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(51) INT CL:

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(56) Documents Cited:

WO 2017/137580 A1 WO 2014/068011 A2 WO 2011/124365 A1 CN 110313312 A US 20200261867 A1

(58) Field of Search:

INT CL **B01D**, **B01F**, **B01J**

- (54) Title of the Invention: Improved method and apparatus plug flow system Abstract Title: An apparatus for continuous axial flow of process material
- (57) A chemical/physical reaction apparatus for continuous processing, comprising a tube 1 with a plug flow length with stationary axial baffles (13, figure 3) mounted to provide a continuous gap between the baffles and the tube interior surface, and axial stirrer blades (10, figure 2) which can be driven 8 to sweep the gap. Process material can flow orderly through the tube continuously through feed 6 and discharge 7 connections. Preferably the apparatus comprises stationary radial baffles which do not extend into the gap. The tube can have covers at its ends and the stirrer blades can be held by a shaft (9, figure 2) which passes through one end cover and the axial baffles can be held in position by the opposing end cover. The axial and radial baffles can be joined together by interlocking slots to form a rigid assembly without welding, bonding, screws or bolts. The axial and radial baffles can be formed of synthetic polymeric material e.g. polytetrafluoreothylene (PTFE) and mounted on the baffle support shaft (16, figure 4). One or more external jackets 2 may be provided for heating/cooling. The process material may be subjected to tangential flow which is converted into turbulence and radial mixing.

