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OPEN IMPELLER AGITATION SYSTEMS

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Open Impeller Agitation Systems

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Fluid mixing operations occur in all phases of the preparation, storage, and application of pigmented paper coatings. An understanding of mixing characteristics and the nature of mixing requirements is therefore helpful in the selection of proper equipment for each stage of coatings makeup. The process requirements are varied, but consist primarily of the blending of low- and high-viscosity fluids and the suspension and dispersion of solids. The type of fluid mixing needed ranges from simple fluid flow to high-energy, intensive mixing with high shear and turbulence.

MIXER CHARACTERISTICS

In fluid mixing we are concerned with the mechanics of fluid streams and with the means used to generate them. Mixing and dispersion are accomplished by material transfer brought about by momentum transfer and turbulence. Flow must extend to all parts of the mixing vessel, and the level of turbulence (shear) must be high enough to match the maximum requirement of the process.

Power Input

The power input of the fluid stream is proportional to the flow and the head.

$$P \propto Qh\rho$$

where

P = power input, ft-lb/min

Q = flow, cu ft/min

h = head, ft (including static, pressure, velocity, and turbulent heads)

ρ = fluid density, lb/cu ft

Since either the flow component or the head component of the input can be emphasized, the same amount of power can be applied to produce large flow–small head or small flow–large head. For a given power input, operations that require high flow will use a large impeller (at low speed), and those that require high head will use small impellers (at high speed). The flow capacity of the impeller controls the circulation rate in the tank. The fluid head, which is proportional to turbulence or shear, defines the intensity of agitation in the immediate vicinity of the impeller. Figure 21.1 shows the tank and mixer diagrammatically.

Utilization of the full mixing capacity of an open impeller agitation system depends on accurate, effective loading of the drive motor.

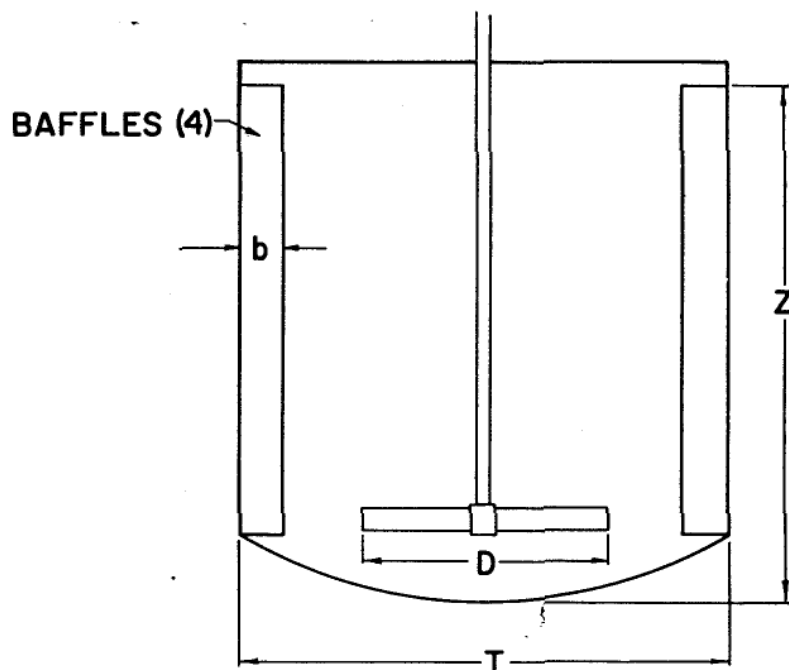


Fig. 21.1. Tank configuration: $b = T/12$; $Z/T = 1.0$

The power input of a rotating impeller is a function of its shape, diameter, D , speed, N , and location in the tank, and of the physical properties of the liquid. The most significant fluid properties are the density, ρ , and viscosity, μ (cp). A typical power curve relating the Reynolds number (for mixing), $Re = D^2 N \rho / \mu$, and the power number, $N_p = Pg / \rho N^3 D^5$, is shown in Fig. 21.2.

The shape of this curve is similar to the characteristic friction factor curve for hydraulic flow in pipes. The section AB is the viscous range of impeller operation, BC is the transition range, and sections CD and

BE define the turbulent range for baffled and unbaffled operation, respectively.

The turbulent operating range (*CD*) describes the *mixer input* to the system for most operations in low-viscosity fluids, such as cold starch slurries, pigment dispersion and storage, and low-solids coatings tanks for cooling, storage, and supply. Unbaffled operation (*BE*) with low

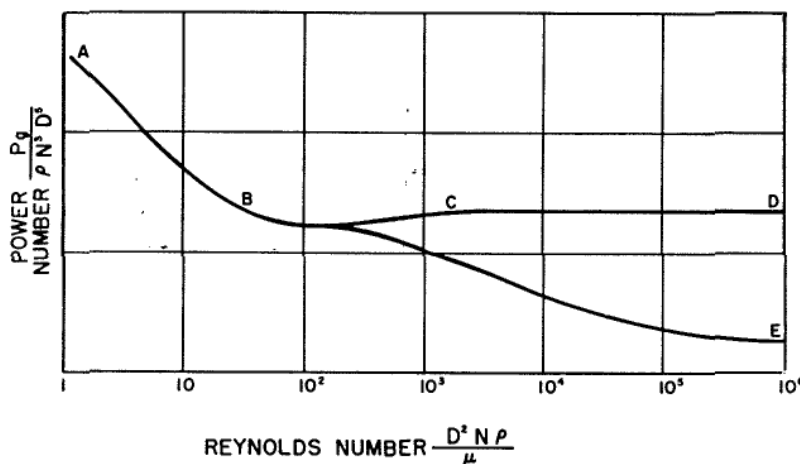


Fig. 21.2 Typical power curve

viscosity fluids is usually not desirable, since it results in a swirling flow pattern lacking vertical blending currents, and because the vortex formation may lead to the incorporation of objectionable air bubbles in the coating.

The viscous range (*AB*) applies for the higher viscosity conditions in high-solids coatings blending, cooling, and storage.

The power relationship in the flat portion of the turbulent curve (*CD*) for geometrically similar impellers is as follows:

$$P \propto N^3 D^5 \rho.$$

where

P = horsepower

N = impeller speed, rpm

D = impeller diameter, ft

Under these conditions, the power input to the system will be proportional to the density of the fluid, to the cube of the operating speed, and to the fifth power of the impeller diameter. With baffled, turbulent conditions, this relationship applies for *all* impeller designs.

