

THE EFFECT OF COMPOST END- PRODUCT IN THE PRE-CONDITIONING OF RAW SLUDGE

Thesis for the Degree of M. S. MICHIGAN STATE COLLEGE Carl Henry Billings 1954 This is to certify that the

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The Effect of Compost End-Product in The Pre-Conditioning of Raw Sludge

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THE EFFECT OF COMPOST END_PRODUCT

IN THE PRE-CONDITIONING

OF RAW SLUDGE

By

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A THESIS

Submitted to the School of Graduate Studies of Michigan State College of Agriculture and Applied Science in partial fulfillment of the requirements for the degree of

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This work is respectfully dedicated to Professor Frank R. Theroux, without whose mature understanding and judicious advice it would never have been completed.

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I. INTRODUCTION

The Sanitary Engineering Department of Michigan State College has been engaged in experimental work on the disposal of municipal wastes by aerobic decomposition or, specifically, the process of composting. Thus far, research has been confined to various effects incidental to the processing of municipal garbage. It is the wish of those concerned with this project to extend the inquiry to the effects of processing either sewage sludge alone or mixtures of sludge and garbage.

Other workers in the field of composting have indicated that successful composts of sludge and garbage mixtures cannot be produced if the initial moisture content of the mixture exceeds 65 per cent (1) (2)*. Thus, with a raw garbage of roughly 60 per cent moisture, a sludge of not more than 75 per cent moisture would be desirable if any appreciable amount is to be used in the mixture.

This investigation was therefore undertaken for the primary purpose of finding a suitable means of dewatering sludge which would not be detrimental in any way to the composting process.

* Numbers refer to items in Bibliography.

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There are two processes for drying sewage sludge presently in widespread use. The first consists of ponding the sludge on sand beds with underdrains. The water drains off by gravity with a considerable amount of moisture being evaporated into the atmosphere. Disadvantages inherent in this process which preclude its application to compost digestion are:

1. Large land area required.

2. Length of holding time.

3. Offensive odor produced.

The other method of dewatering sewage sludge which is widely used is by means of a rotary vacuum filter. In this process the sludge is usually pre-conditioned by means of a suitable chemical coagulant. Ferric chloride alone or mixtures of ferric chloride and lime are most used. The purpose of these coagulants is to neutralize electric charges which are carried on the individual sludge particles and to form a floc from which the water may readily be withdrawn.

The use of ferric chloride as a coagulant in sludges presents considerable difficulty in the composting of such material. Rudolfs and Setter (3) have pointed out that concentrations of ferric chloride in excess of 20 parts per million are extremely toxic to the bacteria in sludges. Further evidence of this is given by Van Kleeck (4).

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It is felt that this may be due in part to the tying up of soluble phosphorus necessary to the metabolism of these bacteria in the form of insoluble ferric phosphate. Since the process of composting is carried out by aerobic or faculative bacteria which require a substantial amount of soluble phosphorus present, it may be reasoned that these sludges would not be the best material for the process.

Another factor which should be mentioned at this time is the use of relatively chemically inert materials, such as diatomaceous earth, for filter aids. These substances may provide a neutralizing effect on the surface charges by offering more surface area over which to distribute those charges, but their primary effect is that of bulking or giving the sludge such consistency that the water is easily drawn out (5). They have not been used to any extent in sewage sludges due to their inefficiency in relation th the coagulants.

With the above facts in mind, this investigation proceeded on the assumption that a rotary vacuum filter would be the most efficient means of dewatering the sludge if a suitable filter aid could be found. It was decided to study the material which was most readily available, namely, the finished compost product. It was felt by the author that this material, having evolved from the process, could certainly have no ill effect on the composting if returned to the process.

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II. HISTORY AND PREVIOUS WORK

The idea of mechanically dewatering sludges by means of vacuum filtration is not new, since it has been applied to chemically precipitated sludges for many years. Edwards states, " The use of this process spread rapidly throughout England, after about 1880 and a little later became popular in this country. One of the first plants of this type was established at East Orange, New Jersey in 1888. Other plants followed, those at Worcester and Providence being the most important." (6)

Around the turn of the century chemical precipitation gave way to plain sedimentation in sewage treatment practice, and filtration temporarily died out due to the difficulty of efficiently dewatering the resulting sludge.

