US Patent & Trademark Office
Patent Public Search | Text View

United States Patent Application Publication 20250257957
Kind Code A1
Publication Date August 14, 2025
Inventor(s) Saltzman; David et al.

INTERWOVEN HEAT EXCHANGER CORE WITH END FACE FEATURES

Abstract

Heat exchangers include a housing with an internal structure that defines sets of first and second fluid passages such that a first fluid within the first fluid passages is prevented from mixing with a second fluid in the second fluid passages. An inlet manifold defines an inlet plenum for receiving the first fluid and directing the first fluid into openings of the first fluid passages. The openings are defined in an inlet end face of the internal structure within the inlet manifold. A set of flow directors are arranged on the inlet end face and are configured to direct a flow of the first fluid into the openings of the set of first fluid passages, with each flow director defining an end face passage that is one of the second fluid passages of the set of second fluid passages.

Inventors: **Saltzman; David (Glastonbury, CT), McCord; Patrick (Norwich, CT), Le; Tung (Enfield, CT)**

Applicant: **Hamilton Sundstrand Corporation** (Charlotte, NC)

Family ID: **1000007694327**

Appl. No.: **18/438907**

Filed: **February 12, 2024**

Publication Classification

Int. Cl.: **F28F9/22** (20060101); **B64D13/06** (20060101); **F28F27/02** (20060101)

U.S. Cl.:

CPC **F28F9/22** (20130101); **B64D13/06** (20130101); **F28F27/02** (20130101); B64D2013/0618 (20130101)

Background/Summary

BACKGROUND

[0001] The subject matter disclosed herein generally relates to heat exchangers and, more particularly, to heat exchangers having end faces features for improved operation.

[0002] Heat exchangers are utilized in various applications to exchange thermal energy between various fluid streams, such as between a first fluid stream and a second fluid stream. For example, in an aircraft environmental control system (ECS), a heat exchanger may be utilized to exchange thermal energy between a relatively low pressure, low temperature RAM airflow and a relatively high pressure, high temperature bleed air flow from a gas turbine engine compressor. Such thermal energy exchange may be provided to cool the bleed air flow upstream of an air cycle machine of the ECS prior to supplying treated air to an aircraft cabin or other volume or space onboard an aircraft.

[0003] In operation, heat exchangers are typically configured to transfer heat between a hot fluid and a cool fluid. To increase the efficiency of heat exchangers, primary surfaces (e.g., walls) and secondary surfaces (e.g., fins) are utilized to increase the surface area through which thermal energy can transfer. The heat transfer through a primary surface is typically very good because the primary surfaces (walls) are thin and the distance the thermal energy needs to travel is relatively small. However, the heat transfer through a secondary surface may be less efficient than through the primary surfaces because the thermal energy must travel a longer distance along the length of the secondary surface (fin). With conventional manufacturing techniques, the most compact heat exchangers (i.e., high surface area per unit volume) are achieved through increasing secondary surface area by adding fins rather than through the addition of primary surface area. As such, by reducing the size of the heat exchangers, the efficiency goes down due to the additional secondary surfaces.

[0004] To address this, interwoven, additively manufactured heat exchangers have been developed. The interwoven nature of such configurations can increase heat transfer while keeping the size and compactness of the heat exchanger low. Although such heat exchangers provide benefits over the wall-fin configurations, further improvements may be made to increase efficiency of heat exchangers.

SUMMARY

[0005] According to some embodiments, heat exchangers are provided. The heat exchangers include a housing, an internal structure arranged within the housing, the internal structure defining a set of first fluid passages and a set of second fluid passages, wherein a first fluid within the set of first fluid passages is prevented from mixing with a second fluid in the set of second fluid passages, an inlet manifold at an inlet end of the set of first fluid passages and defining an inlet plenum for receiving the first fluid, wherein the set of first fluid passages comprise openings to the inlet plenum to receive the first fluid therethrough, wherein the openings of the set of first fluid passages are defined in an inlet end face of the internal structure, and a set of flow directors arranged on the inlet end face and configured to direct a flow of the first fluid into the openings of the set of first fluid passages, wherein each flow director defines an end face passage that is one of the second fluid passages of the set of second fluid passages.

[0006] In addition to one or more of the features described herein, or as an alternative, further embodiments of the heat exchangers may include an outlet manifold at an outlet end of the set of first fluid passages and defining an outlet plenum for receiving the first fluid, wherein the set of first fluid passages comprise outlet openings to the outlet plenum to direct the first fluid into the outlet plenum, wherein the outlet openings of the set of first fluid passages are defined in an outlet end face of the internal structure and a set of outlet flow directors arranged on the outlet end face

and configured to direct a flow of the first fluid into the outlet plenum, wherein each flow director defines an end face passage that is one of the second fluid passages of the set of second fluid passages.

[0007] In addition to one or more of the features described herein, or as an alternative, further embodiments of the heat exchangers may include an inlet manifold at an inlet end of the set of second fluid passages and defining a second inlet plenum for receiving the second fluid, wherein the set of second fluid passages comprise openings to the second inlet plenum to receive the second fluid therethrough, wherein the openings of the set of second fluid passages are defined in a second inlet end face of the internal structure and a second set of flow directors arranged on the second inlet end face and configured to direct a flow of the second fluid into the openings of the set of second fluid passages, wherein each flow director defines an end face passage that is one of the first fluid passages of the set of first fluid passages.

