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FACTORS AFFECTING THE FLOWABILITY OF FERTILIZERS THROUGH ORIFICES*

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A b s t r a c t. The effects of some significant factors on the flow of fertilizers through orifices, such as orifice diameter, orifice shape, particle diameter, fertilizer type, air temperature, and air relative humidity were investigated. The effect of air temperature on the flow rate was small as the effects of the other factors were significant.

K e y w o r d s: flowability, fertilizer, orifice

INTRODUCTION

The study of flow properties of granular fertilizers is important for designing fertilizer distributors and hence even spread pattern [9, 13,14]. Spreading the right amount of fertilizer requires accurate metering of the fertilizer flow through the metering device. This requires a good knowledge of the factors affecting fertilizer flow.

The effects of the height of material in the container, the angle of repose and the particle shape on the flow rate have been found small by many researchers [1-6,10].

De [3] presented a review of the properties of solid chemical fertilizers and their effect on flow characteristics under gravity. He summarised that:

- The flow rate remains mostly independent of the material height as the weight of granular mass is largely borne by the vertical walls, which keeps stress state near the orifice independent of the material height.
- The material flow rate is proportional to (orifice diameter)^n, the varying value of n normally above 2.5.
- When the ratio of orifice diameter to particle diameter is less than about 3 or 4, the flow of material ceases. The exact value depends on the flow characteristics of the material and the dimensions of the container.
- The flow rate remains independent of the diameter of the container provided the ratio of container diameter to orifice diameter can be maintained above 2.5.

Mehring and Cumings [11] investigated of fertilizer drillability and concluded that the effects of temperature changes on the fertilizer drillability were small in comparison to the changes caused by changing relative humidity.

APPARATUS AND EXPERIMENTAL METHOD

A flat-bottomed cylinder of 52 cm height and 19 cm internal diameter was used for measuring the flow rate of fertilizers. In the center of cylinder flat bottom, there were interchangeable openings which could be closed by means of a slide-valve. The openings

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were circular orifices with diameters of 28.2, 42.3, and 56.4 mm, and square orifices with sides of 25.0, 37.5, and 50.0 mm. The areas of the circular and square orifices corresponded to each other, respectively. In order to compare the flow rates through circular and square orifices, the term "hydraulic diameter" was used. "Hydraulic diameter" is equal to four times the area of the orifice divided by the perimeter of the orifice.

The fertilizer used in the tests was calcium ammonium nitrate from two different manufacturers (identified as A and B). The particle diameters used were 3.35 and 4.00 mm of the screen size.

The flow tests were conducted in a controlled room at air temperatures of 20 °C and 25 °C and relative air humidity levels of 50, 65, and 80%.

In order to determine the effects of the relative air humidity and air temperature on the flow rate, the two fertilizers with particle diameters of 3.35 and 4.00 mm screen size were exposed to each relative humidity and temperature during a period of two days in a controlled room. Moisture absorption of the fertilisers exposed to various relative humidity levels and temperatures was determined by weighing the same three samples for each fertilizer and particle diameter before and after the exposure time. One sample consisted of about 500 particles.

The flow rate was obtained by determining the weight of material flowing in a given time interval measured by a stopwatch. This was repeated five times for each combination of fertilizer, temperature and relative humidity.

The angle of repose was determined by measuring the height of material that remained in the bottom of the cylinder when a batch issued the cylinder.

RESULTS

Flow

The measured values of the flow rate of the fertilizers at different conditions are given in Table 1. The results have been analysed with respect to the orifice shape and dimensions, the particle diameter, the fertilizer and air relative humidity and temperature. Analysis of variance is used to determine whether differences are significant or not.

The measurement results show that the flow is significantly affected (critical level <0.01) by the orifice shape (Fig. 1a). The flow rates through a circular orifice are about 9% higher than the flow rates through a square orifice with the same area of the opening. Most of this difference can be explained by the difference in hydraulic diameter of the square and circular orifices with the same area. This changes the hydraulic diameter of the circular openings to about 12.8% more than the hydraulic diameter of the square openings with the same area. The flow rate is related to the hydraulic diameter according to the empirical relation [7]:

$$Q = \mathrm{k} \cdot D^{\mathrm{n}}$$

where Q is the flow rate, D the hydraulic diameter and k and n are flow characterising constants. The values of k and n are determined by means of regression analysis. The results are given in Table 2. The results show that the empirical model provides a good prediction of the flow (all R^2 values are larger or equal to 0.97). The values for n vary between 2.77 and 2.93. Miwa [12] reported that values of n should be between 2.5 and 3.0 for most cases.

