ABUAD Journal of Engineering Research and Development (AJERD) ISSN: 2645-2685
Volume 1, Issue 2, 166-172

Development of a Permeable Meter for Mould Industries Using Locally Sourced Materials

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Date of First Submission: 18/03/2018
Date Accepted: 09/06/2018

Abstract: *One of the major factors for production of quality casting is the control of properties of moulds and cores to make them uniform and consistent quality. Permeable meter is used for the determination of the venting ability of sand moulds and cores. This testing equipment is being imported to the country as at today. The cost is high, and they are not readily available to foundry operators. Hence there is need to design and develop a permeable meter using locally sourced materials and make it available at an affordable price, thereby improving foundry technology in Nigeria. Two different method could be used to measure permeability of sand; determination of air flow rate and measurement of pressure difference between the orifice and the top of sand specimen. The first method was adopted in the development of the Permeable meter. On testing, the values of permeability measured using the equipment was comparable to the results obtained from the standardized imported one. The cost of production was 30% of the cost of imported one, not even now that exchange rate to international currency has skyrocketed. The work has incorporated design and fabrication principles that resulted in a relatively cheap product that can be constructed locally by an average Fabricator and Technician.*

Keywords: *Sand, Permeability, Meter, Foundry, locally-made.*

1. INTRODUCTION

Foundry is considered to be the mother of all industries [1]. With the increase in demand for quality castings, foundry men are constantly trying to improve their products. Foundry is the most basic input industry and stringent demands of quality and quantity are being placed on it with industrialization and growth in other fields of production [1]. One of the characteristics of moulds and cores sand is its ability to allow gas to diffuse freely through the cavity during filling and solidification [2]. The permeability of dry sand is the property of a dried bonded sand to permit passage of gases while molten materials are poured into mould [3]. At the time of metal pouring, the mould is in dry state; these moulds after preparation are baked in oven and this is done in order to drive off the water and intensify the effect of additives. This is used when the mould required greater strength and hardness. But in the case of green sand mould, the sand is in damp condition and contains free water. It is sand that contains the clay binders and therefore calculated amount of water that is added to develop the plasticity of the object. The main constituents of green sand moulds are silica, sands, clay and moisture. And before it may be called green sand, the following must be determined; the green strength, shattered index and the permeability [4]. The grain size distribution has a significant effect on permeability. Silica sand containing finer and a wide range of particle sizes has low permeability as compared to those containing grains of average fineness but of the same size. That is to say that, sand with grains equal but coarser in size have greater void space and have, therefore greater permeability than the finer silica sands [5, 6].

Standard permeability was Determined by measuring the time necessary for 2000cm^3 of air to pass through a standard specimen of 50mm diameter and 50mm height, while it is confined in the specimen tube under a constant pressure of 10g per cm^2[7]. This same principle will be used in designing and development of a permeable meter using locally sourced materials. Study has revealed that advancement can be made by better sand processing which will improve the casting quality and lower total cost [8, 9].

2. DESIGN CONCEPT

Figures 1, 2 and 3 show the orthographic, components and isometric view of the meter respectively. Permeable meter is made up of orifice, air drum, pipes, discharge unit, air valves and pressure gauge

