Reprinted from CHEMICAL ENGINEERING PROGRESS, August 1978

Flocculation Performance Of Mixing Impellers

Here's a look at how different impellers shape the way waste water responds to flocculation.

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Studies were recently conducted of a full-scale flocculation operation, with basins 7.5 meters square, in a municipal water treating plant in Manchester, N.H. While these continuous flow studies were going on, batch experiments were made in 460 and 760 mm. diameter tanks, using water that had been passed continuously through the plant flash mixing system.

This article presents the results of this pilot scale study, which provided an opportunity to study many variables, and yielded relative effects that could be used to interpret full-scale performance.

The raw water was obtained from Massabesic Lake during the period of February, March, and April. Water temperature was a constant 4°C. Other typical properties of the raw water remained relatively constant. The pH of the raw water going into the rapid mix tank was 5.1 to 5.4.

Color readings of the water charged to the batch unit were between 50 and 55 color units. Turbidity (nephelometric turbidity units [NTU] was in the general range of 8. The input water quality was constant enough that final process results after batch flocculation could be treated in an absolute sense, without using a correction factor, which would be needed to take care of marked changes in incoming water quality.

In the full-scale flocculator, there was four parallel trains with two stages in series, each designed for 10 million gal./day. 0.44 m^3/s. In one train there were two Lightnin impeller type flocculators per stage in series, Figure 1. In two of the trains, there were slow-speed "dangling plate" type flocculators in series, Figure 2. In the fourth train, there were two Lightnin impeller-type units in stage I followed by two "dangling plate" impellers in stage 2. Figure 3 shows the terminology. Figure 4 shows the overall plant arrangement. Typical performance of the plant-scale unit gave turbidities coming out of the sedimentation basin of 2 to 4 NTU and color values from 15 to 35.

For batch flocculation, we have a choice of flocculation time, as well as the time for sedimentation. It was determined that flocculation mixing time between 5 and 10 min. did not markedly affect results of a given settling time, and 5 min. of flocculation was generally used during the study.

Turbidity measurements were made for settling times of 15, 30, 60 and 120 min. Figure 5 gives typical data. Values for 60 min. gave turbidity and color readings in the same general range as the full-scale plant performance, and it was thought that this time would give a more representative area to study mixing variables than would other sedimentation times.

Shear rates and pumping capacity

The ability of particles to catch up with one another and make contact can be evaluated by the velocity gradient (shear rate) existing in the fluid. For example, as shown in Figure 6, if one particle has the velocity of 1 m./s., and another particle has the velocity of 1.3 m./s. they would eventually catch up with each other as they flow around through the tank.

Fluid mechanics tells us that, at a point in a fluid, the product of the velocity gradient and the shear stress is equal to the power per unit volume dissipated at that point. Since shear stress is equal to shear rate times viscosity, this results in the relation that the shear rate squared at a point is equal to the power (P) per unit volume divided by the viscosity (μ). Or,

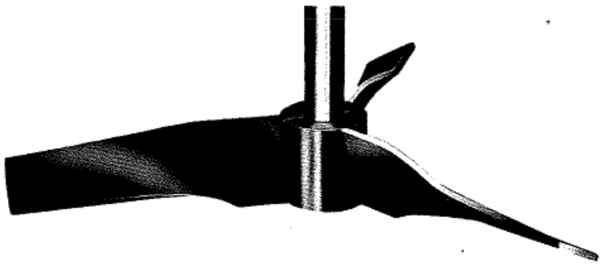

Figure 1. Typical A212 impeller manufactured by Lightnin.

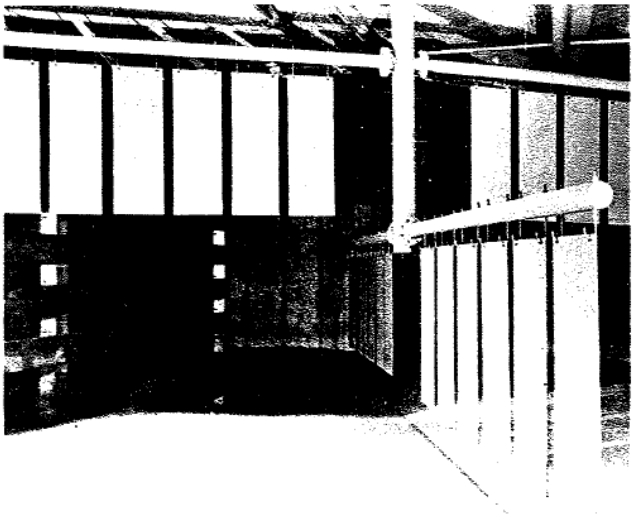

Figure 2. The "dangling plate" type of impeller used in the full-scale plant.

