• *Technical*

An Engineering Approach to the Design of Cottonseed Aeration Systems[1]

W. B. HARRIS, W. D. HARRIS, and A. C. WAMBLE, A. & M. College of Texas, College Station, Texas

IT IS NECESSARY to store enormous quantities of cottonseed from the time of harvest until it can be processed. Preserving the quality of the seed is a major problem since it tends to deteriorate in storage because of enzymatic activity and the growth of micro-organisms. The only method in widespread use for controlling this hazard is to circulate air through the stored material and to control, by this means, its moisture content and temperature.

Very little information of a scientific or engineering nature has been recorded on factors affecting the flow of air through piles of cottonseed as they are ordinarily stored. It appears that no attempts have been made to apply the basic flow-equations to this operation.

The flow of air through cottonseed piles is an example of fluid flow through porous media. The subject has been studied by Darcy (1), who demonstrated that the rate of flow of a fluid per unit of cross-sectional area of a permeable medium is directly proportional to the pressure gradient and inversely proportional to the viscosity of the fluid for laminar flow conditions.

Darcy's equation is as follows:

$$v = \frac{q}{A} = -\frac{k\,dP}{u\,dL}$$

v = superficial air velocity
q = air volume in cubic feet per minute
A = cross-sectional area through which air flows, based upon empty container
k = permeability of media
u = viscosity of air
P = pressure
L = distance along direction of flow

When air is the fluid and the temperature does not vary greatly, the viscosity may be considered constant. Thus $\frac{k}{u}$ may be replaced by a "pseudo permeability," K, and Darcy's equation may be modified to

$$v = -K\frac{dP}{dL} \text{ or } K = -v\frac{dL}{dP}$$

This equation may be used to solve the normal problems involved in designing an air-flow system. For example, if the desired air flow is known, the required pressure drop and horsepower may be calculated.

The permeability, k, is a property of the porous media, in this case cottonseed. The viscosity, u, is a property of the fluid, air. L and A show the effects of the mechanical arrangement of the aeration system. These are subject to change, and different aeration arrangements will affect the quantity of air flow and the power required.

Although Darcy's equation is quite simple, its application can become very complex. In order to integrate the equation the cross-sectional flow area and permeability must either remain constant or their variation must be known as a function of L. This problem can be illustrated by the examples shown in Figure 1.

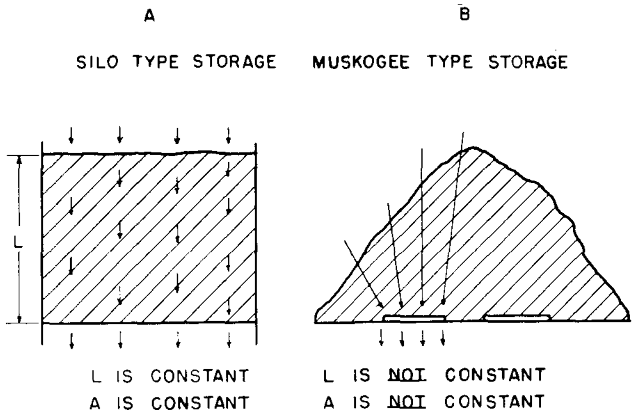


FIG. 1. Comparison of two types of storage.

The calculation of air flow in silos as illustrated by example (A) is not difficult. Here both the cross-sectional area and the seed-pile depth are constant. All that is needed to solve Darcy's equation for this type of storage is a knowledge of the relation between K and L.

However most cottonseed is stored in "Muskogee" houses, where the situation resembles example (B). The solution is complicated by the fact that A is not known as a function of L, also because L is not constant. In short, the geometic arrangement of the system is so difficult to express analytically that a rigorous solution by using Darcy's equation is not practical.

The foregoing indicates that two questions need to be answered before Darcy's equation can be applied. First, what is the permeability of cottonseed at various seed-pile depths? Second, how can Darcy's equation be solved when irregular shapes are encountered?

Essentially all that is required to determine permeability is a device to hold the seed, a method of forcing air to flow through the seed, and a means of measuring the pressure gradients obtained. In these studies a silo was used to hold the seed (2). It was 24 ft. high and 5 ft. in diameter. A positive-displacement cycloidal blower was used to pull air down through the seed. Volume was controlled by means of a valve located in the suction line near the blower. A sharp-edged orifice was installed in the air line in order to measure the air-flow rate. Taps were

---

[1] The research described in this paper was conducted as a cooperative project of the Texas Engineering Experiment Station and the Cotton Research Committee of Texas.

located along the side of the silo so that the pressure drop over each two feet of depth could be obtained.