Correlation of the effect of different designs may be made by direct comparison of their power input at equal speeds and diameters.

In unbaffled tanks, the startup load follows the above relationship, but the load drops off as rotary action develops, indicating a lessening of the turbulence in the fluid and a decrease in the mixing action.

Pumping capacity, Q , for a family of geometrically proportional impellers is directly proportional to the operating speed and to the cube of the diameter.

$$Q \propto ND^3$$

Applying the relationships of power, flow, and head, the fluid head relationship to speed and diameter may be calculated.

$$h \propto N^2D^2$$

This indicates the significance of impeller tip speed ($\propto ND$) in operations requiring high-fluid shear. When considering a particular impeller design, where the proportions are held constant with variations in diameter, tip speed may be increased by increasing either the speed or diameter. Both of these methods increase the power input to the system as well ($P \propto N^3D^5$). Thus, to compare the relative effectiveness of producing shear, whether with a similar impeller or with one of another design, the process result (e.g., fineness of dispersion) must be evaluated on the basis of the power input as well as the tip speed. With impellers of different proportions, the same process result may be obtained at quite different tip speeds, and the design requiring the lowest power input to produce the process result will usually be the best selection.

These relationships are significant not only in the design and selection of new mixing equipment, but also in the operation or modification of existing equipment. Adjustment of the power input of a mixer to make full use of its capacity for changed operating conditions may require either speed or diameter change of the impeller, or both.

In viscous solutions (range AB , Fig. 21.2), as indicated by the shape of the power curve, the power relationship is different.

$$P \propto N^2D^3$$

In this viscous condition,

$$Q \propto ND^2$$

and

$$h \propto ND$$

Use of Baffles

In viscous systems (viscosities greater than 5000 cp) vertical flow currents and overall blending flow pattern can usually be obtained without baffles. The viscous drag of the fluid on the tank wall acts as a "dynamic baffle." In very viscous systems, the presence of baffles or other internal tank fittings such as heating or cooling coils will actually be a deterrent to good flow and should be avoided for optimum vessel design.

Rectangular tanks have "built-in baffles." The corners of the tank act to break up swirling action and produce the desirable vertical blending currents. Only for high-intensity mixing are additional baffles needed. By the same token, viscous operations should not be carried out in rectangular tanks because of this baffling action.

High intensity mixing in low viscosity systems, as in clay make-down, requires the presence of baffles to develop the localized turbulence that develops high shear stresses.

MIXER IMPELLERS

Motion and mixing energy are transmitted to the fluid by means of rotating impellers. Myriad designs of impellers have been used, but in terms of their function and the type of flow produced, the principles of impeller design have been clarified. The function of the impeller is to produce flow having characteristics consistent with the demands of a particular process or operation. Three factors are important in the design or selection of an impeller.

1. Size (diameter) relative to tank.
2. Speed, rpm.
3. Proportions (diameter and number, width, or angle of blades).

The three factors are interrelated and all are necessary to define the mixer input to a system. With full specification of all three factors, and the fluid properties of the liquid in which the impeller will operate, the quantity and nature of the flow produced will be defined and the power required to operate the impeller under those conditions may be determined.

Figure 21.3, the spectrum of impeller designs, shows the range of impeller sizes with respect to tank size, as well as impeller proportions. In general, the smaller the impeller, the higher the speed. In industrial practice, the disks operate in the speed range 1100–3600 rpm;

the bladed impellers, with a wide range of blade size and proportion, may be used from the relatively low speed of 50 rpm to the high speed of 2000 rpm or greater. The axial flow impellers, either the marine type or the pitched flat blade type, will operate over a wide range of speeds, with small sizes operating at 1750 rpm and large propellers

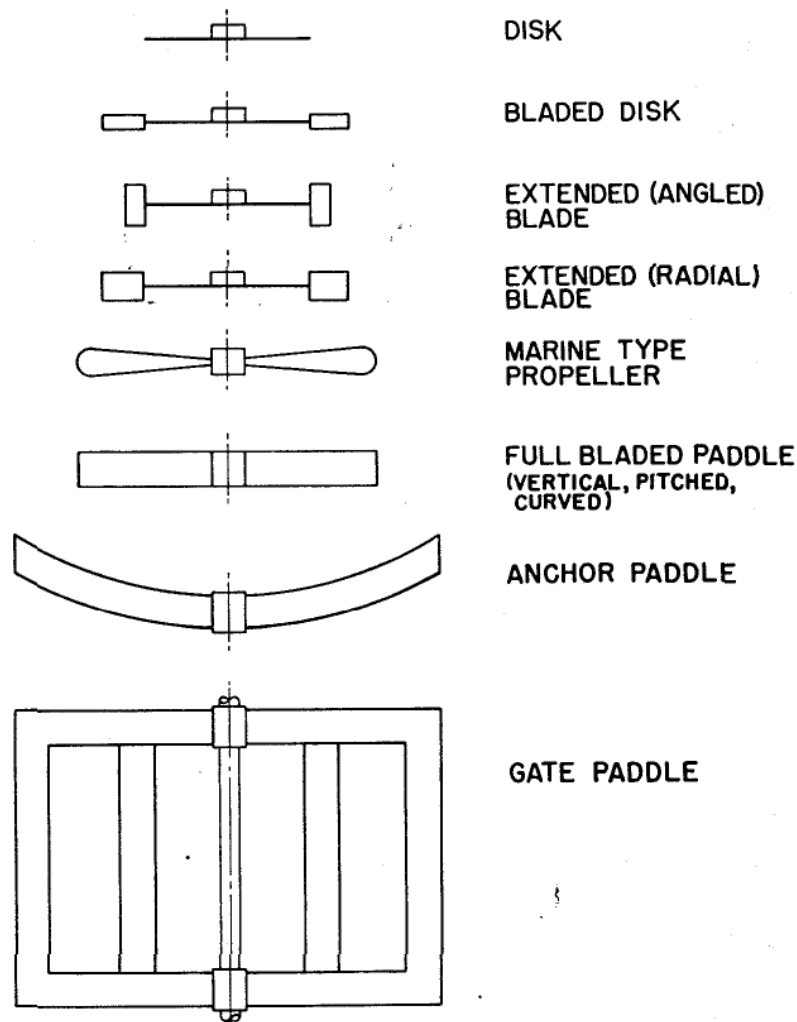


Fig. 21.3. Mixer impeller spectrum

or fans at 50–100 rpm. Generally, paddles, anchors, and gates are used in the speed range below 50 rpm. These ranges of operation are intended to categorize the impellers rather than specify limits of operation.

