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Performance and Design of Paper Stock Mixers

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The process performance of mixers in stock chests was studied to yield quantitative performance definitions. These definitions are complete uniformity, complete motion, partial volume uniformity, motion at the pump suction, and batch blending time. These supplant previous qualitative definitions such as "mild blending," "mixing," and "uniformity," which did not give the rigorous specifications that insure accurate mixer design. The experimental program to develop these definitions was carried out in tanks from 18 in. to 35 ft. in diameter. One of the major sources of data was from a 40-hp. variable speed mixer installed in a 12 ft. diameter stock chest in a paper mill. Various mixer variables were investigated, such as impeller type, impeller to tank diameter ratio, and position. The effect of stock type and stock consistency was established. The application of these definitions to paper mill practice is discussed, including rectangular and vertical cylindrical tanks, with and without midfeathers, and top and side entering mixers.

IN THE industrial application of fluid mixers, one of the most important considerations is the definition of the process performance the mixer is to achieve. Unless quantitative definitions exist, it is impossible to predict what effect the mixer and stock chest components will have in the paper mill system. The lack of such quantitative definitions accounts for the wide variations in mixer designs proposed by various sources.

Definitions of the performance required of the fluid mixer by the terms "mixing," "uniformity," "motion," or "mild blending," does not give the rigorous specifications that insure accurate mixer design. The situation is by no means peculiar to paper stock, since similar kinds of quantitative definitions of process performance must be available for any mixing application before accurate selection and installation of fluid mixers can be achieved.

In order to set up a series of rigorous standards for the performance of paper stock mixers, an extensive series of experiments were conducted which yielded quantitative definitions for this particular application.

Articles by Couture (*1*) and Keon (*2*) have discussed the movement of stock in midfeather type chests. These reports did not give rigorous quantitative definitions of stock chest performance based on extensive experimental measurements.

In order to interpret the results and extend the information to a wide variety of tank shapes, tank sizes, and impeller types, consideration must be given to the fluid dynamics of mixing impellers. Articles by Rushton and Oldshue (*3*) and Oldshue (*4*) are valuable in presenting this theory and practice.

In the second phase of the investigation the effect of various mixer variables such as power, impeller diameter, speed, and ratio of impeller diameter to tank diameter were measured.

This report summarizes results from this extensive research program into the field of paper stock mixing.

The results are presented under four general topics: (1) *summary of process definitions*, (2) *application of* these results to various types of mixers, (3) the effect of mixing variables on process performance, and (4) examples in paper mill operation.

At the end of the report, a detailed description of the apparatus used, measuring technique, and experimental procedure is given.

The types of mixers and stock chest combinations that are common in paper mill practice may be summarized as:

- I. Vertical cylindrical tanks
  - A. Top-entering mixers
  - B. Side-entering mixers, with or without midfeathers
- II. Rectangular tanks
  - A. Side-entering, propeller type with midfeathers
  - B. Side-entering, paddle type
  - C. Top-entering mixer, no midfeathers

SUMMARY OF PROCESS DEFINITIONS

Vertical Cylindrical Tanks

A large share of the data on the quantitative performance of paper stock mixers was taken in vertical cylindrical tanks with top entering mixers. Data from this tank shape will be used to develop the various definitions. The extension to other mixer and tank combinations will be given in a subsequent section. The over-all scope of the project included various tanks from 18 in. in diameter to 35 ft. in diameter.

The majority of the quantitative tests reported here were obtained from an installation of a 40-hp. variable speed mixer in a 12 ft., 4 in. diameter tank with a 9 ft. liquid level, in service in a paper mill. Three different impellers were used on the mixer, a 60-in. four-bladed, square pitch, marine-type propeller (Fig. 1); a 39-in. spiral backswept turbine (Fig. 2); and a 75 in. diameter spiral backswept turbine.

The performance of the mixer was evaluated by analyzing the uniformity of consistency produced throughout the tank. In each run, 21 consistency samples were taken over a 2-hr. period. After the run had

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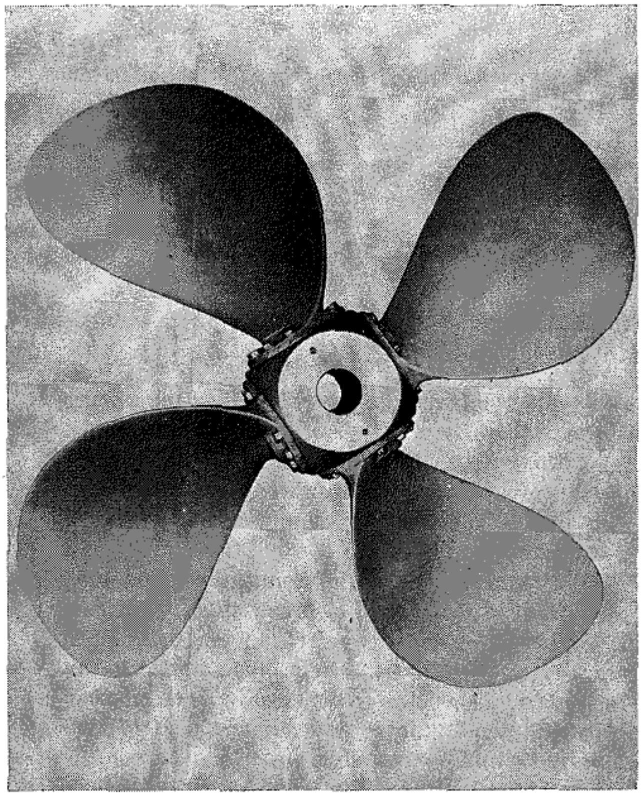


Fig. 1. Photograph of propeller

proceeded for 30 min., 11 samples of stock at various points throughout the tank were taken. Every 15 min. thereafter a sample for consistency from the top and the effluent of the tank was taken.

Various types of stock were used in the experiments—bleached sulphite (high alpha), unbleached kraft, and bleached kraft.

Various amounts of dyes and additives were present. Influent to the tank from the top was between 3 and 3.5%, while influent to the tank at the bottom was between 4.5 and 5%. The effluent withdrawn was nominally 4% (Fig. 3).

Consistency samples were filtered, oven-dried, and weighed, with an expected accuracy of 2.5% (0.1% absolute stock consistency) between duplicate samples.

Impeller Position

In mixing operations with low viscosity fluids, swirl develops unless means are taken to prevent it. By the use of baffles, the tendency to swirl can be eliminated. This has the advantage of giving complete top-to-bottom turnover within the system as contrasted to rotary flow in the swirling system and eliminates a vortex which is normally objectionable.

In paper stock it is not possible to baffle the tank. Baffles cause a severe change in directions of motion, and in paper stock this usually causes the stock to stagnate at the junction of the baffle and the tank wall.

The off-center position with the vertical shaft mounted off the vertical axis of the cylindrical tank was found most satisfactory. The impeller may be anywhere from a few inches off the tank bottom to as high as $^1/_3$ of the fluid depth off bottom. With these positions, a diagonal-type flow pattern is developed which superimposes a top-to-bottom flow pattern on the normal rotary action of an impeller in an unbaffled tank. The flow pattern is completely adequate for producing uniformity and blending of paper stock tanks and is far superior to placing the impeller on the tank centerline. This off-center position was used throughout the tests. Referring to Fig. 4, the distance X is a function of the liquid depth Z.

Continuous Operations

Complete Uniformity. Complete uniformity is the condition obtained when sufficient power has been applied to the system to cause deviations between consistency samples to reach a minimum value which is then unchanged upon the application of additional power.

The criterion used for illustration is the difference in consistency between samples taken at the top of the tank and the effluent for a series of 15-min. intervals at each power level. Figure 5 shows the effect of horsepower on this consistency difference. Table III gives the data used to plot Fig. 5.

It is shown that at a certain power level, these consistency deviations approach the experimental accuracy and additional power will not change that value. This is defined as "complete uniformity," and is the maximum performance that can be expected from a mixer in a paper stock system. The maximum range of values of complete uniformity is 0.2%. The average value from a series of samples taken at 15-min. intervals is 0.1% as shown on Fig. 6.

