May 23, 1972 K. M. GROUT ET AL 3,664,638

MIXING DEVICE

Filed Feb. 24, 1970

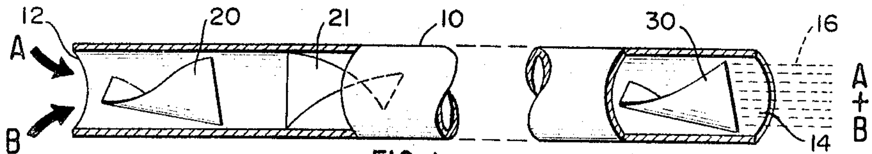


FIG. 1

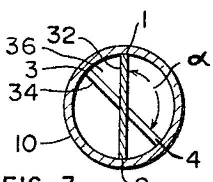


FIG. 3

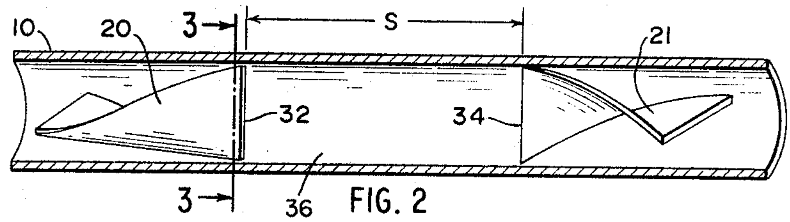


FIG. 2

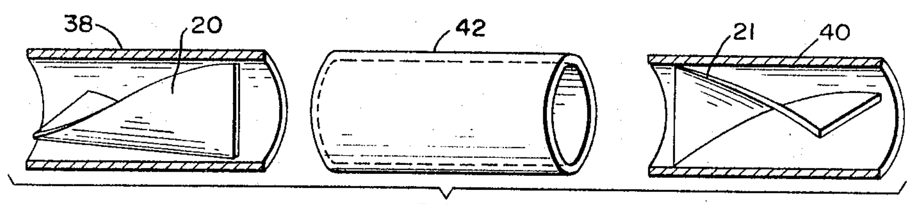


FIG. 4

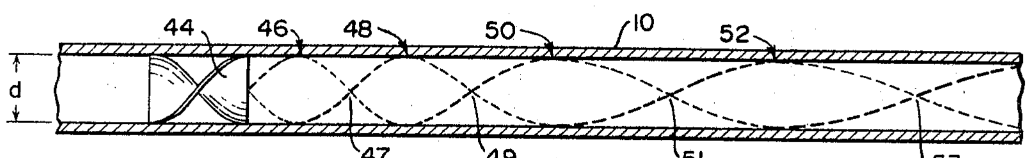


FIG. 5

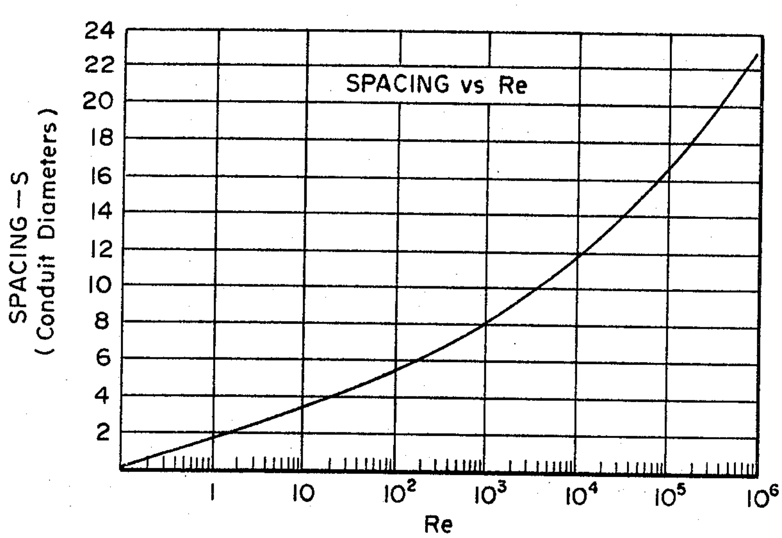


FIG. 6

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# 3,664,638
# MIXING DEVICE

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U.S. Cl. 259—4 3 Claims

## ABSTRACT OF THE DISCLOSURE

A device for thoroughly mixing components of a fluidic material flowing through a conduit which contains a plurality of curved sheet-like elements extending longitudinally through the conduit in which consecutive elements are curved in opposite directions and the adjacent edges of consecutive elements are spaced from each other by a distance dependent on the Reynolds number of the fluid and angularly displaced with respect to each other by an angle which differs from 90° by an amount dependent on said distance.

