Chapter 32

LABORATORY TESTING FOR DESIGN OF THICKENER CIRCUITS

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Introduction

The English word "sedimentation" is derived from the Latin verb "sedere" meaning to sink down. As a mineral processing unit operation, sedimentation has been defined as the separation of a suspension into a supernatant clear fluid and rather dense slurry containing a higher concentration of solid (Brown, G.G. 1960). Sedimentation has been historically subdivided into thickening, which has the primary purpose of increasing the solids content of one of the thickener products relative to the feed stream, and clarification, which has the primary purpose of removing solids from the feed stream to produce a product essentially free from particulate matter. There is no absolutely precise distinction between these subdivisions and in certain applications, both objectives can be accomplished.

Major Design Factors

The capacity of conventional metallurgical sedimentation devices is a function of slurry throughput and its attendant settling rate. Important factors, recognized by early investigators (Taggart, 1972), which influence the settling rate of a given metallurgical slurry include:

Feed dilution or solids-liquid weight ratio
Size and shape of the particulate solids
Specific gravity differential between the solids and liquid phases
Presence of electrolytes and/or flocculants
Pulp viscosity
Slurry temperature

In addition to the foregoing historical factors, recent investigators have noted (Pearse, M.J., 1977) that other parameters which may have an influence upon settling rate and, thereby, thickener performance include:

Method of flocculant application
Particle size distribution
Particulate wetting characteristics
Feeding arrangements
Rake speed and type
Existence of convection currents
Wind disturbance
Evaporation

All of the above factors should be examined and the effect upon thickener performance brought about by manipulating the factor over the expected operating range should be determined if performance optimization is desired.

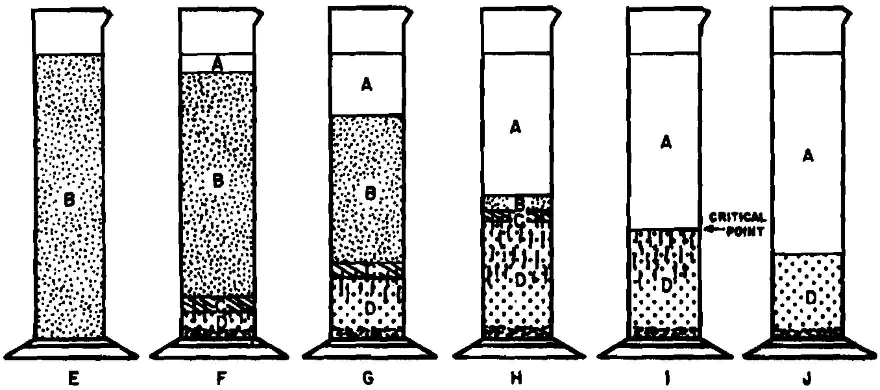
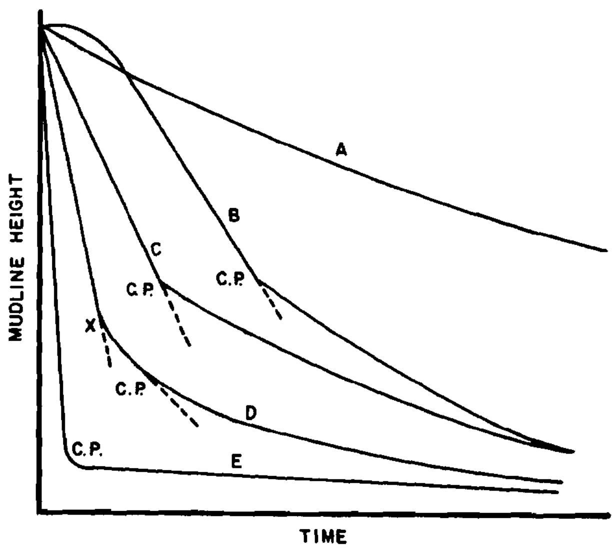


FIG. I EXPERIMENT SHOWING VARIOUS STAGES OF SLIME - SETTLING



A. CONCENTRATED, FLOCCULATED OR UNFLOCCULATED PULP

B. INTERMEDIATE FLOCCULATED OR UNFLOCCULATED PULP SHOWING AN INDUCTION PERIOD

C. AS (B) BUT SHOWING NO INDUCTION PERIOD

D. DILUTE, FLOCCULATED PULP

E. DILUTE, UNFLOCCULATED PULP

FIG. 2 TYPICAL BATCH SETTLING CURVES

Design Methods

The employment of laboratory batch sedimentation data for the design of continuous sedimentation devices was pioneered by Mishler (1912). During the intervening seventy-five years many important contributions have been made resulting in a more precise mathematical definition of important settling variables and an increased understanding of the sedimentation process.