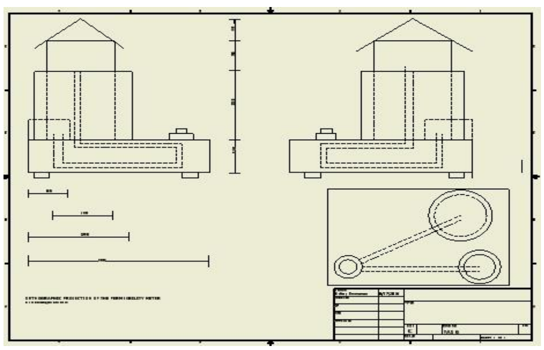

Figure 1: Orthographic projection

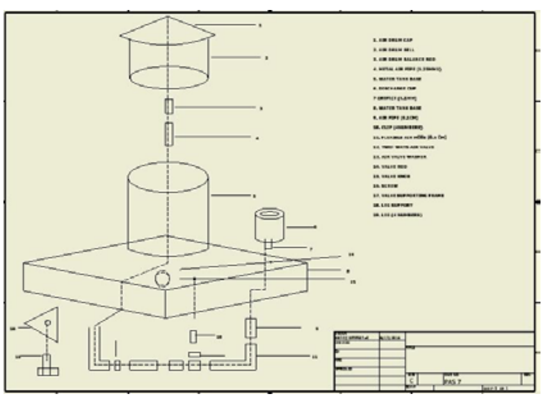

Figure 2: Meter components

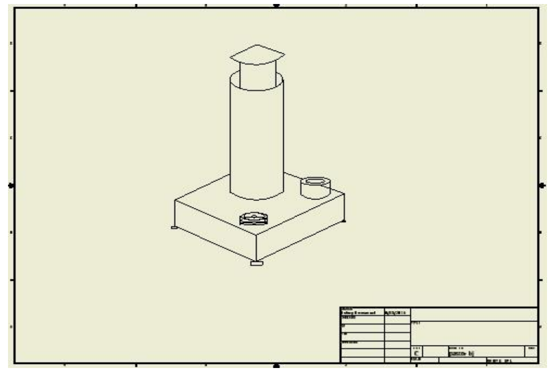

Figure 3: Isometric view of the meter

2.1 Description of a permeable meter

Permeable meter is made up of orifice, air drum, pipes, discharge unit, air valves and pressure gauge. The body of the meter could be made of either Aluminum alloy, plastic or steel sheet consisting of a cylindrical air drum and water tank and a square box base. Inside the water tank floats a balanced air- drum designed to maintain a constant air pressure during its fall. An air pipe is located at the center of the water tank which protrudes out at the base with a little extension above the water level at the top. A flexible air pipe connects the lower protrusion to the discharge unit via an air valve. The discharge unit comprises of the orifice and specimen cup. During measurement, the specimen tube containing the sand specimen is placed in the cup. The cup contains some mercury which acts as a seal against air leakage. When the air drum is raised to the height and released, air flow through the water via the air pipe to the discharge unit, and since there is no other openings, the air passes through the orifice and flow out via the void spaces in the sand specimen. The main components of a permeable meter include:

1) *Orifice*: There are two types of standard orifice size that are recommended by AFS; 1.5mm and 0.5mm diameter. The former is used for sand of high permeability while the later is used for sand of low permeability. Under a standard condition, the larger will allow 2000cm^3 of air to pass through in 30sec (+/- 0.35) while the small orifice should allow 2000cm^3 to pass through in 270sec (+/- 1.35) [6, 9].

2) *Discharge unit:* The discharge unit comprises of a cup and the orifice. The cup sits the specimen tube and bears the weight of the specimen and tube. In order to prevent air loss, the inside of the cup could be filled with liquid sealant (mercury) to a sufficient level. The orifice is carefully incorporated to the center of the discharge cup. The rod that bears the orifice is projected above the bottom of the cup to prevent the entrance of sealant. A cover is provided for the outlet when not in use.

3) *Air valve:* The outlet from the air drum is connected to the discharge cup at the base via a two- way air valve. The valve is marked "open" and "closed". It is positioned "open" where the air drum is raised and during its descend; the valve is turned "closed" when the O- mark on the air drum is leveled with the surface of water in the tank. As soon as reading begins, the air valve is again turned "open" until 2000cm^3 of air has been passed.

4) *Air drum and pipe*: inside the air drum floats a balanced air drum that descends gradually under a constant atmospheric pressure when the valve is opened there are two category of air pipe use, the one that conduct air from the air drum to the lower end of the water tank and the one that incorporates the air valves. The later that is housed by the base has a T- shape configuration. The outlet from the air drum supplies the manometer and discharge unit via the air valve that is located on both air passages.

