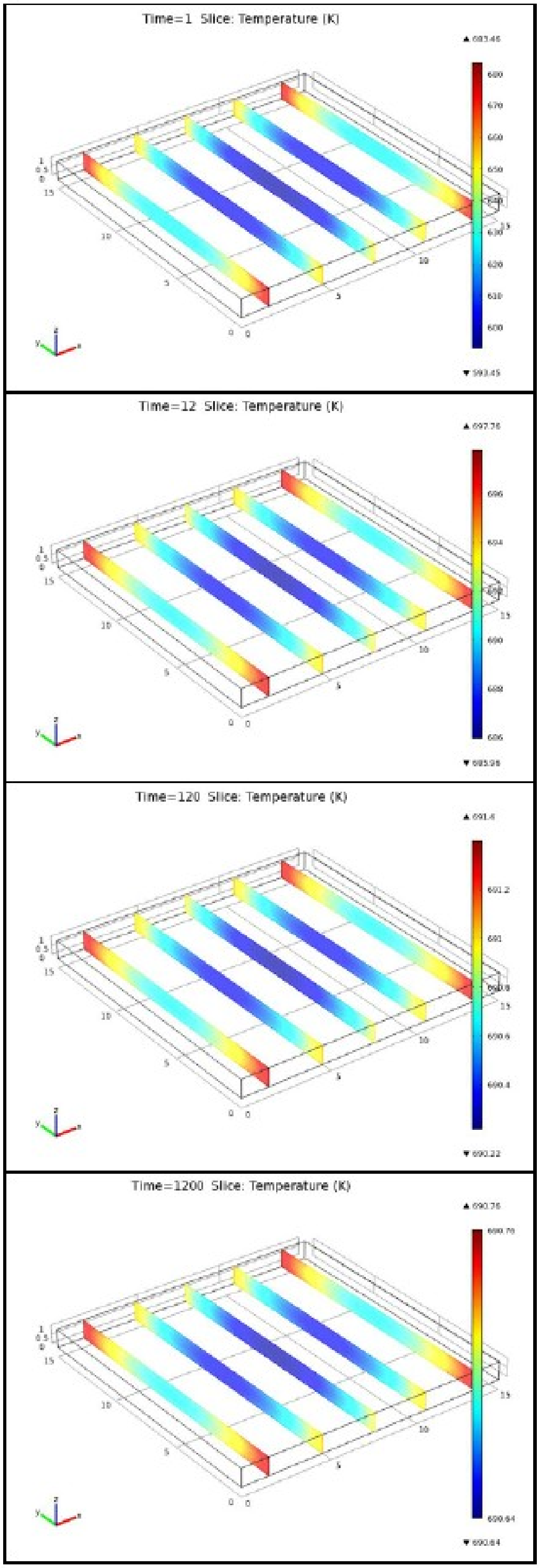

Figure 1. Temperature profile with Heat influx variation.

Duration was found to be in the range of 1s to 1200s. Incase of slow heating the temperature was uniform through out the slab. It was also observed that the temperature profile was changing very rapidly at higher flux values & hence an inflow heat flux in the range of 500-5000 W/m^2 was suggested for actual experiments.

Concentration profiles were also captured for the above case study (Figure 2) and found that the CO_2 concentration is leading to uniform value equal to 0.014 mol/m^3.

$5*10^5$ W/m^2

$5*10^4$ W/m^2

$5*10^3$ W/m^2

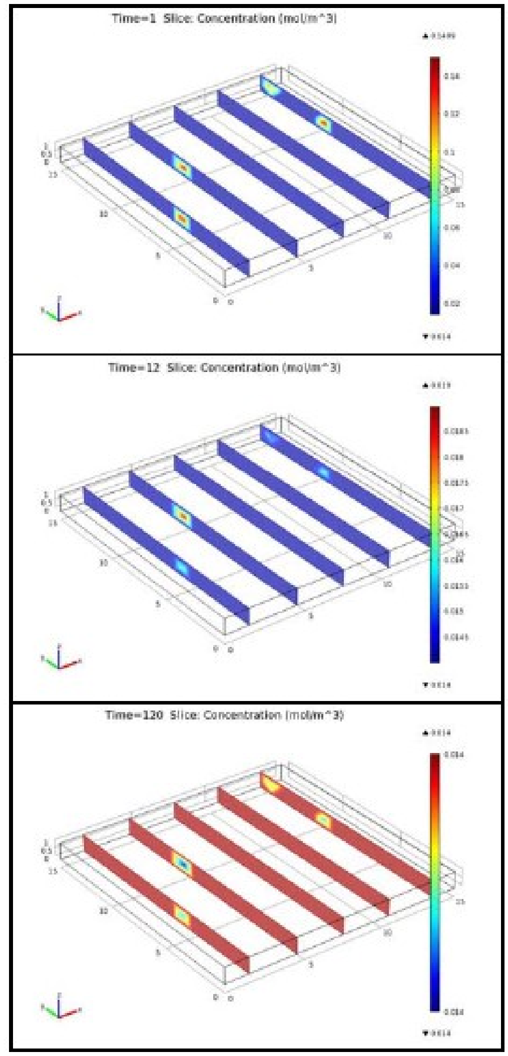

Figure 2. Concentration profile with Heat influx variation.

It was found that the temperature calculations are not very sensitive to step size and the model was converging with a step size of $0.1^{o}C$ also with an accurate solution. However, Concentration calculation found to be sensitive and even the computation time was considerable.

IV. CONCLUSION

COMSOL capabilities to model limestone calcinations was demonstrated using two physics namely Joule heating and Transport of diluted species. Experimental investigations should be carried out based on the inputs from the COMSOL model. Joule heating is showing a temperature profile across the slab & hence the study of microwave heating suggested.

V. REFERENCES

[1] Fall W, S. M. Allan, H. S. Shulman, “Rapid limestone calcination using Microwave Assist Technology”, 35rd International Conference & Exposition on Advanced Ceramics and Composites ICACC-S8-023-2011.

[2] Suryanaraya Murthy P, Srinath M S, Sharma A K, Pradeep Kumar, “An FEM approach to analysis of microwave heating of alumina in Multi-mode applicator”, Int. Conference on Mathematical modeling and applications to industrial problems, NIT Calicut, March 28-31, 2011.

[3] Grégoire, Colette, Joesten, P.K., and Lane, J.W. Jr., 2007, Use of borehole-radar methods to monitor a steam-enhanced remediation pilot study at a quarry at the former Loring Air Force Base, Maine: U.S. Geological Survey Scientific Investigations Report 2006–5191, 35 p.

[4] Boateng Akwasi A., Rotary Kilns-Transport Phenomena and Transport Processes, page-277, Butterworth-Heinemann Elsevier (2008)

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