When the pressure drop over a segment of the seed pile is determined for a given superficial air velocity, K for this segment can be calculated. This was done for 2-ft. segments of the silo, and the K values were plotted as a function of L, the depth, which is shown in Figure 2. Laminar flow was found at the highest air velocity tested, 5 ft. per minute. Therefore, at least up to this point, K is independent of the air-flow rate. In commercial cottonseed operations the flow is usually $\frac{1}{20}$ to $\frac{1}{12}$ ft. per minute, and turbulent flow should not be encountered except perhaps in the immediate vicinity of air ducts.

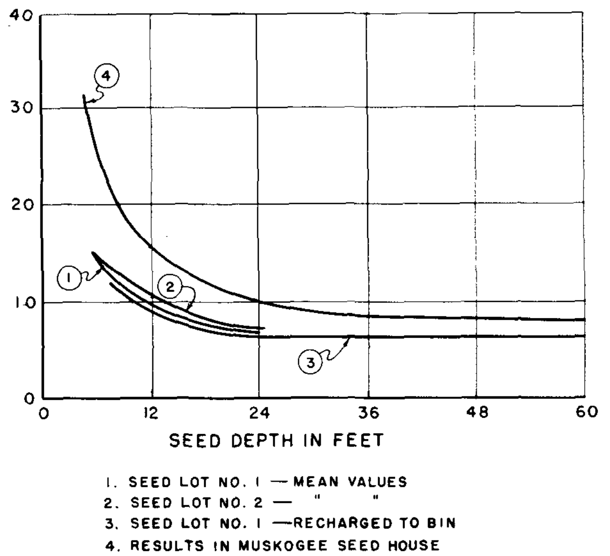


FIG. 2. Pseudo-permeability values.

The effect of seed-pile depth on permeability is immediately apparent. The upper portion of the pile was very permeable, which corresponded to the light fluffy condition of the seed. The first 3 or 4 ft. were usually so permeable that no reliable measure of the pressure drop could be obtained. The change in permeability as the depth increased was initially rapid, but gradually the rate decreased and finally the permeability approached an asymptotic value.

Commercial seed-pile depths frequently approach 70 ft. In order to obtain data for more than 24 ft., extra depth in the experimental silo was simulated by adding weight on top of the seed. The simulated depth was that required to hold an equal number of pounds of seed in a 5-ft.-in-diameter column.

Since a laboratory experiment can never precisely duplicate field conditions, it was desired to measure the permeability of cottonseed stored within a Muskogee seed-house. Actual measurement of air volume and pressure drops in such a unit would be very difficult. For this reason a special instrument was devised for measuring the permeability (Figure 3). In operation the probe was inserted into the pile of seed until it reached the location where a permeability measurement was desired. Air was then forced through the probe at a measured rate. At the same time the pressure at the probe tip was measured. If the seed were highly permeable, the air encountered little resistance while flowing into the pile and the pressure at the probe tip was low. On the other hand, if the seed were less permeable, the air encountered more resistance and the pressure at the probe tip was higher.

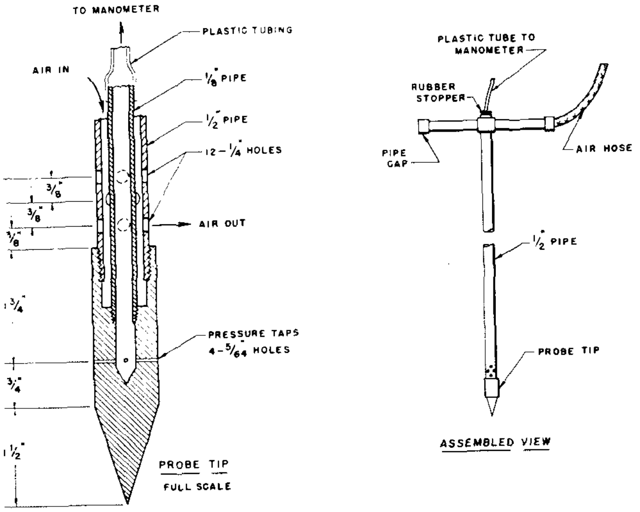


FIG. 3. Construction of permeability probe.

