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Exergetic performance comparison of air and hydrogen gas flowing through the annular curved duct☆

A. Midilli, H. Kucuk, U. Akbulut*

Department of Mechanical Engineering, Faculty of Engineering, Recep Tayyip Erdogan University, 53100, Rize, Turkey

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The main objective of this study is to parametrically compare the exergetic performance of air and hydrogen gas flow through the curved annular duct. For this purpose, it is assumed that, i) air and hydrogen are considered to be ideal gas, ii) the flow of these gases is steady state and laminar fully developed, ii) these gases have constant physical properties, iii) the channel inner and outer walls are exposed to constant wall boundary condition. Moreover, the following important parameters are taken into consideration: i) aspect ratio (four different values which are 5.50, 3.80, 2.90 and 2.36), ii) environment temperature (ranging from −30 to 30 with 10 °C intervals), iii) Dean number (varying between 24 and 208), and iv) operating pressure (=1 atm). Considering these parameters, exergy destruction and exergy efficiencies are calculated for each aspect ratio. Consequently, exergetic efficiency rises with the increase of Dean number, inner wall temperature, aspect ratio and the decrease of dead state temperature. Also, it is noticed that the gas specie highly affects the volumetric entropy generation rate, exergy destruction rate and exergy efficiency.

Introduction

Heat transfer enhancement has become very crucial attempt for energy management in heat transfer equipment. Of the parameters affecting the heat transfer enhancement, curvature is an important for increasing the heat transfer in energy systems such as heat exchangers, nuclear and chemical reactors, gas turbines, drying machinery, solar collector applications, electronic cooling and fuel cells, etc. Curved annular channel applications may be limited because of manufacturing difficulties at the present time but near future the curved annular ducts may be preferred because of their contribution to efficiently and effectively heating and/or cooling processes in energy systems [1]. Curved channels characterized by the secondary flow created by centrifugal effects are generally used for heating and cooling applications because of high heat transfer rate [2]. While secondary flow enhances heat transfer it cause pressure drop in the cross-

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* *Corresponding author.*
E-mail addresses: amidilli@gmail.com (A. Midilli), haydar.kucuk@erdogan.edu.tr (H. Kucuk), ugur.akbulut@erdogan.edu.tr (U. Akbulut).

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section of the curved channel because of interaction between the centrifugal force, the pressure gradient and the viscous forces [2]. The nature of this phenomenon depends upon the Dean number, which is the ratio of the Reynolds number to the square root of the dimensionless radius of curvature [1]. It is known that the Dean number and radius ratio highly affect the friction factor and the Nusselt number in curved circular annular ducts [3–7]. Kucuk and Asan [3,4] numerically investigated fully developed laminar air flow under constant wall temperature boundary condition in concentric and eccentric curved annular square duct, respectively. They determined that viscous forces become more effective upon centrifugal forces while the annulus dimension ratio decreases. However, they found out that when the Dean number increases the centrifugal forces are more dominant than viscous forces. They point out that the heat transfer and friction factor are affected by curvature, annulus dimension ratio and core position. Also, they showed that the secondary flows resulting from centrifugal forces highly affect the distribution of the velocity and temperature fields.

Recently, within the scope of economic sustainability of hydrogen, researchers have focused on the efficiently and effectively production, distribution and utilization of hydrogen and its technologies. It is clear that air and hydrogen gases have been utilizing in some industrial and commercial applications such as fuel cells, gas turbines, hydrogen burners, internal combustion engines, etc. In these systems, air and hydrogen gases flow through the pipes and channels whose entropic effects should be considered. Considering the air and hydrogen will be a cost effective fuel and energy carrier in our daily life near future, it may be quite important to determine the thermodynamic behavior of air and hydrogen gases flowing throughout the pipes and channels whose shapes are different from each other. With the recent developments in industry, it is obvious that, in the near future, air and hydrogen will be used in double-pipe heat exchangers, air conditioning systems, cooling systems, and drying machineries in addition to the above applications. Particularly, for these engineering applications, the curved annular ducts may be preferred because of their contribution to efficiently and effectively heating and/or cooling processes in the energy systems [3–5,7–9]. In case air and hydrogen gases flow in the curved annular ducts, the flow types which are laminar and turbulent flows should be considered to determine and evaluate thermodynamic behavior of air and hydrogen gases under various operating temperatures and pressures. Especially, in order to characterize laminar flow of air and hydrogen gases in a concentric curved annular channel by the secondary flow created by centrifugal effects in the cross-section Dean Number should be taken into consideration [3,4]. Thus, in case of air or hydrogen flows in the ducts, the secondary flow motion in the flow field may enhance heat transfer to air or hydrogen gas from the heating element while it may induce pressure drops in flow field, which may be quite important contribution to improve air or hydrogen flow system for heating applications in the future.

Exergy is a thermodynamic quantity which allows us to obtain information on the useful work obtainable in a process and the analyses of irreversibility are important in the design and development of the productive processes for the economic growth [10–12]. Also, the entropy generation minimization technique is an important tool to designing optimal thermal systems and it uses the analysis of the associated irreversibilities measured by the entropy generation [13,14]. Entropy is generated during every irreversible process due to friction, finite temperature heat transfer and hysteresis effect etc [15]. Thus, second law analysis have been performed by many researchers for different processes and systems from a basic fluid flow to an integrated cycle in the literature [16–28].

Resulting a detailed literature review, it is noticed that many works have been mostly concentrated, and numerically and/or experimentally conducted on the heat transfer and fluid flow in curved annular duct with rectangular or circular cross section [3–9]. Second law analysis or entropy generation studies have been studied by many researchers in different shaped-channels in the literature [29–43]. Moreover, in our previous study we focused on entropy generation of both hydrodynamically and thermally fully developed laminar flow of hydrogen gas under various operating pressures and temperatures in concentric curved annular ducts with rectangular cross section [44]. Continuously, the main objective of this study is to parametrically compare the exergetic performance of air and hydrogen gas flows through the curved annular duct in terms of the second law of thermodynamics. For chosen different channel aspect ratios, the effects of Dean Number and dead state temperature on the exergy destruction rate and exergy efficiency have been investigated in detail. In terms of the scientific and industrial benefits, this study aims to provide the researchers and scientists some detailed comparison on exergetic performance of air and hydrogen flows in a concentric curved annular ducts with rectangular cross section due to the irreversibilities caused by fluid friction and heat transfer.

Modelling and analysis

The problem undertaken in this study is to compare the exergetic performance of air and hydrogen gas flows through the curved annular duct considering both hydrodynamically and thermally fully developed laminar flow. The curved duct geometry and coordinate system of the studied problem is illustrated in Fig. 1.

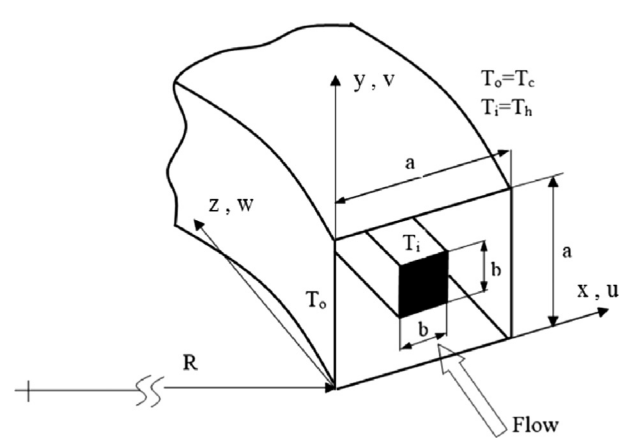

Fig. 1 – Curved duct geometry and coordinate system.