In their classic paper Coe and Clevenger (1916) depicted "various stages of slime-settling" as a series of sedimentation phases in six graduated cylinders. This representation is given in Figure 1.

In this figure, Cylinder E represents the pulp sample after complete mixing. Cylinder F represents the pulp after some slight settlement has occurred. Zone A consisting of clear solution has formed; below it lies Zone B having a pulp density equal to the feed minus any coarse material that has settled. Below Zone B is a transition zone labeled C which may be non-existant in some slurries and of large extent in others. Zones B anc C are termed to be free settling as distinguished from D which is the compression zone. This zone consists of flocs which are in intimate contact with each other and is characterized in the final stages of sedimentation by the formation of channels through which water flows upward. The relative thickness of each zone depicted in Figure 1 will vary for different pulps. The critical point is shown in Cylinder I. Zones B and/or C have just disappeared or, in other words, Zones A and D have just made contact. Cylinder J shows the pulp in the final settling stage. In this example, the settled pulp is at the maximum attainable density.

It is a simple matter to construct a plot of mud line height versus time as in Figure 2. It must be noted that the foregoing is given as an ideal example of sedimentation. In actuality, real pulps will have widely varying batch sedimentation characteristics depending upon factors given previously. The importance of the laboratory batch settling test cannot be over emphasized. This test, as simple as it may seem, has provided the basis for the engineering design of many millions of dollars worth of conventional sedimentation equipment.

As a result of these original observations regarding sedimentation behavior, Coe and Clevenger put forth a model of sedimentation zones in a continuous thickener. These zones are shown in Figure 3 and are characterized by four zones as follows:

Zone A-Clear supernatant liquid
Zone B-Free settling zone
Zone C-Transition zone
Zone D-Compression zone

Coe and Clevenger made the assumption that the settling rate is a unique function of concentration in the "free settling" mode. They concluded that the actual capacity of a continuous thickener was determined by some solids concentration in the thickener that was higher than the feed dilution. Hence, their procedure requires conducting a series of batch sedimentation tests of differing densities in order to determine this limiting pulp density. Usually, six or more samples of the pulp in question, each at a free settling dilution between that of the thickener feed and the onset of compression, are subjected to laboratory batch settling. The settling rate of each sample is determined and the unit area requirement, (A), expressed in square feet per ton of dry solids per day is derived from the expression:

$$A = \frac{1.33\ (F-D)}{R\ r}$$

where F = Feed dilution
D = Underflow dilution
R = Rate of subsidence
r = Specific gravity of liquid

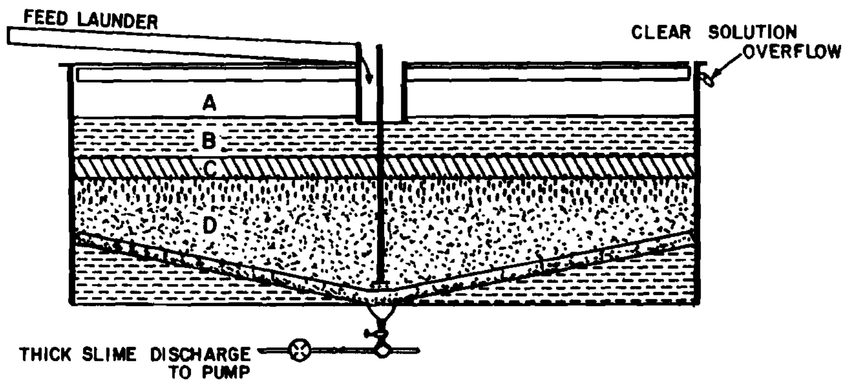


FIG. 3 FOUR ZONES OF SETTLING PULP, ILLUSTRATING CONTINUOUS THICKENING
(COE AND CLEVENGER: TRANS. A.I.M.E., VOL. 55)