In general, the very large impellers, which essentially span the entire tank, are used in viscous, hard-to-move materials where direct pushing action is required in order to assure that all fluid in the vessel

is subjected to positive blending action. Small and thin-bladed impellers are used in low-viscosity materials and to develop a higher degree of shear intensity in the system. The small, thin impellers will operate at high speed to develop the input for both shear and overall circulation.

Comparison of impellers for a particular operation is made on the basis of power input requirement. Thus, a viscous blending operation is best accomplished using a large, slow-moving impeller. Such an operation could be accomplished by a small, high-speed impeller, but would require greater power input. The small impeller at high speed produces flow with high turbulence, which would not be required for the viscous blending operation and would thus be wasted. Conversely, it would not be reasonable to demand of a large impeller, which is primarily designed to produce flow, that it operate at the very high speed necessary to produce a shear level comparable to that developed by a small impeller for a dispersion operation. Again the power input would be exorbitant.

Flow and shear are both required in all operations, but a balance of the two is necessary for good design. Thus, a large impeller produces the mass flow required for circulation and the low level of turbulence needed for blending. A dispersion unit produces the high-intensity input necessary for dispersion, but must also provide sufficient flow to recirculate all the material in the vessel through the zone of high intensity near the impeller.

FLOW PATTERN

Production of flow is the first demand made on the impeller. The flow pattern in the vessel is a function of the impeller used and of the vessel design itself. The rotating impeller will produce radial flow by centrifugal action. Inclining the impeller blades from the vertical will produce axial components, which may be used to draw flow from the surface of the liquid or to direct flow against the bottom of the tank to suspend solids or to increase the rate of heat transfer in a heating coil.

Rotary action in a mixing vessel is generally to be avoided, since, once established, such a flow pattern is essentially static and does not include appreciable radial or vertical components of flow. Vertical wall baffles in the tank will turn the purely radial components into vertical flow streams for blending and will produce the discontinuities in flow that will make for the highest shear in the system. A com-

monly accepted standard for baffle width is one twelfth the tank diameter for low-viscosity systems. The baffles may be set out from the wall a maximum distance equivalent to half their width, to facilitate cleaning. Baffles should extend for the entire straight side of the vessel up to the maximum operating level. For viscous systems, the size of baffles may be reduced, since the viscous drag of the fluid on the tank wall helps produce the vertical components necessary

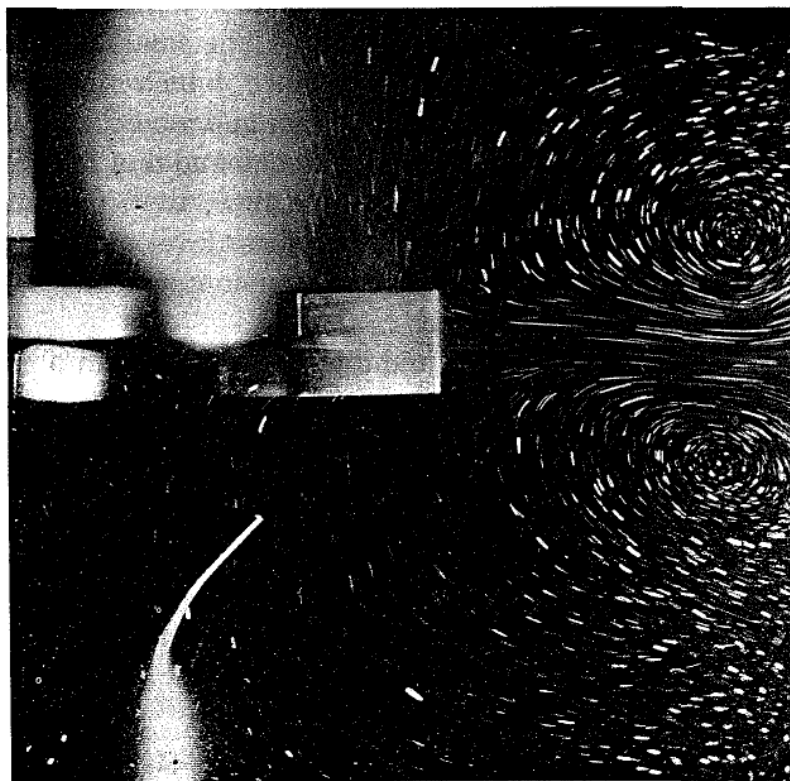


Fig. 21.4. Radial flow in baffled tank
(Cross-section photo taken by the plane-of-light technique in which only a thin slice of the fluid is lighted and the flow pattern is traced by reflecting particles in the lighted zone.)

for blending. For very viscous systems (above 5000 cp), and in rectangular tanks, baffles are not required.

Heating or cooling coils in the tank, along with the necessary coil supports, also act as baffles, and should be taken into account in overall design. Coil spacing should allow flow between adjacent coils, and space equivalent to the coil diameter should be allowed between adjacent turns. Figure 21.4 shows the radial flow pattern developed in a baffled tank. This typical flow pattern applies for any

radial impeller. The direct flow stream from the impeller is at high speed in relation to the surrounding fluid, and shear stresses are developed between the fast-moving fluid stream and the quieter surrounding fluid. It is in this zone that turbulence is developed and blending action or dispersion takes place.

By applying the same power with a thinner blade or a smaller diameter impeller, a higher differential of fluid velocities is developed, and operations having a higher shear requirement are accomplished. Wider blades, or blades of larger diameter, increase the volume of flow and thus improve overall circulation.

TANK DESIGN

The optimum tank design, in terms of the agitation or mixing operation required, will have an operating level approximately equal to the vessel diameter. This allows optimum distribution of power and mixer input throughout the system. However, variable operating levels will frequently dictate other than this so-called "square" batch. Minimum normal operating level should be approximately one third the tank diameter, and additional volume built on top of that. If this results in a tall system, then multiple impellers will be required to provide good mixing throughout the system. Cone- or dish-bottom tanks will increase the depth of the "minimum heel" for a given volume and thus allow for operation at lower levels. In finished coatings, it is particularly desirable to provide for the low-level agitation in view of the twin dangers of separation of the coating through inadequate agitation, or incorporation of air bubbles through excessive agitation.

MIXING OPERATIONS

The fluid agitation requirements of pigmented coatings preparation may be defined closely. Accurate definition and specification of the process result to be obtained in an operation will do much to assure proper selection and design of the mixing equipment.

