Nov. 19, 1963 R. L. BATES ETAL 3,111,305

HIGH SHEAR IMPELLER

Filed Sept. 22, 1960

FIG-1

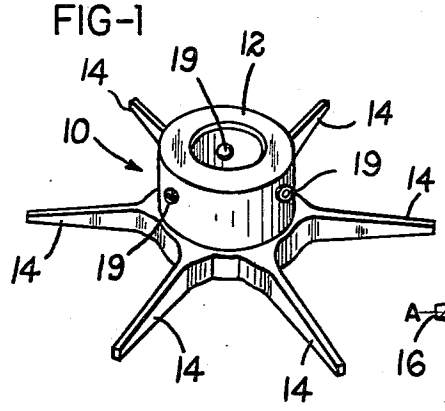


FIG-2

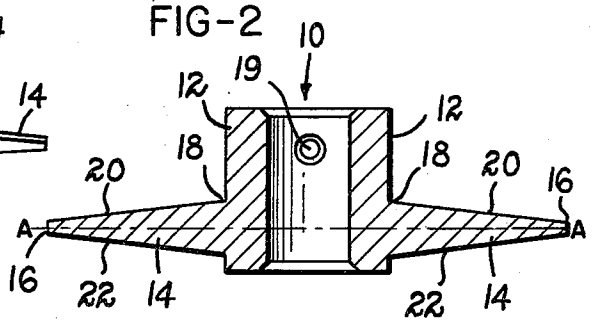


FIG-3

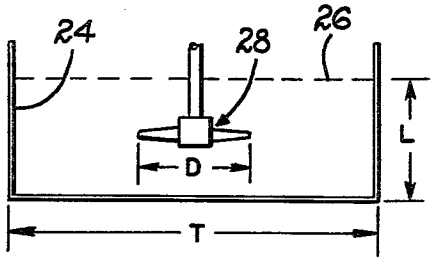


FIG-4

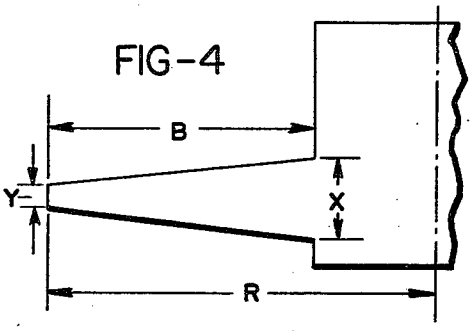
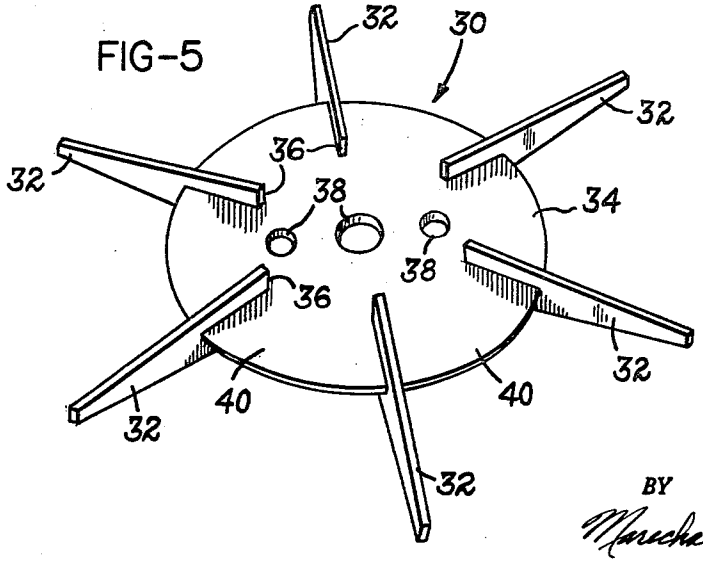


FIG-5



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HIGH SHEAR IMPELLER

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This invention relates to a novel impeller and more particularly to an impeller designed for high shear or high velocity agitation.

