Removal Of Contaminant Effectiveness In Cavity Channel Flow With Different Heated Wall Position

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Abstract. Numerical simulation on removal of contaminated cavity in channel was done for various Richardson number and at three different heated wall inside square cavity. Constrained interpolated profile method (CIP) was used to solve advection part of Navier-Stokes equation while non-advection part was solved by using finite central difference. The contaminant has same properties as the fluid and very small so that the particle can be treated without affected the fluid flow. Simulations shows that heated right wall produced the highest removal process and heated left wall will removed the fewest of contaminant from cavity.

Introduction

Numerical method such as constrained interpolated profile method (CIP) is proven can simulated flow profile accurately and stable. Yabe et al. [1] stated that CIP can simulate fluid problem by maintaining third order accuracy for both time and space yet the result simulated is reliable. Navier-Stokes equation was solved separately by solving advection part of the equation using CIP and non-advection part by using central finite difference as suggested by Yabe et al. [2,3] and they show that it can produce good result on one, two and three dimensional study.

Several study on contaminant removal in cavity has been reported with many different criteria. Azwadi et al. [4] has studied the effect of heated bottom wall of cavity to its removal process. It shows that higher Grashof number will produce higher removal process but the heated wall only limited to cavity bottom wall. Similar work was also been done by Fang [5] and he simulated them for varies aspect ratio, Reynolds number and Grashof number. Saadun et al [7] has done similar study but with different geometry of cavity and found that semicircular with higher Grashof number will produce higher removal of contaminant. Manca et al. [6] has reported the effect of different heated wall position and found that heating right wall of cavity will produced highest thermal performance in term of maximum temperature and average Nusselt number. Unfortunately, they did not include particulate flow in their study.

Although many works has been done related to particulate flow with cavity in a channel, author believe that knowledge on contaminant removal process can be extend by studying the effect of different heated wall location. In this paper, different position of heated wall in cavity will be presented and the percentage of removal will be discussed later. Small particles will be place in cavity randomly and the flow was started from stagnant and stopped after steady flow is achieved. Three different heated wall, with value of Richardson number of 0.01, 1.0 and 10.0 was simulated.

Numerical modeling

Momentum equation in stream function and vorticity equation, together with energy equation will be solved using constrained interpolated profile method (CIP) and central finite difference. Parabolic inlet profile will be used for whole simulation to show that the inlet flow is in fully developed flow.
Fig. 1 shows the configuration of three different heat source location inside the cavity. The simulation was included of isothermal condition. 1600 passive particles were located inside square cavity where the ratio of width, W to height, H is 2.0 and these small particles was scattered inside the cavity. These sphere particles have same properties as the air that flow through the channel. It is treated as point for each particle as their size was considered very small compared to the grid size. Drag force of the particle was calculated based on Kosinski et al. [8] as shown below.

\[
\frac{m_p}{dt} = f_p \\
f_p = C_D A_p \rho \frac{|u - v_p|(u - v_p)}{2}
\]

where \( m_p, v_p, f_p, A_p \) are the mass of particle, velocity, drag force acting on particle due to the surrounding fluid, projected area of solid particle and \( C_D \) is the drag coefficient which given as:

\[
C_D = \frac{24}{Re_p}
\]

The particle’s Reynolds number in the above equation was defined as follow:

\[
Re_p = \frac{d_p |u - v_p|}{\nu}
\]

where \( d_p \) is the diameter of solid particle. The new position of solid particle are determined by using velocities, \( v_{p}^{n+1} \) as follow:

\[
x_p^{n+1} = v_p^{n+1} \Delta t + x_p^n
\]

Momentum equation and energy equation was solved by using CIP and central finite difference as done by Azwadi et al. [4] but the boundary condition for wall inside cavity is different based on the location of heated wall.
Results and Discussion

Small particles removal from square cavity was investigated based on different heated wall inside cavity. The simulation was done for isothermal, Richardson number (Ri) 0.01, 1.0 and 10.0 for aspect ratio two. All simulation was at Re=100 and air was used as the fluid flow inside the channel. Results of flow and isotherm are compared with work done by Manca et al. [6] as shown in Fig. 2. The comparison was made at Ri= 10.0, heated bottom wall and shows comparable results.

![Fig. 2. Comparison of isotherm contour and streamlines for (a) present work and (b) Manca et al.[6].](image)

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![Fig. 3. Particle dispersion at various time until it reach steady state.](image)

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For all different heated wall, the highest particle removal is at right wall heated, Ri=10. From observation of particle dispersion behavior as in Fig. 3, most of particles were removed from the cavity at the beginning of removal process. After some time such as t=10s, circulation began to appeared and remaining particles will separated to those which will remain circulate in the vortex and some of them will be removed from the cavity such as seen at t=17s. At this moment, the removal rate will started to decrease and only small portion left of particle will be removed from cavity such as shown at t=35s. The remained particle will remain circulated in the cavity and steady.
state will be achieved. For this case, the removal of contaminant is 63.4% when it reach steady state.

![Fig. 4](image)

**Fig. 4.** Removal process at various Richardson number and at different heated wall.

Fig. 4. shows the removal process at various Richardson number and at different heated wall. An interesting finding shows that isothermal condition gives better removal process than the left wall heated at both Ri=1 or Ri=10 and heated bottom wall at Ri=1. The highest removal process for the whole simulation is at Ri=10 for heated right wall. There are two same results for removal process which is for heated right wall at Ri=1 and bottom wall at Ri=10 but at the beginning of removal process, they have slightly different rate. This is due to buoyancy effect on the flow affected faster if right wall is heated than bottom wall. This make the particle near right wall will removed faster. There are major different can be seen from Fig. 4 for three cases that required longer time to reach steady state which is Ri=1, for both heated right wall and bottom wall, and Ri=10 for heated right wall. This could be due to vortex formed in at higher Ri need more time to reach steady and the number of vortex formed in cavity change continuously. For Ri=0.01, their results for all heated wall are same as isothermal case.

**Conclusion**

Particle removal from cavity was simulated by using CIP method and central finite difference. the simulation was done for square cavity aspect ratio of two and Reynolds number of 100. Three different wall heating at Ri=0.01, 1.0 and 10 was simulated including isothermal condition. Passive particles were placed randomly inside cavity that affected by flow inside the channel but have no effect to the fluid flow. The highest removal process was at Ri=10, heated right wall and the smallest removal process was Ri=10, heated leftwall. It is found that isothermal condition can gives better removal than some other heated wall case.
References