Solids Dispersion

Solids dispersion involves the wetting of solids to form a suspension in liquid, including reducing the size of agglomerated particles of the solid. Rapid wetting of the solids is essential, requiring vigorous

flow across the surface in order to provide fine initial dispersion and prevent the "balling" or surface wetting of particles, which produces a wetted surface film, with dry material inside the particle. High-intensity or high-shear mixing may be required to reduce further the size of the discrete particles, as in the instance of a spray-dried clay pigment which will be made up of small spheres approximately $150\ \mu$ in diameter. Dispersion to particles of the ultimate $2\text{--}5\ \mu$ diameter will require intensive fluid shear, combined with the necessary flow capacity to recirculate the slurry across the surface and through the intensive mixing zone. Specifications should call for addition and wetting of solids within a specified time, and dispersion to desired particle size within a specified time.

Solids Suspension

Solids must be kept in suspension to prevent settling and provide uniform feed from storage. Fluid flow in the system is the primary requirement, with velocities to be maintained in excess of the settling rate of the solids. With slow settling, nonpacking solids, intermittent mixer operation may be adequate for long-term storage, using a timer to operate the mixer 10 min every hour, for instance. Specifications should call for maintaining uniformity of solids content or to provide uniformity within a specified time for resuspension.

Blending

In combining solutions or suspensions to form a continuous uniform material, the viscosity of the incoming streams and the final viscosity of the mixer will determine the severity of the mixing to be applied. Flow throughout the system is the primary requirement, and this will call for the use of propellers or radial turbine impellers in low-viscosity systems (under 500 cp). With increase in viscosity, the impeller size will be increased for economical and effective selection. Similarly, blending time will increase with viscosity. Low-viscosity systems may be specified for uniformity in 5–10 min, but longer times should be allowed as the viscosity becomes higher. There are two reasons for this: (1) at viscosities in the range 5000–10,000 cp, or higher, blend times shorter than 30–45 min will require extra power input; (2) at these conditions, there is danger of incorporating air bubbles which can be separated from the finished coating only with difficulty.

Heat Transfer

Fluid is circulated over coil or jacket surfaces to increase the heat transfer rate, to keep the heating surface free of fouling, and to avoid localized overheating. It also disperses direct-added steam and maintains uniform temperature throughout the vessel.

Specifications are "to provide mixing and required heat transfer surface for heating or cooling over a specified range in specified time." Viscosity of the fluid coating and its thermal properties are also necessary for complete design. For direct steam addition, maximum steam rates should be specified.

Fluid Motion

Maintaining motion throughout a system is necessary to prevent surface evaporation and crusting during storage. Specification should include statement of an objective, and temperature, viscosity, and flow characteristics.

Summary

Specification of the process results to be obtained in each step of coatings preparation will result in economical equipment design and selection. Comparison of relative requirements for varying solids content of the coating, type and content of pigment and adhesive, and plans for future modification will permit design of the added capacity or flexibility in the system where the design is critical, and thus broaden the application of the entire coating system.

CONTINUOUS PROCESSING

High production requirements call for a continuous supply of uniform coating. Translation of batch systems to continuous operation can lead to improved control and savings in direct labor. Design data may be based on existing batch operations, with close attention given to batch operating times. Major savings may be accomplished through the elimination of between-cycle cleanings, and filling and emptying times for batch tanks.

The primary concern in continuous systems is that the coating materials be held in the system long enough to complete the operation—whether conversion, as in starch cooking, or particle size reduction, as in a clay dispersing operation. Staged operations for retention

time control are frequently necessary. Particular note should be taken, in considering continuous systems, of the consequences of a portion of the coating material staying in the system too long. Where overtreating is a danger, close control of the staging will be necessary to control it, and, in extreme cases, such operations should not be done continuously. Choice between batch and continuous operations for such situations requires intensive consideration of all factors.

PREPARATION PROCESS OPERATIONS

Process operations may be divided into the following categories: pigment dispersion, pigment slurry storage, adhesive cooking, combined pigment-adhesive cooking, coating blending, and coating storage. These operations, and their variations, are discussed in the following pages. The process considerations and operating variables are typical, and may be used as a guide to capacity and equipment requirements. The installation examples given are specific for the operating variables described. Variations in capacity, schedule, or formulation of coatings; in the source and previous treatment of the pigment; in the dispersing agent used; or in the solids content of the slurry affect the specific equipment design for any system. Particularly, changes that affect the flow characteristics or viscosity of the fluid will require close attention from a mixing standpoint.

Figure 21.5 is an overall flow sheet of a generalized clay-starch coating system. Batch adhesive cooking and continuous starch-clay cooking systems are shown. Batch operations are advantageous in specialty systems where frequent changes of recipe are made. Continuous systems have advantages on long runs and in preparing high-solids coatings.

Pigment Dispersion

Pigment slurry makedown techniques are essentially the same for all pigments. Pigment dispersion is a two-part operation. Rapid incorporation and wetting of the dry solids into the liquid requires good surface motion at all levels, particularly in the latter stages when solids content is approaching the maximum and the effective fluid viscosity is also reaching a peak. Secondly, after the wetting, the pigment may require intensive, "high-shear" mixing to reduce the pigment agglomerates to individual particles.

