

1           **“A DESANDING APPARATUS AND A METHOD OF USING SAME”**

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3                           **FIELD OF THE DISCLOSURE**

4           The present disclosure generally relates to an apparatus and a  
5 method for removing particulates from multiphase fluid streams, and in particular,  
6 relates to an apparatus and a method for removing sands from multiphase fluid  
7 streams produced from an oil or gas well while minimizing the abrasion to the  
8 equipment involved.

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10                           **BACKGROUND**

11           Production from wells in the oil and gas industry often contains  
12 particulates such as sand. These particulates could be part of the formation from  
13 which the hydrocarbon is being produced, introduced from hydraulic fracturing, or  
14 fluid loss material from drilling mud or fracturing fluids, or from a phase change of  
15 produced hydrocarbons caused by changing conditions at the wellbore (Asphalt  
16 or wax formation). As the particulates are produced, problems occur due to  
17 abrasion and plugging of production equipment. In a typical startup after  
18 stimulating a well by fracturing, the stimulated well may produce sand until the  
19 well has stabilized, often lasting for several months after production commences.  
20 Other wells may produce sand for a much longer period of time.

21           Erosion of the production equipment is severe enough to cause  
22 catastrophic failure. High fluid stream velocities are typical and are even  
23 purposefully designed for elutriating particles up the well and to the surface. An  
24 erosive failure of this nature can become a serious safety and environmental  
25 issue for the well operator. A failure such as a breach of high pressure piping or

1 equipment releases uncontrolled high velocity flow of fluid which is hazardous to  
2 service personnel. Releasing such fluid to the environment is damaging to the  
3 environment resulting in expensive cleanup and loss of production. Repair costs  
4 are also high.

5 In all cases, retention of particulates contaminates surface  
6 equipment and the produced fluids and impairs the normal operation of the oil  
7 and gas gathering systems and process facilities. Therefore, desanding devices  
8 are required for removing sand from the fluid stream. Due to the nature of the  
9 gases handled, including pressure and toxicity, all vessels and pressure piping in  
10 desanding devices must be manufactured and approved by appropriate boiler  
11 and pressure vessel safety authorities.

12 In one existing system, a pressurized tank ("P-Tank") is placed on  
13 the wellsite and the well is allowed to produce fluid and particulates. The fluid  
14 stream is produced from a wellhead and into a P-Tank until sand production  
15 ceases. The large size of the P-Tank usually restricts the maximum operating  
16 pressure of the vessel to something in the order of 1,000 – 2,100 kPa. In the  
17 case of a gas well, this requires some pressure control to be placed on the well to  
18 protect the P-Tank. Further, for a gas well, a pressure reduction usually is  
19 associated with an increase in gas velocity which in turn makes sand-laden  
20 wellhead effluent much more abrasive and places the pressure controlling choke  
21 at risk of failure. Another problem associated with this type of desanding  
22 technique is that it is only a temporary solution. If the well continues to make  
23 sand, the solution becomes prohibitively expensive. In most situations with this  
24 kind of temporary solution, the gas vapors are not conserved and sold as a  
25 commercial product.

1 Another known system includes employing filters to remove  
2 particulates. A common design is to have a number of fiber-mesh filter bags  
3 placed inside a pressure vessel. The density of the filter bag fiber-mesh is  
4 matched to the anticipated size of the particulates. Filter bags are generally not  
5 effective in the removal of particulates in a multiphase condition. Usually  
6 multiphase flow in the oil and gas operations is unstable. Large slugs of fluid  
7 followed by a gas mist are common. In these cases, the fiber bags become a  
8 cause of pressure drop and often fail due to the liquid flow therethrough. Due to  
9 the high chance of failure, filter bags may not be trusted to remove particulates in  
10 critical applications or where the flow parameters of a well are unknown. An  
11 additional problem with filter bags in most jurisdictions, is the cost associated with  
12 disposal. The fiber-mesh filter bags are considered to be contaminated with  
13 hydrocarbons and must be disposed of in accordance to local environmental  
14 regulation.

15 In Canadian Patent Number 2,433,741, issued February 3, 2004  
16 and in Canadian Patent Number 2,407,554, issued June 20, 2006, both assigned  
17 to the Applicant of the subject patent application, a desander is disclosed having  
18 an elongate, horizontal vessel with an inlet at one end and an outlet at the other  
19 end. The outlet separated from the inlet by a downcomer flow barrier, such as a  
20 weir, adjacent the vessel's outlet or exit. The weir forms, and maintains, an  
21 upper freeboard portion having a cross-sectional area which is greater than that of the  
22 field piping from whence the fluid stream emanates for encouraging water and  
23 particulates to fall out of the freeboard portion. Water and particulates  
24 accumulate along a belly portion. The accumulation of particulates is along a

1 substantial length of the elongate vessel increasing the difficulty of periodic  
2 manual removal of such accumulating using scraper rods and the like.

3 While Applicant has substantially maintained their elongated  
4 horizontal design virtually unchanged for years, there has been a desire to  
5 improve the ease with which the vessel can be cleaned and further improvement  
6 in separation efficiency. Further, due to the nature of the gases handled,  
7 including pressure and toxicity, all vessels and pressure piping must be  
8 manufactured and approved by appropriate boiler and pressure vessel safety  
9 authorities.

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### SUMMARY

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13 Desanding apparatus is provided which is placed adjacent to a  
14 well's wellhead for intercepting a fluid stream flow before prior to entry to  
15 equipment including piping, separators, valves, chokes and downstream  
16 equipment. The fluid stream can contain a variety of phases including liquid, gas  
17 and solids. In one embodiment, a pressure vessel is inserted in the flowstream  
18 by insertion into high velocity field piping extending from the wellhead. The  
19 vessel contains an upper freeboard portion having a cross-sectional area which is  
20 greater than that of the field piping from whence the fluid stream emanates. As a  
21 result, fluid stream velocity drops and particulates cannot be maintained in  
22 suspension. The freeboard portion is maintained through control of the angle of  
23 the desander, obviating the need for a downcomer of Applicant's own prior art  
horizontal desanders.

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25 In a broad aspect, a desanding system receives a gas stream  
containing entrained liquid and particulates. The system comprises a vessel,

1 elongated along a longitudinal axis and inclined from a horizontal at a non-zero  
2 inclination angle. The vessel has a fluid inlet, adjacent an upper end for  
3 discharging the gas stream into the vessel at an inlet velocity, and a fluid outlet,  
4 spaced along the longitudinal axis from, and lower than, the fluid inlet.

5           The vessel further has a gas/liquid interface at the fluid outlet, a  
6 belly storage portion formed below the interface, and a freeboard portion formed  
7 adjacent an upper portion of the vessel above the interface. The freeboard  
8 portion has a freeboard cross-sectional area which diminishes from the fluid inlet  
9 to the fluid outlet, wherein a freeboard velocity, adjacent the fluid inlet is less than  
10 the inlet velocity, the freeboard velocity being such that the entrained liquids and  
11 particulates fall out of the gas stream for collecting in the belly storage portion. A  
12 desanded gas stream flows out of the freeboard portion and out the fluid outlet,  
13 being free of a substantial portion of the particulates.

14           More preferably, a vessel of an embodiment of the present  
15 invention is incorporated in a desanding system to replace existing prior  
16 connective piping for a wellhead, the vessel being supported using structure to  
17 align the vessel with the wellhead piping and downstream equipment. The  
18 desander's fluid inlet and fluid outlet, associated with the inclined world of the  
19 desander, are adapted to connect to the orthogonal world of the connective  
20 piping.