Since complete uniformity meets the requirement that the incoming stock is dispersed instantly and uniformly throughout the tank, it means that the variation of the effluent consistency with time is a function of the difference between the influent and effluent consistency and is predictable by a mathematical equation.

Fig. 2. Photograph of spiral backswept turbine

For example, if the tank were operating normally at 4% and a slug of 5% stock should enter into the system, the rise in consistency from the nominal 4% value with time is given by the equation

$$\frac{dc}{d\theta} = \frac{(c_I - c)F}{V}$$

where c is stock consistency in the tank (and the effluent), c_I is the incoming consistency, F is the feed rate, V is the volume, and $dc/d\theta$ is the change of consistency in the effluent with time, at that instant.

For a tank of 50,000 gal. capacity, and a feed rate of 10,000 gal. per hr., the equation becomes

$$\frac{dc}{d\theta} = \frac{(5 - 4)(10{,}000)}{50{,}000} = 0.2\% \text{ per hr.}$$

Complete Motion. Complete motion was measured by determining the power at which all the stock was in movement across the surface of the tank.

Complete motion is normally used to prevent dewatering of the stock throughout the tank. Figure 5 shows that the deviations between the top and the effluent from the tank may be as high as 1.0%, which gives an indication of what sort of performance can be expected from the system.

It was found that the difference between complete motion and complete uniformity in terms of power ratio is relatively constant, so that visual studies could be correlated in terms of the additional amount of power required for complete uniformity.

Partial Volume Uniformity. Stagnant stock is often thought to be highly undesirable in a mixing chest. Whether this is true or not depends upon the ability to predict what becomes of this stagnant stock.

In many extremely large storage chests it often appears unfeasible to supply enough power and impeller pumping capacity to set the entire chest in motion. In such cases, there usually must be stagnant stock in some area of the tank.

A very careful examination must be made to determine the most effective means of applying power and pumping capacity less than the amount required for complete motion and to see whether any predictable and beneficial results of such applications of power will result.

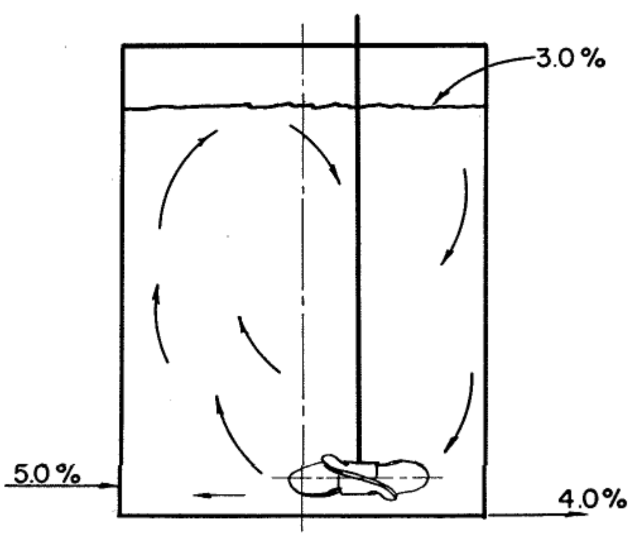


Fig. 3. Flow of stock in experimental tank

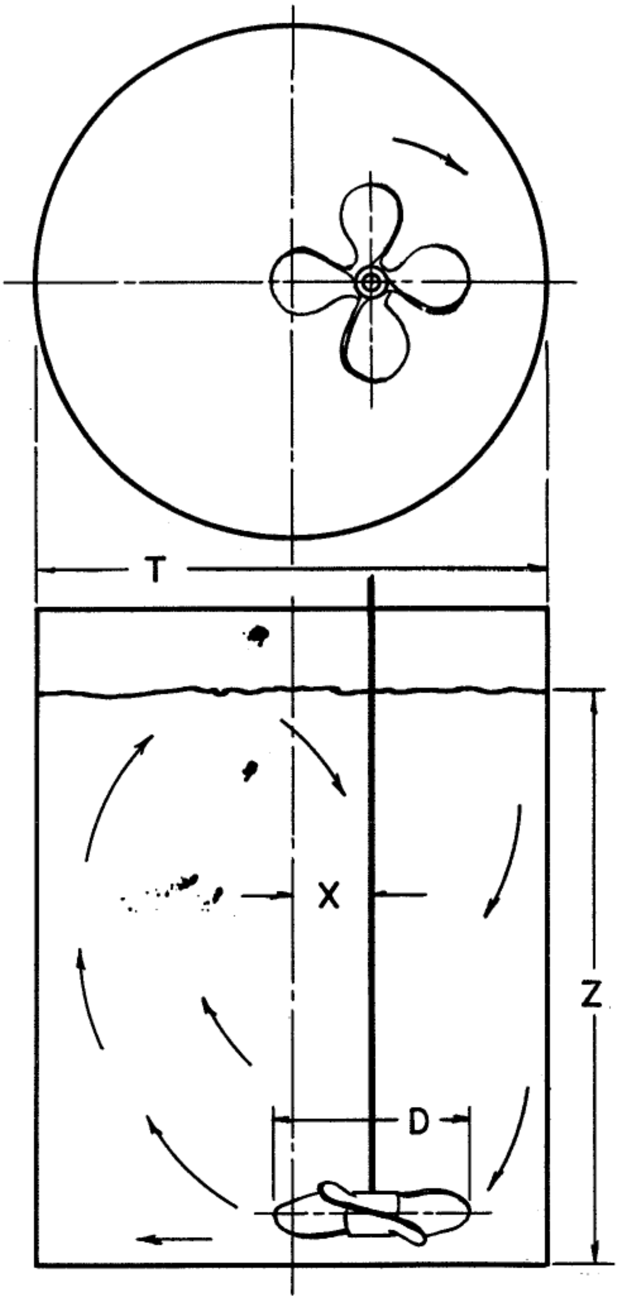


Fig. 4. Off-center position in vertical cylindrical tank

In paper stock, it is quite possible for stock to be moving in one area of the tank and to be relatively motionless in other areas of the tank.

To compare the action of partial volume agitation on various systems, there are four criteria that can be used as being desirable for partial volume motion situations:

1. Complete predictability of the time cycle and the flow path of stagnant stock and mixed stock at all times through the system.
2. No stagnant areas in the tank where the stock is not moving in a definite flow pattern into the mixing zone.
3. No stagnant areas for indefinite time periods.
4. Complete prediction of the behavior of stock effluent.

Of all the various schemes of partial volume agitation, there is only one which meets *all* four requirements. That is obtained by placing the impeller near the bottom of the tank and keeping the lower portion of the tank in motion.

Table I. Types of Performance Possible from Various Chests and Mixers

X Indicates that process can be accomplished

Process definitions	*Tank→* / *Mixer→* / *Impeller→*	*Vertical cylindrical* / *Top-entering* / *Propeller turbine*	*Vertical cylindrical midfeather* / *Side-entering* / *Propeller*	*Vertical cylindrical no midfeather* / *Side-entering* / *Propeller*	*Rectangular midfeather* / *Side-entering* / *Propeller*	*Rectangular no midfeather L/W 1.5* / *Top-entering* / *Propeller turbine*	*Rectangular no midfeather L/W 1.5* / *Top-entering* / *Propeller turbine*
(1) Complete uniformity		X	...	X	...	X	X
(2) Complete motion		X	X	X	X	X	X
(3) Partial volume uniformity		X	X	...	...	X	X
(4) Motion at pump suction		X	X	X	...	X	X
(5) Batch blending		X	X	X	...	X	X

By maintaining the entire tank cross-sectional area in motion the stagnant stock is incorporated continuously into the mixing zone. The stagnant stock has a definite path, and passes in pluglike flow from the top of the tank to bottom, in to the mixed zone with a definite residence time in the stagnant area. In the mixed zone motion extends completely across the tank bottom. There is no opportunity for stagnant stock to remain in the tank for indefinite periods of time (Fig. 7).

