SEDIMENTATION
OF ROCK MATERIAL

" SEDIMENTATION OF FINELY DIVIDED ROCK MATERIAL FROM WATER SUSPENSION, WITH ESPECIAL REFERENCE TO THE THEORY OF DESIGN OF SETTLING TANKS AND SIMILAR APPARATUS "

A thesis
presented to
the Faculty of Graduate Studies
and Research
in part fulfillment of the requirements for
the degree of Master of Science,

by

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Introduction.

In this section of this thesis, I propose to present a brief account of the object of the investigation and also the various methods by which attempts were made to bring solution to the many problems involved.

The question of the settlement of slimes probably dates as far back as 1907, when the basic patent for a Dorr thickener was first brought out. Though there were a number of articles written upon the settlement of slimes, no quantitive results of any importance were forthcoming until Mishler in 1912 in the Engineering and Mining Journal, enunciated certain principles, which he believed to be characteristic of the settlement of Tigre slimes. Coe and Clevenger in 1916 gave a more elaborate analysis of the operation of a thickener, developing a formula for area, and also a method for determining the depth of thickener required. They independently showed that the principles, tentatively announced by Mishler some four years before, were true for all classes of ores. They were the fundamentals of slime settlement as carried out in a Dorr thickener. The methods outlined by Coe and Clevenger for the determination of area and depth ofthickener requirements are precisely the same as the methods employed by the Dorr Co., today.

In January 1923, the writer, as one of a party of four, selected the Settlement of Slimes as an experimental subject for investigation,in connection with the requirements of the 4th.year Ore Dressing Laboratory Thesis. The work that was carried out was elementary - the effect of various concentrations of lime and also the effect of heat drying an ore were studied. Settling rates were carried out in glass graduates and compared.The results were as expected the settling rates showed a critical concentration of lime, above or below which meant a decrease in settling rate. The dried ore showed much faster settling rates than the undried ore.

In the fall of 1923, the writer chose the subject of the title of the present thesis as a suitable subject for research, as required by the Faculty of Graduate Studies and Research. A more ambitious program, of course, was laid out, and a small Dorr thickener was to be installed as a laboratory unit. The writer, in the meanwhile, continued the small scale tests upon tinguaite, which was selected as a holocrystalline rock which could be obtained in great quantity as it was already broken and sized in the laboratory. The question of Natural Slime was also considered.

Realizing the importance of flocculation as a factor in settlement, thw writer delved somewhat at length into the subject of Colloid Chemistry for an explanation of the phenomenon involved. Ore Dressing literature is burdened with references to colloidal slimes, but unfortunately there are some phases which are both poorly and erroneously explained. Free(Eng & Min.Jl Vol 101 pp.249 etc) has written, in my opinion, the best series of articles that has yet appeared, and he has covered at length certain misconceptions which are in evidence in the minds of a majority of mill operators.

The aforesaid misconceptions and false ideas upon colloids are the results of a tendency on the part of the well-informed towards writing carelessly upon the subject. Whether the fault may be due to ignorance or care-lessness does not matter - the fact remains. They have ~~clouded~~ clouded the subject by the inconsistent usage of scientific terms, and in many cases the articles were poorly written. This remark does not only apply to the subject of colloids in Ore Dressing, but the evil has permeated through Ore Dressing literature generally. A notable example of a poorly written paper, which is saved from the dust-laden racks of oblivion solely by the excellence of the subject matter, is the paper by Coe and Clevenger. It might have become a classic, judging it by the merits of the enclosed material, had it not beem for its lack of forceful presentation. Another example of vague and indefinite writing is shown by Coe's remarks upon Mishler's ~~paper~~ paper, where he stated that he believed that Mishler's methods were good, yet he disagreed upon two fundamental points. It is with this thought in mind, that I have here-after presented certain theories upon flocculation, which, in my opinion, must be included in the present thesis -- not for their excellence (for they possess little of that) but for the one reason that they have appeared in Ore Dressing literature and hence must be considered in an ore dressing thesis which deals with flocculation.

Unfortunately the installation of the thickener was delayed, and the middle of March had arrived before any large scale work could be attempted.

The installation of the thickener was a large feature of the work, and some five weeks were spent in its erection. Additions are now being made from time to time, their object being to ~~fa~~ facilitate the transference of pulp from one part of the system to another, and to reduce the amount of manual labor.

In the short space of time left before the end of the term, some seven tests were run. Frankly, they are of little value, being insufficient to draw any positive conclusions, but they were of inestimable value in guaging the possibilities of such a laboratory unit. The artificial conditions under which the thickener is running show that there are numerous pitfalls which must be avoided. Thus a wealth of experience was gained in learning such operations, as the best method of ~~pa~~ procedure during a test, for example.

Early realizingthat the shortage of time was the important difficulty with which I was confronted, I devoted my attention to the problem of area, and abandoned the question of depth. Since depth is a function of area (it may be sacrificed for area, though the converse is not true) the question ~~a~~ of area must be decided first before depth is considered.

There is a tremendous amount of work yet to be done in connection with settlement - there are many phases which are as yet little understood, and the field of research in this direction is still a wide one.

In closing, I must acknowledge with deepest gratitude the untiring efforts of Professor Bell, who has devoted much of his time to the problem, and whose suggestions have always proved helpful.

I am also greatly indebted to Messrs. Johan J. Snijman and Roland E. Legg who collaborated with me in the carrying out of some work on Natural Slime, the results of which appear later.

I must also express thanks towards Messrs. E.Snyder,A.E.Cave, and A.K.Muir, of the 4th. Year Mining Class for their very able assistance in carrying out some of the later tests.

I must also express my thanks towards the members of thee Dorr. Co. Experimental Laboratory, for their courtesy and kind advice offered to me during a visit to their plant, and for instructions which proved very valuable.

A criticism may be levelled at this thesis,which is a justifiable one. My remarks and discussions upon various topics have been based upon theoretical grounds, and where I have criticised, I have but rarely used a practical example to bring out a point. In apologia , I must say that I was driven to it, for there is little reliable data upon the operation of a thickener, which is available. Therefore,under the circumstances, I felt that such a course was necessary, and if I have made any gross errors in my reasoning,it will be the result of taking a "too hypothetical" view of the whole problem.

The theory of colloids in ore-dressing.

Consider the simplest ore pulp imaginable - a heterogenous mass of mineral particles of all sizes from, let us say, 0.1 m.m. in diameter to the molecularly disperse, all suspended in water. As a result of their variance in size, they will settle at varied rates of velocity.

Stokes in 1850 showed that spherical particles of fine dimensions, when suspended in a medium, will fall with a velocity given by the formula

$$V = \frac{1}{18} d^2 (k_1 - k_2) \frac{g}{n}$$

where

V = velocity of fall

d = diameter of particle

k_1 = specific gravity of particle

k_2 = specific gravity of medium

g = acceleration due to gravity

n = viscosity of the medium.

This is known as Stokes' Law or the Law of Viscous Resistance.

Stadler and Richards have both shown that this law is only applicable to particles having a diameter of less than 0.4 m.m., and that particles above this size will settle undera totally different law ,namely Rittinger's Law or the Law of Eddying Resistance. Since slime particles are not affected by this law, due to their fine size, I have not included any discussion upon the law.

Stokes' Law is applicable to all cases between 0.4 m.m. and 0.001 m.m. but at this point it ceases to have any practical value, for if we consider the remaining particles of still finer size, we will see that they will not settle at all, but under the ultra microscope will exhibit a phenomenon that is known as Brownian movement. They will appear to oscillate and move rapidly to and fro in the medium and Perrin has given an explanation of this peculiar motion by attributing it to the result of the impacts of the molecules of the medium upon the particles in suspension. Since the impacts are equal from all directions,the particles will appear to be suspended and in constant motion, though there are migratory tendencies sometimes shown, which can be shown to be a matter of chance. It must be understood that the particles,if rid of Brownian motion, will fall under Stokes' law, but usually the effect is sufficient to keep the particles in suspension indefinitely.

It is not my intention to enter the field of controversy by attempting to present a true and full definition of a colloid - for a definition, to be perfect, must of necessity cover "the truth, the whole truth, and nothing but the truth",yet at the same time being compact and concise. The conception of a"colloid" and of the"colloidal state" is best conveyed by an approximate definition, which however must be supplemented by the consideration of the principal weaknesses of that definition. Thus we can say, with certain reservations and modifications, that " a colloid is the state in which a substance may exist, by virtue of which, it will possess a high specific surface". Specific surface is the surface per unit volume.

Consider a cube of 1 cm. edge.It will have a total surface of 6 sq.cms., and a specific surface of 6 units. Imagine this cube to be divided into smaller cubes of 0.001 m.m. edge.

The total surface of these cubes will be 6×10^{-4} sq.cms., and since the total volume is still 1 cu. cm., the specific surface will be 6×10^{-4} units - a very much higher value than in the case of the cube of 1 cm. edge. Thus the definition implies a high degree of sub-division though there is no line of demarcation between small particles of a solid and the same solid in colloidal form. Zsigmondy has drawn up a classification that considers three classes of dispersoids, and drawing an arbitrary line between the coarse and the colloid dispersoids at 0.1 micron. (A micron is equal to 0.001 m.m.) . The reason for this assumed mark presumably lies in the fact that the limiting size that can be viewed under an ordinary microscope is approximately of this dimension - variations, of course, depending upon the nature of the suspensions viewed and their indices of refraction as compared with that of the suspension medium.

It also implies that a colloid is a state of matter, and a state to which all substances may belong, regardless of whether they are solid, liquid, or gaseous. Thus it must be borne in mind that the condition is a physical one, and is not a property that a substance will possess, by virtue of its chemical nature. It must be admitted however that some substances, e.g. $Fe(OH)_3$, preferentially form colloidal suspensions, though these are chiefly chemical precipitates, the physical characteristics of which are dependent upon temperature, concentration, solubility, etc. at the time of formation and thus can be varied at will. All substances can be brought into the colloidal state by suitable means of preparation - there are seven known methods though they cannot all be applied in the preparation of the same colloid.

Since we are dealing with colloids found in Ore-dressing we can make the following statement, supplementing the definition- of course remembering that it is not true of all colloids : The colloid must be insoluble in the suspension medium, forming a true disperse phase.

The " high specific surface " clause of the definition may be somewhat misleading. A molecule of a solute in water will possess a high specific surface, yet it is not a colloid. Hence there must be a lower limit, arbitrarily taken, to distinguish colloid dispersoids from molecular dispersoids,(the third of the three types of dispersoids recognized by Zsigmondy). It is found that the physico-chemical properties of the liquid suspension medium undergo a marked transformation when the suspension particles are smaller than 1 milli-micron (one-thousandth part of a micron). A true colloid suspension will show the Freezing Point and Boiling Point characteristics of a pure liquid, but a suspension of the above size and smaller will show the characteristics of a true solution. In other words, we have indications of a transformation from a suspension to a molecular dispersion. Summarizing Zsigmondy's classification :

Dispersoids.

1. Coarse - Above 0.1 microns,
2. Colloid - Between 0.1 and 0.001 microns.
3. Molecular - Below 0.001 microns.

In simplifying the problem from the ore-dressing point of view, a scale has been suggested by Mishler to distinguish slime from sand - slime being that finely divided material that must be flocculated in order to increase settling capacities.

He defines Slime as that portion of ~~a pulp~~ an ore that remains suspended after five minutes of settling in a 100 : 1 mixture of fresh water and ore - temperature being 60 degrees Fahrenheit. This definition is duscussed in a later section.