## BACKGROUND OF THE INVENTION

### (1) Field of the invention

Mixing devices for mixing of a plurality of components of a fluid.

### (2) Description of the prior art

The prior art to which this invention relates is most closely represented by the U.S. patent to Armeniades et al. No. 3,286,992. While devices of the type described in that patent produce adequate mixing, the pressure drop required to produce the requisite flow velocity is often undesirably high. This is particularly true where it is necessary to transport fluidic materials long distances through the mixer conduit. The longer the distance, the more extreme are the problems of maintaining a homogenous mixture. Given time and distance, fluidic materials tend to classify themselves, when flowing in the conduit, by physical differences such as density, or thermally by producing a temperature gradient across the diameter of the conduit. In devices, such as shown in the Armeniades et al. patent, where the conduit is filled continuously with mixer blades, the pressure drop through the mixer may become prohibitively large when the nature of the fluidic materials and the results desired require relatively long mixer structures. One class of devices which requires long mixer conduits is that involving mixtures which need residence time to accomplish a necessary reaction to take place. Such reaction may be chemical or biological.

In view of the foregoing, it would be highly desirable to produce a device of the Armeniades et al. type in which the same or improved mixing action could be achieved with lower pressure drops. Furthermore, if the number of mixing blades could be reduced without reducing the degree of mixing, the expense of producing the devices would be reduced substantially.

## SUMMARY OF THE INVENTION

In the present invention the above limitations of the prior art have been eliminated by constructing a conduit in which the adjacent edges of consecutive curved sheet-like elements are spaced from each other by a distance, the optimum maximum length of which is a function of the Reynolds number of the fluid flowing through the conduit. At a Reynolds number of about 10 such optimum maximum spacing preferably is about three diameters of the conduit. At a Reynolds number of about 200 to 300, the spacing may reach about six diameters. The leading edge of the downstream element should preferably inter-

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cept the body of fluid which has left the trailing edge of the upstream element along a line substantially at a right angle to the line along which said trailing edge had divided said body.

Said body of fluid continues to rotate after it leaves said trailing edge in the same direction which was imparted to it by the upstream element and further continues to rotate for many conduit diameter lengths down through the conduit. The pitch of the rotation of said fluid does not remain constant, but in fact, increases as its distance from said trailing edge increases. The rate of increase of the fluid pitch length is proportional to the Reynolds number of the fluid. It can then be determined that at a particular length of spacing, what should be the proper angle of the downstream mixer element in reference to the upstream mixer element. Said angle will differ from 90° by an amount equal to the angle through which said body has rotated in the intervening space. If no increase in viscosity of the fluid occurs as it flows along the conduit, the spacing between successive elements can remain constant. If, however, the viscosity of the fluid increases, as in the case of certain reactions between components of the fluid, then the spacing between successive elements preferably decreases as such viscosity increases and the angle between successive trailing and leading edge pairs adjusted to produce the right angle interception of the rotating body, as described above.

## BRIEF DESCRIPTION OF THE DRAWINGS

In the annexed drawings:

FIG. 1 is a perspective view, partly in section, of a simple form of device according to this invention;

FIG. 2 is an enlarged partial view of the arrangement shown in FIG. 1;

FIG. 3 is a cross-sectional view along line 3—3 of FIG. 2;

FIG. 4 is an exploded view of components from which the device of FIG. 1 may be constructed;

FIG. 5 is a cross-sectional view of an arrangement for illustrating the persistance of rotation of a fluid body in a mixer conduit; and

FIG. 6 is a graph showing the relationships, between the Reynolds number of the fluid flowing through the conduit and the spacing between the trailing and leading edges of successive curved elements to obtain minimum pressure drop without substantial loss of homogeneity.