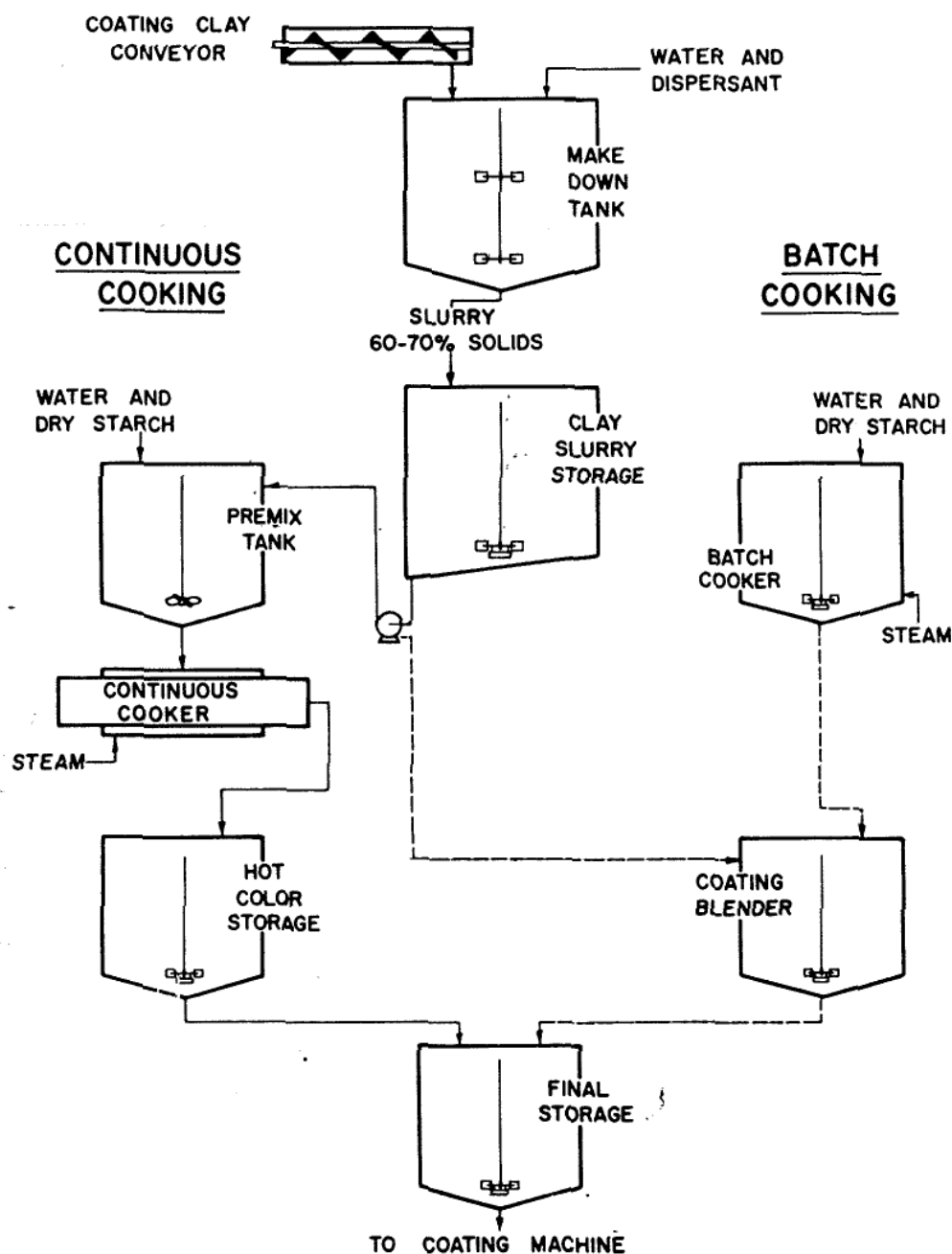


Fig. 21.5. Typical clay-starch system flow sheet

The solids content of the slurry will affect the mixer selection and also the fineness of dispersion that can be attained. Generally, best dispersing action is obtained with high solids content, as shown by Millman and Whitley (1) for kaolin clay, calcium carbonate, and titanium dioxide. The concentration for effective dispersion of kaolin clay is 68-72% solids, and for calcium carbonate or titanium dioxide

the most effective concentration is 75% for fluid mixers. At these concentrations, the volume percentage of solids is high enough that more effective shear stresses can be developed in the turbulent fluid.

The proper chemical dispersants will assist the dispersion and will control the viscosity at the final concentration. The dispersants used should be selected carefully for each pigment to obtain optimum effect with minimum additives. When the dry pigment already contains dispersants, as with most spray-dried clays, only minor addition may be necessary to adjust for local water conditions or later dispersant absorption by other components of the coating. Reliable and specific recommendations can normally be had from the pigment supplier.

The initial wetting of the pigment in water is primarily dependent on flow. Vigorous action, especially at the liquid surface, is essential, and is particularly important during the addition of the final increment of solids. For instance, with kaolin clay, the slurry density at 60% solids approximately equals the bulk density of the dry clay, and strong surface flow currents must be provided to prevent floating, partial wetting, and balling. Unless vigorous surface action is provided through the critical addition range from 60% to 70-72% solids, agglomerates will form, and substantial extra mixing time and overall power input may be required to break them up. Recirculated slurry, combined with the mixer action, may also be used to "wet down" the incoming clay and carry it below the surface.

A typical wetting operation will be designed to make down a full carload of clay (50-90 tons) to a uniform slurry, either for immediate use or for transfer to storage. A 50-ton carload will require 10,000 gal for 70% slurry, but sufficient tank and mixer capacity should be provided to handle larger cars at a later date, when production requirements and clay deliveries may be greater. Moderate power input with a high-flow system will accomplish this wetting or slurring operation. Radial or axial flow turbines are operated to provide vigorous flow at all levels. Filler clays and material for some coating grades may require no further treatment, or the slurry may be transferred to storage for more treatment later.

For fine dispersion, more intensive mixing is required.

The process of dispersion has been described by Robinson (2) as "the disruption of clusters of pigment particles . . . by mechanically applied forces." Physical disruption of the clusters to produce a dispersion of the individual particles is the ultimate objective (see also Chapter 15). The degree of dispersion required should be detailed in

any complete specification for pigment slurry makedown operations. A common limit, readily checked in the control laboratory, is to specify a maximum weight percentage retained on 325 mesh screen (usually 0.03–0.05%). Relative sediment volume (RSV) is another measure of the degree of dispersion, since a pigment dispersed to individual particles will occupy a smaller settled volume than the same weight of agglomerated or clustered particles.

The intensive mixing for dispersion is provided by applying more power (than needed for wetting) to the fluid system, and concentrating that input by using shear-type impellers at higher speed. This may be done in the large slurry tank, wetting and dispersing with the same unit (applying some excess power at the high-shear rate to ensure vigorous overall flow), or by using a high-shear unit in a recirculation loop. The latter method results in lower installed horsepower, although the recirculation period will be longer than for dispersion in the one-tank system and total power input for wetting and dispersion (hp-hr) will be approximately the same.

The high-shear dispersion unit to be used with the aforementioned 50-ton "wetting" system would require approximately 250–300 gpm recirculation and could make use of the transfer pump used on the tank. Recirculation for several hours after all the solids are wetted will be required to assure that all solids have sufficient retention time in the high-shear unit to meet specification. Allowing 6 hr for car unloading, total mixing time would be 10–12 hr, and total power input would thus include the makedown tank mixer, the high-shear unit, and the recirculation pump.

