

[54] **CENTRIFUGAL APPARATUS FOR SEPARATING ENTRAINED LIQUIDS FROM A GASEOUS STREAM**

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[51] **Int. Cl.** **B01d 45/12**

[58] **Field of Search** **55/447-465, 55/466, 424**

[56] **References Cited**

UNITED STATES PATENTS

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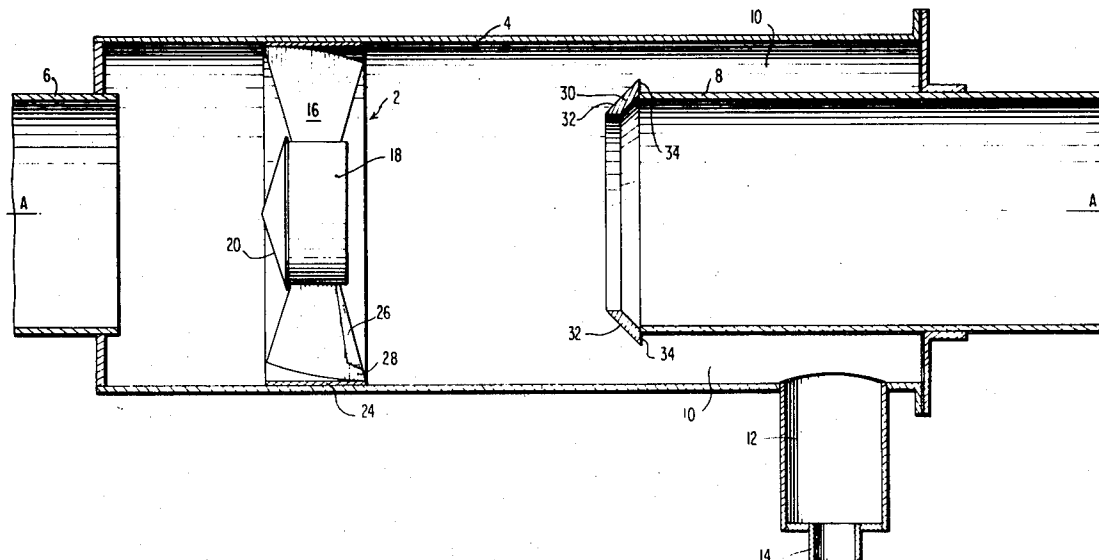
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[57] **ABSTRACT**

Helical motion is imparted to a moving gas stream by a centrifugal tuyere provided with inclined blades which overlap in axial projection so that there is no through open area. A nose cone deflector is located centrally of the tuyere upstream of the blades to deflect the central portion of the stream onto the blades. Liquids which collect on the deflector are prevented from flowing around the edge of the deflector and onto its downstream face for reentrainment by spacing the edge of the deflector from the central hub at the root ends of the blades and by avoiding liquid-supporting surfaces on the deflector which extend downstream from its edge. The gaseous stream leaves the apparatus through a gas outlet pipe which is downstream of and axially aligned with the centrifugal tuyere. Migration of liquid into the gas outlet pipe around its upstream edge is avoided by providing a barrier radiating outwardly from the upstream end of the gas outlet pipe.

A liquid sump promotes removal of the liquid and permits gravitational separation of the liquid and vapor phases.

