Characterization and Dewaterability of Water Treatment Plant Residues

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This study was conducted in two parts, a general characterization of chemical sludges and a more detailed study of sand drying beds. Each part is separated into two distinct reports.

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Part I

A variety of water treatment residues were characterized in order to determine the influence of specific chemical constituents, process flow schemes and raw water quality on the performance of sludge dewatering processes. The use of conventional sludge characterization parameters for process selection and design was evaluated by comparing process yields to sludge characteristics. The extent of dewatering was determined for four sludge dewatering methods and the physical properties of chemical sludges at varying solids levels compared to process performance to determine which of the processes produces a "handleable" sludge.

Part II

In this study the draining and drying rates of chemical sludges applied to sand beds were related to several sludge characteristics. It was found that the time to drain was related to the sludge specific resistance, applied depth and solids concentration. Air drying occurred in two distinct phases. The initial or slow drying phase was governed by the sludge cake depth and drained solids concentration while the rapid drying rate was found to approximate the free surface water evaporation rate. Sludges with a coefficient of compressibility less than 0.7 were found to penetrate into the sand bed.

Key Words: Specific Resistance, Compressibility, Filtration, Settling, Centrifugation, Chemical Sludge, Dewatering, Sand Beds, Draining, Air Drying, Penetration.

PART I

Characterization and Dewaterability of Water Treatment Plant Residues

Introduction

Disposal of waste solids is becoming of increasing importance as disposal sites become more expensive, waste loads increase and haul distances lengthen. Of particular interest to municipalities and industries are the solids produced as a by-product of clarification of water for domestic supply or industrial application. While these solids make up only a small fraction of the total domestic load they may create special problems due to their aqueous state which increases both the volume to be handled and handling problems.

Disposal of these sludges, comprised primarily of inorganic materials, may be of more concern than organic sewage sludges since these materials are neither beneficial to the soil nor subject to incineration. Disposal of such residues appear to require a source of waste land and as such selection of a disposal site may be more a political than economic decision. Costs for disposal will then depend upon the volume of sludge to be handled and the physical state or "handleability" of the sludge. To reduce or minimize the sludge handling costs sludges may be dewatered prior to hauling to reduce the volume and improve handling or the basic water treatment processes may be altered to improve sludge "quality" and/or reduce sludge volumes.

The purpose of this paper is to present process alteration techniques for reducing sludge handling and disposal costs and to show how conventional sludge characterization methods may be used to predict the performance of mechanical sludge dewatering processes.

Sludge Characterization

The nature of sludges generated from water treatment facilities may vary widely depending upon the process flow scheme, the nature of the raw water source and the chemical additions. The bulk of water treatment solids can be divided into two groups; (a.) coagulant sludges, the solids generated by chemical coagulation of colloidal suspensions usually using iron or aluminum salts as coagulants; and b.) softening sludges, the solids generated during chemical precipitation of calcium and magnesium usually by the addition of lime. Other solids may include settled silt from highly turbid waters, filter backwash solids, polymer coagulant sludges, activated carbon slurries, and many others.

Variations in sludge character have been reported as to the rate of sludge dewaterability and the solids level these sludges will attain following mechanical processing (Calkins and Novak 1973; AWWA Committee 1969). The character of a sludge will dictate any process changes needed to improve sludge dewatering or reduce sludge volumes and may determine the best method for dewatering these solids prior to disposal. Therefore, characterization of sludges should be a prerequisite to any engineering selection of a dewatering method or process change.

Characterization Parameters

In characterizing sludges with respect to dewatering and final disposal several factors need to be considered. These are a.) the rate of dewatering and b.) the solids content of the dewatered slurry. The sludge dewatering rate is usually determined by measuring the sludge specific resistance. Specific resistance (r) is a measure of the resistance of a sludge cake to the passage of water when subjected to a vacuum (Eckenfelder 1970), according to the equation shown below:

$$\frac{dV}{dt} = \frac{\Delta P A^2}{r \mu w V}$$

Upon integration and rearrangement the above equation reduces to:

$$\frac{t}{V} = \frac{\mu w r}{2A^2 \Delta P} V + a$$

so the specific resistance can be calculated from the following equation:

$$r = \frac{A^2 \Delta P b}{\mu w}$$

where b is equal to the slope of a plot of t/V versus V.