A 50-ton, one-tank dispersion installation is described by Richardson (3). The makedown tank is filled with the proper amount of water to make up a full 50-ton car to a 71% slurry. With the mixer operating, and after adding a chemical dispersant, the pneumatic car unloader is started and clay is charged to the tank. Normal conveying capacity is 12½ tons/hr, providing a 4-hr charging period. Unloading has been accomplished in as short a time as 2¾ hr. Normal operating time, including time for attaching the adapter and vibrator to the freight car, is between 5 and 6 hr. In initial operation, the importance of surface motion was demonstrated when with a particular batch volume the turbine was too far from the final liquid surface. Even though full power input was used, some floating and lumping of clay on the surface occurred. With the impeller properly positioned for the slurry volume, full unloading rate was maintained right up to the last clay from the car without surface problems.

A series of tests on completed batches showed that dispersion, to the specification of maximum 0.03% by weight retention on 325 mesh screen, was complete in 2 hr after all the clay was in. Thus, a full carload of clay was unloaded, dispersed, and in usable condition in one shift.

Calcium carbonate and titanium dioxide dispersions require greater mixer input, in terms of both horsepower input and shear intensity, than clays. Three to ten times the power input needed for clay may be required, depending on the size of the installation, the dispersion specification, chemical dispersant, and pigment concentration. Carbonate dispersion, for instance, is much more effective at 75% than at 70% solids, but the finished slurry should be diluted back to 70% for storage stability.

Continuous Operations. Continuous operations for pigment make-down require establishing the system with the full solids content, 70 or 75%, making continuous addition of water and solids in the proper proportion, and providing sufficient retention time to effect the reduction in particle size to specification. Special attention must be paid to the wetting chamber of the system, since all the solids are incorporated at the maximum percentage, whereas in a batch system the bulk of the solids is incorporated at low concentration when the system is more fluid and wetting is easier. Design for staging and prevention of short circuiting, which would permit undispersed particles to slip through, will require somewhat longer retention time for dispersion than in a batch system. Total installed horsepower can usually be reduced, however, since the clay is "being dispersed" all the time it is in the system and the volume of slurry being processed at one time is reduced.

Pigment Slurry Storage

Slurry storage of pigments has become far more common and its advantages more evident with increased carload shipment of both dry bulk and slurry pigment. Ease of handling, with pumps, and the elimination of dusting, caking, and multiple handling of dry clay provide significant economic advantages. Further, the storage volume of 60-70% clay slurries is actually less than that needed for dry clay (see Fig. 21.6).

The fluid mixer requirement for slurry storage is for slow motion, in view of the small particle size and low settling rates of the pigment, with a positive flow pattern that sweeps the full tank. Slurry vis-

cosity and density are the main mixing variables and are dependent on the particular pigment, percentage of solids, and dispersing agent used.

Size and shape of slurry storage tanks will depend on several factors. The usage rate will determine the tonnage to be kept on hand in slurry form. With clay, the entire inventory will be maintained in slurry storage, normally two to three weeks' supply, depending on

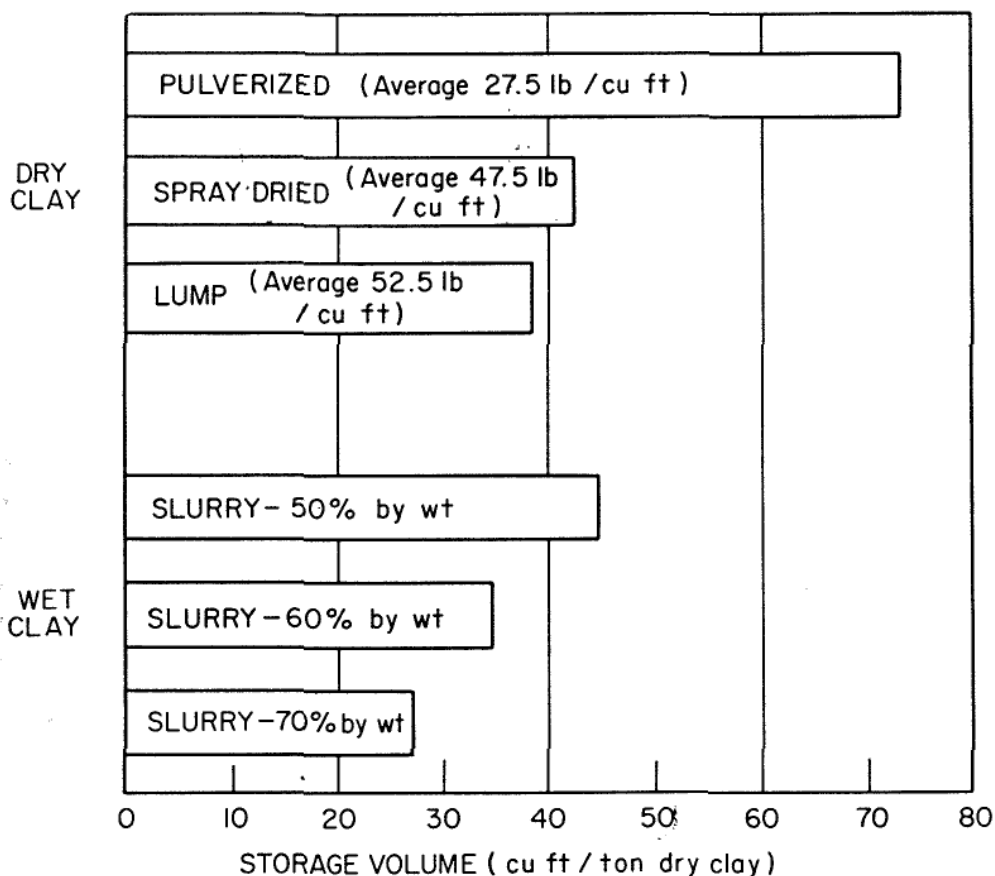


Fig. 21.6. Clay storage volume

the proximity of the supply source. For pigments of smaller usage, dry storage may be maintained for either bulk or bagged inventory, with approximately one week's supply in wet storage.

Tank shape design is exceedingly flexible when using fluid agitation to maintain suspension of the clay. Tall tanks are more advantageous, since they require less floor space and also, by reducing surface area, reduce the surface evaporation rate. Other reasons for avoiding shallow, horizontal tanks is the necessity for multiple agitators and the poor batch shape at low levels.

Small antiscirl baffles in cylindrical tanks will eliminate vortexing and reduce air incorporation at low levels. Baffles are not required in rectangular tanks.

The tank shape may also be influenced by the agitator design. Extremely long shafts will require support bearings at the tank bottom. In the abrasive pigment slurry, periodic maintenance of such a bearing will always be a factor and, where possible, agitator shaft design should provide for an overhung shaft without the bottom bearing.