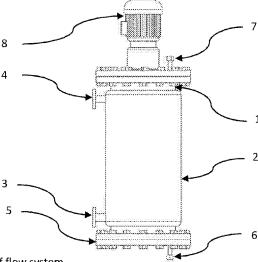


Figure 1 - external view of flow system

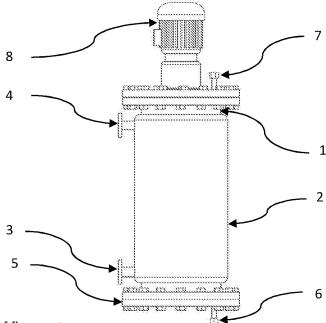


Figure 1 – external view of flow system

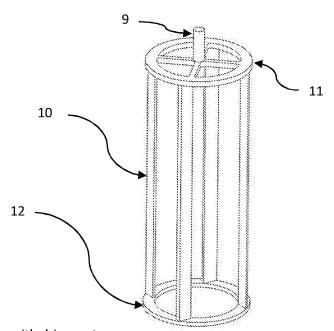


Figure 2 – mixer blades with drive system

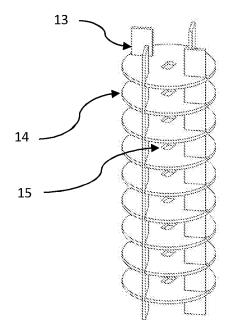


Figure 3 – baffle assembly

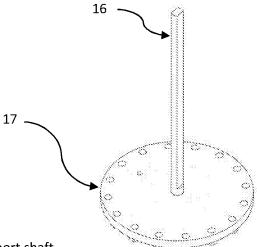


Figure 4 – baffle support shaft

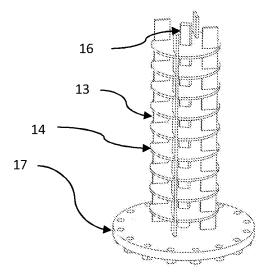


Figure 5 – radial baffles mounted on the axial baffles

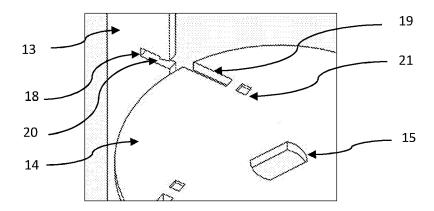


Figure 6 – baffle assembly locks

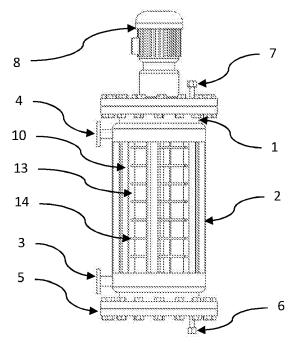


Figure 7 – cutaway view of the assembled system

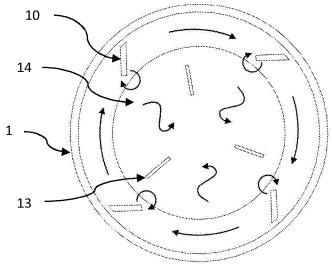


Figure 8 – plan view of mixing pattern

IMPROVED METHOD AND APPARATUS PLUG FLOW SYSTEM

The present invention is a flow system for continuous processing of fluid process materials under orderly or plug flow conditions. Batch equipment process a single system volume at a time. Continuous flow systems process multiple volumes without interruption which makes them more productive and allows the system to be smaller and yet process a similar volume of fluid material in a given period. Reduced size facilitates higher ratios of heat transfer area to working volume of fluid, shorter mixing distances and improved shear characteristics. These factors contribute to lower capital and operating costs with higher performance and better outcomes such as improved yield and purity of product output. Other benefits include improved safety through a reduced inventory of in-process material, more uniform utilities demand and less space used.

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Processing according to this invention means physical or chemical changes made to process materials including but not limited to chemical reactions, enzymatic reactions, polymerisation, crystallisation, cell growth, precipitation, extraction and heating or cooling treatment.

The process material is a free-flowing fluid which may be a liquid and which may also contain gases, solid particles, or other liquids in different phases.

The body of the plug flow system of this invention is a tube and in this application the following terms have the following meanings. Radial refers to the plane across the diameter of the tube. Axial is the plane at 90 degrees to the radial plane and in line with the axis of the tube and the direction of fluid travel through the tube. Plug or orderly flow means fluids of similar density flow at substantially uniform axial velocity through the tube. Axial dispersion or back mixing is deviation from orderly flow. Materials of different densities such as gases, solids or immiscible fluids of different density may travel at different axial velocities to other materials or in the opposing axial direction. Radial mixing of the process material as it flows through the tube is mixing in the radial plane. Tangential flow is rotational flow of the process material in the radial plane. Residence time is the elapsed time between process material entering and leaving the system. Axial baffles are baffles extending along the axis of the tube and are used promote radial mixing of the process fluid. Radial baffles can also be used to reduce axial dispersion. The plug flow length of the tube refers to the stirred plug flow region of the tube.

The invention is primarily concerned with activities within the plug flow length of the tube. However the tube may also contain non-plug flow lengths.

The plug flow length may be separated from any non-plug flow lengths by radial baffles. Non-plug flow lengths may be unstirred or randomly mixed using pitched blade or Rushton turbine blade stirrers. Non-plug flow lengths may be used for other purposes such as premixing or phase separation.

The invention aims to provide flow conditions for the process material comprising radial mixing to maintain uniform temperature and composition in the radial plane, shear at the tubes heat transfer surface to promote heat transfer, and low axial dispersion for good residence time control. Shear and turbulence within the bulk fluid promote improved contact between materials. In the case of biphasic mixtures shear also promotes increased interfacial area between different phases and reduced boundary layer resistance.

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Flow systems which employ passive mixing rely on axial travel of fluid to generate radial mixing. The current invention uses active mixing with sweeping stirrer blades and axial baffles to promote radial mixing and shear. In a preferred embodiment radial baffles are provided in the tube to reduce axial dispersion. Subject to the right design, this offers higher working capacity per unit length than passively mixed flow systems. Mixing and orderly flow are also substantially decoupled from residence time. This makes them more scalable, more versatile in terms of residence time and better able to handle multiphase mixtures.

Extensive prior art exists concerning actively mixed plug flow systems as stirred tubes. WO 2004/026942A1 shows a stirred tube with radial baffles extending across the entire width of the tube. Rotating stirrer blades are provided in the sections defined by the radial baffles and are mounted on a central shaft which extends to the full length of the tube. The combination of a central stirrer shaft and radial baffles makes this solution difficult to build and assemble since the radial baffles need to be stationary and the stirrer shaft cannot be removed without withdrawing the baffles. No axial baffles are used which reduces the effectiveness of radial mixing and shear since the bulk process material rotates only tangentially giving unsatisfactory radial mixing. Furthermore, high mixing speeds promote greater centrifugal separation when materials of different density are present.

The present invention provides an apparatus for continuous axial flow of process material comprising a tube with a plug flow length provided with stationary axial baffles mounted to

provide a continuous gap between the baffles and the interior surface of the tube and further provided with axial blades which can be driven to sweep the gap.