The Milwaukee Sewerage Commission was formed in the early nineteen twenties and charged with providing sewage treatment for the City of Milwaukee and surrounding area. This commission proceeded to study the activated sludge process with a view to installing such a plant. In the course of these extensive studies it was discovered that the sludge produced had a definate fertilizer value and it was felt that a market could be developed for these waste solids provided they could be produced in suitable form. Since the

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proposed location of the plant was an island of limited area, sand beds were out of the question. These facts led to the investigation of various mechanical devices for dewatering, the rotary drum type vacuum filter finally being selected (7).

It was evident from the results of this research and from parallel work carried on at Chicago that the sludge would have to be suitably conditioned before filtering. Temperature, pH, and rate of coagulation were found to be important factors. Sulfuric acid along with alum were used as conditioners. Since these compounds were not very efficient at room temperature it was necessary to heat the sludge in preparing it for the filters (8).

In 1927 Mohlmann and Palmer at Chicago discovered that iron salts, particularly ferric chloride, were far superior to alum (9). This discovery opened the way for widespread use of the vacuum filter.

The toxic effects of ferric chloride on bacteria were first shown in a paper by Rudolfs and Setter which appeared in 1931 (3).

Keefer and Cromwell were the first to report an extended series of experiments on the vacuum filtration of sludges in full detail (10). Extreme difficulty was experienced in the dewatering of fresh solids using ferric chloride alone. This work was carried on at Baltimore for some number of years. As new data became available on specific phases of

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the subject it was set forth in a series of articles by Keefer and Kratz (11) (12) (13) (14) (15).

Mohlmann and Edwards in 1934 investigated the use of various other filter aids in conjunction with ferric chloride in order to reduce the amount of this compound necessary for filtering. The strong acids and chlorine did not appreciably alter the amount required. Sodium dichromate proved to be very efficient in this regard, even in amounts as small as one per cent or less of dry weight of sludge. The addition of lime in sufficient amounts to raise the pH to 9.0 effected some savings. Other chemical coagulants of the several tested were much less efficient. Filter aids of the physical type which were tested were coke breeze, petroleum coke, ground slag, and paper pulp. The first three mentioned were of little value, but amounts of paper pulp as large as 50 per cent dry weight and above gave fair results (16).

Edwards in this same year described the use of diotomaceous earth with ferric chloride at Pasadena, and also the use of filter aids composed of paper pulp, with or without lime in York Township, Ontario; Hagerstown, Maryland; and Rockville Center, Long Island, New York. He went on to point out that these alkaline conditioners, while not as efficient as ferric chloride, are not corrosive when disposed of on land (6).

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The monumental work by Genter also appeared in 1934. This was the first paper to apply the knowledge of colloidal chemistry to the vacuum filtration of sewage sludges. By advancing theory based on colloidal chemistry and confirming it by means of Buchner funnel filtration tests he was able to demonstrate that the washing out of soluble compounds from the sludge prior to filtration, increased the efficiency of the process. This method came to be known by the term which he originally used, elutriation (17).

Snell did considerable work on the drainability of the various sewage sludges in 1936. This work was carried out both by means of vacuum tests and gravity tests on miniature sand beds. The effects of temperature, applied vacuum, addition of alum and ferric chloride, applied voltage, and mixing of types of sludges were noted (18).

In 1938 Van Kleek reviewed the progress of vacuum filtration to that date, and set forth certain operational and laboratory control techniques which were helpful in the application of theory to operation (4).

Genter in 1941 investigated the mathematical relationships in the physical process of filtering. His work was based on the Poiseuille equation for the flow of fluids through capillary tubes and thus assumed an incompressible filter cake (19).

