ISSN : 0974 - 7443 Volume 9 Issue 1
CHEMICAL TECHNOLOGY
An Indian Journal
Full Paper
CTAIJ 9(1) 2014 [22-26]

CFD simulation of gas flow in a rotary kiln: Validation and similarity for an industrial scale kiln

M.Hamidi Ravari, A.Sarrafi*
Department of Chemical Engineering, Shahid Bahonar University of Kerman, (IRAN)
E-mail : sarafi@mail.uk.ac.ir

ABSTRACT

Understanding the gas flow behavior in rotary kilns is very important for predicting thermal conditions. This paper describes CFD simulation of the flow characteristics within an industrial rotary kiln containing a rolling bed of granules. The axis of the cylinder assumed to be horizontal with no axial bulk of flow of particles. The velocity profile of the gas flowing through the cylinder is simulated by CFD. At first, model applied on a laboratory scale rotary cylinder and the results were compared with the available literature for validation. The method is applied to an industrial kiln producing granular lightweight aggregates. The results indicate that the velocity field is asymmetric with respect to a diameter perpendicular to the granular bed. The gas velocity profiles are crucial in determining heat transfer from gas to solid.

KEYWORDS

Rotary kiln;
CFD;
Rolling bed;
Velocity profile;
Asymmetric.

INTRODUCTION

Rotary kilns are widely used in the chemical, mining and metallurgical industries for the processing of materials. Applications include drying, calcining, reduction of oxide ores and pyrolysis. A typical kiln comprises a cylinder with length / diameter ratio between 10 and 40, depending on the required residence time and with an inclination to the horizontal of a few degrees. materials are fed at the raised end, forming a bed of material along the cylinder and removed at the lower end. Rotation of the cylinder causes the axial motion of particles and mixes the bed. Fundamentally rotary kilns are heat exchangers in which energy from a hot gas phase is extracted by the bed material. Gas flow is typically counter-current to the bed movement and the gas is heated to supply the requisite energy for processing the material. The gas can be heated by way of a direct flame or by passing through an external furnace. Both physical processes and chemical reactions can occur inside a kiln.

Depending on the kiln's rotational rate the bed motion in the transverse plane may be characterized into six distinct regimes[1]. In order of increasing speed of rotation these are: (i) slipping, where the bed is approximately stationary in a transverse plane with the kiln slipping underneath it, (ii) slumping, where the granular material falls down the bed surface in discrete avalanches, (iii) rolling, where the part of the bed closet to the cylinder wall rotates in rigid body rotation and there is continuous flow of granular material down the free surface, (iv) cascading, where centrifugal effects cause the free surface to become curved, (v) cataracting, where the rotational speed is high enough that particles are projected into the freeboard region and (vi) centrifuging, where the rotational speed is high enough that the particles form an annulus adjacent to the rapidly rotating cylinder[2]. Industrial rotary kilns typically operate in the rolling or cascading regime[3]. Within a rotary kiln heat can be transferred by conduction, convection and radiation from gas to wall, gas to bed and wall to bed. The exposed wall of the kiln which then rotates to be under the bed and thereby heats it, is sometimes reffered to as regenerative heat transfer. The simplest models of rotary kiln operation treat temperatures within the kiln as depending only on axial position, so the gas and bed are well-mixed over a cross section and lumped heat transfer coefficients have been used to describe each heat transfer mechanism. The gas to bed and gas to wall heat transfer coefficients have often been estimated using duct flow correlations such as the Dittus-Boelter correlation which may be modified to account for surface roughness, as appropriate. However there are indications that the heat transfer coefficient from gas to bed may be somewhat higher perhaps by an order of magnitude than that given by the Dittus-Boelter correlation. Brimacombe and Watkinson[4] compared a model based on the Dittus-Boelter correlation to experimental data and found that the model underestimated the gas to bed heat flow rate by an order of magnitude. Two explanation were proposed:(i) the movement of particles at the bed surface increases heat transfer and (ii) the area for gas to bed heat transfer is underestimated as surface roughness was ignored. Tscheng and Watkinson[5] estimated heat transfer coefficients from their experimental data and found the gas to bed heat transfer coefficient to be an order of magnitude higher than the gas to wall heat transfer coefficient.