A tank 14-ft 6-in. square by 15-ft 6-in. high will provide storage capacity for 110 tons of clay at 70% concentration. Mild agitation to provide surface motion at all levels and to prevent settling in the tank corners, even at very low levels, is the job requirement. An economical agitator selection for this system would be to use a single turbine impeller at moderate speed, located near the bottom of the tank. For power economy, a multispeed motor could be used to operate at lower speed, and consequently lower power input, for levels below a half tankful.

Power economy may be realized as well by increasing the impeller size. In the tank mentioned above, a 14-ft 6-in. square, multiple large paddles at low speed (10–15 rpm) would provide circulation at approximately half the power. However, at this lower speed, larger reduction gear would be required and, with the large impellers, a bottom steady bearing would be required. These factors would increase both the first cost and maintenance required, which must be balanced against the power saving. Considering first cost and operating costs, the most economical selection for the individual mill can be arrived at.

Side-entering propeller mixers can be used, as well, to provide the required circulation for slurry storage. Savings in equipment cost can be realized, since the propeller operates at higher speed and, for a given power input, requires a smaller speed reduction (lower torque). Constant flow of a small amount of flushing liquid through the stuffing box must be maintained, however, in order to prevent too rapid wear of the shaft and packing by the abrasive pigment slurry. Proper stuffing box design for this condition will make the equipment cost savings worthwhile.

Wet storage of pigment not only affords convenient storage and easy handling of the fluid slurry, but also assists in the accurate control and proportioning of clay into the finished coating. When uniform concentration of the clay has been established in the storage

tank, volumetric metering provides a more accurate measurement of pigment weight than is usually possible in solids handling equipment.

Adhesive Cooking

Adhesive preparation consists of two separate operations (as does pigment slurring) which have different mixing requirements. The first requirement is for wetting the dry adhesive. Both starch and casein are wetted readily by vigorous blending action to produce a uniform wetted slurry, thoroughly dispersed and free from lumps. Consequently, propeller mixers of the portable type are commonly used on small tanks and low-power turbine or side-entering propeller mixers are used on large systems.

The second step in adhesive preparation is the heating of the starch or protein suspension to cause its conversion. The system goes through a peak viscosity, which will vary with the concentration, the pretreatment the adhesive has received, and the chemical conditions of cooking. Following the peak, the solution thins out to a range of 200–500 cp.

Starch Cooking. Batch starch cookers are frequently called on to handle a variety of formulations with different fluid properties. This makes it necessary to design the mixer for the maximum density and viscosity and allow it to operate underloaded for lighter cooks. Peak viscosity may be as low as 1500 or as high as 50,000 cp. However, overall fluid motion is only necessary in the initial stages, for distribution of the solids in the liquid and to maintain temperature uniformity up to the peak viscosity range. The mixer will maintain fluidity in a small zone around the impeller and then, as the material thins out, extend the zone and reliquefy the entire tank. Temperature regulation in the vicinity of the impeller controls the addition of direct steam to the system.

A typical operation in the enzyme conversion of starch calls for mixing the dry starch into the proper amount of water, adding steam directly to raise the temperature to 160–170°F, and holding this temperature for 20–30 min to complete conversion. After the conversion, the temperature is raised further to 200°F to kill off the enzyme, followed by cooling before mixing with the pigment.

In continuous starch systems, the mixing requirement is just for the wetting operation, to produce a uniform slurry. The slurry is pumped through a mixing nozzle, into which metered steam is injected to give the desired cooking temperature. The high-viscosity solution is

forced on through the pipeline and agitated slowly in receiver tanks to complete the conversion. Viscosity in the receiver tanks approaches the finish viscosity.

The steam jet continuous cooker provides an accurate control of the cooking temperature, and the turbulent action within the jet ensures uniform cooking. The effect of rapid temperature rise and the very turbulent conditions within the jet cooker lead to rapid swelling and bursting of the starch granules. The temperature, shear, and pressure conditions speed the cooking so that low viscosity conditions are reached by the time the adhesive is discharged into the storage tank. Detailed studies of continuous jet cooking systems are provided by Lauterbach (4), Black and Winfrey (5), and Meador and Cushing (6).

Handling the cooked starch requires blending action only. Viscosities in the neighborhood of 200–1000 cp are encountered, with the latter only at maximum starch solids content for high-solids coatings. Where jacketed tanks are used for cooling, vigorous fluid motion will prevent caking or buildup on the wall. Moderate-speed turbine or paddle impellers are used. Where the adhesive solution is to be diluted, mixing action should still be gentle, but ample time should be provided for uniformity.

Casein Cooking. Casein cooking involves the same mixing considerations as batch starch cooking. The heating requirement is lower, the temperature being raised only to the range of 125°F. Primary mixing variable is the maximum viscosity attained, which is dependent on the chemical conditions and the concentration of the casein. For a particular system this can be accurately specified for reliable selection of a turbine or paddle agitator, or a maximum may be specified for a range of operating conditions. For high-viscosity systems, 10,000 cp or above, it is usually most practical to maintain uniformity of temperature and chemical conditions up to the point of thickening, allow the mass to “soak” at that temperature, and then thin out with the action of the agitator at the end of the cycle.

Coating Blending

Coating (pigment–adhesive) blending involves the incorporation of two moderately viscous materials to uniformity. With proper prior treatment, no dispersion as such is required at this stage of operation. Thorough blending to provide uniform distribution of the adhesive and a thorough coating of the pigment particles with the adhesive solution is the objective.

The viscosity of the blended coating will determine the mixing requirement. Initial viscosity of the unblended components will be lower, increasing to the final figure as the adhesive solution coats the pigment particles. Accurate impeller selection must be made so that overloads will not occur in any normal situations. Thus, a 3000-gal batch of finished coating color having a solids content of 35% and a viscosity of 500 cp would be blended with a turbine mixer, and baffles in the tank would be essential to combine all flow streams rapidly and to avoid swirling or vortexing that would otherwise cause air bubbles. The mixer should have the capacity to handle variations up to 1000 cp without overload, with extended blend time.

In a 60% solids coating, using 70% pigment slurry and starch adhesive at 35% solids from either a batch or continuous cooking system, the resultant viscosity of 2000–3000 cp would increase the mixer power requirement 2–3 times and require a somewhat larger turbine impeller. Baffles would be decreased in the system for the higher viscosity fluid.

Tank shape for blending operations may be varied to suit the available space and headroom within certain limits. Full batch levels should not be less than six tenths the vessel diameter and not greater than the vessel diameter.