[0008] In addition to one or more of the features described herein, or as an alternative, further embodiments of the heat exchangers may include that each flow director comprises an apex and two flow control surfaces that extend from the apex to the internal structure.

[0009] In addition to one or more of the features described herein, or as an alternative, further embodiments of the heat exchangers may include that the apex is rounded and the flow control surfaces are curved and convex as they extend to the internal structure.

[0010] In addition to one or more of the features described herein, or as an alternative, further embodiments of the heat exchangers may include that the apex is pointed and the flow control surfaces are curved and convex as they extend to the internal structure.

[0011] In addition to one or more of the features described herein, or as an alternative, further embodiments of the heat exchangers may include that the apex is pointed and the flow control surfaces are planar surfaces that extend to the internal structure to define a substantially triangular shape of the flow director.

[0012] In addition to one or more of the features described herein, or as an alternative, further embodiments of the heat exchangers may include that the end face passage is similar in geometry to all other passages of the set of second fluid passages.

[0013] In addition to one or more of the features described herein, or as an alternative, further embodiments of the heat exchangers may include that the set of first fluid passages and the set of second fluid passages are defined within an interwoven structure of the internal structure within the housing.

[0014] In addition to one or more of the features described herein, or as an alternative, further embodiments of the heat exchangers may include that the first fluid is bleed air from an aircraft engine and the second fluid is RAM air from a RAM air duct of an aircraft.

[0015] According to some embodiments, methods of manufacturing heat exchangers are provided. The methods include providing a housing, arranging an internal structure within the housing, the internal structure defining a set of first fluid passages and a set of second fluid passages, wherein a first fluid within the set of first fluid passages is prevented from mixing with a second fluid in the set of second fluid passages, wherein the housing defines an inlet manifold at an inlet end of the set of first fluid passages and defining an inlet plenum for receiving the first fluid, wherein the set of first fluid passages comprise openings to the inlet plenum to receive the first fluid therethrough, wherein the openings of the set of first fluid passages are defined in an inlet end face of the internal structure, and forming a set of flow directors on the inlet end face and configured to direct a flow of the first fluid into the openings of the set of first fluid passages, wherein each flow director defines an end face passage that is one of the second fluid passages of the set of second fluid passages.

[0016] In addition to one or more of the features described herein, or as an alternative, further embodiments of the methods may include that an outlet manifold is defined by the housing at an outlet end of the set of first fluid passages and defining an outlet plenum for receiving the first fluid, wherein the set of first fluid passages comprise outlet openings to the outlet plenum to direct

the first fluid into the outlet plenum, wherein the outlet openings of the set of first fluid passages are defined in an outlet end face of the internal structure, and forming a set of outlet flow directors on the outlet end face and configured to direct a flow of the first fluid into the outlet plenum, wherein each flow director defines an end face passage that is one of the second fluid passages of the set of second fluid passages.
[0017] In addition to one or more of the features described herein, or as an alternative, further embodiments of the methods may include that an inlet manifold is defined by the housing at an inlet end of the set of second fluid passages and defining a second inlet plenum for receiving the second fluid, wherein the set of second fluid passages comprise openings to the second inlet plenum to receive the second fluid therethrough, wherein the openings of the set of second fluid passages are defined in a second inlet end face of the internal structure and forming a second set of flow directors on the second inlet end face and configured to direct a flow of the second fluid into the openings of the set of second fluid passages, wherein each flow director defines an end face passage that is one of the first fluid passages of the set of first fluid passages.
[0018] In addition to one or more of the features described herein, or as an alternative, further embodiments of the methods may include that each flow director comprises an apex and two flow control surfaces that extend from the apex to the internal structure.
[0019] In addition to one or more of the features described herein, or as an alternative, further embodiments of the methods may include that the apex is rounded and the flow control surfaces are curved and convex as they extend to the internal structure.
[0020] In addition to one or more of the features described herein, or as an alternative, further embodiments of the methods may include that the apex is pointed and the flow control surfaces are curved and convex as they extend to the internal structure.
[0021] In addition to one or more of the features described herein, or as an alternative, further embodiments of the methods may include that the apex is pointed and the flow control surfaces are planar surfaces that extend to the internal structure to define a substantially triangular shape of the flow director.
[0022] In addition to one or more of the features described herein, or as an alternative, further embodiments of the methods may include that the end face passage is similar in geometry to all other passages of the set of second fluid passages.
[0023] In addition to one or more of the features described herein, or as an alternative, further embodiments of the methods may include that the set of first fluid passages and the set of second fluid passages are defined within an interwoven structure of the internal structure within the housing.
[0024] In addition to one or more of the features described herein, or as an alternative, further embodiments of the methods may include that the housing and the internal structure are additively manufactured as a single structure.
[0025] The foregoing features and elements may be combined in various combinations without exclusivity, unless expressly indicated otherwise. These features and elements as well as the operation thereof will become more apparent in light of the following description and the accompanying drawings. It should be understood, however, that the following description and drawings are intended to be illustrative and explanatory in nature and non-limiting.

