DEVELOPMENT OF A PORTABLE AIR FLOW DIGITAL METER FOR GRAIN DRYING

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ABSTRACT: *Technological progress allows more and more instruments to be developed for different purposes based on the prevailing need. The development of a portable air flow digital meter relied on a computer based design. Assembly language was used in writing a set of instructions that were programmed into the micro controller component of the system. This produced an interface which enabled interaction using a monitor. The codes were translated from analogue to digital using a Digital Converter (ADC) and then interpreted in a Liquid Crystal Display (LCD) in m/s. The speed of the fan or the position of the mesh-like tray regulated how moist the grain is or how fast the drying exercise is to take place. When the speed of the fan is increased, more air was produced and this led to faster drying of the grains as higher values of flow were correspondingly displayed. The meter measures values accurately to over* 1×10^{2}*m/s.*

Keywords: Airflow, Digital Meter, Grain, Drying
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INTRODUCTION

When air is forced through a bulk crop, it must travel through narrow paths between individual particles (Williams, 1993). For packaged crops, air must travel through or between individual containers. Friction along air paths creates resistance to airflow. Fans must develop enough pressure to overcome this resistance and move air through the crop.

The Agricultural Engineer is constantly exploring ways of obtaining data handling and processing, and the instruments available are often crude and prone to errors owing to their analogue format. More modern digital instruments are therefore, required and desirable.

In-bin control systems usually measure the temperature and relative humidity of the ambient air and the temperature of the grain. Some controllers also measure the relative humidity of the air in the interstices of the grain mass. The proper location of sensors in the bin is critical. Control actions are based on the maximum temperature and equilibrium relative humidity of the grain, and thus the sensors should be located where these values are likely to occur, namely in the center of the bin under the loading spout. Multiple sensors increase the chance of detecting a hot spot; the choice of the number of sensors is an economic compromise.

Modern in-bin controllers are equipped with microprocessors that allow the user to change the strategy of the control action.

It is clear that all eight of the criteria cannot be minimized simultaneously. Thus, the manager of a grain depot has to decide which performance criterion should be minimized before a microprocessor is programmed (CIGR, 1999). Higher static pressures decrease fan output. As air enters the grain, it picks up some moisture, which cools the air slightly. As air moves through a deep grain mass, the air temperature is gradually lowered and relative humidity increased until the air approaches equilibrium with the grain. If the air reaches equilibrium with the grain, it passes through the remaining grain without any additional drying. If high relative humidity air enters dry grain, some moisture is removed from the air and enters the grain. This slightly dried air will begin to pick up moisture when it reaches wetter grain. Air in a 12 to 16 inch grain column does not reach equilibrium with the grain.

THEORY

Air Flow Rate Essential in Estimating Fan Power Requirements

Fans, especially axial fans are very essential in continuous flow drying whereby they influence the speed and uniformity of drying. According to Onwualu *et al.,* (2006) the efficiency of an axial fan can be estimated using

$$\eta = P_{in}/P_{out} \quad \ldots\ldots\ldots\ldots\ldots. \quad \text{(i)}$$

η = Efficiency (%)
P_{in} = Input power (watts);
P_{out} = Output power (watts)

The flow rate of drying air is also essential in determining the power output required in the equation stated above. So

$$V\sigma h; \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \quad \text{(ii)}$$

Where,
V = Air flow rate, m^3/s
H = Pressure head, m of water
σ = Density of air kg/m^3

Wilcke and Morey (2002) in their work concluded that fans are usually described by the horsepower (hp) rating of the motor used to drive the impeller. It's helpful when selecting fans to estimate the power requirement first so you know where to start looking in the manufacturer's catalog.

Furthermore fan motor size depends on the total airflow being delivered, the pressure developed, and the impeller's efficiency. Impeller efficiencies generally range from 40% to 65%. If we assume an average value of 60%, we can use the following formula to estimate the fan power requirement.

According to Hunt (1977), the power required by such fans discussed here is given by

$$P = vh/ce \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(iii)}$$

Where;
p = Power required, kW (HP)
V = Air flow, m^3/min (ft^3/min)
h = Static pressure head, mm (in) of water
e = Static efficiency, decimal
c = Constant, 6000 (6350)

Design Considerations

The selection of materials for the design took cognizance of the following basic considerations:

i) Material Conductivity: a wooden box, a poor conductor of both heat and electricity was chosen because of its ability to insulate and prevent heat transfer across the walls of the box from the surrounding environment which could lead to the malfunctioning of the meter;

ii) A good conductor such as a metal has the tendency to short circuit the naked components installed on the board and cause the malfunction of the device, so the preferred choice of the wooden box;

iii) The size of the circuit board was designed to be almost the same with the inner dimensions of the box to enable it fit tightly to avoid wobbling;

iv) A leather outer cover of the wooden box selected to preserve it and to add aesthetic value to the meter.