From the foregoing discussion, it will now be evident that the difficultly settled portion of a pulp will be the very finely divided material. The sand will settle out immediately,and does not enter into the problem directly, but it is the smaller particles, which, falling under Stokes' law, is the material that constitutes the main problem.

Stokes' law can be briefly summed up in the form : $V = \frac{cd^2}{n}$ or $\frac{A}{n}$ where A = area of the particle.

In other words, the velocity is proportional to two elements, viscosity and area.

a. Viscosity. The viscosity of a liquid is inversely proportional to the temperature. Ralston has shown that in the case of kaolin suspensions in water, the rate of settling is proportional to the rise in temperature, for both thick and thin pulps; in other words, the rates of settling are inversely proportional to the viscosity. Temperature however may have a flocculating effect, as in the case of sugar juices, where it is found that good settling is attained at 85 degrees C. but at 55 deg.C. the rate is almost zero. But in the majority of cases, and more particularly in the case of ore pulps, increased settling rates are acquired as a result of a change in viscosity, and not as a result of better flocculation.
In the case of pulps in a solution,the latter may be the case, but it is an indefinite point.

b. Area. It would be impossible to over-emphasise the effect of the area of a particle upon its rate of fall, when it is subjected to Stokes' law. If we double the diameter of a particle, we will quadruple the velocity of fall, and each successive increase of diameter will still further augment the velocity, which is increasing as the square of the diameter.

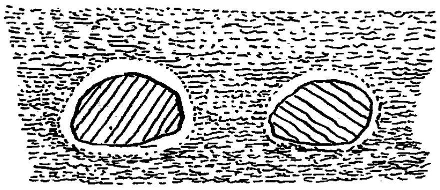
Settling rates can thus be increased by increasing the size of the falling particles, and this can be accomplished by the addition of a flocculating agent to the suspension, whereupon the individual particles agglomerate and form flocs which are comparitively massive as compared with the original particles. These flocs will fall ? with an increased velocity, indicated by Stokes' formula, which is the result of increased area. There is a modification however - since the flocs are not composed of solid homogeneous material, but contain enclosed water, the density of the flocs will differ from that of the original particles, and the velocity of fall will be lessened, but this will not greatly influence the effect of area.

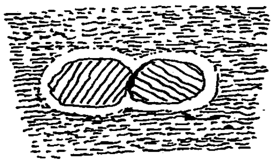
Flocculation may thus rightly be termed the keynote of the whole problem of settlement, and a study of its various phases will often repay the mill operator, for as Free has stated, a more expensive reagent is often preferable to the cheaper and more common types, which have, through tradition, have become hallowed in the minds of the operator.

It must be borne in mind at this point that flocculation is not a definite state or condition, but that there are a variance of degrees of flocculation, for example, slow flocculation, intense flocculation, etc., and that deflocculation is merely a condition of "less flocculation".

In the next few pages, I have attempted to outline some theorie which have been advanced to explain the mechanics of flocculation. Though there are some theories that have not reached the rank of "deserving serious consideration", I however will take each theory in turn, and will try to point out its merits and demerits, and will reserve the most generally theory for the last. As I have before stated, my only object for entering into a consideration of such th-eories is the fact that they have appeared in Ore Dressing literature, and hence must be taken into account. I must however be just in stating that the authors in most cases have not claimed that the theory in question was the only possible explanation, but they have generally remarked that it is the cumulative effect of many such influences that result in flocculation.

1. Strain theory. This theory, I believe, was first advanced by Ostwald, though Sulman was the first to introduce it into Ore Dressing, in a paper upon the theory of flotation (Trans. I.M.M. Vol. 29). It was a paper designed to expain the theory of flotation upon the grounds of "surface energetics and adsorption effects due tothe same", and since, in his opinion, flotation and flocculation were inter-related, he felt it necessary to explain the latter on the same general principles. Briefly, it is this :- The layer of liquid at the solid-liquid interface of an immersed particle is considered to be in a condition of strain. Now Sulman states that there is a normal tendency, characteristic of a liquid , to reduce this strain as much as possible, and the only manner ~~that~~ by which this can be done is by a reduction in surface. Flocs are formed which reduce the amount of specific surface.





The principle is explained by the diagram above.

Changes of interfacial tension as is usually found when a contaminant is added to water, will of course change the amount of flocculation. In other words, any change of interfacial tension will alter the degree of flocculation.

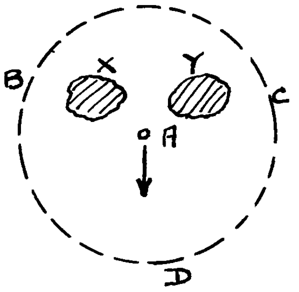
Hatschek however challenges the statement that Ostwald was responsible for the words, "strained layer", though I feel that Ostwald intended to convey this impression. Thus, the phenomenon of flocculation is the direct result of interfacial ~~tensio~~ tension, which" endevours to decrease the surface of a system if free energy is available". (Ostwald).

I cannot place a high value on the merits of this theory, for I feel that there are too many peculiarities in flocculation which are left unaccounted for. For instance, I cannot see any explanation, reasoned on the grounds of this theory, for the presence of a point of maximum flocculation shown by all flocculating agents, from which point an increase or decrease in concentratinn will decrease the degree of flocculation. The amount of adsorbed solute will not vary in this manner.

Anoth-er idea was put forward by Sulman, and though it does not directly explain flocculation, it has direct bearing upon the formation of sols. If the cohesion of the liquid molecules is greater than the cohesion of the solid molecules, the solid tends to disintegrate, with the resultant formation of a suspension, which may become a solution. If the cohesion of the solid molecules is greater than the cohesion of the liquid molecules, " the molecules of the liquid will tend to concentrate at the surface layer of the solid, and the condition typical of 'suspension' will occur". In other words, a reagent which will increase the wetting of the solid by the liquid, will also increase the amount of deflocculation. Sulman cites sodium silicate as an example. The converse must be true, that flocculation will result if a reagent is added which will decrease the amount of wetting. There is very little to support this idea, and I am including it in the present thesis as a matter of little interest.

2. Theory of the repulsion of the water molecules.

This theory was put forward by Edser in a discussion upon Sulman's paper. Consider two particles X and Y, which are suspended in a medium.



Let A represent a molecule of the medium, and let the circle BCD represent its sphere of attraction. If the Molecule A is repelled by the molecules in X and Y, it will be driven in the direction shown by the arrow.

When this is considered as having been applied to many molecules of the liquid, we will find an exodus from the region between X and Y, which results in a tendency to pull X and Y together. The normal attraction of X and Y for each other is aided by this removal of liquid molecules which are "holding" them apart. The reverse will take place, i.e. deflocculation, if the attraction of the solid molecules for the molecules of the liquid is a positive one. This theory is similar to that of "wetting" in which the affinity of the opposite molecules is sufficient to break the solid into a sol. The same remarks and criticisms therefore apply to this case as in the other.

3. Air bubbles and flocculation.

This theory was advanced by Edser in the 4 th. Report of the British Asson. on Colloid Chemistry. His idea can best be explained from an experiment cited by him. Two small specific gravity bottles are half filled with a silver nitrate solution, and an equi-normal solution of sodium chloride is added to fill the remainder of the bottles. One-half of one bottle is poured away, and the two bottles are then shaken. On being allowed to stand, the half filled bottle is seen to contain a densely flocculated precipitate, and it is observed tocontain air bubbles. The full bottle, however, contains a finely disperse precipitate of silver chloride. The inference that Edser draws is that the air bubble have flocculated the particles of AgCl. He states other examples where a highly flocculant precipitant is obtained by agitating the reacting solutions.

There is one other piece of evidence in Edser's ? favor which he does not mention.

Air bubbles, when passed through pure water, are found to be negatively charged. When passed through 0.007 % H_2SO_4, they are found to be neutral, and in higher concentrations of H_2SO_4 they are found to be positively charged. (Sulman). This phenomenon can be applied to the flocculation of similarly charged particles by an oppositely charged bubble. But the collectionof charged particles by oppositely charged bubbles is an electrical phenomenon , and Edser, in no uncertain terms, declared his disbelief in the electrical theory. Edser's case is undeniably weak. He disregards the fact that precipitate formation is a matter of concentration, mass law action, temperature, speed of reaction, etc., and he has given two cases for comparison in which the conditions were totally different. The full bottle, due to poor agitation could not have been thoroughly mixed, and hence the formation of a precipitate was almost entirely the result of diffusion. The half full bottle was thoroughly mixed, and hence precipitation was practically instantaneous, resulting in a coasser precipitate. In another connection, Hatschek remarked to Sulman that Stas recognized four types of silver chloride precipitate, which could be formed under varying conditions. My contention is that Edser merely considered the existence of one type, yet he formed two different types in his experiment.

This theory is the most important of the many aforementioned theories, and is now almost universally accepted as being the correct explanations of flocculation. Unfortunately there is little quantitative evidence, but the theory is borne out by many qualitative experiments.

When in suspension, particles show migratory tendencies when subjected to an electric field, and this phenomenon is known as Cataphoresis. The particles travel to either one or the other of the electrodes. We thus assume that the particles are charged, and that the charges are of the same electrical sign. This is assumed to be the cause of the stability of the sol - the particles repel each other, and are kept in suspension as a result. There are two explanations for the origin of the charge on an ore particle. The first is due to Coehn, who stated that," When two substances are in contact, the substance with the highest dielectric constant will be charged positively". In almost all cases water is known to possess the highest dielectric constant, and as a result the ore particles are found to be charged negatively. The second explanation is based upon adsorption. Water ionizes to form H and OH ions, and it is believed that a particle will adsorb one ion in preference to the other. Thus ore particles are assumed to have preferentially adsorbed OH ions in excess of H ions, and the charge is therefore due to a layer of OH ions in excess on the surface of the particles.

Whatever the true explanation of the ~~origi~~ origin of the charge might be, It is believed that particles are similarly charged, and their charges must be reduced or neutralized before flocculation or agglomeration can take place

The addition of a salt, whose oppositely charged ion will be pfeferentially adsorbed, will reduce the amount of charge on a particle. In support of this, it is found that the coagulating ion is found concentrated on the surface of the particles, and Whitney and Ober, using Sb_2S_3 sols, found that the amount of adsorption is proportional to the molecular weight divided by the valency.

Freundlich then found that the coagulating power of an ion was independent of its chemical nature, and he has given a table showing the minimum concentrations of various electrolytes,(millimols per litre), necessary to produce coagulation of negatively charged As_2S_3.

KCL	49.5	$MgCl_2$	0.717	$AlCl_3$	0.093
KNO_3	50.5	CaCl2	0.649	AL$(NO_3)_3$	0.095
NaCl	51.0	$BaCl_2$	0.691		
LiCl	58.4	$Ba(NO_3)_2$	0.687		
HCl	30.1				

Freundlich found experimentally that $y = a\,C^{\frac{1}{n}}$,

where y = amount adsorbed

C = concentration in original liquid

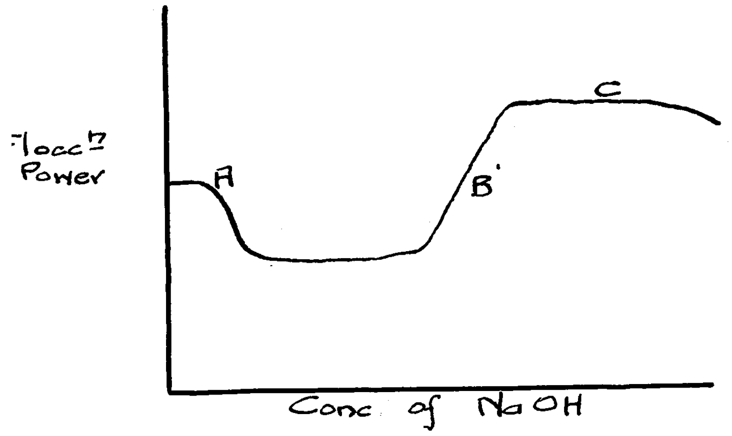
a and n(0.1-0.5) are constants for the sol.