Description

BRIEF DESCRIPTION OF THE DRAWINGS
[0026] The subject matter is particularly pointed out and distinctly claimed at the conclusion of the specification. The foregoing and other features, and advantages of the present disclosure are apparent from the following detailed description taken in conjunction with the accompanying

drawings in which:
[0027] FIG. **1** is a perspective view of an embodiment of a heat exchanger that may incorporate embodiments of the present disclosure;
[0028] FIG. **2**A is a cross-sectional schematic illustration of a heat exchanger in accordance with an embodiment of the present disclosure;
[0029] FIG. **2**B is an enlarged illustration of a detail of an internal structure of the heat exchanger of FIG. **2**A;
[0030] FIG. **2**C is another view of the detail of FIG. **2**B, showing an internal feature thereof;
[0031] FIG. **2**D is an enlarged cross-sectional view of a portion of the internal structure of FIG. **2**A;
[0032] FIG. **3**A is a schematic illustration of flow at an end face of a heat exchanger in accordance with an embodiment of the present disclosure;
[0033] FIG. **3**B is a schematic illustration of a flow at an end face of a heat exchanger without features in accordance with the present disclosure;
[0034] FIG. **4**A is a first example of an end face structure and flow director in accordance with an embodiment of the present disclosure;
[0035] FIG. **4**B is a second example of an end face structure and flow director in accordance with an embodiment of the present disclosure;
[0036] FIG. **4**C is a third example of an end face structure and flow director in accordance with an embodiment of the present disclosure;
[0037] FIG. **5**A is a side elevation cross-sectional illustration of a heat exchanger in accordance with an embodiment of the present disclosure; and
[0038] FIG. **5**B is a plan view cross-sectional illustration of the heat exchanger of FIG. **5**A.
DETAILED DESCRIPTION
[0039] As shown and described herein, various features of the disclosure will be presented. Various embodiments may have the same or similar features and thus the same or similar features may be labeled with similar reference numerals and/or description thereof may be omitted in certain later described embodiments for conciseness. Although similar reference numbers may be used in a generic sense, various embodiments will be described and various features may include changes, alterations, modifications, etc. as will be appreciated by those of skill in the art, whether explicitly described or otherwise would be appreciated by those of skill in the art. Further, it will be appreciated that, unless otherwise stated, features from the various separately described embodiments may be combined in various combinations and each embodiment is not intended to be mutually exclusive from features of other embodiments described herein and/or mutually exclusive from other features and components not explicitly described.
[0040] Referring to FIG. **1**, illustrated is a schematic view of an embodiment of a heat exchanger **100** that may incorporate embodiments of the present disclosure. The heat exchanger **100** is configured to facilitate an exchange of thermal energy between a first fluid flow **102** and a second fluid flow **104** directed through the heat exchanger **100**. In a non-limiting example application, the first fluid flow **102** is a relatively high temperature, high pressure fluid flow such as a bleed airflow from a compressor of a gas turbine engine, and the second fluid flow **104** is a relatively low temperature, low pressure fluid flow such as RAM airflow for use by an aircraft environmental control system (not shown). In some configuration, the heat exchanger **100** may be arranged within a RAM air duct or the like. In other configurations, the heat exchanger **100** may be part of an air cycle machine, part of a RAM air circuit, part of an environmental control system, part of a closed-loop supercritical fluid system, or may be used as a heat exchanger in any thermal exchange system onboard an aircraft. Accordingly, the fluids passing through the heat exchanger **100** may include, but are not limited to, air (from various sources), oil, water, CO.sub.2, sCO.sub.2, fuel, coolant, refrigerant, or the like, as will be appreciated by those of skill in the art.
[0041] The heat exchanger **100** has a housing **106** that contains internal structures **108** that define a first fluid path for the first fluid flow **102** and a second fluid path for the second fluid flow **104**. The

internal structures **108** are configured to prevent mixing of the two fluids while permitting thermal exchange and transfer from one of the first and second fluid flows **102**, **104** to the other of the first and second fluid flows **102**, **104**.

[0042] The first fluid flow **102** enters the heat exchanger **100** at a first inlet manifold **110** which may include a manifold cavity **112** in which the fluid of the first fluid flow **102** is separated and distributed into the internal structures **108** along a first fluid flow structure. The second fluid flow **104** enters the heat exchanger **100** at a second inlet manifold **114** which may include a manifold cavity in which the fluid of the second fluid flow **104** is separated and distributed into the internal structures **108** along a second fluid flow structure. The first and second fluid flow structures of the internal structures **108** may be arranged as interwoven flow paths, such as shown and described in commonly owned U.S. Pat. No. 10,890,381, entitled Cross-flow Heat Exchanger, the contents of which are incorporated herein in their entirety. As the first fluid flow **102** and the second fluid flow **104** pass through the respective fluid flow structures of the internal structures **108** of the heat exchanger **100**, thermal exchange between the two fluids may occur. The first fluid flow **102** will then exit through a first outlet manifold **116** and the second fluid flow **104** will exit through a second outlet manifold **118**.

[0043] The heat exchanger **100** is a crossflow heat exchanger such that as the first and second fluid flows **102**, **104** pass through the heat exchanger **100**, the two flows are flowing in substantially normal directions relative to each other. Although illustrated as a crossflow heat exchanger in FIG. **1**, embodiments of the present disclosure are not limited to such heat exchanger configurations. In other configurations, the two flows may be counter flow or parallel flow, depending on the specific application and/or arrangement of the structure of the heat exchanger.