Agitating equipment falls into several classes ranging from turbine agitators designed to maintain a system in constant turbulent movement to colloid mills which are designed to comminute particles to a size such that they may be colloidally suspended in a vehicle. High shear work constitutes a rather specialized type of agitator work, and may be classified generally as that producing particle sizes considered quite large relative to those produced by a colloid mill and quite small relative to those produced by conventional turbine agitator equipment.

In the class of high shear agitating equipment which is employed in such instances as emulsification, micro dispersion, extraction, improved chemical reaction, some mass transfer, particle size reduction and phase phenomena, several types of impellers have been employed in the past including for example, radial rotor-stator devices, lateral rotor-stator devices, counter-rotating members, orifice devices and open impellers.

Included in the class of open impellers are the following, simple disks, three-blade marine-like propellers, radial turbines, cone devices and saw-tooth impellers. The use of open impellers is desirable since such devices are of relatively simple mechanical design and employ a drive design which is not as complicated as those required in rotor-stator devices or counter-rotating devices wherein hollow drive shafts and other special equipment is required.

In accordance with the present invention, a novel open impeller for high shear work is provided which is so designed that it possesses a high effective circulating capacity. It has been discovered that the ability to reduce a particle to a given size, that is, from a macro to micro, is directly related to the effective circulating capacity of the impeller. Stated another way, the peripheral or tip speed of the impeller determines the particle size of the final product, while the effective circulating capacity determines the time and the power required to reach the desired particle size. The term "effective circulating capacity" as used herein is used to define a circulating capacity which imparts maximum shear to the material being treated and is not used to designate the actual circulation taking place in the system. For example, a marine propeller possesses a very high circulating capacity since a considerable volume of fluid passes the propeller in an axial direction. Such axial movement withdraws the fluid from the influence of high shear which takes place in the area of the impeller tip. Accordingly, while a marine propeller circulates a considerable volume of liquid, there is a low effective circulating capacity due to the decrease in flow around the tip portion of the impeller.

A further consideration in the design of high shear impellers is that of "scale-up," or increasing the size of the impeller in accordance with the increased volume of material being treated. Heretofore, scale-up has been largely a case-by-case proposition, since the mechanics of high shear agitation have not been analyzed to determine the parameters controlling efficient agitation, nor have impellers been designed which simplify scale-up while

maintaining maximum efficiency of the propeller geometry.

Accordingly, it is an object of the present invention to provide a novel impeller capable of imparting high shear to a system while employing minimum power.

It is another object of this invention to provide an open end impeller of tapered blade construction in which input drive power is minimized by control of the blade dimension thereby providing an efficient impeller design which makes maximum use of input power.

A further object of this invention is to provide a designed open end impeller with a tapered blade configuration wherein the fluid is discharged in a radial direction while maintaining circulation to such a degree as to invest the majority of the input power into shear while providing sufficient effective circulation of the liquid.

A further object of this invention is the provision of an impeller which due to the geometric configuration thereof facilitates and simplifies scale-up to a larger system.

Other objects and advantages of the present invention will be apparent from the following description, the accompanying drawing and the appended claims.

In the drawing:

FIG. 1 is a view in perspective of a novel impeller constructed in accordance with the present invention;

FIG. 2 is a view in section of the impeller shown in FIG. 1;

FIG. 3 is a schematic view of an agitation tank and impeller arrangement illustrating the parameters to be considered in scale-up;

FIG. 4 is a schematic view of an impeller illustrating the impeller parameter to be considered in scale-up; and

FIG. 5 is a view of a modified form of the impeller constructed in accordance with the present invention.

In order to determine the most efficient impeller configuration, a series of tests were performed employing several type open end impellers including for example, a saw-tooth impeller, marine propeller, conventional turbine impeller and a plane disk. The test apparatus included a two-gallon vat in which was placed 20 cc. of molten sodium-potassium and a carrier of mineral oil. All test runs were conducted under a nitrogen blanket, taking care to exclude water from the system. Shaft speeds were measured by a tachometer while input power was measured by a watt-meter. The agitation drive employed was a one-half horsepower, 0 to 16,000 r.p.m., universal motor employing a variable voltage powerstat for speed control.