The use of duct flow correlations requires the gas flow characteristics within the kiln to be similar to those in a duct. However the wall conditions are not the same, in that in a rotary kiln the kiln wall is rotating and the surface of the bed is in motion either continuous or avalanching and this might have an effect on boundary layers near the kiln wall and bed surface and thus on heat transfer characteristics. Indeed modeling of a rotary coke calcining kiln by Bui et al. shows a transverse gas flow field and gas temperature field which are asymmetric with respect to a line bisecting the granular bed and perpendicular to it[6]. Modeling of flow and heat transfer in a rotary lime kiln by Georgallis et al. using 3D modeling of the gas flow shows a temperature field displaying similar asymmetry[7]. Davies et al. described an experimental investigation and CFD calculations of the flow characteristics within a rotating cylinder containing granular material[2]. Their results show that velocity field is asymmetric with respect to a diameter perpendicular to the granular bed.

The current paper describes CFD simulation of the flow characteristics within an industrial rotary kiln containing granular material. For simplicity the axis of the cylinder was assumed to be horizontal and with no axial bulk flow of particles.

CFD SIMULATION

The gas velocity profile is simulated in a horizontal cylindrical of length 40 m and variable diameter 2.1 m to 2.6 m containing a bed of granules with mean diameter of 7 mm and angle of repose 42°. The shape of studied kiln is showed in Figure1.

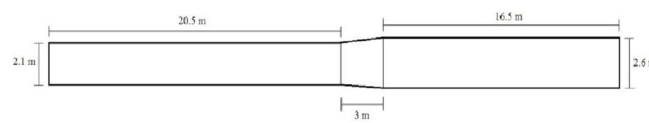

Figure 1 : Schematic of Kiln

The cylinder operates in semi-batch mode with no flow of granular in or out. The bed depth is constant along the cylinder. The entry plate rotates with the cylinder and contained a central hole of 0.5 m diameter for the gas. The gas flow rate is 12.67 m^3/s, corresponding to a Reynolds number of 161230. The cylinder rotation speed is 4.5 rpm.

The objective is to create a simple model to simulate the gas flow in the cylinder. Such model calculations are useful in understanding the nature of gas flow for example entry and exit lengths and could be developed to include heat transfer. The package used is Fluent 6.3. The geometry was constructed and meshed. The appropriate fluid definitions and boundary conditions applied and then the equations solved. The nature of CFD simulation required assumptions and simplifications as follows:

i The system is isothermal, taken to be at temperature 298 K.

ii The k-epsilon turbulence mode; is used.

iii No-slip is assumed for the gas at all moving surfaces, i.e. the wall and bed surface.

iv The roughness used is 1 mm for the wall and 14 mm for the bed surface.

v The walls are treated as rotating.

vi Internally the bed is treated as a solid static body, because modeling of internal circulation of granular material in the bed is not necessary to investigate the gas flow. Motion of gas within the interstices is ignored.

For grid independency test, four different meshes are created and the model is applied for different meshes.

Due to the lack of experimental and/or reported data for the complete validation of the model makes it necessary to use some indirect methods to carry out model validation. In this paper validation of the model is used with the data reported by Davies et al.[2].

RESULTS AND DISCUSSION

Simulation of experimental kiln

First, the model was applied to the experimental scale kiln reported by Davies et al.[2]. Local gas velocity measurements were made at a location 0.1 m from the cylinder exit showed in Figs. 2 and 3. Figure 2 shows axial air flow velocity in x direction and Figure 3 shows axial air flow velocity in y direction. As can been seen in Figs. 2 and 3 the CFD results of the present simulation have good conformity with the reported experimental results[2].