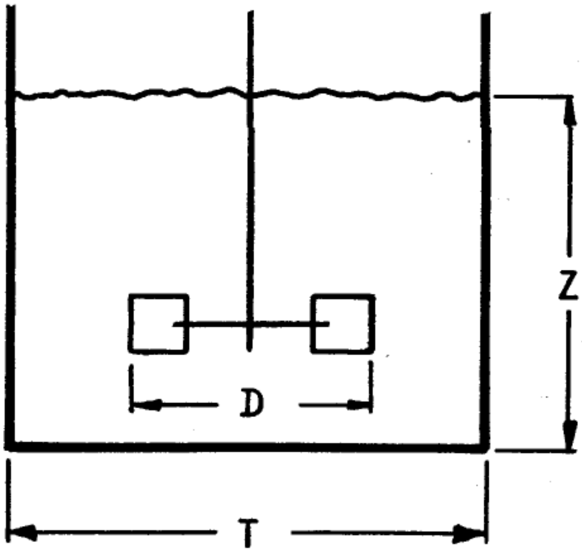

Figure 3. Nomenclature used in this article. D = impeller diameter, T = tank diameter, and Z = liquid level.

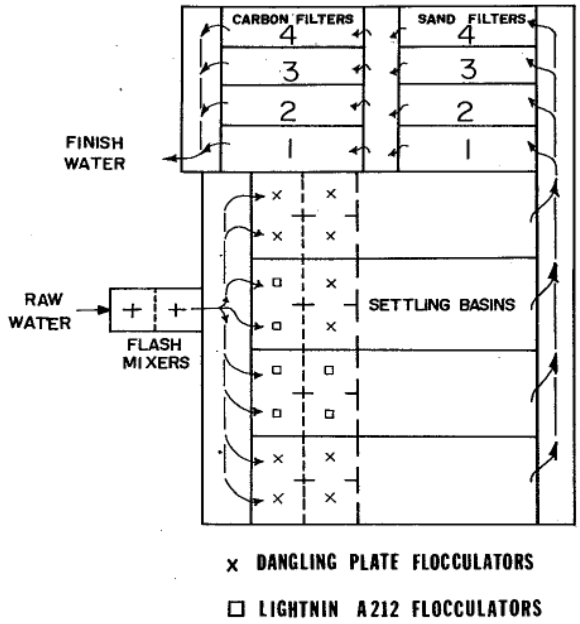

Figure 4. Schematic diagram of flow in full-scale plant.

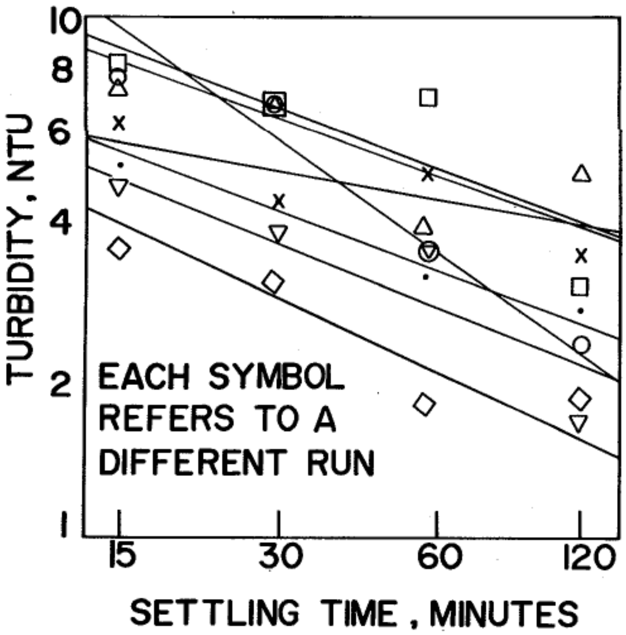

Figure 5. Typical turbidity data as a function on settling time after the mixer has been run for a predetermined flocculation time.

