

DUCT WALL WATER EXTRACTOR

GOVERNMENT INTERESTS

5 **[001]** The invention was made with Government support under contract number DAAB07-03-D-B006-0013 awarded by the United States Air Force. The Government has certain rights in this invention.

CROSS-REFERENCE TO RELATED APPLICATION

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[002] The present application is related to issued U.S. Pat. No. 6,331,195, issued December 18, 2001, which is incorporated herein by reference.

BACKGROUND OF THE INVENTION

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[003] The present invention generally relates to liquid removal apparatus and, more particularly, to duct wall water extractors for aircraft environmental control systems.

20 **[004]** Entrained moisture in environmental control systems (ECS) is transported through the conditioned air ducting at various points in the system. If this entrained moisture is not captured and drained away it can cause excessive moisture in the cockpit and/or avionics bay.

25 **[005]** A dual scavenging separator is described in U.S. Patent No. 4,179,273. The disclosed separator comprises a conical feature with an external spiral blade that swirls water droplets and particulates to the enclosing duct wall where they are drained away through slots in the wall into an external sump. A limited number of slots in the cone provide a flow path for the cleaned air. Although the described separator may capture entrained moisture, the tortuous and limited flow path area induces a significant pressure drop penalty for the cleaned air flowing through the device. The pressure drop results in reduced ECS capacity and/or engine efficiency for some aircraft applications. **[006]** A liquid separator assembly is described in

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U.S. Patent No. 4,769,050. The disclosed assembly comprises two tubes (inlet and outlet), which are crimped, closed, perforated and housed within a surrounding enclosure. The air flow enters one tube, exits through the perforations into the enclosing chamber, and reenters the second tube through its perforations. The water droplets are separated from the air flow in the enclosing chamber and drained away. Unfortunately, this assembly also induces a significant pressure drop penalty caused by its tortuous and limited flow path area.

[007] A liquid/gas separation device that does not require the air flow to go through a reduced airflow path is described in U.S. Patent No. 5,302,301. In the disclosed separator, the water laden air flow enters an enlarged chamber tangentially, inducing a centrifugal force which drives the water droplets to the chamber wall and subsequently drain to the bottom of the chamber and out through a drain tube. The dried air moves to the center of the chamber where it is directed through a filter element that removes particulates prior to the air being discharged from the device. Unfortunately, the filter element induces a significant pressure drop penalty on the dried air flow. Additionally, this device requires a chamber with a large volume to allow the separation to occur. For some aircraft applications, there is limited space for devices to capture the entrained water due to the close packing of hardware and the large volume chamber may not be suitable.

[008] As can be seen, there is a need for a water separator device that does not require a volume expansion or settling chamber to separate the water from the air stream. Because the amount of ECS airflow is critical, a water extraction device that does not excessively restrict the airflow is needed. Further, a water extractor that has a smaller and more compact design is needed.

SUMMARY OF THE INVENTION

[009] In one aspect of the present invention, an apparatus for extracting a liquid portion from a flow comprises a duct adapted to receive the flow; and at least one slot positioned longitudinally along the duct.

[010] In another aspect of the present invention, an apparatus for extracting a

liquid portion from a flow comprises a duct adapted to receive the flow, the duct having a slot; a sump positioned longitudinally along the duct and in flow communication with the slot, the sump adapted to receive the liquid portion; and at least one ridge positioned on an inner surface of the duct and intersecting the slot.

5 [011] In still another aspect of the present invention, an apparatus comprises a duct for receiving a liquid/gas mixture, the duct having a bend; a slot positioned on an outer side of the bend and positioned parallel to a duct axis of the duct; at least one ridge intersecting the slot; and a sump in contact with the duct and designed to enclose the slot, the sump adapted to receive a liquid portion of the liquid/gas
10 mixture.

[012] These and other features, aspects and advantages of the present invention will become better understood with reference to the following drawings, description and claims.