21           In another broad aspect, a method for desanding a fluid stream,  
22 emanating from a wellhead and containing gas and entrained liquid and  
23 particulates, comprises providing an elongated vessel having a longitudinal axis  
24 which is inclined from the horizontal. The vessel has a fluid inlet adjacent an first  
25 end of the vessel and a fluid outlet spaced along the longitudinal axis from the

1 fluid inlet; inclining the vessel at angle from a horizontal at a non-zero inclination  
2 angle so that the fluid outlet is lower than the fluid inlet for forming a freeboard  
3 portion above the fluid outlet. The fluid stream is discharging from the fluid inlet,  
4 into the vessel and substantially parallel to the longitudinal axis for establishing a  
5 liquid interface in a belly portion of the vessel, the belly portion and being formed  
6 below the fluid outlet. Liquid and particulates are being directed along a  
7 trajectory in the freeboard portion of the vessel to intercept a substantial portion  
8 of the particulates at the liquid interface for storage in the belly portion. A  
9 desanded gas stream is recovered at the fluid outlet which is substantially free of  
10 particulates.

11 The inlet can be parallel or non-parallel with the longitudinal axis for  
12 enabling a trajectory to intercept the gas/liquid interface. The fluid stream can be  
13 introduced through a replaceable nozzle. The fluid inlet can be curved to align  
14 the inlet from the inclined desander and orthogonal piping from a wellhead.

15 In yet another broad aspect, there is provided a vessel having a  
16 distal end and a proximal end for removing particulates from a multiple-phase  
17 fluid stream containing gas, entrained liquid and particulates, the vessel  
18 comprising: a volume having a diverging bounding wall, a distal base, and an  
19 apex; the diverging bounding wall having a top wall at a first inclination angle and  
20 a bottom wall at a second inclination angle; the second inclination angle at a  
21 greater angle than the first inclination angle; a fluid inlet interface at the apex for  
22 receiving said fluid stream into the volume of the vessel; a fluid outlet on the top  
23 of the top wall, spaced from the fluid inlet interface; a horizontally extending  
24 freeboard interface separating a freeboard portion formed adjacent an upper  
25 portion of the vessel above the interface and a belly portion therebelow, the belly

1 portion being bounded at its bottom by the bottom wall, the freeboard portion  
2 forming a freeboard cross-sectional area for a freeboard velocity of the fluid  
3 stream less than a fluid stream velocity at the fluid inlet interface; and an  
4 elongated flow path for receiving the fluid stream from the fluid inlet interface and  
5 directing the fluid stream to the fluid outlet; wherein said length of the elongated  
6 flow path and the freeboard velocity are such that an effective amount of the  
7 entrained liquid and particulates fall out of the fluid stream and particulates settle  
8 towards the bottom wall of the belly portion; and wherein a desanded gas stream  
9 flows out of the freeboard portion through the fluid outlet and is free of a  
10 substantial portion of the particulates.

11               The second inclination angle may be greater than the angle of  
12 repose of settled particulates. The top inclination angle may be inclusively  
13 between 2 and 20 degrees. The cross-sectional shape of the proximal base may  
14 be circular.

15               In some embodiments, the central axis may be perpendicular to the  
16 plane of the distal base. In some other embodiments, the central axis may be  
17 oblique to the distal base.

18               Applicable in all instances, at steady state, once the belly portion  
19 fills with liquid and in cases where liquid removal from the belly portion is less  
20 than the rate of incoming liquid, a mass balance of liquid in and out can be  
21 established in which case the incoming liquid co-exiting with the desanded gas.

22               The vessel may further comprise a lower discharge from the belly  
23 portion for discharging liquid and collected particulates. The discharge further  
24 comprises: an inlet valve adjacent and fluidly connected to the discharge; a  
25 particulate accumulation chamber; and a discharge valve, wherein the particulate

1 accumulation chamber is sandwiched between the inlet valve and the discharge  
2 valve.

3 In some embodiments, the fluid inlet interface has a discharge end,  
4 and the discharge end is oriented for discharging the gas stream into the  
5 freeboard at an angle equal to the top inclination angle. The fluid inlet interface  
6 may further comprise a replaceable nozzle having a discharge end oriented for  
7 discharging the gas stream into the freeboard. The replaceable nozzle may be  
8 connected to the fluid inlet interface at a flange.

9 In some embodiments, the desanding system receives a gas  
10 stream emanating from a wellhead and the fluid inlet interface further comprises  
11 a receiving end for receiving the gas stream, the receiving end being orthogonal  
12 to the wellhead.

13 In some embodiments, the top inclination angle is variable for  
14 varying fluid stream conditions. In some other embodiments, the bottom  
15 inclination angle is variable for particulate stream conditions.

16 According to another broad aspect of this disclosure, there is  
17 provided a method for desanding a fluid stream emanating from a wellhead, the  
18 fluid stream containing gas, entrained liquid and particulates, the method  
19 comprising: providing an elongated vessel extending from a proximal end  
20 downwardly towards a distal end and having a diverging bounding wall to define  
21 a top inclination angle and a bottom inclination angle larger than the top  
22 inclination angle; injecting, at a first fluid velocity, the fluid stream into the vessel  
23 from the proximal end at about the first inclination angle; directing, at a second  
24 fluid velocity slower than said first fluid velocity, said fluid stream along an  
25 elongated flow path in the vessel from the proximal end towards the distal end to

1 allow an effective amount of the entrained liquid and particulates fall out of the  
2 fluid stream and move into a belly portion; collecting desanded gas in a freeboard  
3 portion, said freeboard portion being above the belly portion and being separated  
4 therefrom by a gas/liquid interface; and discharging the desanded gas from the  
5 freeboard portion at the distal end; wherein said desanded gas is free of a  
6 substantial portion of the particulates.

7 In some embodiments, the method further comprises collecting  
8 desanded liquid from the belly portion and discharging, from the belly portion, the  
9 desanded liquid with the discharged gas at the distal end.

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#### **BRIEF DESCRIPTION OF THE DRAWINGS**

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Figure 1 is a cross-sectional side view of Applicant's prior art elongated horizontal desander illustrating downcomer flow barrier, fluid streams, falling trajectory of particulates, and accumulations of separated liquid, particulates and particulate-free fluid discharge;

Figure 2 is a cross-sectional view of an embodiment of a tilted or inclined desander;

Figures 3A and 3B are perspective representations of the volumes of the belly portion and freeboard portions of the inclined desander of Fig. 2;

Figure 4 is a cross-sectional view of another embodiment of an inclined desander having a greater inclination angle than that of Fig. 2;

Figure 5 is a cross sectional view of a curved fluid inlet, square to the desander, and having a long radius angular transition elbow between orthogonal piping and the inclined desander;

1                   Figure 6 is a representation of an inclined desander illustrating  
2     parameters for an example 36 inch diameter desander having a horizontal fluid  
3     inlet; and

4                   Figure 7 is a cross-sectional view of a desander having a tilted  
5     conical vessel, according to another embodiment.

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7                   **DETAILED DESCRIPTION**

8                   A desander is typically inserted between or as a replacement for  
9     existing piping such as connecting piping between a wellhead and downstream  
10    equipment such as multiphase separators.

