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An Apparatus for Exchanging Heat with Flow in an Annulus

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Abstract

Present day heat exchangers might not effectively exchange heat with hot or cold fluid flowing through a constrained operational space, such as an annulus. For maximum heat recovery in gas turbine engines, a heat exchanger needs to be placed immediately after the exhaust turbine in the annulus of engine's exhaust system. In case of heat recovery in the family of shaft-powered aircraft engines, any additional component to the aircraft needs to be compact and should weigh less. An innovative design of a compact heat exchanger is presented in this paper. This heat exchanger is specifically designed to be used in applications (including gas turbine engines), where the hot or cold fluid (which act as a heat source or sink relative to the working fluid flowing through the heat exchanger), flows through an annulus. This paper, at a conceptual design phase, presents the construction, orientation for best efficiencies, solution to manufacture the complex geometry of the heat exchanger, and the materials that can be used in its fabrication.

Keywords: apparatus, heat exchanging, Annulus.

1. Introduction

In recent years, exhaust heat recovery in gas turbine engines, especially for ground-based gas turbine engines, by using Organic Rankine Cycle (ORC) is being implemented to develop useful work and therefore to produce electricity from it [1, 2]. ORC is similar to the steam cycle power plants used in power generation, except that the working fluid used in it, is an organic fluid such as a refrigerant [1-3]. Typically, heat recovery from exhaust gas of gas turbine engines is done outside the engine, as recovering heat in gas turbine engine's exhaust system becomes a difficult task. This recovery of exhaust gas heat is done in a special dedicated unit, which leads to loss in energy while the exhaust gas is transferred through a fluid conduit, from the exhaust turbine to the heat recovery system. On similar grounds, research on heat recovery in aircraft gas turbine engines has started gaining momentum, for improving the efficiency of flight or reducing fuel consumption [4, 5]. It is relatively difficult to recover exhaust heat from aircrafts which operate with thrust-powered engines (like turbofan and turbojet engines) than shaft-powered engines, because of sensitive balancing of loss in thrust with corresponding useful work production, accounting the weight of the recovery system added to the aircraft. In case of family of shaft-powered gas turbine engines (like turbo-prop, turboshaft, ground-based engines) majority of the useful work is developed as a mechanical work (shaft work), by the engine. So the exhaust gas velocity and exhaust gas temperature is lesser for shaft-powered gas turbine engines, as compared to the thrust-powered engines [6]. Therefore, potentially heat recovery (medium-grade) from exhaust gas can be done in the family of shaft-powered gas turbine engines. Shaft-powered gas turbine engines have exhaust system (after the exhaust turbine and before the exit) with relatively constant annulus area (and zero or less cylindrical draft angle) [7-9] than thrust-powered gas turbine engines [4, 10, 11]. For maximum heat recovery in shaft-powered gas turbine engines (ground-based and aircraft), a heat exchanger needs to be placed immediately after the exhaust turbine in the annulus of the engine's exhaust system. In case of heat recovery in the family of shaft-powered aircraft gas turbine engines, any additional component to the aircraft needs to be compact (and weigh less). Existing heat exchangers may not be able to effectively recover heat from the exhaust gas of shaft-powered gas turbine engines, flowing through a constrained operational space (annulus) of the engine exhaust system. This ineffectiveness can result from the shape, geometry, non-compactness, or operational orientation (of sub-systems) of the present day heat exchangers, to recover heat effectively from the exhaust gas flowing through the engine's exhaust annulus. This necessity of compact heat exchanger, which is to be used in a constrained operational space (annulus), is a motivation for this work.

2. Construction and Manufacturing

The apparatus described in this work can be called as annular finned-tube heat exchanger, where the author's intention is to describe a heat exchanger with finned-tubes arranged inside an annulus. It is not to be confused with 'annular-finned tube heat exchanger', where the fins on the tubes are annular in shape [12]. The collection of annular-finned tubes makes an 'annular-finned tube heat exchanger' [12]. In order to avoid any confusions in future, this apparatus will be referred as Annular-Shaped Heat

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Exchanger with Finned-Tubes (ASHEFT). The depiction in Fig. 1 is an isometric view of ASHEFT and Fig. 2 gives the multi-view of ASHEFT [1]. It is to be noted that in Fig. 2 the author, by purpose, ignores the hidden lines since ASHEFT has complicated construction and having hidden lines makes the views incomprehensible.