Sludge specific resistance is not constant but has been found to vary with changing applied pressure due to compression of the sludge filter cake. Empirically this has been described adequately by the equation

$$r = r_o \Delta P^s.$$

Using the Buchner funnel test, sludges can be characterized according to their specific resistance, usually determined at an applied pressure of 15 or 20 inches Hg, their coefficient of compressibility (s), and their filter cake solids.

Sludge Characteristics

In order to determine the effect of process variations and chemical additions on the characteristics of water treatment plant sludges a variety of sludges were collected from water treatment plants in Missouri and characterized. Some of the chemical constituents were measured for several of the sludges to evaluate the effects of various sludge components on sludge dewatering parameters.

In Table 1 the specific resistances of several of the sludges from this study are listed. A close look at these data provides some indication of the factors which may influence specific resistance in a chemical sludge. All sludges which contain a substantial portion of $CaCO_3$ were found to filter readily ($r < 10^{11} m/kg$) while those sludges which contained no softening residues had substantially greater resistances. Many of the treatment plants investigated combined the softening and coagulation steps in a single basin, resulting in a coagulant-softening sludge mixture. Such sludges filtered rapidly, substantially better than pure coagulant sludges but less readily than the more nearly pure $CaCO_3$ slurries.

Magnesium, precipitated as $Mg(OH)_2$ during softening, acts in a manner similar to the trivalent metal cations, forming a gelatinous

Table I

Sludge Specific Resistance

	Sludge	Location	Specific Resistance $\times 10^{11}$ (m/kg)
1.	Lime	Mexico	0.2
2.	Lime	Columbia	0.95
3.	Lime & iron	Jefferson City (MR)[1]	2.15
4.	High magnesium softening sludge	Kansas City (MR)	5.45
5.	Lime & alum	Boonville (MR)	5.84
6.	Lime & iron	Jefferson City (MR)	6.12
7.	Lime & iron	Jefferson City (MR)	6.79
8.	Lime & iron	Jefferson City (MR)	7.0
9.	Lime & alum filter backwash	Boonville (MR)	13.2
10.	Catfloc	St. Joseph (MR)	14.1
11.	Lime & iron	St. Louis (MR)	21.2
12.	High magnesium softening sludge	Kansas City (MR)	25.1
13.	Iron	St. Louis (MR)	40.8
14.	Iron filter backwash	St. Louis Co. (MR)	76.9
15.	Iron	St. Louis Co. (MR)	77.6
16.	Catfloc filter backwash	St. Joseph (MR)	80.1
17.	Iron filter backwash	St. Louis (MR)	121.8
18.	Iron	St. Louis Co. (MR)	148.5
19.	Alum	Moberly	173
20.	Alum	Kirksville	191
21.	Alum	Higginsville	241
22.	Alum	Macon	252

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[1] (MR) - Sludge generated from Missouri River water

and highly hydrated floc (Thompson et al. 1973). Increased quantities of magnesium in a softening sludge tend to increase the sludge specific resistance slightly as shown in Figure 1. Similarly, the coagulant metal cation levels strongly influence the sludge specific resistance as shown in the comparison of coagulant sludges from clean surface waters with those from the highly silty Missouri River waters from the data listed in Table 1. The more pure coagulant sludges from the clear streams have specific resistance values which may be several orders of magnitude greater than the Missouri River sludges. Filter backwash solids, which may be expected to be comprised of more nearly pure coagulant solids than those from the preceeding settling basin, almost always have a high specific resistance regardless of the raw water source.

