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- (54) Title: A MIXING APPARATUS

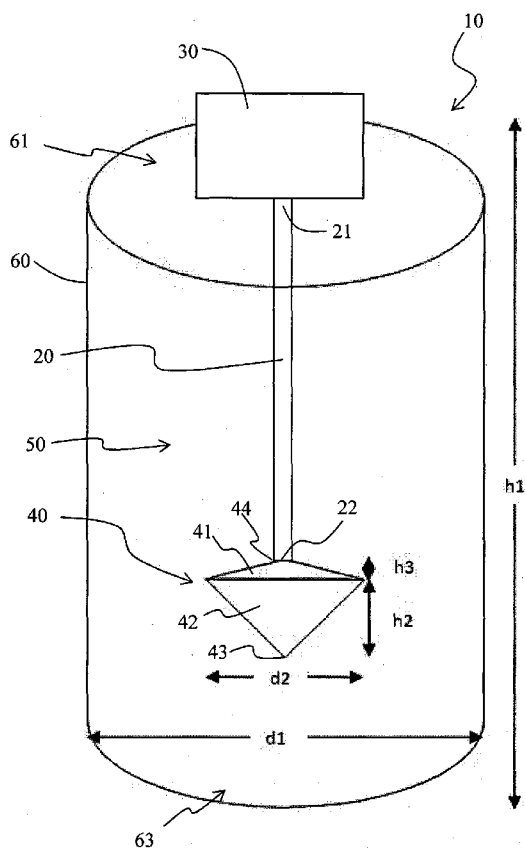


Fig. 1

- (57) Abstract: A mixing apparatus for use in a reactor configured to contain a mixture, the mixing apparatus comprising: a vertically oriented shaft configured to be placed in the reactor; a cone-shaped mixer configured to be connected to a bottom end of the shaft within the reactor; and a rotary-to-linear motion converter mechanism configured to be connected to an upper part of the shaft and to create reciprocating vertical movement of the shaft and the cone-shaped mixer in the mixture.



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A MIXING APPARATUS

FIELD OF THE INVENTION

This invention relates to a mixing apparatus, and in particular, a mixing apparatus for slurry-type fluid mixtures.

BACKGROUND OF THE INVENTION

Many industrial processes commonly use a continuous stirred tank reactor due to its efficient utilization of reactor volume, ability to prevent stratification and temperature gradient, and disperse end products and toxic materials. In the reactor may be slurry-type fluid mixtures that typically consist of a mixture of low-density water-type liquids and solid particles. A potential problem in slurry mixing is that the solid components tend to accumulate at the bottom of the mixing vessel due to gravity.

One of the easiest and most common ways to achieve desirable mixing level inside the reactor is by using a mechanical mixer. There are several types of mechanical mixers which result in different mixing patterns, such as marine impellers, flat vertical blades, Rushton impellers, inclined blades, curved blades, and cage beaters. Based on their flow patterns, mechanical mixers can be classified into radial impellers and axial impellers, which create patterns that encircle the rotational axis and along the line with the axis, respectively. In addition, a draft tube, which is a cylindrical housing around the impeller, can be used to improve mixing performance.

One of the drawbacks of the mechanical mixers described above is that they may create a vortex at the reactor surface. This problem usually occurs in low viscosity fluid mixing. The vortex reduces the effective volume of the mixing tank which decreases operational efficiency, for example decreasing conversion in the stirred tank reactor. In order to prevent vortex formation, the mixing tank is usually equipped with several vertical baffles near the tank's wall. These baffles disrupt mixing patterns and eliminate vortex formation in the reactor surface. Other mixing strategies involve utilization of recirculation flow to create desirable mixing patterns inside the reactor. A compressed gas which enters from the bottom of the reactor is able to create upward mixing pattern to decrease grit accumulation. Another strategy utilizes recirculation of the fluid phase inside the reactor. Some of the fluid phase is sucked out and discharged on the other side of the reactor, creating a spiral mixing pattern. This strategy is usually referred as pump mixing.

When the liquid contains solid particles, installation of mechanical impeller or pump recirculation is

inefficient as it requires more energy to induce solid particle mixing. Moreover, solid particles can be harmful to the pump itself and installation of baffles in a mechanical impeller equipped vessel may not significantly improve mixing performance. Thus, a mixing apparatus which can be maintained at a low energy requirement in mixing liquids containing solid particles would be of great interest for many applications.

