SEGREGATION CHARACTERISTICS OF SAND BY FLUIDIZATION: A METHOD EMPLOYED IN THE PRODUCTION OF SAND FOR FILTERS

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ABSTRACT

Segregation characteristics of sand has been studied so that useful portion of sand for filters can be obtained from raw sources of erosion or river sand. The useful filter sand portion is defined in this paper as the sand particles passing sieve number 16 but being retained on sieve number 40 of ASTM standard with sieve apertures 1.18 mm and 0.425 mm respectively. A 2^3 factorial experiment was conducted which shows that flowrate affects segregation characteristic of sand and that with the use of proper flow rate value, a useful filter sand portion can be generated in the middle layers of a sand bed after removing the top and bottom layers to about 2cm depth each. It was also discovered that the top layer containing fine sand (0.425 mm) can be removed using the relationship between the height of fluidizing column and the expanded height of bed. Lastly, large scale commercialization can be achieved by employing preliminary sieving operation to remove large particle size (> 1.18 mm) which are the particles that settle at the bottom so that only the filter sand (0.425 mm – 1.18 mm) will remain in the fluidizing column.

Keywords: Segregation, fluidization, flowrate, sieving operation and commercialization

1. INTRODUCTION

There are many things provided as essential for the existence of man on earth. These essentials range in degrees of importance and among those that could be classified as being in the first degree is water. Scientific and geological findings have revealed that water is as old as man on the surface of the earth, if not older. this is also proved by the fact that man's existence and water cannot be separated. Water maintains and ecological balance - a balance in the relationship between living things and environment in which they live [1] [2].

It may be reasonable to assume that water in its original state was pure at least relative to its state today, but man been an agent of pollution by nature, in the course of satisfying his other needs domestically, industrially and otherwise has polluted his environment to a great degree. Also nature in the course of maintaining equilibrium has affected many things in the environment [3] [4].

Today, water is found in various places including oceans, lakes, rivers, streams and springs as surface water and underground as ground water and in the atmosphere as vapour. Of all this quantities, a small portion is available for use and this quantity is treated and pumped into cities and towns for various uses which can be categorised as alimentary, industrial, commercial and firefighting purposes [5] [6].

Since the quality of water available for use is constant to some extent and man's population as well as his "ability to pollute" is increasing due to scientific and technological development, the more reason why there should be an advancement in the processes involved in the treatment of water so as to ensure satisfaction in quality and adequacy in quantity that is being supplied .

A typical water treatment plant consists of the following units: the source which could be lakes or rivers, aeration unit, low lift pumps, coagulation unit, sedimentation unit, filters, underground storage, high lift pump and elevated storage. Each of these units perform unique functions which is focused towards making the water fit for use, although local differences due to local conditions may introduce one or more alterations into the processes highlighted above.

Improvement in any of the stages highlighted above by the course of research can eliminate one or more steps since the processes are linked together. Development in filtration process based on advanced study of the filtering medium can eliminate the sedimentation unit alongside with time wasted as detention time if the filtration unit can be developed to perform the functions of both units i.e. removal of both settleable and non-settleable particles.

1.1 Description of the study area

The study area for this project was within the confines of Obafemi Awolowo University. The experiment was set up in front of the Faculty of Agriculture's greenhouse on the way to the new Civil Engineering building. The main reason for choosing this site is as a result of the overhead tank (abandoned by the Solel Boneh after the completion of the construction of Civil Engineering building) available for the generation of water at a pressure needed during the course of the experiment.

2. MATERIALS AND METHODS

The only sample of sand used was obtained from the Road-bend leading to Civil Engineering building. This was justified by the fact that Ogedengbe [3] and other published research work conducted at Department of Civil Engineering, Obafemi Awolowo University, Ile-Ife had worked on various sources of local sands and established that erosion sand and river sand are potentially good sources of filter sand. Erosion sand is the sand obtained from an eroded path.

Overhead tank: The dimensions of the overhead tank which is cylindrical but with elliptical ends are given as: Length of the cylindrical tank = 9.85 m, shortest diameter of the elliptical ends = 1.38 m and height of tank from the base (ground) = 9.75 m

The tank was balanced on an elevated steel structure being supplied with water from the University water supply system through series of pipelines and valves connections.

Fluidizing column: A cylindrical apparatus was adapted for this experiment. The cylinder was 60 cm high from the base of the porous media while the diameter is 28.5 cm. The conical bottom rises with two different gradients so as to minimize the possible effect of spouting and is joined by $\frac{3}{4}$ inch pipe that brings water into the apparatus.