This is called the Adsorption Isotherm, and when plotted, it is in the nature of a logarithmic curve. It indicates that the amount of a poly-valent salt required for coagulation is less than the amount required by a mono-valent salt.

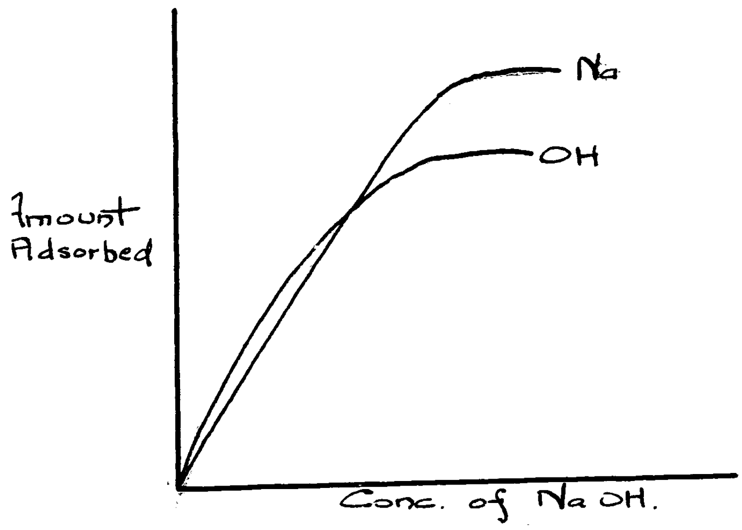
Consider the case of lime. When in solution it becomes $Ca(OH)_2$, which ionizes into Ca and two OH ions. Since the negatively charged particle is saturated with OH ions (due to the logarithmic curve of adsorption), it will have little or no tendency to increase its negative charge, and as a result, Ca is preferentially adsorbed.

This adsorption will ultimately reduce the charge on the particle, and flocculation tendencies are increased. This, I believe, is a better explanation than that given by Free, who explains the action of $Ca(OH)_2$ as being the flocculating action of a precipitate, which is formed, and which collects the particles as it is thrown down.

The flocculation curve of NaOH is an interesting one to consider. It is given by Free, who used kaolin (which is negatively charged), and he noted the flocculation powers of various concentrations of NaOH. Flocculation power can roughly be measured by settling rates. Though the perspective may be wrong, the general tendencies of the results are given by the curve shown. This phenomenon cannot be explained by any other theory of flocculation.



Between A and B on the curve, we have evidences of lesser flocculation, which means a higher preferential adsorption of OH ions over Na ions. But at B, we find a reversal and the Na ions are now adsorbed in excess of OH ions. If we represent the action by adsorption isotherms of Na and OH, we will find an intersection of the curves, as shown by the adjoining sketch. The point C is the result of the parallel-like curves of Na and OH at the point of saturation.



I am indebted to Dr.A.W.Bull, of the DOrr Co.,Ltd., for this explanation of the flocculation curve for NaOH.

Other phenomena noted in settling may be explained by this theory. For example, it has been noted that there is a critical concentration of electrolyte which gives a maximum settling rate. Concentrations above and below this value show a decreased settling rate. This may be explained by assuming that this particular concentration of electrolyte give the right amount of ions for adsorption, making perfect floculation, though it does not necessarily mean that the "charges" have been reduced to zero. It may mean that some of the particles have reversed their sign, and,as a result, have an attraction for other particles which have not changed their sign.

It must now be borne in mind that there are other methods of flocculation, other than by means of adding an electrolyte. Deane has stated five methods :-

1. Addition of an electrolyte.
2. Addition of a colloid.
    a. Direct introduction.
    b. Precipitation.
3. Addition of a colloid and electrolyte.
4. Electric current.
5. Biological action.

The first two are the most commonly used - and in slime metallurgy, they are the only methods used.

Addition of a colloid.

The principles involved are similar to those applied in the case of electrolytes. The colloid used is one which possesses an opposite charge with respect to the sol-the two dissimilar particles unite. A better name, perhaps, is agglomeration instead of flocculation. This is not a very common method, and would be impossible in cyanide plants where the lime also acts as a protective agent for cyanide. The usual reagents used are glue and $Al(OH)_3$. $CaCO_3$ is also used, and the action of flocculation in a thickener may not be due entirely to lime, for $CaCO_3$ is constantly being formed.

The consideration of preferential adsorption may lead one into a possible field of research, and Free has stated the possibilities in a very able manner. By using the correct reagents, we might be able to attain a degree of preferential flocculation, in which the valuable material is flocculated, whilst the valueless gangue material may be allowed to pass off in a slime overflow. The idea is not new, for there are certain electrostatic machines, (of more theoretical than practical interest, it is true) which selectively coagulate the material of high susceptibility. Count Schwerin has patented certain processes for the separation of peat from clay, on principles similar to those I have outlined.

Nomenclature used in slime settlement.

Mishler found that :

1. The settling rate of free settling pulp was independent of the height of the column of pulp. In other words, the elimination of water is a function of area.
2. The settling rate of thickening pulp was dependent upon the depth of pulp. Using Coe-Clevenger's words, " the elimination of water in a pulp below critical dilution is a function of time."

Settling Rate may be defined as the rate at which the pulp line moves downwards, or the rate at which clear liquid is being formed. Thin pulps have a faster settling rate than thick pulps(both being free settling). The reason for this is not very clear. It has been suggested by Prof.Bell that it is due to a rising current effect caused by a falling particle which,during its fall,displaces water. This water is pushed into the space vacated by the particle, and the effect is a seeming rising current which affects the particles following the first. The denser the pulp, the more particles will be affected, and this accounts for the slower settling rate found in a thick pulp as compared with that found in a thin pulp.
I would suggest that it may also be due to a hindered settling effect in which we have a form of classification taking place. The density of the medium is increased and the value ($k_1 - k_2$), in Stokes' formula, is decreased, thus lowering the value for the velocity of fall. The classification seems probable when we consider that the settling rate of a pulp line decreases as time passes, in spite of the fact that the pulp may still be free settling.

When settling rates are taken of a dilution of feed pulp, it must be borne in mind that there is a certain amount of sand present, which settles out immediately, and that the settling rate found is that which is characteristic of the dilution of slime present. Therefore the statement thatthe settling rate of a 6 : 1 pulp is of a certain value is erroneous - it is the settling rate of the dilution of ~~slim~~ slime present which is observed. For this reason it is necessary that the percentage of slime in all settling tests should be the same. If the ratio is constant, its exact value does not affect the application of the theory to practice as I will show later.

The first interval of time or space,during which settling rate readings are taken,generally gives a settling rate which differs from the settling rate of the next two or three intervals. This settling rate is known as the Settling Rate of Feed and is generally slower than the others because it is, as yet, non-flocculated. The first interval should be sufficiently long to allow complete flocculation to occur. When flocculation is set up, the settling rate through the second interval should be observed. This should give a value which should be duplicated during a third and fourth interval. Sometimes, however,it is observed that the settling rate may be a little slower(this is noticeable in thick pulps) but provided it is not too widely divergent from the mean, it may be accepted as the Free Settling Rate of the Feed or the Settling Rate which is characteristic of that dilution of flocculated slime present in the sample.

Slime. Mishler defines slime as that part of the ore which remains suspended after 5 minutes of settling in a 100:1 mixture of fresh water and ground ore; the temperature of separation being 60 deg. Fahrenheit. He calls this Natural Slime for he assumes it to be naturally occuring in a finely subdivided state,and is liberated by crushing.

I have shown in another section that the amount of natural slime present in an ore may be varied by crushing. The formation of more natural slime may be due to the greater liberation of slime by the reduction in size of the ore particles, but I also believe that slime can be produced from sand. Free however states that it is doubtful if sand is ever ground sufficiently in practice to cause it to assume the colloidal properties of natural slime, and certainly the practice of closed circuit ? grinding is decreasing the amount of slime that can thus be formed.

A Free Settling Pulp is one in which the particles are falling independently under the settling rate characteristic of their sizes. The settling rate is therefore independent of the depth of the pulp.

A Thickening Pulp is one in which further settling is taking place as a result of the elimination of water enclosed in the flocs. Cohesion of the flocs and the depth of the pulp both contribute to the elimination of water. The depth of the pulp is a measure of the amount of pressure placed upon the underlying flocs. The water is passed up to the surface by means of channels and tubes which are formed in the pulp and which are kept open by the cohesion of the flocs. Obviously. therefore, the dilution of transition between a free settling pulp and a thickening pulp is the highest dilution at which these tubes and channels form, and this is a definition of Critical dilution. It is also the dilution at which the flocs begin to touch, and further settling then is possible only by the formation of channels which drain the water from the interior. It is also characterized by an abrupt change in the settling rate of the pulp line, though this may be somewhat indefinite.

Theory of the Settlement of Slimes in a Dorr Thickener.

I will attempt to take up in chronological order the various ideas and formulae presented upon the subject of the theory of thickening. I shall take each in turn and I have devoted the following section to the discussion and criticism of the formulae involved.

In 1912, an article appeared in the Eng.& Min.Jl.(~~Bxxx~~ (October 5th) entitled " The settlement of slimes at El Tigre," by R.T.Mishler. By means of tests carried out in graduates, he arrived at certain principles of settlement :

1. Settling rate of free settling pulp is independent of pulp depth.
2. Settling rate of thickening pulp~~xx~~ is dependent upon pulp depth.

Mishler concludes his paper by developing a formula for the area required by a Dorr thickener, operating under given conditions of feed and discharge, The paper is meritorious for this reason - it is the first published account of an attempt to correlate the settlement rates as determined by small scale tests in graduates, with the design of a thickener. I am presenting the arguments of the formula as they were published :

Let S = Rate of settling expressed in terms of depth of clear solution formed per minute,

F = Feed of dry slime expressed in tons per 24 hours.

A = Area expressed in sq. ft.

~~R~~

R_1= L:S ratio of feed

R_2= L:S ratio of discharge

Then tons per day of clear solution formed $= F(R1-R_2)$

Cubic ft. formed per minute $= \frac{32}{1440} \cdot F(R_1-R_2) = 0.0222\ F(R1-R2)$

Depth of clear solution per min. $= \frac{0.0222\ F(R_1-R_2)}{A} = S$

Transposing $A = \frac{0.0222\ F(R_1-R_2)}{S}$

In Sept. 1916 , at the Arizona meeting of the A.I.M.E., a paper was presented by H.S.Coe and H.S.Clevenger entitled Methods for the Determination of the Capacities of Slime Settling tanks. It was a paper which covered both phases of settling - i.e. both free settling and settling under compression, and ~~the~~ formulae were developed for both area and depth of thickener required. The paper ranks as the most important yet written upon the subject, and the methods outlined are fundamentally the the same as the methods used by the Dorr Co. today.

Coe and Clevenger both arrived at the principles which were enunciated by Mishler some four years before, namely :

1. Clarification is a function of area.
2. Thickening is a function of time.

They developed a formula determining the area required, which, on first sight, resembled the formula presented by Mishler. On careful analysis however, it is found to radically differ in its development in its method of application and the logical conclusions which one is forced to make, assuming the correctness of the theory. I shall carefully outline the theory below, and since Coe and Clevenger have not described the evolution of the formula $C = \frac{62.35\ R}{(F - D)}$, I shall present its development in my own words, and,I hope,in the light in which they intended that it should be viewed.