SUMMARY OF INVENTION

The present novel mixing apparatus utilizes longitudinal displacement of a mixing head in a mixing vessel or reactor, acting like a plunger as it moves up and down along the vertical axis of the reactor.

The mixing head is cone-shaped. During operation, the cone-shaped mixing head creates a large turbulent area in the middle of reactor. The cone-shaped mixing head leaves a cone-shaped trail on its way upwards and downwards. The trail left by its upward and downward movements intersects in an area, which basically covers most of the reactor volume. It creates more turbulence in the corresponding "intersection" area which is beneficial for mixing. The cone-shaped trail also promotes gas release where relevant. Installation of baffles for vortex prevention thus becomes unnecessary.

The displacement characteristic of the mixing apparatus, which is oriented along the longitudinal axis of the tank, aims to alleviate the problem of solid accumulation problem. In addition, the shape of the cone has more ability to break excessive flocculent material, which often occurs in slurry type fluid inside anaerobic reactors. While it is generally aimed at multiphase solid and liquid (with possibly gas bubbles included) mixing, it can also be used for single phase liquid mixing.

Utilization of linear motion mixing pattern as the main driving force allows a same level of mixing to be achieved by the mixing apparatus with less energy consumption when compared to mixing using mechanical impellers. Its downward and upward movements are driven by a pumpjack mechanism to facilitate further stroke length necessary to extend mixing area and volume inside the vessel. The downward movement creates more pressure near the wall, while upward movement builds pressure at the centre. In a gas producing vessel, such as an anaerobic reactor, the resulting pressure gradient has the potential to help with gas release from solution and thereafter gas-liquid separation.

The present invention has the potential to be used in various applications, in particular blending tank and stirred tank. Its cone-shaped head creates the potential to be used for multiphase solid-liquid system, such as anaerobic reaction of sludges and wastewater mixture. So far no such mixing head device has been developed for mixing applications.

According to an exemplary aspect, there is provided a mixing apparatus for use in a reactor configured to contain a mixture, the mixing apparatus comprising: a vertically oriented shaft configured to be placed in the reactor; a cone-shaped mixer configured to be connected to a bottom end of the shaft within the reactor; and a rotary-to-linear motion converter mechanism configured to be connected to an upper part of the shaft and to create reciprocating vertical movement of the shaft and the cone-shaped mixer in the mixture.

The cone-shaped mixer may comprise an upper cone and a lower cone connected at their bases, their bases being identical.

The height of the upper cone may be smaller than the height of the lower cone.

The height of the upper cone may be 25% of the height of the lower cone.

The upper cone and the lower cone may be right circular cones. Ratio of the height of the lower cone to the diameter of the base may be 0.5. Ratio of the height of the upper cone to the diameter of the base may be 0.13. Ratio of the diameter of the base to the diameter of the reactor may be 0.40.

The upper cone may have a rounded profile.

The upper cone may be a truncated cone and the bottom end of the shaft may be attached to the truncated top of the upper cone.

Ratio of the stroke length of the reciprocating vertical movement to the height of the reactor may be 0.8.

The mixture may comprise liquid and solid particles, and the conical tip at a lower part of the cone-shaped mixer may be configured for breaking agglomerated solid particles in the mixture.

The rotary-to-linear motion converter mechanism may comprise a pumpjack mechanism.

BRIEF DESCRIPTION OF FIGURES

In order that the invention may be fully understood and readily put into practical effect there shall

now be described by way of non-limitative example only exemplary embodiments of the present invention, the description being with reference to the accompanying illustrative drawings.

Fig. 1 is a schematic diagram of a mixing tank with an exemplary cone-shaped mixing apparatus of the present invention.

5 Fig. 2 is a schematic diagram of a pumpjack.

Fig. 3 is a simulation velocity contour inside the mixing tank.

Fig. 4 is a simulation solid phase volume fraction contour inside the mixing tank.

DETAILED DESCRIPTION

10 Exemplary embodiments of the invention will be described with reference to Fig. 1 to Fig. 4.

As shown in Fig. 1, the mixing apparatus 10 comprises a vertically oriented shaft 20 configured to be placed in a reactor 60, a rotary-to-linear motion converter mechanism 30 connected to an upper part 21 of the shaft 20, and a cone-shaped mixing head or mixer 40 connected to another end 22 of the shaft 20 for immersion in a mixture in the reactor 60. The mechanism 30 is driven by a rotary motor 110 which acts as the main driving force to create upward and downward movement of the shaft 20 and the cone-shaped mixing head 40 in the reactor 60.