Since the resistance is a function of the area through which the air is flowing and since the area is spherical and increases rapidly with the distance from the probe, practically all of the resistance is encountered within a few inches of the probe tip. Effectively the probe measures the local or point permeability within the seed pile. All that is necessary is that the probe be calibrated. This was readily done in the experimental silo unit. Results obtained by using the probe at a Muskogee seed-house are plotted in Figure 2.

When the permeability has been measured, a good picture of the air-flow characteristics of the cottonseed under study is obtained. Computations to determine the power requirements for aeration in the silo type of storage units can readily be made. However, as indicated before, knowledge of the permeability characteristics is only part of the solution when the seed-pile depth and cross-sectional area vary, as in a Muskogee house.

In order to work problems of this type an electrical analogue method of solution was developed. The principle involved can be seen by comparing the equations for electrical flow through a resistance with that for fluid flow through a porous medium, as follows:

A. General flow equation

$$\text{flow} = \frac{\text{driving force}}{\text{resistance}}$$

B. Electrical flow equation

$$\text{amperage} = \frac{\text{volts}}{\text{ohms}} \text{ or } I = \frac{dE}{R} \times \frac{A}{dL}$$

I = amperage R = specific resistance

C. Air-flow equation

$$\text{cubic feet per minute} = \frac{\text{pressure drop}}{\text{resistance}} \text{ or } q = \frac{dp}{\left(\frac{1}{K}\right)} \times \frac{A}{dL}$$

These equations show, for geometrical analogous systems, that if the ratio of permeability to electrical resistance is known and if the ratio of desired air-flow to amperage is known, the pressure drop can be obtained by measuring the voltage drop across the model.

In the electrical analogue simulations a silo type of model was used inasmuch as air-flow patterns within a silo would be symmetrical and therefore could be plotted on two-dimensional surfaces for illustration (Figure 4). Tap water was used as the conductive fluid. Surfaces of the seed pile through which air entered or left the system were simulated by aluminum sheets or strips. The source of electrical current was an audio oscillator set at 1,000 cycles per second. This high frequency was selected to prevent erroneous results from polarization. The voltages were measured by vacuum-tube voltmeters.

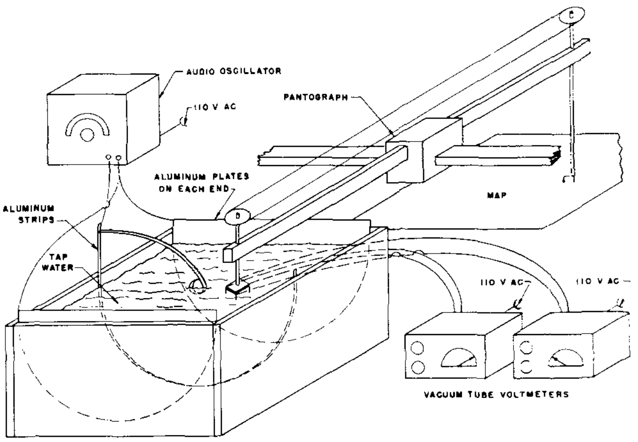


Fig. 4. Model silo and accessory equipment for analogue studies.

In order to simulate a variable cross-section and nonrectilinear flow, two possible alterations were investigated. A simulated air duct was installed halfway up the side of the silo. This duct represented an opening 1 ft. high circumferentially around the tank through which air could exit. The other alteration was to simulate a circular air duct 6 ft. in diameter, located in a horizontal plane at the center of the silo. Air could exit through both vertical sides of the duct. The sides were 1 ft. high.

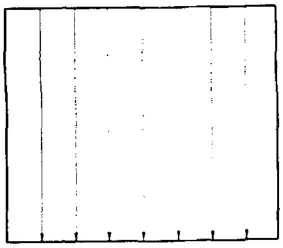
Air-flow patterns obtained with the analogue are shown in Figure 5. Each map shows the direction of air flow and the relative quantity of air flow. The amount of air, using a known amount of power and rectilinear flow, is arbitrarily called unit flow or flow of 1. When the same power was applied to nonrectilinear systems, variation in air-flow rates resulted. The values assigned the various flow-lines indicate the flow rate compared to the unit flow rate of 1. In other words, the maps can be compared and the efficiency of each arrangement for cooling specified locations in the silo can be obtained. For aeration of the entire seed-mass, rectilinear flow could not be improved. In some cases nonrectilinear flow would permit concentrating upon "hot spots" within the pile, and the efficiency would be better if only these spots were considered.

