May 13, 1969 R. H. OVERCASHIER ET AL 3,443,798

FLUID PROCESSING DEVICE

Filed June 15, 1967 Sheet 1 of 2

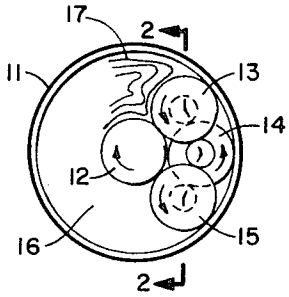



FIG. 1

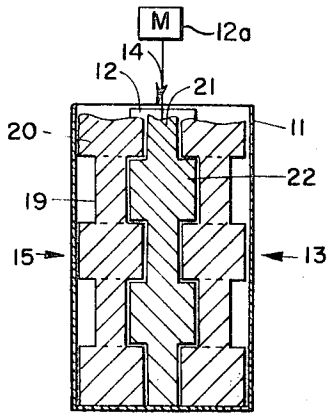



FIG. 2

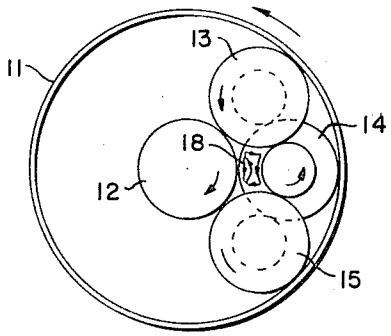



FIG. 3

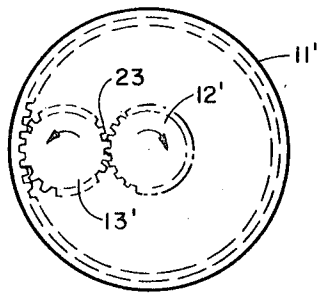



FIG. 4

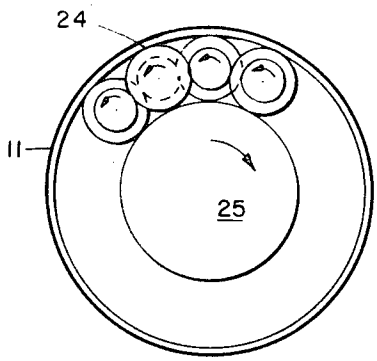



FIG. 5

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Filed June 15, 1967 Sheet 2 of 2

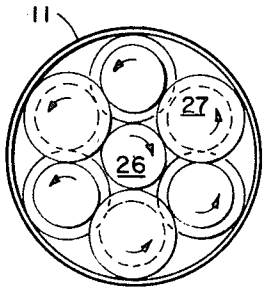



FIG. 6

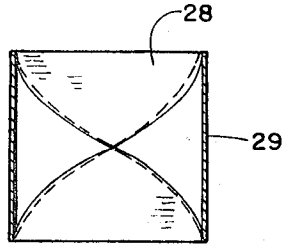



FIG. 7

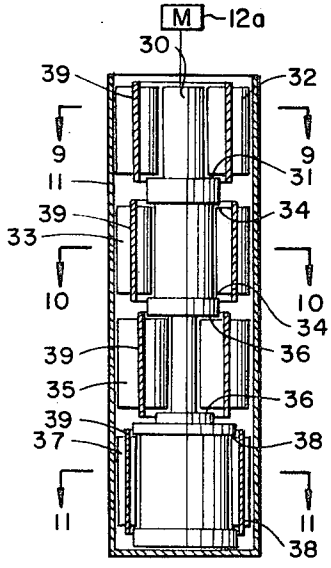



FIG. 8

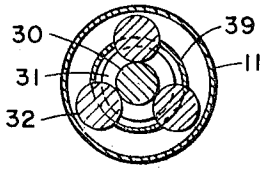



FIG. 9

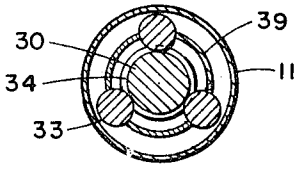



FIG. 10

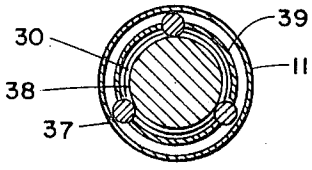



FIG. 11

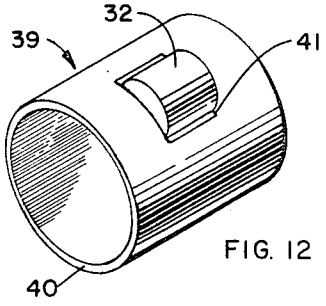



FIG. 12

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3,443,798

# FLUID PROCESSING DEVICE

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Int. Cl. B01f 7/26; B29h 1/10
U.S. Cl. 259—102 15 Claims

## ABSTRACT OF THE DISCLOSURE

A device for processing viscous fluids having a rotor centrally mounted in a cylindrical shell. A plurality of staggered successive horizontal rows are located in the annulus between the rotor and the inner wall of the shell. The rollers are rotated as the viscous fluids are circulated into the device and pass between the surfaces of the rotor, shell and rollers.

