Modelling and Fabrication of a Capacity Air Blower and the Vertical and Horizontal Experimental Hydrodynamics on Circulating Fluidised Bed (CFB) Riser Reactor Systems

M. N. Idris* M. N. Adamu and **S. Salisu**
Faculty of Engineering
Department of Chemical Engineering
University of Maiduguri
Borno State, Nigeria
Tel: +234 (0) 705 877 1096
Email: idrismn@hotmail.com

ABSTRACT

CFB riser reactor are used widely in chemical processing industries for separations, rapid mass and heat transfer operations and catalytic reactions, because it offers excellent heat transfer and have the unique ability to move a wide range of solid particles in a fluid-like fashion at a better convenient operations. The difficulties to predict and calculate the complex mass and heat flows within the bed are the necessities to studying the fluid flow velocities; gas and solid. The hydrodynamics of air flowed in (i) vertical and (ii) horizontal fluidised bed arrangement was studied to determine the flow velocities. Other relevant parameters were used in the construction of capacity air blower, which supply the atmospheric air flown to the pilot-scale CFB rig system. The experimental results for the flow velocity, temperature and frequency were obtained from each designated probe points and along the length of the CFB riser system. It was observed that the air circulation within the riser bed is stable and flow velocity increases with respect to the length of various probe points increases along the riser column.

Keywords: *CFB; probe points; blower; pilot scale; flow velocity and hydrodynamics*

1.0 INTRODUCTION

Fluidization is a phenomenon by which fine solids are transformed into a fluid-like state through contact with gas or liquid or by both gas and liquid. It is a fluid-solid contacting technique, which has found extensive industrial applications (Padhi et al.,2014). Fluidized beds are used widely in chemical processing industries for separations, rapid mass and heat transfer operations, and catalytic reactions. A typical fluidized bed is a cylindrical column that contains particles and through which fluid, either gaseous or liquid, flows. In the case of fluidized bed reactors, the particles would contain a catalyst, and for separations, the particles might be an absorbent or adsorbent. The velocity of the fluid is sufficiently high to suspend, or fluidize, the particles within the column, providing a large surface area for the fluid to contact, which is the chief advantage of fluidized beds. Fluidized beds range in size from small laboratory scale devices to very large industrial systems. Regardless of whether the fluidized bed is used for a separation or reaction, a key goal is to operate the bed at a flow rate that optimizes the application U O F (2015).

Investigations relating to various aspects of fluidization as a novel fluid-solid contacting technique is being carried out since the world war–II, and numerous process applications have been made based on these techniques like drying, adsorption and chemical processes such as combustion, carbonization, gasification and solid-catalysed reaction (Padhi et al.,2014). Accurate models would aid significantly, but modelling, even at a qualitative level, of the complex dynamics in fluidized beds continues to challenge engineers and scientists U O F (2015). The challenge arises from the necessity of considering both the solid and fluid phases and the interplay between them to form a complete picture for understanding the properties of fluidization. Therefore, there is need for enhanced understanding of the hydrodynamics of CFB in order to facilitate the reactor design and selection of appropriate operating conditions to achieve the desired fluidization regime Idris and Burn (2008).

1.1 Problem Statement
Some work has been done, but much is still needed to be carryout. It is quite difficult to predict and calculate the complex mass and heat flows within the bed and the necessities for the fluid to suspend the solid materials make it necessary that a higher fluid velocity be attained in the reactor. Therefore, the need for the development and construction of a pilot scale CFB rig reactor systems to carry out experimental studies is required.

2.0 BACKGROUND STUDIES
The fluidized-bed riser (FBR) reactor has the ability to process large volumes of fluid in an economic ways. For example, the catalytic cracking of petroleum naphtha to form gasoline blends, the virtues of the FBR drove its competitors from the market. Fluidization occurs when small solid particles are suspended in an upward flowing stream of fluid.

The fluid velocity (U_f) is sufficient to suspend the particles, but it is not large enough to carry them out of the vessel. The solid particles swirl around the bed rapidly, creating excellent mixing among them. The material 'fluidized' is almost always a solid and the 'fluidizing medium' is either a liquid and/or gas. The characteristics and behaviour of a fluidized bed are strongly dependent on both the solid and liquid or gas properties. Nearly all the significant commercial applications of fluidized-bed technology concern gas-solid systems. The material that follows is based upon what is seemingly the best model of the FBR developed thus far–the bubbling bed model of Kunii and Levenspiel (1991).