In 1952 Halff formulated a rotary vacuum filter theory considering a compressible cake in which the discrete solid particles follow Hooke's Law. Laboratory work carried on by him seems to substantiate this hypothesis (20).

III. THEORETICAL CONSIDERATIONS

A. Colloidal Chemistry. (17) (22)

Chemically, sewage sludge is an exceedingly complex material. In addition to numerous dissolved inorganic compounds there is contained a large amount of organic matter in the form of proteins, protein derivatives, fats and derivatives, and carbohydrates and their derivatives in various stages of continuing decomposition. These organic compounds exist in both soluble and insoluble states with a large amount of the material being in a colloidal suspension.

It might be expedient at this time to review the principles of colloidal chemistry. The term colloid was originally used to denote certain amorphous solutes such as starch and albumin which diffuse more slowly than the crystalline solutes, the solutions of which have very low osmotic pressures with little effect on the freezing point of the solvent. It now refers more to the state of subdivision rather than the type of material.

The subdividing of a material into extremely small particles and distributing these particles throughout a second substance is known as dispersion, and the system resulting therefrom is called a disperse system. It is obvious that this process creates a much larger surface area than that

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of the original piece of matter, and that surface effects which go undetected on the larger piece would become extremely evident in the divided state.

Although there are no sharp delineations in the determination of the size of particles which behave as dissolved substances, colloids, or ordinary suspended substances, it is arbitrarily considered that particles with diameters between 0.001 and 1.0 microns are colloids.

Colloid particles with their large surfaces are likely to have ions attached to them. A solid may be visualized as a crystal lattice with the surface having atoms arranged in an orderly fashion like a checkerboard. Each atom at the surface has free valences or unattached forces which are available for attaching molecules from the liquid. These molecules so attached will become oriented in the same direction with respect to the surface and thus will form a fixed liquid film being firmly held by induced dipole attraction at the surface of the particle and, because of orientation, attracting ions from the solution to form a second layer. The potential induced by the attraction of this outer layer is known as the Zeta potential and is directly responsible for the dispersion of colloids due to the fact that all particles induce like charges and therefore repel one another. Most substances when dispersed in water acquire negative charges, although some few acquire positive charges.

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When a large concentration of an electrolyte is added to the solution ions of opposite sign cause these charges to disappear and the colloid is precipitated. Colloids of unlike sign may also cause one another to precipitate by this same mechanism.

The phenomena of certain substances such as charcoal to absorb gases, liquids, and ions is well known. This is thought to be due, in part, to the same forces outlined above, but on a much larger scale, since these materials need not be as finely divided. If one of these adsorbents is added to a colloidal solution in large quantities, the colloidal particles will be adsorbed and thus offer no further resistance to separation from the water. These materials usually have large surface area due to their rough texture.

B. Mechanics of Filtration:

Genter (19) expressed the fundamental factors which govern filtration as follows:

1. Effective filter area.

2. Filtration pressure (pressure difference on two sides of the system).

3. Nature of solids (density, particle size and compressibility).

4. Water or solution present in sludge and filter cake and its density.

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5. Rate of solids deposit in filter cake (from filtrate flow rate).

6. Resistance of filter base (cloth) to filtrate flow.

7. Resistance of filter cake to filtrate flow.

8. Time by which rate factors are measured.

9. Coefficient of viscosity of filtrate or sludge moisture.

10. Temperature.

Factor number nine is, of course, dependent upon number ten.

It can be shown that flow through a filter cake is laminar and thus follows **Darcy**'s law for the flow of fluids through porous media. The linear velocity of the fluid at any instant is given by the equation that follows:

$$\mathbf{v} = \frac{1}{A} \frac{d\mathbf{V}}{d\mathbf{t}} = \frac{\mathbf{k} (\mathbf{P}_1 - \mathbf{P}_2)}{\mathbf{L}\mathbf{u}} \qquad \dots \mathbf{1}$$

in which:

V = volume of the filtrate. A = area of the filter medium. L = thickness of the cake. t = time. k = coefficient of permeability. u = viscosity of filtrate P₁-P₂ = pressure drop through the cake. An expression relating to filtration capacity, expressed as the quantity of filtrate, may be obtained by equating the solids in the sludge to the solids in the cake:

(1-X)
$$LAD_s = \frac{(V_{\uparrow}XLA) Dx}{1-x}$$
 ...2

where:

X = porosity of the cake.