The mechanism 30 is provided at a top 61 of the vessel 60 and converts rotational movement of the motor 110 into reciprocating vertical movement of the shaft 20. The mechanism preferably comprises a pumpjack mechanism 30 as shown in Fig. 2. A pumpjack mechanism 30 is preferred as the rotary-to-linear motion converter mechanism as it can provide a larger stroke length than other mechanisms, for example, the slotted link mechanism or the crank and slider mechanism. As shown in Fig. 2, during operation, the motor 110 of the pumpjack 30 runs a set of gears to drive a crank 120. A pitman arm 130 connects the crank 120 to one end of a walking beam 140 which is free to move on a Samson post 150. The crank 120 and pitman arm 130 raise and lower one end of the walking beam 140 to make a horse head 160 on the other end of the walking beam 140 move up and down correspondingly. The shaft 20 connects the horse head 160 with the mixing head or mixer 40 at the bottom end 22 of the shaft 20. The shaft 20 follows the movement of the horse head 160 as it lowers and rises to create a vertical stroke of the cone shaped mixer 40. Stroke length is defined as the distance travelled by the mixing head 40 in each upward or downward movement. This translates to the potential of a larger height to diameter ratio of the vessel 60, which is desirable as it results in smaller requirement of space for tank installation.

35 Displacement of the shaft 20 is adjustable by varying the position of a pivot 170 of the walking beam

140. Preferably, the walking beam 140 is configured such that maximum displacement (i.e. the stroke) of the shaft 20 is achieved when the pivot 170 is shifted to the end of the walking beam 140 that is connected to the pitman arm 130 (shown as dotted lines in Fig. 2). This configuration enables the shaft displacement to be optimized to achieve the desired mixing level for various applications.

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The bottom end 22 of the shaft 20 is connected with the mixer 40, which has a cone or arrowhead form in the three and two dimensional space, respectively. In a preferred embodiment, the mixer 40 is in the form of two cones, an upper cone 41 and a lower cone 42, that are connected at their bases that are identical. The upper cone 41 is preferably a truncated cone such that the bottom end 22 of the shaft 20 is attached to the top 44 of the upper cone 41. In the preferred embodiment, the upper and lower cones 41, 42 are in the form of right circular cones. The mixer 40 is placed such that the conical tip 43 of the lower cone 42 is located at the lower part of the mixer 40 while the broader top 41 or the upper cone 41 is preferably rounded. The cone or arrowhead shape reduces the drag force transferred from the liquid in the vessel 60 to the mixer 40 and thus reduces energy consumption. Due to its sharp edge or tip 43, the downward movement of the mixer 40 is effective at breaking up larger agglomerated solid particles in the vessel 60.

The cone-shaped mixing head 40 also reduces drag force in the reactor 60 as it has less contact area with the liquid which reduces energy requirement. As the head 40 moves downward, it leaves a cone-shape wake in the liquid that resembles the trail in the sea left when a ship passes by. The total reactor volume which experiences turbulence due to movement of the head 40 is thus maximized. Downward movement of the head 40 spreads the liquid tangentially while the liquid in the lower part 62 of the reactor 60 is pushed backward or upward such that turbulence is generated. Although the cone-shaped mixing head 40 has the potential to create a dead zone in the bottom-most part 63 of the reactor 60, such a dead zone is eliminated when the head 40 is pulled up during an upstroke of the shaft 20.

As the cone-shaped mixing head 40 is pulled up, it creates upward movement in the surrounding volume 50. As a result, it creates circular motion where the liquid adjacent to the shaft 20 is shifted upward and the surrounding liquid further away is shifted downward. The cone-shaped mixing head 40 thus creates cone-shaped turbulence in its downward movement and full recirculation pattern in its upward movement. With a cone-shaped mixing head 40, the downward and upward movement creates a mixing pattern which ensures no velocity vector elimination and reduces risk of dead zones forming.