## BACKGROUND OF THE INVENTION

*Field of the invention*

The invention relates to a device for use in processing fluids; more particularly, it relates to a device for processing viscous fluids by circulating the fluids within a cylindrical housing having a centrally mounted rotor and a plurality of rollers mounted in the annulus formed between the inner wall of the housing and the outer wall of the rotor.

*Description of the prior art*

Current equipment for the processing of viscous liquid streams (e.g., polymer melts, elastomers, etc.) do not allow for systematic subdivision and redistribution of the flow streamlines. If the fluids are extremely viscous, much power must be expended to achieve a uniform blending of the so-called "fluid streamlines" of the fluids. Further, the amount of time the fluids remain in the processing equipment (referred to as "residence time") is high, resulting in much energy dissipation as heat, and possibly in the buildup of adherent polymer on the equipment surfaces, etc.

## SUMMARY OF THE INVENTION

It is an object of this invention to provide for a more systematic subdivision and redistribution of the flow streamlines of viscous fluids, thereby leading to a more efficient process, with concomitant savings in power, reduced residence times, and less degradation of the fluid materials.

It is a further object to provide a heat exchanger device for the cooling of melt. Such a device can be used, for example, as a heat exchanger in a polypropylene foam extruder. This heat exchanger will give narrow distribution of residence times which prevents premature crystallization of the polypropylene melt. It also allows close temperature tolerances and prevents channelling. The kneading action of the device produces less heat than existing known devices and does not break down large molecular structures. It also has advantages as a mixer and a reactor. In other words, the fluid processing device of the instant invention can be utilized in the processing applications of blending, heat exchange and reaction. If the clearance between the rollers and its contact surface is kept small, the viscous liquids will be kneaded and complete mixing to a molecular scale will be obtained. The good mixing characteristics of the device are important in the application of heat exchange. There will be no channelling of the flow and large temperature gradients in the liquid should be absent because the streamlines are constantly being subdivided and redistributed. The rotor and outer housing offer surfaces for heat transfer since there are no stagnant liquid layers on the solid walls. Viscous dissipation is less than in conventional scraped heat exchangers since the velocity gradients between the roller and rotor/housing surfaces are small.



Other objects of this invention will become evident from the following detailed description and claims and illustrated in the accompanying drawings, which disclose, by way of example, the principles of this invention and the preferred method of applying these principals.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIGURE 1 is a plan view of one embodiment of the invention;

FIGURE 2 is a vertical sectional, partly schematic view taken along line **2—2** of FIGURE 1 looking in the direction of the arrows;

FIGURE 3 is a pictorial representation of the streamline flow patterns caused by the device of FIGURE 1;

FIGURE 4 is a plan view of a modification of the device of FIGURE 1;

FIGURE 5 is a plan view similar to FIGURE 1 but showing a large diameter rotor relative to the diameter of the rollers;

FIGURE 6 is a plan view similar to FIGURE 5 but showing a small diameter rotor relative to the diameter of the rollers;

FIGURE 7 is a side view similar to FIGURE 2 but showing a further modification of the rollers of the present invention;

FIGURE 8 is a vertical sectional, partly schematic view of still another embodiment of the invention;

FIGURES 9 through 11 are cross-sectional views taken along lines **9—9**, **10—10**, and **11—11**, respectively, of the embodiment of FIGURE 8 looking in the direction of arrows; and

FIGURE 12 is a perspective view of an element of the embodiment of FIGURE 8.