13 Claims, 4 Drawing Figures



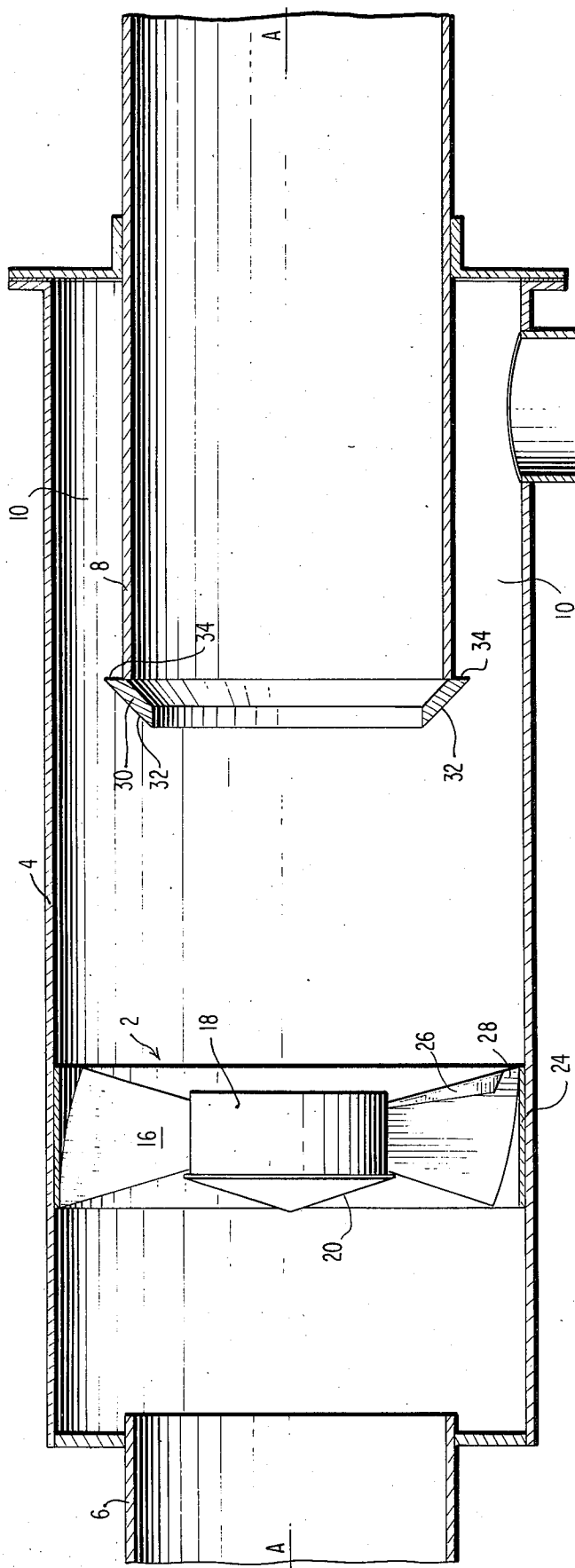


FIG. 1

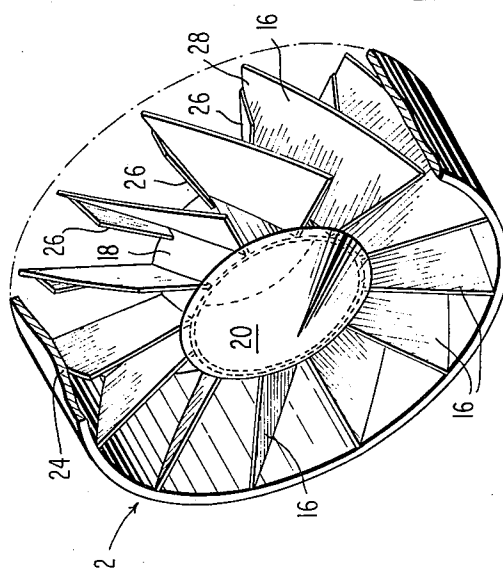


FIG. 2

FIG 4

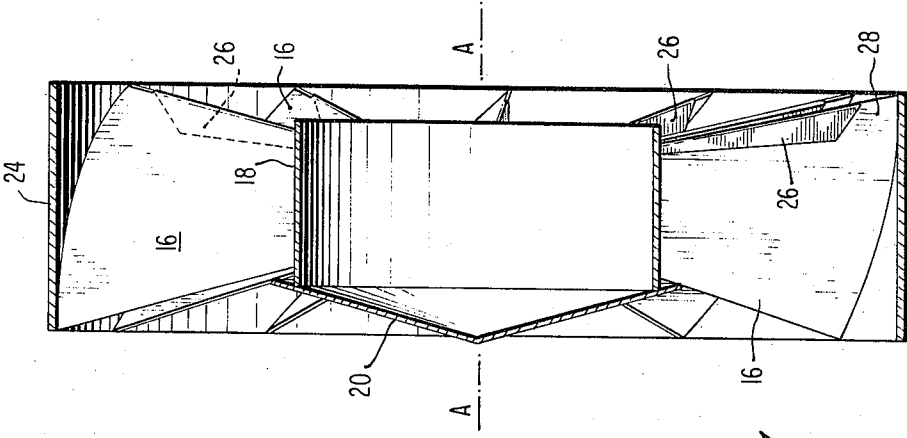
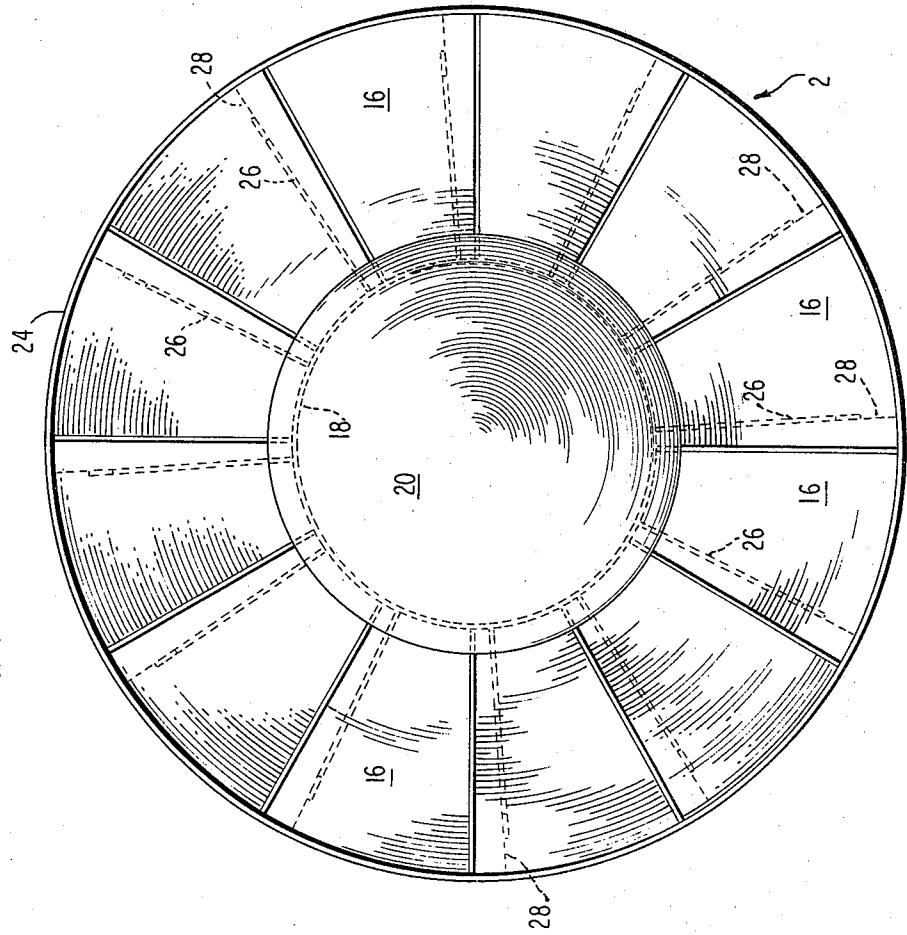


FIG 3



CENTRIFUGAL APPARATUS FOR SEPARATING ENTRAINED LIQUIDS FROM A GASEOUS STREAM

The present invention generally relates to a type of separator apparatus wherein a gaseous stream with entrained liquids passes through a tuyere provided with a plurality of symmetrical inclined blades extending from the center radially outwardly. Each blade has a leading edge, a trailing edge, and upstream and downstream faces which are inclined with respect to the central longitudinal axis of the tuyere and to planes perpendicular thereto. The blades are preferably arranged so that their axial projections overlap whereby there is no open area extending parallel to the longitudinal axis of the tuyere. The gas from an inlet pipe passes through the tuyere where it is given a rapid helical motion. Droplets entrained in the gaseous stream adhere to the tuyere surfaces or are driven outwardly by centrifugal force onto a cylindrical wall which they follow to a liquid collection and drainage area. The cleaned, whirling gas is removed through an outlet pipe which is downstream of and axially aligned with the tuyere.

At low velocities, because of the overlapped blades, the majority of the entrained liquids in the gas stream impinge the hose cone and blades, adhere thereto, and coalesce. At high velocities, the pitch angle of the blades causes rapid spinning of the gas stream and entrained liquids, throwing the entrainment outwardly by centrifugal force to the surface of the collecting vessel, where it adheres and coalesces as a liquid. Both effects contribute to the total separation at all velocities.

The performance of separators of this type is measured in part by the percentage of entrained liquid particles removed from the gaseous stream while passing through the apparatus. This percentage will be referred to in this disclosure as the efficiency of the separator apparatus.

A principal objective of the invention is to improve the efficiency of apparatus of this type.