A set of British standard sieves in the range 0.212, 0.30, 0.425, 0.60, 0.85, 1.18 and 1.70mm size of the aperture were used. This was justified by the fact that the grain sizes of filter sand lies within this range (i.e. 0.425 – 1.14 mm). The corresponding sieves numbers are 70, 50, 40, 30, 20, 16 and 12. While Pipes of various sizes ranging from $\frac{3}{4}$ inch to $1\frac{1}{2}$ inch were used alongside with appurtenances such as reducing coupling, elbows, nipples, unions and gate valves.

2.1 Generation of water pressure

The overhead water tank was set at the required elevation to provide the needed pressure. This pressure can be calculated using equation 1.

$$P = egh \qquad (1)$$

Where: P = Pressure in Pascal, g = acceleration due to gravity, e = density of water, h = head

The tank was placed at a height of 9.75 m from the base of the apparatus set up, but

Available head = Height of tank from apparatus base – Head losses in pipe and appurtenances

The water under pressure was delivered into the apparatus through the pipelines connected to the bottom of the apparatus.

2.2 Measurement of flowrate

The flow rate (in the absence of a flow meter) was measured by collecting a certain quantity of water for a specified period of time using measuring cylinder and stopwatch. This is based on the mathematical expression given as:

$$Q = \frac{V}{t} \qquad (2)$$

Q = Quantity or flowrate (m^3/s)

V = Volume of fluid (m^3 or l)

t = time (s)

At least two readings were obtained for each flow in order to ensure accuracy and eliminate error to some extent.

The flow rate per unit area can also be obtained by the expression:

$$V = \frac{Q}{A}$$

Q = flowrate through the bed

A = area of the fluidizing columv which represent area of the bed

The three parameters studied in this research work were the bed height; time of fluidization and flow rate [7]. Each of these parameters were varied a number of times in order to determine their effects on the segregative characteristics of fluidized bed. This was done in order to be able to determine whether some optimum conditions exists for better segregation based on the results obtained from each or combination of the parameters.

For each experimental determination certain amount of sand was poured into the fluidizing column and the bed height was measured with the aid of a ruler placed beside the cylindrical wall. After this had been done, the water was allowed to flow in from underneath of the apparatus with the flow rate being adjusted by the gate valve attached to the inlet pipe and the value of this flow rate can be determined from the amount of water collected from the overflow within a specified time. The time used for each experimental run can be determined with the aid of a stopwatch and this was used for varying the time as well.

In the case of this research, the parameters were combined together as follows;

i. The bed height was varied while the time and flow rate is kept constant at a particular value.

ii. The time of fluidization was also varied for the same bed height while this process was repeated for some other bed heights noticed to have good segregation from the results obtained above.

iii. The flow rate was also varied for the same bed height keeping the time of fluidization constant.

These procedures were also repeated for some bed heights noticed to have the best segregative characteristic. The time of fluidization used here was the time that gave the best segregative effect from the experiments conducted in stage (ii) above.

2.3 Sieving Analysis

This was the method used for determining the particle sizes (using set of BS sieve numbers 12 to 70) of the sample of sand obtained from the fluidized bed to examine the segregation after it had been subjected to drying. In this project work, representative sample of not less than 400 g was used throughout the analysis and this is in accordance with the suggestion of Amirtharajah [1] who had worked previously on it. However, a time of 5 minutes was chosen for the sieving. This was backed up by the initial work of Amirtharajah [1] who had carried out both experimental and literature survey on this aspect. However for this project, an experiment was still carried out using 400 g sample of sand subjected to sieving for different time intervals between 2 minutes and 15 minutes. The result is as presented in Table 1. Since there was no such difference between the percentage by weight retained on each sieves between 5 mins, 10 mins and 15 mins, the least time 5 mins was chosen and this is backed up with suggestion from literature as well.

Table 1: Grading characteristic of sand as a function of sieving time.