11                  As shown in Fig. 1, a prior art horizontal desander comprises a  
12    cylindrical pressure vessel 11 having a substantially horizontal axis A, a first fluid  
13    inlet end 12 adapted for connection to the fluid stream F. The fluid stream F  
14    typically comprises a variety of phases including gas G, some liquid L and  
15    entrained particulates such as sand S. The fluid stream F containing sand S  
16    enters through the inlet end 12 and is received by a freeboard portion 13. In the  
17    illustrated prior art vessel, the freeboard area is set by a downcomer flow barrier  
18    14. Accordingly, the velocity of the fluid stream F slows to a point below the  
19    entrainment or elutriation velocity of at least a portion of the particulates S in the  
20    fluid stream. Given sufficient horizontal distance without interference, the  
21    particulates S eventually fall from the freeboard portion 13. Particulates S and  
22    liquids L accumulate over time in the belly portion 15 and are periodically cleaned  
23    out at sufficient intervals to ensure that the maximum accumulated depth does  
24    not encroach on the freeboard portion 13. The desanded fluid stream, typically  
25    liquid L and gas G, emanates from fluid outlet 16.

1                   As shown in Figs. 2 through 7, embodiments of an inclined  
2   desander 20 are free of the prior art flow barrier and, through tilting or inclination  
3   of the vessel, maximize freeboard upon entry of the flow stream, and reduce  
4   liquid flow rates for maximizing settling conditions therein and retention of  
5   captured particulates S. Variability of the inclination angle  $\alpha$  enables a measure  
6   of variability between the respective freeboard and liquid-storing belly portion for  
7   adjusting performance.

8                   As shown in Fig. 2, the desander 20 comprises a vessel 22 having  
9   an axis A oriented at an acute angle  $\alpha$  to the horizontal H. The desander 20 has  
10   a fluid inlet 24 at an upper end 25 for receiving a fluid stream F typically  
11   comprising a variety of phases including gas G, some liquid L and entrained  
12   particulates such as sand S. In this embodiment, the fluid inlet 24 is oriented  
13   parallel to a longitudinal axis A of the vessel 22. A fluid outlet 26 is located along  
14   a top 28 of the vessel 22, and spaced from the fluid inlet 24. In an operating  
15   state, a gas/liquid interface 32 forms extending horizontally from about the fluid  
16   outlet 26. A belly portion 40 is formed below the interface 32 for containing liquid  
17   L and particulates S. A freeboard portion 44 is formed above the interface 32.  
18   The fluid inlet 24 discharges into the freeboard 44. Particulate trajectory can be  
19   manipulated by positioning and orienting a discharge end 29 of the fluid inlet 24.  
20   In one embodiment, the discharge 29 of the inlet 24 can be aligned parallel to the  
21   vessel axis A. The inlet 24 or discharge 29 can be oriented in other orientations  
22   including above the inclined axis A, or below the axis A.

23                   The interface 32 is a generally obround, gas/liquid interface  
24   between the belly and freeboard portions 40, 44. The obround interface 32 has a  
25   distal end 33 adjacent the fluid outlet 26 and a proximal end 34, the location of

1 which is intermediate the fluid outlet 26 and fluid inlet 24 and varies with liquid  
2 level and inclination angle  $\alpha$ . As a result of the desander 20 inclination, the  
3 trajectory of the fluid stream F, from inlet 24, converges with the interface 32.  
4 The trajectory for dropping sand S and liquid L into the belly portion 40 is  
5 foreshortened, reducing drop out time. The vessel 22 is long enough to space  
6 the fluid inlet 24 sufficiently from the interface 32 to minimize turbulence of the  
7 liquid L in the belly portion 40, that spacing being dependent upon various design  
8 factors including vessel inclination angle  $\alpha$ , inlet fluid stream velocity and  
9 characteristics.

10 At a steady state, the maximum level of the interface 32, is  
11 controlled at the distal end 33, set by eventual liquid entrainment and discharge  
12 at the fluid outlet 26. Gas G discharges at the fluid outlet 26. At steady state,  
13 when the liquid level reaches the fluid outlet 26, any oil and other liquids are re-  
14 entrained with the gas G exiting at fluid outlet 26. Particulates S continue to be  
15 captured in the belly portion 40 until its volumetric capacity is reached.

16 Connective piping 46, between conventional wellhead and  
17 downstream equipment, is typically in rectilinear or orthogonal arrangements.  
18 Thus, the angle  $\alpha$  of the desander 20 introduces coupling or connection  
19 challenges. The connective piping 46 is generally horizontal or vertical and  
20 incorporation of the inclined desander 20 requires an adjustment made at the  
21 fluid inlet 24 and fluid outlet 26. In many scenarios, with a small inclination angle  
22  $\alpha$ , the fluid outlet 26 can be fit to the top 28 of the vessel 22 at angle  $\alpha$ , orienting  
23 the outlet 26 vertically and thereby obviating the need for an angular transition.

24 Turning to Figs. 3A and 3B, the desander 20 is shown  
25 diagrammatically split at the interface 32 for illustrating the incrementally

1 increasing volume of the belly portion 40 below and the incrementally decreasing  
2 volume of freeboard portion 44, increasing and decreasing as referenced to the  
3 feed stream F. The freeboard portion 44 demonstrates a cross-sectional area  
4 which diminishes from the fluid inlet 24 to the fluid outlet 26. As shown in Figs. 2  
5 and 4, a freeboard velocity at the fluid inlet 24 is such that the entrained liquids L  
6 and particulates S fall out of the fluid stream F and collect in the storage belly  
7 portion 40. The cross-sectional area of the freeboard portion 44, adjacent the  
8 fluid inlet 24, is at its greatest for achieving the lowest average inlet velocity for  
9 maximum drop out efficiency for particulates S and liquids L. As the freeboard  
10 cross-sectional area adjacent the fluid inlet 24 is large and relatively unimpeded  
11 by the belly portion 40, the velocity reduction upon discharge is significantly  
12 greater than that of Applicant's prior art horizontal desander. Particulate removal  
13 is accomplished while minimizing the portion of the vessel allocated to the  
14 freeboard portion 44, maximizing the efficiency of that freeboard portion for  
15 particulate drop out, and resulting in a greater allocation of the overall portion of  
16 the vessel to the belly portion 40 for storage.

17               Velocity in the freeboard portion 44 increases after a substantial  
18 portion of the particulates S have already deposited in the belly portion 40. The  
19 cross-sectional area of the belly portion 40 increases towards the fluid outlet 26  
20 and the velocity of liquids accumulating therein diminishes.

21               With reference again to Fig. 2 and to Fig. 4, in the belly portion,  
22 particulates accumulate and flow downvessel at an angle of repose. The  
23 accumulation of liquid L and particulates S establishes a downward flow in the  
24 belly portion, and as the particulates accumulate and limit the free flow of the

1 liquid L in the belly portion 40, the liquid velocity begins to increase, drawing  
2 more particulates S downvessel.

3 With reference to Fig. 4, the inclination angle  $\alpha$  can be adjusted,  
4 shown here as an increased angle over that of Fig. 2. At increasing angles  $\alpha$  the  
5 trajectory of the feed stream impinges the interface 32 at less acute angle,  
6 impinges the interface 32 sooner and enables selection of shorter vessels 22 and  
7 greater particulate removal efficiency.