[0044] The weave heat exchanger design is an additively manufactured heat exchanger with an interwoven passage geometry. The discrete channels of the two fluid circuits weave around each other to augment heat transfer and ensure that the fluid in each fluid passage is in constant contact with the flow path of the other fluid to maximize thermal exchange therebetween. Although such interwoven configurations may provide improvements and increased efficiencies as compared to a wall/fin arrangement, losses may still occur due to various features thereof.

[0045] Fluid pressure losses may occur as a consequence of forcing the fluid(s) through the internal structures of the heat exchanger. Typically, the fluid passages defined by the internal structures of the heat exchanger are smaller in cross-section than a flow path supplying the fluid into the heat exchanger. As a result, the fluid is forced into smaller (although greater in number) fluid passages, which can result in losses. Further, the inlet and exit faces of the internal structures of the heat exchanger may be flat in order to define an inlet/outlet plenum within a manifold. As the fluid enters the inlet of the internal structures, the fluid is contracted, and as the fluid exits the outlet of the internal structures, the fluid is expanded. The flat surfaces at the inlet and/or outlet may cause a fluid flow stagnation region to form. Such stagnation of fluid can cause increased pressure losses at the inlet and outlet of the heat exchanger.

[0046] Accordingly, in accordance with some embodiments of the present disclosure, the inlet and/or outlet facing ends of the internal structures of the heat exchanger may be modified to improve flow contraction and expansion into the heat exchanger passages on one or more heat exchanger flow circuits. The added feature(s) allows for a more fluid-dynamic face of the heat exchanger without removing/reducing surface area or greatly impacting weight. Such features may be particularly impactful at an inlet end, where a fluid flows and contacts directly with an end face of the internal structures. At the outlet end, such features may be provided to reduce turbulence as the fluid exits the internal structures and is rejoined within an outlet manifold cavity or otherwise at the outlet of the flow path as it exits the heat exchanger.

[0047] Referring now to FIGS. **2**A-**2**D, schematic illustrations of a heat exchanger **200** having an internal structure **202** in accordance with an embodiment of the present disclosure are shown. The heat exchanger **200** includes a housing **204** that contains the internal structure **202**. The housing

204 defines an internal volume that contains the internal structure **202** and is configured to receive at least two different fluids for heat exchange therebetween. FIG. **2**A illustrates a schematic side cross-sectional view of the arrangement of the internal components of the heat exchanger **200**, with FIGS. **2**B-**2**D providing more illustrative detail of the internal structure **202**. That is, the illustrative of FIG. **2**A is merely schematic and is provided for explanation and is merely schematically shown, and the more detailed structural views are provided in FIGS. **2**B-**2**D. The internal structure **202** may be a tube bank, interwoven arrangement, or the like, with sets of fluid passages extending at angles relative to each other. In the illustrative embodiments, the angle of origination is substantially normal or about 90°.

[0048] The housing **204** has an inlet **206** that provides fluid communication into an inlet manifold **208** which defines an inlet plenum for receiving a first fluid through the inlet **206**. The first fluid will then enter and flow through a plurality of first fluid passages **210**. The first fluid passages **210** extend from the inlet manifold **208** to an outlet manifold **212** which defines an outlet plenum where the first fluid exits the first fluid passages **210**. The first fluid will then exit the heat exchanger **200** through an outlet **214**. As shown, second fluid passages **216** are provided as a set of passages that extend perpendicular or normal to the flow direction through the first fluid passages **210**. Although not shown in this view, it will be appreciated that a cross-sectional view looking along a flow direction through the second fluid passages **216** may appear substantially similar to that illustrated in FIG. **2**B, with an associated inlet, inlet manifold, outlet, and outlet manifold provided within the internal structure **202**. As such, the heat exchanger **200** may be a crossflow heat exchanger, as will be appreciated by those of skill in the art.

[0049] The heat exchanger internal structure **202** is arranged with an interwoven geometry, as shown in more detail in FIGS. **2**B-**2**D, to form the crossflow heat exchanger configuration. Within the heat exchanger internal structure **202**, the first fluid passages **210** define a first fluid path or flow path and the second fluid passages **216** define a second fluid path or flow path. As shown, the first fluid passages **210** are arranged in parallel and, similarly, the second fluid passages **216** are arranged in parallel. The first fluid passages **210** extend from an inlet end **218** at the inlet manifold **208** to an outlet end **220** at the outlet manifold **212**.

[0050] As shown in FIG. **2**A, and described in more detail herein, the inlet end **218** of the first fluid passages **210** are defined with end face features in the form of flow directors **222** provided about an inlet into each first fluid passage **210**. The flow directors **222** are structural features that extend into the plenum of the first manifold **208** and may be fluid and/or aerodynamically configured to aid in directing a flow of the first fluid into the first fluid passages **210**. In this illustrative configuration shown in FIG. **2**A, the outlet end **220** of the first fluid passages **210** is not provided with such end face features. However, in other embodiments, the outlet end **220** may also include end face features similar to that of the inlet end **218**. Furthermore, it will be appreciated that the inlet and outlet ends of the second fluid passages **216** may also be similarly provided with end face features, as shown and described herein.

