United States Patent [19]

Miura et al.

[11] **3,893,654**

[45] **July 8, 1975**

[54] **MIXING APPARATUS**

[76] Inventors: **Harunobu Miura**, 8-40 Kumoi-cho, Nishinomiya-shi, Hyogo-ken; **Kenji Asano**, Murakami Sue 2137-2 1-chome Hakozaki, Maekawacho, Fukuokashi, both of Japan

[22] Filed: **Mar. 16, 1973**

[21] Appl. No.: **342,032**

[30] **Foreign Application Priority Data**

Mar. 18, 1972 Japan 47-027558

[52] **U.S. Cl.** **259/4**

[51] **Int. Cl.²** **B01F 15/02**

[58] **Field of Search** 259/4, 18, 36; 138/38

[56] **References Cited**

UNITED STATES PATENTS

2,591,398	4/1952	Brock	138/38
3,051,453	8/1962	Sluijters	259/4
3,195,865	7/1965	Harder	259/4
3,239,197	3/1966	Tollar	259/4
3,286,992	11/1966	Armeniades	259/4
3,620,506	11/1971	So	259/4
3,643,927	2/1972	Crouch	259/4
3,652,061	3/1971	Chisholm	259/4
3,704,006	11/1972	Grout	259/4
3,751,009	8/1973	Archer	259/4

Primary Examiner—Harvey C. Hornsby

Attorney, Agent, or Firm—Browdy and Neimark

[57] **ABSTRACT**

A mixing element for insertion into a conduit for supplying a stream of the liquid mixture comprises a pair of rectangular members having a common transverse axis, and a pair of generally triangular members each leading normal to the rectangular members from one half of the longitudinal edge of one of said rectangular members and having its transverse edge abutting upon the other half of the longitudinal edge of the other of said rectangular members and having quasi-conical bodies abutting the rectangular members and the conduit walls. A mixing apparatus is further disclosed which comprises a conduit of uniform square or rectangular cross section, and a desired number of the above mixing elements disposed therein in the manner described in the specification. The apparatus is not equipped with any mechanically driven agitator and has many advantages such as in manufacture and service thereof.