INSTRUMENT DESIGN

Hardware Design

The major component making the hardware is a rectangular box which serves as the housing and protective cover to the internal components. It consists of a box of size 172x85mm and inner dimension, 160 x 73mm. An opening was made on the top right hand corner of the box to accommodate the LCD projected out to interface with the user. The power control unit and the dynamo are equally projected and fixed adjacent to the LCD on the box. The power unit is made up of the on off switch and the call Button which calls the written program whenever the device is switched on.

Design of Software

The computer programming language used was Assembly language. The coded instructions were programmed into the micro controller component of the system. This program as written in assembly language and burnt into the micro controller is illustrated in a logic flow chart for the digital meter as shown in Figure 1 below. The program listing is appended in appendix 1.

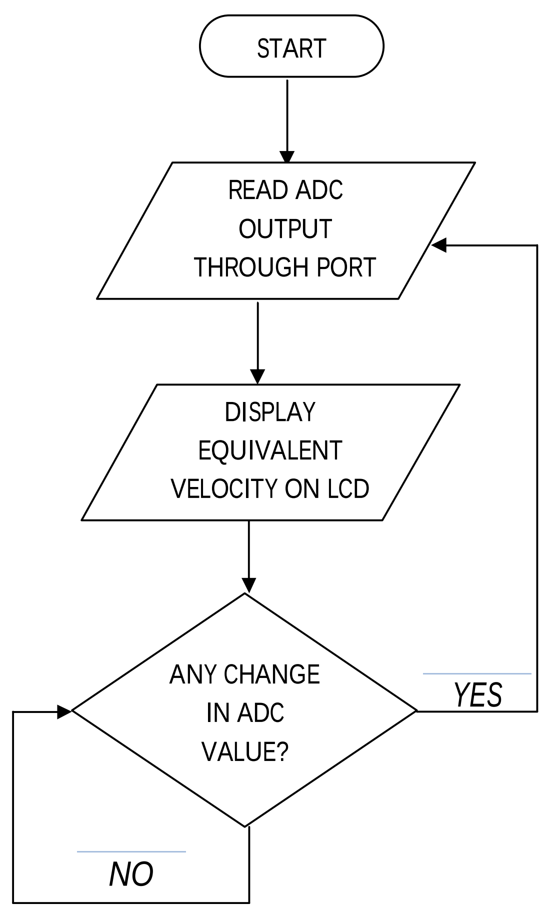

Fig 1: Flow Chart of the Function of the Digital Flow Meter

Assembly Procedure

The components were assembled together in a circuit board (vero board) measuring 171x91mm as shown in Fig.2 using a simple soldering process in accordance to electronic circuit principles.

Faraday's Law states that the electro motive forces (EMF) induced in a circuit is equal to negative change of magnetic flux with time through the circuit. This can be stated mathematically as follows:

$$\oint E.dl = -\frac{d\phi}{dt} \text{..........................(1)}$$

OR

$$\oint E.dl = \frac{-d}{dt}\int_s B.ds \text{....................(2)}$$

Where;

S = Any surface whose ring is the loop under consideration,

B = Magnetic flux

It is observed that rate of change of magnetic flux with time through a circuit is equal to the curl of EMF produced

$$\oint E.dl \text{ l} = \int_s curlE.ds \text{......................(3)}$$

$$\int_s curlE.ds = -\int \frac{dB}{dt} ds \text{.................(4)}$$

$$\text{Curl E} = -\frac{\partial B}{\partial t} \text{..................(5)}$$

$$\nabla XE = \frac{-\partial B}{\partial t} \text{................................(6)}$$

From this observation, when a magnetic flux passes through a coil, an electric current is produced which is proportional to the rate of change of the magnetic flux. In application of this principle a mini dynamo which comprises of a movable magnet and fixed coil is used as sensor.

A blade was fixed on the movable magnet in such a way that air flow can freely turn the blade thereby turning the magnet which then produces a change in magnetic flux which is proportional to the air flow through the blade. In line with Faraday's law, this change in magnetic flux produces electromotive force, EMF which is proportional to the change in the magnetic flux caused by the speed of air flow through the blade.