The invention further provides a process for continuous processing of fluids comprising delivering a process material to a tube for axial flow along the tube wherein the fluid is subject to tangential flow generated by stationary axial stirrer blades and radial mixing by axial baffles during orderly flow along the tube.

The process preferably also uses stationary radial baffles to prevent or reduce axial dispersion.

In the preferred process a circumferential gap is provided between the baffles and the wall of the tube and tangential flow in the fluid is created by axial stirrer blades positioned within the gap and which sweep the gap with process material therein.

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The present invention therefore provides an actively mixed plug flow system with axial baffles. In a preferred embodiment radial baffles are also used. The tube of the system is sealed with end covers. Feed materials are added at one end of the tube continuously and processed material is discharged at the other end of the tube continuously. Intermediate addition and take off points along the tube may also be used. It is preferred that the baffles and stirrer shaft can be removed independently. The design facilitates the use of baffles fabricated in materials with low mechanical strength but good chemical resistance such as synthetic polymers. It also permits assembly of radial and axial baffle elements without bonding or welding.

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The invention is illustrated but in no way limited by reference to the accompanying Figures in which

Figure 1 is an external view of an apparatus according to the invention.

Figure 2 shows the axial stirrer of the apparatus of Figure 1.

30 Figure 3 shows the axial and radial baffles of the apparatus of Figure 1.

Figure 4 shows the baffle support shaft of the apparatus of Figure 1.

Figure 5 shows the baffles mounted on the support shaft of Figure 4.

Figure 6 illustrates the preferred method of assembling the baffles.

Figure 7 is a cut away view of the assembled apparatus of Figure 1.

Figure 8 shows the mixing pattern of a process material as it flows through the plug flow length of the tube.

Figure 1 is an external view of the plug flow length of a tube of this invention. The system body 1 is a rigid tube with rigid cover plates at each end to form a sealed system. The preferred tube length is not greater than 10 times the internal diameter and more preferably not greater than 6 times. It is preferred that the tube length is not less than the internal diameter and more preferably not less than 1.5 times the internal diameter. The tube can be mounted at any angle but vertical is preferred and it may be surrounded by one or more jackets 2 through which heat transfer fluid can be passed for heating or cooling but other means of heating or cooling the tube wall may be used. Connections 3 and 4 are provided on the jacket for the passage of heat transfer fluid. Cover plates are fixed at each end of the tube seal the system. Process connections 6 and 7 allow process material to feed and discharge from the tube at opposite ends, respectively. Multiple inlet and outlet connections may be used as required. The direction of flow, choice of counter current flow and location of feed and take off points will depend on the processing to be performed in the apparatus. The drive system 8 rotates the stirrer shaft (9 of Figure 2) and is mounted on the drive cover plate 5. Different types of drive system may be used such as electrical, hydraulic, or pneumatic. Gear boxes are used according to need. The drive shaft for the rotating stirrer is preferably sealed by conventional means such as mechanical seal, stuffing box, gland, or magnetic coupling.

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Figure 2 shows the axial stirrer. This comprises of a drive shaft 9 which is connected to the drive system 8. The stirrer blades 10 are mounted on arms or a hub 11 fixed to the drive shaft. A support ring 12 may be used as required. The stirrer blades preferably extend the full plug flow length less the clearance needed to rotate freely. It is preferred that the axial blades are straight in the axial plane to minimise axial dispersion of the process material.

The blades are mounted at the perimeter of the tube close to the internal wall of the tube. The number of blades may be varied according to need. The blade angles may be in line with the centre line across the tube or pitched at an angle. It is preferred that the swept path of the blades is 30% of the tube diameter or less.