On comparing the performance of effluent from this tank with a tank that is in complete uniformity, one should examine the equation which governs the change in effluent consistency with a change in influent consistency. If we have an influent consistency of c_I and an effluent consistency c, the rate of change of the effluent with time, $dc/d\theta$, is given by the expression

$$\frac{dc}{d\theta} = \frac{(c_I - c)(F)}{(\text{Volume uniform, } V_u)}$$

In the case of the tank with partial volume motion, the only term that changes is the volume term V. Thus the consistency fluctuations are greater than in the tank with complete uniformity in proportion to the per cent of the volume which is uniform. Instead of the total tank volume the uniform volume, V_u, must be used. The consistency varies in a predictable manner, and if this fluctuation is acceptable, partial volume uniformity is acceptable.

Consider a tank of 200,000 gal. capacity, with partial volume uniformity in the lower 50,000 gal. If the tank effluent is 4%, and a slug of 5% stock at the feed rate of 10,000 gal. per hr., enters the top, the slug will pass through the upper area in pluglike flow in 150,000/10,000 = 15 hr. When it enters the uniform zone, the instantaneous change in consistency will be

$$\frac{(5-4)10{,}000}{50{,}000} = 0.2\% \text{ per hr.}$$

If the entire 200,000 gal. were uniform, the consistency change would be

$$(5-4)\frac{10{,}000}{200{,}000} = 0.05\% \text{ per hr.}$$

To mention one application of partial volume uniformity, a tank 35 ft. in diameter, 35 ft. high using 4% unbleached kraft pulp was equipped with a mixer to provide uniformity in the lower 9 ft. of the tank. In order to evaluate the effectiveness of this installation, a 6% slug of stock was added to the system for a period of 30 min. This slug of stock was traced through the system by measuring the effluent consistency. At the time predicted by knowing the feed rate and the volume of the quiescent zone, a rise in consistency showed up in the effluent from the mixed zone.

By measuring the change in consistency from the mixed zone at periodic intervals, and calculating the expression $dc/d\theta$, and by knowing $c_I - c$, and F, the volume in the mixed zone was calculated as

$$V_u = \frac{(6-4)F}{dc/d\theta}$$

These results checked closely with predicted results.

If there is insufficient power supplied to keep a zone of motion over the entire tank bottom, movement will exist around impellers in a somewhat unpredictable pattern. There is no quantitative way to predict the effluent consistency. There is a possibility of stagnant stock existing in the tank for unpredictable lengths of time.

Motion at the Pump Suction. Motion may be provided near the pump suction to prevent dewatering of the stock before it enters the pump. There is no predictable relationship between the concentration existing in the tank and the effluent. There is a possibility of considerable stock existing in the tank in a stagnant condition.

Table II. Data from Typical Run

Time, min.	*Top consistency (C_T), %*	*Bottom consistency (C_B), %*	ΔC_{TB}
0	3.53	3.93	−0.40
28	3.24	3.71	−0.47
70	3.79	4.06	−0.27
110	3.49	3.51	−0.02
143	3.77	3.64	+0.13
213	3.37	4.01	−0.64
250	3.62	3.85	−0.23
		Average ΔC_{TB}	±0.31
		Maximum $\Delta C_T - C_B$	0.64

Impeller: 75 in. diam. spiral backswept turbine, 12 in. off bottom.
Tank: 12.3 ft. diam. by 9 ft. liquid level, vertical cylindrical.
Stock: Bleached kraft + broke.
Impeller horsepower: 5.5.

NOMENCLATURE

C = *distance from center of impeller to bottom of tank, inches*
c = stock consistency of tank contents and effluent, per cent
c_I = consistency of stock entering tank, per cent
ΔC_{TB} = consistency of sample from top of tank minus consistency sample from bottom of tank, per cent
D = *impeller diameter, inches*
F = rate of flow of stock through mixing tank, gallons per hour
HP = horsepower
N = rotational speed of impeller, revolutions per minute
T = tank diameter, feet
V = volume of stock in tank, gallons
V_u = volume of stock which is mixed to complete uniformity, gallons
X = horizontal distance from vertical centerline of vertical cylindrical tank to vertical centerline of TE mixer shaft
Z = batch depth, feet
θ = time, hours

Table III. Summary of Runs to Prepare Fig. 5

Impeller speed, r.p.m.	*Impeller power, h.p.*	*Consistency at top minus consistency at bottom [ΔC_{TB}]* 1	2	3	4	5	6	*Av.* $\pm\Delta C_{TB}$	*Max.* $\Delta C_T - C_B$
45.5	29.5	0	+0.22	−0.14	−0.06	..	..	0.10	0.22
47.7	36.5	+0.05	+0.08	+0.19	−0.06	+0.10	..	0.10	0.19
34	12.5	+0.04	−0.05	−0.18	−0.06	+0.02	−0.07	0.07	0.18
41	20.5	+0.03	+0.09	+0.03	+0.17	+0.08	−0.05	0.08	0.17
28	7.5	−0.81	−0.18	−0.34	−0.09	−0.05	−0.64	0.35	0.81
24.5	5.5	−0.40	−0.47	−0.02	+0.13	−0.64	−0.23	0.31	0.64
26	6.5	−0.07	−0.52	−0.63	−0.42	−0.07	−0.96	0.45	0.96
29.5	9	+0.01	−0.12	−0.25	+0.26	..	..	0.16	0.26
37	17.5	−0.07	−0.10	+0.14	..	..	..	0.10	0.14
36.5	16.5	−0.06	−0.01	0	−0.13	..	..	0.05	0.13
43.5	24	+0.03	−0.03	+0.05	+0.10	−0.04	..	0.05	0.10
38	16.5	+0.07	−0.09	−0.04	+0.06	0	..	0.05	0.09

Impeller: 75 in. diam. spiral backswept turbine, 12 in. off bottom.
Tank: 12.3 ft. diam. by 9 ft. liquid level, vertical cylindrical.
Stock: Bleached kraft + broke.

Batch Operations

Blending Time. On a continuous basis, it was found that increasing the power above that required for complete uniformity did not affect the process result. This is compatible with the theory of continuous processes, considering the time required to withdraw the samples and the accuracy of the experimental technique. On a batch blending process, at the power required for complete motion, blending takes place in 20 to 30 min. If less horsepower is applied than that required for complete motion, blending will never take place.

If the impeller diameter to tank diameter ratio is increased beyond 0.6, such that a very definite swirling action results in the tank, the blending action is highly unpredictable. In such systems, tests have shown blending times from 1 to 24 hr., and in some cases, infinite time, since there is no top-to-bottom motion in the tank and no inner-to-outer motion in the tank.

At the power level corresponding to complete uniformity, blending takes place usually in 6 to 10 min. If the power level is greater than required for complete uniformity, then trouble is encountered with excessive swirl so that these power levels are usually not practical. They can be used on occasion to get extremely short blending times.

Blending time includes the time to mix ingredients, blend different types of stock, or produce uniformity from a standstill.

MIXERS FOR OTHER TANK SHAPES

After finding the quantitative performance possible in vertical cylindrical tanks with top entering mixers, it is now possible to indicate what types of performance are possible with other tank shapes and mixer designs. Table I summarizes the evaluation of these other combinations.

In the following analysis, the terms and numbers used previously will be referred to by number as listed below:

Complete uniformity (1)
Complete motion (2)
Partial volume uniformity (3)
Motion at pump suction (4)
Batch blending (5)

Figures 8 to 13 show the various configurations referred to. Table I has a summary of the characteristics of these various configurations.

Vertical Cylindrical Tanks, Side-Entering Mixers, No Midfeathers

It was found that complete uniformity (1) and complete motion (2) can be achieved with these mixers. Figure 8 illustrates this arrangement. In case of partial volume uniformity (3) it was found that in order to sweep the entire tank bottom, sufficient velocity must be introduced into the stream to sweep up the side of the tank, putting the entire tank in motion. Therefore, it is not feasible to achieve condition (3). It is possible, however, to put in a relatively small amount of horsepower to mix a conical zone near the pump suction (4).

In the case of batch blending, the complete range of blending times (5) is possible.