4 Claims, 18 Drawing Figures

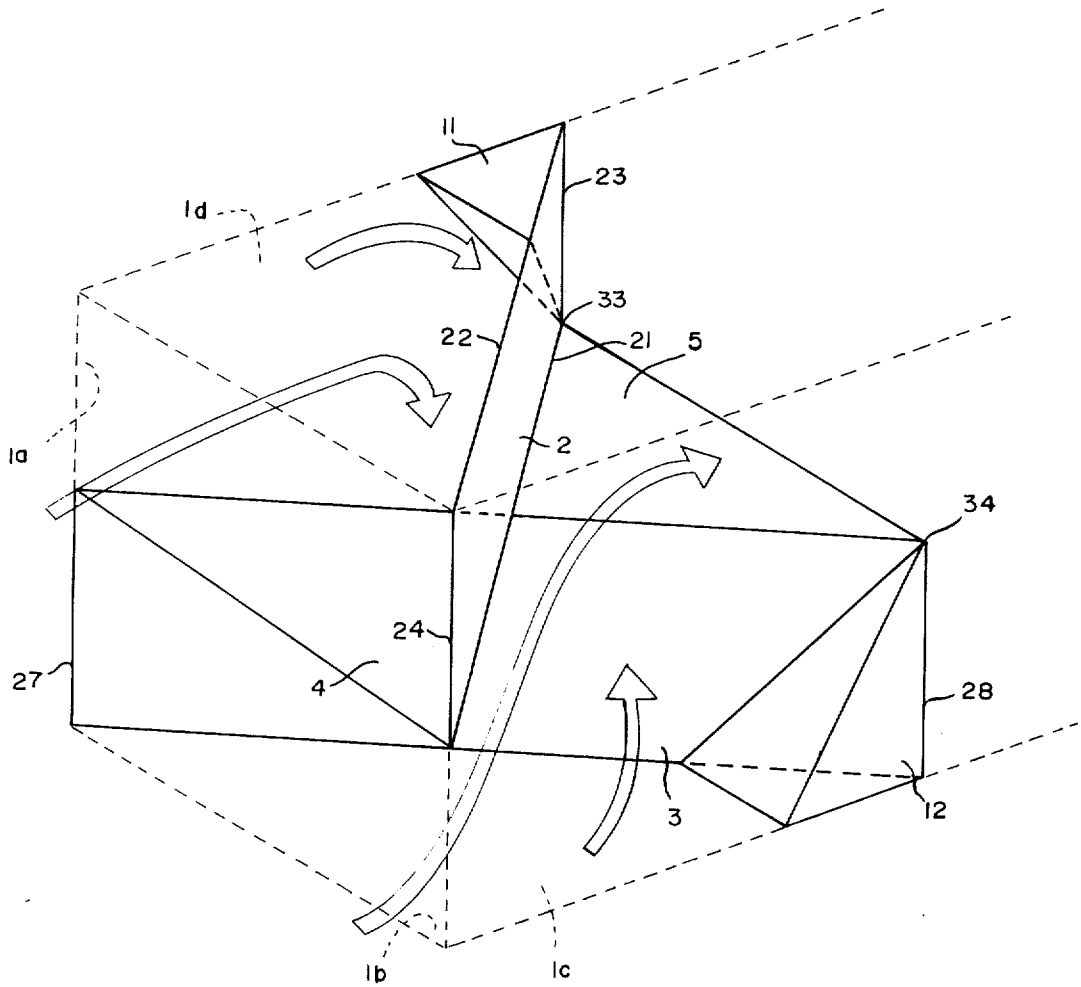


FIG. 1

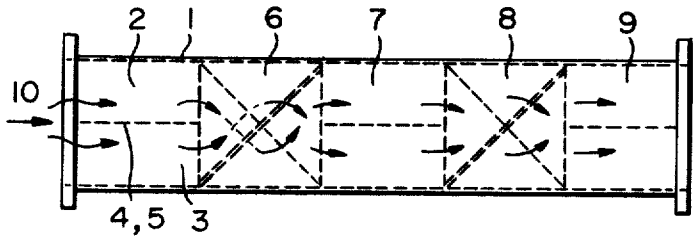


FIG. 2

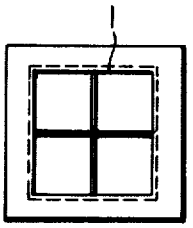


FIG. 3

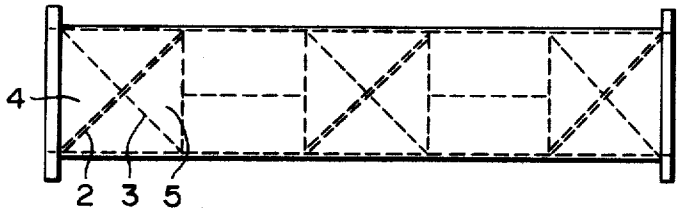


FIG. 4

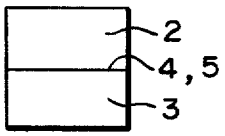


FIG. 6

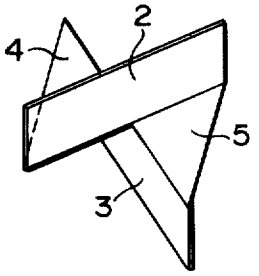


FIG. 5

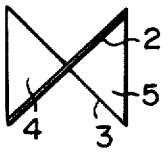


FIG. 7

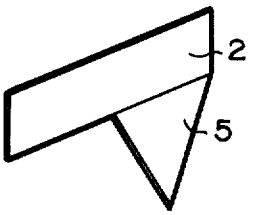


FIG. 8

