Computational Fluid Dynamics Modelling and Experimental Study on Pressure drop through Vertical Packed Clay Composite Pellets

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Abstract: The importance of computational fluid dynamics in the field of packed bed medium is acceptable due to the high-end processor power availability. The studies of the literature have presented the feasibility of CFD as an advanced practical tool for estimating the pressure drop through the packed porous medium. In this work, a CFD model was evolved to simulate the pressure drop through vertical clay pellets packed bed by using CFX analysis. Experiments are conducted to measure the pressure drop across vertical static clay composite pellets bed. The maximum deviation between CFD analysis and experimental results for pressure drop through 500 mm bed height is 13%.

1. Introduction
Packed bed arrangements are commonly used in chemical, absorption, distillation, stripping, catalytic conversion, metallurgy, nuclear industries, thermal storage, building heating and cooling [1]. The important engineering component of the packed bed systems are pressure drop, dispersion, heat and mass transfer. Pressure drop is of prime parameter for the design and configuration of packed bed reactors [2]. Frictional factors during fluid flow and inertia effects are the two causes that result in pressure loss. The drop in pressure along the vertical static bed is dependent on process air and bed parameters. The process air parameters are viscosity, density and velocity. The parameters related to bed are shape and position of particles, void volume, particle periphery roughness and bed to particle diameter ratio. Particle porosity, specific surface area and mean pressure drop across the bed are most indicative factors for the design of packed bed systems [3].

The complex phenomenon of flow of process fluid through packed bed of spheres is parameter dependent. The most convincing way to estimate pressure drop across a packed column is to conduct experiment on actual system. It is costly to build the real system in practice, commonly tests are performed on virtual model of actual arrangement. It involves required geometry generation, transporting fluid through the bed and pressure drop measurement using manometers. This regular mode is also a moderately time intensive and uneconomical.

The flow parameters inside the packed beds are investigated using magnetic resonance imaging (MRI). The other technique is computed tomography (CT). The short coming of these techniques leads toadaptation of other methods for packed beds. Though empirical correlations such as Ergun mathematical statement is employed to find the pressure drop, computational fluid dynamics (CFD) has become a feasible solution to adopted methods. The complexity of packed pressure drop...
can be better understood by CFD with respect to pressure and velocity field profiles. The simulation data proves to be in agreement with the values estimated from empirical counterpart [4].

CFD, is appropriate for the researchers to understand the pressure drop dynamics of fixed beds. It arranges a numerical tool that can precisely demonstrate the fluid flux over the porous packed beds with the focus on pressure drop prediction. The first part of the present work involves CFD modeling and simulating the pressure drop flow patterns in vertical firm bed comprising spherical shaped clay additive pellets.

Though the CFD models provide virtual design and data but the more development still depends on experimental verification. In the second segment experiments are conducted through vertical packed clay additives composite pellets. Finally, the experimentally measured pressure drop values are compared with CFD pressure drop values.

2. Simulation
The numerical analysis work is carried out in two steps, initially design is done using CATIA V5 and analysis is carried out using Computational Fluid Dynamics (CFD). A drafting of 3D model is generated in CATIA, dimensions are indicated. A complete detail view of pellets is shown with scale of 3:1. A model of packed bed and granules is prepared using CATIA V5 software. A cylinder of length 0.5 m, inside 0.05 m and outside of 0.052 m diameter is created. Inside the cylinder the balls of 0.01 m diameter are created. The virtual models created are presented in Figure 1.

![Figure 1. Design of solid three-dimensional models for cylindrical bed and spherical pellets](image)

![Figure 2. (a)Mesh imported for the solid geometry of packed bed system and (b)Pressure contours generated for packed bed system](image)
To generate fine mesh 388803 nodes and 1851886 elements are considered. Quad meshing elements and triangular meshing type are adopted and the mesh is created for imported model. The mesh produced is presented in Figure 2(a). The pressure distribution presented in Figure 2(b) shows inlet pressure as 99.99 kPa and outlet pressure is 99.730 kPa. Medium intensity and eddy viscosity ratio turbulence model is considered for clay bed domain. Subsonic flow regime is considered for the analysis at atmospheric pressure of 1 bar and with air density of 1.145 kg/m³.