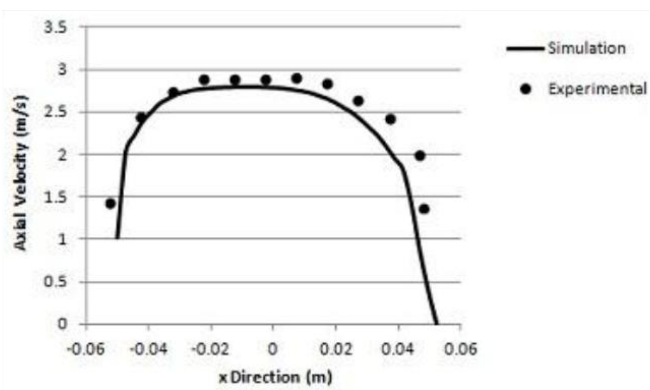

Figure 2 : Axial air flow velocity in x direction

Figure 4 shows computed axial velocity contours over a cross section 0.1 m from the cylinder exit, which shows good agreement with experimental and CFD results. As shown in Figures. 2, 3 and 4, flow asymmetry is evident with a region of slower flows near the foot of the rolling bed.

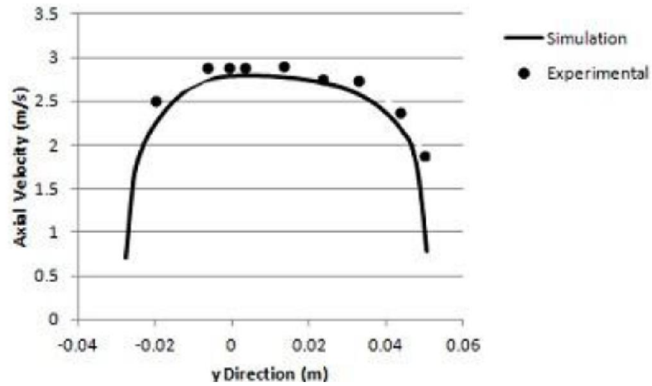

Figure 3 : Axial air flow velocity in y direction

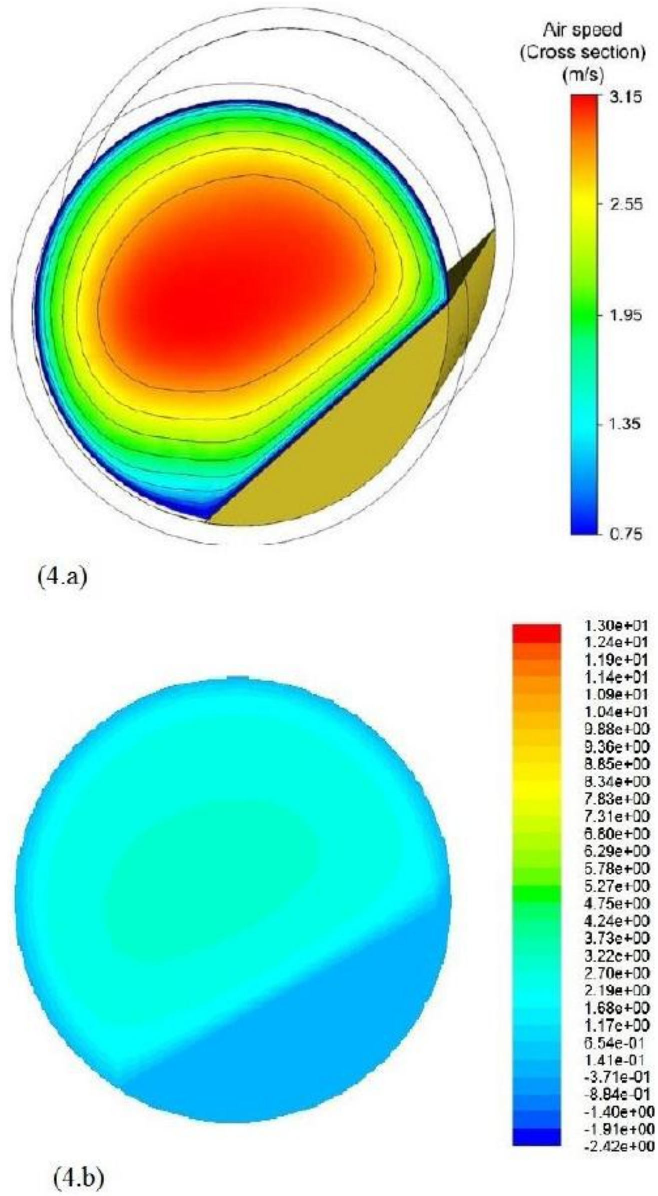

Figure 4 : Axial velocity contours over a cross-section 0.1 m from the air outlet end of the cylinder (4.a: Davies et al. simulation, 4.b: present work)