Vertical Cylindrical Tanks, Side-Entering Mixers, Midfeathers

These tanks normally used midfeathers to give a controlled circulation pattern within the tank. Figure 9 is

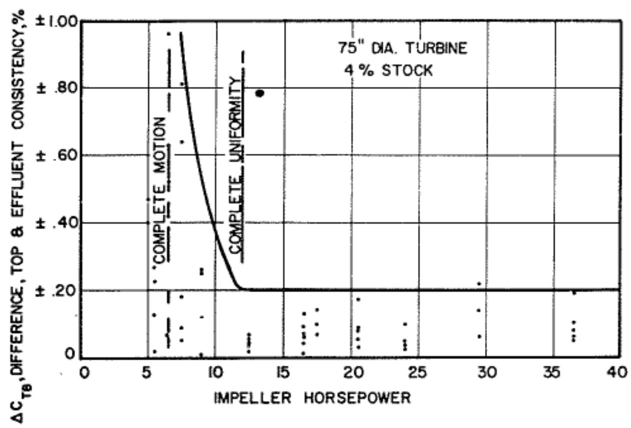


Fig. 5. Effect of power on consistency deviations

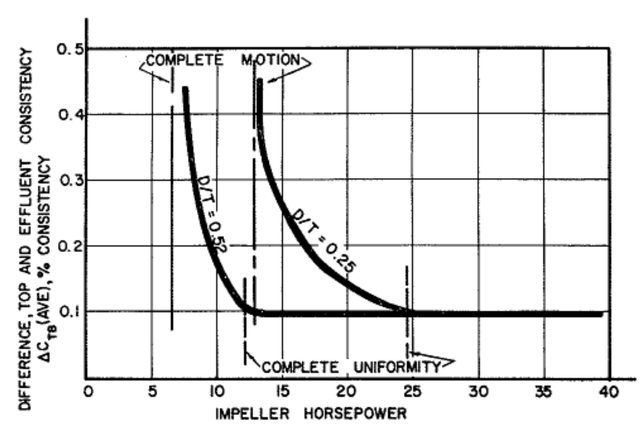
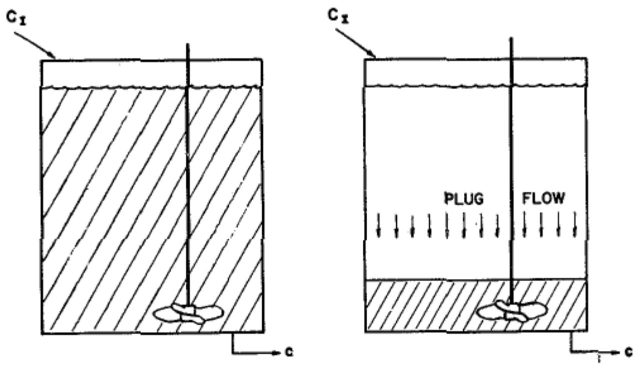


Fig. 6. Effect of D/T ratio upon consistency deviations



$$\frac{dc}{d\theta} = \frac{[C_1 - c]F}{V}$$

Fig. 7. Characteristics of partial volume uniformity

a typical example. The flow is normally in a stream line pattern with little interchange between streams. It is difficult to achieve complete uniformity (1). It is possible to achieve complete motion (2).

In some cases, these systems are designed to provide partial volume uniformity (3) but they do not satisfy the criterion that complete predictability of resulting effluent may be satisfied. They sometimes do not satisfy the requirement that there is no stagnant stock for indeterminate lengths of time in the vessel.

It is possible to provide motion at the inlet to the pump suction (4).

For batch blending operations (5) it is possible to supply sufficient power that blending will occur, although the stream line flow pattern often interferes with effective blending.

Rectangular Chests with Midfeathers, Side-Entering Propeller-Type Mixers

This type of tank is very common in paper stock mixing. The impeller imparts a static head to the stock as it passes through the propeller area so that it may flow by gravity down a sloping bottom through the rest of the path back to the propeller. The flow pattern is basically streamlined around the channel and there is very little blending from top to bottom layers in the system or from different points on the circumference of the flow pattern. Figure 10 illustrates this type of tank and flow.

These chests can do an excellent job of providing complete motion (2) throughout the system. With the proper velocity through the channel, dewatering can be prevented. However, it is extremely difficult to blend any material from point A on the circumference, with material in point B, since the material goes round and round through the circuit. There is some blending which does occur as the stream turns the corner at each end of the tank and between the various layers in the tank, but no exact relationships exist on how to predict time required to achieve complete uniformity (1) or blending (5).

Therefore, these chests can adequately provide for complete motion (2). They are not suitable to provide complete uniformity (1).

They are not suitable to provide partial volume uniformity (3) since stagnant stock will collect at the corners of the tank and remain there indefinitely. They are normally not used to provide motion near the pump suction (4).

In terms of batch blending (5) these tanks are not suitable, since there is no predictable method of defining blending time in such a system.

Rectangular Chests, Cylindrical Bottom, Equipped with Long Horizontal Shaft, Paddles Rotating in Vertical Plane

This system of agitation can be used to prevent dewatering of the stock to some extent, but very little information exists on the quantitative performance of such a system. It is illustrated in Fig. 11.

Square or Rectangular Tanks, No Midfeathers, Top-Entering Mixer, L/W Ratio Less than 1.5

It was mentioned previously that rectangular tanks for side-entering mixers with midfeathers can only be used effectively to produce complete motion (2). In case tanks of this shape are to be used where other types

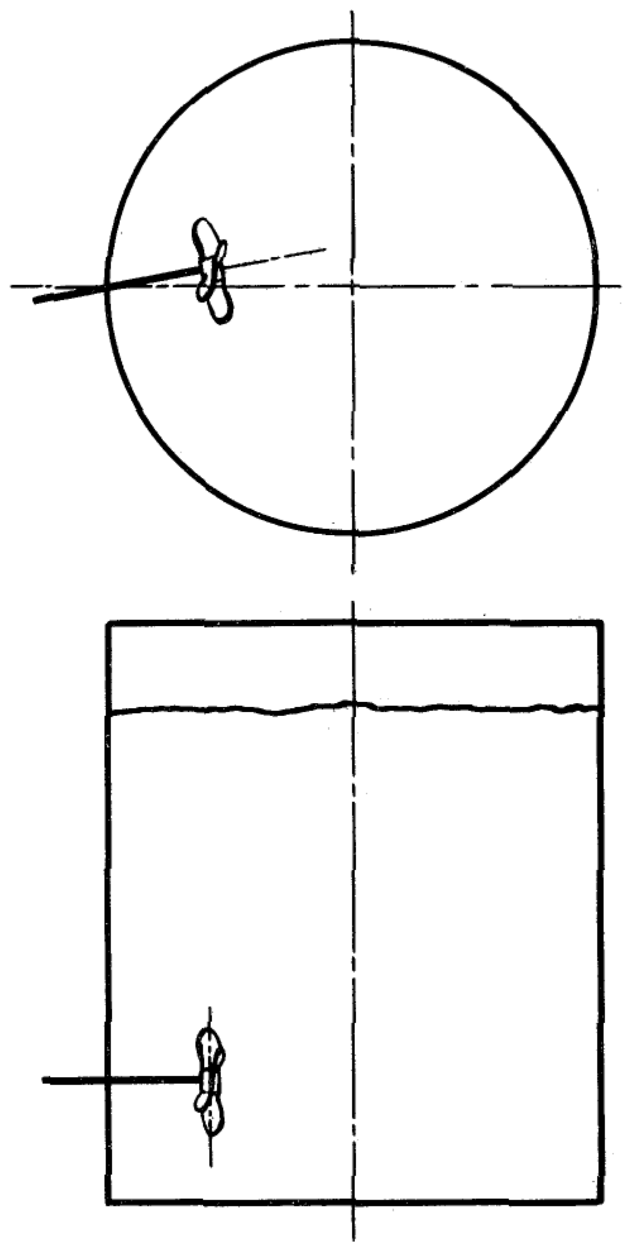


Fig. 8. Side-entering mixer, no midfeather in vertical cylindrical chest

of performance are desired, top-entering mixers without midfeathers can be used, as shown in Fig. 12.