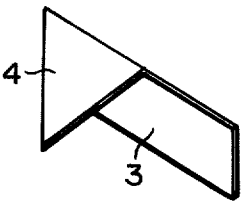


FIG. 11

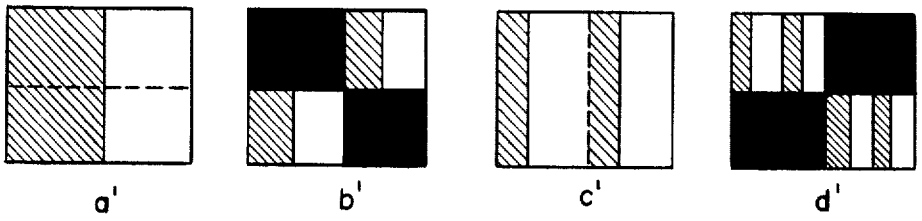


FIG. 12

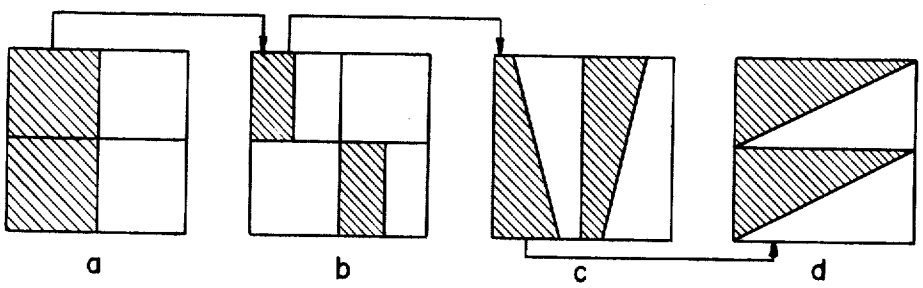


FIG. 9

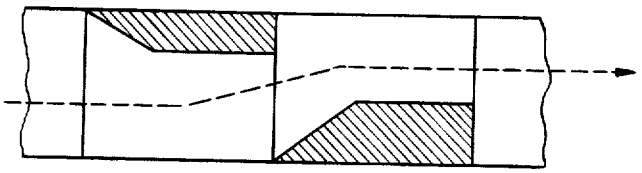


FIG. 10

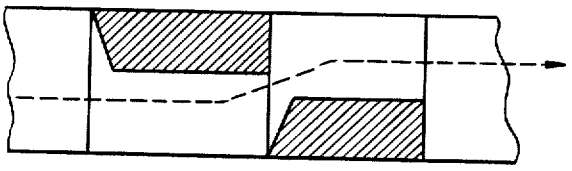


FIG. 13

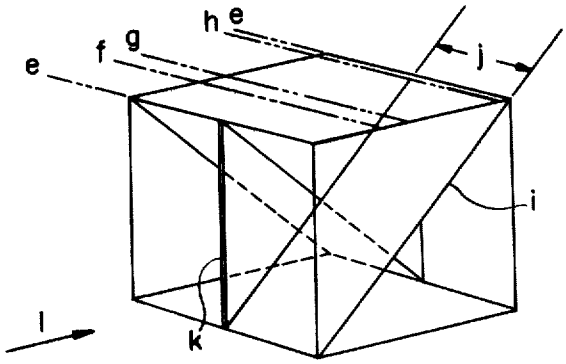


FIG. 14

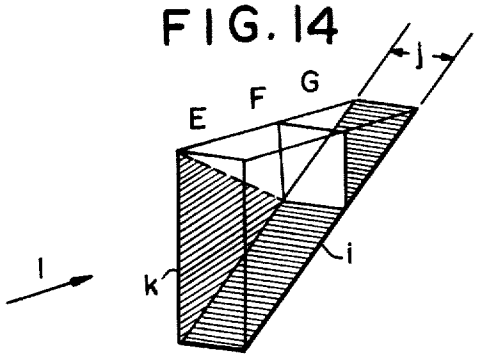


FIG. 15

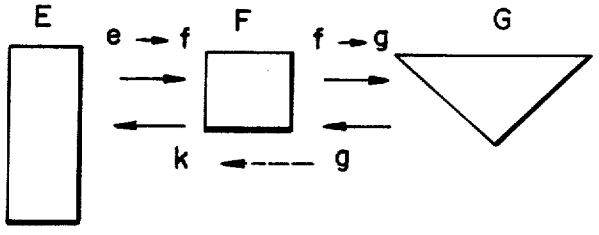
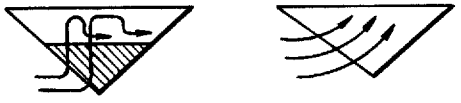