## DETAILED DESCRIPTION OF THE INVENTION

In FIG. 1 and FIG. 2, **10** is a hollow tube, preferably cylindrical in cross-section, and providing a conduit through which fluid components A and B are caused to flow in order to be thoroughly mixed. The fluid components are introduced at an upstream end **12** and discharged at a downstream end **14** at which the elements A and B are thoroughly mixed into a homogeneous stream **16**. Within the tube **10** are disposed a plurality of serially arranged curved elements **20**, **21–30**. Each of these elements are constructed of a thin flat sheet whose width preferably, but not necessarily, equals the inner diameter of tube **10** and whose length is preferably 1.25 to several times its width. Each sheet is twisted so that its upstream and downstream edges are substantially flat and are at a substantial angle to each other. This angle, as detailed in the Armeniades et al. patent, may vary between about 60° to about 210°.

These elements are positioned so that for each pair of successive elements (such as shown in FIG. 2), the downstream edge **32** of the first element and the upstream edge **34** of the next element are spaced from each other by a distance D which is predetermined as will be detailed below and are disposed with respect to each other by an angle $\alpha$, (see FIG. 3) which likewise is predetermined as will be detailed below. If the upper and lower ends of the element **32** in FIG. 3 are designated as **1** and **2** and the corresponding ends of the element **34** in FIG. 3 are designated as **3** and **4**, it will be seen that the angle $\alpha$ will be the radial angle subtended by points **1** and **4**. A plenum chamber **36** is thus formed between said edges **32** and **34**. Each element is twisted in the opposite sense to each adjacent element so that the direction of rotation of the body of fluid which passes along the elements is reversed for each successive element.

Typical arrangements for introducing and discharging the fluid elements and examples of the types of fluid components which may be mixed in a device of this general type are detailed in the Armeniades et al. patent and will not be repeated herein. It should be understood, however, that the fluid components may be any of a vast variety. For example they may be a gas and a liquid, parts of the same liquid at different temperatures, a liquid and finely divided solid particles or, of course, two or more different liquids.

In fact this invention has applicability to all flowable materials and therefore the term "fluidic material" will be used to designate the general class of liquids, gases and other flowable materials which it may be desired to mix. It is further to be understood that the terms "fluid" and "fluidic material" will be used interchangeably herein. It is to be understood, of course, that more than two fluidic material components may be mixed in devices according to this invention, the components A and B being merely illustrative.

When the incoming fluid stream encounters the upstream edge of the first element **20**, it is split into two partial streams. The twisting configuration of the element imparts a double rotational motion to these partial streams and the mixing action starts to occur due to the eddy current motion within each partial stream. In devices constructed according to this invention it has been discovered that, as the partial streams leave the downstream edge **32** of the first element **20** and are permitted to merge into a common stream in the plenum chamber **36**, the mixing activity increases substantially and persists as long as the common stream retains a substantial part of the rotation imparted to its two components by the element **20**.

The nature of the continued rotation of the stream may be better understood from the illustration shown in FIG. 5. In this illustration, is shown a conduit **10** having a single mixer element **44** mounted therein. The left hand end of conduit **10** is the upstream end and the right hand end of conduit **10** is the downstream end. The mixer blade **44** is shown, by way of example, having a length of about 1.5 $d$, where $d$ is the inner diameter of conduit **10**, and turning the fluid body through about 180°. The dotted curves extending from the downstream edge of element **44** represents the manner in which the rotation of the fluid body persists in its downstream flow. At the loops **46, 48, 50, 52** the fluid body will have rotated 90° from the position at which it left the trailing edge of element **44** and at the nodes **47, 49, 51** and **53** the fluid will have rotated 180° from such trailing edge position. The fluid body can be considered as having a pitch whose length is the distance between successive nodes. That pitch may be conveniently defined in terms of the inner diameter $d$ of conduit **10**.

