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Experimental investigation of the performance of an elbow-bend type heat exchanger with a water tube bank used as a heater or cooler in alpha-type Stirling machines

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ABSTRACT

In this work the effect of the elbow-bend geometry and the effect of the tube arrangement on the performance of air-to-water heat exchanger is studied experimentally. In elbow-bend heat exchanger, the direction of the working fluid is bended at 90 degrees to its inlet direction. The heating or cooling fluid flows inside straight tubes while the working fluid flows past the tubes along an elbow pass. Three different types of the geometry of the elbow with three different tube bank arrangements were studied. The results were plotted and analyzed to clarify the effects of the elbow-bend geometry, the tube bank arrangements and the dead volume in the heat exchanger on the heat transfer and pressure drop. Two empirical correlations were deduced for each design, one to predict the relation between Nusselt and Reynolds numbers, while the other relation is between the friction factor and Reynolds number. This work was done to select the more suitable design to be used as a heater or a cooler in Stirling machines.

1. Introduction

Stirling engines can be operated using various heat sources. Referring to the literature of Stirling engines, different designs of heat exchangers are found. Some of them are explained below. A small gamma-type Stirling engine was tested by Iwamoto et al. [1]. In this engine the heat exchangers are located around the displacer cylinder. The heater and the cooler are of the fine-tube type. Hot water flows in the heater tubes. Coolant water flows in the cooler tubes. The working gas flows around these tubes. Hoshino [2] used twelve electrical heaters attached to a gamma-type Stirling engine heater head. The working gas is heated through annular flow passages of a groove-type heater; each of them has 25 plate fins around a cylindrical heater. The cooler is of the shell-and-tube type, which has 322 tubes of 1 mm inner diameter. A heat input system which is composed of a heater and a burner as a newly devised heat exchanger in a Beta-type Stirling engine was designed and tested by Chang [3]. The heater likes a U-cup and it has slits which play the role of the heater tubes on the outer wall of the cup. A 200 W domestic free-piston Stirling electric power system with multi-fuel capability was designed by Biao et al. [4]. The engine was fitted with a fine heater and an annular shaped clearance regenerator. The cylinder head was provided with vertical fins. At operation, the hot gases flow along the vertical fins, and the heat was supplied to the helium working gas through these fins. A thermodynamic analysis of a Stirling engine including dead volumes of hot space, cold space and regenerator was carried out by Kongtragool and Wongwises [5]. The analysis indicated that the engine net work is affected by only the dead volume while the efficiency is affected by both the regenerator effectiveness and dead volume. The heat transfer characteristics and pressure drop of block-type heat exchangers were experimentally investigated by El-Ehawany et al. [6]. The experimental data were compared to get the most suitable block-type heat exchanger to be used as a cooler and a heater in Stirling machines. Generalized correlations of heat transfer and friction factor for air-side plain fin-and-tube heat exchangers were reported by Wang et al. [7], where 31 samples of fin-and-tube heat exchangers were used to develop the correlations. An experimental study to investigate the heat transfer and friction characteristics of fin-and-tube heat exchangers was carried out by Yan and Sheen. [8]. The results were presented as plots of friction factor and Colburn factor versus Reynolds number. Kim et al. [9] used a multiple regression technique to correlate the data of 47 sets of plain fin-and-tube heat