When a model having the same geometric configuration as the seed pile under study has been constructed, various duct arrangements can be tried until the most satisfactory arrangement is found.

There is a problem involved in using the analogue procedure. It has been shown that the permeability of cottonseed varies with pile depth or L. In the model the electrical resistance of the conducting fluid should vary proportionately. This can be accomplished by using successive layers of conductive material with different resistances. Gelatin layers can be used to reduce fluidity and mixing. Another procedure would be to make a correction by distorting the length of the model in proportion to the permeability change.

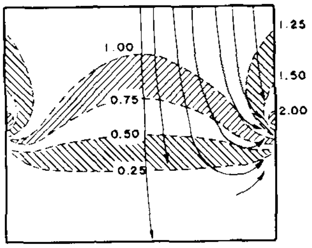
Conclusions

Darcy's equation for fluid flow through porous media can be used to solve engineering problems involved in the aeration of stored cottonseed if their permeability is known. The permeability will vary as the seed-pile depth increases because of compaction in the lower portions of the pile. It is also a function of the length of storage time and the type of seed used. The permeability data given in this paper, based upon laboratory and field tests for several lots of cottonseed, can probably be used in most aeration problems without excessive error. However possible nonuniformity within the seed pile should be considered. Problems can arise on account of



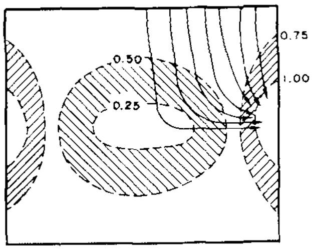
MAP 1

RECTILINEAR FLOW. FLOW UNIFORM THROUGHOUT AND CONSIDERED AS UNIT FLOW RATE.



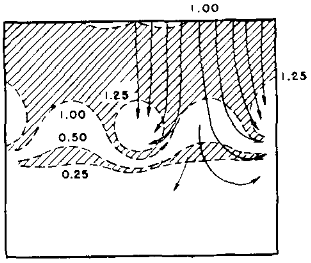
MAP 2

TOP OPEN WITH FLOW TO SIDE DUCT. FIGURES DENOTE FLOW COMPARED TO UNIT FLOW USING SAME POWER AS FOR MAP NO. 1.



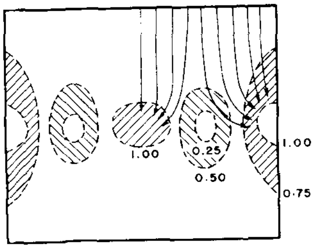
MAP 3

TOP AND BOTTOM OPEN WITH FLOW TO SIDE DUCT.
DOTTED LINES ARE EQUAL FLOW RATE LINES. SOLID LINES ARE DIRECTION OF FLOW LINES.



MAP 4

TOP OPEN WITH FLOW TO SIDE DUCT AND CENTRAL DUCT.



MAP 5

TOP AND BOTTOM OPEN WITH FLOW TO SIDE DUCT AND CENTRAL DUCT.

Fig. 5. Variations in flow.

classification of material while filling or on account of differences between seed lots in the amount of lint, chaff, and debris. In some instances it may be desirable to determine the permeability of a specific seedpile. In this case the "Permeability Probe" devised during this investigation can be used to measure the permeability *in situ* quickly and easily.

Actual solution of Darcy's equation can be relatively simple, as shown in the example presented, or it can be quite difficult when a geometric "Shape Factor" needs to be obtained. It may be desirable to use an electrical analogue as described in this paper to determine the Shape Factor. An analogue also permits flow patterns to be established.

The analogue technique for solving Darcy's equation and the development of the Permeability Probe should be helpful in the design of aeration systems for many commodities other than cottonseed.

REFERENCES

1. Darcy, L., "Les Fontaines Publiques de la Ville de Dijon," Victor Delmont, Paris (1856).
2. Harris, W.B., "A Study of the Flow of Air Through Cottonseed Storage Units," graduate thesis, Texas A&M College, January, 1960.