15 BRIEF DESCRIPTION OF THE DRAWINGS

[013] Figure 1 is a schematic diagram of an environmental control system according to one embodiment of the present invention;

20 [014] Figure 2 is a perspective view of a liquid extractor according to one embodiment of the present invention;

[015] Figure 3 is another perspective view where the extractor of Figure 2 has been rotated to view it from the inlet;

[016] Figure 4 is a cut-away rotated view of Figure 2;

[017] Figure 5a is a cross-sectional view through line 5-5 of Figure 2;

25 [018] Figure 5b is a cross-sectional view through line 5-5 according to another embodiment of the present invention;

[019] Figure 6a is a perspective view of a swirl device according to one embodiment of the present invention;

[020] Figure 6b is a side view of the swirl device of Figure 6a;

30 [021] Figure 6c is a view through line 6c-6c of Figure 6b;

[022] Figure 7 is a cross-sectional view through line 7-7 of Figure 2;

[023] Figure 8a is a cross-sectional view of a portion of a duct according to one embodiment of the present invention;

[024] Figure 8b is a cross-sectional view of a portion of a duct according to another embodiment of the present invention;

5 [025] Figure 9 is a perspective view of a liquid extractor according to one embodiment of the present invention;

[026] Figure 10 is a view through line 10-10 of Figure 9;

[027] Figure 11 is a perspective view of a liquid extractor according to one embodiment of the present invention;

10 [028] Figure 12 is a close-up view of Figure 11;

[029] Figure 13 is a perspective view of a sump body according to one embodiment of the present invention;

[030] Figure 14 is a rotated view of Figure 13;

[031] Figure 15 is a cross-sectional view through line 15-15 of Figure 14;

15 [032] Figure 16 is a cut-away view of a portion of a liquid extractor according to one embodiment of the present invention;

[033] Figure 17 is a perspective view of a liquid extractor according to one embodiment of the present invention;

[034] Figure 18 is a close-up view of section 18 of Figure 17;

20 [035] Figure 19 is a close-up view of section 19 of Figure 17;

[036] Figure 20 is a perspective view of a sump cover according to one embodiment of the present invention;

[037] Figure 21 is a cross-sectional view through line 21-21 of Figure 20;

25 [038] Figure 22 is a perspective view of a sump cover according to another embodiment of the present invention;

[039] Figure 23 is a cross-sectional view through line 23-23 of Figure 22; and

[040] Figure 24 is a flow chart of a method of extracting a liquid portion from a flow according to an embodiment of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

[041] The following detailed description is of the best currently contemplated modes of carrying out the invention. The description is not to be taken in a limiting sense, but is made merely for the purpose of illustrating the general principles of the invention, since the scope of the invention is best defined by the appended claims.

[042] Broadly, the present invention provides liquid separation devices and methods for producing the same. Embodiments of the present invention may find beneficial use in many industries including aerospace, automotive, and electricity generation. Embodiments of the present invention may be beneficial in applications including aircraft environmental control systems (ECS) and heating ventilation and air-conditioning (HVAC) duct systems. Embodiments of the present invention may be useful in any liquid/gas separation application.

[043] In one embodiment, the present invention may comprise a water extractor device having two primary features for removing entrained water from the interior wall of an ECS duct. The first primary feature may comprise a slot in the duct wall that is oriented longitudinally along the duct. An enclosing sump may be positioned on the outside of the duct and over the slot. Unlike the prior art, the longitudinal orientation may allow the extractor to fit in the aircraft better than a more traditional circumferential slot and housing or an extractor having a large volume chamber. Unlike the prior art that positions the extractor in a straight section of duct, the longitudinal slot of some embodiments of the present invention may be located on the outside of a bend in the duct, where inertial forces direct the entrained water. An upstream swirl device may or may not be used in conjunction with the slot.