2.1 The Phenomena of Fluidisation Regime
Consider a vertical bed of solid particles supported by a porous or perforated distributor plate, as shown in Figure 1 where the direction of gas flow is upward through this riser bed.

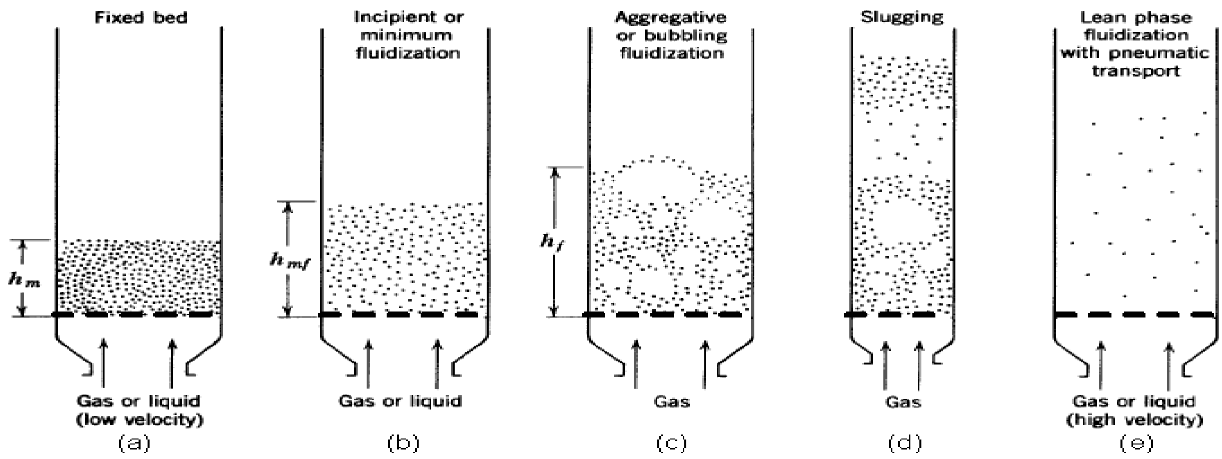

Figure 1 Various kinds of contacting of a batch of solids by fluid. Adapted from Kunii and Levenspiel (1991).

There is a drag exerted on the solid particles by the flowing gas, and at low gas velocities the pressure drop resulting from this drag will follow the Ergun model as described in Eq. (1), just as for any other type of packed bed. When the gas velocity is increased to a certain value however, the total drag on the particles will equal the weight of the bed, and the particles will begin to lift and barely fluidise. If ρ_c is density of the solid catalyst particles, *A*c is the cross sectional area, h_s, is the height of the bed settled before the particles start to lift, *h*, is the height of the bed at any time, ε and ε_s are the corresponding porosities of the settled and expanded bed, respectively; then the mass of solids in the bed, *W*s, is

$$W_S = \rho_C A_C h_C (1-\varepsilon_S) = \rho_C A_C h(1-\varepsilon) \quad (1)$$

This relationship is a consequence of the fact that the mass of the bed occupied solely by the solid particles is the same no matter what the porosity of the bed. When the drag force exceeds the gravitational force, the particles begin to lift, and the bed expands (i.e., the height increases) thus increasing the bed porosity, as described by Eq. (2). This increase in bed porosity decreases the overall drag until it is again balanced by the total gravitational force exerted on the solid particles (Figure 1(b)).

If the gas velocity is increased still further, expansion of the bed will continue to occur; the solid particles will become somewhat separated from each other and begin to jostle each other and move around in a restless manner. Increasing the velocity just slight amount further causes instabilities, and some of the gas starts bypassing the rest of the bed in the form of bubbles (Figure 1(c)). These bubbles grow in size as they rise up the column. Coincidentally with this, the solids in the bed begin moving upward, downward, and around in a highly agitated fashion appearing as a boiling frothing mixture. With part of the gas bubbling through the bed and the solids being moved around as though they were part of the fluid, the bed of particles is said to be 'fluidized'. It is in a state of aggregative, non-particulate, or bubbling fluidization (FBRs), Kunii and Levenspiel (1991).
A further increase in gas velocity will result in slug flow (Figure 1(d)) and unstable chaotic operation of the bed. Finally, at extremely high velocities, the particles are blown or transported out of the bed (Figure 1(e)). The range of velocities over which the Ergun equation applies can be fairly large. On the other hand, the difference between the velocity at which the bed starts to expand and the velocity at which the bubbles start to appear can be extremely small and sometimes non-existent (Fluidized-Bed Reactors). This observation means that if one steadily increases the gas flow rate, the first evidence of bed expansion may be the appearance of gas bubbles in the bed and the movement of solids. At low gas velocities in the range of fluidization, the rising bubbles contain very few solid particles. The remainder of the bed has a much higher concentration of solids in it and is known as the *emulsion phase* of the fluidized bed. The bubbles are shown as the *bubble phase*. The cloud phase is an intermediate phase between the bubble and emulsion phases Levenspiel, (2007).