Consider a Dorr thickener being fed with pulp consisting of slime, sand, and water. When it is running at capacity, the feed should be sufficiently large to keep the slime level at a constant height. The sand settles out immediately, while the slime must be allowed to settle. We therefore adjust the feed so that the settling rate of the pulp line is balanced by the incoming solids.

Since we have a clear overflow and a thick discharge, it is perfectly normal assumption to make that we have zones within the thickener, ranging from the very high dilutions above to the zone of critical dilution, after which, settling is a function of time. Within the free settling zonesof the thickener, flocs of slime are falling through each zone, and are piling up upon the thickening zone below.

Let us consider any zone in the free settling zone. Let the dilution of the zone be L : 1 (ratio of liquids to one part of solid). Consideration of the constituency of a floc indicatesthat there is some included water in each floc; in other words, each floc possesses a liquid to solid ratio,which is dependent on many factors, E.g. electrolyte and its concentration, temperature, etc. The ratio is assumed to be a constant for the particular case - let it be represented by a dilution of D : 1.

In other words, in each pound of solids dischargedfrom a zone of dilution L , there will also be discharged D pounds of liquids. Hence for each pound of solids leaving the zone, there will be (L-D) pounds of liquid clarified.

Let C represent the capacity of the zone, in terms of pounds of solids discharged by 1 sq.ft. of the zone per hour. Therefore C(L - D) represents pounds of liquid clarified per hour by 1 sq.ft. of zone.

The zone possesses a settling rate which is characteristic of its dilution. Let R represent the settling rate of the zone. Then R will equal the cu,ft, of clear liquid formed per sq.ft. per hour. Hence 62.35 R equals the pounds of clear solution formed(1 cu.ft.=62.35lb)

Obviously, the liquid left behind by the departing flocs must equal the amount of clear solution formed, i.e.

$$C\ (L - D) = 62.35\ R$$

Transposing, $$C = \frac{62.35\ R}{(L - D)} \qquad \ldots\ldots\ldots\ldots(1)$$

The area required to settle one ton per 24 hours is equal to

$$A = \frac{2000}{24\ C}$$

$$= \frac{1.33\ (L - D)}{R} \qquad \ldots\ldots\ldots(2)$$

It will be noted that the above formula is expressed in terms of slime, since that is the part of the ore which is flocculated to aid settling.

Coe and Clevenger now propose to take a sample of the solids in the feed, and settling rates are found for a number of dilutions between the feed and critical dilution, This will give various values for L, and each will have its corresponding R, and if we assume a discharge as if D , the formula can be applied to a series of hypothetical zones in the tank. Note this step. Since slime represents some percentage of the total solids present, this factor, when applied to both L and D in bringing them to terms of slime, will be found in C (equation 1). If C is reconverted to terms of total solids (sand plus slime), it will be found that the result will be the same as that found if the factor had been neglected. In other words, the factor cancels, and, for a given feed of given sand content, in a given tank, we have a definite capacity for total solids, which bears a relation to the capacity for slime in the ratio of sand-plus-slime to slime. The amount of slime in the pulp can be disregarded, and provided the ratio is constant, the exact value, which is difficult to ascertain, need not be found.

Also note the assumption that the L:S ratio of the floc equals the L:S ratio in the discharge.

In Coe and Clevenger's own words, " Given the ratio of fluid to total solids in a pulp with a known settling rate and the ratio of fluid to total solids to be discharged, it is not necessary to know the percentage of fluid in the flocs in order to determine the ~~maximum~~ maximum capacity of such a layer of pulp to discharge pulp of the consistency required."

It will be apparent that the capacity of each zone will differ from any other, due to the nature of the two variables L and R, and their places in the formula. Coe and Clevenger thus reason : Since each floc must, sometime or other, pass through the zone having the least capacity, the ability of the free settling zones to handle free settling material is limited by the ability of this zone to discharge solids. In other words, the area of the tank required must be the area required by the zone of least capacity. This is the first important point.

The second important point is this : Since the zone of least capacity will be receiving more solids than it can discharge, it will build up gradually until it will extend from the point of thickening to the top level of the slime in the tank. The top layer should possess a settling rate equal to that of the zone of least capacity. In other words, we will make a predominating zone of slime which will extend throughout the free settling zone of the tank, and which is equal in density to the density of the slime in the calculated zone of least capacity.

These are the two features that Coe and Clevenger emphasise in their paper, as being logical conclusions from their theory. I have included other points, which are not specifically mentioned in their paper, in the discussion in the next section.

In 1917, in the Transactions of the A.I.M.E., a paper was published entitled," Methods for the Determination of the Capacities of Slime Settling Tanks". It was a more complete paper than previous his article, inasmuch as he gives a method for the determination of the depth of thickener required, and he also gives a summary of the chief features of flocculation and other settling phenomena.

Mishler claimed that his formula for determining the area required was precisely the same as that given by Coe and Clevenger. He considers the existence of another zone, which is of a feed dilution. It is nonflocculated in the centre of the tank, but is flocculated at the periphery. Hence another zone must be considered, which is at the dilution of the feed, and which possesses a settling rate equal to that of non--flocculated feed. This zone, of course, has a low valued settling rate which is sufficiently small to make the zone become the zone of least capacity, I believe, in nine cases out of ten.

He has also stated certain facts in connection with slime settlement that I have covered elsewhere in this paper. He has also presented a graphical method by which both area and depth may be found.

Coe, in a discussion upon the paper, remarks that Mishler's methods should give good results, but he very weakly criticises the formula for area determination, which is rather unfortunate as I will attempt to show. The formulae are so widely divergent in their fundamentals that reconciliation is impossible. Obviously, the formula as applied in 1917 was that developed by Coe and Clevenger, for Mishler agrees with the idea of a predominant zone, which may be other than that of the feed.

Analysis and Criticism of the Formulae upon Area.

Any discussion upon the problem of area in settlement may be summarized into the relative values of the formulae presented by Mishler and by Coe and Clevenger.

Let us consider the development of the formula as given by Mishler in his 1912 article. He assumes that the upper layer of slime is at a dilution equal to that of the feed. In 1917, he explains this by stating that, at Tigre, area is governed by the feed dilution horizon. This pulp therefore settles at a rate equal to that of the feed. He does not state whether this rate was equal to the Settling Rate of the Feed or the Free Settling Rate of the Feed. In 1917, however, he applies the formula, using the Settling Rate of the Feed. He then explains his reason for this, by assuming that there is a horizon at feed dilution which extends from the centre of the thickener to the periphery. Since the centre is non-flocculated while the periphery is fully flocculated, the mean of these two settling rates is the correct one. To be on the safe side, he takes the smaller of the two.

He, curiously enough, states that his formula is " similar to that adopted " by Coe-Clevenger. The formulae are so radically different, both in their development and the conclusions that one must draw , that I cannot see any justification for this remark.

Applying Coe-Clevenger's formula to the figures found by Mishler (1917) upon the settling rates of Tigre ore at various dilutions, I find that the result so obtained differs from the result found by Mishler, by almost 20%. It is interesting to note that the governing zone is but slightly different from the dilution of the feed.

It is reasonable to suppose that there is a zone of constant density in the thickener when it is operated at capacity. We have both experimental and logical evidence that such is the case. It is also a mathematical fact that if we have many zones in a tank, with various capacities, the zone of least capacity will build up. Its inability to discharge solids as fast as solids are being fed into it, will cause it to increase in size.

Under the terms of Mishler's formula, we are to assume that in some cases, there is a zone of least capacity, the inability of which to discharge solids is due to its non-flocculated condition. The conclusion that we must make is that this zone will build up in the thickener ; in other words, the free settling portion of the thickener will then consist of non-flocculated slime -- a condition which is both ridiculous and inconceivable.

The second and most striking argument perhaps, is that if the dilution of the feed should happen to be lower than critical dilution, we cannot possibly use the formula, for the value of the settling rate of the feed will be indeterminable.

Another important conclusion that we must make, assuming the truth of Mishler's formula, is that the dilution of the feed is an important feature of the design of the area. Curiously enough, this seems to be borne out, for analysis of the tests made upon the thickener show a decided tendency in this direction. Its significance is as yet indeterminable, for there are some thick feeds which are below critical dilution. I have discussed this point in a later section.

Consideration of Coe and Clevenger's formula show that there are many points that they have left unexplained.

They gave no explanation of the reason why the percentage of standard slime could be neglected in their formula for capacity. They merely indicated that such was the case by a numerical example, but did not show that it was a factor which, when applied both to the denominator and also to the result obtained, cancelled. They did not show that it was therefore numerically insignificant, provided it was of constant value. Its only value lies in the conversion of capacity-for-solids into capacity-for-slime.

Another important feature is the assumption that the dilution of floc equals the dilution of discharge. I have quoted their statement in this connection in another section. Their reason for this is obscure, and they have clouded it by a numerical example. I believe that equation 1. is just as applicable if we consider " d " to represent dilution of the discharge, instead of the dilution of the floc. It is apparent that if thickening is taking place, there must be a return of water from the thickening zone of the tank. This returning water enters the free-settling zone above, and as a result the true discharge from the zone is the algebraic sum of the downward passing of floc dilution and the upward return of the water which has been squeezed out of the flocs. This sum is equal to the actual dilution of discharge. The theoretical result may be affected somewhat by this upward current from the thickening zone, but I consider that this is negligible. The process of thickening is a slow one, and water is released as a result of the pressure of the overlying material and the cohesion of the flocs themselves. Thus it may be seen that it is a very gradual process.

The settling rate of the surface layer is the important point in the theory for it is the rate at which clear liquid is being formed. That it will not be affected by the rate at which liquid is liberated in the thickening zone can be shown from the following example: Suppose that there is three feet of free settling pulp in the tank, and let us suppose that there is a returning current of 0.1 ft. per hour velocity. Then it will be seen that the current will affect the surface after thirty hours from the time of liberation, and I believe that the following will take place: The rising current will dilute the free-settling zone above for a distance of, let us say, two or three inches. This will give a new dilution, which as a result will have a greater capacity than before. An adjustment will then take place, and the tankwill come back to normal. It will be precisely the reverse phenomena (from that which would occur when a zone of least capacity is building. Since it would be receiving more solids than it could discharge, it would momentarily become thicker, but this resulting change in dilution means an increase in capacity, and the zone would then discharge faster than it would be receiving. When the dilution is increased sufficiently, the zone comes back to normal. It must be distinctly borne in mind that the rising current effect is a very small one, due to the slow rate of thickening, and that the velocity is very small, very much smaller than the value of 0.1 ft. per hour, which I assumed in the above discussion. This is the reason, I think, which makes the assumption valid, and that the dilution of floc is not the only factor involved in the discharge from a zone.

We thus have a peculiar condition arising in the thickener . We have a dilution of the zone, which should give an increased settling rate. But obviously the settling rate will be decreased by the rising current. Will these two opposing factors balance as I have described, so that the capacity of the zone affected will be the same as that of the predominant zone? Prof. Bell has suggested that if my explanation is found to be incorrect, the formula should then be modified by a factor which includes the rate of thickening, which can be converted to terms of a rising current. This value can then be subtracted from the settling rate of each dilution of zone.

What are the experimental conditions that must be fulfilled in order to test Coe and Clevenger's theory? What indications should one expect to find to verify the truth of the theory? The answers to these two questions are the fundamentals of thickener operation.

A thickener is running at capacity when :

1. The density of the discharge-plus-overflow equals the density of the feed.
2. The slime level is at a constant height, and further adjustment of feed is unnecessary.
3. The discharge is constant in density.
4. The slime-to-total-solids ratiois equal in both discharge-plus-overflow and feed. This can be verified by settling rates. If the densities are the same but the settling rates are found to differ, it is evident that the sample with the highest settling rate will contain more sand and less slime than the other sample.