Sieve No	Weight Retained (g)			
	3 mins	5 mins	10 mins	15 mins

Pan	6.87	6.81	8.73	7.58
70	19.87	21.37	20.57	21.00
50	79.01	84.34	88.00	88.52
40	34.28	34.17	33.58	34.84
30	110.81	107.63	107.83	107.68
20	64.26	61.69	60.43	61.00
16	43.59	43.87	44.21	43.48
12	36.66	36.82	36.22	35.90

3. RESULTS AND DISCUSSIONS

The effects of the three variable height of bed, flowrate and time of experimental run on the yield were studied using a 2^3 factorial (H, Q, T) experiment. In considering the two levels of the flowrate, it was difficult to obtain distinct values. The range of values representing the two levels have been given below with the effect that their average values which are put in the bracket are taken to represent the two levels.

Maximum range: 39.35 - 43.11 $l/s.m^2$ (41.23 $l/s.m^2$)

Maximum range: 48.75 - 50.16 $l/s.m^2$ (49.46 $l/s.m^2$)

4.1 Effect of flowrate on the yield

It was observed that as the flowrate value increases, the yield increases as well. This can be explained by the fact that as the flowrate value is increased, the void ratio of the bed increases and the number of particles occupying a unit volume is decreased which is a better condition for segregation to occur.

4.2 Effect of height of bed on the yield

To study this effect, the bed height was varied for additional values of 6 cm, 8 cm, 10 cm and 12 cm apart from the heights i.e. 16 cm and 20 cm used for the 2^3 factorial experiment. The yield values obtained from the results are presented in Table 2. It can be observed that better yields are obtained from 10 cm and 12 cm. This can be explained by the fact that appropriate void ratio which allows for classification of sand in the bed was achieved. In the case of 16 cm and 20 cm which indicates lower yield, approximate void ratio which allows for better segregation has not been achieved. A single explanation on this is that the same flowrate value was used to achieve expansion in all the four conditions but since the number of particles per unit volume is more for 16 cm than for 10 cm and 12 cm, the void ratio values were smaller for the former [8].

This indicates that appropriate void ratio which allows for proper classification of sand particles for a particular bed height is a function of flowrate in a fluidized system and a significant parameter affecting the yield of useful filter portion. For other bad heights 6 cm and 8 cm, though appropriate values of void ratio were achieved but spouting in the bed affects the yield due to the partial disturbances of the bed.

Table 2: Yield values determined from varied bed heights

Heights Of Bed (cm)	**Yield in each layer (% values)**						
	1	**2**	**3**	**4**	**5**	**6**	**7**
6	33.39	55.36	40.33	41.16	-	-	-
8	24.35	60.95	52.20	40.18	-	-	-
10	26.14	68.57	66.86	52.09	42.35	20.44	-

12	42.46	70.04	65.69	63.05	52.88	44.50	17.57
16	56.15	58.31	55.51	53.28	50.88	47.86	25.13
20	55.92	57.23	52.06	46.59	55.35	52.94	50.23

4.3 Segregation – Expansion Characteristics of the Bed

Table 3 indicates the expansion characteristics of the bed. It can be observed from the table that increase in flowrate leads to increase in expansion. The table indicates the relationship between the flowrate value, height of fluidizing column which is constant. It can be deduced from the table that adequate combination of the heights of fluidizing column and expanded bed in designing the column will give a system capable of removing the top portion of fluidized bed after expansion must have occurred beyond the height in which the fluidizing column can accommodate, and since this top portion always contain sand grains 0.425 mm in size. This grain size can be removed with overflow water.

Table 3: Expansion characteristic of the bed

Flowrates $l/s.m^2$	Height of bed (cm)	Expanded height (cm)	Height of fluidizing column (cm)
42.85	16	41	60
40.50	20	45	60
50.16	16	45	60
48.75	20	50	60

4.4 Uniform Coefficient (U_c) And Effective Size Values (D_{10})

These two values define the grading characteristics of sand and range of values for which the filter must satisfy. The $\mathbf{D_{10}}$ and $\mathbf{U_c}$ values of the middle layers of the experiments conducted for 2^3 factorial design so as to be able to check whether they satisfy these conditions which is necessary for specification and characterization of any filter sand is presented in Table 4 and 5.

The values are presented in Table 4 and 5 respectively. It can be observed from the tables that all the layers in the middle (excluding top and bottom layers) satisfy the requirement of effective sizes and uniformity coefficient values for rapid sand filters given as $\mathbf{U_c}$ ranging within 1.2 to 1.7 and $\mathbf{D_{10}}$ within 0.35 – 0.60 mm range given by [9].

