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Numerical Analysis of effect of fluid-structure interaction on Heat Transfer in square cavity using openFOAM

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The present study discuss about the effect of FSI (fluid-structure interaction) in a square cavity with top wall oscillating i.e. sinusoidal variation of velocity of top wall. Due to this varying motion of top plate, fin (flexible fin) start moving in the transverse direction of the fin length and due to flexible plate motion, fluid motion get disturbed because of this it will increase or decrease the heat transfer of the hot wall. For checking the effect of fin, flexible plate is set on left, right and bottom wall and all these three walls are hot.

***Keywords*:** FSI, sinusoidal, flexible fin.

1. Introduction

In a lid driven cavity heat transfer is mainly due to air circulation by moving wall and to increase the heat transfer rate of heated wall is a matter of concern and also it also have some engineering application i.e. cooling of micro-electronic devices, flat-plate solar collectors, cooling of electrical component. For increasing the heat transfer rate flexible flap has used and related to this some literatures are also there i.e. [1] Abdalla Al-Amiri et.al. studied the fluid-structure interaction of mixed convection heat transfer with flexible bottom in a lid driven cavity, it said that with respect to bottom rigid wall flexible bottom is having higher heat transfer rate.

Flow-induced deformation of a flexible thin structure as demonstration of increase in heat transfer, investigated by Atul Kumar Soti et.al [2] concluded that cylinder with flexible flap having highest heat transfer rate as compared to cylinder with no flap and cylinder with rigid flap is having least heat transfer because it reduces the vortex shedding. [3] Sameer Ali et.al investigated the heat transfer and mixing enhancement by free elastic flap oscillation found that flow through channel with rigid flap is having less transfer rate with respect to flexible flap.

2. Methodology

For numerical simulation we used C++ base open source platform (openFOAM) with the help of modified Finite Volume Method base fsiFoam solver which is PIMPLE based algorithm. Unsteady Navier-Stokes equation governs the flow field of incompressible, viscous laminar flow. An Arbitrary Lagrangian-Eulerian Approach (ALE) is used to solve the flow equation:

Continuity equation:

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

Momentum equation:

$$\frac{\partial u_f}{\partial t} + \left(u_f - u_{m,f}\right) . \nabla u_f = -\frac{\nabla P}{\rho_f} + \vartheta_f \nabla^2 u_f \quad (2.)$$

Energy equation:

$$\frac{\partial T_f}{\partial t} + \left(u_f - u_{m,f}\right).\nabla T_f = \alpha \nabla^2 T_f \qquad (3.)$$

u_f = velocity of fluid, $u_{m,f}$ = mesh motion velocity in fluid domain, α = thermal diffusivity, ϑ_f = kinematic viscosity of fluid, T_f = temperature of fluid.

The equation of motion for an elastic adiabatic solid structure can be described from Lagrangian view point as:

$$\rho_s \frac{\partial^2 d_s}{\partial t^2} = F_\vartheta + \nabla \sigma \qquad (4.)$$

ρ_s = density of solid structure, d_s = displacement of solid structure, F_ϑ = resultant body force.

2. 1. Validation and geometric detail

As a validation study, square cavity with flexible bottom and oscillating top wall is considered. All the geometric detail and boundary condition has taken from Hubchi et.al. [4].The validation graph shows the mid-point displacement of flexible bottom wall with respect to time.