[0051] Referring now to FIGS. **2**B-**2**D, more detailed schematic illustrations of the arrangement of the internal structure **202** are shown. FIG. **2**B is a perspective view of a portion of the internal structure **202** of the heat exchanger **200** having flow directors **222**, in accordance with an embodiment of the present disclosure. FIG. **2**C is a similar perspective view, illustrating the internal structure **202** without the flow directors **222** shown for illustrative and explanatory purposes regarding the internal structure of the flow directors **222**. FIG. **2**D is a cross-sectional illustration of a portion of the internal structure **202** of the heat exchanger **200**.

[0052] As shown in FIGS. **2**B-**2**D, the internal structure **202** has an interwoven configuration of the first fluid passages **210** and the second fluid passages **216**. At the inlet end **218**, the first fluid passages **210** have inlets **224** defined between the flow directors **222**. The flow directors **222** are defined by one of the second fluid passages **216**, with such end face second fluid passages within the flow directors **222** referred to herein as end face passages **226**. The end face passages **226** are flow paths for the second fluid, but are arranged such that a portion of the material or walls defining the end face passages **226** extends outward from an end face **228** of the internal structure **202**, as shown in FIG. **2**D. The flow directors **222**, having the end face passages **226** of the second fluid passages **216** defined therein, are arranged to guide and direct a flow of the first fluid into the inlets **224** of the first fluid passages **210**. As a results, the flow of the first fluid as it enters the first fluid passages **210** may not become turbulent. Accordingly, fewer pressure losses may occur as the first fluid flows into and through the first fluid passages **210**.

[0053] As shown in FIG. **2**D, the end face passages **226** which extend through the flow directors **222** are defined with an extension of material that extends beyond the end face **228** of the internal structure **202**. The flow directors **222** are defined with flow control surfaces **230** that join at an apex **232** such that the inlet **218** of a first fluid passage **210** is defined between two adjacent flow directors **222**, with the flow control surfaces **230** directing a flow of fluid into the respective first fluid passage **210**. The apex **232** may be pointed or curved, but is generally arranged such that an incoming flow will smoothly divide at the apex **232** and travel along the flow control surfaces **230**. The flow control surfaces **230** may be curved (e.g., as shown in FIGS. **2**B-**2**D), or may be straight walls (e.g., substantially triangular in cross-section). Thus, a divided flow will be directed into first fluid passages **210** in a smooth and non-turbulent manner. The geometry of the flow directors **222** may reduce contraction losses (at the inlet) or expansion losses (at the outlet), depending on which end of the flow passages the flow directors **222** are arranged.

[0054] The internal structure **202** may be formed through various known means. In some embodiments, the internal structure **202**, as shown, is an interwoven structure that may be additively manufactured. In other embodiments, the features shown and described herein may be implemented on a tube assembly configuration, where the first and second flow paths are substantially straight through tubes configured in a crossflow arrangement. The internal structure **202** may be formed from various thermally conductive materials, including, but not limited to, aluminum and/or steel. In some embodiments, the internal structure may be formed from the same material as the housing in which it is installed (or integrally formed with in some cases of additive manufacturing) or may be formed from a different material than the housing.

[0055] It will be appreciated that any crossflow heat exchanger arrangement may incorporate embodiments of the present disclosure. Furthermore, although shown as a crossflow heat exchanger arrangement, it will be appreciated that other types of flow arrangements of heat exchangers may incorporate embodiments of the present disclosure. For example, and without limitation, heat exchangers having multi-pass flow arrangements, counter flow arrangements, parallel flow arrangements, and/or multi-circuit flow arrangements may each incorporate the structures and features described herein, and the present disclosure is not intended to be limited to crossflow heat exchanger configurations, but rather such illustrations and description are for illustrative and explanatory purposes. Furthermore, with any type of heat exchanger, the fluid passages of one fluid flow may be fluidly separated from the fluid passages of the other fluid flow and mixing thereof is prevented. As noted, the sets of fluid passages may be angled relative to each other to provide for a crossflow configuration. The particular angle of one set of fluid passages relative to the other may be any angle that may be governed by thermal exchange considerations, fluid type, requirements for sizing, flow requirements, arrangement of fluid passages that supply the fluids into the inlet manifolds or receive the fluids from the outlet manifolds, or the like. In some configurations, the sets of fluid passages may be arranged parallel to each other, with separate inlet/outlet headers and supply of fluids into the respective passages. In such configurations, the inlet and outlet manifolds may include end faces with flow director features as shown and described herein. As such, an angle my not exist between the individual fluid passages within the internal structure, but rather the fluid separation and directions may be governed by the arrangement of the inlet and/or outlet manifolds, as will be appreciated by those of skill in the art.

[0056] Referring now to FIGS. **3**A-**3**B, an illustrative comparison of flow between a first heat exchanger internal structure **300** in accordance with an embodiment of the present disclosure (FIG. **3**A) and a second heat exchanger internal structure **302** without features as described herein (FIG. **3**B) is provided. The general structure of the two internal structures **300**, **302** are similar, having interwoven fluid passages arranged in an interwoven fashion. However, the first internal structure **300** of FIG. **3**A includes flow directors **304** arranged at the inlet end **306** of first fluid passages **308**, similar to that shown and described with respect to FIGS. **2**A-**2**D. In contrast, the second internal structure **302** shown in FIG. **3**B does not include such flow directors.

