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Investigating the Fluid-Solid Interaction in Incompressible Flow and The Effect of Oscillation Amplitude on Heat Transfer

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ABSTRACT: In this study, the effect of fluid-solid interaction on forced convection flow in a channel with the two-dimensional incompressible fluid flow is investigated. One surface can exchange heat and the other is elastic and insulated. As the fluid flows through the hot and oscillating elastic surfaces, the rate of heat transfer to the fluid varies. In this case, the heat exchange rate behaves as a function of the conditions of the oscillating elastic surface, one of the factors affecting the heat exchange is the vibration amplitude of the elastic surface. Therefore, the aim of the simulation is to investigate the application of the replacement of the elastic boundary with the rigid boundary in a part of the channel and the effect of the maximum size of the amplitude of vibration of the vibrating elastic surface on the heat transfer rate. It was found that the average Nusselt number and the average temperature of the air leaving the channel increase with the replacement of the elastic surface with a part of the rigid channel boundary. Also, with increasing the maximum amplitude of oscillation wall vibration, the Naselt number, the average temperature of the output fluid, and the rate of heat transfer from the constant temperature level to the operating fluid increases..

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1- Introduction

Different approaches have been proposed to enhance the heat transfer rate, one of the newest of which is using elastic vibration surfaces. The review of previous studies showed that theoretically and from a simulation view, the issues of heat transfer in Fluid-Solid Interaction (FSI) flows have been under-evaluated. Moreover, FSI in industry, including heat exchangers, has many applications. Thus, by considering the fluid and channel flow with an oscillating elastic surface, one can examine the effect of elastic surface vibration on heat transfer rate in different geometric compositions. In this study, a duct with solid and elastic surfaces is considered to be a solid surface where the solid surface is associated with heat transfer and the oscillating elastic surface is insulated. The study tried the effect of elasticity and maximum vibration amplitude of the surface on the rate of heat transfer considering the elastic surface and the development of this design. Reference [1-4] studied the effect of surface and elastic blades on heat transfer. In most of the studies, the elastic surface under the force of the moving operating fluid begins to oscillate freely and the elastic surface under free vibration affects the flow. In such cases, Young's modulus is the main factor in the surface oscillation. Nonetheless, the present study considered the forced sinusoidal vibration at a frequency of 1Hz and various amplitudes for the elastic surface, and the effect of the maximum oscillation amplitude on the current, which is less studied.

2- Physical and Mathematical Models

Fig. 1 shows the geometry diagram examined where the part of the rigid wall of the upper canal insulation has been replaced with an elastic wall. In this case, fluid is the air agent entering the two-dimensional channel with the velocity profile developed with Reynolds number 100. The lower surface of this channel is kept constant at a temperature of 343.15 K and the upper surface of this channel is insulated. The average inlet flow temperature is 293.15 K. The length of the replaced elastic surface is 8 cm and its thickness is 1 mm and its Young modulus is 50 MPa. This level with a frequency of 1 Hz in four amplitudes of 1.3 cm, 1.0, 0.7, and 0.4 is subjected to forced vibration.

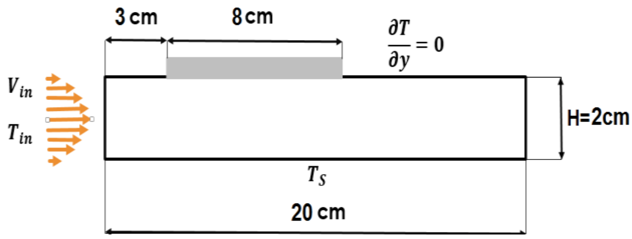

Fig. 1. . Elastic channel scheme

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The study considered slow, two-dimensional, unstable, and incompressible flow, accompanied by forced convection heat transfer, and the effect of gravitational force is ignored [5].

$$\nabla . V = 0 \quad (1)$$

$$\frac{\partial V}{\partial t} + \left(V - \mathbf{V}^{ms}\right).\nabla \mathrm{V} = -\frac{1}{\rho_f}\nabla p + \upsilon_f \nabla^2 V$$

$$\frac{\partial T}{\partial t} + \left(V - \mathbf{V}^{ms}\right).\nabla \mathrm{T} = \alpha_f \nabla^2 T \quad (1)$$

$$\rho_s . \frac{\partial^2 \boldsymbol{d_s}}{\partial t^2} = \nabla . \sigma_s + F_s$$

At the above equations, t is the time, v the kinematic viscosity, α the diffusion coefficient, p the density, ds the elastic surface displacement, σ_s the stress tensor, and Fs external force.

Moreover, in solving FSI equations, the two boundary conditions shown in Eq. (8) must be established, which is the condition for the displacement and stress matching: [5]

$$\frac{\partial \boldsymbol{d_s}}{\partial t} = V \quad , \quad \sigma_s . n = -p + \mu_f \nabla V \quad (2)$$

3- Results and Discussion

First, the rigid channel (without elastic surface) is solved and the average Nusselt number and the coefficient of friction of the surface are examined to ensure the accuracy of the results. The results show a difference of 5.3 and 5.4%, respectively.