After the drag exerted on the particles equals the net gravitational force exerted on the particles, that is, the pressure drop will not increase with an increase in velocity beyond this point. (Refer to Figure 1 above).

$$\Delta P = \left(\rho_c - \rho_g\right)(1-\varepsilon)h \qquad (2)$$

From the point at which the bubbles begin to appear in the bed, the gas velocity can be increased steadily over a quite appreciable range without changing the pressure drop across the bed or flowing the particles out of the bed. The bubbles become more frequent, and the bed, more highly agitated as the gas velocity is increased (Figure 1(c)); but the particles remain in the bed. This region is bubbling fluidization. Depending on the physical characteristics of the gas, the solid particles, and the distributor plate; and the internals (e.g., heat exchanger tubes) within the bed, the region of bubbling fluidization can extend over more than an order of magnitude of gas velocities (e.g., 4 to 50 cm/s in Figure 2). In other situations, gas velocities in the region of bubbling fluidization may be limited; the point at which the solids begin to be carried out of the bed by the rising gas may be a factor of only three or four times the velocity at incipient fluidization[2]. Eventually, if the gas velocity is continuously increased, it will become sufficiently rapid to carry the solid particles upward, out of the bed. When this begins to happen, the bubbling and agitation of the solids are still present, and this is known as the region of fast fluidization, and the bed is known as *fast-fluidized bed*. At velocities beyond this region, the particles are well apart, and the particles are merely carried along with the gas stream. Under these conditions, the reactor is usually referred to as a *straight through transport reactor* or STTR (Figure 1(e)).

The various regions described earlier display the behaviour illustrated in Figure 2.2. This figure presents the pressure drop across a bed of solid particles as a function of gas velocity. The region covered by the Ergun equation is the rising portion of the plot (Section I: 1 < U_0 < 4 cm/s). The section of the figure where the pressure drop remains essentially constant over a wide range of velocities is the region of bubbling fluidization (Section II: $4 < U_0 < 50$ cm/s) FBR. Beyond this are the regions of fast fluidization and of purely entrained flow Kunii and Levenspiel (1991).

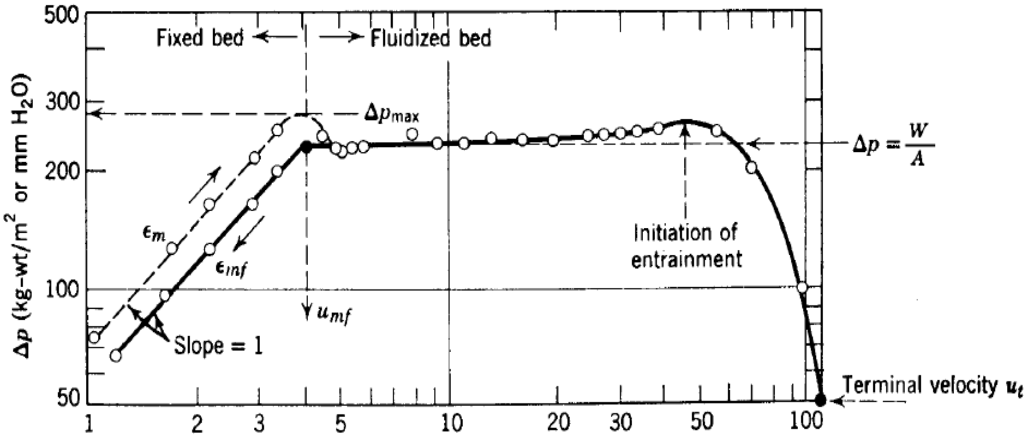

Figure 2 pressure drop across a bed of particles as a function of a gas velocity, Kunii and Levenspiel (1991).