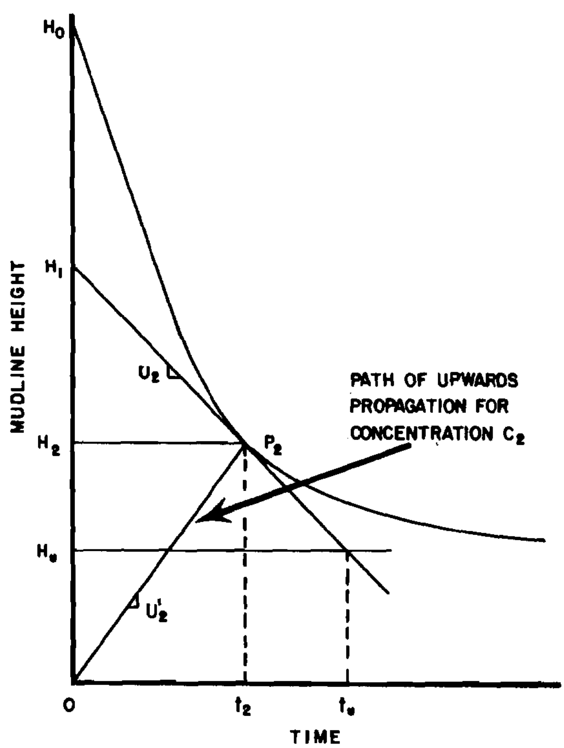


FIG. 4 TALMAGE AND FITCH CONSTRUCTION ON A BATCH SETTLING CURVE

When a tabulation of unit area requirement and related feed dilutions is constructed, the largest unit area noted is selected as the basic design criterion. It is imperative to note that this unit area requirement is always modified by safety factors derived from knowledge of the behavior of similar pulps and, more importantly, experience.

The mathematician Kynch (1952) presented a sophisticated analysis of batch sedimentation based upon the single postulate that the settling rate is a function of solids concentration only. It is important to mention that if any other factor exists such that settling can be influenced, the Kynch analysis does not apply.

The treatment by Kynch concerned batch settling only. Talmage and Fitch (1953) extended this treatment to continuous operations. Essentially, their method of arriving at unit area requirement consists of developing a curve of interface (or mudline) height versus time by the standard laboratory procedure and applying in a special way, the Kynch analysis.

For example, Figure 4 shows a plot giving the construction for the underflow time (tu) determination when the underflow concentration (Cu) is above compression. The method involved the calculation of equivalent underflow height (Hu) from Cu by mass balance and reading tu from the curve as indicated. The unit area requirement (A) is given by the equation:

$$A = \frac{tu}{Co\ Ho}$$

Where Co = Initial concentration
Ho = Initial height

If the selected underflow concentration occurs at an equivalent height below the compression point, a tangent is drawn to the curve a the compression point and the critical time (tu) is given by the intersection of the underflow height with the tangent line as shown in Figure 4. The unit area requirement is arrived at by the procedure previously described.

The Talmage and Fitch procedure works very well for underflow concentrations higher than the compression concentration or for those pulps having a well defined batch compression point. Unfortunately, real pulps do not always act in an ideal manner and investigators have developed various methods to attempt to more precisely define the compression point of this type of pulp. Most of these attempts have involved clever manipulation and plotting of parameters derived from basic batch sedimentation curves. These investigators include Roberts (1949), Hassett (1965), Yoshioka (1959), Scott (1967), Moncrieff (1964), Tarrer et al (1974), Fitch (1962) (1975), and Barnea (1977). A mathematical modeling method for thickener sizing has been described by Wildhelm and Naida (1979). More recently a computer program which reproduces the method of Talmage and Fitch has also been demonstrated.

The method developed by Wilhelm and Naidel (1979) utilizes data from the graduated cylinder batch sedimentation tests with the addition of rakes rotating at a very slow speed to attempt to achieve the maximum density of the settled solids. The data is plotted in the standard format of mudline or interface height vs. time, and the slope of the tangent line at each level is calculated and represents the settling rate. The settling rate is plotted against the concentration of solids on log-log paper. This usually produces two or three straight lines at different slopes consistent with the constant settling rate area, the "conjugated concentration front" defined by the Kynch theory, the transition area and the compression area. These curves fit a from of:

$U = kD^{-m}$ = settling velocity
K = constant defined as U when D = 1.0
D = pulp density in weight per unit volume
m = slope