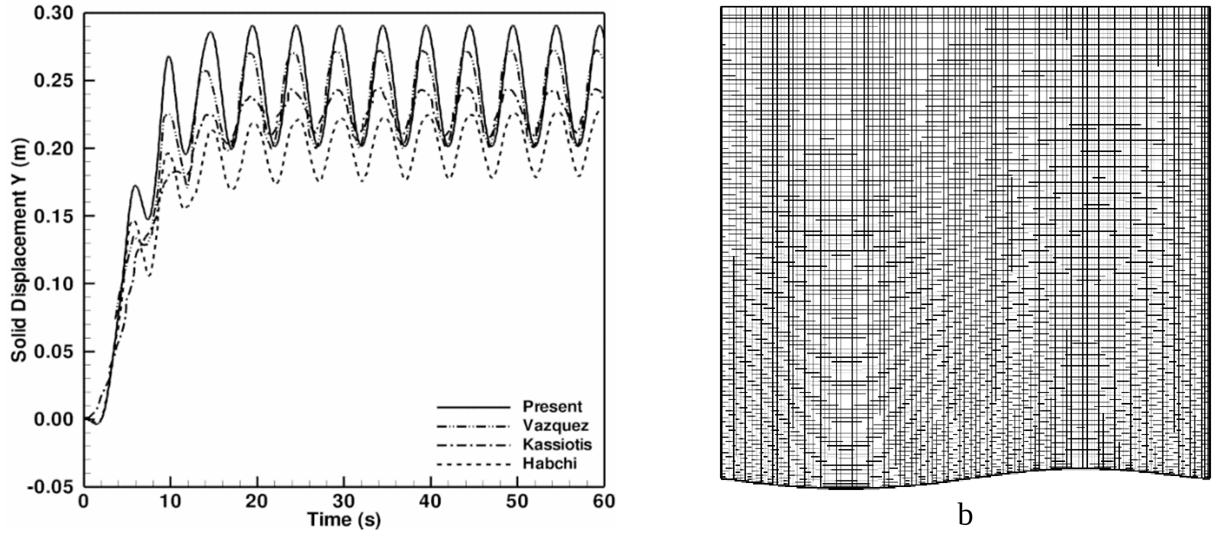

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Fig1. (a) Displacement of mid-point on flexible bottom-wall w.r.t time, (b) mesh diagram of the geometry.

Oscillating velocity of the top wall $U = 1 - cos\left(\frac{2\pi t}{7}\right)$ and no-slip condition has used on other three wall as per the validation test case.

For the simulation of test case three meshes has considered i.e.100x100, 120x120, 140x140 out of which 120x120 has chosen for the further simulation with 0.001 element size near the wall and 0.01 in the fluid domain with top wall oscillating with sinusoidal variation, the frequency of 0.5 cycle/sec and velocity of top wall is 1m/s, zero velocity on other three walls and for simplicity there is a temperature difference of one degree between hot and cold wall. The length of the fin is 15 percent the domain length (a = 1).

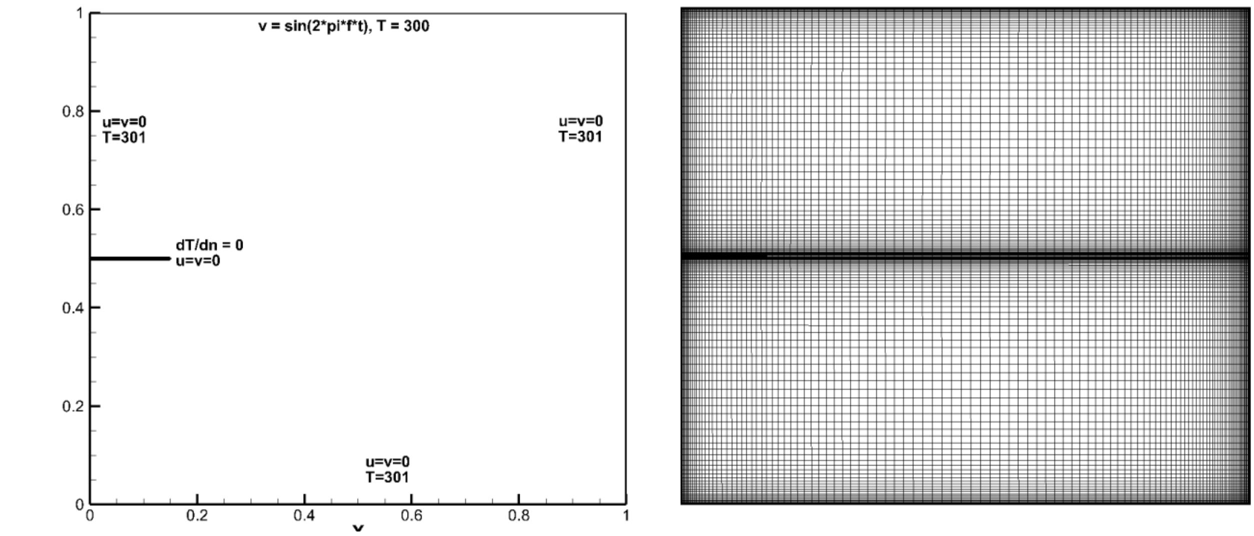

Fig2.Boundary condition and mesh of the test case for simulation

3. Results and Discussion

The effect of fin (flexible plate) on different-different wall for the increase or decrease of heat transfer of hot wall with respect to wall without fin.

3. 1. Effect of flexible plate

In the square cavity, top wall is at lower temperature and other three walls has isothermally heated with equal temperature and stationary, due to oscillation of top wall the fluid inside the cavity start circulating in the enclosure in clockwise and anticlockwise direction depending upon the direction of velocity.