2.2 Minimum Velocity of Fluidization

The minimum velocity at which a bed of particles fluidizes is a crucial parameter needed for the design of any fluidization operation. The details of the minimum velocity depend upon a number of factors, including the shape, size, density, and polydispersity of the particles. The density, for example, directly alters the net gravitational force acting on the particle, and hence the minimum drag force, or velocity, needed to lift a particle. The shape alters not only the relationship between the drag force and velocity, but also the packing properties of the fixed bed and the associated void spaces and velocity of fluid through them. To find the minimum fluidizing velocity, U_{mf}, experimental and theoretical approaches can be used. Methods for calculating the flow rate at which fluidization occurs are described first, as a review of fundamental ideas that govern the behaviour of the bed of particles. Then, a procedure for estimating the minimum velocity from experimental measurements is described in U O P (2015).

3.0 MATERIALS AND METHODOLOGY

3.1 Air Blower

Air blower is a mechanical device for moving air or other gases. These fans increase the speed of air stream with the rotating impellers UNEP (2006). They use the kinetic energy of the impellers or the rotating blade to increase the pressure of the air/gas stream which in turn moves them against the resistance caused by ducts, dampers and other components.

3.1.1 Fabrication of Air Blower

Main parts of air blower are; (i) fan housing, (ii) impellers, (iii) inlet and outlet ducts, (iv) drive-shaft and (v) drive mechanism.

3.1.2 Materials used for Fabrication

The materials used for the construction are; (i) mild steel, (ii) high carbon steel, (iii) sand casting (developed at various stages) and sand molding at various stages. The design specification of the fabricated air blower is given below in Table 1.

Table 1 Designed air blower components with their specifications

S/N	Components	Units	Specifications
1	Fan house diameter	(m)	0.305
2	Fan house thickness	(m)	0.010
3	Inlet Air ducts diameter	(m)	0.053
4	Outlet air duct diameter	(m)	0.071

5	Outlet air duct thickness	(m)	0.005
6	Impellers	Blades	8
7	Blades thickness	(m)	0.002

3.2 The CFB Experimental Equipments

The equipments used in this research project are stated as follows; (i) control panel, (ii) Bypass valve for air, (iii) power switch for air blower, (iv) power supply for control panel, (v) column for air 10 Bypass valve for air, (vi) CFB riser reactor, (vii) cyclone, (viii) anchor rope, (ix) silicon gum, (x) damper rubber (cork) and (xi) razor.

3.3 Experimental Procedure

The experimental setup is shown as depicted in Figures 3 – 6 below. In each case, the equipment is sufficiently connected to provide the data that can be used to determine the gas flow-velocities at various probe-points along the CFB riser reactor systems.

3.3.1 Operating Procedure

The following text lists the operating procedures for the experiment.

3.3.1.1 Start-up

A vertical set-up of CFB riser rector was installed as shown in Figure 3(a). The power supply was sufficiently connected as required and all Safety was observed. The thermocouples cables from the CFB riser were connected to the control panel. All the hose were properly secured at the designated points. The needle valve was fully closed to tight on the inlet region of the CFB riser reactor. All checks were confirmed to ensure that everything were in the right position. Finally, the air blower was ON and the operations were properly conducted.

3.3.2 Shut-down

The steps to shut-down procedure are as follows. Firstly, bypass valves for air must be fully open at this stage. Then, the air blower was turned-off. The power supply was disconnected.
Then finally, the cables from the control panel were disconnected.

(a) Vertical CFB riser reactor (b) Mounted air blower

Figure 3 Vertical CFB riser systems experimental step-up. (Monday, 23rd May 2016, 10:30:59 AM)