A computational fluid dynamics simulation to describe and compare the performance of the mixing apparatus 10 was carried out. The simulation aimed to find the optimum dimensions of the cone 40,

by investigating the mixing pattern when various shapes and dimensions of cone head 40 were used. The computational fluid dynamic simulation was performed using FLUENT software, using unsteady state SST omega turbulence model. The simulated vessel 60 had a height to diameter ratio of 1.8. It contained a slurry type liquid having a viscosity of 0.1 kg/m.s. The mixer 40 formed a solid region inside the vessel 60, which moved up and down in a straight line. The movement was simulated using moving mesh algorithm. Tetrahedral meshing was utilized for both liquid and solid regions.

Subsequently, various mixer 40 dimensions were evaluated to find its optimal dimension in terms of homogeneity. The simulation was carried out for three cycles, i.e., three upward and downward movements. Table 1 below shows the proposed optimal parameter of the proposed cone-shaped linear motion mixing apparatus 10.

No.	Item	Parameter	Value
1	Mixer to vessel diameter ratio	d_2/d_1	0.40
2	Lower height to diameter ratio	h_2/d_2	0.50
3	Upper height to diameter ratio	h_3/d_2	0.13
4	Stroke length to vessel height ratio (including mixer height)		0.80

Table 1: Recommended dimensions of cone-shaped mixing head

In a case study evaluated, a 3m³ anaerobic digestion vessel 60 was considered. The diameter and height of the vessel 60 were 1.26m and 2.28m, respectively. The tank 60 was filled with a slurry-type liquid, where the solid content was 15%. The cone-shaped mixing head 40 was rigid, moving up and down in a straight line. The liquid viscosity was 0.1 kg/m.s. Tetrahedral meshing was utilized for both liquid and solid regions.

Based on the recommended dimensions of the linear motion mixer 40, the recommended mixer 40 diameter was 0.50m. The heights of its upper and lower cones 41, 42 were 0.07m and 0.25m, respectively. The mixer 40 was moved at the velocity of 0.5m/s and the stroke length was 1.5m. Thus, it took approximately 6 seconds for the mixer 40 to perform one complete cycle.

In the simulation, the drawing and meshing were carried out using GAMBIT while the problem was solved using FLUENT package. Fig. 3 and Fig. 4 show the simulation results on distribution of

velocity magnitude and solid volume fraction inside the mixing tank 60, respectively. The simulation was carried out for three cycles, i.e., three downward and upward movements. All tank walls 64 were assumed to be rigid and the reactor surface was set to be an interface. The SST omega turbulence model was used in the simulation.

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The contour analysis was carried out at the upper and lower turning point of the mixer, i.e. the highest 44 and lowest point 43 of the mixing head 40. Based on Fig. 3, the downward movement creates larger turbulence area compared to its upward movement, which may be caused by downward gravitational force. Further analysis on turbulence kinetic energy showed that the surface and the area surrounding the wall 64 have least turbulence compared to other areas in the mixing vessel 60, even though the velocity magnitude contour does not indicate any dead zone formed in the area. The computational fluid dynamic simulation also indicates even distribution of solid particle throughout the mixing vessel 60 and the presence of laminar flow in the liquid surface.

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The optimization in the dimension of the cone-shaped mixing head 40 revealed that it requires a smaller cone 41 at the upper part 41 as well. Based on the computational fluid dynamic simulation, the tiny upper cone 41 slightly decreases homogeneity during downward movement. Nevertheless, it significantly improves the homogeneity during its upward movement, such that it is a worthwhile trade-off. The recommended height of the upper cone 41 is approximately 25% of the height of the lower cone 42. Further studies showed that increasing the height of the upper cone 41 further does not have any effect on increased homogeneity.

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Increasing mixing condition inside the reactor 60 eliminates dead zone, the inactive area of the reactor. In addition, it improves homogeneity inside the reactor 60. Improvement in mixing condition and homogeneity may result in conversion increase. Given that linear motion mixing utilizes upward and downward motions, it has more potential to provide a more uniform condition compared to other mechanical mixers, in particular in the axial direction. Therefore, it can be expected to promote conversion increase by means of increasing homogeneity inside the reactor 60.

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A potential implementation of the proposed mixing apparatus is in biochemical reactors for mixing of anaerobic digestion processes with their specific characteristics, such as the presence of solid particle and the requirement to release the biogas as the result of the anaerobic reactions, where the organism is used as the catalysts. The microorganisms form the solid phase inside the reactor. The presence of biomasses in the form of solid particles incurs additional challenges in mixing as these particles have to be distributed evenly to enable optimal exposure to the substrates and thus improving yield. The

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mixing apparatus 10 is able to prevent formation of suspended biomass which decreases substrate conversion. Similarly, chemical reaction which includes solid phase catalysts may benefit from the mixing apparatus 10 as it ensures effective contact between catalyst and substrate inside catalytic reactors.