[0057] As shown in FIG. **3**A, the flow directors **304** provide a smooth transition of a fluid **310** as it enters the first fluid passages **308**. In contrast, in the configuration of FIG. **3**B, a fluid **312** will interact with an end face **314** of the internal structure **302** and result in turbulent flow **316** and associated losses.

[0058] The flow directors described herein, which may be applied to the inlet and outlet faces of the heat exchanger, will reduce component-level pressure losses while minimally impacting weight and heat transfer. With reduced pressure losses, a more aggressive core geometry can be used in the heat exchanger to increase overall heat rejection and/or thermal exchange. Furthermore, in the case of small heat exchangers, the inlet and outlet losses can be substantial, and, thus, the described flow directors arranged at the end faces of the internal structures of the heat exchangers can provide large performance benefits. It will be appreciated that a small heat exchanger is one that has a relatively small passage flow length compared with a passage size (e.g., a length-to-size ratio of about 10 or less). As such, the frictional losses in the channel passage will be the same order of magnitude as the expansion and contraction losses. This results in a heat exchanger that has a relatively short passage length has large percentage of pressure loss from contraction and expansion because of the low value of its length-to-size ratio. In many aerospace applications it may be required to have small heat exchangers due to physical size constraints in aircraft. Consequently, expansion and contraction losses across many components will add up quickly and degrade system performance. The flow directors of the present disclosure can decrease such losses even with a relatively short passage length and/or relatively small heat exchanger. For example, and without limitation, by incorporating the flow directors at the end faces of a heat exchanger internal structure, inlet and/or outlet losses may be improved (decreased) by 10% to 50% as compared to an internal structure without such flow directors.

[0059] As noted above, the flow directors of the present disclosure may have a geometry to provide a smooth flow transition for fluids entering a flow path of a heat exchanger. Referring to FIGS. **4**A-**4**C, schematic illustrations of examples of the geometries that may be employed for the flow directions are shown.

[0060] FIG. **4**A illustrates a portion of a heat exchanger internal structure **400***a* having a first flow passage **402***a* and a second flow passage **404***a*. The first flow passage **402***a* is arranged at an end face **406***a* of the internal structure **400***a* and the second flow passage **404***a* is arranged downstream or behind the first flow passage **402***a* relative to a flow of a first fluid **408***a*. A second fluid may be directed through the first and second flow passage **402***a*, **404***a*, which may be normal to the flow direction of the first fluid **408***a* (i.e., in/out of the page of FIG. **4**A). The first flow passage **402***a* is an end face passage that extends through a flow director structure **410***a*, and the second flow passage **404***a* is an internal flow structure **412***a* arranged downstream from the flow director structure **410***a* with respect to the flow of the first fluid **408***a*. In this configuration, the flow director structure **410***a* has an apex **414***a* with flow control surfaces **416***a* that join at the apex **414***a*. The apex **414***a* and the flow control surfaces **416***a*, in this configuration, define a substantially oval or curved geometry with the apex **414***a* providing a substantially continuous and smooth transition between the flow control surfaces **416***a*.

[0061] FIG. **4**B illustrates a portion of a heat exchanger internal structure **400***b* having a first flow passage **402***b* and a second flow passage **404***b*. The first flow passage **402***b* is arranged at an end face **406***b* of the internal structure **400***b* and the second flow passage **404***b* is arranged downstream or behind the first flow passage **402***b* relative to a flow of a first fluid **408***b*. A second fluid may be directed through the first and second flow passage **402***b*, **404***b*, which may be normal to the flow direction of the first fluid **408***b* (i.e., in/out of the page of FIG. **4**B). The first flow passage **402***b* is an end face passage that extends through a flow director structure **410***b*, and the second flow passage **404***b* is an internal flow structure **412***b* arranged downstream from the flow director structure **410***b* with respect to the flow of the first fluid **408***b*. In this configuration, the flow director structure **410***b* has an apex **414***b* with flow control surfaces **416***b* that join at the apex **414***b*. The apex **414***b* and the flow control surfaces **416***b*, in this configuration, define a pointed geometry with the apex **414***b* providing a dividing surface to split an incoming flow of the first fluid **408***b* along the flow control surfaces **416***b*. The flow control surfaces **416***b* in this configuration are curved or bowed (convex) and thus define a curved surface along which the first fluid **408***b* may travel as it enters flow paths on opposite sides of the flow director structure **410***b*.

[0062] FIG. **4**C illustrates a portion of a heat exchanger internal structure **400***c* having a first flow passage **402***c* and a second flow passage **404***c*. The first flow passage **402***c* is arranged at an end face **406***c* of the internal structure **400***c* and the second flow passage **404***c* is arranged downstream or behind the first flow passage **402***c* relative to a flow of a first fluid **408***c*. A second fluid may be directed through the first and second flow passage **402***c*, **404***c*, which may be normal to the flow direction of the first fluid **408***c* (i.e., in/out of the page of FIG. **4**C). The first flow passage **402***c* is an end face passage that extends through a flow director structure **410***c*, and the second flow passage **404***c* is an internal flow structure **412***c* arranged downstream from the flow director structure **410***c* with respect to the flow of the first fluid **408***c*. In this configuration, the flow director structure **410***c* has an apex **414***c* with flow control surfaces **416***c* that join at the apex **414***c*. The apex **414***c* and the flow control surfaces **416***c*, in this configuration, define a substantially triangular geometry with the apex **414***c* being a pointed geometry that extends axially (in a direction of flow of the first fluid **408***c*) along substantially planar surfaces.