XLA = volume of fluid in the cake.

x = per cent solids in sludge /100.

D = density of filtrate.

 $D_s =$ density of solids in the cake.

If equation two is solved for L and substituted into equation one, a convenient relationship between V and t may be shown:

$$\frac{dV}{dt} = \frac{kA^2 (D_s(1-x)(1-x) - Dxx)(P_1 - P_2)}{uVDx} \dots 3$$

By combining many of the terms into a single coefficient, C_{u} , this may be simplified to:

$$\frac{\mathrm{d}\mathbf{V}}{\mathrm{d}\mathbf{t}} = \frac{\mathbf{A}^2(\mathbf{P}_1 - \mathbf{P}_2)}{2\mathbf{C}_{\mathbf{v}}\mathbf{V}} \qquad \cdots 4$$

Equation four is a simplified expression for the instantaneous rate of filtration in terms of the properties of the sludge and cake, quantity of filtrate, and pressure drop through the cake (23). The foregoing equation, while correct, is difficult to apply to sewage sludges. It can be readily seen that to assume that C_v is a constant is to assume that there is no compression of the cake while filtering. This is not the case in filtering sewage sludges.

Halff (20) has suggested a new line of approach which appears to have merit. It is based on the adaption by Terzaghi of Fourier's method for the solution of heat conduction problems to the consolidation of solids. The proposed hypothesis assumed that the driving force varies with time and distance. In addition to other factors heretofore considered it was assumed:

1. If any sludge is subjected to a constant pressure, the ratio of the weight of the liquid in the cake to the weight of dry solids will reach an equalibrium.

2. The portion of externally applied pressure which is carried by the solids varies inversely as the ratio of the weight of the liquid in the cake to the weight of the dry solids.

Under these assumptions the partial differential equation for the filtration process is:

 ${}^{c}f \frac{d^{2} \phi}{dz^{2}} = \frac{d \phi}{dt} \qquad \dots 5$

in which:

 $\oint = a$ new term called "press" (equal to $k(P_1 - P_2)/u$ in equation one).

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z = distance above the bottom of the filter.

 c_{f} = the coefficient of filtration further defined as: $c_{f} = \frac{cy}{us!a}$...6

in which:

c = a constant of proportionality.

y = the specific weight of the liquid.

s' = the weight of solids per unit or original volume.

a = a coefficient of compressibility similar to Terzaghi's.

Integration of equation five gives:

$$F = 1 - \sum_{n=0}^{n=0}^{n=0} \frac{8}{(2n-1)^2 \pi} 2 \cdot e^{-(2n-1)^2 (\frac{\pi}{2})^2 T} \dots 7$$

let:

$$j = \frac{\pi}{2} (2n - 1)$$
 ...8
 $F = 1 - \sum_{j=0}^{j=0} \frac{2}{j^2} e^{-j^2 T}$...9

and:

$$T = \frac{c_{f}t}{L_{f}^{g}} \qquad \dots 10$$

in which:

T = a dementionless time factor. L_f = the final cake thickness. F = the ratio of the volume of filtrate removed to the volume of filtrate which can be removed at 100 per cent filtration.

The time factor, "T", is determined by analysing the data graphically to determine the per cent of filtration accomplished. It may then be selected from the following table which is a solution of equation number nine.

TABLE 1

RELATION BETWEEN FILTRAT AND TIME FACTOR (20)	ION
Per cent Filtration	Time
Accomplished	<u>Factor</u>
0	0
10	0.008
20	0.031
30	0.072
40	0.126
50	0.195
60	0.287
70	0.405
80	0.565
90	0.848
95	1.127

Given the time factor for any particular time, the coefficient of filtration may be found by measuring the final cake thickness and by rearranging equation ten as follows:

$$c_{f} = \frac{TL_{f}^{2}}{t}$$

IV. EXPERIMENTAL PROCEDURE

A. Apparatus

The apparatus used as shown in Figure 1 and diagrammatically presented on Plate I compared closely with Genter's (17), but was actually patterned after that used by Snell (18).