3. Experimental work

Experimental work goes in two stages. The first part of the work involves preparation of spherical shaped 0.01 m clay - horse dung pellets. The heat treatment at 500°C produces burnt clay composite particles or pellets. Second part of work experiments are conducted to investigate pressure drop of burnt clay - horse dung of different size and shape. The clay and additive horse dung are collected from a local pot maker. The clay and horse dung are manually cleaned and processed by using a sieve. Horse dung of 20 g per 100 g of clay is mixed and pasty clay composite material is produced. Water is added to produce the pasty and dough clay material. The pasty raw material is then molded manually to a size of 0.01 m spherical shape. The fabricated pellets are shadow dried and then heated in a muffle furnace of 3.5 kW capacities. The prepared samples are heated to a temperature of 500°C for the duration of one hour. The pellets are air cooled to cool in the furnace. Finally, prepared samples are weighed and checked for identical weight and shapes. The second part of experimental work involves setting and arranging the experimental set up. The lab scale arrangement is drawn in Figure 3.

![Figure 3. Schematic layout of experimental setup](image)

The air from the reciprocating air compressor is made to flow through the galvanized iron pipe of 0.025 m. The atmospheric air drawn by the compressor is stored in air tank. The air from the air tank is let into the packed bed. The gate valves are used to direct and control the flow of air through the pressure line and the bed. A calibrated orifice meter with diameter 0.010 m and with discharge coefficient of 0.68 is used to find the volume flow rate of process air. The estimated bed inlet velocities are from 0.5 to 2 m/s. The vertical column is made of perspex or acrylic material enables visualization of cylindrical vertical packed bed. The height of the column is 0.5 m and the diameter is 0.05 m. The column is connected to the pressure line by a flange. A U-tube manometer connected across the column measures the bed pressure drop.

4. Results and Discussion

The prediction of pressure drop characteristics of static beds of spherical shaped clay composite pellets is carried by CFD. The experimental measurements for drop in pressure through vertical packed
spherical clay pellets having a bed to particle diameter ratio of 5 are recorded. The effect of changing the bed mass and bed inlet velocity on pressure drop across the vertical packed bed is presented. As presented in Figure 4, for the fixed bed mass of 250 g and 500 g and for the increase in bed inlet velocity results in higher drop in pressure. The inertial and viscous effects causes pressure drop. At lower velocities the inertial effects causes pressure drop, whereas at higher velocities viscous effects are prime to cause the pressure drop through the packed bed. The frictional losses due to obstructions results in pressure loss for the fluid passing through the packed bed. With increase in bed height and for the identical bed inlet velocities the resistance to flow increases. Due to increase in friction and resistance the pressure drop increases.

**Figure 4.** Variation in pressure drop with velocity for 250 mm and 500 mm bed heights.

The comparison of simulated and experimental pressure drop values for bed height of 500 mm and bed inlet velocity of 1 m/s are graphically shown in Figure 5. The comparison shows lower values of pressure drop values as depicted by simulation. The deviation between experimental and CFD results is due to complexity of flow phenomenon through the packed beds.

**Figure 5.** Comparison of theoretical and experimental pressure drop values
5. Conclusion
A CFD model was developed for simulating the pressure drop of process air through vertical packed clay pellets. The observation of experimental measurements shows good agreement with the CFD simulation. The CFD analysis and experimental results for packed bed of 500 mm height with inlet pressure of 1bar yielded the pressure drop of 260 Pa and 294 Pa respectively. The deviation between simulation and experimental values is about 13%. In consequence to this study, it is inferring that using CFD could dispense useful data for the pressure drop through packed bed systems and better predict the pumping power required.

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