Flow Behaviour in the calciner of cement production

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Abstract Calciner was one of the cement production unit that used momentum, heat, mass distribution and chemical reaction to change calcium carbonate into calcium oxide. One of the important processes was fluid flow. Thus, the computational fluid dynamic was used to predict the flow behavior in the calciner. Regarding gas hydrodynamics, the Navier-Stokes equations were applied along with all practical operating conditions. The simulation results showed that both sides of calciner had the same velocity. High velocity was originated from decreasing of flow area. The velocity in the conjunction zone between TAD and Kiln had high unsteady velocity distribution but, in the higher level, the velocity approached a steady state. This simulation model could be used as a preliminary data in order to predict the temperature distribution.

1. Introduction
Cement is considered as the crucial substance in the construction of buildings because it is a material for production of concrete which is strong and resistant to the environment. Cement is mainly composed of limestone and additives such as silica, alumina, iron, gypsum, etc. The cement production process involves the addition of limestone and additives through a heat treatment process at 850 - 1,400°C. The process can be divided into two steps; the first step is the pre-combustion between hot gas and fuel including gas, coal and biomass. In the combustion chamber or calciner, the temperature is set between 850 - 900°C [1]. Calcium carbonate is cracked called calcination. The second step, the substrate after calcination is fed to the rotary kiln to produce the clinker at temperature between 1,200 – 1,400°C. Then clinker crushed together with gypsum called Portland
cement. The energy required in cement production is supplied by electricity and thermal energy. In the manufacturing process, thermal energy is used mainly during the burning process [2].

The cement production industry is another industry that has released CO$_2$ from the production process and uses heat energy from the enormous amount of fuel used. In the production of 1 metric tons of cement products, CO$_2$ emissions can be reached by up to 1 metric ton of CO$_2$, especially in the Calcination process, which is one of the cement production processes at 60% of CO$_2$ generated in this process another 35% of CO$_2$ emissions are caused by the combustion of the kiln fuel and inside the preheating pipe. [3]

As shown in figure 1, the cement production process begins with the crushing of limestone i.e. CaCO$_3$ which is the main raw material for cement production. After that, add additives such as clay, clay, sand and iron to make it a raw material. There is an appropriate proportion to cause chemical reactions as in equation (1) to become cement. The next step is to bring all the raw materials to mix (Grinding) and get the product out in the form of raw meal. After that, bring the raw meal into the same form (Homogenization) and leading to the next step of burning [7].

$$CaCO_3 \xrightarrow{1,160^k} CaO + CO_2 + 178 \frac{kJ}{mol}$$ (1)

The advantages of generating calcination before importing raw materials into the furnace are increasing the temperature caused by the calcination process. The calciner will allow more space for the combustion capacity within the furnace because some of the raw materials are heated and removed in the form of CO$_2$, making it possible to extend the time of the furnace and reduce fuel demand for heat production in furnaces and reduce hot waste gas emissions to the external environment [8].

Based on the above information, controlling the occurrence of calcination within the calciner is extremely important in controlling the total fuel consumption that occurs in the cement production process. As well as directly affecting CO$_2$ emissions caused by cement production. Therefore, in order to be able to use the calciner to achieve the highest efficiency, this study aims to investigate the flow behavior within the calciner using a computational fluid dynamic (CFD).

2. Simulation Approach

COMSOL MULTIPHYSICS was used to model the flow pattern in the calciner. The structure of calciner consisted of cylindrical and conical sections. There were three inlets located on the bottom
section i.e. kiln and TAD (Tertiary Air Duct), and two outlets on the top section as shown in figure 2. The detailed geometry of calciner was summarized in table 1.

![Figure 2. Geometry of calciner unit in cement production plant](image)

![Figure 3. Mesh generation of the calciner model](image)

### Table 1. Geometry of the calciner.

| Part of calciner | Length (m) |
|------------------|------------|
| Calciner height  | 58.6       |
| Kiln diameter    | 5.20       |
| TAD diameter     | 2.04       |

The three dimensional flow field was obtained by solving conservation equations i.e. the Incompressible Navier – Stokes and the Continuity equations at steady state as shown in equation (2) and (3).

\[
\nabla \cdot \left( \eta \left( \nabla u + (\nabla u)^\top \right) \right) + \rho (u \cdot \nabla)u + \nabla p = 0 
\]

\[(2)\]

where \( \eta \) denotes the dynamic viscosity, \( u \) the velocity vector, \( \rho \) the density of the fluid, and \( p \) is the pressure.

\[
\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0
\]

\[(3)\]

where \( \rho \) denotes the density of the fluid, \( t \) is time and \( u \) is flow velocity vector field. In subdomain setting, air with density of 1.225 kg/m\(^3\) and the viscosity of 1.81x10\(^{-5}\) kg/m\(\cdot\)s were used in the simulation. The inlet velocity of Kiln and TAD were set from the industrial operation flow rate i.e. Kiln’s inlet velocity was 29 m/s and TAD’s inlet velocity was 30 m/s. The outlets conditions were atmospheric pressure. All wall boundaries were set as No-Slip boundary conditions. In the mesh
generation stage, the discretized mesh consisted of 379,744 cells as shown in figure 3. In the mesh generation stage, the type of mesh was tetrahedral and the discretized mesh consisted of 379,744 cells as shown in figure 3.

3. Result and discussion
The main features of the flow were shown in figure 4. The velocity contour was displayed as 3D slices. In figure 4(a) and figure 4(b), it could be observed that the gas velocity was changing from the specified value of 29 m/s to the higher velocity (marked with 1) near the combustion zone. The cross sectional area of kiln in x-z plane was 21.23 m². The velocity changed from 35 to 56 m/s in the combustion zone with the cross section area in x-y plane of 11.78 m² (marked with 2). Due to the decreasing surface area, the velocity in the area marked 2 exhibited high flow. Because of the expansion of the surface area in the conjunction zone of TAD and Kiln (marked with 3), the velocity varied between 15 - 40 m/s. In figure 4(a), it can be observed that the velocity of fluid is mainly high again in in the upper of calciner. The fluid flew out with the velocity about 38 m/s to 40 m/s to the atmosphere at the outlets.

![Figure 4](image-url)

**Figure 4.** Gas velocity contour in the vertical x-z plane: (a) overall view and (b) enlarged view in combustion zone.

Figure 5 shows the variation of velocity field on the left and right sides of the calciner. Both inlets were located at z = -30 m. The velocity of both sides was increased to about 50 – 54 m/s at z = -26. At z = -22 m, the velocities on both sides didn’t change because of the mixing of TAD inlet and Kiln inlet. At z = -20 m, both velocities mixed and hot air flew through the upper part. At z = 20 m, the velocity was uniform due to strong mixing.
Figure 5. (a) Velocity magnitude both side of combustion zone in different distance in z-axial, (b) Distance of considered velocity magnitude in both calciner side.

Figure 6 shows the overview of velocity vector. It can be observed that the velocity from all of inlets are mainly in sideward in axial y then when the velocity came to the combustion zone the direction of velocity mainly inform in upward direction because of the fix of geometry combustion zone then with the curve of the calciner it made velocity inform to downward direction to blown out.

Figure 6. (a) Velocity vector of calciner in z-x plane, (b) Velocity vector.

4. Conclusion
The computational fluid dynamic presented the velocity distribution at various locations in the calciner. With the fluctuation of high velocity in the combustion zone, the velocity distributed consistently in the upper part of calciner. Finally, with uniform distribution of velocity, it would cause the heat transport.

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