In a conduit of uniform diameter, such as shown in FIG. 5, the velocity of the fluid flowing through the conduit will be substantially constant throughout its length. However, as the stream passes along the conduit, frictional forces, of a nature analyzed below, will progressively reduce the rotational velocity of the stream. As a result, as indicated in FIG. 5, the pitch of the stream increases progressively toward infinity as it flows along an extended conduit.

There are a number of factors which determine the rate



at which such rotational velocity decreases as the fluid proceeds through such a plenum chamber. These are the frictional effects at the inner walls of tube **10**, the viscosity of the fluid, its density and its flow rate. It will be recognized that these factors are all involved in the determination of the Reynolds number for any predetermined fluid which is passed through the device at a predetermined flow velocity. Thus the Reynolds number may be expressed as:

$$Re = \rho V d / \mu$$

(Equation 1)

where

$Re$ is the Reynolds number
$d$ is the inner diameter of the tube **10** at the plenum **36**
V is the flow velocity
$\rho$ is the density of the fluid
$\mu$ is the viscosity of the fluid

The rate at which the fluid pitch in FIG. 5 increases will be inversely proportional to the Reynolds number and likewise the actual length of each complete rotation or pitch will be inversely proportional to the Reynolds number. Therefore at low Reynolds number, where the viscosity is high and thus introduces large frictional losses, the rotation of the fluid is reduced at a greater rate making each such pitch length longer than at the higher Reynolds number where the frictional effects are less and the rotational persistence of the fluid body is greater. Thus each arrangement of the kind shown in FIG. 5 will have a specific characteristic fluid pitch profile for each Reynolds number of fluid passage through the device. A practical and simple procedure for determining such pitch profile for each size of conduit and mixer blade configuration is to construct a full-size model, as shown in FIG. 5, with the conduit **10** made of a transparent material. Then a fluid is passed through the device at a predetermined Reynolds number, whereupon the pitch pattern can be seen and accurately measured. In some cases, it may be desirable to add a trace of additional particles such as air bubbles or colored droplets to enhance the visibility of the pitch pattern. In any event, each mixer structure will possess a "characteristic fluid pitch profile" for each Reynolds number.

In accordance with this invention it has also been found that for each Reynolds number a certain spacing S between successive mixer blades exists at which the pressure drop is a minimum without substantial loss of homogeneity in the fluid body. In FIG. 6 such spacing S is plotted, in terms of the diameter $d$ of the conduit, against the Reynolds number. Preferably this invention will be used at Reynolds numbers at above about 100. At $Re=100$, S is between about 5 and 6 diameters $d$. For spacings greater than S it has been found that various components of the fluid stream segregate themselves so that the degree of homogeneity of the stream deteriorates substantially. For the purposes of this invention the distance S is termed "the homogeneity loss distance" for each Reynolds number and such distance can be determined from the curve in FIG. 6. As previously indicated the fluid components may be portions of the fluid at different temperatures, components with different densities, and the like. To the degree that some loss of homogeneity can be tolerated, the actual spacing between mixer blades can be greater than S in order to achieve an even greater degree of pressure drop.

As the mixer blades are spaced closer than the distance S, some of the benefits of this invention may still be achieved although with some increase in pressure drop over the minimum possible pressure drop. However, the actual spacing between mixer blades must be substantial in order to achieve substantially reduced pressure drops over the prior art. In general the spacing between blades should be a substantial distance which is of the order of the homogeneity loss distance or less.

In order to achieve the best mixing action (referring to FIGS. 1, 2 and 3), the leading edge **34** should intercept the rotating body of fluid in the plenum **36** at right angles to the line along which the preceding trailing edge **32** had divided said body. In such case, the angle $\alpha$ will differ from 90° by the angle through which the fluid will have rotated in the plenum **36** between the time it left the trailing edge **32** and reaches the leading edge **34**. To determine such angle $\alpha$ for any device according to this invention, such device will have assigned to it a characteristic Reynolds number at which it will be designed to operate. The characteristic fluid pitch profile will then be determined as described above. Under the principles explained in connection with FIG. 6, a specific spacing between successive mixer blades will be chosen. This spacing will fix the point on the characteristic fluid pitch profile at which the leading edge of the downstream mixer blade will be located. If it is located at a loop of such profile, it will be seen that the fluid body will have rotated through 90° after leaving the upstream trailing edge and therefore the angle $\alpha$ will be 180°. If such leading edge is located at a node the angle $\alpha$ will be 90°. Therefore, as the position of the leading edge is moved from a node along one pitch length to a loop and then on to the next node, the angle $\alpha$ will increase from 90° to 180° and then back to 90°.