Three 8.5 cm. diameter Buchner funnels taking 7.0 cm. diameter filter paper were supported in a wooden frame 15 inches high. Below these were placed three 100 ml. graduates, the tops of which had been flared to receive rubber stoppers. The stoppers were drilled with two holes each. One hole was connected by means of 10 mm. glass and rubber tubing to the funnel above. The other hole was connected by means of 8 mm. glass and rubber tubing to a manifold arrangement and thence to a large carboy bottle.

A glass tee was installed in the line between the bottle and the manifold to which a mercury manometer was attached. The bottle was connected by means of glass tubing and heavy duty rubber tubing to a laboratory aspirator which was capable of pulling a vacuum measuring 700 mm. of mercury. The purpose of the large bottle in the line was to serve as a safety measure against backlash of the vacuum pump and as a vacuum equalizing chamber.

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FIGURE I. Showing the apparatus used in the filtration experiments.



Screw type stopcocks were installed on the lines to each of the funnels and on the main line between the manifold and the manometer. As originally described in the aforementioned paper (18) this latter stopcock was for the control of applied vacuum. It was discovered after using it a short time that the applied vacuum could easily be controlled by adjusting the pump whereas the stopcock adjustments gave much too rapid a change in value. For this reason its use was abandoned.

Use of the other screw type cocks was soon found to be unwise. If the three funnels were being used simultaneously it was found to be practically impossible to loosen all the stopcocks in less than a half minutes time. This gave quite a varience in readings. Heavy duty spring type cocks which could be removed almost instantly solved this problem.

For the sake of uniformity of results, a particular grade of filter paper was selected and used throughout the tests. Whatman's Number 30 was the grade used. It was found that wetting the paper previous to placing it in the funnel precluded leaks around the edges.

B. Materials

The sludge used for these determinations was taken from the primary sedimentation tanks at the East Lansing Sewage

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Treatment Plant. This material was primarily raw sludge. However, about fifty per cent of the dry solids on a weight basis were derived from waste activated sludge which was returned from the separation box to the primary tank.

Throughout these experiments it was found that the pH of the separate batches of raw sludge varied between 5.6 and 6.3 with practically all of the batches having a pH of 5.8 or 5.9. The moisture content of the sludge used remained practically constant at 96.0 per cent plus or minus 0.5 per cent. The specific gravity of the sludge averaged 1.015. All tests were carried out within eight hours of collection.

The compost end-product was obtained from the cell type compost boxes at the garbage plant which had been used in experiments in cold weather composting. The pH of this material was 7.0. The fact that it was a stable product was indicated by the musty odor usually associated with finished compost and by chemical oxygen demand tests performed in accordance with instructions given by letter from Lederle Laboratories. This test consists of a modified dichromate oxygen demand test in which 0.25 grams of the material is refluxed with water, potassium dichromate solution and an excess of concentrated sulfuric acid. The resulting solution is then diluted and titrated with a standardized ferrous

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ammonium sulfate in the presence of ferrion indicator. The results are not expressed as a definate quantity, but as an index. Preliminary work by Lederle and by this laboratory has indicated that composts having an index greater than 11,000 are biologically unstable. The index determined by the above method for the compost end-product used in these experiments was 9,900.

After procuring the compost material it was passed through a number ten sieve to remove sticks, rags, paper and other deleterous material. It was then dried twenty four hours at 103°C., ground, and graded by means of a stack of sieves placed in a Ro-tapper.

The ferric chloride used was in the lump form averaging 60 per cent FeCl₃. This was ground to a fine powder by means of a morter and pestle.