ASHEFT consists of a set of finned-tubes arranged in circular pattern within the annulus formed by two co-axial metal tubes/pipes/hollow cylinders [5]. It is to be noted that the metal tubes/pipes/hollow cylinders, can have respective draft (draft angle) where the application is inside a converging/diverging annulus. In this work, a simple form of zero draft angle on metal tubes/pipes/hollow cylinder will be discussed. For ease in manufacturing, the two co-axial metal tubes/pipes/hollow cylinders can be cut into two halves [5]. The annular region is maintained by providing rigid supports at specific locations along the circumference and the length of the two co-axial half metal tubes/pipes/hollow cylinders (after cutting) [5]. The rigid supports can be welded between the two co-axial half metal tubes/pipes/hollow cylinders (i.e. now two half annulus) or can be formed by using mechanical joints [5]. Within each of the half annulus formed (after cutting), finned-tubes are connected/welded along the length of two co-axial half metal tubes/pipes/hollow cylinders, with caps (tubes of U-shape to connect the adjacent finned-tube), in order to create 'flat zigzag coil' [13] flow arrangement, except at both ends of ASHEFT (for working fluid inlet and outlet) [5]. After the assembly of the finned tubes as described above, the two half annulus can be welded together [5]. The two ends of each set of 'flat zigzag coil' [13] finned-tubes arranged in circular pattern, are kept open to form a circular parallel-flow arrangement [5]. All the ends (on the radially outward/outer side) of the finned-tubes in circular arrangement at both ends of the now complete (after welding) annulus, are connected/welded to a fluid channel or tube (with tube for fluid inlet/outlet), of circular shape/geometry (i.e. not cross-section wise) to provide a circular parallel flow [5]. This way the ASHEFT is manufactured [5].

3. Details of Sub-Components and Materials for Fabrication

The ASHEFT can be composed of high grade carbon steel, stainless steel, copper, brass, aluminum or any other appropriate material [5]. The ASHEFT can be made uniformly with one material or it can be made of different materials for different sub-components in it [5]. This will be helpful in applications where 'weight' is a sensitive parameter (in case of aircrafts). The length of this heat exchanger depends on operational/design requirement. The fins on the tubes in an ASHEFT can be radial fins or any other efficient fin-type, and the cross-section of tubes can be circular or polygonal [5]. The fins on the tubes can have triangular, rectangular, concave parabolic or convex parabolic cross section [5]. The fins can be continuous spirally wound fins or helically wound fins, both may have corrugations on it [5]. The thickness of the fins and the number of fins depends on operational/design requirement [5]. The design procedure for ASHEFT is similar to a 'Finned Tube Heat Exchanger' (FTHE) [14]. In case of FTHE, the effective flow area is a rectangle. The diameter size and thickness of tubes, number of finned-tubes, number fins on tubes, and size, shape and type of fins is dependent on the effective flow area (rectangle) and the length. On the other hand, the effective flow area for ASHEFT is annular in shape. Therefore, for ASHEFT, the number of finned-tubes, the diameter and thickness of tubes, number fins on tubes, and size, shape and type of fins is dependent on the effective flow area (annular area) and the length. It is important to note that, the existence of fins on the tubes of the mentioned heat exchange depends on the mode of operation or application (considering the pressure constraint at exit of the flow through annulus).

4. Best Operational Orientation

ASHEFT primarily comprises of finned tubes, therefore it can be classified under 'regenerative-tubular-fin tube heat exchangers' class [5]. Such tubular heat exchanger when used in cross-counter flow orientation have higher effectiveness [15]. The heat source/sink fluid flows through annulus of the ASHEFT [5]. For heating the working fluid passing from the tubes of ASHEFT, the ASHEFT is oriented in such a way that its end (tube) which has the hot working fluid leaving it, faces the hot fluid stream of source fluid, while the end (tube) of ASHEFT which has cold working fluid entering it faces the cold fluid stream of source fluid [5]. This creates a cross-counter flow arrangement (combination of cross flow and counter flow) between the working fluid and the source fluid, making heat exchange effective [5]. Similarly, for cooling the working fluid passing from tubes of ASHEFT, the ASHEFT is oriented in such a way that its end (tube) which has the cold working fluid leaving it, faces the cold fluid stream of sink fluid, while the end (tube) of ASHEFT which has hot working fluid entering it faces the hot fluid stream of sink fluid [5]. This creates a cross-counter flow arrangement (combination of cross flow and counter flow) between the working fluid and the sink fluid, making heat exchange effective [5]. This orientation of the ASHEFT is the 'best and the most effective' way of carrying out the heat exchange process [5]

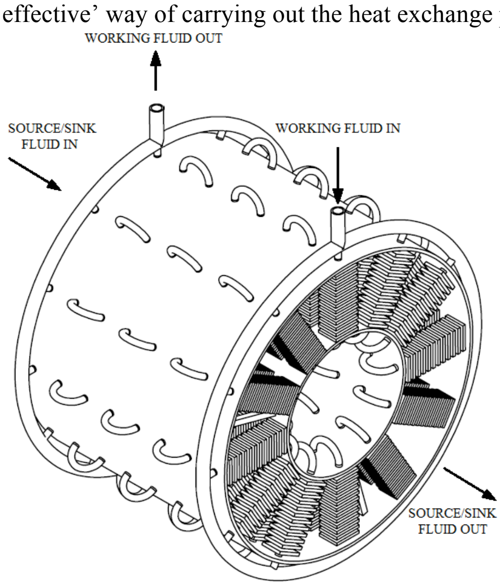

Fig. 1. Annular-Shaped Heat Exchanger with Finned-Tubes (Isometric view

[1] The heat exchanging apparatus described in this work is covered by the author's patent application in reference [5], and the readers are advised to not model/manufacture it, in any form, without the author's permission, to avoid patent infringement.