If the viscosity of the fluid to be mixed remains constant as it flows through the length of tube **10**, then the spacing between mixer elements and the angle $\alpha$ will be the same for each successive pair of elements. However, in some cases there may be a change in the viscosity of the fluid during its passage through the present mixer due to a reaction occurring in the fluid in such passage. Since the user will know the elements of the fluid which he desires to mix and also the velocity at which he will pass the fluid through the device, he will be able to predetermine the viscosity of the fluid at each point along the tube **10**. By applying the teachings of this invention, as given above, a mixer with values of spacing and $\alpha$ adapted to match the changing Reynolds numbers along the tube **10** can be constructed.

It will be seen that each device constructed according to this invention will be characterized by a specific Reynolds number or, in the case of varying viscosity, by a Reynolds number profile along the length of the device. This number or profile thus becomes a permanent characteristic of the device so that each such device can be said to possess a "characteristic Reynolds number." Such term will be used in the above sense in the claims hereof. Thus any user of the device will know the limits of the viscosity and velocity of the fluid which he will mix by means of any given model of the device.

In order to construct a mixer having any characteristic Reynolds number, such a mixer may be assembled, for example, with components as shown in FIG. 4. Each curved element or mixer blade is initially mounted in a separate short length of tubing, the left hand turning element **20** being mounted in a short length of tubing **38** and the right hand turning element **21** in a short length of tubing **40**. The spacing between each successive pair of elements is determined by the length of a simple piece of tubing **42** interposed between the lengths of



tubing **30** and **40**. Having predetermined the spacing by applying the principles of this invention, the length of **40** is so selected as to result in such spacing when the tubing members **38**, **42** and **40** are assembled and secured to each other, in the order as indicated in FIG. 4. Likewise, having predetermined the angle $\alpha$, the tubing elements are rotated on their axes with respect to each other until the desired angle is achieved, whereupon the members **38** and **40** are held fixed in such position until the parts have been secured to each other. Depending upon the material of which the members **38**, **40** and **42** are made, any means of fastening such members together may be used, such as brazing, welding, gluing, plastic setting, clamping or the like.

It has been found that when a device as shown in Armeniades et al. is compared with a device constructed in accordance with this invention, a less expensive device results with a lower cost of operation due to fewer mixer elements and lower pump pressures required for the same mixing action.

What is claimed is:

**1.** A device for mixing fluid components which comprises:

(a) a conduit through which a stream of said components is adapted to flow, said conduit containing a plurality of curved sheet-like elements extending longitudinally within said conduit, each of said elements extending substantially to the inner walls of said conduit;

(b) successive elements being spaced from each other to provide a plenum between successive elements, whereby the body of fluid is caused to rotate by such elements and to continue to rotate as a body in the same direction as it passes along said plenum;

(c) the length of each plenum being of the order of or less than the characteristic homogeneity loss distance at the characteristic Reynolds number of said device;

(d) each successive element being curved in the opposite sense to that of the preceding element;

(e) the leading edge of each successive element being disposed to intercept said body at a substantial angle to the line of said body along which the trailing edge of the preceding element has divided said body of fluid.

**2.** A device according to claim **1** wherein said angle is substantially a right angle.

**3.** A device according to claim **1**, wherein the characteristic Reynolds number of said device is greater than about 100.

**References Cited**

UNITED STATES PATENTS


| | | | |
|---|---|---|---|
| 3,297,305 | 1/1967 | Walden | 259—4 |
| 3,286,992 | 11/1966 | Armeniades et al. | 259—4 |

FOREIGN PATENTS

| | | | |
|---|---|---|---|
| 735,033 | 8/1932 | France | 259—4 |


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