[044] The second primary feature may comprise one or more continuous ridges positioned on the interior duct wall surface. The ridges may be positioned to direct water on the duct wall to the slot where the water is extracted. The ridges may be single or multiple and may have gaps to direct the water to specific locations. Unlike the complicated flow path of the prior art, the water may flow along the ridges to the slot using Coanda effect on the downstream side of the ridges. Unlike the tortuous and limited flow path area of the prior art, the low profile ridges may not induce a

significant pressure drop penalty.

[045] In one embodiment, the present invention may provide a liquid extractor 60 for an environmental control system 70, as depicted in Figure 1. The liquid extractor 60 may be positioned downstream from an existing ECS water separator 72. The liquid extractor 60 may be in flow communication with an ECS duct system 74. The liquid extractor 60 may be positioned upstream from a cockpit flow 76 and/or an avionics flow 78.

[046] The liquid extractor 60 according to an embodiment of the present invention is depicted in Figures 2- 4. The liquid extractor 60 may comprise a duct 61, at least one slot 62 (see Figure 3), at least one ridge 63 and a sump 64. The duct 61 may be designed to receive a flow 29 comprising a liquid/gas mixture. The slot 62 may be positioned longitudinally along the duct 61. The ridge 63 may be positioned on an inner surface 25 of the duct 61 and designed to direct a liquid portion 29a (see Figure 3) of the flow 29 towards the slot 62. The sump 64 may be positioned radially outward from the slot 62 and designed to receive the liquid portion 29a. Although the embodiments of the liquid extractor 60 depicted in the figures include at least one ridge 63, it is contemplated that the invention may also lack the ridges 63.

[047] The duct 61, such as, but not limited to, an ECS duct, may comprise a tube shaped structure having an inlet 26 and an outlet 27. The dimensions of the duct 61 may vary and may depend on the application. For a non-limiting example, the duct 61 may have a length of about 10.0 inches and a diameter of about 3.0 inches for some ECS applications. The duct 61 may comprise various materials including, but not limited to, sheet metal and plastic. For some applications, the duct 61 may comprise aluminum. The inlet 26 may be designed to receive the flow 29. The flow 29 may comprise various liquid/gas mixtures, such as a water/air mixture or an oil/air mixture.

[048] The duct 61 may include a bend 28. As the flow 29 passes through the bend 28, inertial forces may direct the liquid portion 29a (see Figure 3) of the flow 29 to be thrown toward an outer side 33 of the bend 28 and onto the inner surface 25 of the duct 61. For some applications, the duct 61 may comprise a straight cylindrical

member having no bends (not shown) and the duct 61 may be positioned such that gravity may direct the liquid portion 29a of the flow 29 towards the inner surface 25 of the duct 61.

[049] The duct 61 may include a swirl device 32 (see Figures 6a-6c), such as a static swirl vane. The swirl device 32 may be positioned upstream from the slot 62. The swirl device 32 may impart a centrifugal swirl on the flow 29. In Figures 3 and 4 the swirl is in a counter-clockwise direction looking downstream. The centrifugal swirl may cause the heavier liquid portion 29a (e.g. entrained water) of the flow 29 to be separated from a lighter portion (not shown) (e.g. air) of the flow 29. The centrifugal swirl may throw the entrained water downstream and outward towards the inner surface 25 of the duct 61. Embodiments of the liquid extractor 60 may comprise the bend 28, the swirl device 31, both the bend 28 and the swirl device 31, or neither the bend 28 nor the swirl device 31 to direct the liquid portion 29a of the flow 29 towards the inner surface 25 of the duct 61.

[050] The liquid extractor 60 may include at least one slot 62, as depicted in Figure 3. The slot 62 may allow for capture of the liquid portion 29a of the flow 29, which may be traveling on the inner surface 25 of the duct 61. The slot 62 may comprise a slit through the wall of the duct 61 and may be oriented longitudinally along the duct 61. For some applications, the slot 62 may be positioned lengthwise along the duct 61 and parallel to a duct axis 30, as depicted in Figure 3. For some applications, the slot 62 may include a keyhole 34 (see Figure 3) positioned at an upstream end 40 and/or a downstream end 41 (see Figure 18) of the slot 62 to reduce the stress gradient of the duct 61 resulting from the flow 29 and associated pressure.