Analysis of the effect of the particle diameter shows a significant effect of the particle diameter on the flow rate (critical level 0.015). The flow rate decreases by about 7% when the particle diameter increases from 3.35 to 4.00 mm screen size (Fig. 1b).

The effect of the air relative humidity changes on the flow rate is significant (critical level < 0.01). The relationship between the flow rate and the air relative humidity is shown in Fig. 2. The flow rate increases very slightly as the relative humidity changes from 50% to 65% for both fertilizers. However, the flow rate of both fertilizers decreases significantly when the

Table 1. Flow rate in kg s^{-1} of fertilizers through different orifices at different environmental conditions

Air temp. (°C)	Air relative humidity (%)	Fert. type	Particle diameter (mm)	Circular orifice			Square orifice		
				Small	Medium	Large	Small	Medium	Large
20	50	A	3.35	0.143	0.475	1.055	0.123	0.435	1.008
20	50	A	4.00	0.129	0.435	1.007	0.116	0.400	0.922
20	50	B	3.35	0.128	0.433	1.002	0.112	0.396	0.922
20	50	B	4.00	0.120	0.412	0.950	0.103	0.371	0.861
20	65	A	3.35	0.145	0.478	1.073	0.125	0.438	1.004
20	65	A	4.00	0.130	0.439	1.005	0.112	0.400	0.929
20	65	B	3.35	0.140	0.447	0.994	0.124	0.402	0.916
20	65	B	4.00	0.126	0.423	0.965	0.092	0.387	0.862
20	80	A	3.35	0.137	0.431	0.992	0.109	0.390	0.889
20	80	A	4.00	0.121	0.408	0.942	0.052	0.360	0.834
20	80	B	3.35	-	-	-	-	-	-
20	80	B	4.00	-	-	-	-	-	-
25	50	A	3.35	0.144	0.470	1.109	0.125	0.441	1.018
25	50	A	4.00	0.129	0.437	1.004	0.110	0.400	0.939
25	50	B	3.35	0.130	0.428	0.996	0.112	0.393	0.917
25	50	B	4.00	0.121	0.407	0.948	0.103	0.368	0.859
25	65	A	3.35	0.145	0.481	1.112	0.126	0.447	1.033
25	65	A	4.00	0.129	0.437	1.018	0.113	0.401	0.936
25	65	B	3.35	0.139	0.445	1.026	0.124	0.403	0.923
25	65	B	4.00	0.123	0.421	0.975	0.117	0.385	0.895
25	80	A	3.35	0.134	0.445	1.030	-	0.405	0.924
25	80	A	4.00	-	0.431	0.981	-	0.381	0.888
25	80	B	3.35	-	-	-	-	-	-
25	80	B	4.00	-	-	-	-	-	-

Each value is the mean of five replications.

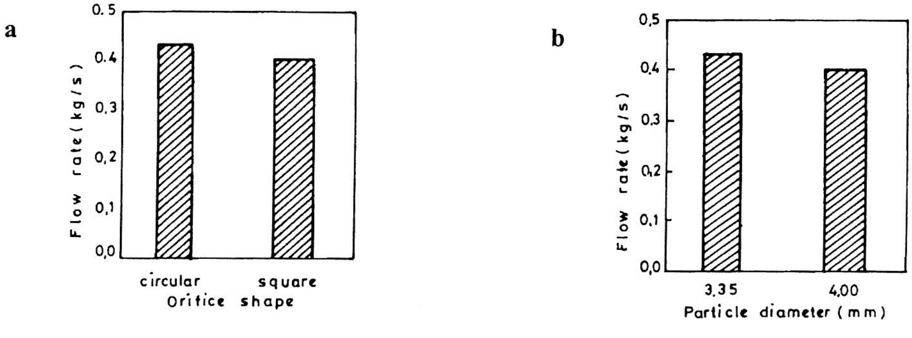

Fig. 1. Effect of particle shape (a) and diameter (b) of fertilizers on the flow rate.

relative humidity further increases from 65% to 80% for the two fertilizers. Analysis of variance indicates that the difference between values of the flow rate at the relative humidities of 50 and 65% is small and between 65 and 80% is significant ($p=0.01$). At the relative humidities of 50 and 65%, two fertilizers tested were dry and in good condition could flow satisfactorily through all orifices. At the relative humidity of 80%, the flow of fertilizer A was erratic, especially through the small orifices. Fertilizer B did not flow at all through the orifices. It appeared that fertilizer B was more hygroscopic than fertilizer A.

