UNIVERSITY OF SOUTHERN QUEENSLAND

Inducing Swirl Flow within Stationary Cylindrical Split Channel

A dissertation submitted by

SAFIA R. AL-ATRESH

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Faculty of Health, Engineering and Sciences

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Abstract

There are many free sources of energy around the globe. By investing in them, the world can reduce its dependence on fossil fuels and improve the quality of the environment. Waste heat is considered a hidden energy source and waste heat recovery creates a green energy source with low cost. In addition, natural thermal energy, such as geothermal and solar energy, is a low-cost sustainable heat source with large amounts emitted and produced annually. The stationary cylindrical split channel (where the cylinder is sliced in half along the axis and the two c-shaped halves are translated laterally), commonly used to induce a fire-whirl in the laboratory, is one device that can utilise these heat sources. This research investigates inducing swirl flow within a stationary cylindrical split channel with two identical slots (without using moving parts) using a hot air flow inlet at its base. The objectives of this research are: Firstly, to examine the generation of swirl flow in the split channel when the used heat source is a hot air flow inlet instead of fire. Secondly, to study the effect of possible design parameters on specific variables, including the conversion efficiency of thermal energy to kinetic energy, to determine some possible applications of the new, naturally-induced swirl generator.

This research was divided into experimental and computational components to accomplish the above objectives. First, a preliminary experiment using a fog machine was conducted to visualise the swirl smoke. This was followed by measurements of the generation of the swirl flow using a two-dimensional Particle Image Velocimetry system (2D PIV system). Olive oil particles were used as seeds and to collect the required measurements of velocity components for subsequent validation of the computational fluid dynamics (CFD) results. The scaling analysis was conducted to present the experimental and computational results in normalized form, and to investigate the scaling effect on the turbulence of the swirl flow. Moreover, thermocouples were used to measure the instantaneous temperatures. Second, the computational study was used to solve the continuity, momentum and energy equations in a steady-state condition, using the ANSYS 13.0-CFX software. The Shear Stress Transport model was used for the turbulence. Thermal radiation and heat transfer to the channel walls were ignored. The channel walls and the base of the domain were assumed to be smooth and non-slippery walls. All sides of the cubic domain, representing the surrounding air (with the exception of the bottom), were assumed to be open with an initial wind speed of zero. The ambient temperature was constant. The pressure boundary condition on the sides and top of the cubic domain was set to atmospheric pressure, which decreases with the height. The thermal properties of air changed with temperature and the transport properties were also functions of temperature, using the Sutherland formulas.

To prove the existence of swirl flow, both fog machine visualization and 2D PIV visualisation and measurements were used. The cylindrical split channel used throughout the experimental investigation had a height of 0.25 m and an internal diameter of 0.095 m. Furthermore, the diameter of the inlet at the base of the split channel was 0.03 m, the width of gap (the translation distance along the split) was 0.0115 m, and the depth of gap (the translation distance normal to the split, creating an overlap) was 0.01 m. The PIV measurements were taken for tangential and radial velocities at three different heights within the channel (33.5 mm, 125 mm and 240 mm), while the axial velocity component was measured for a plane including the centreline of the channel.

A three-dimensional CFD model of the swirl flow produced within the current experimental work was validated by the current PIV measurements. A parametric study was then conducted where design parameters such as the inlet temperature and pressure, all geometric quantities (all the sizes of the channel, holes and gaps) and the number of gaps were varied. The effects of these variations on the normalized centreline axial velocity, normalized centreline temperature, normalized centreline axial vorticity, normalized inlet and exit axial velocities, normalized inlet mass flow rate, entrainment ratio and conversion efficiency of thermal energy at the inlet to kinetic energy along the split channel were investigated. This parametric study was conducted on a cylindrical split channel having dimensions similar to Kuwana's channel (Kuwana, Morishita, Dobashi, Chuah & Saito, 2011, Proceedings of the Combustion Institute, vol. 33, pp. 2425–2432). In this study, when one parameter was varied, the remainder were maintained constant.

The results from the smoke and PIV visualisation showed that a swirl flow was generated within the cylindrical split channel. The validation of the CFD showed that average relative deviations were 17.7% and 55.3% for the tangential and radial velocities at a height of 32 mm, while it was 49.56% for the axial velocity. The shapes of the profiles for each velocity component were reproduced by the CFD, but the large relative error in the radial velocity is due to its small magnitude, while the error in the axial velocity is due to an inability to predict the large increase and rapid decrease immediately downstream of the inlet. The scaling analysis produced 16 dimensionless groups representing the characteristic of the generated swirl flow. The parametric study for the channel similar to Kuwana's channel showed that several reported variables affected the conversion efficiency of thermal energy to kinetic energy (η). The inlet temperature, pressure and diameter, the size of the gap (in both directions) and number of gaps are the major variables for designing a split channel for power production because η increases with their increase. In addition, many variables affect the entrainment ratio and inlet mass flow rate, and high values of inlet temperature, gap width and using two gaps (instead of one) are the major variables for building a split chimney for dilution purposes. The inlet temperature, pressure and diameter, the size of the gap (in both directions) and number of gaps are the major variables for the design of a split channel as a fuel saver for an automobile.

Certification of Dissertation

I certify that the ideas, experimental work, results, analysis, and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any award, except where otherwise acknowledged.

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Signature of candidate Date
Safia Ramadan Al Atresh

ENDORSEMENT

………………………………… / /2014

Signature of supervisor/s Date

………………………………… / /2014

Signature of supervisor/s Date

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Safia R. Al-Atresh
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Associated Publications

Refereed Conference Proceedings

1. Al-Atresh, SR, Sharifian, SA & Kueger, B 2012, 'Using a Split Chimney for Dilution of Exhaust Pollution: A CFD Approach', in International Conference on Fluid Dynamics and Thermodynamics Technologies: *proceedings of the International Conference on Fluid Dynamics and Thermodynamics Technologies*, Z Ni (ed.), IACSIT Press, Singapore, pp. 156-61.

2. Al-Atresh, S, Sharifian, A & Al-Faruk, A 2012, 'The effect of inlet velocity and temperature on the strength of the swirling induced by a spilt channel: A CFD approach', in Proceedings of the 18th Australasian Fluid Mechanics Conference: *the Proceedings of the 18th Australasian Fluid Mechanics Conference*, PA Brandner & BW Pearce (eds.), Australasian Fluid Mechanics Society, Australia.

3. Al-Faruk, A, Sharifian, A & Al-Atresh, S 2012, 'Numerical Investigation of Performance of a New Type of Savonius Turbine', in Proceedings of the 18th Australasian Fluid Mechanics Conference: *the Proceedings of the 18th Australasian Fluid Mechanics Conference*, PA Brandner & BW Pearce (eds.), Australasian Fluid Mechanics Society, Australia.

Journal Papers

4. Al-Atresh, SR, Sharifian, AS & Wandel, AP 2014, 'The Effect of the Width and Number of Gaps on the Characteristic of Swirl Flow Induced Naturally Inside Split Channel Using Hot Air Inlet', *International Journal of Materials, Mechanics and Manufacturing*, vol. 2, no. 4, pp. 339-44.

5. Sharifian, AS & Al-Atresh, SR 2014, 'Characteristics of flow in cylindrical split channels and assessment of constant thermal properties model on computational time and accuracy ', *Journal of Applied Fluid Mechanics*, accepted

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