The diagrammatic representation of the top view, dimension view, side view, isometric view and the circuit diagram of the airflow meter are shown below in Figures 2-6 respectively.

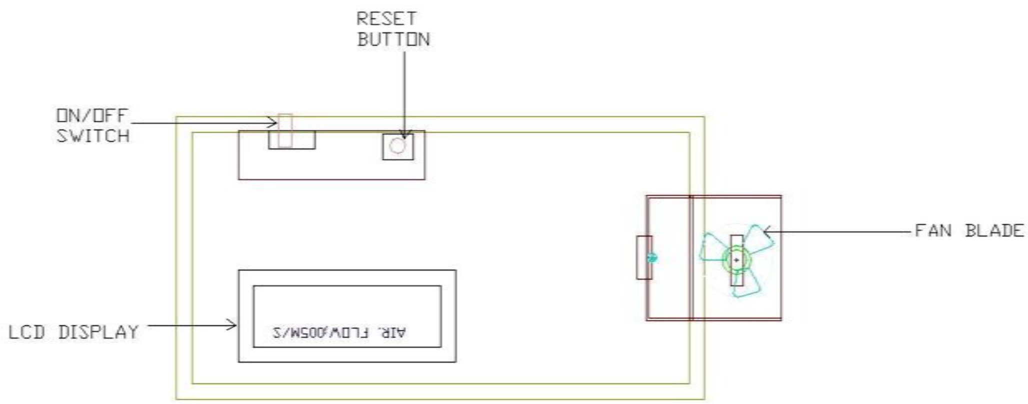

Fig 2: Top View of the Air Flow Meter

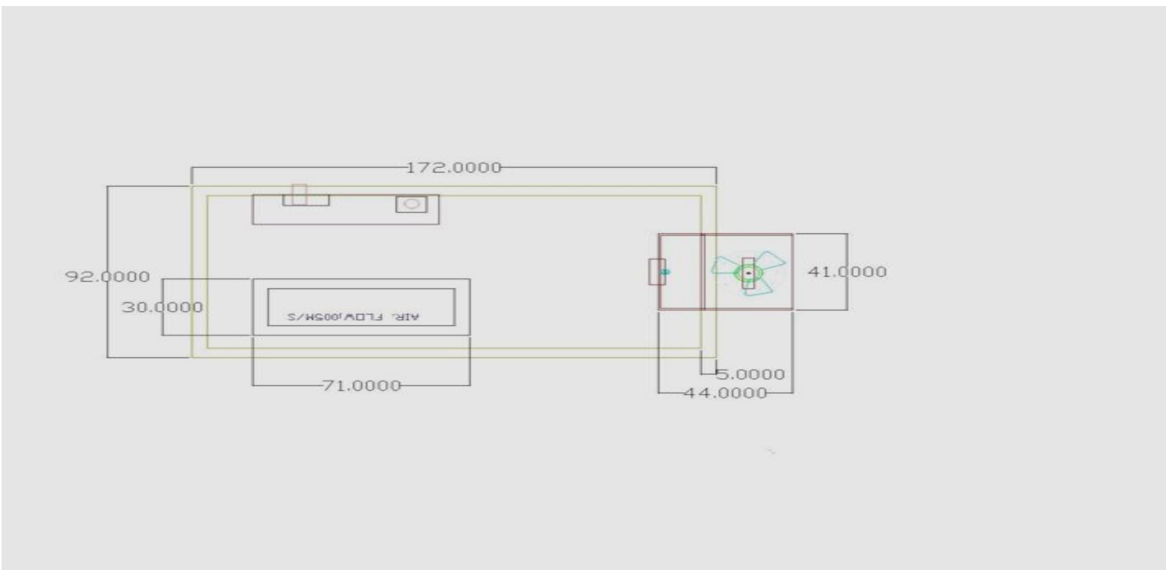

Fig. 3: Dimension View of the Flow Meter

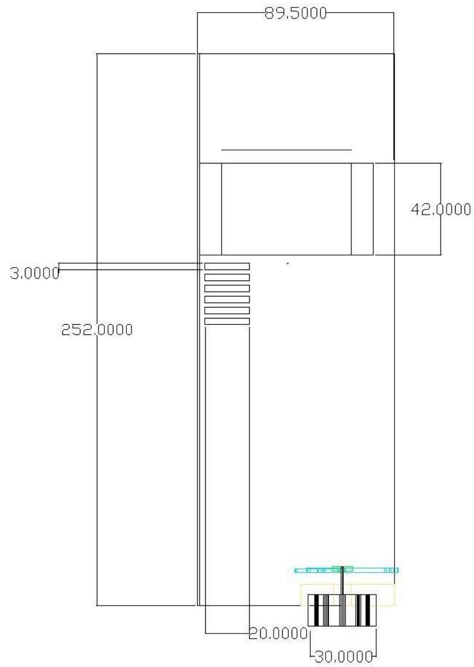

Fig. 4: Side View Dimensions of the Airflow Meter

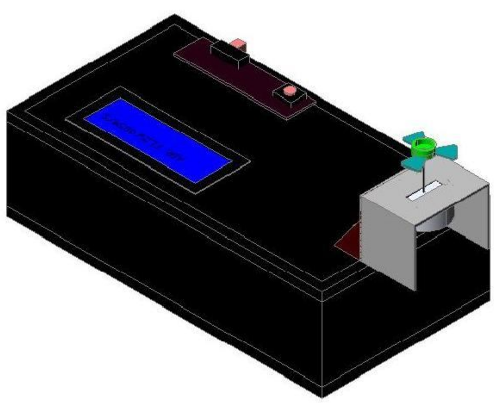

Fig.5: Isometric View of the Air Flow Meter

The circuit board contains the arrangement of all the electronic components used in the design and development of the instrument. This arrangement is represented in figure 6.

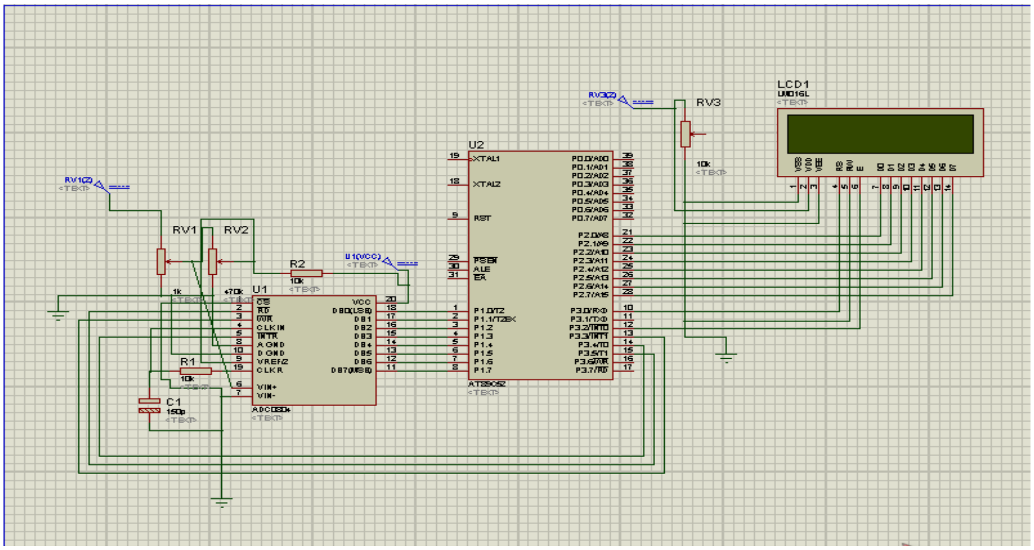

Figure 6: Circuit Diagram of the Portable Digital Air Flow Meter

Although the rate of air flow has been converted into electrical quantity by the sensor (Mini dynamo) but it cannot be used for display nor computation since it is still in its **analogue** form. Computers or microcontrollers only understand codes in binary form (ones and zeros). To convert this analogue voltage form the sensor into binary which the micro controller understands, we need a device known as analogue to digital converter (ADC 0804). ADC 0804 is a twenty pin integrated circuit (IC) which monitors a change in voltage at its input (pin 6) and displays the result in binary form (as demonstrated in table 1) which is equivalent to the voltage at the input. This output is taken from pin 11 to pin 18.These actions of the Analogue to Digital Converter is shown in table1 below.