5) *Pressure gauge*: pressure gauge is introduced at the outlet of the air drum before the air gets to the discharge unit. Differential manometer is used, in this type, a liquid column balances the pressure as it is indicated by a displacement. It consists of a U- tube made of flexible rubber hose which incorporate glass tube on both ends. One end is connected to the outlet of air pipe while the other end is open to the atmosphere.

2.2 Operation Principle

Standard permeability is determined by measuring the time necessary for 2000cm^3 of air to pass through a standard specimen of 50mm diameter and 50mm height, while it is confined in the specimen tube under a constant pressure of 10g per cm^2. 2000cm3 of air under a constant pressure is allowed to flow the air drum (bell jar) though an orifice (1.5mm and or 0.5mm). Permeability value is usually expressed in terms of permeability number [7]. The scabbing, buckle and rat-tailing tendencies are reduced with as increase of permeability, at the expense of surface finish, when no mould protective coatings are employed [8]. The air delivered by the orifice must pass through the sand to escape. If the sand specimen is completely open, the discharge pressure will be zero or atmospheric. Following the principles of working and design of a standard permeability meter, the meter can be developed locally with no variation and can be used for permeability measurement. The heat from the casting causes green- sand mould to evolve a great deal of steam and other gases. The mould and core must be permeable to permit gases to pass out [10, 11].

$$P= \frac{V \times H}{p \times A \times T} \quad (1)$$

Where P= Permeability meter (2000cm^3), V= volume of air in cm^3

H= height of the sample (5cm) in cm, p= pressure of air (10g/cm^2)

A= area of the sample in cm^2 (19.635cm^2), T= time in minute.

Green permeability of moulding sands, as used in sand control is considered a quick fineness and distribution test [12]. Figure 4 is a sketch diagram of the operational principle of a permeability meter

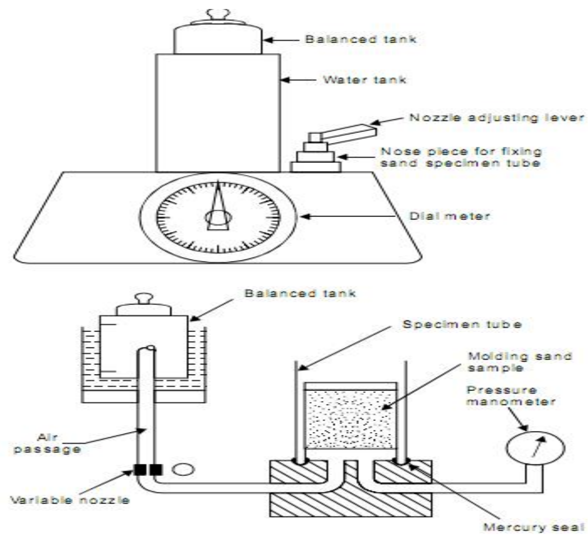

Figure 4: Operational principle of a Permeability Meter.

2.3 Design calculations

Calculation of air drum:

i. Calculation of air drum diameter

Required volume $V_a = = \pi r^2 \frac{h}{4}$ (2)

Where, $V_a =$ Volume of air drum (body)

r= radius of air drum

h= height of air drum (height of air drum selected= 30cm and volume of 6,000cm^3)

$$d_a = \sqrt{\frac{4V}{\pi h}} = 16.0\text{cm}$$

ii. Circumference of air drum body $C_a = \pi d_a$ (3)
Where C_a= effective circumference of air drum, C_a= 50.30cm

Surface area of material required for the air drum body, $A_a = (C_a + 2a_w) \times h_a$ (4)

Where A_a= surface area of air drum material

a_w= overlapping for joining sheet (weld leg= 1.5cm) A_a= 1590cm^2

iii. Surface area of conical head

$A_c = d\frac{\pi}{2} \times l$ (5)