FIG. 17 FIG. 16



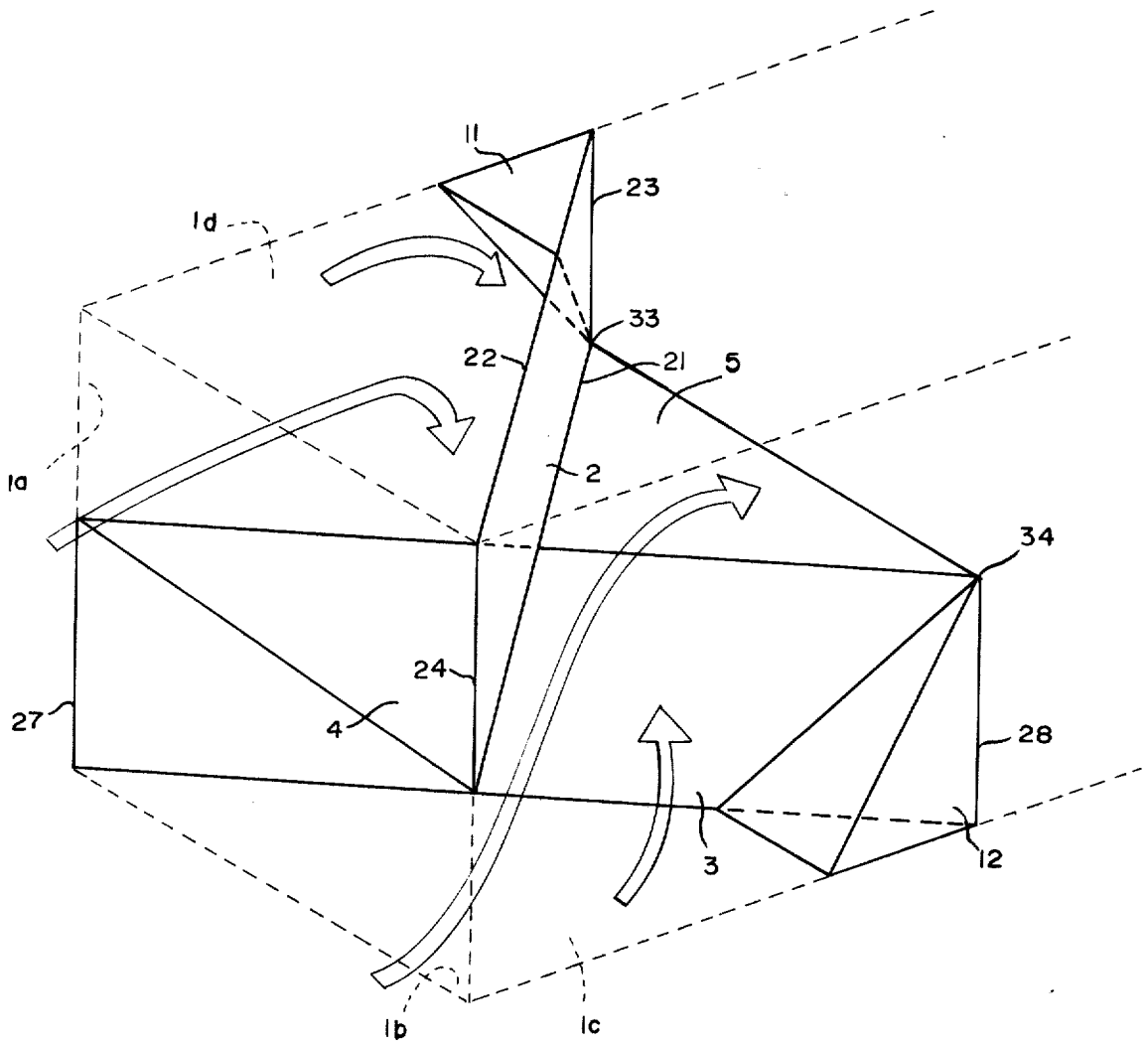


FIG. 18

MIXING APPARATUS

BACKGROUND OF THE INVENTION

a. Field of the Invention

This invention relates to the mixing of flowing streams of liquids, and more particularly, to a mixing apparatus having no rotor for mechanical agitation but having a structure wherein the stream of liquids is repeatedly divided and joined as it flows.

b. Description of the Prior Art

Hitherto, liquids have generally been blended or mixed in a tank or tube which is agitated by a mechanically driven impeller. Such a mechanically driven mixing apparatus has many defects in that it inevitably vibrates and leaks liquids and, therefore, it is in frequent need of repair and is difficult to maintain. Further, since such a mixing apparatus is often set up as one unit of a continuous process in a large scale chemical plant, such defects affect not only the operation of itself but also the process control of the entire plant.

Therefore, there have been developed static mixing apparatus which have no mechanically driven impeller and which can be directly disposed in the pipeline. Static mixing apparatus are, however, generally equipped with more intricate mixing elements than the mechanically driven mixers, and, therefore, they have less effective space for flowing passage, resulting in economical disadvantage not only in manufacturing but also in operation due to the energy loss by the pressure drop of the stream. It is also difficult to maintain the same. On the other hand, if a static mixing apparatus is equipped with relatively simple elements, such as a pipe equipped only with divider or deflector plates, the essential mixing effect is not attained sufficiently, although it is easy to manufacture and maintain.

SUMMARY OF THE INVENTION

A primary object of this invention is to provide a mixing apparatus not having the above mentioned disadvantages of the prior art, but which is more economical to manufacture and easier to service.

Another object of this invention is to provide a unitary mixing element which can be disposed in the supply line of flowing liquids in order to insure thorough and uniform homogenization of liquids.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a front view of a mixing apparatus according to the invention.

FIG. **2** is a side view of the same.

FIG. **3** is a plan view also thereof.

FIG. **4** and FIG. **5** are respectively a front view and a plan view of a unitary mixing element according to the invention which element comprises a pair of rectangular members **2** and **3**, and a pair of triangular members **4** and **5**.

FIGS. **6**, **7** and **8** diagrammatically illustrate the unitary mixing element according to the invention.

FIGS. **9** and **10** illustrate the relation between the dead spaces and the liquid stream in mixing apparatus of the prior art.