Prior to this invention, it had been proposed to increase the efficiency of apparatus of this type by forming a liquid collecting and drainage trough which extends along the downstream edge of each blade, the trough terminating short of the outer end of the blade in order to provide a space through which liquid may flow from the trough. This has contributed significantly to the efficiency of the apparatus. The present invention resides in further improvements which serve to reduce the amount of liquid reentrained into the gaseous stream from the tuyere, and to prevent the flow of liquid into the gas outlet pipe from its exterior surface.

Heretofore, it has been customary to provide a centrifugal tuyere with a nose cone deflector positioned centrally of and upstream of the tuyere blades. Upon striking such a deflector, some of the entrained liquids adhere thereto, coalesce and flow to the edge of the deflector. I have discovered that a significant amount of the liquid flowing from the edge of the deflector has been permitted to flow along paths which lead to reentrainment in the central portion of the apparatus downstream of the tuyere. In some instances, such reentrainment results by flow of the liquid along the central hub which connects the tuyere blades together, and in other cases typified by the Wright et al. U.S. Pat. No. 2,565,902 and the Muller U.S. Pat. No. 3,546,854, such reentrainment is possible by virtue of the orienta-

tion of the downstream face of the deflector and its connection to the central hub and/or roots of the tuyere blades, all of which contribute to provide liquid-supporting surfaces which lead from the edge of the deflector to the central area of the apparatus immediately downstream thereof.

In order to prevent such reentrainment downstream of the tuyere, the present invention contemplates a deflector which is devoid of any liquid supporting surface extending downstream from the deflector edge. The downstream face of the deflector adjacent to its edge is spaced from the root ends of the blades to prevent the flow of liquid along and adjacent to the root ends for consequent reentrainment.

Another source of reduced efficiency of separator apparatus of this type occurs in the vicinity of the liquid collection chamber and the gas outlet pipe. It has been discovered that there is an upstream helical flow of gases adjacent to the exterior surface of the gas outlet pipe. Liquids which adhere to the exterior surface of the gas outlet pipe are driven by this gaseous flow in an upstream direction to the upstream end of the gas outlet pipe, around the upstream edge of the gas outlet pipe and into the gas outlet pipe where it again becomes associated with the gaseous stream. In order to prevent this flow of liquid into the gas outlet pipe, this invention proposes to provide a barrier to prevent upstream movement of the liquid along the exterior surface of the gas outlet pipe. This barrier has a downstream face which lies at an angle no greater than about 90° with respect to the central longitudinal axis downstream of the barrier.

Under certain operating conditions, some previous centrifugal tuyere separator apparatus has been unable to discharge the liquid as rapidly as it is deentrained from the gaseous stream, thereby resulting in a backup of liquid in the liquid collection area downstream of the tuyere. The liquid loading of such apparatus was maintained a relatively low level. In contrast to this, the apparatus disclosed herein is capable of operating under higher conditions of liquid loading. This is achieved by the use of a downcomer pot or sump which is located below the liquid collection area in order to receive liquid from the liquid collection area. The liquid held in the downcomer pot or sump has an increased residence time in the apparatus, thus permitting gravitational separation of the liquid and vapor phases. Also, by minimizing the amount of liquid on the walls within the apparatus, the downcomer pot or sump reduces the tendency for liquid to be reentrained in the gaseous stream. It also increases the centrifugal action since the gaseous stream impels a smaller mass of liquid.

A preferred embodiment of an apparatus embodying the principles of the invention is shown in the following description and in the accompanying drawings wherein;

FIG. 1 is a sectional view showing a separator apparatus constructed according to the invention;

FIG. 2 is a perspective view of the upstream side of the tuyere used in connection with the preferred embodiment of the invention, broken away to show certain details of construction;

FIG. 3 is an elevational view of the upstream face of the tuyere; and

FIG. 4 is a sectional view of the tuyere.

FIG. 1 shows separator apparatus including a centrifugal tuyere 2 with radiating inclined blades positioned

in a gas separator vessel 4 which has an inlet 6, with an outlet pipe 8. The elements 2, 4, 6 and 8 are circular in transverse cross-section and axially aligned on the central longitudinal axis A—A.