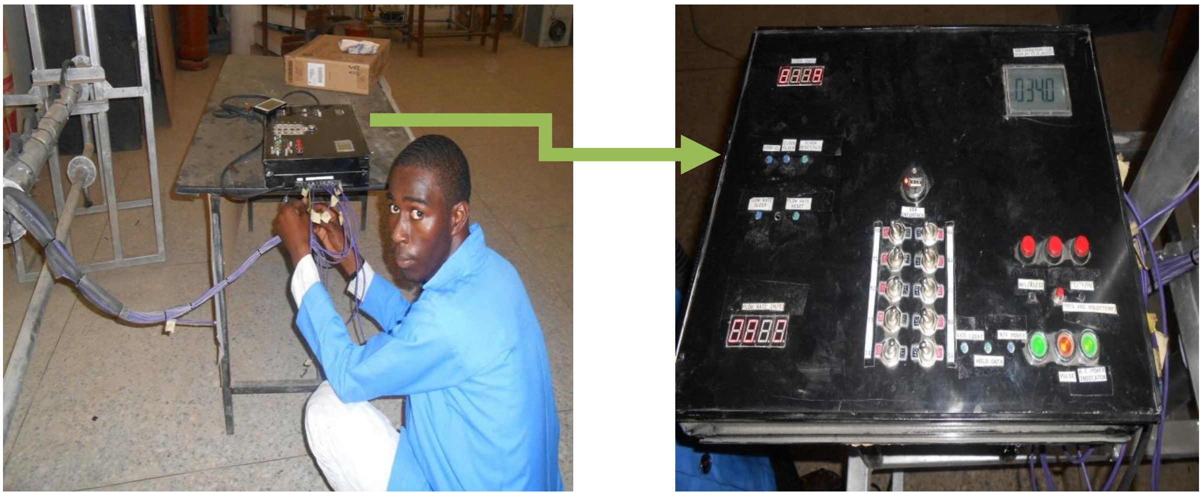

Figure 4 Stage connections of probe-point cables to sensor pots (Tuesday, May 24, 2016, 10:55:11 AM)

3.3.3 Calibration of the Temperature vs. Frequency

The steps used for the calibrations are stated below.

1. Air was supplied into the CFB riser systems using the air blower.
2. Respective values of the temperature and corresponding frequency were recorded.
3. The experiment was repeated and the readings were record as accurately as possible. The results were completed as at Tuesday, May 31, 2016, 12:15:14 AM).

4.0 EXPERIMENTAL RESULTS AND DISCUSSIONS

4.1 Results

Table 2 and 3 respectively shows the experimental results for vertical and horizontal set-ups of the CFB flow along the riser reactor systems. The details of all the calculations involved in this work can be found from Adamu (2016).

Table 2 Experimental results for CFB vertical arrangement

S/N	Length L(m)	Temperature T(K)	Frequency *f* (Hz)	Flow velocity U_f (m/s)
1	0	304.95	50.03	0
2	0.31	307.45	50.26	15.581
3	0.49	307.45	50.10	24.549
4	0.98	307.75	50.18	49.176
5	1.22	307.55	50.02	61.024
6	1.71	307.65	50.10	85.671
7	2.19	307.85	50.01	109.523
8	2.44	307.85	50.08	122.195
9	2.93	307.55	50.01	146.529

Table 3 Experimental results for CFB horizontal arrangement

S/N	Length L(m)	Temperature T(K)	Frequency *f* (Hz)	Flow velocity U_f (m/s)
1	0	306.65	50.00	0
2	0.31	306.35	50.01	15.50
3	0.49	306.65	50.02	24.51
4	0.98	307.75	50.03	49.03
5	1.22	307.55	50.05	61.06
6	1.71	306.95	50.05	85.67
7	2.19	306.35	50.09	109.61
8	2.44	306.55	50.01	122.21
9	2.93	306.45	50.01	146.53

4.2 Discussions of Results

Figure 5, 6 and 7 respectively depicts the comparison of the experimental results data from Table 2 and 3 with the CFD predictions of Idris et al., (2015). The flow velocity profile along the CFB riser indicates a positive gradient with respect to the riser length. In comparison with the CFD predictions, it is observed that there were some over-predictions. However, the comparisons were in good agreement.