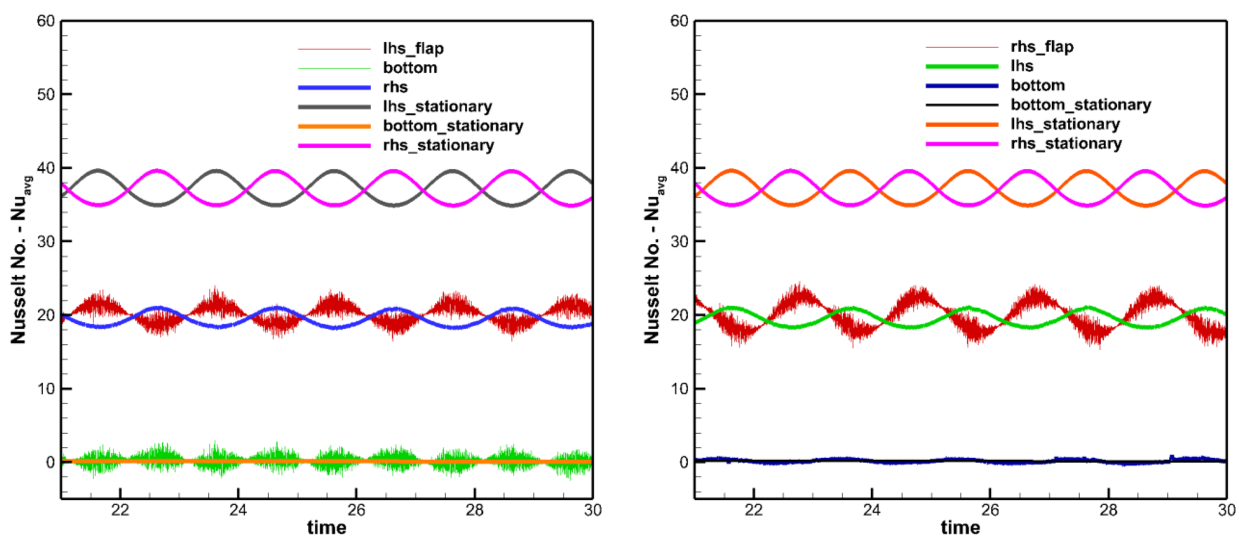

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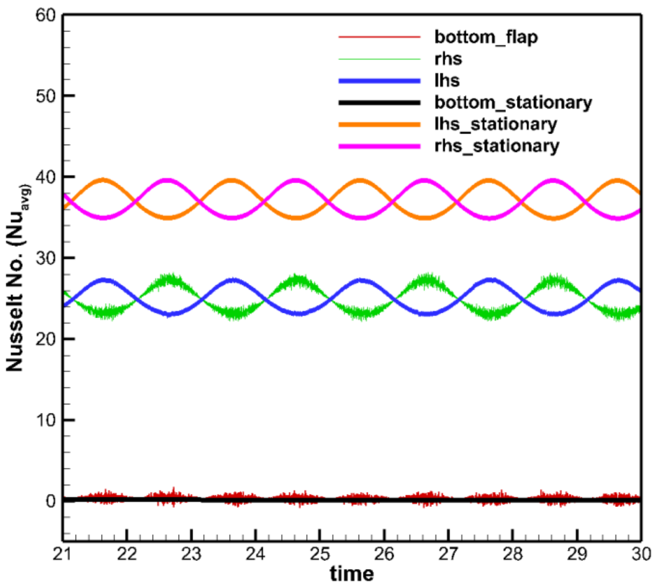
Fig3. Variation of average Nusselt number for left, right and bottom wall with time (a) flap on left wall, (b) flap on right wall, and comparison with square cavity without flap.

In Fig 3(a) flap is on the left wall and 3(b) for the right wall flexible plate, as compared to the case of square cavity without any flap, Nusselt Number of left and right wall with flexible fin is less. In square enclosure without any flap, the to and fro motion of top plate disturbs the formation of boundary layer over the stationary wall and due to this Nusselt number increases in turn which increases the heat transfer. But with fin either on left of right wall, motion of fin obstructing the disturbance of fluid created by moving wall and the heat transfer decreases and average Nusselt number of left and right wall. However, the oscillation of the top wall do not have that much effect on the bottom wall and therefore the Nusselt number of bottom wall is least.