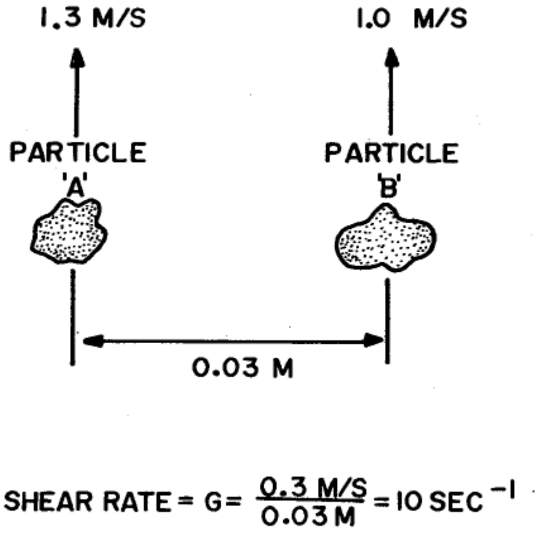

Figure 6. Shear rate.

$$\text{Shear Rate} = \sqrt{\frac{P/\text{Vol.}}{\mu}} = \text{“}G\text{ factor”}$$

This concept has been extended to say that if we consider the entire mixing vessel, then by calculating the average power per unit volume divided by viscosity, we have an approximation to the average shear rate in the tank. This has been given the name, "*G* factor;" and it is a useful concept, although not rigorously accurate in every regard when extended to overall tank averages rather than a point value in the fluid.

Work done by Camp in 1955 (*1*) using this concept on the two kinds of flocculators in existence at that time, indictated that with underflow-overflow baffle type flocculators and the reel type, slow speed, large D/T flocculators, *G* factors of about 30 to 100 s^{-1} were quite typical.

One problem is that this value of the *G* factor is not a parameter that can be related to other kinds of mixing impellers, since the shear rate distribution in the tank can be quite different with various other kinds of impellers at the same *G* factor value. In addition, there is a concept of shear work, or strain, that is the product of shear rate times time. This gives a dimensionless number, *Gt*, that can be thought of as the meter per meter of strain in the fluid, which is a measure of the total work done on the fluid.

The flocculation process is also affected by shear stress, which is the property that can break up floc particles after they have agglomerated due to the shear rate. The shear

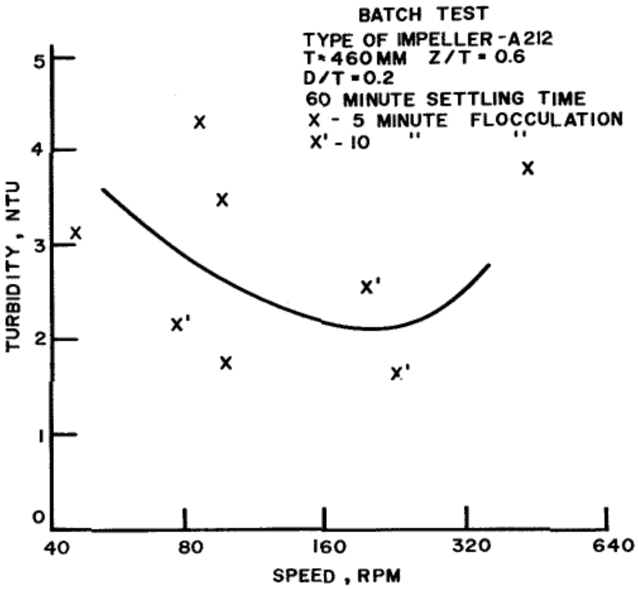

Figure 7. Turbidity as a function of impeller for batch test, A212 impeller in the 460 mm. tank.