Table 1: Analogue to Digital Conversion Actions of the Decoded Output Voltage of the Digital Air Flow Meter

Analogue Voltage Value(Ohms)	Enable Pins Causing Output	Select pins (Indicating the State of Conversion)	Outputs (Level or Decoded Output Voltage)
Input (pins)	G1 G2 G3	A B C	Y0 Y1 Y2 Y3 Y4 Y5 Y6 Y7
0	1 0 0	0 0 0	1 0 0 0 0 0 0 0
1	1 0 0	0 0 1	0 1 0 0 0 0 0 0
2	1 0 0	0 1 0	0 0 1 0 0 0 0 0
3	1 0 0	0 1 1	0 0 0 1 0 0 0 0
4	1 0 0	1 0 0	0 0 0 0 1 0 0 0
5	1 0 0	1 0 1	0 0 0 0 0 1 0 0
6	1 0 0	1 1 0	0 0 0 0 0 0 1 0
7	1 0 0	1 1 1	0 0 0 0 0 0 0 1

These values from the ADC are in volts and can only be observed using a voltmeter. In order to display these values in a way everybody will read and understand (high level language), liquid crystal display (LCD) is used through the help of micro controller which computes the machine language (binary code) and displays it in a high level language.

According to Mazidi (2006) in his book "Micro controller and embedded systems", a micro controller is a logic IC which can do nothing unless when programmed to do so. Micro controller used here is a forty (40) Pin IC which comprise of four ports, port zero to port three. Each port is a group of eight (8) pin of the IC. From Pin 32 to pin 39 is the port zero, from pin 1 to pin 8 is port one, from pin 21 to pin 28 is port two, and from pin 10 to pin 17 is port three.

The value from ADC is fed into the micro controller through port one. This means that the eight (8) pin output (pin11 to pin 18) of the ADC is fed into port one of the micro controller (Pin 1 to pin 8). This connection is as shown in the circuit diagram in Fig.6.

As these values have entered the micro controller, the only way for one to appreciate what is happening is when it is displayed in an LCD which acts as a monitor in a computer system. This LCD (Liquid Crystal Display) is a sixteen pin display device which is used to display alphabet and numbers (alpha-numeric). It is connected through port two and three of the micro controller as shown in the circuit diagram. This ADC, micro controller and LCD all work within the voltage limit of 5v.

Although the connections are rightly placed but the micro controller will not understand nor do anything without set of instructions called programs. This is in line with the statement of Hunt, (1977). The program is the software aspect of the project which includes calibrations, display unit, timing unit, memory unit etc.

It is also with this set of codes that the micro controller understands the codes from the ADC and interprets it in the LCD for people to understand. This is actually the intelligent part of this research work.

Mini Dryer

This is a device consisting of electric fan and mesh-like tray, all embodied in a rectangular pan for drying of grains. Although it is not part of the air flow meter, it is necessary to include it so as to simulate the air stream situation in the plenum of deep-bed system where the meter would normally work.

The fan is situated facing downward (90^0) at the top of mesh-like tray such that air produced by the fan can easily pass through the grains on top of the mesh-like tray. When the fan is plugged in a mains supply, the air produced pass through the wet grain and blow away the moisture content of the grains.

The speed of the fan or the position of the mesh-like tray can be altered depending on how moist the grain is or how fast the drying exercise is to take place. When the speed of the fan is increased, more air will be produced and this will lead to faster drying of the grains.

Also, when the mesh-like tray is moved closer to the fan, the grains will dry faster. The air flow can be determined using the device described above. The sensor of the device is placed in between the air flow, [that is in between the fan and the grains]. As this device is moved closer to the fan or speed of the fan increased, the value of the air flow rate (m/s) increase

PERFORMANCE TEST

The meter was evaluated using the improvised mini dryer described in section 5 above using some samples of cereal grain of maize (corn), sorghum and rice. The fan located at a position (90^0) at the above the mesh-like tray loaded with samples of the grain. Two loading depths of 20mm and 40mm of the grain were maintained throughout the experiment: the corresponding distances (of the meter from the fan) of 40mm and 90mm were adopted for taking the readings of the air speed.

The fan was plugged into the mains supply which made the fan to rotate very fast and the air produced transmitted an air stream to the meter through the externally fixed blade of the dynamo. This process was repeated two times for each sample of crop according the chosen levels of height and depth stated above. Various readings of the velocity of air were recorded. The speed of the fan or the position of the mesh-like tray can be altered depending on how moist the grain is or how fast the drying exercise is to take place.

Test Results

Grains were placed on a mesh like bowel in the dryer. This was done in such a way that the air flowing from across the grains could pass from top to bottom of the mesh like bowel and even pass out through the mesh. This was also done in such a way that the moisture content of the grains can be carried away in the flowing air. This flowing air volume was measured relative to the time spent in seconds. The mini dynamo in the device built to have a blade which enables the flowing air to turn when the measuring device is brought beneath the blowing fan in the dryer at an angle of 90^0.