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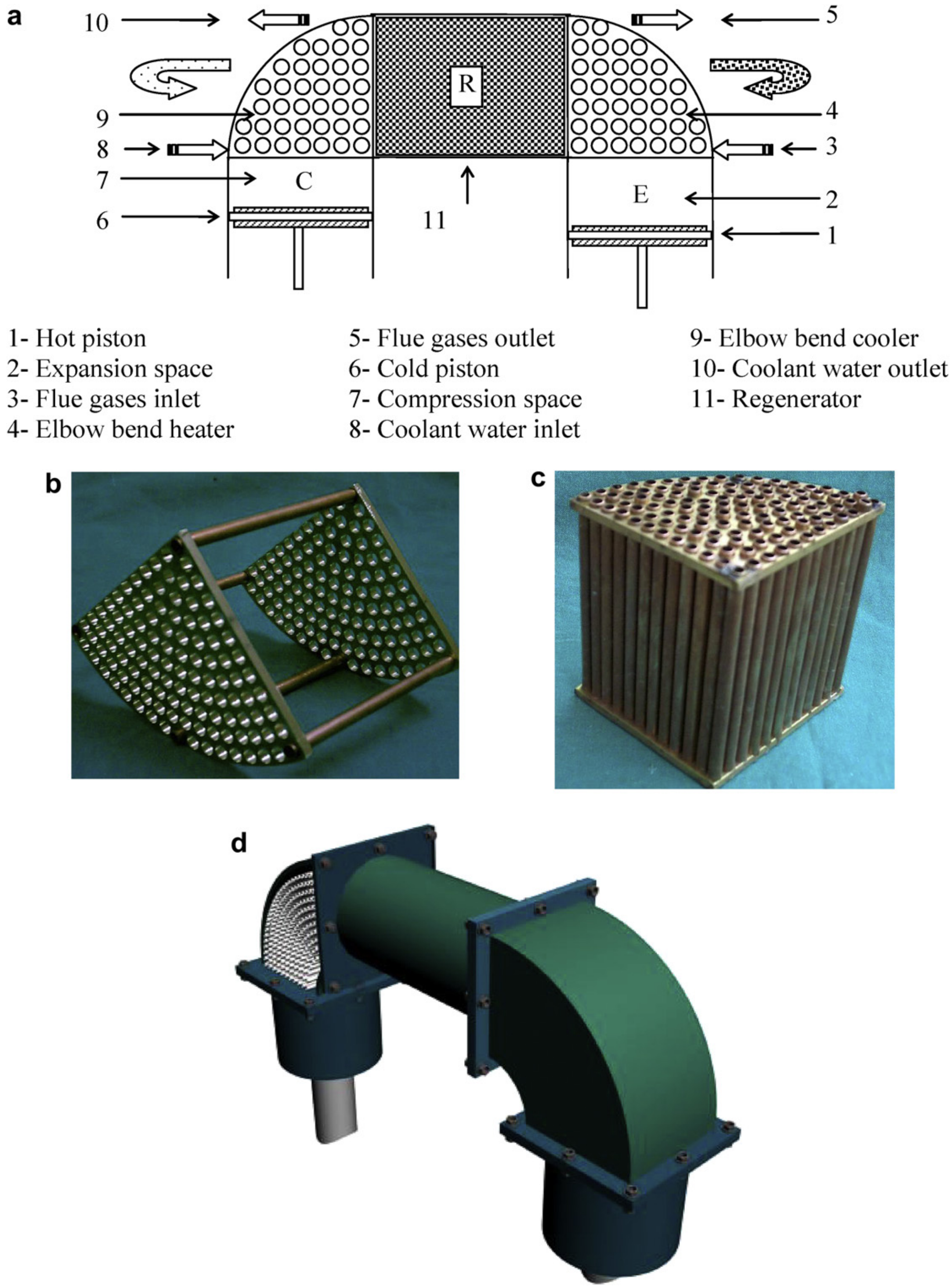

Fig. 1. a. Schematic diagram of the main parts of an alpha-type Stirling engine. b. Elbow-bend heat exchanger assembly. c. Elbow-bend heat exchanger. d. Isometric of the main parts of an alpha-type Stirling engine with elbow-bend heat exchangers.

exchangers with staggered tube arrangements to develop the heat transfer and friction correlations. The geometry and the dimensions of the heat exchangers have a strong influence on the performance of Stirling engines. Therefore, the processes in the heat exchangers should be carefully considered in the modeling of the engine processes. Modern second-order thermodynamic model was used to simulate Stirling cycle to calculate the heat transfer and pressure drop during the engine cycle, and as a consequence, the obtained information is in turn used to rectify the prediction of the engine performance as provided by Mahkamov and Ingham [10]. Moreover, recently, 2 and 3-dimensional CFD models have been developed for the modeling of the heat and mass transfer processes in heat exchangers of Stirling engines, which were considered as integral parts of the gas circuit as provided by Mahkamov [11,12]. The heat exchangers were also analyzed separately as given by Mahkamov and Ingham [13].