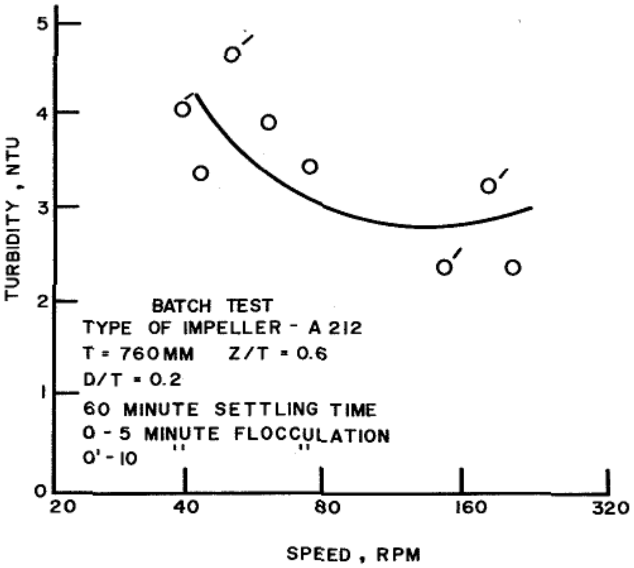

Figure 8. Turbidity vs. impeller speed for A212 impeller, 760 mm. tank.

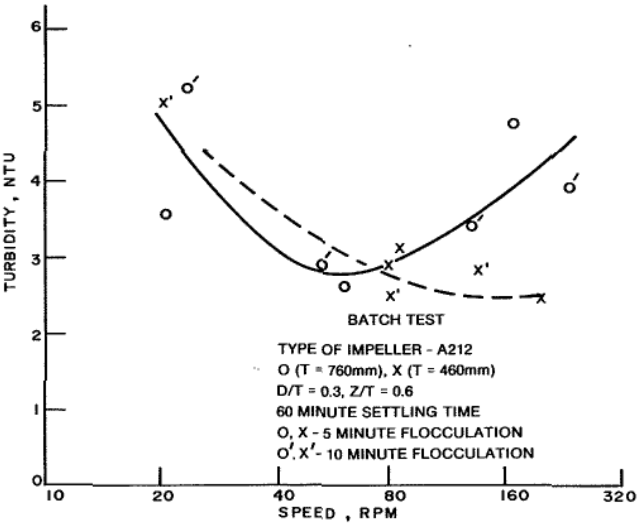

Figure 9. Turbidity vs. impeller speed for A212 impeller, 460 mm. and 760 mm. tanks.

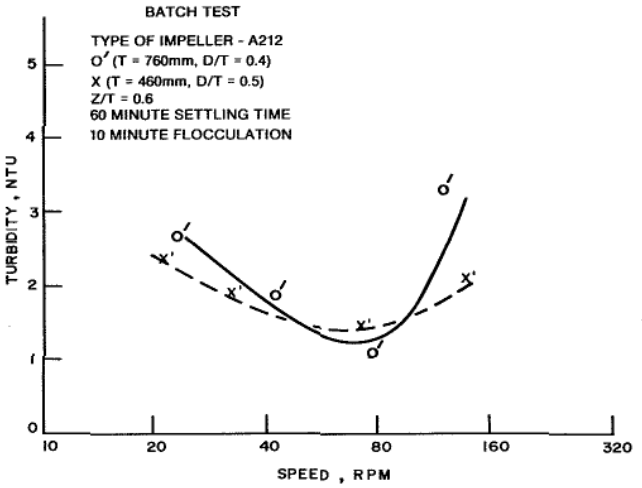

Figure 10. Turbidity vs. impeller speed, A212 impeller, 460 mm. and 760 mm. tanks.

stress has a different relationship than G factor,

$$\text{Shear stress} = \sqrt{(P/\text{Vol.})(\mu)}$$

Recent work on the distribution of shear rates in mixing tanks indicate that there is a macro-scale shear rate

Table 1. Minimum turbidity values at different D/Ts.