As this dynamo (sensor) rotates, it produces an electric current which is directly proportional to the rate of Air flow passing through the mass. This electric current produced is fed to an Analog to Digital convertor (ADC). The ADC is a twenty pin IC which is meant to receive voltage from a sensor and convert it into binary codes. The output of the ADC has eight pins which correspond to a point of the Micro Controller.

The device under the above arrangement displayed some figures rising rapidly from 0 in the following progression:-1m/s, 2ms, 3m/s 4m/s……………………nm/s. It is worthy to note that the speed of the meter reading varied with its distance from the fan as well as with the size of the fan used at any giving instance. Hence the device is always subject to detect any rate of discharge incident on it. The results obtained are presented in table 2 below.

Table 2: Results of Performance Test of the Portable Air Flow Digital Meter

Crop	Moisture Content of Grain %wb	Distance of Digital Meter from Fan (mm)	Depth of Grain in Tray (mm)	Recorded Airflow on Meter (m/s)
Red corn I	13.84	40	20	56
		60	40	37
Red corn II	16.07	40	20	56
		60	40	36
White corn	14.01	40	20	57

		60	40	36
Sorghum	13.84	40	20	57
		60	40	37
Rice	13.37	40	20	56
		60	40	36

The velocity of air recoded at the instrument distance of 40 and depth of 20 mm was 56m/s and this was common for red corn I and II, and rice; then 57m/s for white corn and sorghum. This is an insignificant variation of 1m/s which may have been likely caused by some slight fluctuation in the value of current generating the flow.

On the other hand, a common air flow value of 36m/s was read for the samples of red corn II, white corn and rice at the fan distance of 60mm and drying depth of 40mm respectively; while red corn I and sorghum at the same levels recorded the air speed of 37m/s. This similarly, may be attributed to the same factor of fluctuating current. It was observed generally, that moving the digital meter away from the fan by 20mm results in a drop in its recorded value. This phenomenon practically implies that the air velocity generated diminishes with distance moved away.

Moisture Content Results

The moisture content determination was carried out only on two different samples of maize grains and not on other crops. The results obtained for the moisture from the two samples are presented as follows.

Table 3: Results of Moisture Contents Test for White Corn

Weight of Empty Crucible	Weight of Air Dry	Weight of Oven Dry	Weight of Water	Mc Wb %
16.1	24.3	23.2	1.1	13.41
16.3	26.9	25.4	1.5	14.15
16.1	24.7	23.5	1.2	13.25
			Total	**41.51**
AV MC FOR SAMPLE I = 41.51/3 = 13.84%				

Table 3b: Results of MC Test for Red Corn

Weight of Empty Crucible	Weight of Air Dry	Weight of Oven Dry	Weight of Water	Mc Wb %
16.1	30.8	28.4	2.4	16.32
16.1	32.6	29.9	2.7	16.36
16.1	32.2	29.7	2.5	15.53
			Total	**48.21**
AV MC FOR SAMPLE II = 48.21/3 = 16.07%				

CONCLUSION

The velocity of the air movement and absolute pressure exerted by the airflow within the open space and inside the grain pile and between the mesh and grain surface interface denote an important advancement in local technology. This indeed has a correlation with the outputs of developed technologies in the developed economies. For each mass flow case, the velocity magnitude and the absolute pressure exerted by the airflow increased near each of the air inlets. Hence, the findings suggest that the nearer the meter to the source of drying air, the higher the impact of the stream of air flow on the meter. This also implies that in a deep-bed drying system, the layers closer to the air blowers are likely to dry faster than those at the middle and the extreme end. This adequately agrees with the views of (Chakraverty,1988; CIGR,1999 and Ojha and Michael,2006).

RECOMMENDATIONS

More room exist for further research work on this instruments which should be explored for the purposes of improving on either the design, construction or otherwise. Hence:

- The instrument may be compressed to look more Compaq and portable.
- The sensor (dynamo) may be changed to a smaller one and be built into the rectangular box without protrusion.
- Any other valid improvement aimed at enhancing the features of the existing device.

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APPENDIX

The Computer Program

```
Org 00h
Initialization:
Mov A #38h
Acall command
Acall delay
Mov A, #och
Acall command
Acall delay
Mov A, #06h
Acall command
Acall delay
Mov A,
'AIR_ FLOW'
Data _ out:
Mov p2, A
Set b P3 .0
Clr P3.1
Ret
end
```

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