[051] The dimensions of the slot 62 may vary with application. Computational fluid dynamics analysis (CFD) may be useful for determining the dimensions of the slot 62 for some applications. By way of non-limiting example, some applications may have a slot 62 comprising a slot width 31 (see Figure 5a) of less than about 0.25 inch. The slot width 31 may be, but not limited to, approximately 0.15 inch for some aircraft applications. For some applications, turbulence within the sump 64 may be proportional to the slot width 31. In other words, the larger the slot width 31,

the greater the turbulence within the sump 64. Excessive sump turbulence may result in the liquid portion 29a reentering the duct 61 from the sump 64 and a reduction in extractor efficiency. The length of the slot 62 may vary and may depend on factors including the diameter of the duct 61. For some applications, the length of the slot 62 may be about equal to or greater than the diameter of the duct 61. For example, a duct 61 having a 3.0-inch diameter may include a slot 62 having a length between 4 and 5 inches.

[052] The slot 62 may be positioned on the outer side 33 of the bend 28, for applications including the bend 28. The slot 62 may be positioned downstream from the swirl device 32, for applications including the swirl device 32. For some applications, the duct 61 may comprise more than one slot 62 and the slots 62 may be positioned axially in-line with respect to the duct axis 30. Alternatively, the slots 62 may be positioned parallel to each other about the circumference of the duct 61. As a third alternative, the slots 62 may be positioned parallel and axially staggered. The number and positioning of the slots 62 may vary with application and may depend on factors including the dimension of the duct 61 and the composition of the flow 29.

[053] The liquid extractor 60 may include at least one ridge 63, as depicted in Figure 7. The ridge 63 may comprise a ridge-shaped structure that extends radially inward from the inner surface 25 of the duct 61. A radial height 35 of the ridge 63 may be between about 0.050 inches and about 0.100 inches. The radial height 35 may be such that the ridge 63 produces minimal resistance to the flow 29 in the duct 61 and such that the ridge 63 directs the liquid portion 29a of the flow 29 towards the slot 62. The ridge 63 may be formed by various methods. For example, weld penetration techniques may be used to provide the ridge 63. Alternatively, the ridge 63 may comprise a strip of metal attached to the inner surface 25 of the duct 61. The method of providing the ridge 63 may depend on manufacturing preference.

[054] Some embodiments of the liquid extractor 60 may comprise two or more ridges 63 parallel to one another, forming a group of ridges 63. Ridges 63 within a group may be spaced axially from one another by a minimum axial distance 42 of about 0.35 inches, as depicted in Figure 7. Some embodiments of the present

invention may comprise more than one group of ridges 63. For example, the liquid extractor 60 may comprise one group of ridges 63 towards the upstream end 40 of the slot 62 and another group of ridges 63 towards the downstream end 41 of the slot 62. For some embodiments, for example when the duct 61 has a bend 28, the groups of ridges 63 may not be parallel to one another. The number and positioning of the ridge(s) 63 may vary with application and may depend on factors including the dimensions of duct 61 and the length of the slot 62. For some ECS applications, the liquid extractor 60 may comprise less than about ten ridges.

[055] At least one ridge 63 may intersect the slot 62, as depicted in Figures 3 and 11. For some embodiments, the ridge 63 may intersect the slot 62 at a position at least about 2.0 inches upstream from the downstream end 41 of the slot 62. The ridge 63 may intersect the slot 62 at an angle (ridge/slot angle 36) less than or equal to about 90 degrees, as depicted in Figures 8a and 8b. The ridge 63 may run circumferentially along the inner surface 25 such that the ridge 63 may be about perpendicular to the duct axis 30, as depicted in Figure 8a. Alternatively, the ridge 63 may have a swirl orientation relative to the duct axis 30, as depicted in Figure 8b. The ridge 63 may direct the liquid portion 29a to the slot 62 where it may be captured. Some embodiments may further include at least one non-slot-intersecting ridge (upstream ridge 63b) upstream from the slot 62, as depicted in Figures 9 and 10. The upstream ridge 63b may concentrate the liquid portion 29a of the flow 29.