Where A_c= surface area of cone, d_c= diameter of cone, l_c= length of cone, h_c= height of cone, $A_c = 10 \times 10.3 \times \pi$= 323.70cm^2

iv. Inner volume of cone $V_c = \frac{\pi \times h}{12} \times d^2 = \pi \times 2.5 \times 20^2/12$ V_c= 262cm^2

v. Total quantity of material required for the air drum = 1913.70cm^2

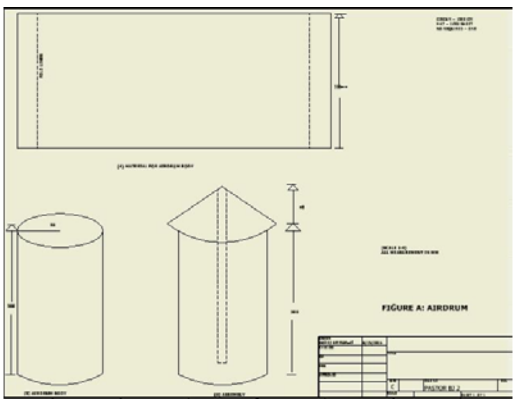

Figure 5: Air drum

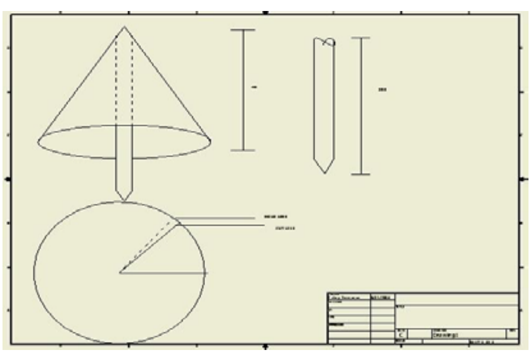

Figure 6: Air drum cap

Calculation of water tank

i $d_{wt} = d_t + c_t$

Where, d_{wt}= diameter of water tank, c_t = clearance between air drum and tank

ii Calculation of height:

Volume of water required= 6000cm^3, the height of water in water tank (h_t)

$V_w = \frac{\pi \times 20 \times 20 \times h}{4}$ (h_t= h_w + c_w= 23cm)

Volume of water tank= 7226.60cm^3

iii Effective circumference of water tank sheet. $c_{wt} = \pi d_t$= 62.84cm (including overlapping for joining, give allowance of 1.5cm), c_{wt}= 65.84cm (Fig. 5).

iv Actual size of material for water tank, $q_t = (c_{wt} + 2a_w) \times h_t$ = 1504.30cm^3

Calculation of water tank base

Total surface area of water tank base

$q_b = l_b \times b_b$= 3400cm^2 (Fig. 8)

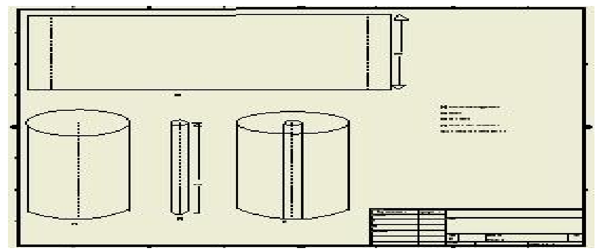

Figure 7: Water tank

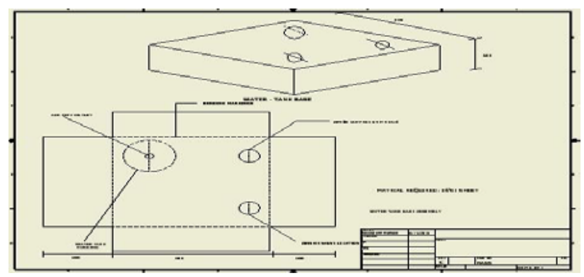

Figure 8: Water tank base assembly

Calculation of discharge cup

Thickness of cup, = t_p= 0.25cm, Outer diameter of cup, d_p= 8.5cm

Height of cup, h_p= 4.5cm, Base thickness of cup= 0.5cm, hence volume of hollow centre,