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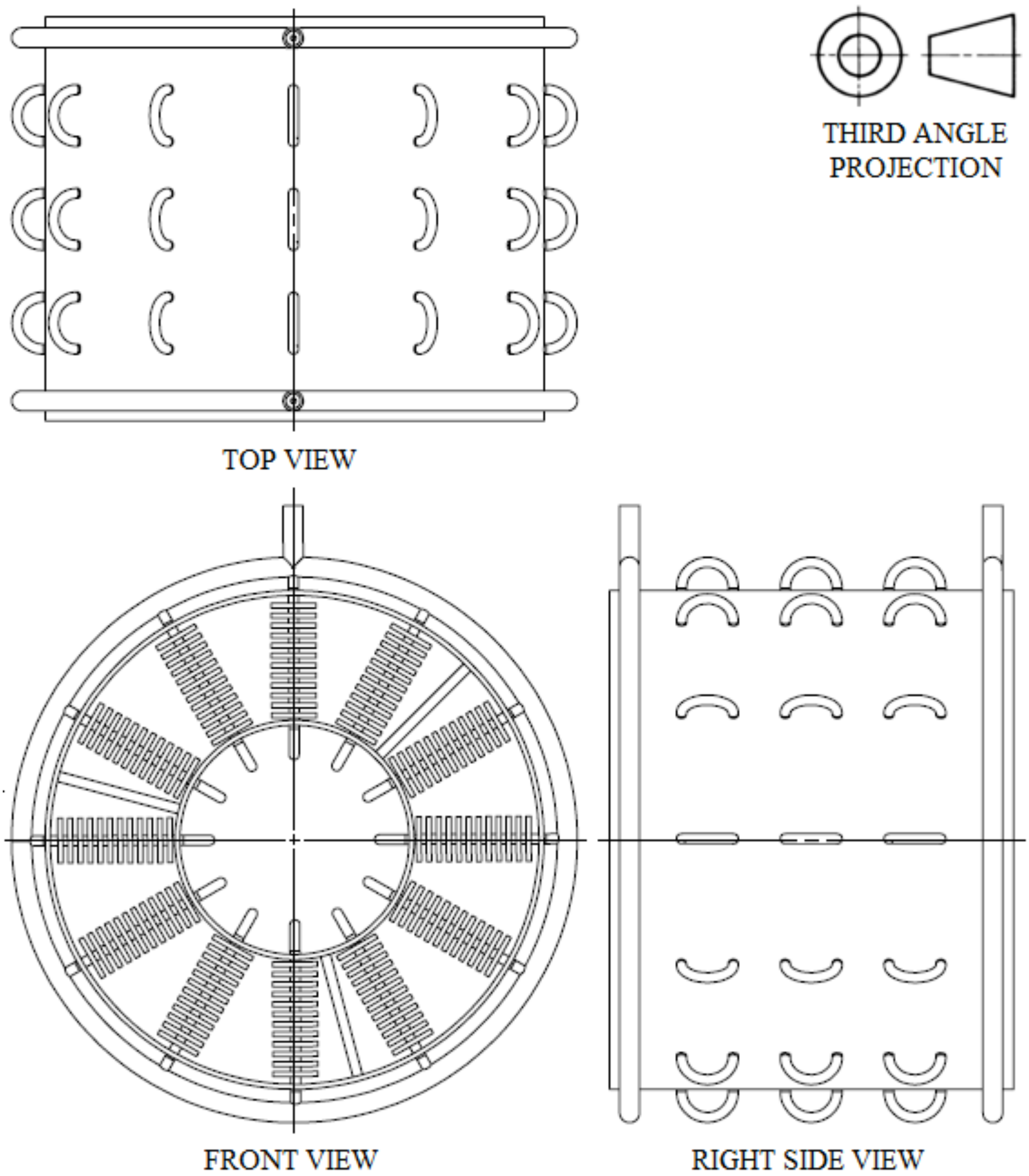

Fig. 2 Multi-views of Annular-Shaped Heat Exchanger with Finned-Tube

5. Conclusion

The heat exchanger described in this work, is novel in design and its geometry is based on space constraints, thereby making it compact. The functioning and design process of ASHEFT is similar to any type of finned tube heat exchanger, where the design process is dependent on custom requirement. A generic design process and thermodynamic performance, will be produced in a follow-up study as a full length paper. The advantages (and application) of this heat exchanger is that it can recover heat effectively from flow in annulus as it can fit inside the annulus due to its geometry. It is compact, effective and fits inside the annulus, therefore it can replace the conventional large and bulky heat exchangers, which are placed outside the annulus for heat recovery. Therefore, it prevents the loss of energy, while the exhaust gas is transferred through a fluid conduit, from the starting point of heat source (viz. downstream to the exhaust turbine in the exhaust system) to the heat recovery system, which helps to improve the efficiency of the overall system.

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