When the apparatus is in use, a gaseous stream with entrained liquid particules is introduced through the inlet pipe 6, and is deflected by the inclined blades 16 of tuyere 2 to give the stream a helical motion. Some liquid particles collect on the upstream face of the nosecone 20 and flow over the edge thereof and onto the upstream faces of the blades. Other liquid particles adhere to the blades of the tuyere which are constructed to lead the liquid radially outwardly and discharge it in the vicinity of the cylindrical inner wall of the vessel 4. Still other liquid particles pass through the tuyere and are thrust outwardly by the helical motion of the gaseous stream, whereupon such particles are collected on and travel in a helical path along the inner wall of the vessel 4. The gaseous stream leaves the apparatus through the gas outlet pipe 8. Ultimately, the liquid arrives at the liquid collection area 10 which is at the downstream end of the vessel 4, radially outside the gas outlet pipe 8. This liquid drains into a downcomer pot sump 12. The upper end of the sump 12 is open to the liquid collection area 10, forming an enlarged sump inlet which is preferably coextensive with the horizontal cross section of the sump. This promotes flow of the liquid into the sump, and reduces the volume of liquid in the vessel 4, thereby deterring reentrainment and reducing the mass of liquid which must be moved by the gaseous currents. The sump outlet 14 is smaller and lower than the sump inlet, to provide the liquid with a residence time in the sump for gravitational separation of the gas and vapor phases. The outlet 14 leads to a liquid reservoir maintained at system pressure.

Referring now to FIGS. 2-4, the centrifugal tuyere 2 includes an upstream nose cone deflector 20 and a plurality of blades 16 which are attached to and extend radially outwardly from a central hub 18 to which the upstream ends of the blades are attached. The blades 16 have leading edges extending outwardly in an upstream direction, and trailing edges extending outwardly in a downstream direction. The upstream and downstream faces of the blades 16 are preferably oriented in planes which lie at an angle of about 45° with respect to the central longitudinal axis A—A. The tip ends of the blades are attached to an outer cylindrical ring 24 by welding or other suitable methods. As shown in FIG. 3 which is a view from the upstream side of the tuyere 2, the axial projections of blades 16 overlap so that there is no unobstructed area axially through the tuyere 2 along paths parallel to the axis A—A.

During experimentation with centrifugal tuyeres of the type shown in U.S. Pat. No. 2,565,902 and in the previously-mentioned application Ser. No. 177,251, it was discovered that the liquid which impinges the nose cone is often reentrained in the gaseous stream rather than being carried by the tuyere blade to the walls of the separator chamber. This shortcoming of the previous devices is attributable in the instance of the device of U.S. Pat. No. 2,565,902, to the fact that the downstream face of the deflector provides a liquid-supporting surface leading to the interior of the device, with the downstream flow of liquid toward the point of reentrainment being promoted by the connection of the root ends of the blades directly to the downstream

face of the deflector at its liquid discharging edge. Further, this prior device has blades oriented at a highly acute angle with respect to the longitudinal axis of the tuyere so that some liquid leaving the edge of the nose cone will strike the blades at a very small angle of incidence, raising the tendency for the liquid to skip off the blades and be reentrained by the gaseous stream which is flowing between adjacent blades.

With respect to apparatus of the type shown in U.S. Pat. No. 1,896,897, the edge of the upstream deflector merges with the hub to which the blades are connected, so that liquid is permitted to bypass the blades and flow directly along the hub. To minimize reentrainment of this liquid, U.S. Pat. No. 1,896,897 discloses a supplemental conical deflector located downstream of the tuyere blades.

In order to minimize reentrainment of the liquid which forms on the nose cone, it will be seen in the drawings that the nose cone deflector 20 of the present invention does not have any liquid supporting surfaces which extend downstream from its edge. The deflector 20 has a downstream face which is inclined adjacent to the edge in an upstream direction. This deters migration of liquid around the edge and onto the downstream face of the nose cone deflector 20. The downstream face of deflector 20 is also spaced from the root ends of the blades to prevent liquid from flowing along and adjacent to the root ends of the blades for consequent reentrainment.