When these four conditions are attained, the thickener is known to be operating at capacity.

We should then expect to find,in verification of Coe and Clevenger's theory, the following :

1. That the maximum theoretical area required by the feed (determined by small scale settling tests) equals the actual area found in a test.
2. That the dilution of slime of the dilution requiring maximum theoretical equals the predominant dilution found in actual test, or

   Dilution of actual zone : Dilution of theoretical maximum area zone

   (total solids dilution) :: 1 : Percentage of slime in total solids

In closing, I may review certain of the distinguishing features of Coe and Clevenger's theory, and more particularly those points which show that it has a more logical aspect than the other.

1. It is the only theory which proves the existence of a zone of constant density - the presence of which is an experimental fact.
2. The theory shows the applicability of small scale tests to the design of a thickener. By locating the predominant zone or zone of least capacity, we can design the thickener to handle the required tonnage.
3. A conclusion that we must make is that the tonnage handled by a given thickener, giving a constant discharge, will be the same, irrespective of the dilution of the feed. For since every solid particle must pass through the zone of least capacity, this zone will be the same for all dilutions of feed.
4. The theory shows that the ratio of slime-to-total-solids in the feed is of immaterial value, and provided it does not vary, the capacity or area determined will be the actual capacity or area found by test. It must be realized that any change in the slime- to-total-solids ratio of the feed or discharge will change the predominant zone and hence change the capacity for total solids. The capacity for slime should be the same in all cases, though it is an arbitrary line between slime and sand.

Thickening of Pulps.

Mishler.

This formula was brought forward by Mishler in 1917, and it is a very ingeneous method for the determination of depth.

Let C = Critical dilution(expressed as an L:S ratio).

D = Discharge dilution(expressed as an L:S ratio),

T = Average settling rate per foot of depth, in settling from the dilution of C to the dilution of D.

X = Depth of the tank in feet.

Using the reasoning as applied to the case of free settling pulps,

Cubic feet of clear solution per hour = $1.33\ (C - D)$

Since the rate of settlement in the thickening zone is proportional to the depth,

Cubic feet of clear solution per hour = $X \times T \times A$

Therefore

$$X = \frac{1.33\ (C - D)}{A \times T}$$

It is obvious that T is to found by settling rates ~~[illegible]~~ conducted in a special cylinder, in which the depth of pulp is the important point.

The method of testing is as follows :

A cylindrical graduate must be used, and it must be marked at the following depths :

Depths in feet	Depths in feet	Depths in feet
1.160	0.778	0.521
1.050	0.704	0.471
0.950	0.636	0.427
0.860	0.576	0.386

It will be observed that each depth is 95/105 th, of the preceding depth, and that the distance settled between two consecutive marks is one-tenth of the mean depth of pulp.

Fill the graduate to the 1.050 ft. mark with pulp at exactly critical dilution, and add solution of the same strength to bring the level to the 1.160 ft. mark. Agitate and allow the pulp to settle. When the pulp line reaches the 1.050 ft. mark, it should be fully flocculated, and readings should then be taken when the pulp line passes each mark. The dilutions of pulp may be successively calculated from the value of critical dilution by the formula :

$$D = 0.905\ C - \frac{0.095}{G}$$

where

D and C are dilutions at two consecutive depths, and

G is the specific gravity of dry pulp.

The average settling rate for any dilution of discharge can be calculated by assuming each interval as one-tenth of a foot, and by dividing the total distance settled by the time taken in settling to the dilution of ~~dis~~ discharge.

It will be observed that no mention is made of attempting to duplicate the action of the rakes. The rakes aid the flocs in the elimination of water, by pressing the liquid out. Faster thickening and a thicker maximum density is attainable when the pulp is stirred, and it should give a more representative thickening rate. Coe and Clevenger mention this point but do not emphasise it, and do not refer to it when the method for determining height is being explained. The Dorr Co. however insist that the pulp should be stirred continously or intermittently, preferably after each reading.

The method used by the Dorr Co. today is essentially that outlined by Coe and Clevenger. The method for the calculation of height is as follows :

The time required in the thickening of a pulp from critical dilution to the dilution of discharge required, is noted. This value multiplied by the capacity of the tank will give the tonnage which must be stored in the thickening zone. From the settling test which was made in order to find the time required for thickening, we may calculate the average dilution of the thickening zone.Thus, knowing the dilution of the thickening zone and tonnage which must be stored, we can calculate ~~th~~ the volume required for storage. Since area has already been determined, the height required can be calculated.

In the section upon "Testing", I have copied the Coe-Clevenger Method for the determination of area and height from the Dorr laboratory manual - for their methods are essentially ~~those~~ the same as suggested by Coe and Clevenger. For this reason,I have not included them at this point, and I have also copied an example which was fully worked out in the manual, showing the application of the method described above.

Unfortunately, lack of time prevented any serious attempt being made upon the problem of height, for, as I have outlined in the introduction, all available time was devoted to the problem of area. Since height can be sacrificed for area, slight errors can be compensated for by allowing a margin of safety in the area required. Area is the most important of the two, and all problems in connection with it, should be cleared up first. Area decides the capacity of the thickener, ~~which~~ whilst height decides the discharge dilution. The two,of course, are interrelated and this must be borne in mindwhen thickener operation is considered.

Testing

I am presenting the two methods of testing for comparitive purposes alone. There is but little doubt that the methods outlined by Mishler are more laborious than the methods followed by the Dorr Co. I have carried out tests on both free settling pulps and thickening pulps, and using both methods, and my personal opinion is that the Dorr Co method is the easier of the two. In the determination of area, the principle is the same, but Mishler's method requires more preliminary work than the other. Bottles of each dilution of pulp have to be made up, whereas in the Dorr method dilutions are changed by siphoning off clear liquid. This gives a closer series of dilutions, and they can be easily checked by making up a new graduate-ful of pulp equal in density to the last dilution in the previous graduate. I do not feel qualified to criticise the two methods for determining height, but they appear to be similar in principle. I have found, however, that the Dorr method is the simpler and the least tiresome of the two, for readings are taken at time intervals instead of space intervals, which require a little more supervision. Whether it is the more accurate of the two is problematical.

Mishler's method for determining area.

A graduate is filled to the 1 ft, mark with pulp of the required dilution. It is agitated and allowed to settle. The settling rate is observed as the pulp line passes through the first 0.05 ft. This gives the settling rate of the feed. The settling rate through the second 0.05ft. is the free settling rate of the dilution. The value for each dilution and its corresponding settling rate is then substituted inthe formula. The dilution of the feed and its settling rate is also applied. The largest area found is the area required by the thickener per ton per day.

Mishler's method for determining depth. I have outlined the method in the section upon " Thickening".

Dorr Co. Methods.

I

I have copied the methods below described from the laboratory manual of the Dorr Co. and I have made no attempt to explain the procedure outlined. It is also found in Hamilton's Manual of Cyanidation, though in briefer form.

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Sources of error.

The principle sources of poor results from settling tests are :-

1. The proportion of sand to slime in the same sample is not truly representative of actual conditions.

2. The quantity of reagents in solution is allowed to change.

3. The screen analysis of the solids does not conform to practice.

4. The testing is conducted at a different temperature from practice.

5. The sample is ground dry instead of wet.

6. Standing a long time in solution may decrease rate.

Unless each of the above conditions is very carefully avoided, the results of the settling tests may be valueless.

Procedure 1. Determination of specific gravity of solution and solids.

Pour the sample into an earthen-ware vessel of sufficient capacity to hold the entire volume. Thoroughly mix by stirring with a paddle, being sure that all lumps are disintegrated. Weight a 1000 c.c. calibrated flask. Again mix the sample thoroughly and fill the flask up to the mark with a representative sample of pulp. Weigh the flask full. Filter off the solids, dry and weigh.

Determine the specific gravity of the filtered solution by means of a hydrometer or by weighing a carefully determined volume.

The specific gravity of the solids should now be calculated and recorded for furture use.

Let Weight in grams of 1000cc flask and pulp = a

Weight in grams of 1000cc flask = b

Weight in grams of pulp = a - b = c

Weight of solids in 1000cc pulp = d

Specific gravity of solution = e

Then

$$c - d = \text{grams of solution}$$

$$\frac{c - d}{e} = \text{c c of solution}$$

$$1000 - \frac{c - d}{e} = \text{c c of solids}$$

$$\frac{d}{1000 - \frac{c - d}{e}} = \text{specific gravity of solids.}$$

Procedure 2. Determination of the maximum density of thickener discharge, Mix the sample as in Procedure 1 and fill a 1000 cc graduated cylinder up to the 1000 cc mark. Thoroughly mix while in the graduate. Allow the pulp to settle undisturbed, taking readings in cc every 20 mins. at the line of demarkation between the solution and settling solids. When there is an abrupt decrease in the rate of settlement, after which settling constantly gets slower and slower, compression or hindered settling has begun. After this, record readings at one, two or three hour periods, depending on quickness of settlement, stirring the pulp gently with a glass rod after each reading. When no further subsidence of the pulp line is noticed after five hours, consider that the final density has been reached.

Filter, dry and weigh the solids. Calculate the final density as follows, recording all figures for subsequent use:

Only consider the pulp in the compression zone and let a, b, c, etc. represent the graduate readings after the respective intervals.

Let W = grams of dry solids in graduate

G = specific gravity of dry solids

D = specific gravity of solution

$\frac{W}{G}$ = cc of dry solids in graduate = C

Then $\frac{D(a-C)}{W}$, $\frac{D(b-C)}{W}$ etc, is the ratio by weight of solution to solids after the respective intervals of time.

Calculate each dilution and record the results. The final density will represent the final density of thickener discharge.

Procedure 3. Determination of settlement area required.

Mix the sample as in procedure 1 and fill a 1000 cc graduate up to the 1000cc mark. Thoroughly mix while in the graduate. After mixing allow the solids to settle approximately 1/4 ". Record the cc reading of the pulp line and the time at which this reading was taken. Allow to settle undisturbed for three minutes, at which time again record the reading of the pulp line. Take similar readings at 6 and 9 minutes.

Allow the pulp to settle until 100 cc of clear solution can be decanted off. Decant off 100 cc, mix and repeat the readings as before. When this has been done, decant off 100 cc more of clear solution. The pulp volume will now be 800 cc. Again rate the settlement as before. Take one more decantation of 100 cc and repeat. Filter, dry and weigh the solids.

Thoroughly mix the sample in the earthen-ware vessel, measure out 1500cc of pulp and place in a suitable vessel. Allow the solids to settle and decant off 500 cc of solution. Place the remaining 1000cc of pulp in a 1000 cc graduated cylinder and get the rates of settlement at dilutions corresponding to 1000cc, 900cc, etc., as outlined before.

Measure out 2000 cc of pulp , thicken to 1000 cc and repeat.

Do the same with 3000 cc of pulp, after decanting 2000 cc.

Calculate the required area as follows :

Measure the number of cc graduations on the cylinder corresponding to one foot. From this get the value of 1 cc in feet. From this convert all the readings in cc per 9 minutes into feet per hour. Calculate from the weight of solids in the cylinder and from the specific gravity of the solids the dilutions corresponding to the respective rates of settlement. Apply the formula $A = \frac{1.333\ (F-D)}{R}$, where F is the dilution at which each of the readings R were taken, and D the final density found in Procedure 2. The largest value of A will be the thickener area required in sq. ft. per ton of solids settled per 24 hours.

Procedure 4. Determination of the depth of compression zone.