$V_i = \frac{\pi \times di \times di \times hi}{4}$, Volume of inner hollow= 201cm^3 (Fig. 7)

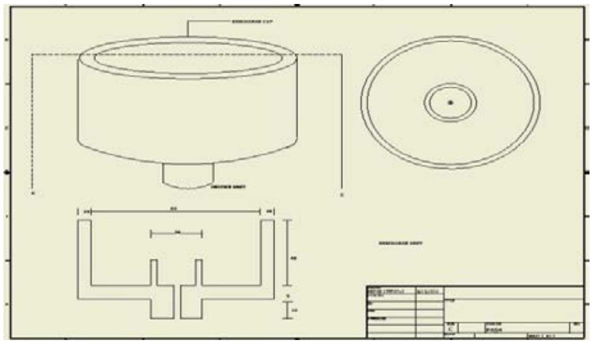

Figure 9: Discharge unit

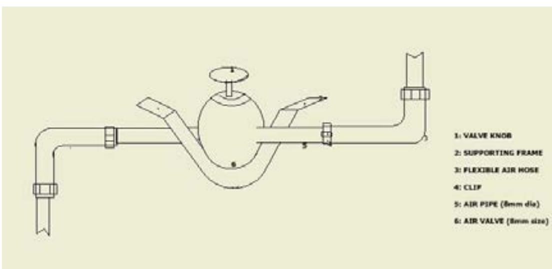

Figure 10: Air valve arrangement

3. RESULTS AND DISCUSSION

When the development of the meter was completed, it was subjected to test in order to verify its compliance with a standard imported meter. Firstly, the discharge rate of air from the fabricated orifice without sample was determined. The time taken for the volume of 2000 cm^3 of air to pass through the orifice of 1.5mm diameter at 10cm of water pressure was measured to be 45 seconds while the standard time is 30seconds. The multiplying factor derived was 1:1.5. Following this, samples were produced with different types of soil. Samples of soil were prepared as follow: silica sand and clay binder were thoroughly mixed in a sand mixer. Known amount of tempering water was added to the moulding sand. An amount of sand mixture adequate to form a standard 50mm diameter and 50 mm high test specimen after 3 rams were determined using the standard sand specimen tube and sand rammer. The permeability measurement is done while the specimen is confined inside the tube.

The permeable meter was placed on a level bench, and the tank was filled with water to the upper mark of 20.0cm height. The orifice was checked to be in the right position in the discharge unit. The standard specimen tube containing the specimen was placed inside the discharge cup which containing mercury liquid as the seal. The air valve was turned to "open" position while the air drum was raised until it was above the water level. The valve was now turned to "closed" position as the drum descends slowly into the water. The air valve was gradually turned towards "open" so that the air drum could descend until mark "X" on the drum is leveled with the top edge of the tank. Then, valve was turned to "closed" position. The air drum was allowed to descend down by turning the air valve to a position midway between "closed" and "open". The time for the air drum to descend from zero to 2,000cm^3 marks was measured with the aid of a stop watch Appendices 1 and 2).

4. PERFORMANCE EVALUATION

Category one, at moisture content of 8%, the first measured time was 114sec.

From equation 1, $P = \frac{3007.2}{T} \times 1.5$ (multiplying factor) $= \frac{3007.2}{114} \times 1.5 = 39.453$

Category two, at moisture content of 10%, the first measured time was 150sec,

$P = \frac{3007.2}{T} \times 1.5$ (multiplying factor) $= \frac{3007.2}{150} \times 1.5 = 30.08$

Category three, at moisture content of 5%, the first measured time was 90sec,

$P = \frac{3007.2}{T} \times 1.5$ (multiplying factor) $= \frac{3007.2}{90} \times 1.5 = 33.42$