[0063] It will be appreciated that the geometries illustrated in FIGS. **4**A-**4**C are for example purposes, and other geometries and arrangements may be employed with out departing from the scope of the present disclosure. Furthermore, in some embodiments, a single heat exchanger internal structure may include multiple different types of geometries on the end face thereof. For example, triangular geometries may be used for mid-portion locations, whereas a curved geometry may be used close to walls of a manifold or the like (or vice versa), or other combinations may be used without departing from the scope of the present disclosure. Various other geometries may be used that are arranged to direct and/or scoop flow in a smooth manner to reduce stagnation and/or pressure losses. Furthermore, although shown with the flow director structure arranged at an inlet end of a flow path of a heat exchanger, it will be appreciated that similar structures may be provided at the outlet of such flow paths and/or at both the inlet and the outlet of such flow paths. When provided at the outlet, a smooth flow transition of the conditioned fluid mixing in an outlet manifold may be achieved.

[0064] Referring now to FIGS. **5**A-**5**B, schematic illustrations of a heat exchanger **500** in accordance with an embodiment of the present disclosure are shown. The heat exchanger **500** includes an internal structure **502** formed of internal fluid passages, such as shown and described above. A first set of fluid passages, within the internal structure **502**, extends in a fluid flow direction from a first inlet manifold **504** to a first outlet manifold **506**. A second set of fluid passages, within the internal structure **502**, extends in a fluid flow direction from a second inlet manifold **508** to a second outlet manifold **510**. As illustrated, the first set of fluid passages includes first inlet flow directors **512** arranged on a first inlet end face of the internal structure **502** within the first inlet manifold **504** and first outlet flow directors **514** arranged on a first outlet end face of the internal structure **502** within the first outlet manifold **506**. Similarly, the first set of fluid passages includes second inlet flow directors **516** arranged on a second inlet end face of the internal structure **502** within the second inlet manifold **508** and second outlet flow directors **518** arranged on a second outlet end face of the internal structure **502** within the second outlet manifold **510**. As shown, the flow directors **512**, **514** of the first set of fluid passages have different geometries, with the first inlet flow directors **512** having rounded or curved geometries whereas the first outlet flow directors **514** have triangular or pointed geometries. In contrast, as shown, the flow directors **516**, **518** of the second set of fluid passages have the same geometries (i.e., both rounded/curved). It will be appreciated that other configurations where all flow directors are the same or each is different from the other, or combinations thereof, may be employed without departing from the scope of the present disclosure.

[0065] Advantageously, embodiments of the present disclosure provide for improved heat exchangers with improved pressure loss controls. In accordance with some embodiments of the present disclosure, a modification is made to the inlet and/or outlet end faces of the heat exchanger to reduce component-level pressure losses while minimally impacting weight and heat transfer. Advantageously, with reduced pressure losses, a more aggressive core geometry can be used in the heat exchanger to increase overall heat rejection. The inlet and outlet losses can be substantial for small heat exchangers and the proposed geometry modifications can provide large performance benefits as compared to small heat exchangers that do not include such end face features. For example, in typical heat exchanger configurations, the end faces are flat and can cause fluid flow stagnation. The stagnation of the fluid causes increased pressure losses at the inlet and outlet, whereas embodiments of the present disclosure can reduce or eliminate such stagnation.

[0066] The use of the terms “a”, “an”, “the”, and similar references in the context of description (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or specifically contradicted by context. The modifier “about” used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (e.g., it includes the degree of error associated with measurement of the particular quantity). All ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other. As used herein, the terms “about” and “substantially” are intended to include the degree of error associated with measurement of the particular quantity based upon the equipment available at the time of filing the application. For example, the terms may include a range of ±8% of a given value or other percentage change as will be appreciated by those of skill in the art for the particular measurement and/or dimensions referred to herein.

[0067] While the present disclosure has been described in detail in connection with only a limited number of embodiments, it should be readily understood that the present disclosure is not limited to such disclosed embodiments. Rather, the present disclosure can be modified to incorporate any number of variations, alterations, substitutions, combinations, sub-combinations, or equivalent arrangements not heretofore described, but which are commensurate with the scope of the present disclosure. Additionally, while various embodiments of the present disclosure have been described, it is to be understood that aspects of the present disclosure may include only some of the described embodiments. Accordingly, the present disclosure is not to be seen as limited by the foregoing description but is only limited by the scope of the appended claims.

Claims

1. A heat exchanger comprising: a housing; an internal structure arranged within the housing, the internal structure defining a set of first fluid passages and a set of second fluid passages, wherein a first fluid within the set of first fluid passages is prevented from mixing with a second fluid in the set of second fluid passages; an inlet manifold at an inlet end of the set of first fluid passages and defining an inlet plenum for receiving the first fluid, wherein the set of first fluid passages comprise openings to the inlet plenum to receive the first fluid therethrough, wherein the openings of the set of first fluid passages are defined in an inlet end face of the internal structure; and a set of flow directors arranged on the inlet end face and configured to direct a flow of the first fluid into the openings of the set of first fluid passages, wherein each flow director defines an end face passage that is one of the second fluid passages of the set of second fluid passages.