The mixer is positioned in the center of the tank since the corners give sufficient baffle action and off-centering of the shaft is not necessary. The position of the impeller with respect to the bottom of the tank is the same as in the case of vertical cylindrical tanks. It is desirable to fillet the corners as much as possible, with the radius at least equal to one tenth of the tank width.

With this sort of a mixer system, complete uniformity (1), complete motion (2), partial volume uniformity (3), motion at the pump suction (4), and batch blending (5), may be achieved.

Rectangular Tanks, No Midfeathers,* L/W *Ratio Greater than 1.5

When these tanks are equipped with midfeathers and side-entering mixers, complete motion (2) is the usual requirement. When complete uniformity (1), partial volume uniformity (3), or batch blending (5) is required, it may be achieved by operation of a top-entering mixer without a midfeather in the system. Usually several mixers (Fig. 13) are required, the mixers being spaced so that each one handles a portion of the tank corresponding to a length-to-width ratio in its own section of about $1^1/_2$ to 1. Each mixer sets up its own flow pattern, creating several zones in the tank. Complete uniformity, complete motion, partial volume uniformity, and batch blending exists in each zone. The tank behaves as a series of tanks, and the inlet and outlet should be on opposite sides of the over-all rectangular tank.

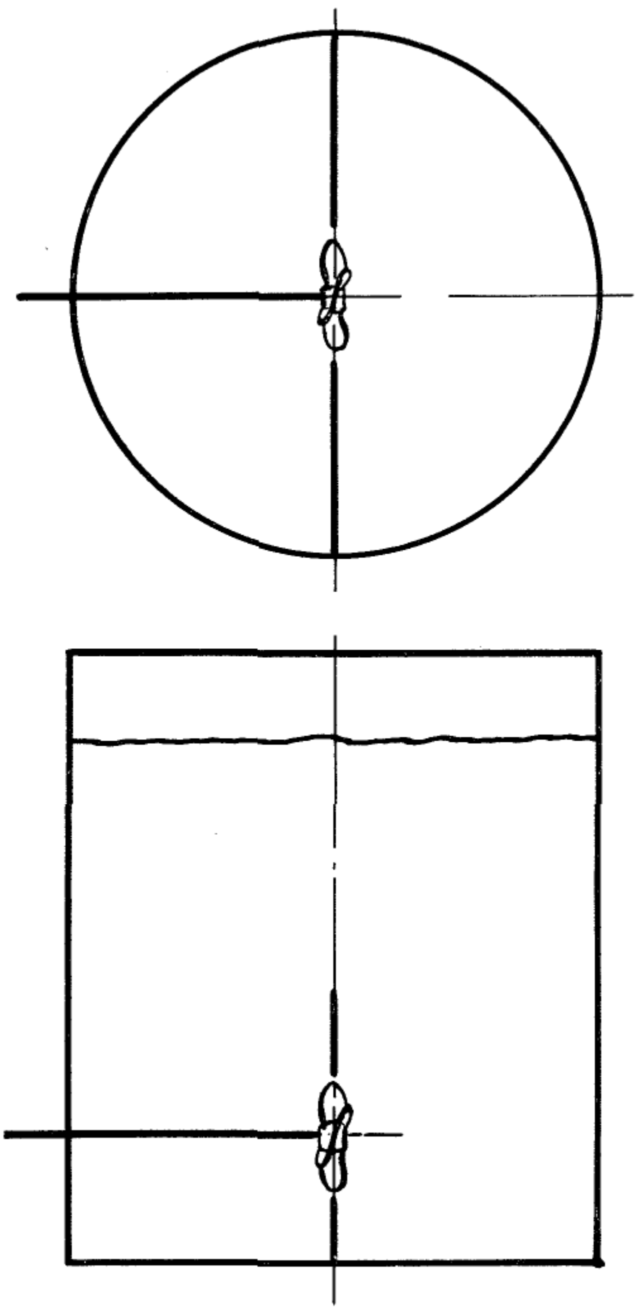


Fig. 9. Side-entering mixer with midfeather in vertical cylindrical chest

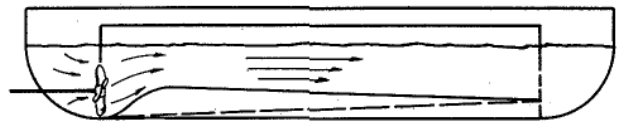


Fig. 10. Side-entering mixer with midfeather in rectangular chest

Partial Volume Uniformity in Long Rectangular Tanks

Concept of partial volume uniformity has been given in terms of providing motion across the complete tank bottom. This is the most effective scheme for this sort of motion. However, partial volume uniformity in one end of a long rectangular tank can sometimes be used. The tank that has a flow from one end to the other, in which the bottom is sloped giving gravity flow, or which may be equipped with a mixing device throughout the tank length to propel the stock from one end to the other may be used. A mixer installed near the pump suction to provide a definite volume of the tank in uniformity will often give the desired effluent control.

EFFECT OF MIXING VARIABLES

Several mixing variables were examined in the test work in a vertical cylindrical tank. Among these variables were: (1) impeller diameter to tank diameter ratio (D/T ratio), (2) impeller type, (3) stock consistency, (4) stock type, and (5) scale-up factor.

In general, the relative effect of these variables is the same for all process criteria—complete uniformity, complete motion, partial volume uniformity, motion at the pump suction, and batch blending. The same relative effect of these variables was found for rectangular and square tank configurations.

Effect of* D/T *Ratio

The power consumption of an impeller produces an impeller flow Q and an impeller head H.

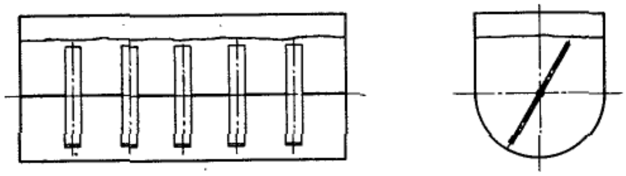


Fig. 11. Paddle mixers on horizontal shaft

$$P = QH$$

The impeller head H is related to fluid shear and to turbulence.

Large impellers produce a relatively high level of fluid flow Q and a low level of fluid shear H. Small impellers produce the opposite effect.

A study of process result as a function of D/T ratio (D = impeller diameter, T = tank diameter) will indicate whether fluid flow or fluid shear is more effective in that particular process.

Comparing the 39 in. diameter impeller to the 75 in. diameter impeller in Fig. 6, it is seen that the 39 in. diameter impeller requires more horsepower to produce the same process results than does the 75 in. diameter impeller. This indicates that motion and uniformity in paper stock systems is done with less horsepower with large diameter impellers. By plotting the two points from Fig. 6 on a curve, Fig. 14, the effect of D/T ratio upon power requirement is shown. Data from other sizes of systems, from 18 in. to 35 ft., in which the point for complete motion was used as the criterion, have yielded data verifying the line shown in Fig. 14. The line is stopped at 0.60 D/T ratio since above that point the diagonal flow pattern degenerates into a complete swirling action and it is impossible to achieve top-to-bottom turnover. The lower limit on D/T ratio can go down to 0.125.

Propeller versus Turbine

The power requirements for complete uniformity for the 60 in. propeller and the 39 and 75 in. turbines in the experimental tank have been used to plot Fig. 14. The power requirements are plotted as a function of D/T ratio. Data in other size systems have substantiated the correlation shown on this figure.

These data confirm results from other mixing applications, namely: "the process result is determined by the ratio of impeller flow Q and impeller head H and not in the device used to generate that flow and head."

There is no difference in the job done by the propeller and the spiral backswept turbine. The major difference is mechanical, and the fact that the propeller runs at a *higher speed to do the same process performance gives* a decided mechanical advantage to the use of propellers in terms of the size of gear reducer required. The cost of the impeller and the reducer must be considered to obtain the total cost of the mixer, which is the criterion used to determine which impeller will be used on a given application. For the majority of paper stock mixing applications, the propeller gives the most economical *initial cost of the mixer.*

Effect of D/T *on Process Design*

Curves shown on Fig. 14 indicate that as the impeller size is increased, the power required goes down. However, reducing the speed of the mixer and increasing the size of the impeller, increases the torque required by the mixer and those two lines are plotted on Fig. 15. The torque required by the mixer represents the initial cost of the assembly. The power required by the mixer represents the operating cost of the mixer. Depending upon the relative importance assigned to the initial cost and operating cost, the optimum mixer design can be selected for any particular combination.