	460 mm. Tank				760 mm. Tank			
D/T	R100	A200	Rake	A212	A212	Rake	A200	R100
0.8	—	—	1.3	—	—	1.0	—	—
0.5	—	—	—	1.5	—	—	—	—
0.4	—	—	—	—	1.1	—	—	—
0.3	—	—	—	2.5	2.6	—	—	—
0.2	2.5	3.0	—	2.0	2.4	—	4.0	3.0
0.13	—	—	—	—	2.3	—	—	—

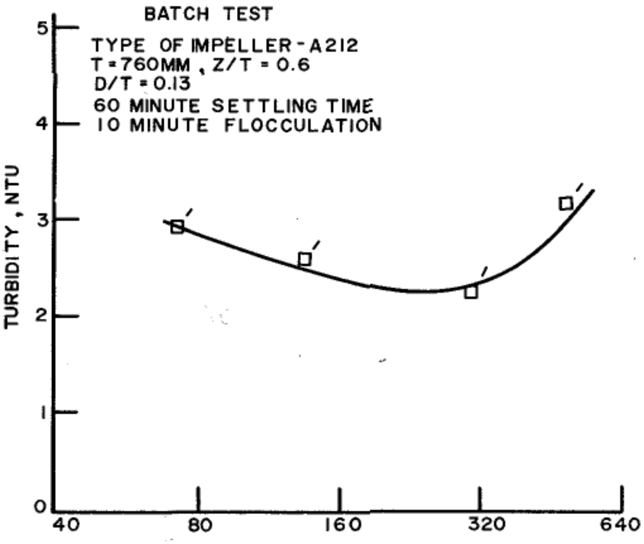

Figure 11. Turbidity vs. impeller speed, A212 impeller, 760 mm. tank.

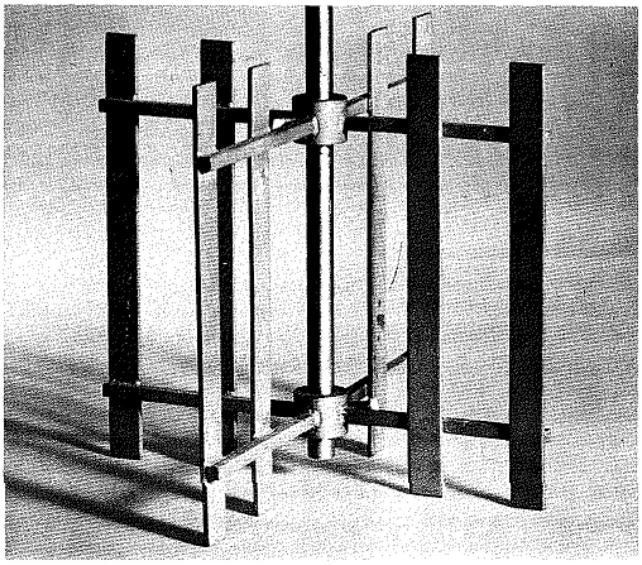

Figure 12. Rake impeller used in both 460 mm. and 760 mm. tanks.

that operates on the average velocities between the individual particles, and a micro-scale rate that is related to the fluctuating shear rates due to turbulent fluctuations.

There are four zones in a mixing tank that need to be considered for both macro-scale and micro-scale shear rates: 1) the maximum impeller zone shear rate, 2) the average impeller zone shear rate, 3) the average tank zone shear rate, and 4) the minimum tank zone shear rate.

Macro-scale occurrences seem to affect particles that are 200 microns and larger, while the micro-scale shear rates seem to affect particles that are less than 100 microns.

The general result from our program showed that the *G* factor is too simplistic to be a single constant correlating parameter for a wide variety of flocculating impellers and mixing variables. If it is used as a parameter, it changes on scaleup, and should not be used as a constant over a wide variety of tank sizes and geometries.

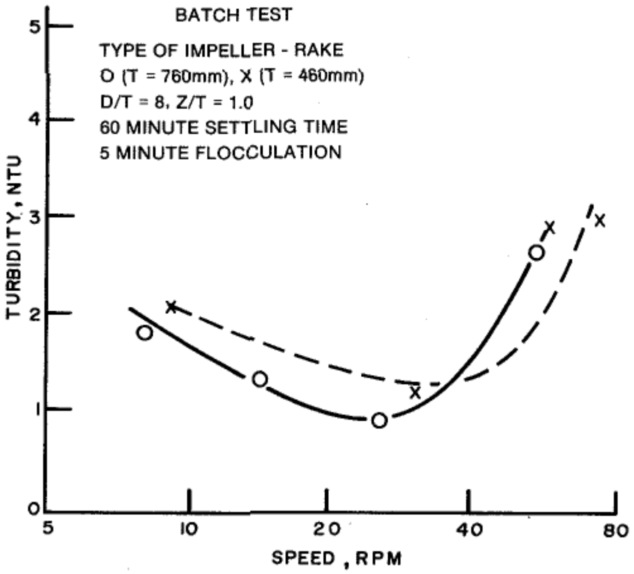

Figure 13. Turbidity vs. impeller speed for rake impeller, 460 mm. and 760 mm. tanks.