It was also learned during experimentation with prior art devices that separated liquid enters the gas outlet pipe 8. This occurs due to the helical movement of the gas into the liquid collection area 10. The return flow of these gases toward the opening in outlet pipe 8 occurs in an upstream direction, thus moving any liquid which as collected on the exterior wall of the pipe 8 in an upstream direction, around its leading edge and then into the pipe 8 where it is carried away by the gaseous stream. This problem is avoided according to the present invention by imposing a barrier to such movement, the preferred form of barrier being on the external wall of the gas outlet pipe. The barrier element 30 has a forward inclined surface 32 which ends in a sharp trailing edge and a rear face 34. The rear face 34 is preferably as shown, lying perpendicular to the longitudinal axis A—A of the device. Alternatively, the face 34 may extend rearwardly and outwardly, provided that it lies at an angle no greater than about 90° with respect to the central longitudinal axis A—A downstream of the surface 32.

A third desirable feature developed in the course of experimentation is the downcomer pot or sump 12 which contributes to the operation of the apparatus under conditions of high liquid loading. As explained above, this sump 12 reduces the amount of collected liquid in the vessel 4 to deter reentrainment and to enhance the centrifugal action since the gaseous stream acts on a smaller mass of liquid. It also gives the liquid a longer residence time in the apparatus for gravitational separation of the liquid and vapor phases.

On the trailing edge of each blade 16 there is a lip 26 which extends therefrom and is turned back in an upstream direction toward the front face of the blades to make an acute angle of 45° with the blade. Each lip lies substantially in a plane which is parallel to the central longitudinal axis A—A of the tuyere. The lips 26 extend from the hub 18 radially outwardly toward the

ring 24, but terminate short of the ring 24. By shortening the lip 26, a liquid drainage space 28 is formed between the radial terminus of the lip 26 and the ring 24.

When the tuyere of the present invention is mounted in axial alignment with and adjacent to the inlet pipe 6 as shown in FIG. 1, the gas stream with entrained liquid droplets impinges the nose cone deflector 20 and the various blades 16. Some liquid will coalesce on the nose cone deflector and will be driven by the gaseous stream off the edge of the nose cone and onto the upstream faces of the blades 16. Liquid from the gaseous stream also coalesces on each blade 16 and will run along the blade to the lip 26, then radially outwardly in the trough formed by the lip 26 to the liquid drainage outlet 28, where the liquid will impinge and flow along the inner wall of the vessel 4. The tuyere gives the gas stream with entrained liquid droplets a rapid helical motion to throw the droplets outwardly by centrifugal force to the inner wall of the vessel 4 where they adhere.

As the liquid flows along the length of the liquid collecting vessel 4, due to the general helical downstream movement of the gas therethrough, the liquid reaches the liquid collection area 10 where it flows into the downcomer pot 12. The downcomer pot 12 traps the liquid swirling by, holds it long enough to permit some gravitational separation of some of the gaseous phase from the liquid and transfers it by gravity flow to a reservoir with a liquid level control means that is maintained at system pressure. The gas stream continues its flow by leaving the separator through the gas outlet pipe 8.

The invention may also be practiced by arranging a plurality of units similar to that of FIG. 1 inside a single enclosure vessel, with the units connected in parallel between the tube sheets in opposite ends of the vessel. Liquid may be removed from each such unit through slots in the vessel 4 and an annular axial opening at the downstream end of the liquid collection area 10.

It is preferred that the longitudinal axis of the apparatus be substantially horizontal, but it is expected that it will also operate when vertically oriented. Preferably, the cross-sectional area of the inlet pipe is substantially equal to the minimum flow area of the tuyere measured transverse to the gaseous path so that the gas stream inlet velocity is not greater than that through the tuyere to create an unnecessary pressure drop. Further it is preferred that the gas outlet pipe have an area the same as the inlet pipe.

Those skilled in the art will appreciate that there are many variations of and modifications to the present invention which will achieve the declared objectives thereof in substantially the same manner. For example, the deflector may lie against the leading edges of the blades radially beyond their root ends; or, the deflector may be formed integrally with the outlet pipe 8, eliminating the inclined upstream surface 32. Therefore, it is emphasized that, while a presently preferred embodiment of the invention has been given for the purposes of disclosure, numerous changes in the details of construction and the combination, shape, size and arrangement of parts can be resorted to without departing from the spirit and scope of the invention as claimed hereinbelow.