C. Method of Procedure

Mixtures were prepared for filtering by weighing out 100 grams of the sludge plus about 1.0 gram to the nearest 0.1 gram in a beaker of known weight. It was determined that about 1.0 gram would adhere to the beaker upon pouring the contents out of it. The required quantity of filter aid was weighed out (the ferric chloride being weighed on analytical balance) and placed in the mixing bottle. This was an eight ounce wide mouthed bottle with a rubber stopper

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FIGURE II. Showing standard sieves, mixing bottle, and samples of compost of various grain sizes.

as shown in Figure Two. The sludge was poured into the mixing bottle and the mixture was agitated with a rolling motion for 60 seconds.

The stopcocks above the graduates were closed and the aspirator was turned on. Moistened filter paper was placed in each of the three funnels. A vacuum of 600 mm. of mercury was used throughout the tests as it closely approximated that used at most rotary vacuum filter installations. Upon reaching this value, the pump was adjusted to a flow low enough to merely hold the vacuum steady.

▲ 25 ml. portion of the sludge-filter aid mixture was then placed in each of the funnels. Graduates of 50 ml. capacity which had been checked against a burette were used to measure this mixture. The amount of sludge mixture adhering to the graduate was pre-determined by pouring from one graduate into another and allowance was made on this.

A stop watch was started, the stopcocks were removed from the apparatus and the vacuum was immediately adjusted to exactly 600 mm. by means of the pump hand wheel. Readings of the amount of filtrate in the graduates were taken at intervals until 15 minutes had elapsed. The material was then allowed to continue filtering at 600 mm. mercury vacuum until a break occured, at which time a reading of the amount of filtrate was taken. A vacuum break was arbitrarily considered to have occurred when the mercury column

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dropped 20 mm. This time was recorded and in some cases, the final thickness of the filter cake was measured with a metric scale. Hydrogen ion concentration readings were taken of the raw sludge and all mixtures by means of a Beckman pH Meter. The moisture content and specific gravity of the raw sludge were determined in accordance with Standard Methods for the Examination of Water and Sewage of The American Public Health Association. The specific gravity of the compost was determined in a similar manner.

After weighing the bottle empty and filled with water, thirty grams of dried compost passing a number 50 sieve were weighed out and placed in the bottle. The bottle was then filled half-way with distilled water, shaken to completely wet the material, completely filled with water and weighed.

The difference in the weight of the bottle filled with this mixture and with distilled water when subtracted from the weight of the compost gives the volume displaced by the compost.

Thus: Specific Gravity =

$$\frac{30 \text{gm}}{30 - (308 - 304)} = 1.15$$

V. EXPERIMENTAL RESULTS

The results obtained from these experiments have been presented in graphical form on Plates II thru VII.

Plate II is a plot of the per cent moisture remaining in the filter cake at any given time when using compost endproduct which passed a number 60 sieve as a filter aid. The various percentages of the raw sludge shown are computed on a wet weight basis. This means that in terms of the dry weight of the sludge these percentage values would be roughly 25 times the value showm.

The moisture content of the filter cake was computed in the following manner. Assuming the specific gravity of the raw sludge and compost mixture to be 1.00:

$$M = 100 - \frac{100(S + F)}{25 - V} \qquad \dots 11$$

where:

M = per cent moisture in filter cake.

S = weight of dry sludge solids in sample expressed, in grams.

F = weight of filter aid added in grams.

V = volume of filtrate in ml.

Table two shows a complete computation for one such sample.

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COMPUTATIONS FOR SLUDGE AT 96 PER CENT MOISTURE WITH EIGHT PER CENT COMPOST ADDED*						
Time in <u>Minute</u>	Volume Of Filtrate s Drained	Volume of Water & Sludge Remaining	Per Cent Solids In Cake	Per Cent Moisture In Cake		
0.0	0.0 ml.	25.0 ml.	12.0	88.0		
0.5	5.0	20.0	15.0	85.0		
1.0	6.5	18.5	16.2	83.8		
2.0	7.0	18.0	16.7	83.3		
3.0	7.5	17.5	17.2	82.8		
4.0	8.0	17.0	17.7	82.3		
5.0	8.5	16.5	18.2	81.8		
6.0	9.0	16.0	18.7	81.3		
8.0	10.0	15.0	20.0	80.0		
10.0	11.0	14.0	21.5	78.5		
12.0	12.0	13.0	23.0	77.0		
<u>15.0</u> *	13.0	12.0 grams	25.0	75.0		

TABLE 2

Note: Compost passed 60 mesh sieve.