8 Inclination angles  $\alpha$  can be adjusted, for a given length of vessel 22,  
9 between fluid inlet 24 and fluid outlet 26, to accommodate gas G and liquid L  
10 content in the feed fluid stream F. Inclination angles  $\alpha$  would generally be in the  
11 range of about 2 degrees to about 20 degrees. The shallowest operating angle  $\alpha$   
12 is limited by the minimum requirement for a minimum freeboard 44 cross-  
13 sectional area adjacent the inlet 24 once the interface 32 builds to about the fluid  
14 outlet 26. The steepest operating angle  $\alpha$  is limited by the requirement for a  
15 minimum storage capacity in the belly portion 40. The minimum inclination angle  
16 would be the condition where the inlet 24 is entirely in the gas phase of the  
17 freeboard portion 44 and the gas phase at the discharge is of zero height. The  
18 maximum inclination angle would be the condition where the inlet 24 is well  
19 above the gas/liquid interface allowing substantial freeboard to handle slug flow.  
20 Angles above 45 degrees limit the performance of desander considerably since  
21 the residence time of the liquid phase in the belly portion 40 is reduced.

22 With reference to Figs. 4 and 5, the fluid inlet 24, exposed to  
23 entrained particulates S in the fluid stream, is subject to greatest risk of erosion.  
24 While the inlet 24 can be integrated with the vessel 22, one can also provide an  
25 inlet 24 or discharge 29 that is replaceable for ease of maintenance. Options

1 include accepting eventual wear and shutdown of the desander 20 for  
2 replacement of an integrated inlet 24; modifying the material or configuration of  
3 the inlet 24 to prolong service life, or using replaceable discharge of nozzle for  
4 minimizing turnaround time. As stated, one approach is to make the discharge  
5 29 replaceable including incorporating features of a replaceable nozzle as set  
6 forth in Applicant's Patent CA 2,535,215 issued May 8, 2008. A replaceable  
7 nozzle 50 can be fit to a compatible coupling at the upper end 25 of the vessel  
8 22. One form of replaceable nozzle 50 comprises the discharge 29, and a  
9 threaded connection or nozzle flange 29i, for connection to a compatible  
10 threaded connection or flange 24i at the inlet 24 of the vessel 22. The orientation  
11 of the discharge is dependent on the coupling 24i, 29i and arrangement of the  
12 discharge relative thereto. The replaceable nozzle 50 includes a connecting  
13 piping coupling, such as a connective flange 47i for connecting to the piping 47.

14 To maximize service life, the nozzle 50 can incorporate a curved  
15 portion 51, such as a long radius elbow, transition between the orthogonal world  
16 of the connecting piping and the inclined axis A of the vessel 22. That curved  
17 portion 51 can be integrated with the inlet 24, nozzle 50 or located in advance  
18 thereof, such as in a transition pup joint.

19 In operation, various sizes are desanders are employed in the prior  
20 art for differing operational conditions. Prior art desanders 10, such as that  
21 described in US 6,983,852 to Applicant, for different feed fluid streams F, might  
22 include one typical standard vessel 11 having a nominal 0.3 m (12 inch) diameter  
23 by 3.048 m (10 feet) long and another vessel 11 having 0.3 m (12 inch) diameter  
24 by 6.096 m (20 feet) long, both of which are fitted with a downcomer weir to set  
25 the freeboard portion.

1                   Herein, in the inclined desander 20, the prior art downcomer flow  
2 barrier, such as a weir, can be eliminated by providing similar 0.3 m (12 inch)  
3 diameter vessels 22 and tilting the upper end 30 of the new desander 20 at about  
4 twice the prior art weir height so as to form the interface 32 at the fluid outlet 26.  
5 To mimic the minimum operating performance of the 3.048 m (10 feet) and  
6 6.096 m (20 feet) prior art desanders, a 20 foot long inclined vessel 22 would only  
7 need to be inclined about  $\frac{1}{2}$  the angle  $\alpha$  of the 10 foot long inclined vessel 22.  
8 Performance can be adjusted by varying the angle.

9                   An example of an inclined desander 20 includes that sized to  
10 receive a fluid stream F of 50 m<sup>3</sup>/d, bearing particulates S having an average size  
11 of 150  $\mu$ m. The fluid stream typically includes sufficient liquid to accumulate in  
12 the belly portion. The fluid stream F is discharged to vessel 22, having a 0.3 m (1  
13 foot) diameter and 3.048 m (10 feet) long. A typical pressure of the fluid stream F  
14 is about 7000 kPa (1015 psia). At an inclination angle  $\alpha$  of 4.9 degrees, the  
15 freeboard volume is 0.10 m<sup>3</sup> and the belly portion is 0.486 m<sup>3</sup>. The resulting belly  
16 portion capacity is about 502 kg of liquid and sand particulates.

17                  As shown in Fig. 6, another embodiment of an inclined desander 20  
18 illustrates some additional optional characteristics including a fluid inlet 24  
19 oriented horizontally, the inlet being directly connectable to orthogonal connection  
20 piping. The discharge 29 is oriented at an angle to the longitudinal axis A, in this  
21 case in a generally horizontal plane, which is angled upwardly from axis A. The  
22 initially horizontal trajectory of a substantial portion of the feed stream falls off  
23 before engaging the vessel 22. In part, the inlet 24 can be square to the  
24 connective pipe as, in this embodiment, the vessel 22 is of sufficient diameter,  
25 such as 36 inches, to permit inlet placement in the freeboard 44 while the

1 trajectory is such that it minimizes or avoids vessel wall involvement. As shown,  
2 a horizontal spacing between the inlet 24 and inside wall of the vessel 22 is about  
3 1.5 feet.

4 Removal of accumulated particulates is conducted periodically with  
5 the vessel 22 shut in, adjacent the inlet 24 and outlet 26, and depressurized.  
6 Conveniently, access can be through a pressure-rated access closure and port at  
7 the lower end 42, as the angle of repose and flow in the belly portion carries  
8 particulates thereto. A suitable closure is shown in Fig. 1 of the prior art and in  
9 Fig. 6 as adapted to the inclined desander 20. The vessel 22 is supported  
10 sufficiently high of the ground or otherwise positioned for angular access thereto,  
11 such as with scrapers and the like. A pressure vessel, hemispherical head-form  
12 of closure 60 can be pivoted from the vessel 22 and counterweighted to close  
13 flush to the inclined cylindrical end of the vessel 22. A gantry 62 assists in  
14 manipulation of the head for access to the belly portion 40.

15 Further, the illustrated vessel 22 includes an eccentric end 64 at the  
16 lower end 42, to reduce the diameter of the vessel 22 downstream of the fluid  
17 outlet 26. Advantages of reducing the vessel diameter at the lower end 42  
18 include adapting to a smaller, more easily manageable or standard form of clean  
19 out. As shown the cleanout is a pressure-rated closure 60 supported upon gantry  
20 62. In this embodiment, a 36 inch vessel, having 33 inch internal diameter, is  
21 inclined at 4 degrees. The cylindrical portion of the vessel is about 20 feet long  
22 with a 3 foot long eccentric portion, reducing the diameter from 3 to about 18  
23 inches for fitting an 18 inch clean out.

1                   Conventional pressure safety valves and other gas phase related  
2 devices and instrumentation, not shown, are reliably located in the freeboard  
3 portion 44 between the fluid outlet 26 and the upper end 25.