Two types of tests were conducted, the first series included agitation at a given speed for twenty minutes followed by sampling to determine particle size, the second series of tests involved operation at a given speed and sampling at regular intervals of one to thirty minutes. In all tests the following data was recorded: particle size, input watts, and shaft speed.

The analysis of the data collected in all of the above tests led to the following conclusions:

(1) The ultimate particle size is a function of peripheral speed for a given impeller geometry,

(2) Ultimate particle size appears to be independent of input power since a three-inch impeller used much more power than a one and one-half inch impeller,

(3) The turbine and propeller type devices waste power in circulation while the disk is not efficient in transmitting shear to the fluid, and

(4) Above a given point, the shear zone is "flooded," and particle size versus agitation time is independent of circulating capacity.

Based on the conclusions arrived at during the analysis of the test data, an open end impeller was designed as shown in FIGS. 1 and 2 of the drawing, which illustrates a preferred embodiment of the present invention. The

impeller **10** includes a cylindrical hub **12** with a plurality of blades **14** circumferentially spaced about the hub **12** and extending radially outward therefrom. While six blades are shown, it is possible to employ any number of blades which can be evenly spaced about the outer periphery of the hub **12**, for example, 3, 4, 6, 8, 9, 10 and 12, etc. so as to provide a balanced impeller.

The blades **14** are of tapered configuration being thinner at the tip end **16** than at the root portion **18**, that is, the portion at which the blades are attached to the hub **12**. The blades are usually formed having a transverse dimension or thickness which is less than the root dimension, and the blades should be of sufficient thickness to withstand the torque developed during agitation. Moreover, in order to assure good shear characteristics of the impeller, it is preferred that the blades have a substantial free length, that is that the individual blades be unattached to adjacent blades by interconnecting webbing and the like which would preclude exposing the entire working surface of each blade to the fluid.

Means such as set screws **19** are provided around the outer periphery of the hub **12** for affixing the impeller **10** to a shaft, and it is of course understood that other means well known in the art may be employed in securing the impeller to the shaft.

One feature of the present invention concerns blade symmetry, and it will be noted with reference to FIG. 2, that the upper surface **20** and the lower surface **22** are each tapered to the same degree to define a blade which is symmetrical about a center line A—A extending in a direction perpendicular to the axis of the hub **12** and passing through a plane which is approximately midway between the blade surfaces. It is possible to provide an impeller wherein only one surface of each blade is tapered, and since the majority of the shear takes place along the tip portion of the blade, several geometric blade configurations are possible. Thus, it is also possible to have a blade configuration such that each surface of the blade is tapered a different amount, for example surface **20** could be tapered six degrees while surface **22** could be tapered nine degrees.

Tests of the open end tapered blade impeller of the present invention showed improved impeller performance at decreased power due to the relatively high effective circulating capacity thereof which causes the majority of power input to be transferred to the liquid as shear and not merely circulating capacity. The flow of fluid is radial, and as the blade moves through the liquid, the tapered surfaces impart some shear to the liquid and move the fluid out of contact with the blade towards the tip end thereof. The liquid which is in the area of the tip portion of the blade is exposed to the high shear zone which is located around the blade tips.

By way of comparison, the conventional turbine impellers wherein the blades are of non-tapered design consume considerable power in circulation and therefore are inefficient in imparting shear to the fluid. Since the conventional turbine impeller has a root dimension which is approximately the same as the tip dimension, and due to the fact that the fluid flow in a turbine type impeller is initially axial and then radial in the area of the blades, power is consumed in circulation and thus represents an inefficient design for high shear work. In the tapered blade design, according to the present invention, the fluid flow is again initially axial and then radial in the area of the blades. However, due to the tapered configuration of the blade, the circulation taking place between the root of the blade and the tip is maintained at a minimum because of the decreasing surface area of the blade, thereby allowing the majority of the input power to be invested in shear along the tips of the tapered blades.