[Received April 5, 1960]

Studies of the Chick Edema Factor. II. Isolation of a Toxic Substance

ANDREW YARTZOFF, DAVID FIRESTONE, DANIEL BANES, WILLIAM HORWITZ, LEO FRIEDMAN, and STANLEY NESHEIM, Bureau of Biological and Physical Sciences, Food and Drug Administration, Department of Health, Education and Welfare, Washington, District of Columbia

A crystalline halogen containing material producing chick edema symptoms at 0.1 part per million in the diet has been isolated from a sample of triolein which was toxic to monkeys. This material is similar to that reported by Harman *et al.* (4) but differs somewhat in ultraviolet spectral properties.

IN A SYMPOSIUM on the chick edema disease in October, 1958, several laboratories (1,2,3) presented reports on their progress toward the isolation and elucidation of the toxic factor responsible for the occurrence of this unusual syndrome. It was established that the disease is caused by a toxic factor in the unsaponifiable fraction of a fatty by-product of industrial stearic and oleic acid manufacturing operations, and it was further suggested that the factor might possess a polynuclear or steroidal structure. A note, later published as an addendum to the contribution from this laboratory (2), reported that the toxic factor was associated with eluates from alumina and "silane-treated Celite" chromatographic columns which exhibited the ultraviolet absorption spectra of polysubstituted naphthalenes (λ_{Max} at 236 mμ, secondary λ_{Max} at 286 and 296 mμ). Neighboring cuts from these chromatograms showed the characteristic spectra of phenanthrene derivatives (λ_{Max} at 259, 282, 292, 300 mμ) and of simpler naphthalene derivatives (λ_{Max} 228–233 mμ, secondary λ_{Max} 270–280 mμ).

Subsequent purification of substances that had an absorption peak at 236 mμ demonstrated that they were not the most toxic fractions in our materials. Furthermore our computations showed that the toxic factor must be potent when present in the diet at levels of a fraction of one part per million. Recently Harman *et al.* (4) have reported the isolation of the chick edema factor in crystalline form from a feed-grade tallow. Their substance was toxic to chickens at 0.1 p.p.m. in the diet and had an ultraviolet absorption spectrum with a major peak at 244 mμ, a lesser peak at 312 mμ, and a shoulder at 238 mμ. A private communication from Tishler of the same laboratory (5) disclosed that the crystalline substance contains chlorine to the extent of about 47%.

Ames *et al.* (6) have observed the presence of the toxic factor in some commercial oleic acids. We have studied a sample of triolein which had been an ingredient in a series of dietary treatments involving changes in the level and types of fats to which a group of Cebus monkeys had been subjected.

The following summary of experimental results reltive to these monkeys was received from O. W. Portman and S. B. Andrus of the Department of Nutrition, Harvard School of Public Health.

> Of a group of nine monkeys that received this triolein in their diets at a level of 25% by weight, one died at one month and four at three months. After three months on the triolein diet corn oil was substituted for the triolein. The other four monkeys died from three weeks to five months later even though triolein had been discontinued and replaced by corn oil. Of 14 monkeys in the colony that did not receive triolein but were supplied other fats and oils at 25% of the diet by weight, there was only one spontaneous death. Eight of the nine monkeys fed triolein were autopsied and showed the following findings: jaundice (4,8?); pancreatic atrophy and fibrosis (6); hemosiderosis (6); fatty liver (5); bile duct proliferation (3); extramedullary erythropoiesis (3); necrosis of liver (2); gross hemorrhage in gastrointestinal tract (2); and erythrocytophagocytosis (1). Several features including marked anemia in several instances suggested the possibility of a hemolytic process. Pancreatic changes were most pronounced in the two monkeys that survived longest (seven to nine months from the beginning of triolein feeding). The severity of the lesions in the pancreas was unrelated to that of the hepatic changes. With the exception of fatty changes in the liver, the above findings have not been reproduced in rats. These observations are from an experiment not designed to study a toxic principle, and it would be unwise to draw firm conclusions with respect to the toxicity of the triolein from these limited data.

The fact that, in our laboratory, marked symptoms of chick edema disease were produced by this sample of triolein suggests the possibility that the chick edema factor may have been responsible for the toxic effects noted in the triolein-fed monkeys.

We now wish to report the isolation of a highly toxic crystalline substance from this triolein and to describe its properties.