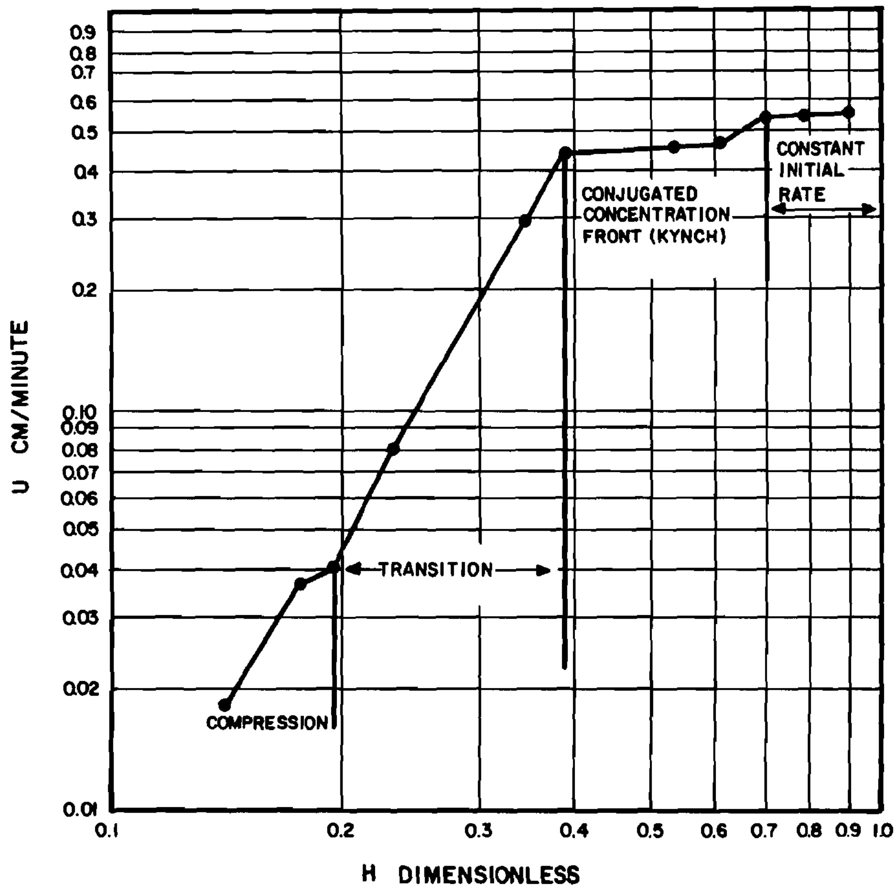


FIG. 5 BATCH SETTLING TEST DATA

BARNEA PLOT

The units for these values must be consistent with calculations for establishing the area requirement per unit weight per day. Such as meters/day for settling velocity and tons of dry solids per cubic meter for solids concentration. With these equations, the unit area requirement can be calculated for the desired underflow concentration. In most cases a correction factor must be applied for the height of the mudline or sludge zone in the laboratory test compared to this height in the actual thickener.

Another method for analyzing data has been proposed by Barnea (1977) that appears to be similar to the Wilhelm and Naidel procedure. This method offers an improved method of interpreting the results of laboratory tests and provides a positive identification of the various zones encountered during sedimentation (Figure 5). The method utilizes the specific settling rate, ie. rate at each measurement, plotted against a dimensionless number. This number is ratio of the height of the mudline above the ultimate settled height at each measurement compared to the total settling distance from time zero to the ultimate settled height. The raw test data are defined as:

h_o = mudline at time 0
h_n = mudline at time N
(Usually determined by averaging)
t_n = time of measurement

The calculated terms are as follows:

U_n = rate of settling
$= (h_{n-1} - h_{n+1})/(t_{n+1} - t_{n-1})$
H_n = dimensionless number
$(h_n - h_\infty)/(h_o - h_\infty)$
$h_n = (h_{n-1} + h_{n+1})/2$
h = usually defined as mudline height after settling overnight

When batch tests with varying initial concentrations are compared, a slightly modified version of the dimensionless number, H_n will be beneficial. In these cases:

$$H_n = (h_n - h_\infty)/h_\infty$$

Based on the above, it would appear prudent to plot the date in several ways to help to determine the most appropriate settling rate. The Wilhelm and Naidel plot could help define the proper slope (settling) rate and the Barnea plot would assist in identifying the influence of changes in initial concentration and the addition of flocculants.

Other workers have made substantial contributions regarding compression subsidence but this part of the sedimentation curve is not considered size-determining in most metallurgical applications, with the notable exception of concentrate thickeners, yellow cake precipitate sedimentation, and, perhaps, high capacity thickening applications.

<u>Equipment Sizing from Laboratory Data</u>

Regarding conventional sedimentation machinery, individual thickeners and CCD trains for copper, uranium, molybdenum, and precious metals installations have been designed from laboratory batch sedimentation tests only. It is usually preferable to have back-up pilot information for final design but it has been proven that pilot sedimentation circuits are difficult to operate continuously and the data derived must still be subjected to modification by the application of safety factors.

Equipment sizing recommendations for high capacity thickeners vary according to the manufacturer. Enviro-Clear machines are usually sized by information derived from small-scale batch-continuous laboratory testing in a specially designed laboratory unit. This unit is said to replicate actual operational parameters. The Eimco-Process Machinery Company has given and delivered several seminars outlining a laboratory batch sedimentation procedure which is said to result in sizing criteria for high capacity thickeners. This procedure involves a modification of the standard laboratory batch sedimentation test by changing method of pulp mixing and subsequent flocculant introduction into the mixed slurry.

Since the selection of thickeners for any given installation usually involves substantial capital outlay and can make the difference in whether or not the associated metallurgical installation quickly attains required throughput, thickener design and evaluation procedures should only be undertaken by those knowledgeable in the science and art of thickener sizing. If sedimentation data and sizing is generated by a single laboratory or contractor it is usually prudent for the ultimate purchaser to authorize a few additional sedimentation tests, perhaps by flocculant vendors, and to have design criteria reviewed and corroborated by equipment manufacturers.

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