[056] A gap 43, as depicted in Figure 12, may be incorporated into the ridge 63 and/or 63b at a strategic position, which allows the flow 29 to redirect the liquid portion 29a away from the ridge 63, 63b to another ridge(s) 63, 63b or the slot 62.

[057] The ridge 63, 63b may be angled with respect to the flow 29. The ridge 63, 63b and the surface of the flow 29 may form an angle (ridge/flow angle 37) of between about 10° and about 70°, as depicted in Figures 8a and 8b. For some applications, the ridge/flow angle 37 may be less than about 60°. For applications including more than one ridge 63, 63b, the ridge/flow angle 37 may or may not be the same for each ridge 63, 63b. The ridge/flow angle 37 may vary with application and may depend on factors including the diameter of the duct 61 and the velocity of the flow 29.

[058] Due to the low radial height 35 (e.g. about, but not limited to, 0.060 inches for some ECS applications), the ridge 63, 63b may produce minimal resistance to air flow (flow 29) in the duct 61. The ridge 63, 63b may capture the liquid portion 29a (e.g. water) on the downstream side of the ridge 63, 63b due to the low pressure zone created there, and the liquid portion 29a may run along the ridge 63, 63b due to the relative angle of the air flow (ridge/flow angle 37). The liquid portion 29a running along the ridge 63 may pass through the slot 62 and enter the sump 64.

[059] The sump 64 of the liquid extractor 60 may comprise a structure having a sump cavity 47 adapted to receive the liquid portion 29a of the flow 29, as depicted in Figures 5a and 5b. The sump 64 may comprise a structure that encloses the slot 62 such that the liquid portion 29a passing through the slot 62 from the duct 61 may enter the sump cavity 47. The sump 64 may be positioned radially outward from the slot 62 and attached to the duct 61. The sump 64 may comprise a body member 38 and a cover member 39, as depicted in Figures 2 and 4.

[060] The body member 38, as depicted in Figures 13-15, may comprise a structure having a drainage orifice 46 and an opening 45. The drainage orifice 46 may be in flow communication with a drain boss 44, as depicted in Figure 16. During assembly, the opening 45 may be positioned over the slot 62, as depicted in Figures 17-19. The opening 45 may be in flow communication with the slot 62 such that the liquid portion 29a the passes from the slot 62, through the opening 45 and into the sump cavity 47, as depicted in Figure 5a and 5b.

[061] The dimensions of the opening 45 may vary with application and may depend on the dimensions of the slot 62. A first edge distance 48a measured from the slot 62 to a first inner wall 49 of the body member 38 may be, but not limited to, between about 0.20 inches and about 0.35 inches, as depicted in Figure 5a. For some ECS applications, the first edge distance 48a may be approximately 0.25 inches. A second edge distance 48b measured from the slot 62 to a second inner wall 50 of the body member 38 may be, but not limited to, between about 0.25 inches and about 0.50 inches, as depicted in Figure 5a. For some ECS applications, the second edge distance 48b may be approximately 0.38 inches. The second edge distance 48b may be large enough that the liquid portion 29a does not reenter the

duct 61, but instead exits the sump cavity 47 through the drainage orifice 46.

[062] The body member 38, as depicted in Figures 5a and 5b may include a retaining wall 51. The retaining wall 51 may comprise a structure positioned within the sump cavity 47 and along the length of the slot 62. A gutter 52 may be created
5 between the retaining wall 51 and an interior surface 53 of the sump 64. The gutter 52 may capture, retain, and direct the liquid portion 29a towards the drainage orifice 46. For some applications, the retaining wall 51 may allow the second edge distance 48b to be reduced. For example, a second edge distance of about 0.38 inch may be reduced to approx 0.28 inch when the retaining wall 51 is included.