For example, a conventional turbine impeller was rotated for twenty minutes at a tip speed of 2180 feet a minute and employed 245 watts to provide a 14-micron particle. An impeller according to the present invention with the tapered blade configuration operating for twenty minutes at a tip speed of 2110 feet a minute consumed 74 watts in reducing a particle to 14.5 microns. A marine propeller was rotated for twenty minutes at a tip speed of 2010 feet a minute and employed 50 watts to produce a 40-micron particle. An impeller constructed in accordance with this invention, having a tip speed of 1690 feet a minute was run for twenty minutes consuming 45.5 watts to produce a 19.2 micron particle size. A saw-tooth impeller rotated at a tip speed of 2070 feet a minute for twenty minutes produced a 14.6-micron particle size consuming 76.0 watts, while an impeller as shown in FIG. 1 rotated at a tip speed of 2040 feet a minute for twenty minutes and produced a 14.5-micron particle size after consuming 75.0 watts.

While the above results indicate better performance of the impeller constructed in accordance with the present invention, comparison of the configuration of the several impellers should be considered since geometric configuration is an important consideration not only in impeller manufacture but in scale-up. The saw-tooth impeller is considered in the art a highly efficient impeller but represents a rather intricately designed device since high shear is provided by a series of saw-like teeth arranged around the outer periphery of a planar disk. Two sets of teeth are provided, the first set extending in one direction perpendicular to the plane of the disk and the second set depending in an opposite direction in the plane of the disk. The teeth are arranged so that alternate teeth extend in the same directions. Each of the teeth is canted slightly so as to expose one surface thereof as a cutting edge which bites into the fluid, so to speak. Manufacture of this type impeller is not as simple as manufacture of the impeller shown in FIGS. 1 and 2, for example, since each of the teeth must be in the proper relation and canted to the same degree. The marine propeller and conventional turbine represent more simplified designs but do not possess the desired high shear capabilities. In considering the procedure involved in scale-up and the desire to maintain impeller geometry constant during such scale-up, it is apparent that the tapered impeller of the present invention offers a considerable advantage over a saw-tooth impeller due to simplicity of impeller geometry.

In determining the proper size impeller and proper speeds for a particular particle size, the usual procedure is to set up a test system as shown in FIG. 3, for example. A tank **24** having a diameter T filled with a liquid **26** to a level L is provided with an impeller **28** of diameter D driven by a suitable motor of the required size. The initial selection of T, L and D, as well as the tip speed depend to a great degree on the characteristics of the fluid system, for example, viscosity and specific gravity, etc. as is well known in the art. The impeller diameter is normally a function of the viscosity, the more viscous liquids requiring larger diameter impellers. The tip speed of the impeller is a function of the anticipated shear to be imparted to the liquid and thus controlled by the desired particle size. Having arrived at a proper selection of tank size, impeller diameter and tip speed for achieving the desired particle size while maintaining total power expenditures at a minimum, the scale-up procedure is as follows. The L/T ratio is maintained constant while maintaining the D/T ratio constant. For example, assume that the tank **24** has a diameter of ten inches and contains 3.4 gallons of liquid having a depth of ten inches, and that an impeller having a two inch diameter produced acceptable results requiring a minimum power expenditure. The D/T ratio is 2/10 or 20% and the L/T ratio is 1. In the scale-up, a thirty inch diameter tank is filled to a level of thirty inches thereby maintaining the L/T ratio the same. Such a thirty inch tank filled to thirty inches would contain 91.7 gallons of liquid which represents a rather average quantity of liquid in high shear work. The impeller employed in the larger volume sys-

tem would then be 20% of thirty inches (D) thus giving an impeller of six-inch diameter and maintaining the D/T ratio the same.