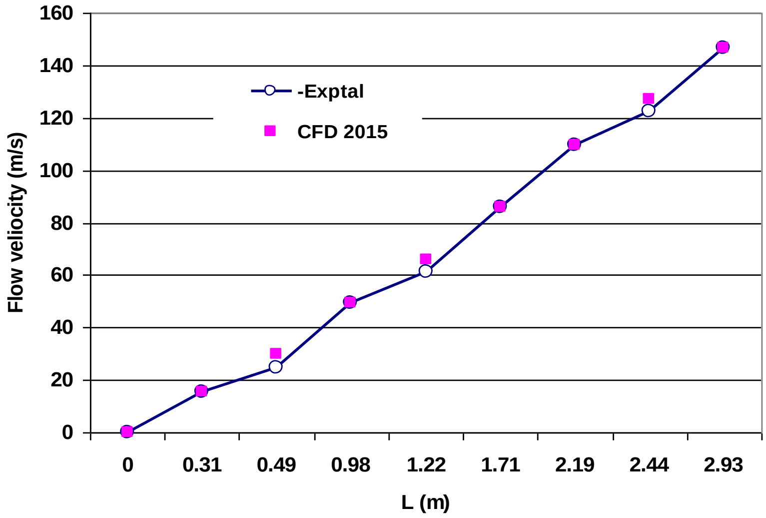

Figure 5 Flow velocity along the CFB riser system

But when we look at the minimum fluidisation velocity, U_{mf}, in classical representations, it was observed that it is a constant flow with respect to the riser length [9]. Figure 6 represent the slight and negligible changes in temperature along the CFB riser length. This temperature difference is in the range of ΔT equals 2.5 K, that is the inlet was 32^0C (305K) and the outlet was 34.5^0C (307.5K). In comparing with the CFD predictions; the inlet was 32.02^0C (305.02K) and the outlet was 35.75^0C (308.75K). It was observed that these temperatures were due to the increase in the mechanical activities of the air blower, which developed the rise in temperature, and lately became steady and finally dropped slightly. There was no heat added to the processes, the operations was in ambient temperature condition, that is, the heat dissipation noticed was practically generated from the air blower, which causes the rise in temperature above the ambient temperature. However, the CFD predictions still record steady values at the riser outlet. The disparities were not much when compared the experimental results (data) and the CFD predictions. Therefore, they are in concise agreement. The CFD predictions can be referred from the open literature as presented from (Idris et al., 2015).

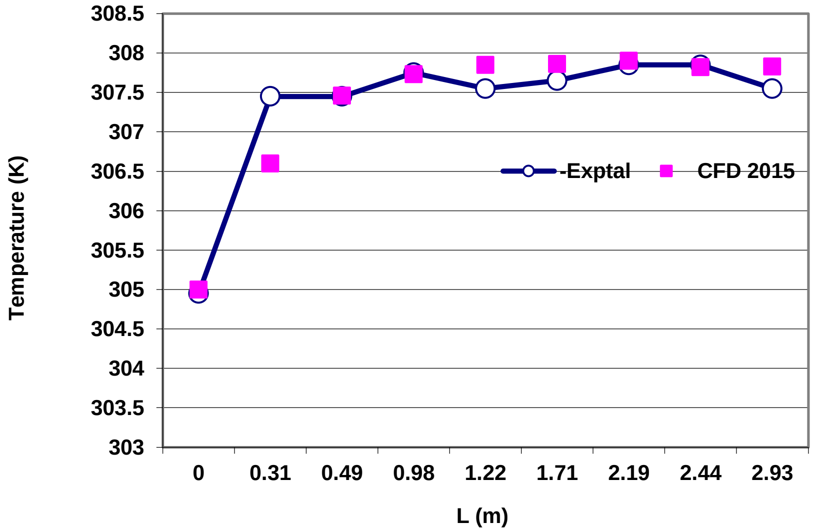

Figure 6 Temperature profile along the CFB riser

Figure 7 is a representation of frequency profile with respect to the riser length, which was recorded at various probe-points. The rapid increase is between the entering probe point and second probe point;

the second probe point is peak point. In this figure, there was a noticeable fluctuation (typically random) of the gas-flow development along the CFB riser systems. We may attribute this effect to both mechanical and electrical component devices constructed. It is very good to notice this effect, because in a situation where the flow is multiphase, e.g. gas-solid fluidisation, the back-mixing would have a significant effect to this perturbation, because back-mixing is one of the critical problems we experience in CFB riser operations (Idris et al., 2015), (Idris et al., 2016).