Category four, at moisture content of 6%, the first measured time was 130sec,

$P = \frac{3007.2}{T} \times 1.5$ (multiplying factor) $= \frac{3007.2}{130} \times 1.5 = 34.65$

At average moisture content of 8% and time 530second, P_{actual}= 8.55

Table I shows the data sheet for the readings of permeability values obtained

Table 1: Data sheet for permeability readings using equipment developed

Sample Description	MC	Time (T) in Sec	Permeability		
			Reading (R)	Average	
				T	R
Sample 1	8%	114	39.45		
Sample 2	8%	120	37.59		
Sample 3`	8%	123	36.67		
Sample 4	8%	110	50.45		
Sample 5	8%	118	38.23	117	40.48
Sample 6	10%	150	30.08		
Sample 7	10%	145	31.11		
Sample 8	10%	152	29.67		
Sample 9	10%	148	30.48		
Sample 10	10%	149	30.27	147.33	26.43

Sample 11	5%	90	50.12		
Sample 12	5%	95	47.48		
Sample 13	5%	100	45.11		
Sample 14	5%	92	49.03		
Sample 15	5%	102	44.22	95.8	47.19
Sample 16	6%	130	34.65		
Sample 17	6%	125	36.08		
Sample 18	6%	132	34.17		
Sample 19	6%	127	35.52		
Sample 20	6%	135	33.41	129.8	3477

5. CONCLUSION

The technology of making sand castings is developed mainly with the development in moulding sand and core making processes. In this work, permeability meter was developed using locally available material. Other moulding equipment could be developed locally, which will invariably reduce cost, and by this promote our local manufacturers.

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APPENDICES

Appendix 1: Material requirements for the permeability meter accessories

S/no	Description	Size required	No
1.	Air drum a. Body b. Conical head	1904cm^2 sheet 30 × 53cm^2 ø 10.3 (323.7cm^2)	1
2.	Water tank	23 × 72 cm^2	1
3.	Discharge cup	9cm ø × 5.0cm	1
4.	Orifice	1.5mm (on a rod, 2.0cm ø and 30cm high	1
5.	Air pipe	2.54 cm ø and 29cm length	1
6.	Air hose	1.0cm ø and 15cm length	1
7.	Air valve	1,0cm ø	1
8.	Water tank base	30 ×30 ×10 cm^3	1
9.	Iron rod	1.0cm and 25cm length	1
10.	Air valve supporting frame	2cm × 15cm	1
11.	Mercury	28.30cm^3	-
12.	Nuts	17mm ø	8
13.	Screw	17mm ø	4
14.	Brass air pipe	1.0cm ø by 15cm	4
15	Supporting frame	10 × 21cm^2	1

Appendix 2. Market prices of material selected for the construction

S/No	Material specification	Dimension Required	Unit	Unit Price (₦)	Cost (₦)
1.	16 Gauge G.I. Sheet	2/5(244×122cm^2)	Sheet metal	8, 000	3200
2.	9.5cmø rod	5.0	Length in cm	-	250
3.	2.0cm ø rod (orifice)	3.5	Length in cm	1800	200
4.	Electrodes	15	No	50	750
5.	Air Valve	2	No	500	1000

6.	Air pipe	29	Length in cm	-	500
7.	Air pipe (1.0cm)	25	Length in cm	-	300
8.	Iron rod (1.5cm)	31.5	Length in cm	-	200
9.	Nuts (M17)	8	No	50	400
10.	Mercury sealant	28.3	cm^3	-	3000
11.	Clips	4	No	50	200
12.	Flexible hose (1.0cmø)	20	Length in cm	-	500
13.	Manometer tube (1.0cmø)	45	Length in cm	-	500
14.	Red oxide paint	1	Cup (250 g)	500	500
15.	Glossy paint	1	Cup (250 g)	500	500
16.	Levelers	4	No (M17)	50	200
17.	Supporting plate	$21*10cm^2$	Sheet	-	500
18.	Workmanship				2,500
			TOTAL		**15,200.00**