Table 4: Uniformity coefficient values of each layer

Experiment No.	Uniformity coefficient value (U_c) of each layer						
	1	2	3	4	5	6	7
1	2.15	1.94	1.92	1.80	1.72	1.90	1.90
2	2.15	2.01	1.93	1.86	1.77	1.93	-
3	1.19	1.85	1.73	1.72	1.78	2.10	-
4	1.50	1.90	1.85	1.75	1.76	1.90	2.00
5	1.54	2.09	1.88	1.85	1.26	1.67	2.14
6	1.95	1.96	1.88	1.88	1.88	1.98	1.96
7	1.31	1.88	1.89	2.02	1.71	1.96	2.37
8	1.05	2.07	1.88	1.85	1.67	1.67	1.60

Table 5: Effective size (D_{10}) of the representative sample from each layer

Experiment	Effective size (D_{10}) of each layer

No.	1	2	3	4	5	6	7
1	0.41	0.44	0.48	0.50	0.55	0.50	0.60
2	0.33	0.43	0.48	0.53	0.57	0.60	0.73
3	0.42	0.46	0.52	0.58	0.56	0.62	0.85
4	0.40	0.44	0.49	0.52	0.60	0.54	0.65
5	0.37	0.43	0.48	0.54	0.78	0.60	0.70
6	0.41	0.45	0.48	0.50	0.50	0.47	0.47
7	0.32	0.43	0.45	0.46	0.58	0.50	0.76
8	0.41	0.43	0.48	0.48	0.55	0.60	0.75

4. CONCLUSION

The results obtained coupled with the analysis had established that it is possible to eliminate almost all the sand grains that are below 0.425 mm in size within the available flowrate per unit area as well as making use of the relationship between height of fluidizing column, height of sand above the bed support and the flowrate per unit area. Suggestions had been made as regards the possibility of eliminating coarser grains (1.18 mm) by preliminary sieving.

Among the three parameters (H, Q, T) considered as likely factors that are affecting the efficiency of fluidization in grading the sand particles, flowrate per unit area (Q) is the only significant factor. However, due to limitation imposed by the equipment used, the extent of its effect has not been fully verified. The useable yield obtained from this method i.e. in the middle layers excluding top and bottom layers is at present around 50 %. This can be improved by modifying some of the parameters affecting the system.

However, in order to improve the efficiency of the system, there is the need for further work to be carried out on the following areas;

(i) Establishment of a value of flowrate per unit area which will be capable of giving the best yield in the middle layers.

(ii) Design of a good underdrainage system for even distribution of water in the fluidizing column such that large head losses do not occur in the orifices. It should also be capable of eliminating channeling and spouting in the bed to some extent irrespective of the geometry of the fluidizing column (circular or rectangular).

REFERENCES

[1] Amirtharajah, A. (2014). 'Expansion of graded sand filters during backwashing' An unpolished M.Sc. thesis, Iowa State University, Ames, Iowa, U.S.A.

[2] Volpe M., Panno D., Volpe R., Messineo A., 2015, Upgrade of citrus waste as a biofuel via slow pyrolysis, *J. Anal. Appl. Pyrol*.115, 66-76.

[3] Ogedengbe, M.O. (1984). 'Characterization and specification of local sands for filters' *Filtration and separation journal* Vol. 1 pp 189-197

[4] Wu, S. Y. and Baeyens. J. (1998). Segregation by size difference in gas fluidized beds. Powder Technology, 98(2): 139-150.

[5] Rao, T. R. and. Ram J. V. (2016). Minimum fluidization velocities of mixtures of biomass and sands. Energy, 26: 633-644.

[6] Ruoppolo G., Miccio F., Brachi P., Picarelli A., Chirone R., 2013, Fluidized bed gasification of biomass and biomass/coal pellets in oxygen and steam atmosphere , Chemical Engineering Transactions 32, 595-60

[7] Brachi P., Miccio F., Miccio M., Ruoppolo G, (2016). Torrefaction of Tomato Peel Residues in a Fluidized Bed of Inert Particles and a Fixed-Bed Reactor, Energy Fuels 30, 4858-4868.

[8] Formisani B., Girimonte R., Longo T., (2008). The fluidization process of binary mixtures of solids: Development of the approach based on the fluidization velocity interval, Powder. Technol. 185, 97-108.

[9] Bruni G., Solimene R., Marzocchella A., Salatino P., Yates J.G., Lettieri P., Fiorentino M., 2015, Selfsegregation of high-volatile fuel particles during devolatilization in a fluidized bed reactor, Powder. Technol. 128, 11-21.