The results remain constant for a period of about 7 seconds in 1 second. Thus, the desired parameters such as the Nusselt number of the mean instantaneous moment after 8 seconds and the stability of the answers in a periodicity are averaged and the Nusselt number is obtained as the overall average, which is compared with the Nusselt number of the average instantaneous channel stiffness.

The flow lines become out of uniform and vortices are created along the channel, the findings indicated that with the oscillation of the elastic wall. Indeed, by fluctuating the elastic surface and increasing the cross-sectional area of the channel, the fluid moves near the elastic wall under the oscillator and reduces the pressure in the elastic surface range, and causes the fluid to flow to the desired range with relatively high pressure upstream and downstream. This factor causes the vortices revealed. On the other hand, by decreasing oscillation cross section, the flow velocity increases, and the number of vortices increase. Hence, with the increase in the maximum amplitude of the oscillation, the strength and number of vortices increase and the current is more affected by the oscillation of the elastic surface, changing the flow velocity throughout the channel.

Indeed, with the oscillation of the elastic surface, the cross-sectional area of the continuous channel changes and causes the pressure along the continuous channel to decrease and increase, which causes a return flow and the formation of a vortex along the channel. Thus, with increasing vibrational amplitude, the pressure gradient increases and causes strong vortices.

With the vibration of the oscillator, the operating fluid due to the formation of vortices and return flow, besides the longitudinal motion, has transverse motion in the channel. Hence, with an increase in the oscillation amplitude of the fluid, it is more affected and the thickness of the temperature boundary layer changes more. Additionally, it is affected by increasing the oscillation amplitude of the downstream fluid, which results in an increase in the heat transferred to the downstream fluid.

Furthermore, to understand the results of replacing the elastic surface instead of the rigid surface better, besides the Nusselt number, the average temperature at the channel output surface for the rigid and elastic channel in the mentioned oscillating amplitudes has been calculated relative to the rigid channel.

Ultimately, the parameters of the average Nusselt number and the average temperature of the channel output surface in a fixed time interval of 8 to 9 seconds are stabilized and the results are mediated in the table to summarize the rate of improvement of heat transfer in the channel with fluctuating elastic surface relative to the rigid surface and given in Table 1 for comparison. Additionally, the change of the studied parameters in the elastic channel differs from oscillation ranges compared to the rigid channel results is given in this table. For instance, with the vibration of the elastic surface under the conditions mentioned in the range of 1.3, the Nusselt average increases by 4.4%, and the average output temperature increases by 0.6% compared to the rigid channel, which indicates an increase in heat transfer.

Table 3. Mean Nusselt number and mean temperature at the outlet section in a rigid channel with an elastic channel in different amplitude

	A=0 cm	*A*=0.4 cm	*A*=0.7 cm	*A*=1.0 cm	*A*=1/3 cm
Tave[K]	322.91	322.49 (-0.1%)	322.87 (-0.01%)	323.88 (+0.3%)	324.92 (+0.6%)
NUave	4.58	4.58 (0.0%)	4.60 (+0.45%)	4.67 (+2.0%)	4.78 (4.4%)

4- Conclusions

The fluctuation of the elastic surface causes the flow lines opposite the rigid channel to be non-uniform and changes at every moment and eddies with various powers are created along the channel.

Creating vortices caused by the oscillation of the elastic surface causes more interference with the flow thus increasing the rate of heat transferred from the surface to the flow. This value increases continuously with the maximum increase of the range.

Given the direction of flow shown in the velocity profiles along the channel and the oblique nature of the flow lines, descaling of the surfaces can be stated as one of the advantages of replacing the elastic surface in the rigid channel.

References

[1] S.M.H. Zadeh, S. Mehryan, E. Izadpanahi, M. Ghalambaz, Impacts of the flexibility of a thin heater plate on the natural convection heat transfer, International Journal of Thermal Sciences, 145 (2019) 106001.

[2] X. Sun, Z. Ye, J. Li, K. Wen, H. Tian, Forced convection heat transfer from a circular cylinder with a flexible fin, International Journal of Heat and Mass Transfer, 128 (2019) 319-334.

[3] M.A. Ismael, Forced convection in partially compliant channel with two alternated baffles, International Journal of Heat and Mass Transfer, 142 (2019) 118455.

[4] F. Selimefendigil, H.F. Öztop, Forced convection in a branching channel with partly elastic walls and inner L-shaped conductive obstacle under the influence of magnetic field, International Journal of Heat and Mass Transfer, 144 (2019) 118598.

[5] M. Ghalambaz, E. Jamesahar, M.A. Ismael, A.J. Chamkha, Fluid-structure interaction study of natural convection heat transfer over a flexible oscillating fin in a square cavity, International Journal of Thermal Sciences, 111 (2017) 256-273.

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