FIGS. **11** and **12** illustrate the comparison in the dividing efficiency between mixing apparatus of the prior art and the present invention.

FIGS. **13**, **14** and **15** illustrate the dividing effect caused by the deflector, namely, the rectangular plate of the unitary mixing element. In these drawings, *e*, *f*, *g* and *h* indicate the direction normal to the flowing direction. E, F and G indicate respectively the divider plate, the flowing passage and the passing-through passage.

FIGS. **16** and **17** illustrate the flowing-up action and the straight flowing action of the liquid stream.

FIG. **18** shows a further embodiment of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Preferred embodiments of this invention will be described hereinafter with reference to the accompanying drawings.

As is shown in FIGS. **1**, **2** and **3**, a mixing apparatus according to the present invention comprises a conduit of uniform square or rectangular cross section, having four sides **1***a*, 1*b*, 1*c*, 1*d*, each of which has a substantially flat inner surface, for supplying a stream of the mixture of liquids, and a number of mixing elements disposed therein in a specific manner described hereinafter.

As is shown in FIGS. **6**, **7** and **8**, each of said mixing elements is composed of a pair of units each comprising a rectangular member (namely, deflector plate) and a generally isosceles triangular member (namely, divider plate) leading normal to said rectangular member from one half of the longer edge thereof. As is shown in FIG. **6**, a pair of said units is assembled into a mixing element in such a manner that one rectangular member is positioned on the center of the longitudinal edge of the other rectangular member in crossing relationship and that the rectangular members have a common central transverse axis **20**. Thus, the mixing element comprises a pair of rectangular members, a first rectangular member **2** having a first longitudinal edge **21**, a second longitudinal edge **22**, a first lateral edge **23** and a second lateral edge **24**, and a second rectangular member **3** having a first longitudinal edge **25** (FIG. **8**), a second longitudinal edge **26**, a first lateral edge **27** (FIG. **5**) and a second lateral edge **28**, having a common transverse axis **20**, and a pair of generally triangular members **4**, **5** each leading normal **20** to one of the rectangular members from one half of the longitudinal edge thereof and having its transverse edge abutting upon the other half of the longitudinal edge of the other of said rectangular members **2**, **3**. Generally triangular member **5** leads normal to first rectangular member **2** from one half of the first longitudinal edge **21** of the first rectangular member **2** and has one edge **30** abutting the first longitudinal edge **25** of the second rectangular member **3**. Generally triangular member **4** leads normal to second rectangular member **3** from one half of the first longitudinal edge **25** of the second rectangular member **3** and has one edge **31** thereof abutting the first longitudinal edge **21** of the first rectangular member **2**. Said rectangular members are preferably assembled normal to each other. In this preferred embodiment, the triangular members **4**, **5** are right-angled triangles.

The conduit **1** may be provided with a desired number of the mixing elements. In an embodiment of this invention, at least two mixing elements are disposed in the conduit **1** in such a manner that the mixing element is spaced therein in a reversed disposition to any of the adjacent elements i.e., the common transverse axis **20** of adjacent elements are rotated 90° with respect to

each other. In another embodiment, at least four mixing elements are disposed in the conduit **1** in such a manner that each of said mixing elements is spaced angularly at right angles from the preceding element upon the line passing the centers of the triangular members **4, 5.** Therefore, within each element, in which the two triangular members **4, 5** meet at their apex, the line passing through the apex and joining the center of the base of each triangular member of each mixing element, is always parallel to the longitudinal axis of the conduit **1.**

If the materials to be mixed or blended contain a fluid material or high viscosity, a powder or a solid material, the flowing stream is often caused to hold up due to the viscosity resistance generated at the corner among the rear portions of the rectangular members and the inner wall of the conduit **1.** For the purpose of preventing hold-up of the flowing stream, quasi-trigonal pyramids or quasi-cones **11** and **12** may be provided at said corners as shown in FIG. **18**; as shown in FIG. **8.**

In FIG. **18** it can be seen that a first quasi-conical body **11** has an apex **33** at the end of the one half of longitudinal edge **21** of the first rectangular member **2** from which leads triangular member **5.** The mixing element fits into the conduit with the first lateral edges **23,** 27 of respectively the first and second rectangular members **2, 3** abutting the inner surface of one of the sides **1***a* of the conduit **1.** In addition, the second lateral edges **24, 28** of the first and second rectangular members **2, 3** abut the inner surface of side **1***c* of the conduit. The quasi-conical body **11,** also abuts the same surface **1***a* which the first lateral edge **23** of the first rectangular member **2** abuts and it further abuts the inner surface of **1***d* which is also abutted by the second longitudinal edge **22** of the first rectangular member **2.**

The second quasi-conical body **12** has an apex **34** at the end of the other half of the longitudinal edge **25** from the half of longitudinal edge **25** from which leads triangular member **4.** Quasi-conical body **12** abuts the inner surface of the conduit side **1***c* which surface is also abutted by the second lateral edge **28** of the second rectangular member and further body **12** abuts the inner surface of conduit side **1***a*, which surface is also abutted by the second longitudinal edge **26** of the second rectangular member **3.**

Operation of the mixing apparatus according to this invention will be described in detail hereinafter.