The solids concentration which sludges were able to attain following gravity settling are listed in Table 2. The extent of dewatering is shown to depend upon the coagulant metal ion being used, the calcium to magnesium ratio of the sludge and the "purity" of the coagulant in the sludge. In Figure 2 the concentration obtained following gravity settling for two days is shown for two metal ion coagulant sludges at varying calcium to magnesium ratios. In this figure both the effect of coagulant type and Ca/Mg on the dewatering level of a sludge can be seen. From these data it appears that alum sludges lose less water following settling than iron coagulant sludges at similar Ca/Mg levels. The effect of magnesium on

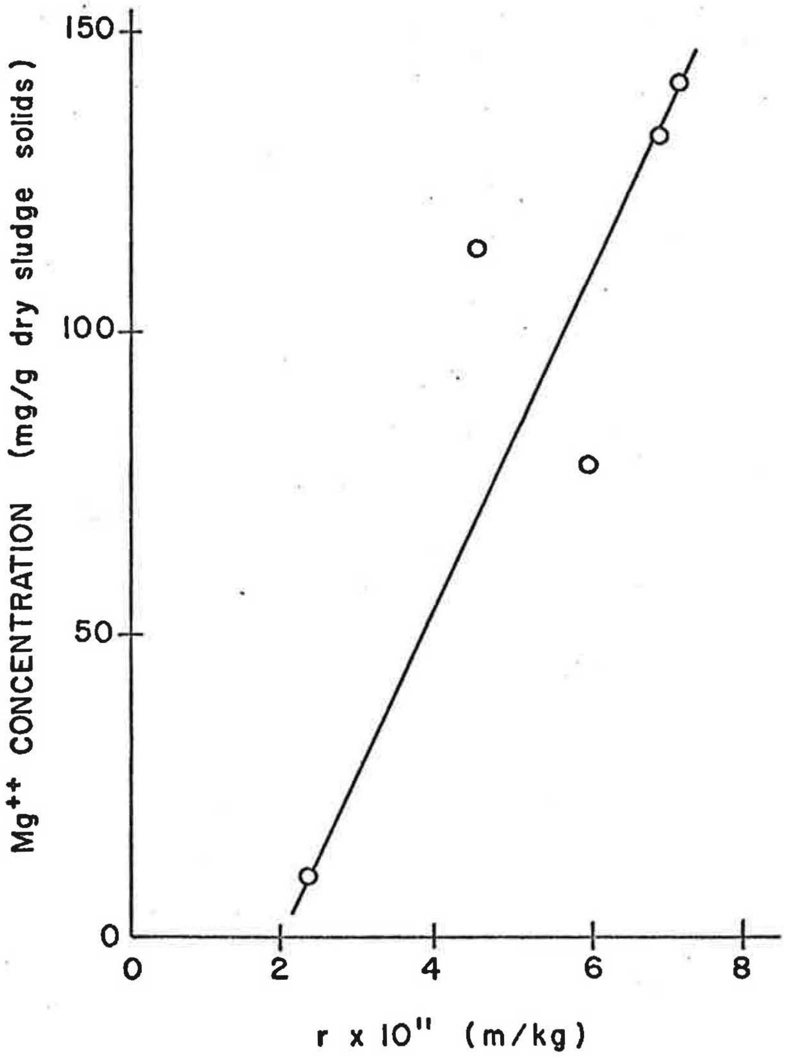

Figure 1. Effect of Mg concentration on the specific resistance of sludge.