4                   Fig. 7 shows a cross-sectional view of a desander 100, according to  
5 an alternative embodiment. The desander 100 comprises a tilted vessel 102  
6 coupled to a particulate collection structure 180. The desander 100 does not  
7 require a flow barrier. The vessel defines an elongate, enclosing volume having  
8 a surface or diverging bounding wall terminated at opposing ends; a proximal end  
9 accommodating a flow inlet, and distal end. A portion of the bounding wall is  
10 oriented as a top wall and a portion of which is oriented as a bottom wall. The  
11 top wall is tilted downwardly in the direction of flow at a first angle of inclination.  
12 The bottom wall is also tilted downwardly in the direction of flow. The slope of the  
13 bottom wall is divergent from the top wall so as to have a second angle of  
14 inclination that is greater than that of the top wall.

15                  Such volumes are accomplished by vessel geometries including a  
16 conical shape. Generally a conical vessel can be a circular cone having an axis  
17 extending from the apex to the base and a surface thereabout, the axis of which  
18 is angled so that the top wall has the downward and first angle of inclination. A  
19 right conical vessel has a circular cross-section; however, non-circular cross-  
20 sections are contemplated including elliptical, obround and polygonal. One  
21 skilled in the art would have to account for the use of non-conventional shapes  
22 when considering pressure boundaries or use a conventional pressure boundary  
23 with non pressure bearing internals of the proposed shapes.

24                  By exploiting a tilted or inclined vessel 102 with divergent top and  
25 bottom walls, the desander 100 maximizes the effectiveness of the freeboard

1 portion, and reduces liquid flow rates to optimize settling conditions therein and  
2 improve retention of captured particulates S. Herein, components described as  
3 proximal and distal as related to their proximity to the inlet.

4 In the context of a right conical shape vessel 102, a conical body  
5 104 extending from a lower, distal end 106 tapering to an upper, proximal end  
6 108 with a central axis 110 upwardly slanting from a horizontal line (not shown).  
7 In this embodiment, the vessel is a right circular conical frustum having a circular  
8 distal base 112 at the lower, distal end 106 perpendicular to the central axis 110,  
9 a geometric surface comprising a conical wall 114 shown axially symmetrical to  
10 the central axis 110, and an apex 116 at the upper, proximal end 108. For  
11 accommodation of a flow inlet, apex 116 is truncated for installation of connecting  
12 hardware such as flanges.

13 The vessel 102 is characterized by a first, acute top inclination  
14 angle  $\alpha$  defined by a top wall 118 of the body 104 and a horizontal line 120, and a  
15 second, bottom inclination angle  $\beta$  defined by the bottom wall 122 of the body  
16 104 and a horizontal line 124. The top inclination angle  $\alpha$  is selected for forming  
17 the freeboard portion of the vessel, and the bottom inclination angle  $\beta$  is selected  
18 for forming a belly portion that minimizes sand deposition and instead  
19 encourages a mobile sand dune for migration of settled particulates to a sump at  
20 the bottom of the vessel and subsequent transferring to a sand accumulator.

21 The relationship between the top and bottom inclination angles  $\alpha$   
22 and  $\beta$ , the diameter of the circular distal base 112, the diameter of the circular  
23 truncated apex 116 and the length (i.e., the distance between the distal base 112  
24 and the truncated apex 116) of the vessel 102 is:

25 
$$\beta = \text{Arctan}((D_{\text{distal}} - D_{\text{proximal}}) / 2 / L) \times 2 + \alpha,$$

1 where  $\text{Arctan}()$  represents the arctangent function,  $D_{\text{distal}}$  represents the  
2 diameter of the circular distal base 112,  $D_{\text{proximal}}$  represents the diameter of  
3 the circular truncated apex 116, and  $L$  represents the length of the vessel 102  
4 measured along the central axis 110. Therefore, the vessel 102 may be  
5 customized in design by selecting a proper vessel length, diameter of the circular  
6 distal base 112, ratio of the diameter of the circular distal base 112 to that of the  
7 circular truncated apex 116, and top inclination angle  $\alpha$  to meet a process  
8 performance requirement.

9           The vessel 102 comprises a fluid inlet interface 140 at the upper  
10 proximal end 108 and a fluid outlet 142 located on the top side of the vessel in  
11 proximity with the distal end 106 and spaced from the fluid inlet interface 140.  
12 The fluid inlet interface 140 comprises a receiving end 144 outside the vessel 102  
13 for receiving a fluid stream  $F$  typically comprising a variety of phases including  
14 gas  $G$ , some liquid  $L$  and entrained particulates such as sand  $S$ , and a discharge  
15 end 146 inside the vessel 102 for discharging the received multiphase fluid  
16 stream  $F$  into the vessel at an inlet velocity. The position and orientation of the  
17 discharge end 146 determine the particulate trajectory. In this embodiment, the  
18 discharge end 146 is oriented such that the received fluid  $F$  is injected into the  
19 vessel along a direction 148 parallel to the top wall 118. However, in some other  
20 embodiments, the discharge end 146 may alternatively be oriented in other  
21 orientations, e.g., an angle smaller or larger than that of the top wall 118,  
22 depending on the design.

23           In an operating state, a gas/liquid interface 160 forms extending  
24 horizontally in the vessel 102 from about the fluid outlet 142. The gas/liquid  
25 interface 160 is a generally elliptic, gas and liquid interface having a distal end

1 166 adjacent the fluid outlet 142 and a proximal end 168, the location of which is  
2 determined by the lower end of the fluid outlet 142 and the top inclination angle  $\alpha$ .  
3 A freeboard portion 164 is formed above the gas/liquid interface 160. A belly  
4 portion 162 is formed below the gas/liquid interface 160 for containing liquid L  
5 and particulates S. The belly portion 162 has a large volume as the diameter of  
6 the vessel 102 increases towards the distal end 106.

7           A fluid stream discharged from the fluid inlet interface 140 travels  
8 along an elongated flow path from the fluid inlet interface 140 to the fluid outlet  
9 142. As the freeboard portion 164 has a cross-sectional area greater than that of  
10 the fluid inlet interface 140, the fluid velocity in the freeboard portion adjacent the  
11 fluid inlet interface 140, is less than that in the inlet, and particulates cannot be  
12 maintained in suspension.

13           By properly selecting length of the vessel to be sufficiently long and  
14 the freeboard velocity to be sufficiently low, when a fluid stream is discharged  
15 from the fluid inlet interface 140 and travels along the flow path, an effective  
16 amount of the entrained liquid L and particulates S fall out of the fluid stream and  
17 collect in a belly portion 162 (described later). A desanded fluid stream is  
18 discharged from the vessel via the fluid outlet 142.

19           The trajectory of the fluid stream F, from inlet 140, converges with  
20 the gas/liquid interface 160. The trajectory for dropping sand S and liquid L into  
21 the belly portion 162 is foreshortened, reducing drop out time. The vessel 102 is  
22 of sufficient length to space the fluid inlet 140 sufficiently from the gas/liquid  
23 interface 160 to minimize turbulence of the liquid L in the belly portion 162, that  
24 spacing being dependent upon various design factors including vessel top

1 inclination angle  $\alpha$ , bottom inclination angle  $\beta$ , inlet fluid stream velocity and  
2 characteristics.