Since it is desirable to maintain the horsepower per gallon constant during scale-up, it is necessary to increase the horsepower by a factor of 27 which represents the volume scale-up (91.7/3.4). The scale-up requires an increase in tip speed in the rtaio of $(D/D_1)^{1/3}$ or an increase in tip speed of 44%. Thus by increasing the tip speed by a factor of 1.44, at least the same amount of shear is imparted to the larger system than was imparted with the test system. This scale-up procedure is well known in the art, and is set forth merely for purposes of illustration and to facilitate explanation of impeller scale-up. Scale-up of the impeller constructed in accordance with the present invention, with the relatively simple geometric configuration which facilitates scale-up, can be understood with reference to FIG. 4 wherein R represents the radius of the impeller, B the blade length, X the root dimension and Y the tip dimension. All of the impellers constructed in accordance with the present invention will possess a geometric arrangement such that the following relationships are established: X is always greater than Y, and B is always less than R. For most systems, it is preferred to maintain the X dimension such that it is approximately one-fifth the R dimension while the Y dimension is approximately one-twentieth the R dimension. Thus the two-inch impeller employed in the test unit would have a 1.0-inch R dimension, a 0.2-inch root or X dimension, an 0.05-inch tip or Y dimension.

In scaling-up from a two to a six-inch impeller having a three-inch R, the X dimension would be 0.6 inch and Y would be 0.15 inch. By maintaining X equal to $R/5$ and Y equal to $R/20$, blade geometry is maintained during scale-up resulting in a larger system which possesses characteristics comparable to those of the test system. While it is preferred to maintain the X and Y ratios as above described, since they represent optimum proportions for most systems, use of other dimensions is possible provided the tip or Y dimension is less than the root or X dimension.

As will be noted from the above example, which is cited only for purposes of illustration and is in no way to be construed as a limitation, the impeller diameter was approximately 20% of the tank diameter. It has been discovered that best results are achieved with small diameter impellers which minimize power consumption, and thus it was found that the impeller diameter should be at least 10 to 20% of the tank diameter. At high D/T ratios, for example above 25 to 35%, the approach to ultimate particle size is essentially independent of circulating capacity, and hence power is wasted when the D/T becomes too high since power is invested in circulation rather than shear. Accordingly, the use of the novel impeller of the present invention not only provides an efficient impeller from the standpoint of ultimate particle size per unit running time, but additionally makes maximum use of input power especially if the impeller diameter to tank diameter ratio or D/T is about 10 to 20%.

The above discussion may be more clearly understood with reference to experimental data and the following analysis: A one-inch diameter impeller when operated at the same power level as a one and one-half-inch diameter impeller had a tip speed 31% higher than the larger impeller. Based on experimental data, the ultimate particle size was 62.5% of that obtained with the larger diameter impeller. Thus the smaller diameter impeller, rotating at a higher speed produces a smaller particle size for given power input and demonstrates the advantage of investing power at high tip speeds and holding the impeller diameter to a minimum. It is of course understood that reduction of impeller diameter to diameters significantly below 10% of the tank diameter may produce "dead" zones due to the decreased actual circulation of the impeller. Power consumption is an important consideration in scale-up, and by maintaining the impeller diameter to within 10 to 35% of the tank diameter, power is not wasted by unnecessary circulation, and the liquid is being circulated to a degree sufficient to prevent "dead" spots while imparting maximum shear to the system per unit power input.

In cases where the impeller is affixed to a shaft by threaded bolts which extend through the base of the impeller to engage the shaft, the impeller may be modified as shown in FIG. 5, wherein an impeller 30 is provided with a plurality of blades 32 affixed to the hub 34, which is in the form of a disk. Both the blades and the disk may be formed of any plastic or metallic material which possesses sufficient strength to withstand the force generated during agitation.

Each of the blades 32 is of the tapered configuration, as discussed above in connection with FIGS. 1 and 2, and affixed to the hub or disk 34 by welding or any suitable manner as is well known in the art. One method of affixing such blades to the hub is by providing a slot having a thickness approximately equal to the thickness of the disk 34 and arranged such that as the blade is positioned on the disk, the root portion 36 will be positioned at a point along the outer periphery of the center portion of the disk which is normally occupied by the shaft. A plurality of apertures 38 are provided in the center section of the disk for attaching the impeller to the base of the shaft by means of bolts which are threaded into internally threaded holes located in the base of the shaft, as is well known in the art.

The presence of an annular portion 40 to which the blades 32 are affixed does not significantly reduce the shear characteristics of the impeller, since each blade still has substantial free length. Due to the fact that the majority of the shear which is imparted to the system takes place along the outer periphery or tip portion of the impeller, a small amount of interconnecting webbing is permissible provided the flow characteristics of the system are not significantly altered.