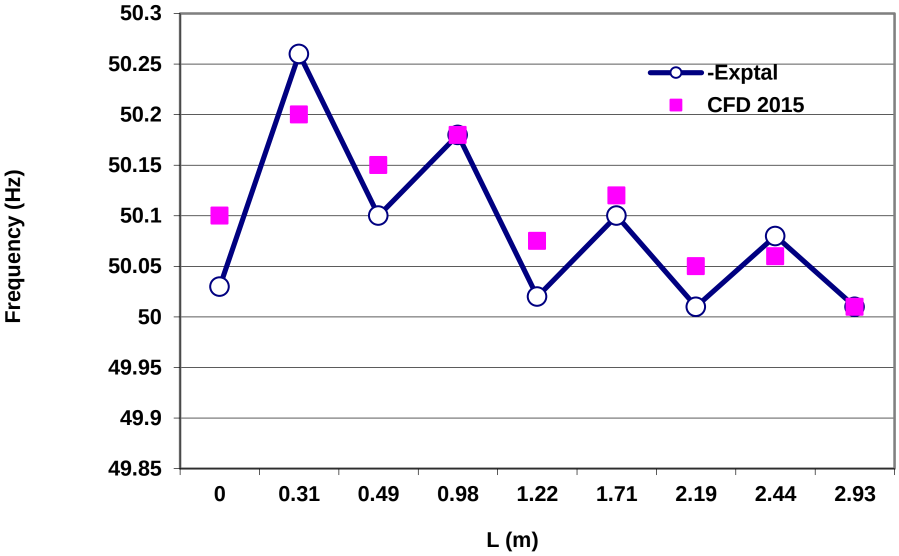

Figure 7 Frequency profile along the CFB riser

5.0 CONCLUSIONS

In conclusion, the aims and objectives of this paper were to present the achievement of using a locally designed and fabricated air blower to operate on a locally designed CFB riser rig plant successfully. The air blower comprises of both mechanical and electrical components which were assembled and it works efficiently with the CFB riser systems at an attributed revolution of 2850 rpm, power of 1Hp and air flow-rate was 6-60L/min.

The experiment on single-gas flow hydrodynamics studies were also carried out on a vertical CFB riser reactor and the following conclusions were drawn: (i) it was observed that there were noticeable positive gradient of gas flowing fluid along the riser length; (ii) the temperature is slightly stable along the riser height, the flowing frequency changes (fluctuations) along the riser height were due to mechanical implications.

List of Symbols and Abbreviations

CFB	=	Circulating Fluidised bed
FBR	=	Fluidised bed riser
G	=	gravitational acceleration (m/s^2)
H_{riser}	=	height of riser (m)
T	=	temperature (K)
UNEP	=	United Nation Education Programme

Recommendation

In this work, it is recommended that:

1. Upgrading of the control panel (sensor controller) for more accurate and precise reading, so that the fluctuation of panel readings may be error-freed.
2. The inclusion of rheostat (variable resistors) to varies the current supply to the air blower in order to achieving different kind of readings/parameters.

3. Further experiment to carry out in order to determine the pressure drop (ΔP) along the riser reactor, minimum fluidized velocity (U_f) and other relevant parameters.

REFERENCES

Adamu M. N. (2016), *'Mechanical modelling and construction of air blower and the experiment of a vertical CFB riser system'*. Unpublished B.Eng (Chemical) project report submitted to the Department of Chemical Engineering, University of Maiduguri, Borno State.

Kunii, D., and Levenspiel, O. (1991) *Fluidized Engineering* (Huntington, NY: Robert E. Krieger Publishing Co., 1977) pg. 24-56.

M. N. Idris and A. Burn (2008) *'Hydrodynamics Studies on an Injection System as Applicable to Modern Circulating Fluidized Bed (CFB) Riser using Computational Fluid Dynamics (CFD)*', AIChE centenary journal, pg. 36-46.

M. N. Idris*, B. Tijjani and F. U. Mukhtar (2015), *'Hydrodynamic studies of an injection flow-conduit using computational fluid dynamics (CFD)'*, Faculty of Engineering seminar series Vol.6, pg. 106-114

M. N. Idris*, O. Stephen and A. J. Aduma (2016), *'Studies on the flow phenomena of a designed and fabricated circulating fluidised bed (CFB) riser reactor*'. Academic journal of Engineering and Technology Research. ISSN 2006-9790

Octave Levenspiel, (2007) *'Chemical Reaction Engineering'*, (3rd edition), Prentice Hill publication, New York, pg. 447-470.

Padhi, R. K., Mohanty, Y. K., and Saranji, B. (2014), *'Hydrodynamics studies of gas-solid fluidization in non-cylinderical conduits for spherical and non-spherical particles'. International journal and research publication, 4*, pg. 14-21

UNEP (2006), 'Electrical energy equipment: fans and blowers. United Nation Education Programme.

U O F (2015). *Fluidisation: A unit operation in Chemical Engineering.* University of Florida, Department of Chemical Engineering, Florida. USA, pg. 15-51.