Liquid stream **10** to be mixed or blended is divided into upper and lower smaller partial streams by the divider plate of the first mixing stage at the up-stream side, and thereafter, each partial stream is again divided into two partial streams by the divider plate of the mixing stage **7,** therefore, the initial liquid stream is resultantly into four partial streams. Such division occurs at the divider plate of the mixing stage **8** into 16 partial streams and at the divider plate of the mixing stage **9** into thirty two partial streams and so forth, thereby intimately mixing the materials. The stream divided by each divider plate is guided by the deflector plates to thereby trace a vertical and horizontal zigzag course, and is repeatedly divided and combined, thereby attaining a prominant mixing effect. Further, since the liquid stream takes a zigzag course and passes through, flows over and is compressed by the deflector plates **2, 3** and divider plates **4, 5** with an increased velocity, the mixing effect more prominantly increases.

When the substances to be mixed have a high viscosity or contain a powder or solid material, quasi-conical bodies **11** are disposed at the corners between the deflector plates **2, 3** and the inner wall of the conduit **1** for the purpose of preventing the hold-up of the flowing stream and to thereby pass the substances smoothly through the conduit **1.** In this case, the quasi-conical bodies constitute "dead spaces" in the conduit **1,** however, the occupation ratio of the quasi-conical bodies in the conduit **1** may be as low as 2 percent. Therefore, the disposition of the quasi-conical bodies is considered to be highly effective in uniformly mixing and dispersing the substances.

Now, the mixing efficiency of the mixing apparatus according to the present invention will be described in detail hereinafter in comparison with those of the prior art.

The representative line or static mixing apparatus of the prior art include the following:

A. "MIXING DEVICE" U.S. Pat. No. 3,286,992; CL.259-4

B. "MIXING APPARATUS" U.S. Pat. No. 3,051,453; CL.259-4

C. "A METHOD FOR MIXING FLUIDS AND AN APPARATUS THEREOF" U.S. Pat. No. 3,239,197; CL.259-4 and U.S. Pat. No. 3,195,865; CL.259-4

These prior art patents are indicated hereinafter as (A), (B), and (C). These have been developed in the U.S.A. and are similar to the present invention in that they also are not equipped with any mechanical driving means or rotary agitator.

The device of the prior art patent (A) comprises a circular conduit, and unit elements each comprising spiral blades jointed normal to each other. Therefore, the device (A) is completely different in its construction from that of the present invention. Further, since, in the prior art patent (A), the functions of the divider and deflector plates are not distinguished, the action and effect obtained by such distinct classification as in the present invention cannot be obtained.

As is shown in FIG. **1,** in the apparatus according to this invention, the stream passes through all of the spaces in the conduit **1.** On the other hand, as is shown in FIGS. **9** and **10,** the apparatus of the prior art (B) or (C) has much dead space in its conduit due to the blocks disposed therein. Especially, in the apparatus of the prior art (C), the dead spaces occupy a volume larger than the effectively usable space therein, and therefore, it is not considered to be particularly economical either from the manufacturing cost standpoint or from the operation cost standpoint. Accordingly, it should be noted that the present invention is distinguishable from the prior art in that there is substantially no dead space in the conduit.

Now, referring to the dividing effect on the flowing stream, FIG. **11** shows a diagram of the dividing action by the apparatus of the prior art patent (B) and (C), and FIG. **12** shows that of the present invention. In FIGS. **11** and **12,** the obliquely lined portions indicate the stream of a material to be mixed. FIG. **12** shows a progressive modification of the sectional configuration of flowing streams. It is understood from FIGS. **12** and **15** that the flowing streams are complicatedly modified due to a converting action thereon accompanied by the displacement of streams indicated in *c* and *d* of FIG. **12,** and modification of the flowing passage shown in "G"

of FIG. **15.** This was also experimentally understood. Such complicated modification of the flowing streams can be readily understood in that the modification of the obliquely lined portion $a - b - c - d$ in FIG. **12** is very different from that shown in FIG. **11.** In FIG. **11,** the black portions indicate the dead spaces, while they don't appear in FIG. **12.** As is readily understood, in the prior art, the dividing action indicated as $a - b - c - d$ in FIG. **11** is repeated, while in the present invention, the dividing action indicated as $a - b - c - d$ in FIG. **12** is also repeated.