These data make it possible to choose a mixer custom tailored to the economic picture at each mill. The choice of the mixer would depend on the relative cost of operating power and initial cost at the particular *mill under consideration.*

Vertical Cylindrical Tanks with Multiple Impellers

Multiple impellers can be used in paper stock mixing chests. Multiple impellers have a greater tendency to swirl the stock than do single impellers, especially when the spacing between the impellers is less than one impeller diameter.

In experimental runs to establish the effect of dual impellers in the system, it was found that up to a Z/T (liquid depth/tank diameter) ratio of 1.0, dual impellers could be used but there was practically no advantage in them when considering the combination of operating cost and initial cost. If the Z/T ratio is greater than 1.0, dual impellers have an advantage, and are normally used when complete motion or complete uniformity is desired.

When multiple impellers are used for partial volume uniformity, two situations may exist. The lower impeller can be designed to consume sufficient power to produce partial volume uniformity in the lower part of the chest. All the characteristics of this process definition are then available. The upper impeller serves pri-

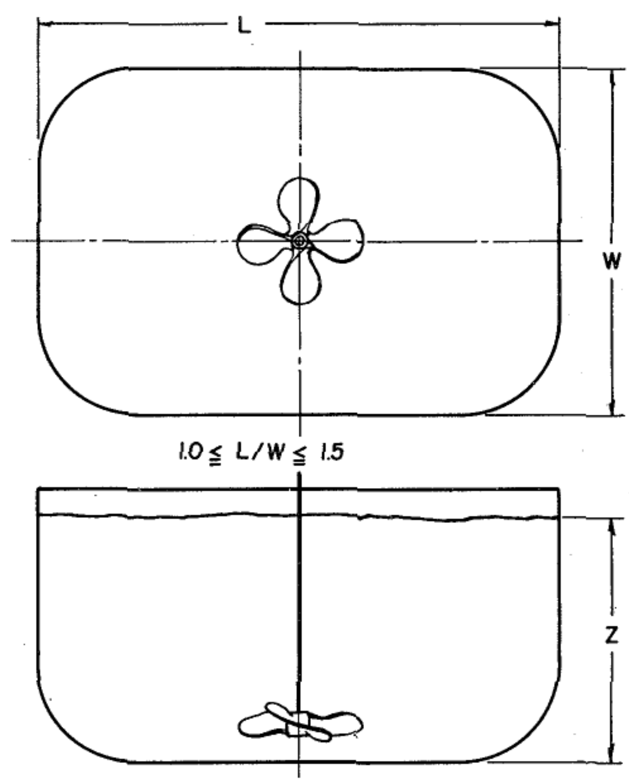


Fig. 12. Top-entering mixer, no midfeather in square or rectangular chest

marily to move the stock near the surface but the zone of uniformity is not well defined nor accurately predictable.

In the second case the lower impeller does not have sufficient power to provide partial volume uniformity in the bottom of the chest. Each impeller sets up a flow pattern around itself, and the zone of uniformity is not accurately predictable. Stagnant areas are produced in the tank. The mixing action often sets up a central core of mixed stock and a considerable short circuiting of flow into the chest may occur.

Effect of Stock Consistency

The plant scale runs were carried out with about 4% stock consistency. The effect of consistency in bleached sulphite pulp is quite marked, giving a curve shown on Fig. 16. The steep character of this curve indicates that it is extremely important that the exact consistency to be designed for be specified. While a half a per cent variation in consistency may not sound like a large value, it may affect the design of the mixer by 50%. Performance of the equipment is usually set to meet a given consistency, and large increases in consistency cannot be made and still give the same degree of performance.

Effect of Type of Stock

The basic data were calculated to conform to power requirements for bleached sulphite stock. Various types of stock were found to have a relationship to bleached sulphite depending upon the type of stock and the consistency. For example, unbleached kraft from northern woods was found to require more power than bleached sulphite, while unbleached kraft from southern woods was found to be less difficult. Groundwood stock was found to be more difficult in higher consistency ranges and less difficult in lower consistency ranges.

Scale-Up

In the experimental program, tanks from 18 in. to 35 ft. were studied. Geometric similarity was maintained between impellers and tank. It was found that there was a definite relationship between mixer horsepower and scale ratio for a given process definition.

It was further found that the effect of D/T ratio, stock type, stock consistency, and the relationship between complete uniformity, complete motion, and partial volume uniformity was similar for various tank sizes. Therefore, data on requirements for various process conditions, coupled with data on the effect of mixing variables need only to have a tank scale factor to enable the complete prediction of mixing performance for any operating condition.

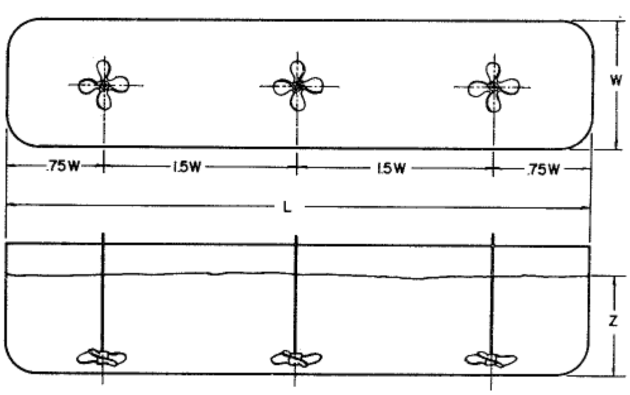


Fig. 13. Multiple top entering mixers in rectangular tank

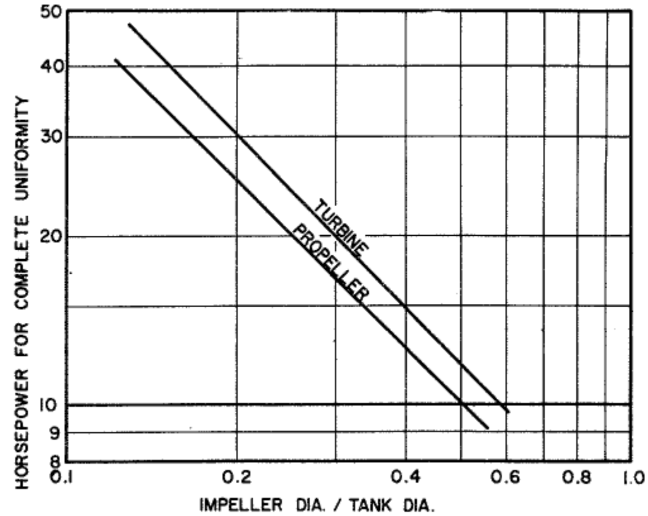


Fig. 14. Effect of D/T ratio upon power requirement

APPLICATION OF THESE PROCESS DEFINITIONS TO PAPER MILL INSTALLATIONS

In looking at the action of a paper stock tank in a paper mill, it is usually necessary to set up a process definition for each tank in the system. Many times the process requirement will be relatively simple, perhaps to prevent stock from dewatering, or to prevent stagnant stock from remaining for indefinite periods of time. However, if the stock chest is to serve its full role in the paper mill process, it should usually serve a definite function in the paper mill procedure in addition to primarily being for storage. By the use of these process definitions, the possible action of a stock chest in the system can be predicted. By examining very carefully all the process definitions, it can then be decided which definition best fits the economics of the mill and the proper mixer can be specified.

It is impractical to provide too high a level of performance in the stock chest just as it is impractical to provide too low a performance. In the one case, excess horsepower and dollars can be expended, while in the latter case many problems will result in the operation of the paper mill with many possible economic losses before the final product specification is achieved.

As examples of some of the things that can be done in paper stock chests, the following cases below are cited. These represent some of the more effective means of applying mixing to paper stock applications. If none of these appear to be of benefit in the paper mill system, it usually means that the tank is serving merely as storage capacity, and compensation for wide fluctuations in performance are to be made somewhere else in the system.