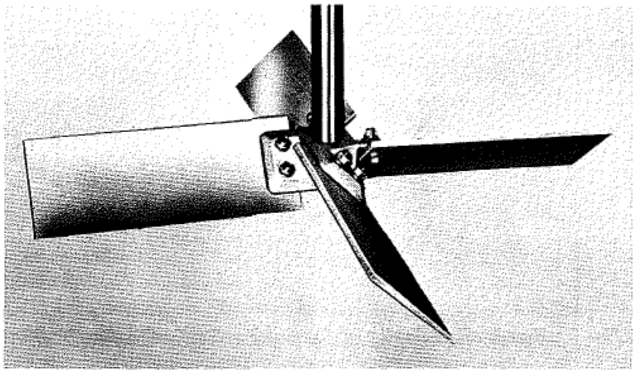

Figure 14. Photograph of A200 impeller.

It also should be added that tip speed is a measure of shear rate with some impellers in measuring maximum shear rate, while with other impeller types it is a measure of average shear rates. In addition, each impeller has a different constant relating shear rate to impeller diameter or impeller speed, so tip speed cannot be used as a universal parameter among different impellers. Several publications treat the matter of these shear rates in greater detail. (*2, 3*)

Experimental procedure and results

Chemically dosed water was flocculated batchwise, with the various impellers discussed later, at a series of speeds with new water from the flash mixing unit being used for each of the more than 60 runs. Initial studies used 5 min. and 10 min. flocculation mixing periods, then measured color, turbidity, and suspended solids at 15, 30, 60, and 120 min. of settling.

Suspended solids proved to be a very difficult quantity on which to obtain reproducible readings, and was not thought to be sufficiently unique that color and turbidity could not be used as parameters. Therefore, color and turbidity were used in the evaluation. As to be expected,

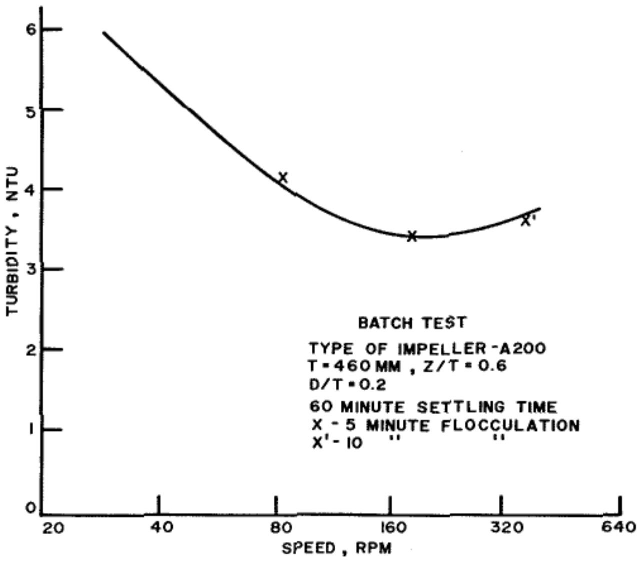

Figure 15. Turbidity vs. impeller speed, A200 impeller, 460 mm. tank.

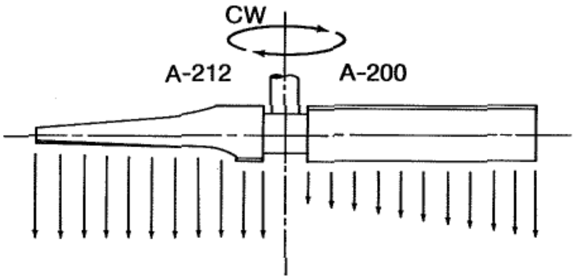

Figure 16. Schematic of the difference in pitch line velocity profiles between A212 and A200 impellers. Actual flow in mixing tank is modified, but A200 has higher internal velocity gradients than A212.

both of these quantities decreased with sedimentation time.