Simulation of industrial kiln

For grid independency test, model was applied on four meshes with different cells (Mesh 1: 2988000 cells, Mesh 2: 3990400 cells, Mesh 3: 5170400 cells and Mesh 4: 5991200 cells). Results related to different meshes are displayed in Figure 5. Axial velocity in x direction at a location 4 m from the kiln exit is shown in this Figure As can be seen, with increasing the mesh number the difference between the results decreases. Increase of the mesh more than 3990400 cells has not considerable effect on the results.

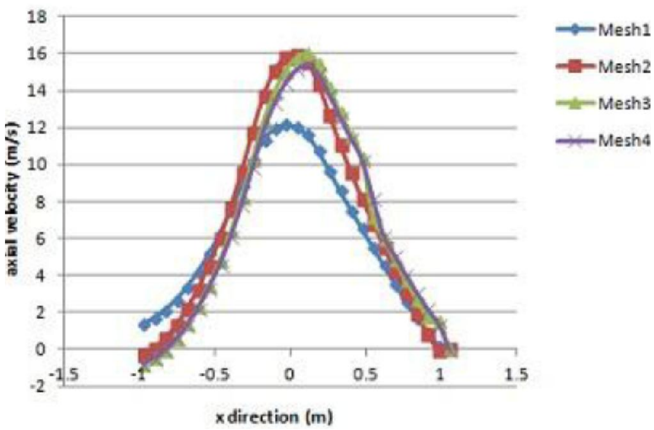

Figure 5 : Axial velocity in x direction for different meshes

Figure 6 shows axial velocity contours over the axis of cylinder at the central plate. The computation results show that a jet is formed the inlet of the kiln, and its main effect is in the first 5 meter of the kiln inlet. As can be seen the flow is fully developed near the discharge end.

Figure 7 shows computed axial velocity contours over different cross sections from kiln. Asymmetric flow