## DESCRIPTION OF PREFERRED EMBODIMENTS

Referring more particularly to the drawings, FIGURE 1 shows a stationary outer cylindrical shell **11** having an inner centrally-mounted rotor **12** and a plurality of rollers **13** through **15** located in the annulus **16** formed between the outer wall of rotor **12** and the inner wall of shell **11**. The rollers **13** through **15** touch both the shell and the rotor in rolling contact and are driven with or without gears by their contact with rotor **12** and shell **11**. Of course, more than three rollers may be mounted in annulus **16**, three being shown as a matter of convenience. The rotor **12** is driven by any known means, mechanically or electrically, as indicated by motive means **12***a* operatively engaging rotor **12**. The central roller **14** is also in rolling contact with rotor **12** and shell **11**; there is a certain amount of slippage between roller **14** and rollers **13** and **15** as will be discussed in more detail shortly. A clearance of approximately .002 inch should preferably be maintained between the points of contact of the rollers **13** through **15** with the shell **11** and the rotor **12**. The rollers **13** through **15** will then rotate about both their own axes and the axis of the rotor **12**. Viscous fluids **17** flowing in the device, the shell **11** preferably being closed at at least one end, will flow in the annulus **16** and between the rollers **13** through **15** to produce streamline flow patterns similar to patterns **18** of FIGURE 3 as will be discussed more fully infra.

Each of the rollers **13** through **15** preferably includes a plurality of roller sections of different cross-sectional diameters as shown in FIGURE 2. Here the rollers **13** through **15** can be seen to be disposed annularly about rotor **12** within annulus **16**. The roller sections of different cross-sectional diameters can comprise individual units

but preferably include a plurality of single units, each of the units including at least a pair of cylindrical sections of different cross-sectional diameters, as, for example, smaller diameter section **19** and larger diameter section **20** of roller **13** in FIGURE 2. Section **20** of roller **15** is disposed vertically above section **19** and laterally of a similar section **20** in roller **13**. Thus, sections **20** of rollers **13** and **15** are disposed in one horizontal layer while sections **19** of rollers **13** and **15** are disposed in a second successive horizontal layer. It can be seen in FIGURE 2 that some of the cylindrical sections are in sliding contact with the outer surface of some of the cylindrical sections of its adjacent unit (such as cylindrical sections **20** and **21**, respectively, and cylindrical sections **19** and **22**, respectively, in FIGURE 2). However, the spacing between adjacent rollers must be such that a certain amount of slippage is retained so that roller **14**, for example, will not jam up in the device. The rollers **13** through **15** of FIGURES 1 and 2 are preferably cylindrical with the longitudinal axes parallel to the centerline of rotor member **12**. The outer surfaces of all of said rollers **13** through **15**, rotor member **12** and the inner wall of shell **11** are smooth so that rotation of rotor **12** can impart rotation to rollers **13** through **15**.

If desired, all of the surfaces can comprise mating gear teeth as shown in FIGURE 4 wherein rotor **12'**, shell **11'** and roller **13'** (only one being shown for convenience) are illustrated as having mating gear teeth **23**. The gear teeth are disposed normal to the longitudinal axes of shell **11'**, rotor **12'** and roller **13'** so that all of the gear teeth remain in engagement while rotor **12'** is rotated.

Mixing of the fluid streamlines **18** can be achieved by redistribution of the streamlines **18** in the direction of the net flows as shown by the arrows in FIGURE 3. For the purpose of illustration, shell **11** is shown as rotating in the direction of the arrow while member **12** rotates in the opposite direction. The scale of mixing can be reduced by increasing the number of rollers in each row. Mixing can also be achieved by making the cross-sectional diameter of the rotor considerably larger than the cross-sectional diameter of the rollers as can be seen in FIGURE 5, thereby increasing the velocity of the rollers about the rotor. This would be more desirable with a fluid of low viscosity. Here, the annular velocity of rollers **24** about the central axis of rotor **25** is much higher than in the embodiment of FIGURE 1, thus producing greater mixing characteristics. The streamline flow patterns **18** of FIGURE 3 are formed by rotating the rotor axis **25** at the angular velocity of the rollers **24**. For reasons of convenience of illustration, the distance between exemplary rollers **24** has been exaggerated. FIGURE 6 shows an embodiment similar to the embodiment of FIGURE 5 in which the cross-sectional diameter of rotor **26** is considerably smaller than the cross-sectional diameter of the rollers **27**. Accordingly, the degree of mixing will be less than the embodiment of FIGURE 5, and it can be seen that the desired degree of mixing can be regulated by varying the cross-sectional diameter of the rollers relative to the cross-sectional diameter of the rotor. The flow patterns caused by the embodiments of FIGURES 5 and 6 are similar to those illustrated in FIGURE 3.