The displacing action on the flowing streams indicated in $c - d$ of FIG. **12** does not appear in the prior art patents B or C. This means that local mixing effect is obtained according to the present invention. Such displacement of the flowing streams is shown in more detail in FIGS. **13, 14** and **15.** As is shown in FIGS. **13, 14** and **15,** the displacing action is attained in the modification of the flowing pass F – G or G – F in FIG. **15.**

If desired, a fin member may be disposed in the portion indicated by FIG. **16** so that the stream passes more smoothly therethrough. In FIG. **17,** the stream flows over the fin member and passes through a narrow passage, and it is contracted smoothly without any appreciable pressure drop. Such a member is not disclosed in the prior art patents (B) and (C).

In a line or static mixing apparatus, it is important to prevent "short-pass" of the flowing stream in order to increase the local mixing effect, which can be attained by changing the flowing pattern wherein the flowing stream is shortly passed through the conduit into a pattern wherein the velocity of the flowing stream is increased in a direction normal to the longitudinal axis of the conduit. As is shown in FIGS. **9** and **10,** in the apparatus of the prior art patents (B) or (C), the flowing stream tends to pass shortly through the conduit, resulting in an insufficient mixing effect, On the other hand, in the apparatus according to the present invention, the flowing direction of the stream can be smoothly changed without causing any appreciable pressure drop. The deflector plates of the mixing element of this invention are very effective in preventing the stream from shortly passing through the conduit, since they always face the flowing stream and have wall faces to guide the same. Further, the flowing direction of the stream is smoothly changed at right angles by the passage shown in F – G or G – F of FIG. **15,** thereby increasing the velocity of the stream in a direction other than longitudinal axis to prevent the "short pass" of the stream. Therefore, the present invention is distinguishable from the prior art in view of the above mentioned effect.

The advantage in operation cost obtained according to this invention is described quantitatively hereinafter, by comparison with the apparatus of the prior art.

If a mixing apparatus of a circular conduit has,

coefficient of friction; f

radius of the conduit; D

average velocity of the liquid stream; U

density of the liquid; ρ

the consumption of power per volume; $P_t g_c$ is calculated as,

$$P_t g_c = \frac{2f\rho U^3}{D}$$

wherein g_c indicates the gravimetric factor, P_t is indicated, for example by kg-m/sec.m^3. If the stream is in laminar flow, coefficient of friction is

$$f = f_o = \frac{16}{\mathrm{Re}},$$

f: the coefficient of friction of only the conduit

$$\mathrm{Re} = \frac{DU\rho}{\mu},$$

μ: viscosity of liquid

When a rotary mixing apparatus for liquid of a high viscosity has consumption power Pg_c, length of the blade d, revolutions per minute n, the following experimental equations are obtained:

if it is a helical ribbon mixer,

$$\frac{Pg_c}{\rho n^3 d^5} = \frac{340}{\frac{(d^2 n\rho)}{\mu}}$$

if it is an anchor blades mixer,

$$\frac{Pg_c}{\rho n^3 d^5} = \frac{200}{\frac{(d^2 n\rho)}{\mu}}$$

By dividing Pg_c by the volume of the mixing tube V, we obtain consumption power per volume,

$$P_t g_c = \frac{Pg_c}{V}$$

Further, homogenization period is deemed to be mixing duration M, the coefficient which can be usable in "SCALE UP" of system can be obtained as the product of mixing duration θ_M and $\sqrt{P_t g_c/\mu}$.

In a usual rotary mixing apparatus for high viscosity, said coefficient is,

$$\theta_M \sqrt{\frac{P_t g_c}{\mu}} = 400 - 900$$

On the other hand, in the apparatus according to this invention, since $P_t g_c$ depends mainly upon the value of f, and ρ is in proportion with pressure loss ΔP, f and ΔP are important factors.

A static mixing apparatus commercially sold by CHENICS Corp. has,

$$f = (5 - 6) f_o$$

According to the research of the present invention, a system in a worse condition than said mixing apparatus of CHENICS Corp. has a coefficient of SCALE UP, if,

$$f = 2.25 f_o,$$

$$\theta_M \sqrt{\frac{P_t g_c}{\mu}} = 290\text{–}370$$

Therefore, it is more advantageous than the usual rotary mixing apparatus described hereinbefore. However, such advantage is determined by the scale of coefficient of friction f and, therefore, even if the construction is unique, it is meaningless unless the value of f is small.