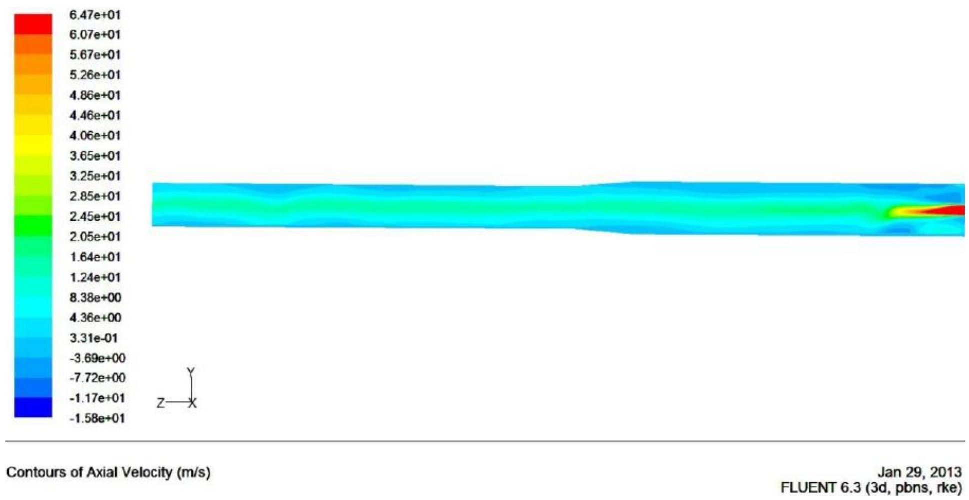

Figure 6 : Axial velocity contours over the axis of cylinder and central plate

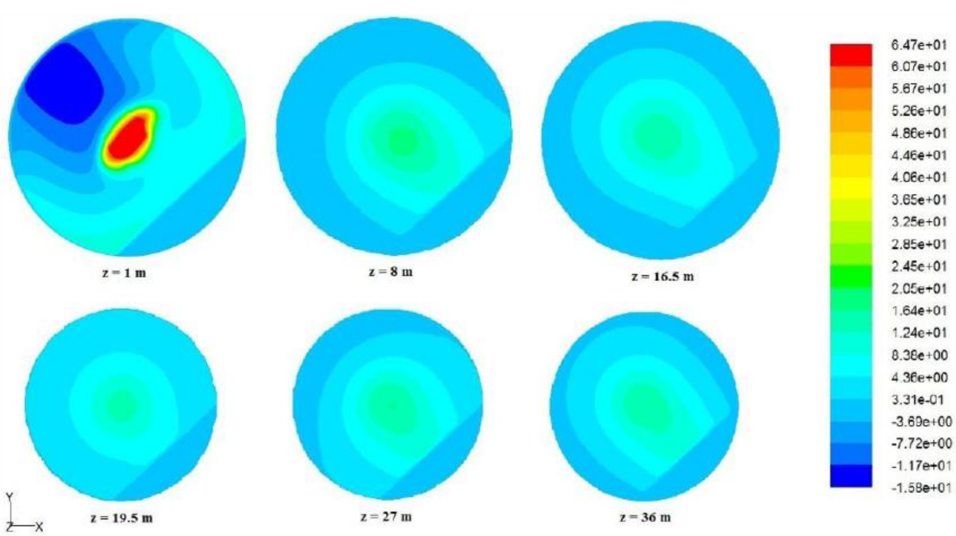

Figure 7 : Axial velocity contours over different cross sections from kiln

can be seen in different sections of the kiln. The computational results clearly show the assumption that the air flow pattern in the rotary kiln is not similar to that in a duct. Estimation of the gas-wall and gas-bed heat transfer coefficients based on the pipe flow correlations do not predict these parameter correctly.

CONCLUSIONS

Modeling and simulation of an experimental kiln is done with the available literature and the results are used for simulation of an industrial kiln. The industrial kiln is producing granular lightweight aggregates. The gas velocity profile has been estimated to be asymmetric with respect to a diameter perpendicular to the granular bed with a region of slower flows near the foot of the rolling bed. These results are similar in experimental and industrial scale kiln. The asymmetry is contrary to a common assumption in modeling that of plug flow. In industrial scale kiln the entry length that jet formation at the inlet can be seen in approximately 5 m. The results presented here indicate that the bed-gas interaction is significant on the scale of the apparatus. The implication for the modeling of heat transfer warrant further investigation.

REFERENCES

[1] A.A.Boateng; Rotary Kilns, First Edition, Elsevier; United States of America, **(2008)**.

[2] P.R.Davies, M.J.S.Norton, N.D.Wilson, J.F.Davidson, D.M.Scott; Gas Flow in Rotary Kilns, Particuology, **8**, 613-616 **(2010)**.

[3] P.V.Barr, J.K.Brimacombe, A.P.Watkinson; A heat-transfer model for the rotary Kiln: Part II. Development of the cross-section model, Met Trans B, **20B**, 403–419 **(1989)**.

[4] J.K.Brimacombe, A.P.Watkinson; Heat transfer in a direct-fired rotary kiln. I. Pilot plant and experimentation, Metallurgical Transactions B: Process, Metallurgy, **9**, 201–208 **(1978)**.

[5] S.H.Tscheng, A.P.Watkinson; Convective heat transfer in a rotary kiln, The Canadian Journal of Chemical Engineering, **57**, 433–443 **(1979)**.

[6] R.T.Bui, G.Simard, A.Charette, Y.Kocaefe, J.Perron; Mathematical modeling of the rotary coke calcining kiln, Canadian Journal of Chemical Engineering, **73**, 534–545 **(1995)**.

[7] M.Georgallis, P.Nowak, M.Salcudean, I.S.Gartshore; Modelling the rotary lime kiln, The Canadian Journal of Chemical Engineering, **83**, 212–223 **(2005)**.