Table II

Sludge Settled Solids

	Sludge	Location	% Settled Solids
1.	Alum	Higginsville	3.1
2.	Alum	Macon	3.4
3.	Lime & alum backwash	Boonville (MR)[1]	3.96
4.	Lime & iron backwash	Jefferson City (MR)	4.1
5.	Iron backwash	St. Louis Co. (MR)	4.62
6.	Alum	Moberly	6.3
7.	Alum	Kirksville	7.8
8.	High magnesium softening sludge	Kansas City (MR)	8.0
9.	Lime & alum	Boonville (MR)	8.17
10.	Iron backwash	St. Louis (MR)	8.95
11.	Lime & alum	Boonville	10.1
12.	Catfloc backwash	St. Joseph (MR)	11.3
13.	Iron (secondary basin)	St. Louis Co. (MR)	12.2
14.	Lime & magnesium	Kansas City (MR)	15.2
15.	Lime & iron	Jefferson City (MR)	19.1
16.	Iron (secondary basin)	St. Louis (MR)	19.3
17.	Iron (primary basin)	St. Louis Co. (MR)	21.1
18.	Softening sludge	Kansas City (MR)	25.3
19.	Lime & iron	Jefferson City (MR)	26.8
20.	Lime	Columbia	33.0
21.	Lime & iron (primary basin)	St. Louis (MR)	35.6
22.	Catfloc	St. Joseph (MR)	35.8
23.	Lime	Mexico	54.0

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[1] (MR) - Sludge generated from Missouri River water

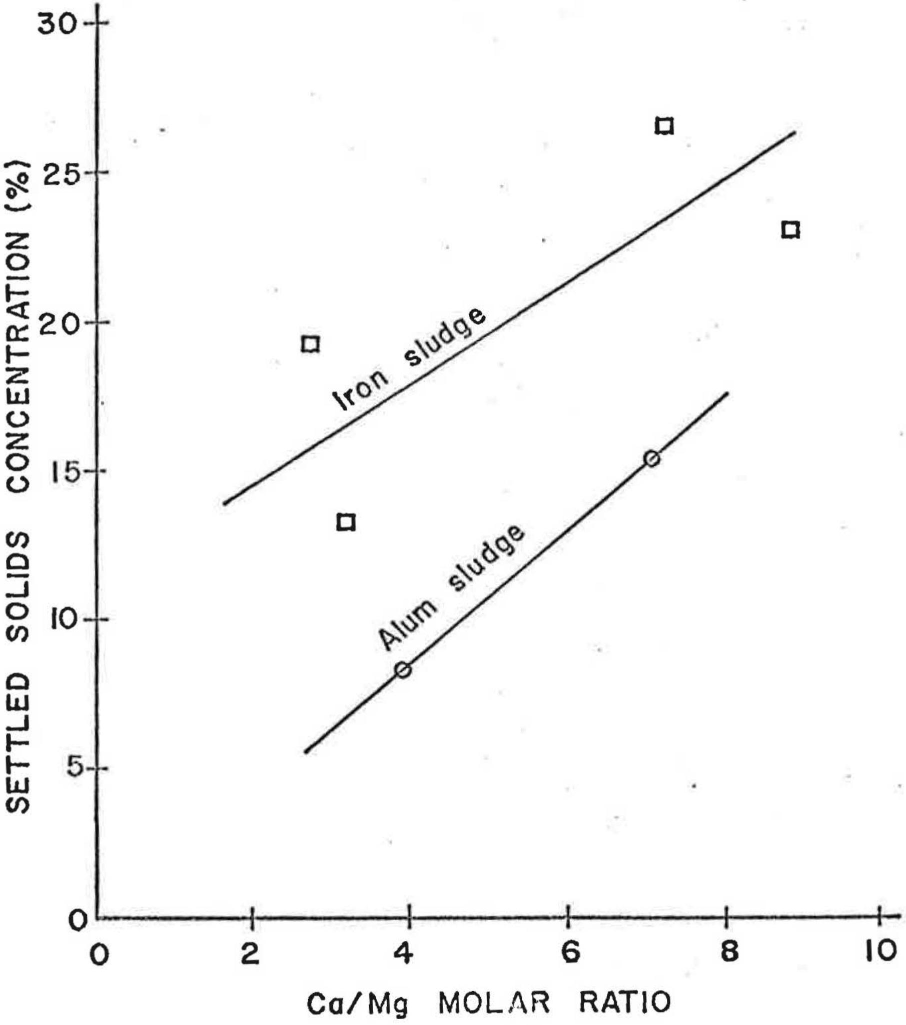

Figure 2. Effect of Ca/Mg ratio on the solids concentration of two softening-coagulant sludge mixtures.