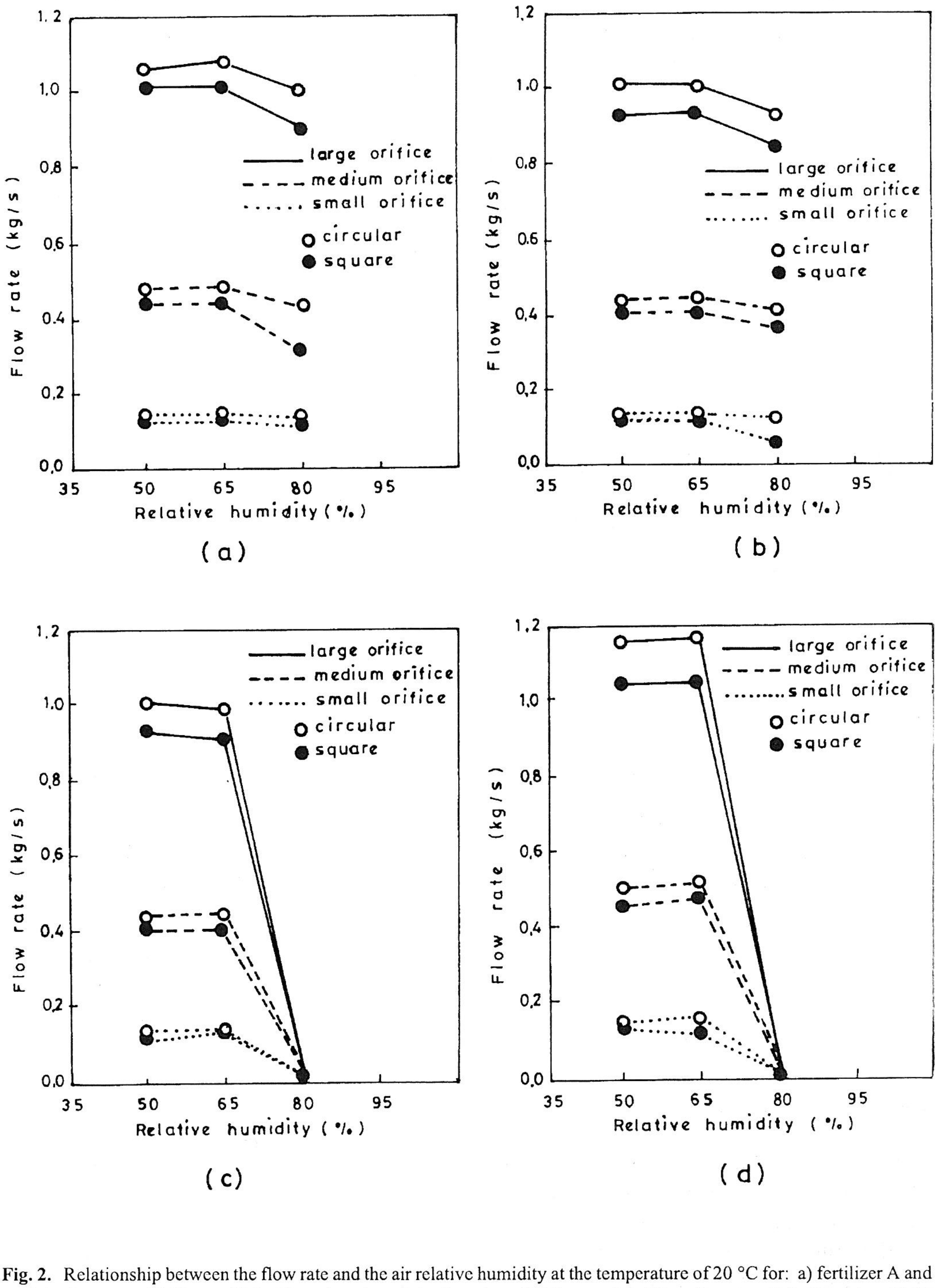

Fig. 2. Relationship between the flow rate and the air relative humidity at the temperature of 20 °C for: a) fertilizer A and particle diameter of 3.35 mm, b) fertilizer A and particle diameter of 4.00 mm, c) fertilizer B and particle diameter of 3.35 mm, d) fertilizer B and particle diameter of 4.00 mm.