The data necessary for this determination have been obtained under Procedure 2. Calculate from these data the average dilution in the compression zone, The area necessary for the settlement has been obtained under Procedure 3. Convert this figure into pounds of solids per sq.ft. per hour by multiplying the area by 24 and dividing the result into 2000, as $\frac{2000}{24\ A}$. The pounds per sq.ft. per hour multiplied by the number of hours which the pulp must be held in the compression zone will give the pounds of solids which it is necessary to hold in storage. The pounds of pulp may then be calculated , knowing the average dilution. From this, the cubic feet necessary may be computed. As, however, we are on a base of 1 sq.ft., the cubic feet in this case is equivalent to the vertical feet." To this value is there added the depth required by the feedwell. Another factor which must be added isthis :Two-thirds of the maximum depth of the arms (slope of 1.75 inches per foot) is ineffective due to the solids building up under the rakes, and this must be included in the depth required.

Apparatus used.

A Dorr thickener was installed and erected during February and the first two weeks of March 1924. It was 6'-2" high and 5' in diameter. The walls were continueddown for a further 2'-6", and the thickener was supported by this cylindrical shell. A circular doorway was cut in this, to allow free access to the thickener discharge cock. The centre of the floor of the thickener was cut out, and an 18" 90degree cone of cast iron was placed in it. A 1" hole in the apex gave an orifice for discharge. The discharge was regulated by a cock which is ~~regulated~~ operated from ~~within~~ without the cylinder. The discharge passes down, and is turned at right angles into a 3/8" pipe which leads the discharge out of the cylinder. Another right angle bend and the 3/8" pipe is rebushed to a 1" nipple, vertically downwards. On the end of this, caps with drilled orifices of known diameter are screwed. The orifices are changed when changes in the amount of discharge are required. The discharge falls into a launder, which leads to the collecting cone. At first, the discharge pipe was not used, and the discharge was passed into a ~~larger~~ short launder, which fed the collecting cone launder. But the splashing of the discharge and the discomfort of changing orifices under the thickener were features that were not desirable, and the pipe was put in to allow greater freedom. It was found that no thickening was taking place in the pipe, and the results could not be affected.

The thickener overflow launder is 4'-11" in diameter, and is suspended within the thickener by three rods, fastened to the launder by nuts(locked), and which were drilled at foot lengths to allow the insertion of a pin, which held the thickener launder at levels which could be changed. The pin was locked by a plate which was bored to take the rod.

The overflow launder bottom is drilled in one place ~~at~~ and the overflow passes through it down a pipe in the thickener, and is directed through a cock in the side to an external pipe leading to the

Discharge launder. 1" cocks are placed at intervals of 1' throughout the depth of the thickener, so that the launder can be placed at different levels without changing the internal overflow pipe.

In the side of the thickener are placed 12 ≠1/2" cocks, the first 8" from the top, and the remainder are 5" apart and are staggered 2" from the vertical. Small samples from the interior are taken by these cocks for specific gravity measurements. A 5" pipe and elbow are screwed into each so that a good sample, unaffected by the walls of the thickener, can be obtained from each.

The feedwell is 13" in diameter, of galvanized iron, and is 15" deep, being 3" above the level of the ~~feedwell~~ overflow. A 1 1/2" thick boardis rigidly bolted in the centre of the feedwell, tightly fitting the cylinder and a 2 1/2" hole is bored out of the centre for the central shaft. A great number of 1/2" holes are bored in the wood which serve to baffle the feed. A sieve(40mesh) was used to take any coarse foreign matter from the feed before it entered the thickener, and this was bolted to the feedwell.

The feed is tapped from the central pipe of a pachuca, just below the ~~feedwell~~ cone, by a horizontal pipe leading to the feedwell. The central pipe gives a more representative sample of the contents of the pachuca than a sample taken from without the central pipe. The pachuca when full is approximately 14' high but 12' of pulp constitutes a charge. Samples are taken from a 3/4" cock, 3' from the bottom of the pachuca, which taps the central pipe.

The central pipe of the pachuca has an extension of galvanized iron with a brass frustrum at one end which can be lowered to tightly fit the apex of the cone of the pachuca. The top of the extension is covered with a hood, which diverts the uplift of pulp into a horizontal direction with little splash.

When the pachuca air is closed, the extension is lowered and the frustrum seals the upper part of the pachuca from the lower. This means that less slime is allowed to settle on the bottom and the air can be used to recommence agitation, even after considerable lapse of time, during which the slime has caked at the bottom. Without this, all the slime would cake and cover the air inlet which would be rendered useless as sufficient pressure could not be supplied to break up the slime.

The discharge and the overflow meet in a launder which convey~~s~~ the two products to a collecting cone. They are mixed in the swirl caused by the overflow. The Discharge-and-overflow sample is taken from the the edge of the launder ~~before~~ as the two are feeding into the cone. The pulp in the cone is returned to the pachuca, or to the feedwell.

A floortank or sump is used to store the slime which is not required.

A cross is provided at the pump to handle:-

1. Stamp battery product which is passed to a cone classifier - the slime from which is fed to a settling cone.
2. The material in the floor tank - which can be added to the circuit when necessary.
3. The discharge and overflow in the collecting cone which is returned to the pachuca or to the thickener.

Procedure

This may be divided into two sections :

1. The preliminary proceedings which must be carried out to give a free flow through the discharge pipe,
2. The procedure to be followed during the test i.e. samples and sampling, "balancing" of the thickener, final samples, etc.

1. Preliminary proceddings .

Whenthe slime in the thickener has been allowed to settle after a test, it cakes or cements upon the floor of the thickener, and the stirring arms must be run daily to ~~bx~~ break this up and to give the settled pulp a slight agitation. A 1" pipe is screwed into the cross at the bottom of the cone, and the discharge cock is opened. The discharge pipe is then closed(either by placing the palm of the hand over the opening or by screwing a cap over the end), and high pressure water is admitted through another arm of the cross. It breaks its way through the pulp in the cone, thus giving a free flow. A few applications of this high pressure water is sufficient to give the desired result.

The thickener is then given an overflow which combines with the discharge and the two are passed into the collecting cone, from whence the pulp is ~~xek~~ returned directly to the thickener.

The pachuca can then be agitated. The air is admitted, and the extensible air lift in the pachuca is then lifted from its resting place at the bottom of the cone. The amount of slime covering the air inlet is but a very small portion of the total slime in the pachuca, and the air should break its way through easily.

The thickener meanwhile has been put in agitation by means of the discharge plus overflow feed. The lime content in both pachuca and thickener can then be brought up to the required strength. The specific gravity of the

Pachuca can then be brought to the required value either by feeding it with discharge slime or by diluting it with water and lime, thus raising or lowering the specific gravity, respectively.

When the thickener has been agitated sufficiently, the slime from the feed becomes distributed throughout the thickener, and the pulp level in the thickener rises. When it reaches the desired level, the test can then be started. Put on the 3/8 " discharge pipe, bushed to take a 1" cap.

Starting the test.

Adjust the overhead cocks so that the discharge plus overflow is returned to the pachuca, and open the pachuca feed pipe to the thickener. Put a cap on the discharge pipe with an orifice of sufficient diameter to give a discharge plus overflow equal in density to the density in the pachuca. The feed should be opened sufficiently wide to keep the pulp line at a constant height. Increasing the feed means an increased overflow, and the discharge orifice must be increased to balance the fall in density which would result.

Density samples are taken every fifteen minutes of discharge, discharge plus overflow, and feed. The thickener is considered ~~to~~ be balanced when :

1. The feed density equals the density of the discharge plus overflow.
2. The slime level remains at a constant height without change.
3. The density of the discharge is constant.

In the light of experience, I would also suggest that settling rates should be carried out on both feed and discharge-plus-overflow , and these should be found to be equal. This is one of the most important features of the balance, for a discrepancy between feed and discharge-plus-overflow settling rates mean that the ratio of slime to total solids is not constant and is therefore changing the quality of the feed. The test for the balance of the thickener must also include this test. When the two settling rates are equal, we are then positive that the discharge is of the same quality as the feed, and that we are taking out of the thickener exactly the same material as we are feeding.

When these four conditions have been complied with, the thickener may be considered as being balanced.

Then this balance must be maintained over a certain period which may be one hour or even longer, depending on the confidence that the operator holds, whether or not the thickener is running at capacity.

When the operator feels that the thickener is running at capacity, and sufficient time has elapsed to show that further change is unlikely, the final weight samples can be taken. Let us suppose that the discharge-plus-overflow density has been very steady for a considerable time. It is then reasonable to suppose that any slight difference that it may have had in comparison with the feed, at the beginning, is now reduced to nothing - for the feed changes with change of discharge. We can thus say that the weight of solids in the discharge equals the weight of solids in the feed. By taking careful samples of the discharge and overflow, we can say that their sum equals the weight sample of the feed. The two samples should be taken simultaneously, so that the pachuca is unchanged. The collecting cone must be regulated so that the lack of discharge-plus-overflow feed will not allow the level to fall too low in the cone.

The second step is to take specific readings of all the small cocks in the side of the thickener. This can be carried out in a ~~WTR~~ 250 cc flask and funnel. The samples should be taken from the top cock downwards, as this will not affect the ~~tx~~ thickener so appreciably as if the samples were taken in the reverse order.

A check sample of the feed can now be taken. The feed is diverted from the feedwell into a small pipe leading to the discharge-plus--overflow launder. This sample should weigh the same as the discharge plus overflow combined.

Testing can now be carried on . The sample of feed can be diluted with overflow liquid, if necessary, and settling rates are determined. Testing should also be carried out for the slime in the tank. Samples are taken from the small cocks in the tank, and the settling rates of the slime dilution of the predominant zone are observed.

Changing the dilution of the feed.

If the dilution required is higher than the ~~dil~~ dilution of the completed test, the discharge cock should be closed and clear overflow is then passed to- the pachuca. Another method is to divert the material to the feedwell instead of ~~ta~~ the pachuca . This will give a discharge-plus-overflow feed to the thickener. The Pachuca can then be diluted by letting slime pass into the floor tank, and replacing it with water and lime of the required amount to bring the strength back to the original value. When the dilution required is attained, the feed can can be opened, and the material in the collecting cone can be pumped again into the pachuca. Another test can then be run without loss of time.

If the dilution required is less than that of the test, the feed pipe should be closed and the discharge can then be pumped into the pachuca, thus altering the dilution to a lower value. The overflow will cease when the feed is closed. If there is a storage of slime in the floor tank, it may be pumped directly into the pachuca, and thus altering ~~th~~ the feed. Some water of course must be taken out of the system, and this may best be taken from the overflow.

RESULTS OF TESTS CARRIED OUT ON A FIVE&FOOT THICKENER.

Test 1. March 14-24. D & O = Discharge-plus-overflow.

Log Sheet of Test

	Feed		D & O		Discharge		
Time	SpGr	CaO	SpGr	CaO	SpGr	CaO	Notes
4.40		.47	1.17		1.71		Room 64deg.
4;45	1.16		1.15				#28orifice
5.00							tank .47
5.15	1.16		1.17	.47			
7.05	1.18		1.15				Room65deg
7.35	1.12	.48	1.12				
8.00	1.09		1.07				
8.15	1.09	.49	1.115		1.66		
8.45	1.090		1.110		1.65		
9.00	1.09		1.110				
9.10							#29
9.15	1.09		1.110				
9.30	1.09		1.110				#30
9.45	1.09		1.090				
10.30	1.10		1.105				
10.50	1.105		1.110		1.62		

Sample	Density	L : S	lbs/min	Solids	Liquids
Feed	1.105	5.6	36.25	5.5	30.75
Discharge	1.62	0.65	9.31	5.6	3.7
Overflow	1.00		27.2		27.2

Small cocks	Density
1.	1.066
2.	1.112
3.	1.122
4.	1.124
5.	1.128
6.	1.132
7.	1.140
8.	1.170

Small cocks	Density
9.	1.212
10.	1.388
11.	1.460
12.	1.502

Average density of zone 1.126
or 4.6 : 1.