Blending of Stock Types

In newsprint mill operation, it is often necessary to blend various types of groundwood to get a uniform groundwood mixture, and then to blend in some type of wood pulp, normally bleached sulphite. The operation of the entire system depends on obtaining the proper

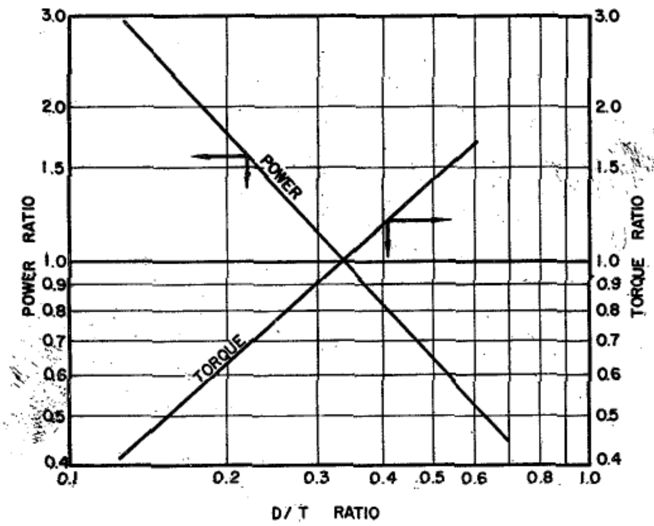


Fig. 15. Effect of* D/T *ratio upon power and torque requirements

blend of these types of stock in the stock chest. By providing either complete uniformity or partial volume uniformity, it is possible to control the blend of materials to any desired specification. The more rigid the specification, the more nearly will the mixer requirement approach complete uniformity.

Blending in Large Storage Tanks

When paper mills use various types of wood species, it is usually desirable to blend materials from various cooks to provide uniform stock to be fed through the mill. This can often be accomplished in the large storage chests which can be 30 to 60 ft. in diameter. Many times providing partial volume uniformity is sufficient. If the zone of partial volume uniformity is sufficiently large to hold several digester loads, the blending action can be calculated and performance throughout the plant predicted.

Prevent Stagnation on Tank Bottom

If stagnant stock remains in a tank for indefinite periods of time, it often decomposes, and if it should be incorporated in the stream at a later date, it causes problems throughout the entire mill system. Stagnation in a tank bottom can be prevented by providing partial volume uniformity which keeps the entire bottom of the tank clean and insures that there is no stock in the system which remains quiescent for an indefinite period of time. This can also be prevented by supplying complete uniformity or complete motion, but these are not often indicated when the only requirement is to prevent stagnation of the tank bottom.

Control of Consistency

Consistency fluctuations are of two types: One type is a high frequency fluctuation which results from nonuniformity in the various stock chests and other items of equipment in the flow stream. The other type is a slow frequency fluctuation due to the response of the over-all flow diagram to the initial feed of stock. This low frequency fluctuation results from the fact that all of the material fed to the system must ultimately come out, and this results in a gradual decrease and increase of the consistency throughout the entire system.

The desired level of consistency control is usually set by the type of paper a particular mill is producing and the required uniformity of this paper. There are various means of providing for consistency control in a paper mill circuit and a mixing tank can be a valuable component in that consistency control.

Many times a consistency controller operating in the effluent line from a mixing chest is the only device used for control. The controller has a difficult job of following high frequency fluctuations due to improper mixing in the circuit without considerable overcorrection and undercorrection. There are considerable time lags in the response of the pneumatic valve, water flowing in circuits, and the time required to blend the water into the flowing stock.

The controller can only control consistency by adding water, so that the basic level of the stock consistency must be decreased to the lowest consistency experienced in the fluctuations. The basic level of stock consistency must decrease each time a consistency controller is used in the circuit.

By providing either partial volume uniformity or complete uniformity in the mixing chest preceding the controller, the high frequency fluctuations from the chest may be almost eliminated, and the controller can exercise its most satisfactory function, that of leveling out the low frequency fluctuations due to the change in stock inventory in the system. These low frequency fluctuations are caused by the fact that digester drops

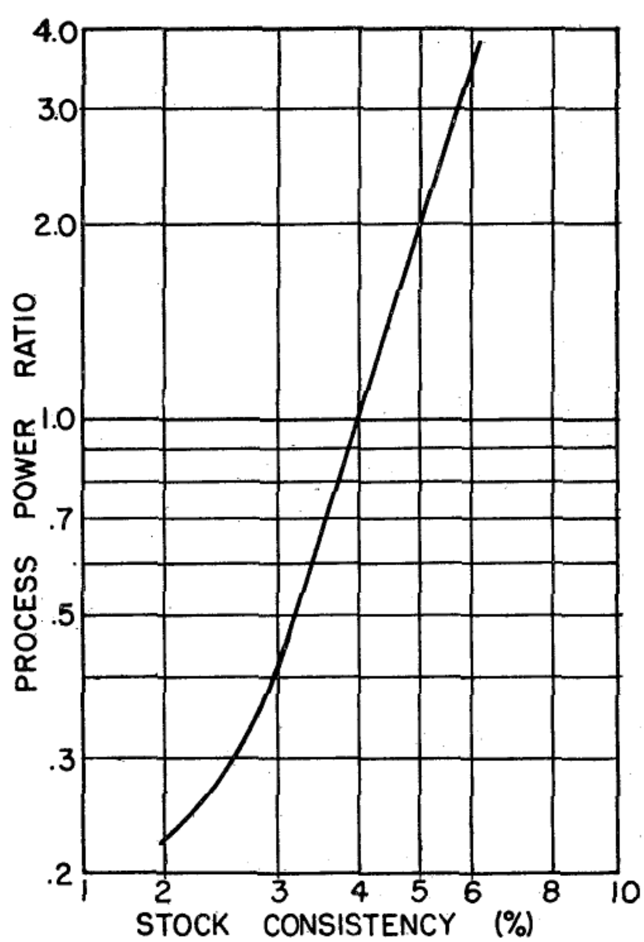


Fig. 16. Effect of stock consistency upon power requirement

and beater drops are made at finite intervals, and also a normal fluctuation inherent in making up pulp stock.

Thus, the mixing tank can aid immeasurably in leveling out the high frequency fluctuations and the consistency controller can then react to control the low frequency, long time cycle fluctuations in the circuit.

Batch Blending Operation

Many places in a paper mill require batch blending of ingredients. By using the off-center position, maintaining the impeller to tank diameter ratio less than 0.6, and providing a horsepower level at least commensurate with complete motion, thorough and rapid blending of ingredients can be achieved in the system. In many operations, blending times are somewhat unpredictable due to the slow movement and swirling action of the mixer. By setting the mixer up to blend the material in 5 to 20 min., the mixing cycle is completely predictable and very smooth operation throughout the system is obtained.

Controlling Paper Weight Uniformity

The value of these various mixing conditions depends ultimately on the effect they have in the operation of other machines in the circuit and on the operation of the paper machine itself. Using these process definitions, it is possible to predict the performance from the various stock chests in the system. This eliminates several troublesome variables in analyzing the paper mill circuit. The ultimate effect on paper quality is one which must be weighed in terms of the present performance of the stock chest, with estimates on how the improved performance will affect the over-all system operation. In a new mill circuit, specifications can often be set by previous experience with various types of mixing systems. It is also possible to go back and analyze each mixer and tank in the paper mill circuit to see what role it is playing in the ultimate product quality.

EXPERIMENTAL EQUIPMENT

The quantitative experiments involved in taking consistency samples were carried out on a 12-ft. tank in an actual paper mill installation. This experimental program is described in detail in the following section.

In addition, runs were made in an 18 and a 30 diameter tank, made of Lucite plastic. In these tanks, accurate visual observations of the horsepower required for complete motion were possible and also accurate observations of horsepower required for partial volume uniformity. A brief description of these tanks is given also.