SHOWING THE RELATION BETWEEN THE PER CENT OF MOISTURE REMAINING IN THE SLUDGE FILTER CAKE AND TIME FOR VARIOUS PERCENTAGE MIXTURES OF SLUDGE, AND COMPOST PASSING A GO MESH SIEVE



SHOWING THE EFFECT OF QUANTITY OF COMPOST PASSING A GO MESH SIEVE ON THE ELAPSED TIME TO VALUUM BREAK, DASHED CURVE IS EXTRAPOLATE FOR 100 MESH SIEVE.



SHOWING THE EFFECT OF GRAIN SIZE ON FILTRATION RATE USING A COMPOST ADMIXTURE OF 10 PER CENT CF THE WET WEIGHT OF THE SLUDGE,



TIME TO VACUUM BREAK USING A COMPOST ADMIXTURE OF 10 PER CENT OF THE WET WEIGHT OF THE SLUDGE.





SHOWING EFFECT OF FERRIC CHLORIDE ON , PH AND ELAPSED TIME TO VHEUUM BREAK

Plate III graphically shows the time to vacuum break with each of these percentages of compost passing the number 60 sieve. The solid line is a plot of the data obtained, while the dashed line is a parallel interpolation representing the values for materials passing a 100 mesh sieve. This dashed curve is based on the one value of 10 per cent compost added which is shown on Plate V.

Plate IV gives data on the effect of grain size on filtering rates. The material was graded in a stack of sieves as before described and 10 per cent of the wet weight of the sludge was used in every case.

Plate V shows the effect of grain size on the elapsed time to vacuum.

Plates VI and VII are inserted for the purpose of comparing the action of ferric chloride with that of the compost. Extreme difficulty was encountered in gathering this data due to the rapid action of the ferric chloride. It is suggested, therefore, that the data shown on these plates be used for comparison only, and that it should not be used as a basis for any future work.

Percentages of ferric chloride shown on Plates VI and VII are based on the dried weight of the sludge.

Since there were numerous values upon which to base the curves shown on Plates II, IV and VI, these curves could be

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drawm substantially to an exact fit of the data. For this reason individual plotted points were not shown. However, the curves drafted on Plates III, V and VII, were delineated by only a few points. These points were shown as well as the best curve to fit.

Measurements of the pH of mixtures of sludge and ferric chloride were made in all cases and are given as an extra scale on Plate VII. The pH for the compost-sludge mixtures measured 6.3 plus or minus 0.2 for all tests.

Final thicknesses of cake were measured as follows:Raw Sludge2 mm.Sludge plus 10 per cent No. 60 compost2 mm.Sludge plus three per cent FeCl₃1 mm.

VI DISCUSSION OF RESULTS

A. Chemical Effects

The raising of pH from 5.9 to 6.2, 6.3, or 6.4 in the compost materials indicated some slight leeching into solution of alkaline materials contained in the compost. However, no relation could be discovered between the amount of compost material added and the change in pH.

Ferric chloride, depending on the exchange of ions to neutralize the electrical charges, alters the pH considerably. The point at which a sufficient amount of ferric ion is present to just neutralize these charges is the isoelectric point of the sludge. It is determined as that pH at which the greatest amount of filtering efficiency is gained from the coagulent. It may be seen from Plate VII that the isoelectric point of this sludge is somewhere near a pH of 4.2.

The compost-sludge mixtures did not approach the isoelectric point at any time, but tended to veer away from it.

B. Physical Effects

<u>1. Amount of Filter Aid.</u> The efficiency of the compost-end-product as a filter aid is a direct function of the amount added. Further, the amount required seems to be of very large order in terms of the dried weight of the sludge.