Figure 5 shows typical data obtained. The criteria used in picking conditions for the batch test were to pick conditions such that NTU and color values were in the general range of the full-scale performance, so that batch mixing would be related to practical performance ranges. For example, in the initial stages of the batch flocculation, at 15 or 30 min. settling time, optimum conditions for the mixing variables would be different than the results obtained at our choice of a 60 min. settling time. We therefore chose the 60-min. settling time because it gave NTU values similar in magnitude to the full-scale plant performance.

The greatest number of runs were made with the A212 impeller at a D/T ratio of 0.2. Figure 7 shows a plot of turbidity as a function of operating speed in the 460 mm. diameter tank. Figure 8 shows turbidity in the 760 mm. diameter tank. Table 1 summarizes the results.

At the optimum point of minimum turbidity, we have the optimum combination of shear rates, shear stresses, pumping capacity, and all the other mixing variables for that particular operating condition. It can be observed that the *G* factor is not constant at these optimum points, Table 2.

Studies made with D/T ratios of 0.13, 0.3, 0.4, 15, are shown in subsequent curves, in Figures 9, 10, ond 11.

As shown in Table 1, the flocculation performance for the A212 impeller at its optimum speed is improved as the D/T ratio is increased. Experience indicates there is no major advantage for D/T ratios to exceed 0.5 for impeller type flocculators.

Looking at Table 2, it is seen that the *G* factor increases for the A212 impeller as the D/T ratio increases. This indicates one possible explanation for the improved results. The optimum point for the bigger D/T impellers occurred at a higher power input and a higher average shear rate, which means that there is more opportunity for the positive effects of shear rate before the detrimental effect of shear stress enters the picture.

In terms of power cost for flocculation, however, it is seen that the power required to achieve the better absolute performance with the bigger D/T ratios is considerably higher than with small D/T ratios. So, if these higher flocculation performances are not required for satisfactory water quality, there is considerable savings in both power and equipment cost by using smaller D/T impeller type units, in the D/T range of 0.2 to 0.3.

Comparing the 460 and 760 mm. diameter tank, it is seen that the *G* factor decreases as the tank size increases. The dimension differences between the 460 mm. and 760 mm. tank are not far enough apart to make quantitative statements on the scale-up slope of full-scale flocculation performance.

The rake impeller, shown in Figure 12, was used to simulate the performance of the general class of slow-speed, reel-type impellers. In our experience, rake, dangling plate and anchor type impellers have similar characteristics. The rake was run at a D/T ratio of 0.8 and had a performance, Figure 13, equal to the large D/T A212 impellers. It can be considered to have the necessary combination of flow and turbulence to give optimum flocculation performance.

It can be seen in Table 1 that the performance of the A212 impeller at an 0.4 to 0.5 D/T is about the same as the performance of the rake type impeller at its normal operating D/T of 0.8.

In looking at the rake impeller, it is seen that it has a higher *G* factor, and therefore a higher power consumption for the same performance. In addition, since it has a higher

Table 2. *G* Factor at minimum turbidity (1/sec.).

	460-mm. Tank				760-mm. Tank			
D/T	R100	A200	Rake	A212	A212	Rake	A200	R100
0.8	88	—	148	—	—	112	—	—
0.5	—	—	—	92	—	—	—	—
0.4	—	—	—	—	106	—	—	—
0.3	—	—	—	110	34	—	—	—
0.2	116	77	—	58	27	—	60	59
0.13	—	—	—	—	31	—	—	—

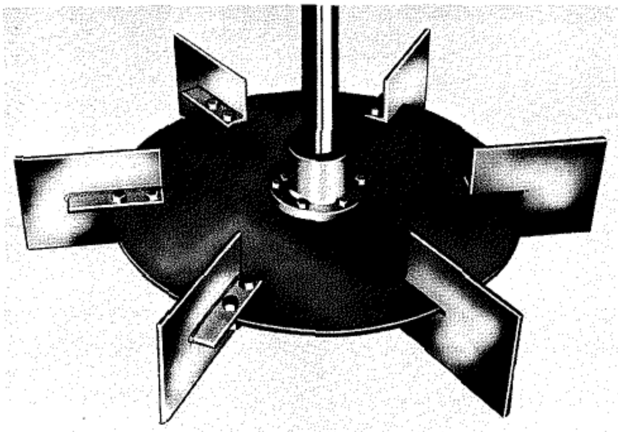

Figure 17. R100 impeller used in flocculation study.

impeller power number, it runs at a much lower speed for the same flocculation performance. This means that not only is the power consumption 50 to 100% higher, but also *the torque, and therefore the mixer drive required is increased* by a factor of two or three.