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Whilst there has been described in the foregoing description exemplary embodiments of the present invention, it will be understood by those skilled in the technology concerned that many variations in details of design, construction and/or operation may be made without departing from the present invention. For example, although one of the envisaged applications is in biochemical reactors for

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mixing of anaerobic digestion processes, the proposed mixing apparatus has a broad range of potential applications in any type of stirred tanks in general. While the cone-shaped mixer has been depicted as having a circular identical base for the top and bottom cone, in alternative embodiments, the identical base of the top and bottom cones may be polygonal in shape. Besides using a pumpjack mechanism as the rotary-to-linear motion conversion mechanism, other mechanisms that can effect a long stroke

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length may also be used.

CLAIMS

1. A mixing apparatus for use in a reactor configured to contain a mixture, the mixing apparatus comprising:
 - 5 a vertically oriented shaft configured to be placed in the reactor;
 - a cone-shaped mixer configured to be connected to a bottom end of the shaft within the reactor; and
 - a rotary-to-linear motion converter mechanism configured to be connected to an upper part of the shaft and to create reciprocating vertical movement of the shaft and the cone-shaped mixer in
10 the mixture.
2. The mixing apparatus of claim 1, wherein the cone-shaped mixer comprises an upper cone and a lower cone connected at their bases, their bases being identical.
- 15 3. The mixing apparatus of claim 2, wherein the height of the upper cone is smaller than the height of the lower cone.
4. The mixing apparatus of claim 3, wherein the height of the upper cone is 25% of the height of the lower cone.
- 20 5. The mixing apparatus of any one of claims 2 to 4, wherein the upper cone and the lower cone are right circular cones.
6. The mixing apparatus of claim 5, wherein ratio of the height of the lower cone to the diameter of
25 the base is 0.5.
7. The mixing apparatus of claim 5 or 6, wherein ratio of the height of the upper cone to the diameter of the base is 0.13.
- 30 8. The mixing apparatus of any one of claims 5 to 7, wherein ratio of the diameter of the base to the diameter of the reactor is 0.40.
9. The mixing apparatus of any one of claims 2 to 6, wherein the upper cone has a rounded profile.

10. The mixing apparatus of any one of claims 2 to 7, wherein the upper cone is a truncated cone and the bottom end of the shaft is attached to the truncated top of the upper cone.

5 11. The mixing apparatus of any preceding claim, wherein ratio of the stroke length of the reciprocating vertical movement to the height of the reactor is 0.8.

12. The mixing apparatus of any preceding claim, wherein the mixture comprises liquid and solid particles, and wherein the conical tip at a lower part of the cone-shaped mixer is configured for breaking agglomerated solid particles in the mixture.

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13. The mixing apparatus of any preceding claim, wherein the rotary-to-linear motion converter mechanism comprises a pumpjack mechanism.