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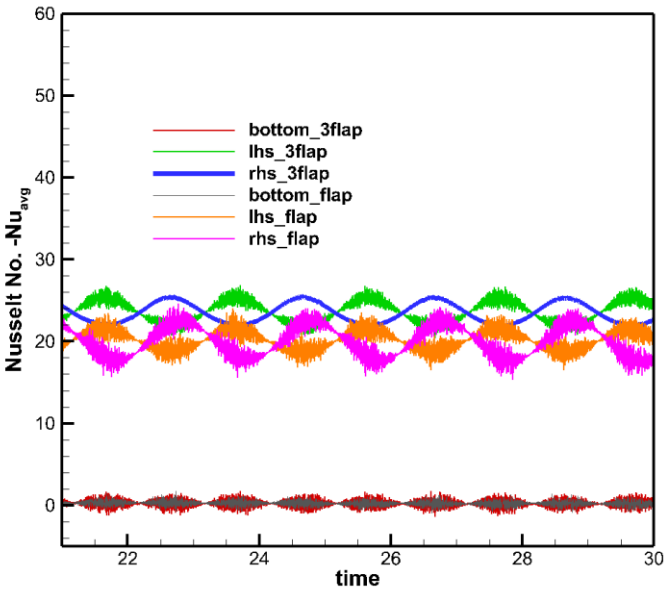

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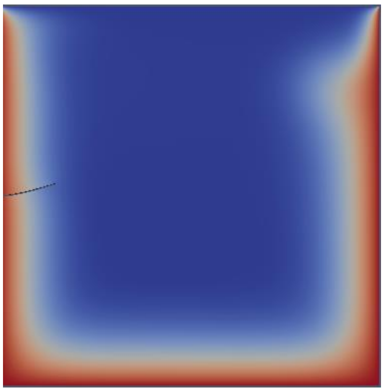
Fig4. (a) Variation of Nusselt Number for flap on bottom wall w.r.t square cavity with no flexible plate. (b) Variation of Nusselt number with 3 flap on left, right and bottom wall of cavity compared with the cases of single flap on individual wall.

There is not much variation in the Nusselt number of bottom wall with flap attached on it Fig4 (a) but in this condition, the heat transfer increases for left and right wall as compared to the moving plate on left and right wall.

In Fig4 (b) three flap attached inside the square enclosure on the left, right and bottom wall, the result has compared with the moving flap on individual wall of different cases. With the three flap, heat transfer increases for left and right wall but still its Nusselt number is lesser than the case of square cavity without flap.



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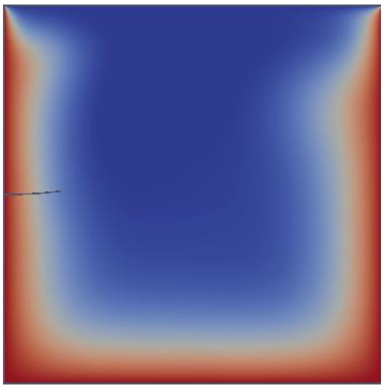

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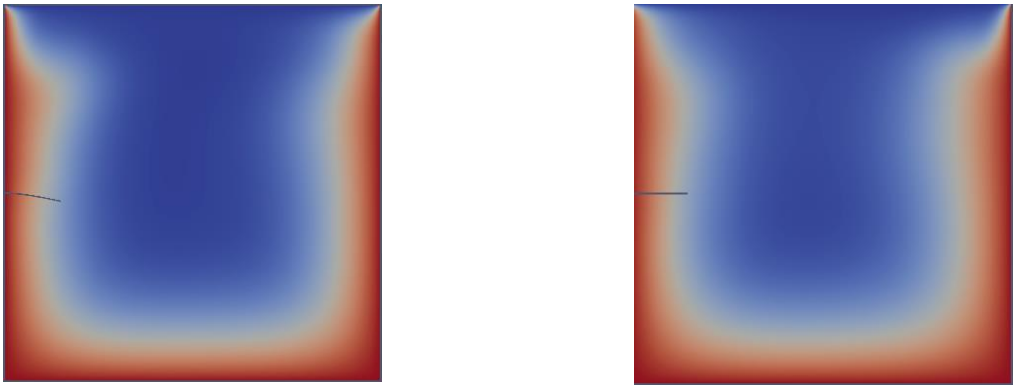

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Fig5. Showing the flapping motion of flexible fin due to oscillation of top wall.

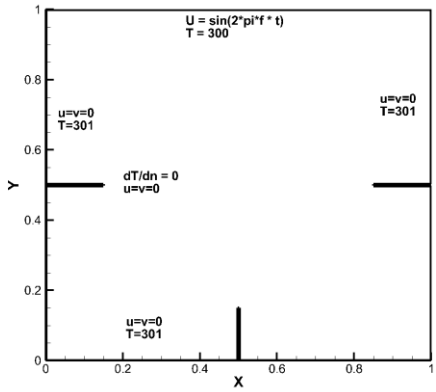

Fig6. Geometric detail with boundary condition of three flap wall

4. Conclusion

In the present study, we compared the Nusselt number i.e. the heat transfer rate with or without the flexible fin on the hot surface. Following conclusions can be made from this:

1. The heat transfer rate i.e. the Nusselt number is highest of the case with no flap on the hot surface.

2. It is not necessary that by putting flexible fin heat transfer get increase, it can decrease also as it happened in this case.

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