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Radiation heat transfer between the externally heated surface and the regenerator of the thermoacoustic engine

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Abstract

The SCORE thermoacoustic engine (TAE) depends of an external heat source from the waste heat of wood burning stove or propane gas. The overall efficiency of TAE depends a lot on the efficiency of the heat transfer process from the cooking stove to the regenerator. It is important to supply most of the heat to the engine directly to the regenerator top surface for best performance of the engine. The combined and complex mode of heat transfer from the cooking stove to the engine makes this task extremely difficult to be achieved. In this work analytical calculations are used to calculate from the fundamentals the radiation heat transfer from two types of heat exchangers used by the SCORE project to transfer heat from the external heat source to the engine. The objective of this study is to understand and evaluate the proportions of heat transferred from the inner side of the external hot surface to the engine. A detailed analysis of the view factors, the surface and space resistances were conducted to calculate the radiation heat transfer in each case at different temperatures. The results obtained showed the actual radiation performance of each part of the convolution and the bulge. Although the convolution performed better in terms of the total heat transfer, but the bulge showed higher radiation. The analytical results were compared with the published numerical results.

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Keywords: Heat transfer; Radiation; Thermoacoustic; Regenerator; Bulge; Convolution.

1. Introduction

Thermoacoustic engine (TAE) is a kind of device to realize the conversion between heat and sound energy. When a compressible fluid is rapidly exposed to a localized heat flux at a solid wall, part of the fluid in the immediate vicinity of the wall expands. This gives rise to a fast increase in the local pressure, and leads to the production of pressure waves, which are called thermoacoustic waves [1-3]. Advantages of thermoacoustic devices include environmental friendliness, no moving parts and reasonable efficiency.

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SCORE, one of the leading thermoacoustic research projects has designed engines powered by the waste heat from cooking stoves [4]. The main concern about the designed SCORE engine is the thermal interaction between the bulge (or convolution) and the regenerator. The present work is a contribution to the study of the temperature field and radiative heat flux distribution generated in the engine analytically, the complete study of the total heat flow will be done on the next stage of this research and is not discussed in full details in this work. With an objective to improve the performance of the current SCORE engine. Radiative heat transfer has been deemed to be of particular importance in the engine which is expected to have direct effect on the performance of the engine. This work discusses some important issues to be taken into consideration in order to maximize the amount of heat transfer to the top layer of the regenerator while minimizing the intrinsic losses. The results obtained were compared with the published numerical results and an agreement was found [4].

2. The challenge of heat transfer from the heating surface to the HHX in the SCORE TAE

In idealized thermoacoustic engine, heat is supplied to the engine directly at the top layer of the regenerator, which is called the hot heat exchanger (HHX), and removed at the other side of the regenerator at the cold or ambient heat exchanger (AHX). An important feature to notice is that heat is supplied to the oscillating air inside the loop of the engine at a very short length as it is crossing through the HHX. In this configuration heat is transferred from the HHX to the air mainly by conduction through the small gaps which are smaller than the thermal penetration depth. For an externally heated thermoacoustic engine it is difficult to design for the oscillating air to cross through the HHX. The external heat source in the SCORE project is burning wood or propane gas, which is difficult to accommodate inside the engine, the alternative is either to use a bulge or a convolution in an alternative arrangement that may differ from the original concept illustrated above to transfer heat from the bulge or the convolution to the regenerator as depicted in figure (1).

For this investigation the bulge and convolution dimensions are constructed in such a way that they possess the same volume which is 0.00123 m^3 (based on real measurement of Demo 2.1 SCORE TAE) but their effective surface area is different. The bulge has 0.0424 m^2 effective surface area whereas the convolution has a surface area of 0.231 m^2. The regenerator dimensions for both the bulge and convolution are the same; each of 200 mm length, 200 mm width and 10 mm thickness.

3. View factor calculations for the convolution and the regenerator integrity

The view factor (configuration factor) for diffuse surfaces is a pure geometrical property and has nothing to do with the surface emissivity. The view factor F_{12} is defined as the fraction of the radiation leaving surface 1 that will reach surface 2. A simple analysis can be done by dividing the convolution channel into smaller sections A, B, and C. Two virtual planes 2 and 4 which have flat surfaces are created as shown in figure (1). The calculations are performed with the aid of the view factor formulas [5].

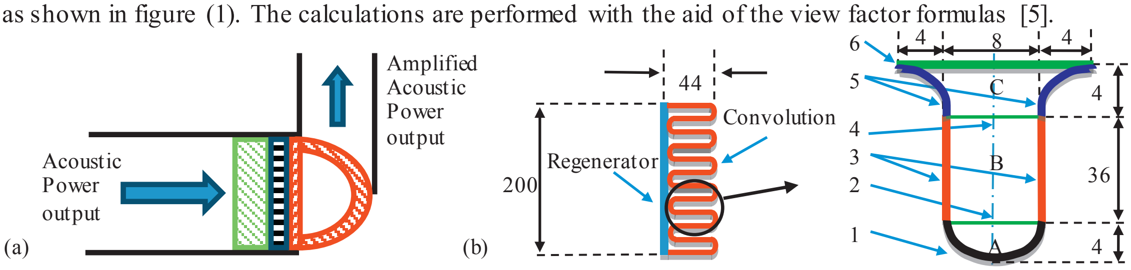


Fig. 1: (a) External heating of the thermoacoustic engine through Bulge; (b) Divisions of one convolution element for the view factor calculations (all the dimensions are shown in mm, not to scale).