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In this respect it is similar to paper pulp. Experiments indicated that with compost passing a 60 mesh sieve 10 percent of the wet weight of the sludge or about two and one half times the dry weight would be required for suitable filtering efficiencies. For material passing a 100 mesh sieve five per cent of the wet weight or one and one quarter times the dry weight would be required. It is felt that these percentages could be reduced considerably if the sludge were concentrated or elutriated before conditioning with compost.

2. Grain Size. Grain size has a marked effect on the efficiency of compost filter aid. It may be noted that the greatest increase in efficiency is between material passing the number 50 sieve and that passing the number 100 or between the 0.30 and 0.15 mm. diameters. For this reason it is not recommended that the material be reduced in grain size to smaller than 0.15 mm. diameter.

It has heretofore been pointed out that finer division of material exposes greater surface area. The fact that the more finely divided compost is a more efficient filter aid lends credence to the theory that some of the colloids in the sludge are adsorbed on its surfaces thus decreasing the resistance to filtering.

<u>3. Effect of Bulk.</u> The effect of adding inert solids for the purpose of preconditioning sludge is reflected in the

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value for the coefficient of **fil**tration. Although **measure**ments of the volume of filtrate were not made with sufficient accuracy to perform the graphical analysis suggested by Halff (20), this coefficient may be roughly evaluated by assuming that the amount of filtrate that can be removed at 100 per cent of filtration is equal to the amount measured at the time of vacuum break.

Two separate filtration determinations were selected for comparison. The first consisted of the raw sludge. No observed vacuum break occurred, but the last half hour of an hour and a half observation gave a constant reading of 14.5 ml. of filtrate from 25 ml. filtered. The final cake thickness of this sample was 2 mm.

The other sample selected for this comparison was a 12 per cent mixture by wet weight of sludge and compost passing a 60 mesh sieve. A cake thickness of 2 mm. was also measured for this sample. By examining Plate III it may be seen that a vacuum break occurred at an elapsed time of 12 minutes. At that **t**ime the volume of the filtrate was 15 ml. from a 25 ml. sample. At the elapsed **t**ime of **tem** minutes, the raw sludge had given up 9.5 ml. of filtrate, while at this same elapsed time, the compost mixture had a filtrate volume of 14 ml.

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Thus, the coefficients of filtration may be computed in the following manner:

Raw Sludge	10% Compost
F = 9.5 = 65% 14.5	$F = \frac{14}{15} = 93\%$

From Table 1:

$$T = 0.343$$
 $T = 1.083$

(Interpolations made with exponential table)

$$c_{f} = \frac{0.343(2)^{2}}{10} = 0.137$$
 $c_{f} = \frac{1.083(2)^{2}}{10} = 0.473$

If equation six is examined it may be noted that for this computation it may be assumed that:

 $c_{f} = \underline{a \text{ constant}}$ $a = \underline{a \text{ constant}}$ s'a or $s'c_{f}$

Thus for the raw sludge:

 $a(compressibility) = \frac{K}{0.04 \times 0.137} = 220 K$

And for the compost mixture:

$$a = \frac{K}{0.16 \times 0.473} = 13 K$$

It appears from this analysis that the mere addition of dry solid to a sewage sludge will reduce compressibility and increase filtration rate, providing, these solids are of such form and size as to act in accordance with the assumptions upon which these equations are based.

VII. CONCLUSIONS

It is concluded that:

1. Compost end-product is of possible use as a filter-aid, although some pre-concentration of the sludge may be necessary to secure economical results.

2. Best results on raw sludges with moisture contents ranging above 95 per cent are obtained with grain sizes smaller than 0.15 diameter and with amounts of compost greater than the dry weight of the sludge.

3. The action of compost is probably due to two factors. One of these factors is felt to be the adsorbent property of the material which may or may not be due to electric charges on the surface. The other factor is that of bulk which by its **wery nature** changes the compressibility of the material, and thus allows faster filtering rates.

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