Table IV. Data Tabulation

Type of stock	*Type of impeller*	*Impeller diam., in.*	*Off bottom distance, in.*	*Impeller speed, r.p.m.*	*Impeller, h.p.*	*Av.* ΔC_{TB}	*Max.* $\Delta C_T - C_B$
Semibleached kraft + broke	Turbine	75	12	See Table III			
		39		130	36.5	0.13	0.29
				118	26	0.14	0.29
				97	12.5	0.26	0.55
				107	19	0.19	0.25
				113.5	23	0.20	0.32
				70	6	0.15	0.38
				58	31	0.13	0.19
				126	33	0.16	0.36
				120	28.5	0.09	0.21
				105	18.5	0.17	0.27
				98	14	0.13	0.21
				97	13	0.30	0.98
Unbleached kraft + broke				128	35	0.12	0.22
				24	12.5	0.38	0.83
				108	19	0.18	0.45
				103.5	16.5	0.22	0.36
				117	25	0.19	0.34
	Propeller	60		86	11.5	0.17	0.40
				69	6.1	0.13	0.32
				98	15.3	0.06	0.09
				107	19.1	0.16	0.15
				77	9	0.07	0.13
				90	13	0.13	0.27
				114	23	0.07	0.13
Semibleached kraft	Turbine	39		115	25	0.22	0.33
				129	35.5	0.10	0.30
				88	10.5	0.30	0.49
				100	15.5	0.26	0.54
				108	20	0.21	0.39
	Propeller	60		91	13	0.07	0.19
				78	9	0.12	0.23
				67	6.1	0.20	0.39
				89.5	11.7	0.10	0.25
				102	16.2	0.09	0.17
				72	7.3	0.08	0.22
			36	88.5	11.5	0.08	0.21
				100	16.4	0.10	0.23
				71	6.1	0.18	0.39
				82	9	0.10	0.24
				96	14.2	0.11	0.36
				63.5	4.1	0.36	0.67
				77.5	7.9	0.17	0.37
				84	8.4	0.14	0.24
				68	5	0.36	0.58

Plant Installation—12 Ft. Diameter Tank, Paper Mill Installation

A diagram of the plant installation is shown in Fig. 17. The experimental work was done in a machine stock chest, which was a vertical, cylindrical, tile-lined tank, 12 ft. 4 in. in diameter with a liquid level maintained at about 9 ft. The tank was filleted at the junction of the bottom and sides, and the bottom was sloped slightly to the outlet valve.

This chest was connected by an 8-in. overflow to a similar chest used as the beater chest. The agitation in the beater chest was provided by a mixer on the tank centerline. The impeller on this mixer consisted of a number of planks bolted together horizontally and at acute angles with the vertical. The clearance between the outer tips of the planks and the tank wall was approximately 1 ft. and the agitator rotated at a slow speed (estimated 30 r.p.m.).

Auxiliary equipment included beaters, regulator box, pumps, and valves.

The stock furnish was fed to the beater along with water to dilute it and chemicals and color were added. After beating, the contents of the beater were pumped into the beater chest below, using additional water to flush out the beater. Various types of stock were used: bleached sulphite, bleached kraft, unbleached kraft, and broke. Stock was continually pumped from the beater chest to the machine chest so that a constant level was maintained in the machine chest at the level of the overflow pipe. Since beating of the furnish was a batch process, the level in the beater chest varied with time.

Another pump continuously pumped stock from the bottom of the machine chest to the regulator box. Here by means of weirs, this stock was divided into two flows. One stream went through the regulator box to be diluted for the paper machine, and the other stream was returned undiluted to the machine chest. After the former stream was diluted with water in the regulator box, it also was divided by weirs into two streams. One stream of diluted stock was fed to the papermaking machine, and the excess diluted stock joined the undiluted overflow and both were returned to the machine chest through the same pipe.

The mixer unit used was driven by a 40-hp. d.c. motor. It had a $3^1/_2$ in. diameter shaft with a 75-in. spiral backswept paper stock turbine. In addition, a 39 in. diameter turbine and 60-in. four-bladed propeller were used.

Because the stock chest was unbaffled, the centerline of the agitator shaft was placed off the tank axis. This position produces a diagonal flow pattern which promotes turnover of tank contents, instead of the rotary swirl produced by an impeller on the centerline of an unbaffled tank.

Procedure in Plant Installation

To make a run, an arbitrary impeller speed was set by adjustment of the rheostat. After 15 min. or more to allow equilibrium to be obtained, a sample was dipped from the top of the machine chest and a sample was taken from the undiluted overflow from the regulator. This latter sample represented the consistency of the stock at the bottom of the machine chest, since this is the point from which it was pumped.

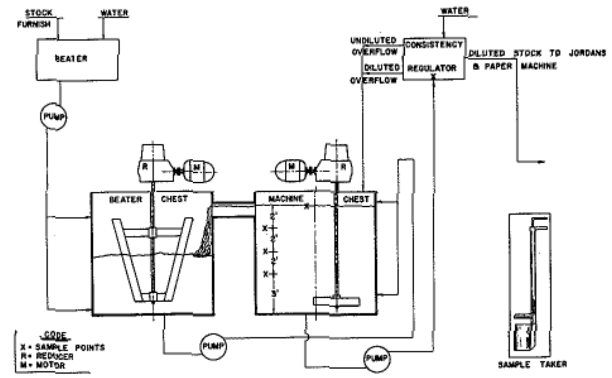


Fig. 17. Experimental equipment in plant installations

After a period of time (10 to 30 min.), a second pair of samples was obtained from the top of the chest and the regulator. These samples were obtained by dipping the sample bottle into the stock. This procedure was repeated until six pairs of samples had been obtained.

At the time of taking one pair of these samples, usually near the middle of the run, a series of tank traverse samples were obtained. These were taken by means of a thief sampler on a pipe, illustrated in Fig. 17. The sampler was closed when immersed in the stock, then opened to obtain the sample, then closed again for withdrawal of the sample. With this sampler, three samples were obtained at a distance of 2 ft. below the liquid surface, three samples at a distance of 4 ft. below the surface, and three samples at a distance of 6 ft. below the surface.

Power (horsepower) and speed (N) measurements were made during the run. At the end of a run, the power input was changed by changing the speed and a similar series of 21 samples was again taken. Complete visual observations were made at each horsepower level.

The consistency samples were dried to constant weight at 105°C. and consistency was calculated. The data are summarized in Table IV.

Analytical Calculations for Plant Installation

It was desired to determine the variation in consistencies throughout the tank so it could be plotted as a function of horsepower as shown in Fig. 6. Consistency variation was calculated by two different methods and the methods were checked against each other.

Method 1. Only the six top and bottom pairs of samples were used. For each pair of samples the consistency of the bottom sample was subtracted from the consistency of the top samples and these differences were used without regard to sign to obtain an average difference, Table II, which was plotted versus horsepower, Fig. 6.

Method 2. The samples used were the tank traverse samples and the one pair of top and bottom samples which were taken at the time of the tank traverse. This was a total of 11 samples. The deviation of each consistency from the average consistency was determined. These deviations were used without regard to sign to obtain a mean deviation from the average consistency, which was plotted versus horsepower.

The leveling out of consistency variations, or "complete uniformity" occurred at approximately the same horsepower for both methods of calculation.

18 and 30-Inch Vertical Cylindrical Tank Experiments

Under laboratory conditions, an extensive range of investigations with 18 and 30 in. diameter plastic tanks was carried out. A complete range of variables of various stock levels, stock types, D/T ratios, and impeller types was used. These tanks were made of plastic, so that visual observations could be made under all conditions.

Observations from this type of experiment were confined to complete motion and partial volume motion.

30 by 60 by 30-Inch Rectangular Tank

A tank 30 in. wide, 60 in. long, and 30 in. deep was constructed of Lucite plastic. The length of the tank could be varied from 30 to 60 in. A complete range of impeller types, D/T values, stock levels, and types were used in these experiments. The mixing conditions required in the rectangular tank to achieve various process performance definitions were compared with that required in vertical cylindrical tanks.

Other Tank Conditions

During the course of experimentation, laboratory data were obtained in tanks up to 8 ft. in diameter. Plant installation data have included many sizes of tanks including a 35 ft. diameter tank mentioned in the section on partial volume uniformity. A complete range of tank variables was used to establish the scale factor line mentioned in the scale-up.

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