By neglecting the radiation between surface 1 and 5, the radiation resistance network can be produced. The surface resistance of any surface is given by $R_i = (1-\varepsilon_i)/(A_i-\varepsilon_i)$ and the space resistance between any two surfaces is given by $R_{ij} = 1/(A_iF_{ij})$, stainless steel emissivity ε can be taken as 0.78. The list of the view factors, the surfaces resistances and the space resistances are illustrated in table (1) below:

Table 1: Summary of radiation parameters of the convolution sections.

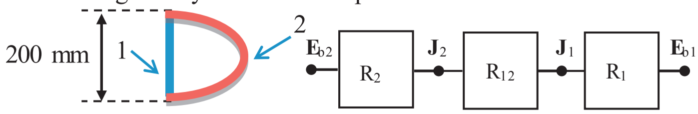
View factors	-
F13	0.576
F16	0.0493
F36	0.0815
F53	0.107
F56	0.754

Space Resistance	K/W
R13	691
R16	8075
R36	959
R53	3720
R56	528

Surface Resistance	K/W
R1	70.3
R3	13.8
R5	70.3
R6	34.7

3.1 The radiation analysis for the bulge

The bulge analysis is less complicated because it consists of only two surfaces as shown in figure (2).



Thermal resistance	R_1	R_2	R_{12}	R_{total}
K/W	4	7	25	37

(a) (b) (c)

Fig. 2: (a) Radiation heat transfer between the bulge (1) and the regenerator (2); (b) Radiation thermal resistance network between the bulge and the regenerator; (c) Surface and space resistance of the bulge and the regenerator.

4. Results and analysis

The comparison of the convolution radiation to the regenerator surface and the bulge radiation to the regenerator surface indicate that the bulge is radiating more heat at the same temperature. The amount of heat radiated from the bulge is found to be around three times the amount of heat radiated from the convolution at the same temperature conditions. Figure (3) shows the radiation heat transfer from the convolution and from the bulge to the regenerator. The bulge has a deeper volume resulting in bigger distance between the hot surface of the bulge and the regenerator, this feature may result in reducing the effect of having the hot surface of the bulge inside the engine as the air is oscillating away from this surface in comparison to the convolution in which the air is oscillating inside the convolution as it is representing part of the HHX. A CFD simulation for the two cases was conducted as a separate study including different types of the shapes for the heat exchanger [4]. It is found that the results obtained by the CFD simulation and the analytical calculations are in good agreement. As an extension to this investigation an engine operating with a convolution heat exchanger will be equipped with a bulge instead of the convolution to verify and validate the conclusions of this study.

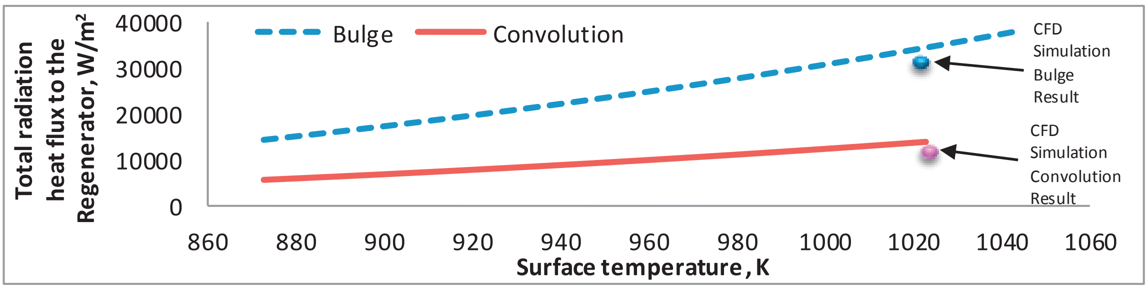


Fig. 3: Radiation heat transfer from the convolution and from the bulge to the regenerator, with the comparison to the CFD simulation results.

6. Conclusion

An analytical approach was taken to study the radiation heat transfer between the convolution (or the bulge) and the regenerator, the results obtained revealed that the bulge is better in radiation heat transfer compared to the convolution. Convection need to be reduced to improve the performance of the thermoacoustic engine. Despite the CFD results agree with the analytical results, an experimental investigation is advised to validate against the actual performance of the HHX and the regenerator integrity. However, the convolution and the bulge were considered as isothermal surfaces, assuming that they are made from good conducting material. Other modes of heat transfer should also be considered.

Acknowledgements

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References

[1] Syeda Humaira Tasnim, Shohel Mahmud, Roydon Andrew Fraser. Measurements of thermal field at stack extremities of a standing wave thermoacoustic heat pump. *Frontiers in Heat and Mass Transfer* 2011;**2**;1-10.

[2] Yufeng Huang, Haim H. Bau. Thermoacoustic waves in a confined medium. *International Journal Heat and Mass Transfer* 1997;**40**;407-419.

[3] Bakhtier Farouk, Elaine S. Oran, Toru Fusegi. Numerical study of thermoacoustic waves in an enclosure. *Physics of Fluids* 2000;**12**;1052-1061.

[4] David K. W. Yang, Yousif A. Abakr, Normah M. Ghazali. CFD investigation of the heat transfer between an external heat source and the regenerator of a thermoacoustic engine. *Elsevier Procedia Engineerring* 2013;**56**;842-848.

[5] Yunus A. Cengel. Heat and Mass Transfer: A practical approach. *The McGraw-Hill companies* 2006.

Biography

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