3           At a steady state, the level of the gas/liquid interface 160 is  
4 controlled by the fluid outlet 142 in proximity with the distal end 106, set by  
5 eventual liquid entrainment and discharge at the fluid outlet 142. At steady state,  
6 when the liquid level reaches the fluid outlet 142, any oil and other liquid is re-  
7 entrained with the gas G exiting at fluid outlet 142. In this state, the fluid stream  
8 discharged from the fluid outlet 142 has about the same gas/liquid ratio as the  
9 stream received at the inlet 140. In other words a mass balance is established in  
10 that discharged liquid matches incoming liquid.

11           Particulates S continue to be captured in the belly portion 162,  
12 creating an unstable sand bank. In a steady state liquid filled environment, the  
13 particulates form a sand bank on the lower portion of the vessel 102. The bottom  
14 inclination angle  $\beta$  of the vessel 102 is selected to be steep enough, e.g., to be  
15 about or larger than the angle of repose of a bank of wet particulates. Thus, the  
16 sand and liquid migrate towards the bottom of the vessel 102 via a lower  
17 discharge 172 into the particulate collection structure 180, and fall through the  
18 open valves 182 into the sand accumulation chamber 184. In the embodiments  
19 in which particulates are periodically or continuously removed from the lower  
20 discharge 172, the liquid discharged from the fluid outlet 142 will, on occasion, be  
21 less than that in the incoming liquid by the amount removed with the particulates.

22           Having a lower discharge 172, at least particulates are collected  
23 and discharged from the belly portion. Typically particulates and liquid are  
24 collected in the belly portion and are periodically or continuously discharged

1 therefrom. With a gas/liquid interface formed, liquid is discharged with desanded  
2 gas from the freeboard portion at the distal end at the fluid outlet 142.

3           When in use, the fluid inlet 140 and the fluid outlet 142 are  
4 connected to the connective pipes of a conventional wellhead and downstream  
5 equipment (not shown), respectively. The receiving end 144 of the fluid inlet  
6 interface is typically orthogonal to the wellhead. As the connecting pipes are  
7 typically in rectilinear or orthogonal arrangements, the fluid outlet 142 is  
8 configured in a vertical orientation and thereby obviates the need for an angular  
9 transition.

10           As described above, the fluid inlet 140, being exposed to entrained  
11 particulates S in the fluid stream F, is subject to significant risk of erosion, and  
12 has to be properly designed to ensure the regular use of the desander 100.  
13 Methods described above, e.g., using appropriate material or configuration to  
14 prolong its service life, regularly replacing the worn-out fluid inlet, and/or using a  
15 replaceable discharge of nozzle, may be used in various embodiments. In this  
16 embodiment, a replaceable nozzle as shown in Fig. 5 that has a discharge end  
17 with an inclination angle  $\alpha$  and a horizontal receiving end is used for coupling to  
18 the horizontal connective pipe (not shown).

19           Velocity in the freeboard portion 164 increases after a substantial  
20 portion of the particulates S have already deposited in the belly portion 162. The  
21 cross-sectional area of the belly portion 162 increases towards the fluid outlet  
22 142, and the velocity of liquids accumulating therein diminishes.

23           In the belly portion 162, particulates accumulate and flow down the  
24 vessel 102 at an angle of repose. The accumulation of liquid L and particulates S  
25 establishes a downward flow in the belly portion 162, and as the particulates

1 accumulate and limit the free flow of the liquid L in the belly portion 162, the liquid  
2 velocity begins to increase, drawing more particulates S down vessel. As the  
3 bottom inclination angle  $\beta$  is greater than the angle of repose of a bank of wet  
4 particulates, the sand will migrate towards the particulate collection structure 180.

5           For a given length of vessel 102, or a given distance between the  
6 fluid inlet 140 and the fluid outlet 142, the top inclination angle  $\alpha$  may be selected  
7 to meet the requirement of accommodating gas G and liquid L content in the feed  
8 fluid stream F. The smallest top inclination angle  $\alpha$  is limited by the minimum  
9 requirement for a minimum freeboard 164 cross-sectional area adjacent the inlet  
10 140 once the gas/liquid interface 160 builds to about the fluid outlet 142. The  
11 largest top inclination angle  $\alpha$  is limited by the requirement for a minimum  
12 freeboard gas capacity to accommodate particulate removal of any sand S in the  
13 gaseous phase G of the incoming fluid stream F. In particular, the minimum top  
14 inclination angle  $\alpha$  is the minimum inclination angle of the top wall 118 that  
15 ensures the inlet 24 be entirely in the freeboard 164 when the gas/liquid interface  
16 160 reaches the bottom of the fluid outlet 142. The maximum top inclination  
17 angle  $\alpha$  is the inclination angle of the top wall 118 at which the inlet 140 is well  
18 above the gas/liquid interface 160 allowing substantial freeboard to handle slug  
19 flow. Moreover, if a greater top inclination angle  $\alpha$  is used, the trajectory of the  
20 injected fluid stream F impinges the gas/liquid interface 160 at less acute angle,  
21 impinges the gas/liquid interface 160 sooner and allows the use of shorter  
22 vessels 102 and greater particulate removal efficiency. As increasing the top  
23 inclination angle  $\alpha$  also increases the bottom inclination angle  $\beta$ , a larger top  
24 inclination angle  $\alpha$  thus reduces the need for a steeply tapered cone shape of the  
25 vessel 102.

1                   In this embodiment, the top inclination angle  $\alpha$  is preferably selected  
2                   from the range of about 2 degrees to about 20 degrees.

3                   For a given length of vessel 102, the bottom inclination angle  $\beta$  may  
4                   be selected to be great than or equal to the estimated angle of repose of a wet  
5                   sand bank to facilitate smooth particulates drop-off. Generally, the bottom  
6                   inclination angle  $\beta$  is larger than the top inclination angle  $\alpha$ . The conical shape  
7                   vessel 102 is determined after the length of the vessel 102, the top and bottom  
8                   inclination angles  $\alpha$  and  $\beta$  are selected.

9                   In one example, a desander 100 comprises a conical shape vessel  
10                  102 having a circular distal base of diameter 0.91 meter (36 inches), a circular  
11                  truncated apex of diameter 0.154 meter (i.e., 6 inches) and a length of 3.05  
12                  meters (i.e., 10 feet). The vessel is tilted such that the bottom inclination angle  $\beta$   
13                  is 35 degree.

14                 Referring again to Fig. 7, the vessel 102 comprises a lower  
15                 discharge 172 coupled to the particulate collection structure 180 to allow  
16                 particulates and liquid to migrate thereto. The particulate collection structure 180  
17                 comprises a sand accumulation chamber 184 sandwiched between an inlet valve  
18                 182 and a discharge valve 186. The inlet valve 182 is connected to the vessel  
19                 102 on top thereof and to the sand accumulation chamber 184 therebelow, and  
20                 the sand accumulation chamber 184 is in turn connected to the discharge valve  
21                 186 therebelow. The particulate collection structure 180 also comprises a  
22                 particulate detector 188, e.g., an ultrasonic sand detector, to detect particulate  
23                 accumulation in the sand accumulation chamber 184.

24                 The inlet valve 182 may be set to the open position and the  
25                 discharge valve 186 set to the closed position in normal operation to allow the

1 sand accumulation chamber 184 to collect particulates and liquid from the vessel  
2 102.