The viscous fluid is kneaded as it flows between the rollers and the contact surfaces on the rotor and shell. As a heat exchanger, the rollers provide cleaned surfaces on both the rotor and the shell. Since the liquid flowing through the device is continually being subjected to the action of the rollers, the rotor, shell and rollers offer surfaces for heat removal. These are no stagnant layers to act as a barrier to the transport of heat and the length of the path of conduction of the heat is short. Viscous dissipation is less here than in conventional scraped heat exchangers. There should be no channelling because of the good mixing characteristics of the device. The device can also find use as a reactor since, for example, in many polymerization reactions the final molecular weight distribution is dependent on local mixing and temperature conditions inside the reactor. Hence, this device would provide a control over the product quality. Since, as a reactor, it may be desirable to achieve a narrow distribution of residence times (that is, the length of time the fluid remains in the reactor) the prevention of channelling by the redistribution action of the successive rows of rollers is especially valuable.

A further pumping action can be achieved by making rollers **13** through **15** of FIGURE 1, for example, open at both ends and hollow with a fixed diametrical helical flight **28** having a displacement of 180° as shown in FIGURE 7. It is noted that the helical surfaces are generated by a series of straight lines normal to the central axis of the helix. These modified rollers **29** can also be staggered as suggested above. Further, the cross-sectional diameter of the rollers **29** can also be varied as discussed above. Of course, the modified rollers **29** need not be staggered but rather single units of approximately the same length as rotor **12** (not shown). These helical flights **28** will give a forward thrust to the fluid material as said fluid circulates within the rollers **29** and about the helical flights **28**.

In FIGURE 8, rollers of varying diameters are spaced between larger diameter portions of the rotor member. This embodiment imparts transverse subdivision to the fluid streamlines. Here, rotor **12** has been replaced by a cylindrical rotor **30** having a series of shoulders for spacing the rollers from one another. Thus, a first shoulder **31** on rotor **30** prevents rollers **32** on the first horizontal row from coming into contact with rollers **33** on the adjacent horizontal row. Shoulders **34** on rotor **30** prevent rollers **33** from coming into contact with rollers **35**. Shoulders **36** on rotor **30** prevent rollers **35** from coming into contact with rollers **37**. Finally, shoulders **38** on rotor **30** prevent roller **37** from contacting adjacent rollers **35**. Of course, the inner wall of shell **11** serves to prevent radial movement of rollers **32**, **33**, **35** and **37** and retain them between their respective shoulders on rotor **30**. A series of collar spacers **39** prevent rollers on the same horizontal row (for example, rollers **32**) from contacting one another as will be explained further in the discussion of FIGURES 9 through 12. As can be seen in FIGURE 8, the cross-sectional diameter of rollers **32**, **33**, **35** and **37** varies from one another. For example, the cross-sectional diameter of rollers **32** is approximately equal to the rotor cross-sectional diameter between the upper portion of rotor **30** and shoulder **31**. The diameter of rollers **33** is approximately one-half the diameter of rotor **30** between shoulders **34**. The diameter of rollers **35** is approximately twice as great as the diameter of rotor **30** between shoulders **36**. Finally, the diameter of rollers **37** is negligible compared to the diameter of rotor **30** between shoulders **38**. This variation in the diameter of the rollers compared to the diameter of the rotor subdivides the flow streamlines in a transverse manner. Thus, chopping action will occur whenever two rollers of differing diameters are used in successive rows since the angular velocity $\omega$ of the roller about the central axis of the rotor increases with decreasing rotor diameter. For example, where $\omega$=angular velocity of the member about the central axis of the rotor and $\alpha$=ratio of the roller to rotor diameter, then:

$$\frac{\omega \text{ roller}}{\omega \text{ rotor}} = \frac{1}{2}\left(1+\alpha\right)$$

Where the roller diameter is extremely small with respect to the rotor diameter, $\alpha$ approaches zero and

$$\frac{\omega \text{ roller}}{\omega \text{ rotor}} = \frac{1}{2}$$

As the roller diameter substantially increases with respect to the rotor diameter, $\alpha$ approaches one and

$$\frac{\omega \text{ roller}}{\omega \text{ rotor}} = \frac{1}{4}$$

Thus, differing velocities ensue from varying the roller diameter with respect to the rotor diameters, resulting in greater subdividing of the flow streamlines of the viscous fluid or fluids being processed.