10 **[063]** The cover member 39, as depicted in Figures 20-23, may comprise a structure adapted to attach to the body member 38. In some embodiments, the cover member 39 may be designed to be welded to the body member 38, as depicted in Figures 5a, 20 and 21. In an alternate embodiment, the cover member 39 may be designed to be brazed to the body member 38, as depicted in Figures 5b,
15 22 and 23. In another alternate embodiment, the cover member 39 may be integral to the body member 38. The design of the cover member 39 and the body member 38 may depend on manufacturing preference.

[064] A method 100 of extracting a liquid portion from a flow is depicted in Figure 24. The method 100 may comprise a step 110 of passing the flow 29 through a duct
20 61, a step 120 of directing the liquid portion 29a of the flow 29 towards an inner surface 25 of the duct 61, a step 130 of directing the liquid portion 29a towards a slot in the duct 61 and a step 140 of capturing the liquid portion 29a in a sump 64. The step 110 of passing the flow 29 may comprise passing a water/air mixture through a duct of an ECS. The step 120 of directing the liquid portion 29a towards an inner
25 surface 25 of the duct 61 may comprise imparting a centrifugal swirl on the flow 29. The step 120 may comprise passing the flow 29 through a bend 28 in the duct 61 such that inertial forces direct the liquid portion 29a to be thrown toward an outer side 33 of the bend 28 and onto the inner surface 25. The step 130 of directing the liquid portion 29a towards a slot in the duct 61 may comprise running the liquid
30 portion 29a along at least one ridge 63 on the inner surface 25 of the duct 61. The step 140 of capturing the liquid portion 29a in a sump 64 may comprise flowing the

liquid portion 29a into a gutter 52 of the sump 64.

[065] As can be appreciated by those skilled in the art, the present invention provides improved liquid extractors. The longitudinal sump configuration allows embodiments of the present invention to be effectively used in envelope constrained applications. The slot and ridge design of the present invention provides liquid
5 extractors that can be used in straight and/or elbow sections of a duct.

[066] It should be understood, of course, that the foregoing relates to exemplary embodiments of the invention and that modifications may be made without departing from the spirit and scope of the invention as set forth in the following claims.

WE CLAIM:

1. An apparatus for extracting a liquid portion (29a) from a flow (29) comprising:
a duct (61) adapted to receive said flow (29); and
at least one slot (62) positioned longitudinally along said duct (61).
2. The apparatus of Claim 1, further comprising at least one ridge (63) positioned on an inner surface (25) of said duct (61) and adapted to direct said liquid portion (29a) to said slot (62).
3. The apparatus of Claim 2, wherein said ridge (63) intersects said slot (62).
4. The apparatus of Claim 2, wherein said ridge (63) and a surface of said flow (29) forms a ridge/flow angle (37) between about 10° and about 70°.
5. The apparatus of any one or more of Claims 1-4, further comprising a sump (64) positioned radially outward from said slot (62) and attached to with said duct (61).
6. The apparatus of any one or more of Claims 1-5, further comprising a swirl device (32) positioned upstream from said slot (62).
- 5 7. The apparatus of any one or more of Claims 1-6, wherein said duct (61) has a bend (28) and said slot (62) is positioned on an outer side (33) of said bend (28).
8. The apparatus of any one or more of Claims 1-7, further

comprising at least one upstream ridge (63b) positioned on said inner surface (25) and upstream from said slot (62), said upstream ridge (63b) having a gap (43).

5 9. The apparatus of any one or more of Claims 1-8, wherein said apparatus comprises at least two slots (62).

 10. The apparatus of Claim 9, wherein said two slots (62) are axially aligned.

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