I claim:

1. In a centrifugal separator having a central longitudinal axis and a tuyere provided with a plurality of radi-

ating blades extending from the central axis; each of said blades having a leading edge, a trailing edge, a root end, a tip end, and upstream and downstream faces which are inclined with respect to the central longitudinal axis and to planes lying perpendicular thereto, whereby a gaseous stream passing through the separator is given a helical motion to throw entrained particles of liquid radially outwardly; the improvement which comprises a deflector, means locating said deflector forwardly of the upstream faces of the blades in the path of the gaseous stream, said deflector having an upstream face which terminates at its periphery in an edge positioned directly upstream of the upstream faces of the blades to release liquid from the deflector onto the upstream faces of the blades, said deflector being devoid of any liquid supporting surface extending downstream from said deflector edge, said deflector having a downstream face which is located upstream of said blades, each of said blades having its root end located entirely downstream of the deflector and radially inward of the deflector edge, each of said blades having its leading edge extending radially from a point located downstream of the deflector and radially inward of the deflector edge to a point which is radially beyond the deflector and is at the outer periphery of the tuyere, said downstream face adjacent to said deflector edge being spaced from the root ends of the blades to prevent the flow of liquid along and adjacent to the root ends for consequent reentrainment.

2. The apparatus of claim 1 wherein each of the blades is provided at its trailing edge with a trough for preventing the release and reentrainment of liquid from the downstream edge of the blade.

3. The apparatus of claim 1 having a liquid collection chamber freely in communication with the separator chamber and being located radially outside the gas outlet pipe, and liquid outlet means in the liquid collection chamber for removal of liquid from the liquid collection chamber, a gas outlet pipe in axial alignment with the tuyere, a barrier on the external wall of the gas outlet pipe to prevent liquid on the external wall from flowing in an upstream direction and into the gas outlet pipe, said barrier having a downstream face which lies at an angle no greater than about 90° with respect to the central longitudinal axis downstream of the barrier.

4. The apparatus of claim 3 wherein each of the blades is provided at its trailing edge with a trough for preventing the release and reentrainment of liquid from the downstream edge of the blade.

5. The apparatus of claim 1 wherein the upstream faces of the blades are disposed at least about 45° with respect to the central longitudinal axis to reduce the tendency for liquid to skip off the blades for reentrainment.

6. The apparatus of claim 5 having a liquid collection chamber freely in communication with the separator chamber and being located radially outside the gas outlet pipe, and liquid outlet means in the liquid collection chamber for removal of liquid from the liquid collection chamber, a gas outlet pipe in axial alignment with the tuyere, a barrier on the external wall of the gas outlet pipe to prevent liquid on the external wall from flowing in an upstream direction and into the gas outlet pipe, said barrier having a downstream face which lies at an angle no greater than about 90° with respect to the central longitudinal axis downstream of the barrier.

7. The apparatus of claim 6 wherein each of the blades is provided at its trailing edge with a trough for preventing the release and reentrainment of liquid from the downstream edge of the blade.

8. The apparatus of claim 1 wherein the downstream face of the deflector adjacent to said edge is inclined in an upstream direction from said edge to deter migration of liquid around the edge and onto the downstream face of the deflector.

9. The apparatus of claim 8 having a liquid collection chamber freely in communication with the separator chamber and being located radially outside the gas outlet pipe, and liquid outlet means in the liquid collection chamber for removal of liquid from the liquid collection chamber, a gas outlet pipe in axial alignment with the tuyere, a barrier on the external wall of the gas outlet pipe to prevent liquid on the external wall from flowing in an upstream direction and into the gas outlet pipe, said barrier having a downstream face which lies at an angle no greater than about 90° with respect to the central longitudinal axis downstream of the barrier.

10. The apparatus of claim 8 wherein each of the blades is provided at its trailing edge with a trough for preventing the release and reentrainment of liquid from

the downstream edge of the blade.

11. The apparatus of claim 8 wherein the upstream faces of the blades are disposed at least about 45° with respect to the central longitudinal axis to reduce the tendency for liquid to skip off the blades for reentrainment.

12. The apparatus of claim 11 having a liquid collection chamber freely in communication with the separator chamber and being located radially outside the gas outlet pipe, and liquid outlet means in the liquid collection chamber for removal of liquid from the liquid collection chamber, a gas outlet pipe in axial alignment with the tuyere, a barrier on the external wall of the gas outlet pipe to prevent liquid on the external wall from flowing in an upstream direction and into the gas outlet pipe, said barrier having a downstream face which lies at an angle no greater than about 90° with respect to the central longitudinal axis downstream of the barrier.

13. The apparatus of claim 12 wherein each of the blades is provided at its trailing edge with a trough for preventing the release and reentrainment of liquid from the downstream edge of the blade.

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