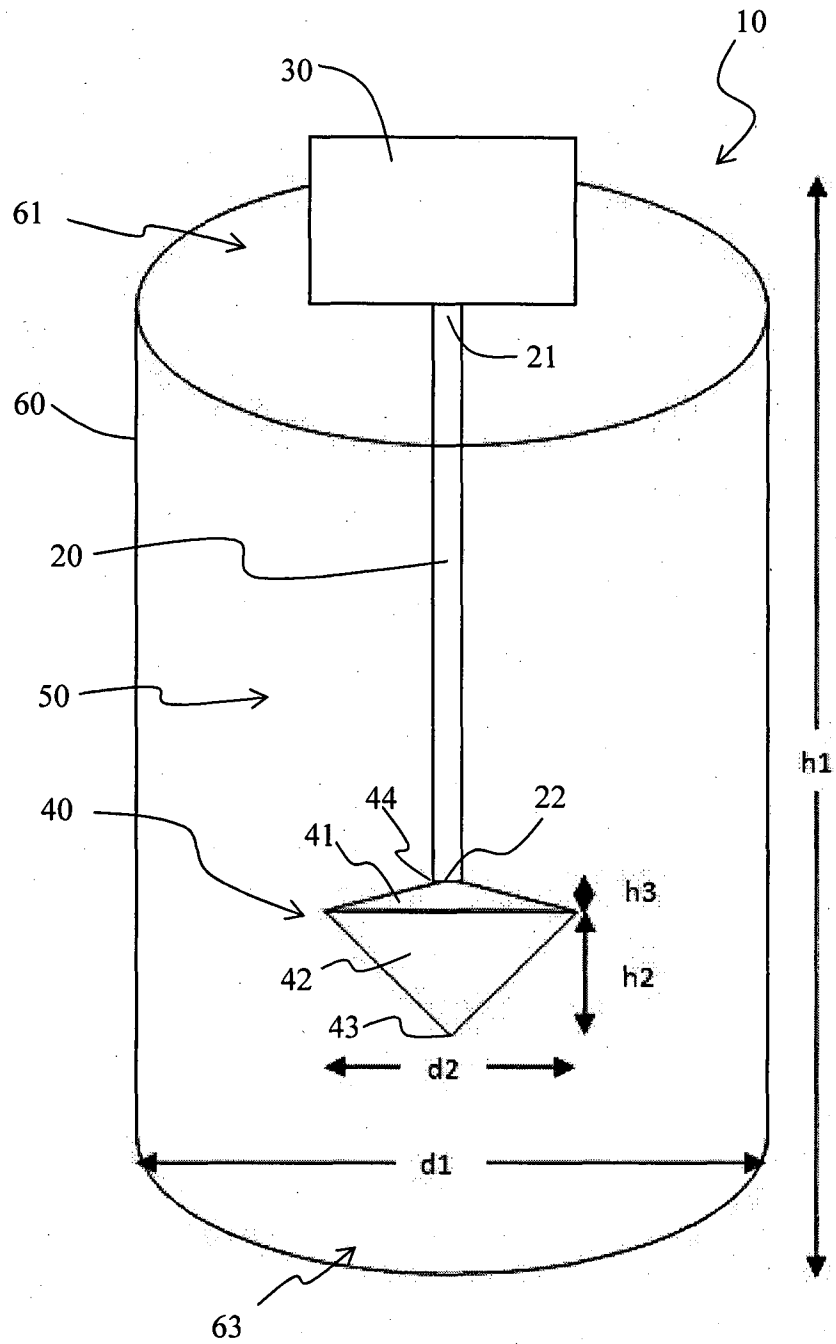


Fig. 1

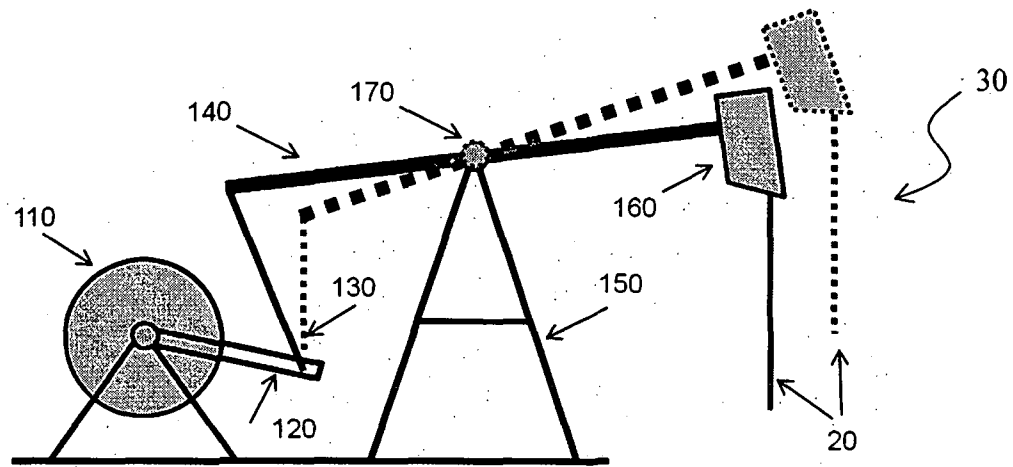


Fig. 2

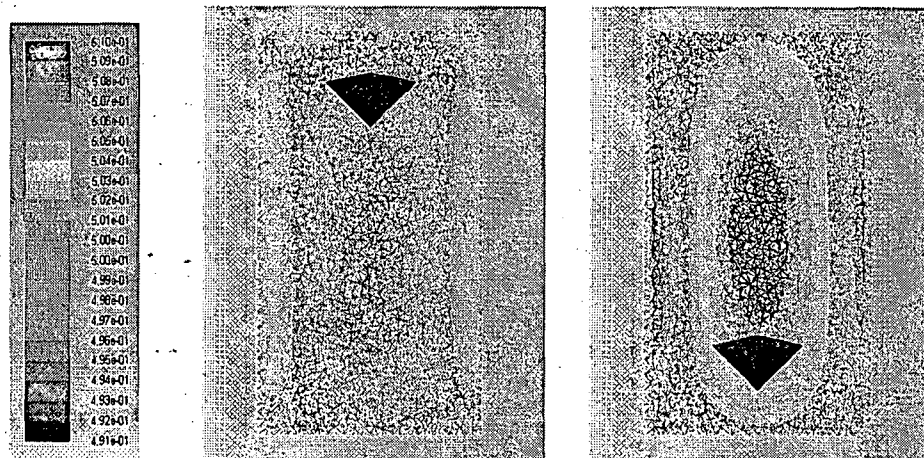


Fig. 3

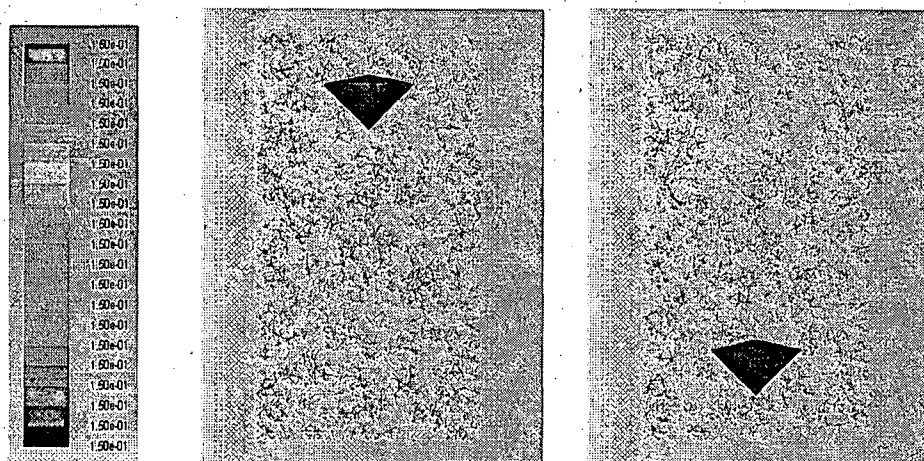


Fig. 4

INTERNATIONAL SEARCH REPORT

International application No.
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A. CLASSIFICATION OF SUBJECT MATTER

B01F 11/00 (2006.01) B01F 15/00 (2006.01)

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPODOC AND wpi: International and/or Cooperative Patent Classification symbols (B01F11, B01F15 and similar) with keywords (CONE, CONICAL, RECIPROCATING, PUMPJACK, SHAPE, PROFILE and similar)

USPTO patents database: US patent classification 366/256 and 336/258

Espacenet: applicant/inventor searches

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	Documents are listed in the continuation of Box C	

☒ Further documents are listed in the continuation of Box C

☒ See patent family annex

* "A"	Special categories of cited documents: document defining the general state of the art which is not considered to be of particular relevance	"T"	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"E"	earlier application or patent but published on or after the international filing date	"X"	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"L"	document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"Y"	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"O"	document referring to an oral disclosure, use, exhibition or other means	"&"	document member of the same patent family
"P"	document published prior to the international filing date but later than the priority date claimed		
Date of the actual completion of the international search 9 February 2015		Date of mailing of the international search report 09 February 2015	
Name and mailing address of the ISA/AU AUSTRALIAN PATENT OFFICE PO BOX 200, WODEN ACT 2606, AUSTRALIA Email address: pct@ipaustalia.gov.au		Authorised officer Rajeev Deshmukh AUSTRALIAN PATENT OFFICE (ISO 9001 Quality Certified Service) Telephone No. 0399359622	

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C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT		PCT/SG2014/000560
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INTERNATIONAL SEARCH REPORT		International application No.	
Information on patent family members		PCT/SG2014/000560	
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Form PCT/ISA/210 (Family Annex)(July 2009)			

INTERNATIONAL SEARCH REPORT Information on patent family members		International application No. PCT/SG2014/000560	
This Annex lists known patent family members relating to the patent documents cited in the above-mentioned international search report. The Australian Patent Office is in no way liable for these particulars which are merely given for the purpose of information.			
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