Table 2. Values of the parameters k and n for the prediction of the flow rate as a function of the hydraulic diameter for the air temperature of 20 °C

Relative humidity (%)	Fertilizer	Particle diameter (mm)	k^* (x 10^{-5})	n	R^2
50	A	3.35	1.131	2.87	0.98
50	A	4.00	0.965	2.89	0.97
50	B	3.35	0.865	2.92	0.98
50	B	4.00	0.770	2.93	0.98
65	A	3.35	1.171	2.86	0.98
65	A	4.00	0.884	2.92	0.98
65	B	3.35	1.542	2.77	0.98
65	B	4.00	1.129	2.84	0.98
80	A	3.35	1.036	2.87	0.98
80	A	4.00	Erratic flow		
80	B	3.35	No flow		
80	B	4.00	No flow		

The effect of air temperature on the mass flow is found to be not significant (critical level 0.83).

Moisture absorption

Fertilizers are salts and absorb water. Most are able to absorb water when air relative humidity exceeds a certain value, the critical relative humidity (CRH). The CRH for most fertilizers ranges between the 60 and 70% of air relative humidity. Hignett [8] gives a value of 59% for ammonium nitrate. The flow measurements are executed in the conditions below and above the CRH of ammonium nitrate. The moisture absorption of a fertilizer has been measured by exposing fertilizer samples for two days to a certain relative humidity and temperature condition and weighing the samples before and after exposure. The results are given in Table 3. The values in table indicate the relative increase of mass. Moisture absorbtion of fertilizer B at 25 °C was that high that it was not possible to measure the increase of the mass due to the presence of free water. The consequence of water absorption is that the actual flow rates (on the nutrient content base) in Table 1 have to be adjusted by the percentages given in Table 3.

Angle of repose

The measured angles of repose are given in Table 4. The values in the table show that the angle of repose is mostly affected by air relative humidity. The effects of particle diameter and temperature are small. Differences between the fertilizers are small at air relative humidity of 50% but are considerable at air relative humidities of 65 and 80%.

Table 3. Effect of temperature and relative humidity on the moisture absorption of fertilizers during an exposure time of two days. The values in the table are the relative increase of the mass due to the absorption of water

Fertilizer	Particle diameter (mm)	20 °C			25 °C		
		50%	65%	80%	50%	65%	80%
A	3.35	0.00	0.08	1.92	0.00	0.27	4.31
A	4.00	0.00	0.14	1.46	0.00	0.29	4.31
B	3.35	0.00	1.02	-	0.00	2.24	-
B	4.00	0.00	0.77	-	0.00	2.46	-

Table 4. Effect of relative humidity, temperature, particle diameter and fertilizer on the angle of repose (in deg)

Fertilizer	Relative humidity (%)	20 °C		25 °C	
		3.35 mm	4.00 mm	3.35 mm	4.00 mm
A	50	35.7	36.7	35.0	36.9
	65	37.4	38.6	35.1	37.1
	80	51.2	49.1	49.3	49.7
B	50	37.0	36.6	37.5	37.2
	65	52.2	54.7	44.9	45.3
	80	-	-	-	-

CONCLUSIONS

1. The flow rate of fertilizers through orifices was significantly affected by orifice diameter, fertilizer type, air relative humidity, orifice shape, and particle diameter. The effect of the air temperature on the flow rate was small.

2. The flow rate through orifices was in agreement with the equation of $Q = k\ D^n$. The values of n were between 2.77 and 2.93.

3. For the same opening area, the flow rate through the circular orifices was higher than that of square orifices by about 9%.

4. For the particle diameter of 4.00 mm, the flow rate was less by about 7% than that of the particle diameter of 3.35 mm.

5. The flow rate increased very slightly as the relative humidity changed from 50 to 65% and then decreased significantly as the relative humidity changed from 65 to 80%.

6. At the relative humidities of 50 and 65%, the two fertilizers tested could flow satisfactorily through all orifices. At the relative humidity of 80%, the flow rate of fertilizer B was erratic specially through small orifices. The flow of fertilizer A did not occur through all orifices because fertilizer A was more hygroscopic than the other.

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