Agitator selection and tank design for this blending should take particular note of the dangers of air entrapment, since removal of air from the viscous coating is difficult.

Combined Pigment-Adhesive Cooking

Preparation of coating colors by conversion of the adhesive in the presence of pigment offers advantages in process result from a quality standpoint and becomes a necessity for fluid handling in the preparation of high solids coatings. Hughes (?) discussed the Vanderbilt process of batch operation, pointing out that the uniformity of the combined suspension of pigment and adhesive prior to cooking carried through the cooking operation, with the result that each pigment particle appeared to be coated with a film of adhesive immediately.

Chemical conditions for the operation must be carefully controlled, since the adhesive may consume the chemical dispersant used to prepare the pigment slurry and/or the pigment may act as an absorbent for the converting enzyme, in the case of starch, or the casein itself. These conditions require specific study to determine the fluid conditions that must be handled by the mixer in the operation.

The intimate mixing of the pigment and adhesive prior to conversion is reported to make possible a reduction of adhesive requirement, and of course, adhesive cost.

The peak viscosities in cooking operations with the pigment present are very substantially higher than with the adhesive alone. Particularly with high-solids coatings, the available water to convert the adhesive is also necessary to suspend the pigment. When this water is taken up with the adhesive, the viscosity may reach 100,000 cp or more. Movement of the "fluid" under these conditions requires the pushing and scraping action of the gate type impeller, and, in addition, a shearing or fluidizing action within the bulk of the coating. This, for batch operation, leads to the use of double motion agitator systems, in which a large, slow-moving gate impeller wipes the wall and a high-speed unit operates near the center of the tank to provide for rupture of the starch granules and fluidizing the system after conversion is complete.

The magnitude of this viscosity is critical in the design of the agitation equipment and of the power requirement for it. The low-speed paddle or gate operation requires high torque, and consequently the equipment requirement is for large drives. While it is possible to handle the systems from a fluid mixing standpoint under these conditions, the economic considerations have led to development of continuous jet cooking processes for the high-solids conditions where peak viscosity would be the highest.

Continuous Cookers. Continuous jet cooking systems offer further equipment advantages with all the inherent advantages of the combined cooking process. Blending of the total solids to values in excess of 70% by weight is accomplished at low viscosity and with low, blending power input. The system described by Richardson (1) is for a high-solids coating. Batch mixing of the cold starch slurry is done with propeller mixers in a baffled tank, and the uniform slurry is blended with the proper volume of 70% clay slurry in the mixing tank, also with mild propeller agitation. The low viscosity of the clay-starch suspension at this stage allows the attainment of uniformity with low mixer input.

After thorough blending, the slurry is pumped through the continuous steam jet cooker. The cooking reaction takes place rapidly as the clay-starch slurry meets 125 psi steam in the combining tube of the cooker, and the cooked mixture drops to the hot color storage tank, which is the same size as the cold mixed slurry tank.

The mixer for the hot color tank handles material of approximately

2500 cp at 60–62% solids. A turbine agitator will maintain motion at all levels, once the impeller has been covered. For handling higher solids coatings, up to the range of 65–68%, viscosity control of the coating is the important factor concerning the agitator. With higher viscosities, larger impellers and mixer input are required.

Dilution through the jet cooker due to the live steam injected for cooking is of the order of 6%, using dry steam. Thus, using a cold clay–starch mixture of 73–75% total solids, readily attainable with fluid mixers, high-solids coatings of 68% solids content are quite practical. The viscosity specification following cooking is the important variable for fluid agitator design, but blending action alone is required, since all dispersion has been accomplished previously.

It is good engineering practice in fluid mixing, as well as in other fields, to design for the conditions under which the operations can best be carried out. Specifically, it is advantageous to carry out dispersion at moderate or low viscosities, and pass through the adhesive gel stage quickly in the jet cooker, rather than to carry out the dispersion at high viscosity where greatly increased mixing input would be required.

Coating Storage

The final storage of prepared coatings is a maintenance operation, to keep the coatings in their finished prepared state. Since the coating is usually circulated to the machine or to the head tanks from the storage tanks, with an excess returning to storage, blending action to maintain uniformity of temperature, viscosity, and solids content is essential. The blending requirement is determined by the rate of turnover of the recycled coating under normal operating conditions and by the differences in temperature and/or viscosity between the returned coating and the material in storage. This requirement is then translated into a mixer requirement for the viscosity of the coating. The mixer is designed to handle the highest expected viscosity, or to provide for later increases in viscosity with process change and improvement.

Turbine type impellers to produce flow are desirable, with wall baffles placed to minimize vortexing and swirl (consistent with viscosity). In low-solids, low-viscosity coatings, the baffles should extend the full straight side of the vessel. For viscosities above 5000 cp, the baffles may be limited to the bottom section of the tank only,

because for these viscosities impellers will be larger and operating speeds lower to provide flow and avoid air incorporation at low level.

For example, a 65% casein-clay-latex coating with a specific gravity of 1.6 and maximum viscosity of 50,000 cp required a large anchor operating at 20 rpm for a volume of 1000 gal. The thixotropic nature of the coating required the proximity to the vessel wall and the overall pushing action of the large anchor impeller. While another coating might have the same measured viscosity under flow conditions, the action in the storage tank will be dependent on the effect of the low impeller shear rate on the viscosity, and close study of the particular viscosity characteristics of the coating are in order.

As coatings become more viscous the requirement for mixing input becomes more stringent, and the need for good mixing becomes more critical. As the need for closer examination of fluid properties becomes greater and the need for more information about the process is increased, so the value of good results is increased.

SUMMARY

Fluid mixer design and selection should be focused on the mixing operation to be accomplished in each step of the preparation of pigmented paper coatings.

Where dispersion is to be done, the optimum conditions for solids content and chemical dispersant action should be established, and the mixer input designed to do the job best within the framework of required use capacity, storage capacity, and pigment and adhesive supply. Optimum overall result is the sum total of the individual operations in the process.

Blending operations designed for effective viscosity control throughout the system demand knowledge of the fluid characteristics of the coating at each step. Full and proper consideration of these facts, and the knowledge by the equipment manufacturer of the potential variations in operations, will simplify design and selection and assure a more effective and economical system.

Fluid mixer design and selection must be closely tied to the process result for best operation. Additional capacity in the mixing equipment for further expansion is desirable where practical, but excessive fluid action must be avoided where it would be harmful. Close correlation of the process operations with the equipment design produces the multiple advantages of ample capacity, reliable mechanical equipment, and the right result.

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