Figure 3 shows the baffle assembly. Axial baffles 13 increase turbulence and radial mixing by diverting tangential flow to the centre of the tube. It is preferred that the axial baffles are straight in the axial plane to minimise axial dispersion. Radial baffles 14 reduce axial dispersion. The axial and radial baffles are stationary. The number of axial baffles may be varied according to need. They are parallel to the stirrer blades in the axial plane and are preferably of the same length less clearance needed to allow free movement of the stirrer. The axial baffles lie inside the swept path of the stirrer blades and may be in line with the centre line across the tube or pitched at an angle. It is preferred that they do not extend to

the centre to allow free movement of fluid across the diameter of the tube. Radial baffles lie inside the swept path of the stirrer blades. These are preferred but the system can operate without them. When used the radial baffles may be a solid plate or have perforations or openings. Their role may also be limited to serving as anchor points to prevent lateral movement of the axial baffles. Five or more radial baffles spaced along the plug flow length of the tube are preferred and eight or more are more preferred. The hole 15 is preferred for mounting the baffles as a slide fit on the baffle support shaft (16 of Figure 4). This may be offset from the centre, but a central hole is preferred. The baffles can be assembled and fixed in place by welding, bonding, screws, or bolts but the assembly method described below is preferred.

Figure 4 shows the baffle support shaft 16. Alternative mounting arrangements can be used for holding the baffles in place, but the support shaft described here is the preferred method. The baffle support shaft 16 is fixed to the baffle cover plate 17 which is fixed to the tube at the opposite end to the drive cover plate. Although the profile of the shaft can be round, non round is preferred and of a shape which matches the profile of the holes 15 of the radial baffles 14. This shaft 16 holds the baffles in the axial and radial plane and prevents them from rotating. The baffles can rest on the baffle support shaft 16 or the axial baffles can rest on the baffle end cover 17.

Figure 5 shows the baffles mounted on the baffle support shaft 16. It is preferred that the axial and radial baffles are coupled together as an assembly to form a slide fit on the baffle support shaft. A locking cap can be fitted to the end of the baffle support shaft if required to prevent the baffle assembly from lifting. The outer edge of the axial baffle may lie parallel to the outer edge of the radial baffle, outside it or inside it.

Figure 6 shows the preferred method for assembling the axial and radial baffles. The axial baffle 13 has a slot 18 and the radial baffle 14 has a slot 19. The radial baffle and axial baffle slots overlap and push together to form a rigid 3-dimensional structure. The radial and axial baffles can be locked in place by different methods such as interference fits, keys, or lips. One example is shown with tab 20 locking into slot 21. This method of assembly which does not require bonding, welding, or fixing devices is preferred. It has a lower fabrication cost and enables the components to be made from materials which are difficult to weld or bond such as PTFE or sheet metal. The PTFE may also be glass filled for additional rigidity.

Figure 7 shows the assembled system with a cut away view of the internals the reference numerals indicating the same components as in the other Figures. In operation the stirrer

blades 10 sweep the gap formed outside of the baffles to generate tangential flow in the process materials; they are supported by the drive end plate. The axial baffles divert the tangential flow to generate radial mixing, shear and turbulence in the radial plane. The radial baffles reduce axial dispersion. The axial and radial baffles are formed as a single assembly and supported by the baffle end plate. Slots in the axial baffles hold the radial baffles in the desired radial position. Slots in the radial baffles hold the axial baffles in the desired axial position. The baffle support shaft holds the baffle assembly in the required axial position and prevents twisting.

The arrows within the tube 1 of Figure 8 show the mixing pattern of a process fluid as it flows through the plug flow length of the tube. The pattern comprises tangential flow at the perimeter of the gap with radial movement as fluids pass round the mixing blades 10. Internally axial baffles 13 convert tangential flow into radial mixing within the spaces defined by the radial baffles 14.

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Materials of construction for the various components are selected according to the needs of mechanical strength, operating temperature, and chemical resistance. This can include but not limited to metals, metal alloys, glass, ceramic, plastic, composites, and lined metal.

20 Process materials are fed into to the tube at a controlled rate typically using pumps which can be in the feed or discharge lines. Other possible means of fluid transfer include gravity transfer, pressure padding the head space in the feed tank with a gas or applying vacuum to the head space of the discharge tank. Gas may be added by a compressor or from a pressurised container. Flow of process material may be controlled by a pump or a flow control valve.

The required operating temperature at a given point is set or controlled by regulating the flow or temperature of the heat transfer fluid passing into the heating/cooling jacket (2 in Figure 1). Temperature measuring instruments may be used in the jacket fluid and the process fluid. A flow measuring element may be used to measure the flow of the heat transfer fluid.

Intermediate addition or take off points, and instruments can be inserted into any position within the system using pipes or probes which may be fixed to the baffle end plate. These can either pass up through the baffle support shaft or through holes cut in the radial baffles.