FIGURES 9 through 11 are cross-sectional views taken along lines 9—9 through 11—11 of FIGURE 8, respectively. The spacers 39 in FIGURES 8 through 11 comprise a series of rings 40 (FIGURE 12) loosely mounted in the annulus formed by rotor 30 and shell 11. Rollers 32 are loosely mounted in openings 41 formed in rings 40 as can be seen in FIGURE 12. In FIGURE 12, only one of the rollers 32 is shown; however, the remaining rollers 32 are also loosely mounted in like openings 41 in ring 40 as can be seen in FIGURE 9. This prevents rollers 32 on the same horizontal plane from coming into contact with one another. Since rollers 32 are prevented from engaging adjacent rollers 33 by shoulders 31 as discussed above, spacers 39 are also prevented from contacting each other as can be seen in FIGURE 8. In other words, the diameter of spacers 39 varies with the variation in diameters of rollers 32, 33, 35 and 37 so that the rings 40 cannot engage the adjacent shoulders on rotor 30.

If desired, this concept could be carried out even further by providing similar spacers (not shown) of smaller diameter than spacers 39 in the annulus formed between the rotor 30 and spacer 39. At the same time, spacers of larger diameter than spacers 39 could be provided in the annulus formed between the inner wall of shell 11 and spacer 39. In both cases ,suitable rollers of smaller diameter can be provided in the openings in these spacers to further subdivide the fluid streamlines.

The promising heat exchange and mixing properties of the device strongly suggest that its most useful application will be in the reaction operation with viscous melts where large concentration and temperature gradients have to be avoided. The flow patterns of FIGURE 3 show the flow reversal at the rollers, the fluid material at the walls of the rotor and the shell being transported away from said walls and towards the center of the annulus.

We claim as our invention:

1. A device for processing viscous fluids, said device comprising:
   - an outer cylindrical shell;
   - an inner cylindrical rotor member centrally mounted in said shell and of a cross-sectional diameter less than the cross-sectional diameter of said shell, thereby forming an annulu between the outer wall of said member and the inner wall of said shell;
   - inner member rotating means for rotating said inner member;
   - a plurality of roller means disposed annularly of said rotor member within said annulus, each of said roller means including a plurality of roller sections of different cross-sectional diameters; and
   - roller means rotating means to rotate said roller means whereby said roller means rotate about both their own axes and the axis of said member and said fluids flow between said roller roller means within said annulus to produce streamline flow patterns.

2. A device as in claim 1 wherein said shell is stationary.

3. A device as in claim 1 wherein said roller means rotating means comprises rolling contact of said roller means with both said inner wall of said shell and the outer wall of said member.

4. A device as in claim 3 wherein said roller means are cylindrical with their longitudinal axes parallel to the centerline of said member.

5. A device as in claim 4 wherein at least some of the surfaces of the outer walls of said roller means, the outer wall of said member and the inner wall of said shell comprise mating gear teeth.

6. A device as in claim 1 wherein the surfaces of all of said roller means, the outer wall of said member and the inner wall of said shell are smooth.

7. A device as in claim 1 wherein some of said roller means comprise a single unit of at least a pair of cylindrical roller sections of vertically-aligned different cross-sectional diameters.

8. A device as in claim 7 wherein at least some of said cylindrical roller sections are in rolling contact with the outer surface of at least some of the cylindrical roller sections of its adjacent unit.

9. A device as in claim 8 wherein the cross-sectional diameter of the largest cylindrical roller section of each of said units is substantially greater than the cross-sectional diameter of the rotor member.

10. A device as in claim 8 wherein the cross-sectional diameters of the cylindrical roller sections of each of said units is substantially less than the cross-sectional diameter of the rotor member.

11. A device as in claim 1 wherein at least some of said roller means are hollow and open at least at one end and have a diametrical helical section extending therethrough to give a forward thrust to the fluids as said fluids circulate within said roller means.

12. A device as in claim 1 wherein said roller sections comprise roller sections loosely mounted within the annulus of said device and said device has spacing means loosely mounted in the annulus of said device for spacing all of said loosely mounted roller sections in a horizontal row from one another.

13. A device as in claim 12 wherein the spacing means comprises cylindrical collars loosely mounted with the the annulus of the device having openings to accommodate therein the loosely mounted roller sections.

14. A device as in claim 13 wherein the cross-sectional diameter of said rotor member varies and the cross-sectional diameters of said roller sections vary with respect to the variation in diameter of the rotor member.

15. A device as in claim 14 wherein said rotor member has shoulder portions for spacing each successive horizontal row of said loosely mounted roller sections from one another.

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U.S. Cl. X.R.

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