3           Unlike the prior art desanders that require shutting down the  
4 operation to depressurize the vessel 102 for removing accumulated particulates,  
5 the removal of accumulated particulates can be conducted periodically with the  
6 vessel 102 being pressurized and in operation. For this purpose, the valves 182  
7 and 186 are controlled automatically by the particulate detector 188 to  
8 periodically open and close. Typically, an interlock is used to prevent the inlet and  
9 discharge valves from being open at the same time. In particular, the valve 182,  
10 between the vessel 102 and the sand accumulation chamber 184 is normally  
11 open except at the time of particulate removal, allowing particulates to fall into the  
12 accumulator. The discharge valve 186 is normally closed except at the time of  
13 particulate removal.

14           To remove particulates while maintaining the desander 100 in  
15 operation, the valve 182 is first closed. Valve 186 is then opened allowing the  
16 particulates contained in the sand accumulation chamber 184 to exit. Usually,  
17 valve 186 is opened only for a short period of time sufficient to allow the volume  
18 of the sand accumulation chamber 184 to be evacuated. After removing  
19 particulates from the sand accumulation chamber 184, valve 186 is closed and  
20 valve 182 is then reopened to allow particulates in the particulate drop out the  
21 vessel 102 to migrate into the sand accumulation chamber 184. The belly portion  
22 162 of the vessel has sufficient space to store particulates inside the vessel 102  
23 during the particulates-removing process, and the volume of the sand  
24 accumulation chamber 184 is sufficiently large to discharge enough particulates  
25 within a cleaning cycle so as not to cause a backup of particulates into valve 182

1 thereby preventing the valve to close. Both valves 182 and 186 are required to  
2 have service rated for abrasive slurries.

3 As an alternate, if line washing is desired and the downstream  
4 piping is able to support the pressure, valve 182 can be left open. Valve 186 is  
5 opened only for a short period of time, sufficient to allow the volume of the sand  
6 accumulation chamber 184 to be evacuated.

7 Conventional pressure safety valves and other gas phase related  
8 devices and instrumentation, not shown, are reliably located in the freeboard  
9 portion 164.

10 Although not shown in the figures, the vessel 102 is supported by  
11 supporting structure to maintain the vessel 102 in its vertical orientation.

12 In an alternative embodiment, the top inclination angle of the vessel  
13 102 is adjustable at the time of installation. The fluid inlet 140 and outlet 142 are  
14 rendered orthogonal. After installation, the orientation of the vessel 102, the  
15 receiving end 144 of the inlet 140, the fluid outlet 142 and the particulate  
16 collection structure 180 is then fixed for operation.

17 In another embodiment, the support structure comprises an  
18 inclination adjustment structure for adjusting the inclination angle of the vessel  
19 102 to adapt to fluid stream conditions and or particulate stream conditions. For  
20 example, the support structure may comprise a first support anchor pivotably  
21 coupled to the vessel 102 at a position near the distal end thereof, and a second  
22 support anchor pivotably coupled to the vessel 102 at a position near the  
23 truncated apex thereof. The height of the first and/or second support anchors is  
24 adjustable such that the inclination angle of the vessel may be adjusted by  
25 adjusting the height of the first and/or second support anchors.

1           The fluid outlet 142 and the particulate collection structure 180,  
2 each facilitated by a correcting insert or spool attached thereon, may be pivotable  
3 within a predefined range of angle to allow a generally orthogonal orientation  
4 under any suitable inclination angle of the vessel 102. The inlet 140 may also be  
5 pivotable within a predefined range of angle such that the orientation of the  
6 receiving end 144 thereof may be adjusted to adapt to the orientation of the  
7 vessel. In yet another embodiment, a set of inlets 140 are provided to allow users  
8 to choose an inlet 140 suitable for an orientation-adjusted vessel 102 and install it  
9 thereon.

10           Persons skilled in the art appreciate that various alternative  
11 embodiments are readily available. For example, although in above embodiment,  
12 a particulate detector 188 is used for detecting particulate accumulation in the  
13 sand accumulation chamber 184, in an alternative embodiment, a timer may  
14 alternatively be used to periodically control valves 182 and 186 to remove  
15 particulates from the sand accumulation chamber 184. In another embodiment,  
16 no particulate detector or time is used, and the valves 182 and 186 are manually  
17 controlled to remove particulates from the sand accumulation chamber 184.

18           Although in above embodiments, the vessel 102 is a tilted, right  
19 circular conical frustum, in some other embodiments, the vessel 102 may be an  
20 oblique circular frustum such that the circular distal base located at the lower,  
21 distal end of the vessel is not perpendicular to the central axis.

22           Although in above embodiments, the vessel 102 tapers from the  
23 distal end to a smaller, truncated apex at the proximal end, in some alternative  
24 embodiments, the vessel 102 has a constant diameter from the distal end to the  
25 proximal end.

1                   Those skilled in the art appreciate that the particulate collection  
2 structure 180 may alternatively comprise different components. For example, in  
3 some alternative embodiments, the particulate collection structure 180 may be a  
4 simple sand sump having no valve.

5                   As appreciated by persons skilled in the art, the desanding devices  
6 in the embodiments described above are made of suitable material for the  
7 environment, fluid and pressures, such as steel or the like, with specifications  
8 satisfying relevant safety code requirements.

9

1                   THE EMBODIMENTS OF THE INVENTION FOR WHICH AN  
2 **EXCLUSIVE PROPERTY OR PRIVILEGE IS CLAIMED ARE DEFINED AS**  
3 **FOLLOWS:**  
4

5                   1.       A vessel for removing particulates from a multiple-phase fluid  
6 stream containing gas, entrained liquid and particulates, the vessel comprising:

7                   a volume having a diverging bounding wall, a distal base, and an  
8 apex; the diverging bounding wall having a top wall at a first inclination angle and  
9 a bottom wall at a second inclination angle; the second inclination angle at a greater  
10 angle than the first inclination angle;

11                  a fluid inlet interface at the apex for receiving said fluid stream into  
12 the volume of the vessel;

13                  a fluid outlet on the top wall and spaced from the fluid inlet interface;

14                  a **horizontally extending freeboard interface** separating a freeboard  
15 portion formed adjacent an upper portion of the vessel above the freeboard  
16 interface and a belly portion therebelow, the belly portion being bounded at its  
17 bottom by the bottom wall, the freeboard portion forming a freeboard cross-  
18 sectional area for a freeboard velocity of the fluid stream less than a fluid stream  
19 velocity at the fluid inlet interface; and

20                  an elongated flow path for receiving the fluid stream from the fluid  
21 inlet interface and directing the fluid stream to the fluid outlet; wherein

22                  said length of the elongated flow path and the freeboard velocity  
23 being such that at least a portion of the entrained liquid and particulates fall out of  
24 the fluid stream, the particulates settle towards the bottom wall of the belly portion,  
25 and desanded gas is collected in the freeboard portion; and

1                    wherein the desanded gas flows out of the freeboard portion through  
2 the fluid outlet and is free of at least a portion of the particulates.

3

4                    2.        The vessel of claim 1 wherein the second inclination angle is  
5 greater than the angle of repose of settled particulates.

6

7                    3.        The vessel of claim 1 or 2 wherein the first inclination angle is  
8 inclusively between 2 and 20 degrees.

9

10                   4.        The vessel of any one of claims 1 to 3 wherein the shape of  
11 the distal base is circular.

12

13                   5.        The vessel of any one of claims 1 to 4 wherein the central axis  
14 is perpendicular to the distal base.

15

16                   6.        The vessel of any one of claims 1 to 4 wherein the central axis  
17 is oblique to the distal base.