Area actually required 4.9 sq.ft./ ton/ day.

Test 2.

	Feed		D & O		Discharge		
Time	SpGr	CaO	SpGr	CaO	SpGr	CaO	Notes
2.30							#10
2.30	1.27		1.33		1.60		#16
2.45	1.27	.37	1.27		1.60		
3.05	1.27		1.29		1.595		#17
3.15		.44	1.27		1.60		
3.30	1.27		1.25		1.59		
3.45	1.265		1.24				#16
3.50	1.26	.44	1.28		1.595		
4.05	1.26	.55	1.26				
4.30	1.26		1.26		1.585		
4.45	1.27		1.27		1.58		12=.39
5.00	1.27		1.27		1.58		
5.20	1.265		1.255		1.58		1 =.42
5.30							#15
5.45	1.26		1.26		1.58		#14
6.00			1.24		1.58		#13
6.15	1.255		1.275		1.58		
6.30	1.255		1.275		1.58		
6.45	1.255	.45	1.215		1.58		#12
7.00	1.24		1.225				
7.05			1.23				
7.15	1.24		1.28				#13
7.25	1.245		1.29				#14
7.40	1.25		1.255		1.60		
7.50	1.265		1.27				
8.40"	1.255		1.27		1.57		
9.00	1.25		1.22				
9.10	1.255		1.22				#12
9.25	1.24		1.23				
9.30	1.24	.42	1.25				
9.40	1.24		1.26				#13
9.45	1.24		1.26				#14
10.00	1.245		1.235		1.59		
10.05	1.245		1.245				

Cock	Density	Cock	Density	Cock	Density
1.	1.100	5.	1.132	9.	1.146
2.	1.108	6.	1.136	10.	1.150
3.	1.132	7.	1.136	11.	1.162
4.	1.132	8.	1.140	12.	1.202

Average density of zone 1.135 or 4.3 : 1.

Sample	Density	L : S	Lbs/min	Solids	Liquids
Feed	1.245	2.2	27.4	8.55	18.9
Overflow	1.000		13.4		13.4
Discharge	1.59	0.70	15.0	8.8	6.2

Actual area required = 3.1 sq.ft./ton/day.

Test 3. March 21-24.

	Feed		D & O		Discharge		
Time	SpGr	CaO	SpGr	CaO	SpGr	CaO	Notes
1.25	1.18		1.07		1.31		
1.35			1.03				#16
1.40			1.08				
1.45	1.16		1.12				
1.50			1.12				
1.55			1.12				
2.10		.51	1.12	.54			#10
2.15	1.14		1.13				
2.20	1.13		1.16		1.24		
2.35	1.14	.52	1.13	.56	1.24		
2.50	1.13		1.12		1.24		
3.05	1.13	.52	1.12		1.25		
3.20	1.13		1.11		1.25		
3.35	1.135	.52	1.14		1.26		
3.50	1.13		1.14		1.26		
4.05	1.14	.52	1.14	.54	1.25		
4.20	1.135		1.15		1.26		
4.35	1.14	.52	1.14		1.26		
4.50	1.14		1.14		1.26		
5.05	1.14	.50	1.12		1.26		
5.20	1.13		1.145		1.26		
5.35	1.13	.53	1.145		1.255		
5.50	1.14	~~xxx~~	1.15		1.25		
6.00	1.145	.46	1.145		1.26		
6.15	1.145		1.145		1.25		
6.30	1.14	.53	1.145		1.265		
6.45	1.14		1.145	.51	1.26		
7.00	1.14	.50	1.145		1.26		
7.15	1.14		1.14		1.255		
7.30	1.14	.52	1.145		1.26		
7.45	1.14		1.145		1.255		
8.00	1.14	.50	1.14		1.26		
8.15	1.14		1.135		1.255		
8.30	1.145	.51	1.14		1.26		
8.45	1.145		1.145		1.255	.47	
9.00	1.14	.47	1.15		1.265		

Cock	Density	Cock	Density	Cock	Density
1.	1.100	5.	1.120	9.	1.1~~1~~22
2.	1.108	6.	1.120	10.	1.122
3.	1.120	7.	1.120	11.	1.128
4.	1.120	8.	1.120	12.	1.188

Average density of zone 1.120 or 4.9 : 1.

Sample	Density	L:S	Wt/min.	Solids	Liquid
Feed	1.145	3.9	28.8	5.9	22.9
Discharge	1.265	2.0:	17.7	5.9	11.8
Overflow	1.000		11.6		11.6

Actual area required ~~R~~ 4.5 sq.ft./ton/day.

Test 4. March 21-24.

	Feed		D & O		Discharge		
Time	SpGr	CaO	SpGr	CaO	SpGr	CaO	Notes
							#27
12.00	1.06		1.10				#30
12.05	1.065		1.08				Feed cl.
12.15	1.055		1.08				#31
12.25	1.07		1.07		1.41		
12.30		.52	1.07	.51			
12.45	1.06		1.07		1.38		
1.00	1.06	.48	1.07		1.37		
1.15	1.06		1.07		1.34		
1.30	1.06	.48	1.06		1.34		
1.45	1.06		1.07		1.345		
2.00	1.06	.47	1.06		1.34		
2.15	1.06		1.06		1.33		
2.30	1.06	.46	1.06	.47	1.335		

Cocks	Density	Cocks	Density	Cocks	Density
1.	1.052	5.	1.100	~~10~~.9.	1.248
2.	1.088	6.	1.100	10.	1.276
3.	1.100	7.	1.100	11.	1.280
4.	1.100	8.	1.10~~0~~2	12.	1.292

Average density of zone 1.100 or 5.9 : 1.

Sample	Density	L:S	Lbs/min.	Solids	Liquid
Feed	~~10.2~~1.06	10.2	39.2	3.5	35.7
Discharge	1.335	1.5	8.35	3.35	5.0
Overflow	1.000		30.9		30.9

Feed.

L:S	Sett.Rate	Area	L:S	Sett.Rate	Area
10.2	3.00	3.85	5.9	1.15	5.1
9.2	2.6 0	3.94	5.3	0.85	5.9
8.3	1.78	5.08	4.7	0.71	6.0
7.5	1.63	4.90	3.9	0.60	5.3
6.8	1.34	5.26			

Settling Rate of feed 2.2 ft/hr. Area(Mishler) 5.2

Feed contains 58 % Standard Slime.

Computed Area required 6.0 sq.ft./ton/day.
Actual Area required 7.6 sq.ft,/ton/day.
diln.
Computed of zone 4.7:1 or 8.8:1 of slime.
Actual diln.of zone 5.9:1 of slime.

Test 5. **March 27-24.**

	Feed		D & O		Discharge		
Time	SpGr	CaO	SpGr	CaO	SpGr	CaO	Notes
12.30							#21
12.40	1.09		1.11		1.48		
12.50	1.09		1.095		1.43		#15
1 .00			1.12		1.365		#9
1.15	1.10		1.10				
1.30	1.11		1.10		1.36		
1.45	1.11		1.10				
2.00	1.11		1.10		1.38		
2.15	1.10	.40	1.12		1.39		
2.30	1.12		1.14	.38	1.385		#8
2.45	1.125		1.17		1.39		
3.00	1.14	.40	1.16		1.40		#35
3.15	1.15		1.15		1.395		
3.30	1.15		1.15		1.39		#4
3.45	1.18		1.18		1.39		
4.00	1.185		1.18		1.39		
4.15	1.19		1.20		1.38		
4.30	1.19		1.23		1.38		#5
4.45	1.185		1.195		1.39		
5.00	1.19		1.20		1.385		
5.15	1.20		1.205				#8
6.45	1.20		1.20		1.37		
7.00	1.20	.48	1.20		1.36		#9
7.15	1.20		1.22	.40			#80
7.30	1.20		1.17				
7.45	1.20	.38	1.20		1.39		
8;00	1.19		1.19		1.39		
8.20			1.20				Samples taken.
8.30			1.20				
8.45			1.22				#11
8.50			1.215				#12
8.55			1.205				#13
9.00	1.20		1.205		1.40		+33%-90feed op.
9,40			1.18				
9.15	1.19		1.19		1.40		
9.30	1.18	.41	1.18				#12
9.40	1.185		1.195				

Cocks	Density	S.R.	Cocks	Density	S.R.	Cocks	Density
1.	1.076	.553	5.	1.112	.545	9.	1.114
2.	1.096	.535	6.	1.112	.525	10.	1.116
3.	1.108		7.	1.112	.540	11.	1.124
4.	1.112		8.	1.112		12.	1.152

Average density of zone 1.112 **or** 5.25:1.

Sample	Density	L:S	Lbs/min	Solids	Liquids
Feed	1.190	2.9	31.4	8.0	23.4
Discharge	1.40	1.2	15.1	6.9	8.2
Overflow	1.00		14.5		14.5

Feed contains 60% **standard slime.**

Test 5. (continued)

Feed.

L:S	Sett.rate	Area
9.5	3.79	2.9
8.0	3.45	2.6
7.0	3.03	2.5
6.3	2.72	2.5
5.7	2.30	2.6
5.0	1.92	2.6
4.5	1.55	2.8
3.9	1.23	2.9
3.5	0.98	3.1
3.1	0.73	3.5
2.9	0.62	3.7

Discharge.

L:S	Sett.rate	~~Area~~
6.3	2.28	
5.7	1.86	
5.3	1.71	
5.0	1.50	
4.7	1.38	
3.9	1.03	
3.5	0.78	
3.1	0.64	

Sett.rate of feed .63 Area(Mishler) 3.6

Computed area 3.7 sq.ft./ton/day.
Actual area 3.4 sq.ft./ton/day.

Computed dilution of zone 2.9:1 or 4.8:1 of slime.
Actual dilution of zone 5.25:1 of slime.

Test 6.

	Feed		D & O		Discharge		
Time	SpGr	CaO	SpGr	CaO	SpGr	CaO	Notes
1.00	1.17	.41	1.205	.46	1.255		#9
1.15	1.17		1.205		1.26		
1.30	1.17	.41	1.19		1.255		
1.45	1.18		1.20		1.26		
2.10	1.18	.40	1.29	.44	1.26		
2.30	1.18	.39	1.195		1.27		
2.45	1.18		1.20		1.28		
3.00	1.18	.42	1.205	.44			
3.15	1.19		1.20		1.28		
3.30	1.185	.42	1.20				#10
3.45	1.18	.43	1.18	.44	1.30		
4.05	1.18		1.18		1.30		
4.15	1.18		1.18		1.30		
4.30	1.18		1.18		1.30		Pump primd.
4.45	1.175		1.18				
5.00	1.17	.42	1.18	.42			
5.15	1.17		1.19		1.30		
5.30	1:185	.44	1.185		1.30		
5.45	1.165		1.165		1.30		
5.55	1.17	.43	1.205	.44			
6.10	1.18		1.20		1.285		#11
6.20	1.18		1.20				#12
6.30	1.185	.42	1.19				
6.45	1.185		1.19		1.30		
7.00	1.185	.40	1.19	.42	1.30		
7.15	1.19		1.19		1.31		
7.30	1.185		1.19		1.30		

Cocks	Density	S.R.	Cocks	Density	S.R.	Cocks	Density
3.	1.076	.55	7.	1.088		10.	1.100
4.	1.080		8.	1.092		11.	1.100
5.	1.080		9.	1.092	.47	12.	1.116
6.	1.084	.50					

Average density of zone 1.084 or 7.1:1.