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The volumetric capacity of the plug flow length may vary from 100 millilitres to 10 m³ according to need. The preferred capacity is 1 litre to 200 litres. The stirrer blades can

operate at different speeds with different blade shapes, numbers, and angles. The same variability applies to the baffles. The design and operating parameters will be chosen according to the scale of the operation and the nature of the processing to be performed within the apparatus.

CLAIMS

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- 1. An apparatus for continuous axial flow of process material comprising a tube with a plug flow length provided with stationary axial baffles mounted to provide a continuous gap between the baffles and the interior surface of the tube and further provided with axial stirrer blades which can be driven to sweep the gap.
- 2. An apparatus according to Claim 1 for the processing of process material wherein process material flows through the tube continuously with orderly flow and the tube is provided with connections for feed and discharge of materials.
- 3. An apparatus according to Claim 1 or Claim 2 provided with stationary radial baffles within the plug flow length which do not extend into the gap.
- 4. An apparatus according to any of the preceding claims wherein the tube is provided with covers at its ends and the stirrer blades are held in position by a shaft which passes through one end cover and the axial baffles are held in position by the opposing end cover.
- 5. An apparatus according to Claim 3 or Claim 4 wherein the axial and radial baffles are joined together by interlocking slots to form a rigid assembly without welding, bonding, screws or fixing bolts.
- 6. An apparatus according to Claim 5 wherein the axial and radial baffles are mounted on a baffle support shaft as a slide fit.
 - 7. An apparatus according to any of the preceding claims in which the baffles are formed of synthetic polymeric material.
- 30 8. An apparatus according to Claim 7 in which the synthetic polymeric material is polytetrafluorethylene.
 - 9. An apparatus according to any of the preceding claims provided with one or more external jackets for heating or cooling the process fluid.
 - 10. A process for continuous processing of fluids comprising delivering a process material to a tube for axial flow along the tube wherein the fluid is subject to tangential flow

generated by rotating axial stirrer blades and radial mixing generated by axial baffles during orderly flow along the tube.

- 11. A process according to Claim 10 which also uses stationary radial baffles
- 12. A process according to Claim 10 or Claim 11 wherein a circumferential gap is provided between the baffles and the wall of the tube and tangential flow is created by the axial stirrer blades which are positioned within the gap and sweep the gap.

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Application No: GB2100193.8 Examiner: Contract Unit Examiner

Claims searched: 1-12 Date of search: 1 October 2021

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

	Category Relevant Identity of document and passage or figure of particular relevance					
Category	to claims	Identity of document and passage or figure of particular relevance				
X,Y	X: 10-12 Y: 3-5, 9	US2020/261867 A1 (ASHE ROBERT ET AL) paragraphs [0001], [0018] - [0033], [0041]; claims 1, 23; figures 1-5				
X,Y	, ,	WO2017/137580 A1 (ASHE MORRIS LTD) page 4, line 12 - page 6, line 30; claims 1-19; figures 3-8				
A	-	WO2014/068011 A2 (ASHE MORRIS LTD) page 3, lines 5-25; figures 1-7, page 10, line 8 - page 11, line 35				
A	-	WO2011/124365 A1 (ASHE MORRIS LTD; ASHE ROBERT; MORRIS DAVID) page 1, line 33 - page 2, line 2, page 4, line 19 - page 5, line 15; figure 4				
A	-	CN110313312 A (UNIV QINGDAO AGRICULTURAL) abstract; figures 1-2				

Categories:

X	Document indicating lack of novelty or inventive	A	Document indicating technological background and/or state
	step		of the art.
Y	Document indicating lack of inventive step if	P	Document published on or after the declared priority date but
	combined with one or more other documents of		before the filing date of this invention.
	same category.		
&	Member of the same patent family	Ε	Patent document published on or after, but with priority date
			earlier than, the filing date of this application.

Field of Search:

Search of GB, EP, WO & US patent documents classified in the following areas of the UKC^X :

Worldwide search of patent documents classified in the following areas of the IPC

B01D; B01F; B01J

The following online and other databases have been used in the preparation of this search report



International Classification:

Subclass	Subgroup	Valid From
B01J	0019/18	01/01/2006
B01F	0009/02	01/01/2006
B01J	0019/00	01/01/2006