sludge concentrating ability is shown in Figure 2 for mixed sludges and is also in evidence for the softening sludges shown in Figure 3. As the magnesium level increases, the ability to achieve a high level of solids concentration is lost.

The effect of the coagulant metal content of the sludge may again be best shown by comparing the more pure coagulant sludges from the filter backwash to those from the preceeding settling unit. As a water progresses through a plant the sludge generated contains less turbidity causing solids and is increasingly less subject to a high percentage of water removal. In Figure 4 the sludges from a St. Louis County water plant are shown along with the plant flow scheme showing this loss of dewaterability more clearly.

Comparison of coagulant sludges from clean surface waters with coagulant sludges from highly turbid waters in Table 2 shows the dependency of sludge dewatering upon raw water source. Sludges numbered 1, 2, 6, and 7 from surface reservoirs retain much more water following gravity settling than the analageous Missouri River sludges, 17 and 22.

The sludge compressibility data collected in this study followed no predictable pattern. The sludge compressibility index, S, varied from 0.45 to 1.45 for a variety of sludges. The softening residues which might be expected to be relatively incompressible were found to be similar to coagulant slurries with S values commonly around 1.0. Other researchers (Eckenfelder 1970; Kovach 1972) have reported similar ranges for a variety of sludges including sewage sludges.