Another type of axial flow impeller, the A200 impeller is shown in Figure 14. In general, its absolute flocculation performance, Figure 15, was not as good as the A212, and it also operated at *G* factors 50 to 100% higher than the A212.

Figure 16 shows a schematic of the difference in the pitch line velocity of the A200 and the A212 impeller, and it gives some indication of why the shear rate level is less for an A212 impeller at the same general pumping rate. *The A212 has a lower shear rate and turbulence loss* in the impeller zone, which is normally an advantage in shear rate sensitive processes, such as flocculation. Power consumption of the A200 impeller and its higher torque requirement means that it has a capital and operating cost disadvantage compared to the A212.

A radial flow impeller, the R100, Figure 17, gave the performance shown in Figure 18. It did not give as good an absolute flocculation performance at its optimum point, and has a still higher power consumption as well as a higher torque requirement. It does not lend itself to be a *cost effective device for flocculation.*

Effect of filtration

The full-scale Manchester treatment plant obtained final water qualities after filtration of 0.5 NTU or less. As a prelude to experiments to determine whether floc produced from the various impellers differed in their ability to be filtered, some runs were made using a vacuum filter with Whatman BF/A glass fiber filter paper on a Buechner funnel. This was usually done with a 100 ml. sample at a vacuum of 35 kPa. NTU readings of about 4 (similar to pilot results after settling) were reduced to 0.4 to 0.8, which made this appear to be a very practical method for simulating performance on the filterability of solids produced at various levels of flocculation. This was only a preliminary indication, however, and the particular experiments were not carried out further.

Shear rates are necessary to good flocculation performance. In fact, there have to be shear rates (velocity gradients), or particles will not make contact. On the other hand, shear stresses that tend to break up the particles are undesirable. This leads to an optimum speed for any given impeller, geometry, and process result.

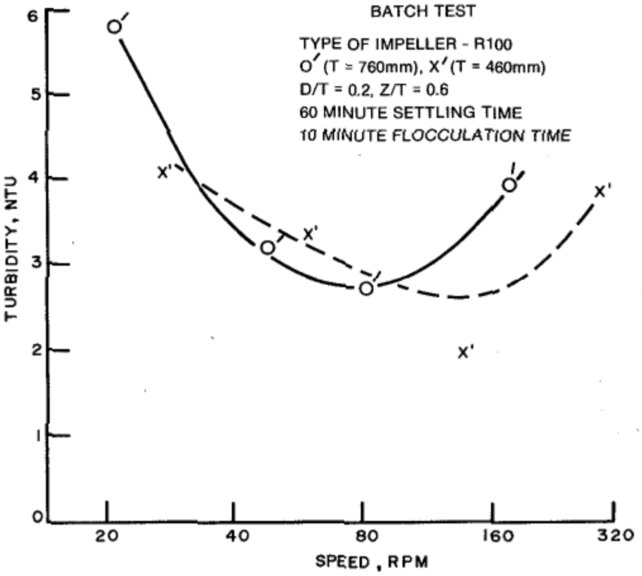

Figure 18. Turbidity vs. impeller speed for R100 impeller, 460 mm. and 760 mm. tanks.

The use of the process parameters of turbidity and color appear to be relatively complimentary in their performance, and obey similar principles. However, as explained, *we chose a 60 min. settling time since that gave* NTU values in the magnitude of the full-scale plant performance.

The 0.4 to 0.5 D/T A212 impeller produces the same result as the large diameter, 0.8 D/T, rake type impeller used. In our opinion, this indicates that the combination of pumping capacity and fluid shear rates are quite similar as we go throughout the mixing tank. A small diameter A212 impeller running at high speed is, however, not as effective as the large D/T A212 impeller. On the other hand, if the small D/T A212 produces satisfactory water *quality under the operating conditions, it does offer a much* lower power cost and capital cost for the same type of process operation. #

Literature cited

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