A NUMERICAL STUDY OF MULTIPHASE FLUID FLOW ACROSS TWO HEATED CIRCULAR CYLINDERS IN TANDEM ARRANGEMENT

B.K.Dhar[1], S.K Mahapatra[2], S. K. Maharana[3], A.Sarkar[4]

[1]PhD Student &[4]Professor, Dept. of Mechanical Engineering, Jadavpur University, West Bengal(India)

[2]Professor, School of Mechanical Sciences , IIT, Bhubaneswar(India)

[3]Professor, Dept of Aeronautical Engineering, Acharya Institute of Technology, Bangalore(India)

ABSTRACT

The situations of fluid flow and heat transfer across an array of cylinders have been quite common in the fluid dynamics and , particularly, industry applications. One such situation is flow of water over heated cylinders arranged in tandem. The flow of water over heated cylinders faces a phenomenon of phase change from liquid (water) to vapour phase(steam).The mechanism of this phase change is studied through a numerical simulation in this project. The Eulerian model is used in the present simulation method to comprehend the multiphase physics.

The effect of variation of inter-cylinder spacing on the phase change is quite evident during the post processing of the results obtained from simulation.

Keywords: Multiphase Fluid Flow, Eulerian Model, Tandem Arrangement, Volume Fraction, Phase Change

I. INTRODUCTION

The problems of fluid flow and heat transfer phenomena over array of cylinders are quite prominent in the fluid dynamics and industry applications [1, 2]. These problems give rise to some of the important aspects in fluid dynamics theory such as fluid flow interaction, interferences in flow, vortex dynamics and a variety of engineering applications such as compact heat exchangers, cooling of electronic equipments, nuclear reactor fuel rods, cooling towers, chimney stacks and offshore structures, hot-wire anemometry, and flow control. Quite a few studies on these problems have been carried out analytically, experimentally, and numerically, especially under the configuration of two tandem cylinders for simplicity.

Some of outstanding research activities in above field have focused on the effect of spacing between the cylinders on the flow characteristics, heat transfer around them. It was observed that the qualitative nature of the flow depends strongly on the arrangement of cylinders [1, 3, 4].

The objective of the work is to simulate the multiphase fluid flow and heat transfer phenomena over two circular cylinders of equal diameters and are in tandem arrangement by changing the spacing between the two heated cylinders.

The fluid flow over a single cylinder is amply covered by many literatures in the past and hence this has motivated to take up a situation where there is more than one cylinder. The fluid flow (either laminar or turbulent) over these cylinders with certain heat flux is more relevant as far as the challenges of phase change are concerned. In the present case it is deemed appropriate to attempt to simulate numerically the phase change phenomenon. This attempt would throw light upon the various challenges and opportunities of phase change from water to steam in a simple case like two-cylinder arrangement in tandem. This is kept as one of the objectives for a faster understanding of physics of phase change.

II. GOVERNING EQUATIONS OF MULTIPHASE FLOW

The basic set of governing equations used to solve the multiphase flow problem is given below.
The first step in solving any multiphase problem is to determine which of the regimes provides some broad guidelines for determining appropriate models for each regime, and how to determine the degree of interphase coupling for flows involving bubbles, droplets, or particles, and the appropriate model for different amounts of coupling. Eulerian model is used in the solution of the current problem.
The Eulerian model is the most complex of the multiphase models in Ansys(R) Fluent. It solves a set of **n** momentum and continuity equations for each phase. Coupling is achieved through the pressure and interphase exchange coefficients. The manner in which this coupling is handled depends upon the type of phases involved; granular (fluid-solid) flows are handled differently than nongranular (fluid-fluid) flows. For granular flows , the properties are obtained from application of kinetic theory. Momentum exchange between the phases is also dependent upon the type of mixture being modeled. FLUENT's user-defined functions allow you to customize the calculation of the momentum exchange. Applications of the Eulerian multiphase model include bubble columns , risers , particle suspension, and fluidized beds. In the current problem the two phases are water and steam and hence the flows are nongranular.

Volume fraction equation

The description of multiphase flow as interpenetrating continua incorporates the concept of phasic volume fractions, denoted here by α_q . Volume fractions represent the space occupied by each phase, and the laws of conservation of mass and momentum are satisfied by each phase individually.