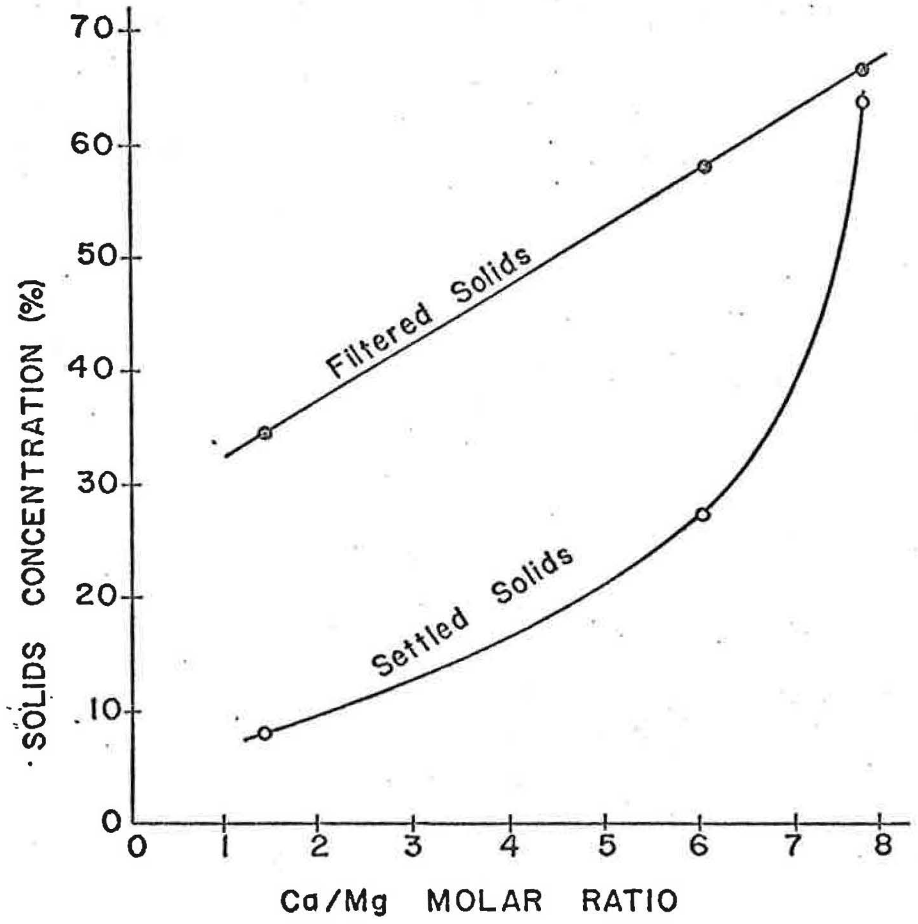

Figure 3. Effect of Ca/Mg ratio on the solids concentration of softening sludge.

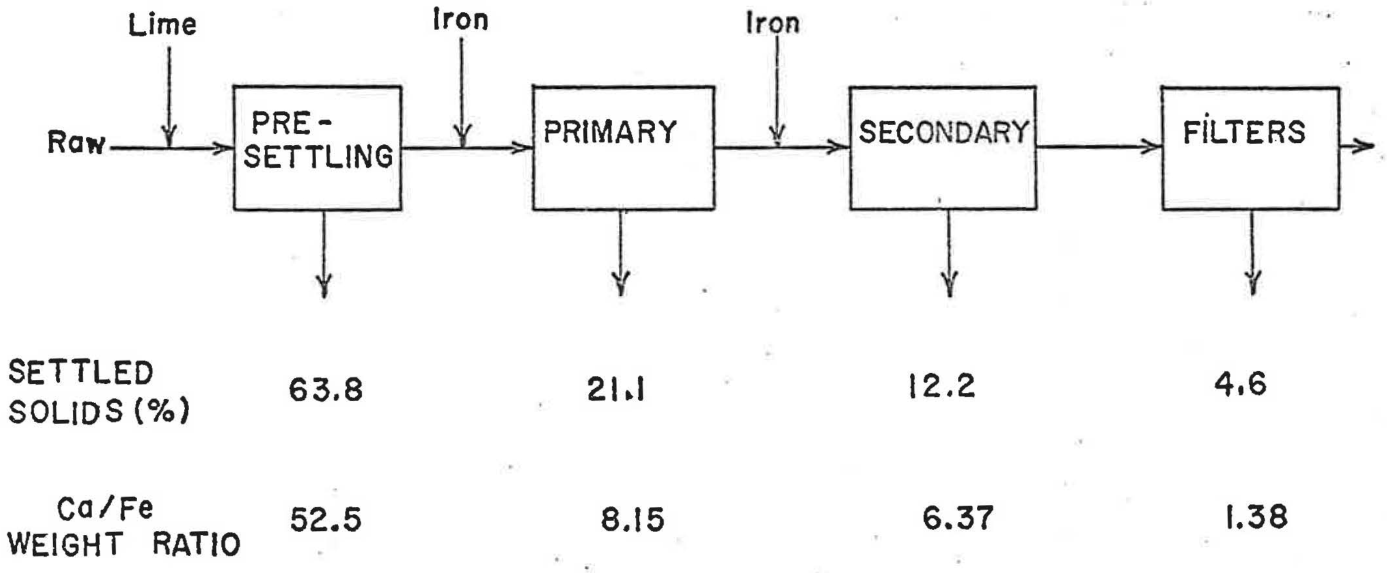

Figure 4. Change in sludge settled solids concentration through a treatment plant.

Sludge Dewatering Methods

Four sludge dewatering methods were evaluated in the laboratory to determine the rate of dewatering, the process yield, the extent of dewatering and the physical properties of the dewatered solids. The methods studied were sand bed draining, centrifugation, gravity thickening/lagooning, and vacuum filtering.

The solids concentration of four sludges following dewatering by the above mentioned methods are listed in Table 3. In evaluating each dewatering method it is obvious that the concentration obtained by each method may vary widely, however, the sludge which obtains the greatest solids level by one method also is "best" by all other methods.