2. The heat exchanger of claim 1, further comprising: an outlet manifold at an outlet end of the set of first fluid passages and defining an outlet plenum for receiving the first fluid, wherein the set of first fluid passages comprise outlet openings to the outlet plenum to direct the first fluid into the outlet plenum, wherein the outlet openings of the set of first fluid passages are defined in an outlet end face of the internal structure; and a set of outlet flow directors arranged on the outlet end face and configured to direct a flow of the first fluid into the outlet plenum, wherein each flow director defines an end face passage that is one of the second fluid passages of the set of second fluid passages.

3. The heat exchanger of claim 1, further comprising: an inlet manifold at an inlet end of the set of second fluid passages and defining a second inlet plenum for receiving the second fluid, wherein the set of second fluid passages comprise openings to the second inlet plenum to receive the second fluid therethrough, wherein the openings of the set of second fluid passages are defined in a second inlet end face of the internal structure; and a second set of flow directors arranged on the second inlet end face and configured to direct a flow of the second fluid into the openings of the set of second fluid passages, wherein each flow director defines an end face passage that is one of the first fluid passages of the set of first fluid passages.

4. The heat exchanger of claim 1, wherein each flow director comprises an apex and two flow control surfaces that extend from the apex to the internal structure.

5. The heat exchanger of claim 4, wherein the apex is rounded and the flow control surfaces are curved and convex as they extend to the internal structure.

6. The heat exchanger of claim 4, wherein the apex is pointed and the flow control surfaces are curved and convex as they extend to the internal structure.

7. The heat exchanger of claim 4, wherein the apex is pointed and the flow control surfaces are planar surfaces that extend to the internal structure to define a substantially triangular shape of the flow director.

8. The heat exchanger of claim 1, wherein the end face passage is similar in geometry to all other passages of the set of second fluid passages.

9. The heat exchanger of claim 1, wherein the set of first fluid passages and the set of second fluid passages are defined within an interwoven structure of the internal structure within the housing.

10. The heat exchanger of claim 1, wherein the first fluid is bleed air from an aircraft engine and the second fluid is RAM air from a RAM air duct of an aircraft.

11. A method of manufacturing a heat exchanger, the method comprising: providing a housing; arranging an internal structure within the housing, the internal structure defining a set of first fluid passages and a set of second fluid passages, wherein a first fluid within the set of first fluid passages is prevented from mixing with a second fluid in the set of second fluid passages; wherein the housing defines an inlet manifold at an inlet end of the set of first fluid passages and defining an inlet plenum for receiving the first fluid, wherein the set of first fluid passages comprise openings to the inlet plenum to receive the first fluid therethrough, wherein the openings of the set of first fluid passages are defined in an inlet end face of the internal structure; and forming a set of flow directors on the inlet end face and configured to direct a flow of the first fluid into the openings of the set of first fluid passages, wherein each flow director defines an end face passage that is one of the second fluid passages of the set of second fluid passages.

12. The method of claim 11, wherein an outlet manifold is defined by the housing at an outlet end of the set of first fluid passages and defining an outlet plenum for receiving the first fluid, wherein the set of first fluid passages comprise outlet openings to the outlet plenum to direct the first fluid into the outlet plenum, wherein the outlet openings of the set of first fluid passages are defined in an outlet end face of the internal structure; and forming a set of outlet flow directors on the outlet end face and configured to direct a flow of the first fluid into the outlet plenum, wherein each flow director defines an end face passage that is one of the second fluid passages of the set of second fluid passages.

13. The method of claim 11, wherein an inlet manifold is defined by the housing at an inlet end of the set of second fluid passages and defining a second inlet plenum for receiving the second fluid, wherein the set of second fluid passages comprise openings to the second inlet plenum to receive the second fluid therethrough, wherein the openings of the set of second fluid passages are defined in a second inlet end face of the internal structure; and forming a second set of flow directors on the second inlet end face and configured to direct a flow of the second fluid into the openings of the set of second fluid passages, wherein each flow director defines an end face passage that is one of the first fluid passages of the set of first fluid passages.

14. The method of claim 11, wherein each flow director comprises an apex and two flow control surfaces that extend from the apex to the internal structure.

15. The method of claim 14, wherein the apex is rounded and the flow control surfaces are curved and convex as they extend to the internal structure.

16. The method of claim 14, wherein the apex is pointed and the flow control surfaces are curved and convex as they extend to the internal structure.

17. The method of claim 14, wherein the apex is pointed and the flow control surfaces are planar surfaces that extend to the internal structure to define a substantially triangular shape of the flow director.

18. The method of claim 11, wherein the end face passage is similar in geometry to all other passages of the set of second fluid passages.

19. The method of claim 11, wherein the set of first fluid passages and the set of second fluid passages are defined within an interwoven structure of the internal structure within the housing.

20. The method of claim 11, wherein the housing and the internal structure are additively manufactured as a single structure.