In accordance with the invention as above disclosed, an efficient impeller has been provided combining the desirable characteristics of relatively simple geometry to facilitate manufacturing of the impeller, and a high shear zone which exists along the outer periphery of the impeller. The use of an impeller in an agitation system wherein the impeller to tank diameter ratio is approximately 10 to 35% has been shown to require less power per unit time in achieving a desired particle size since the configuration of the impeller is such that input power is effectively transmitted to shear by providing a high efficiency circulating capacity with a minimum of actual fluid circulation. Due to the relatively uncomplicated geometric configuration, scale-up is readily accomplished by establishing D/T and L/T ratios thereby determining impeller diameter for the larger system and enabling selection of root and tip dimensions which will maintain the characteristics of the larger system comparable to those of the test system. This of course is a very desirable characteristic for an impeller, and coupled with a design which is inherently efficient, provides a novel impeller adapted to be used in high shear work with a minimum of power.

While the forms of apparatus herein described constitute preferred embodiments of the invention, it is to be understood that this invention is not limited to these precise forms of apparatus, and that changes may be made therein without departing from the scope of the invention which is defined in the appended claims.

What is claimed is:

1. In an agitation apparatus wherein hydraulic shear is imparted to a liquid and the like by a rotating impeller which is driven by a power operated motor assembly; the improvement comprising an impeller having a high effective circulating capacity mounted on a shaft, said impeller including hub means and a plurality of blades having substantial free length and extending radi-

ally outward from said hub means, each blade being positioned in a plane which is perpendicular to the axis of said hub means and having a thickness dimension less than the root height dimension thereof, and the root height dimension of each blade being greater than the tip height dimension thereof to define a blade of tapered configuration having at least one surface which is inclined with respect to the axis of each said blade and providing a hydraulic shear zone along the tip of each said blade.

2. An apparatus as set forth in claim 1 wherein each surface of each said blade is inclined with respect to the axis of each said blade to provide a hydraulic shear zone along the tip of each said blade.

3. An apparatus as set forth in claim 1 wherein each blade surface is inclined to substantially the same degree with respect to the axis of each said blade to provide a hydraulic shear zone along the tip of each said blade.

4. An apparatus as set forth in claim 1 wherein said hub means includes a disk member having a diameter at least as great as that of said shaft, and wherein said plurality of blades extend radially outward from said disk.

5. An agitation system comprising a tank having a diameter T filled to a level L with a mixture to be agitated, a shaft having one end thereof positioned below the level of said mixture, means drivingly connected to the other end of said shaft for causing rotation thereof, an impeller having a high effective circulating capacity mounted on said shaft, said impeller including hub means and a plurality of blades having a substantially free

length extending radially outward from said hub means, each blade being positioned in a plane which is generally perpendicular to the axis of said hub means and having a thickness dimension less than the root height dimension thereof, the root height dimension of each blade being greater than the tip height dimension thereof to define a blade of tapered configuration having at least one surface which is inclined with respect to the axis of each said blade, and said impeller having a diameter of about 10% to 35% of said tank diameter whereby input power is efficiently transmitted into shear by said impeller of high effective circulating capacity.

6. An agitation system as set forth in claim 5 wherein each blade surface of said impeller is inclined to substantially the same degree with respect to the axis of each said blade to provide a hydraulic shear zone along the tip of each said blade.

References Cited in the file of this patent

UNITED STATES PATENTS

675,949	Haywood	June 11, 1901
839,714	Blanchat	Dec. 25, 1906
1,040,682	Huberty	Oct. 8, 1912
1,333,379	Block	Mar. 9, 1920
1,402,380	Schaedler	Jan. 3, 1922
1,537,076	Gilchrist	May 12, 1925
2,201,947	Valentine	May 21, 1940
2,269,736	Rogers	Jan. 13, 1942
2,461,720	Cadwood et al.	Feb. 15, 1949
2,520,540	Green	Aug. 29, 1950
2,697,589	Davey	Dec. 21, 1954