<u>Feed.</u>

L:S	Sett.rate	Area	L:S	Sett.rate	Area	L:S	Sett.rate	Area
9.0	2.30	4.2	6.0	1.20	4.78	4.2	0.65	5.12
7.6	1.81	4.3	5.3	0.99	4.33	3.6	0.58	4.4
6.7	1.47	4.5	4.7	0.76	5.24	3.3	0.57	4.2

<u>Discharge</u>.

L:S	Sett.rate	~~Area~~
7.7	1.74	
6.8	1.45	
6.0	1.16	

Feed contains 57% standard slime.

Test 6.(continued)

Sample	Density	L:S	Wt/min	Solids	Liquids
Feed	1.185	3.0	20.2	5.1	15.1
Discharge	1.30	1.7	14.1	5.2	8.9
Overflow	1.00		6.1		6.1

Computed Area required ~~T/HR~~ 5.24 sq.ft./ton/day.
Actual Area required 5.25 sq.ft./ton/day.

Computed dilution of zone 4.7:1 or 8.2;1 of slime.
Actual dilution of zone 7.1:1 of slime.

Test 7.

	Feed		D & O		Discharge		
Time	SpGr	CaO	SpGr	CaO	SpGr	CaO	Notes
9.30		.44					#12
9.45	1.13		1.09				#8
9.55	1.13	.43	1.13	.42			
10.00			1.122		1.28		
10.10	1.12		1.127				
10.15			1.12		1.28		
10.30	1.124		1.130		1.29		Feed cl.
10.50		.46	1.132	.43			" " #9
11.15			1.13				
11.30			1.13		1.28		
12.35	1.13				1.28		

Cocks	Density	S,R.	Cocks	Density	S.R.	Cocks	Density
3.	1.076	.53	7.	1.084		10.	1.088
4.	1.080		8.	1.084		11.	1.088
5.	1.080		9.	1.088	.48	12.	1.100
6.	1.080	.53					

Average density of zone 1.084 or 7:1 : 1.

Feed contains 52% standard slime.

Feed.

L:S	Sett.rate	Area
7.6	2.92	2.6
6.9	1.71	3.9
6.1	1.38	4.05
5.6	1.15	4.3
5.2	0.95	4.6
4.6	0.75	4.8
4.0	0.62	4.5
3.5	0.55	3.9
3.2	0.46	3.8

Discharge.

L:S	Sett.rate
7.7	2.00
6.8	1.73
6.1	1.46
5.5	1.22
5.1	1.09
4.7	0.97
4.2	0.83

Sett.rate of feed .63   Area % (Mishler) 5.5

Sample	Density	L:S	WT/Min	Solids	Liquid
Feed	1.13	4.5	33.4	6.1	27.3
Discharge	1.28	1.9	18.2	6.3	11.9
Overflow	1.00		15.2		15.2

Computed area required 4.8 sq.ft./ton/day.
Actual area required 4.4 sq.ft./ton/day.

Computed dilution of zone 4.6:1 or 8.85:1 of slime.
Actual dilution of zone 7.1 :1 of slime.

Analysis of results.

The figures are almost self-esplanatory, but I intend to take up each test and comment upon it, stating any reasons, if any, for doubting the reliability of the figures. In the final tests, where I have compared theoretical results with the results found by test, there does not seem to be any connection between the theoretical dilution of the thickener zone and the result found by practice. This, I believe is due to the inaccurate determinations of natural slime. The presence of lime in the sample caused immediate flocculatio with the result that I was obliged to shorten the settling interval to thirty seconds. The use of a deflocculating agent may be found practicable, but I would suggest the application of an elutriator in the determination of natural slime. A very small current could be applied to the sample, and it could be washed free of adhering solution of lime. The correct velocity could then be gradually acquired, and the solids in the overflow will represent the amount of slime present in the sample. This material is therefore a standard slime.

Test1. Shows a high discharge, but since it shows a good gradation in the thickening zone, the test is presumably a good one.

Test2. Shows a high discharge, but with a very low density in the 12th. cock. This seems highly improbable, and for this reason, I do not place a high value on this test. Prof. Bell then suggested that the trouble lay in the sand which was present. It was not being discharged as fast as it was being fed, because a blanket of it was formed over the discharge cone. A discharge of constant density was the result, which would not vary when the conditions were changed. The small area required showed that the feed held a high sand content, thus giving a high capacity. The material was then classified by allowing the slime to ~~settl~~ settle in a tub. The top slime was decanted off, and poured ~~be~~ back in the system.

The discharge pipe was then installed, and it was used in the remaining tests.

Test 3. The 12th. cook seems reasonable when compared with the discharge, and I think that this test is a good one.

Test 4. The dilution of the predominant zone seems to be higher than the dilution in the previous tests.

When we compare the settling rates of the feed dilutions with the rates of Test 5 , we see that the slime content is evidently greater, hence the smaller capacity of the test is accounted for.

Test5, The settling rates of the feed and the discharge dilutions do not check, indicating that the thickener was not in balance. The high settling rates indicate ~~that~~ a high sand content, with the result that the area required is a normal value. The actu al value approximates the theoretical.

Test 6. The feed sample contains more slime than Test 5. The capacity of the thickener in this test is therefore less than in Test 5, and the actual figure checks closely withthe theoretical.

Test 7. The feed contains ~~more~~ less slime than in Test 6, and the capacity is therefore greater. The theoretical value for area checks closely with the actual requirements.

As I have before remarked, the theoretical dilution of the slime zone does not check with the actual dilution found. This is due to erroneous values found for the percentage of natural slime present. The proof of the error lies in the relation between the settling rates of the feed dilutions and the capacity of the thickener during each test.

Conclusions.

The figures show that there is some evidence in Coe and Clevenger's theory, for in the four tests which were run, and upon which dilutions of feed samples were also tested for settling rates, three of these show agreement between theory and practice. The fourth test(Test 4) showed a discrepancy of about 25% between theory and practice. I am unable to account for it, for I do not think that the high dilution of the feed was a significant feature.

Unfortunately, time did not permit any tests to be run with high discharges. The high discharges found in the early tests were the result of a local trouble, the thickener being filled with slime from a hose. The sand therefore was found covering the bottom of the thickener, whereas the sand is discharged, in actual practice, as soon as it is fed to the thickener and is allowed time to settle. In Prof. Bell's own words, the sand falls out immediately in a steady downpour from the feedwell, and does not become wafted out, as is the case with slime.

Some tests upon natural slime, and crushing.

The following tests were carried out in order to find the variation, if any, in natural slime, when ground to various lengths of time.

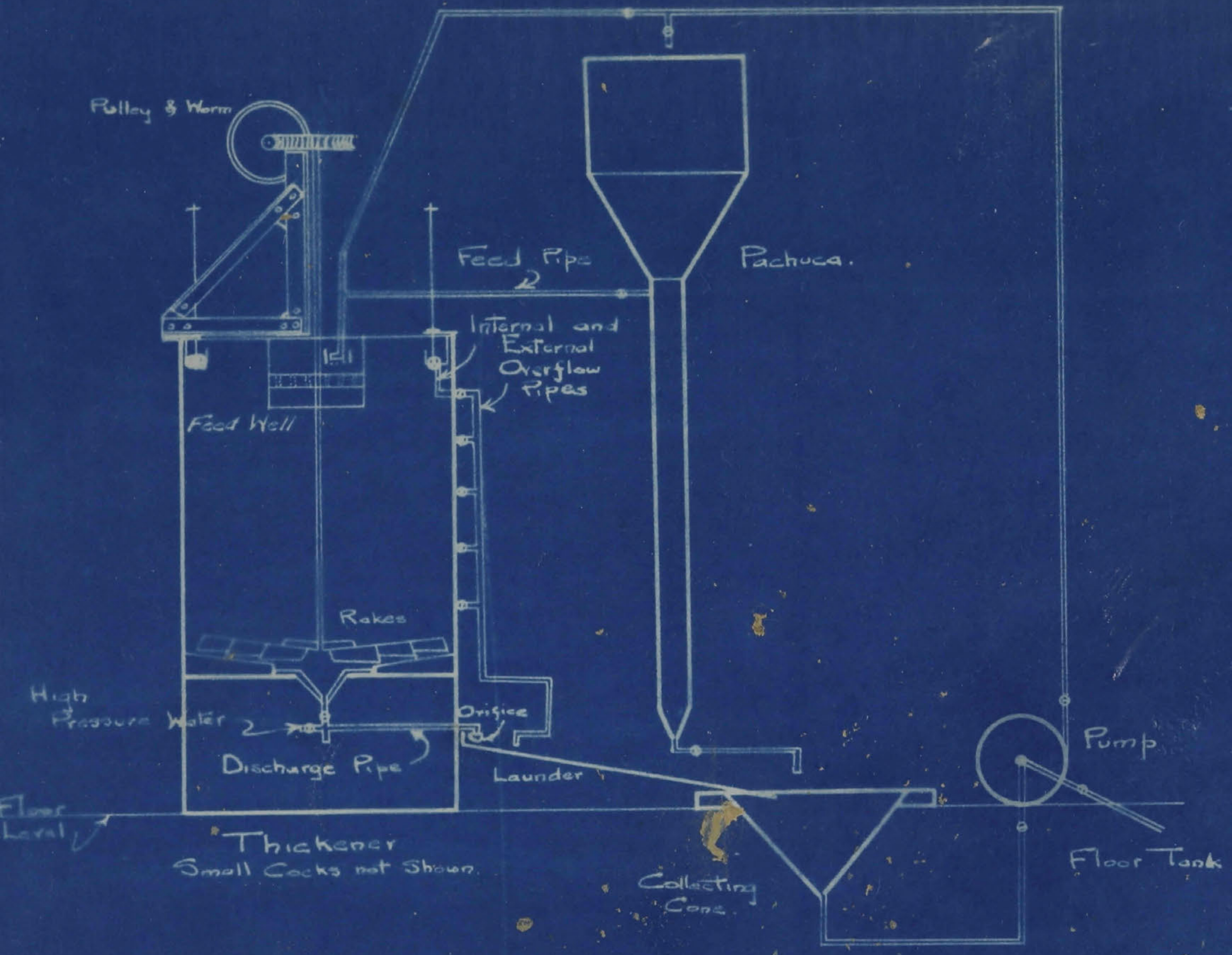
The following results were obtained by Messrs. Legg and Snijman upon tinguaite. Natural slime was determined from the -200 mesh size, and the percentage in total solids was then calculated.

Time of grinding	% -200	% std. slime
3 mins.	4.6	1.4
6	5.9	2.7
8	12.9	3.0
9	14.4	4.0
12	19.7	5.0
15	18.0	4.5
18	29.2	7.8
20	32.2	9.1
21	34.3	9.4
24	39.0	10.3
30	47.2	13.7
37	53.5	18.1
40	58.5	20.6
49	67.9	27.8
50	68.2	24.7
62	70.5	29.3

The following results were obtained by Mr, Snijman and myself, upon Rand ore. The same procedure as above was carried out.

Time of grinding	% -200	% std. slime
0 mins	17.3	0.95
5	26.6	1.7
12	38.5	3.7
21	51.1	5.4
30	63.8	6.7
40	77.6	10.1
50	85.3	11.1
60	90.6	13.6

The figures indicate that the amount of slime varies with the amount of crushing, but whether this is due to greater liberation of slime or the conversion of sand to slime is problematical.



Not Strictly to Scale

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