18

19                   7.        The vessel of any one of claims 1 to 6 further comprising a  
20 lower discharge for discharging liquid and particulates.

21

22                   8.        The vessel of claim 7 wherein the lower discharge further  
23 comprises:

24                   an inlet valve adjacent and fluidly connected to the lower discharge;

25                   a particulate accumulation chamber; and

1                   a discharge valve, wherein  
2                   the particulate accumulation chamber is sandwiched between the  
3 inlet valve and the discharge valve.

4  
5                   9.     The vessel of any one of claims 1 to 8 wherein the fluid inlet  
6 interface has a discharge end, and wherein the discharge end is oriented for  
7 discharging the gas stream into the freeboard portion at about the top inclination  
8 angle.

9  
10                  10.    The vessel of any one of claims 1 to 9 wherein the fluid inlet  
11 interface further comprises a replaceable nozzle having a discharge end oriented  
12 for discharging the gas stream into the freeboard portion.

13  
14                  11.    The vessel of claim 10 wherein the replaceable nozzle is  
15 connected to the fluid inlet interface at a flange.

16  
17                  12.    The vessel of any one of claims 1 to 11 wherein the gas stream  
18 emanates from a wellhead, and wherein the fluid inlet interface further comprises  
19 a receiving end orthogonal to the wellhead for receiving the gas stream.

20  
21                  13.    The vessel of any one of claims 1 to 12 wherein the first  
22 inclination angle is variable for adapting to fluid stream conditions.

23  
24                  14.    The vessel of any one of claims 1 to 13 wherein the second  
25 inclination angle is variable for adapting to particulate stream conditions.

1  
2                   15.    The vessel of any one of claims 1 to 14 wherein the fluid outlet  
3 is located on the top of the top wall.

4  
5                   16.    A method for desanding a fluid stream emanating from a  
6 wellhead, the fluid stream containing gas, entrained liquid and particulates, the  
7 method comprising:

8                   providing an elongated vessel extending from a proximal end  
9 downwardly towards a distal end and having a diverging bounding wall to define a  
10 top inclination angle and a bottom inclination angle larger than the top inclination  
11 angle;

12                  injecting, at a first fluid velocity, the fluid stream into the vessel from  
13 the proximal end;

14                  directing, at a second fluid velocity slower than said first fluid velocity,  
15 said fluid stream along an elongated flow path in the vessel from the proximal end  
16 towards the distal end to allow at least a portion of the particulates to fall out of the  
17 fluid stream and collect in a belly portion;

18                  collecting desanded gas in a freeboard portion, said freeboard  
19 portion being above the belly portion and being separated therefrom by a gas/liquid  
20 interface; and

21                  discharging the desanded gas from the freeboard portion at the distal  
22 end; wherein

23                  said desanded gas is free of at least a portion of the particulates.

24

1           17.    The method of claim 16 further comprising:  
2           collecting particulates in the belly portion; and  
3           discharging at least the collected particulates from the belly portion.

4  
5           18.    The method of claim 16 further comprising:  
6           collecting liquid and particulates in the belly portion; and  
7           discharging collected particulates and liquid from the belly portion.

8  
9           19.    The method of any one of claims 16 to 18 further comprising:  
10          discharging the desanded gas and liquid from the freeboard portion  
11          at the distal end.

12  
13          20.    The method of any one of claims 16 to 19 wherein injecting  
14          the fluid stream into the vessel from the proximal end comprises:  
15          injecting, at a first fluid velocity, the fluid stream into the vessel from  
16          the proximal end at about the top inclination angle.

17  
18          21.    A vessel for removing particulates from a multiple-phase fluid  
19          stream containing at least gas, liquid and entrained particulates, the vessel  
20          comprising:

21                a volume defined by a diverging bounding wall, a distal base, and an  
22          apex; the diverging bounding wall having a top wall at a first inclination angle and  
23          a bottom wall at a second inclination angle; the second inclination angle being a  
24          greater angle than the first inclination angle;

25                a fluid inlet at the apex;

1                   a fluid outlet having an intake opening spaced from the fluid inlet;  
2                   wherein the fluid inlet injects the fluid stream into the volume and  
3                   directs the fluid stream along an elongated flow path from the fluid inlet towards  
4                   the fluid outlet, to allow at least a portion of the entrained particulates fall out of the  
5                   fluid stream and move into a lower portion of the volume, and to allow gas being  
6                   collected in an upper portion of the volume in fluid communication with the intake  
7                   opening of the fluid outlet for being discharged via the fluid outlet; and  
8                   wherein the intake opening of the fluid outlet determines a  
9                   horizontally extending freeboard interface, said freeboard interface separating the  
10                  upper portion of the vessel above the interface and the lower portion therebelow,  
11                  the upper portion forming a cross-sectional area for establishing a velocity of the  
12                  fluid stream therein being slower than the fluid stream velocity at the fluid inlet.

13

14                  22.     The vessel of claim 21 wherein at least a portion of the liquid  
15                  falls into the lower portion of the volume.

16

17                  23.     The vessel of claim 21 or 22 wherein, at a steady state, the  
18                  level of the liquid surface is at an elevation about the intake opening of the fluid  
19                  outlet.

20

21                  24.     The vessel of claim 23 wherein, at the steady state, at least a  
22                  portion of the liquid is re-entrained with the gas and discharged from the fluid outlet.

23

24                  25.     The vessel of any one of claims 21 to 24 wherein the second  
25                  inclination angle is greater than the angle of repose of settled particulates.

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26. The vessel of any one of claims 21 to 25 wherein the first inclination angle is inclusively between 2 and 20 degrees.

27. The vessel of any one of claims 21 to 26 wherein the shape of the distal base is circular.

28. The vessel of any one of claims 21 to 27 wherein the central axis is perpendicular to the distal base.

29. The vessel of any one of claims 21 to 27 wherein the central axis is oblique to the distal base.

30. The vessel of any one of claims 21 to 29 further comprising a lower discharge for discharging liquid and particulates.

31. The vessel of claim 30 wherein the lower discharge further comprises:

- an inlet valve adjacent and fluidly connected to the lower discharge;
  - a particulate accumulation chamber; and
  - a discharge valve, wherein
- the particulate accumulation chamber is sandwiched between the inlet valve and the discharge valve.

1                   32.    The vessel of any one of claims 21 to 31 wherein the fluid inlet  
2 interface has a discharge end, and wherein the discharge end is oriented for  
3 discharging the fluid stream into the volume at about the first inclination angle.

4

5                   33.    The vessel of any one of claims 21 to 32 wherein the fluid inlet  
6 interface further comprises a replaceable nozzle having a discharge end oriented  
7 for discharging the fluid stream into the volume.

8

9                   34.    The vessel of claim 33 wherein the replaceable nozzle is  
10 connected to the fluid inlet interface at a flange.

11

12                   35.    The vessel of any one of claims 21 to 34 wherein the gas  
13 stream emanates from a wellhead, and wherein the fluid inlet interface further  
14 comprises a receiving end orthogonal to the wellhead for receiving the gas stream.

15

16                   36.    The vessel of any one of claims 21 to 35 wherein the first  
17 inclination angle is variable for adapting to fluid stream conditions.

18

19                   37.    The vessel of any one of claims 21 to 36 wherein the second  
20 inclination angle is variable for adapting to particulate stream conditions.

21

22                   38.    The vessel of any one of claims 21 to 37 wherein the fluid  
23 outlet is located on the top of the top wall.