A usual rotary mixing apparatus has,

$$\theta M \sqrt{\frac{P_r g_r}{\mu}} = 600, \text{ and}$$

a static mixing apparatus has,

$$\theta_M \sqrt{\frac{P_r g_r}{\mu}} = 300, \text{ (calculated as } f = 2..25\, f_o)$$

Therefore, assuming that θ_M and viscosity of liquid μ are respectively identical in both apparatus, we obtain,

$$\frac{P_r g_r \text{ (rotary mixing apparatus)}}{P_r g_r \text{ (static mixing apparatus)}} = 4$$

Since we obtain said equation from the data that coefficient f is assumed to be 2.25 times larger than f_o when the mixer is empty, pressure loss can be allowed as low as $4 \times 2.25 = 9$, about 10 times.

In the mixing apparatus according to the present invention, pressure loss remains between 3 and 10 times in laminar flow and, therefore, it is very economical. However, as is readily understood from the description of Chemte - Ing. - Techn. 43, No. 6, page 348 (1971), Brunemann, etc., the mixing apparatus according to the prior art (C) has a coefficiant of friction more than 10 times f as follows:

$$f = (50 - 60)\, f_o$$

Further, ISGMIXER (according to U.S. Pat. No. 3,404,869) which gives rise to displacement of liquids by means of a number of tortuous tubes, has a coefficient $f = 300\, f_o$ accordingly, these static mixing apparatus of the prior art are inferior to the rotary mixing apparatus with respect to operation cost.

As described hereinbefore, the mixing apparatus according to this invention is superior in operation cost to those of the prior art.

The foregoing description of the specific embodiments will so fully reveal the general nature of the invention that others can, by applying current knowledge, readily modify and/or adapt for various applications such specific embodiments without departing from the generic concept, and, therefore, such adaptations and modifications should and are intended to be comprehended within the meaning and range of equivalents of the disclosed embodiments. It is to be understood that the phraseology or terminology employed herein is for the purpose of description and not of limitation.

What is claimed is:

1. A mixing apparatus for mixing a substance comprising:

an elongated hollow conduit having a substantially rectangular cross section, and having four sides each of said four sides having a substantially flat inner surface;

a plurality of mixing elements contained within said hollow conduit, each mixing element comprising:

first and second rectangular members, disposed on a common transverse axis and having first and second longitudinal edges and first and second lateral edges,

first and second generally triangular members each leading normal to said first and second rectangular members,

said first generally triangular member leading from one half of said first longitudinal edge of said first rectangular member and having one edge thereof abutting one half of said first longitudinal edge of said second rectangular member, and

said second generally triangular member leading from the other half of said first longitudinal edge of said second rectangular member, and having one edge thereof abutting the other half of said first longitudinal edge of said first rectangular member;

said mixing elements being placed in said hollow conduit, such that, said second longitudinal edge of said first rectangular member abuts said flat inner surface of one of said sides of said conduit, and said first lateral edge of said first rectangular member abuts said flat inner surface of one of the sides adjacent said one of said sides and said second lateral edge of said first rectangular member abuts said flat inner surface of the other of said sides adjacent said one of said sides, and said second longitudinal edge of said second rectangular member abuts said flat inner surface of the side opposite said one of said sides, and said first lateral edge of said second rectangular member abuts said flat inner surface of said one side adjacent said one of said sides and said second lateral edge of said second rectangular member abuts said flat inner surface of the other of said sides adjacent said one of said sides;

a first quasi-conical body having an apex substantially coinciding with the end, away from said transverse axis, of said one half of said first longitudinal edge of said first rectangular member, said quasi-conical member being disposed on the opposite side of said first rectangular member from said first triangular member, and abutting said flat inner surface of said one of said sides of said conduit and also abutting said flat inner surface of said one side adjacent said one of said sides;

a second quasi-conical body having an apex substantially coinciding with the end, away from said transverse axis, of said other half of said first longitudinal edge of said second triangular member, said quasi-conical member being disposed on the same side of said second rectangular member as said second triangular member, and abutting said flat inner surface of the side opposite said one of said sides and also abutting said flat inner surface of said other of said sides adjacent said one of said sides; and

said quasi-conical bodies acting to prevent viscosity resistance which would normally be generated in the space occupied by said quasi-conical bodies thereby aiding the substance to smoothly flow through said conduit.

2. A mixing apparatus in accordance with claim 1, wherein said first and second rectangular members are normal to each other.

3. A mixing apparatus according to claim 1 wherein said mixing elements are spaced in said conduit in a reversed disposition to any of the adjacent elements.

4. A mixing apparatus in accordance with claim 3 wherein said conduit is of uniform square cross section; and including at least four of said mixing elements, each being spaced in said conduit angularly at right angles from the immediately preceding element upon the line passing the centers of said triangular members.

* * * * *