In Figure 5 data comparing the solids concentration obtained by gravity settling to that obtained by the other methods is shown. From these data it is possible to predict from a single sludge dewatering analysis the concentration which may be obtained by all other methods. While Figure 5 shows that the concentration of solids depends upon the dewatering method used, the applied pressure of the process would also be expected to affect the solids concentration. The variation in dewatered solids is shown in Figure 6 for the vacuum filtering and centrifugation processes operated at various pressures and rotational speeds. Of particular interest in this figure is the relatively small increase in solids concentrating ability obtained by large increases in applied force indicating that changing processes may be more beneficial than increasing pressure if a higher solids sludge was desired.

Table III

Solids Level Obtained by Several Dewatering Methods For Four Sludges

	% Solids			
	Settling	Draining	Centrifuge	Filtration
Sludge A	7	16	15	30
Sludge B	14	22	26	40
Sludge C	21	33	34	48
Sludge D	37	48	44	59

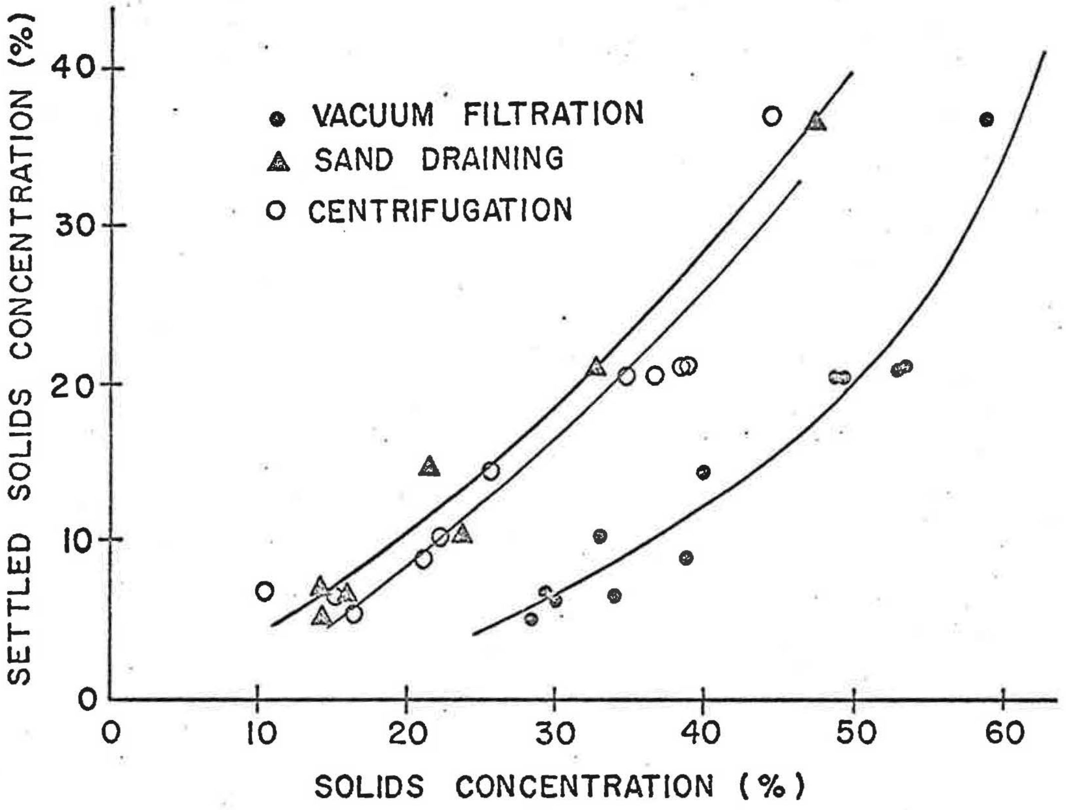

Figure 5. Relationship between settled solids and solids level achieved by other dewatering methods.