The volume of phase q is defined by V_q

$$V_q = \int \alpha_q dV \quad (1)$$

Where,

$$\sum_{q=1}^{n} \alpha_q = 1 \quad (2)$$

The effective density of phase q is $\hat{\rho}_{q} = \alpha_q \rho_q$

Where ρ_q is the physical density of phase q. The volume fraction equation may be solved either through implicit or explicit time discretization.

Conservation Equations: The equations are given in General Form. The three equations are for conservation of mass, conservation of momentum and energy.

Conservation of mass

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q\right) + \nabla.\left(\alpha_q \rho_q \vec{v}_q\right) = \sum_{p=1}^{n}\left(\dot{m}_{pq} - \dot{m}_{qp}\right) + S_q \qquad (3)$$

Where $\vec{v}_q$ is the velocity of phase q and $\dot{m}_{pq}$ characterizes the mass transfer from the p^{th} to q^{th} phase, and $\dot{m}_{qp}$ characterizes the mass transfer from phase q to phase p, and you are able to specify these mechanisms separately.By default, the source term $S_q$on the right-hand side of the above equation is zero, but we can specify a constant or user-defined mass source for each phase.

Conservation of Momentum and Energy

The momentum balance for phase $q$yields

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q \vec{v}_q\right) + \nabla.\left(\alpha_q \rho_q \vec{v}_q \vec{v}_q\right) = -\alpha_q \nabla_p + \nabla.\bar{\bar{\tau}}_q + \alpha_q \rho_q \vec{g} + \sum_{p=1}^{n}\left(\vec{R}_{pq} + \dot{m}_{pq}\vec{v}_{pq} - \dot{m}_{qp}\vec{v}_{qp}\right) + \left(\vec{F}_q + \vec{F}_{lift,q} + \vec{F}_{vm,q}\right) \qquad (4)$$

Where

$$\bar{\bar{\tau}}_q = \alpha_q \mu_q \left(\nabla\vec{v}_q + \nabla\vec{v}_q^T\right) + \alpha_q\left(\lambda_q - \frac{2}{3}\mu_q\right)\nabla.\vec{v}_q \bar{\bar{I}} \qquad (5)$$

This is q^{th} phase stress-strain tensor.

Conservation of energy in Eulerian multiphase applications .The current problem uses this form of the equation

$$\frac{\partial}{\partial t}\left(\alpha_q \rho_q h_q\right) + \nabla.\left(\alpha_q \rho_q \vec{v}_q h_q\right) = -\alpha_q \frac{\partial}{\partial t} p_q + \bar{\bar{\tau}}_q : \nabla\vec{u}_q - \nabla.\vec{q}_q + S_q + \sum_{p=1}^{n}\left(Q_{pq} + \dot{m}_{pq} h_{pq} - \dot{m}_{qp} h_{qp}\right)$$

Turbulence Models

The number of terms to be modeled in the momentum equations in multiphase flows is large, and this makes the modeling of turbulence in multiphase simulations extremely complex. One of three different $k - \epsilon$ turbulence multiphase models used in ANSYS(R) Fluent for Eulerian model regime is mixture turbulence model.

III. METHODOLOGY

Below is shown in Fig. 1 an arrangement of two cylinders inside the fluid flow domain which is meshed. The inlet, outlet and other four surfaces of the domain are shown in the figure. The mesh density is higher near the walls of cylinders. The total number of nodes of the mesh generated is 5117 and that of elements is 3984. The flow enters at INLET where the inlet velocity is specified and leaves the domain at OUTLET .Other four surfaces (TOP, BOTTOM, LEFT and RIGHT) are treated as walls including the surfaces of the cylinder. The heat flux at the cylinder surface is maintained at 20,000 Watt per m^2. All walls are stationary and have no slip boundary conditions. The computation of the flow variables starts from INLET.

To solve the problem defined above commercially available CFD(computational fluid dynamics) software, ANSYS(R) Fluent is used.

During and after the heat transfer from the walls of cylinders to water, which is liquid, it starts to go to a new phase , steam. The mechanism of heat and mass transfer from water to steam is set during the multiphase flow settings in ANSYS Fluent solver.

The spacing between the centres of cylinders, which is changed during the study, is expressed in terms of the diameter. The numerical experiments are done at a particular Reynolds numbers (Re) of the flow and spacing is changed in terms of diameter, D. The study aims to observe the wake dynamics of the multiphase flow when there is an interaction between the flows of cylinders and while the flow becomes non-interacting for a gradual increase of spacing.

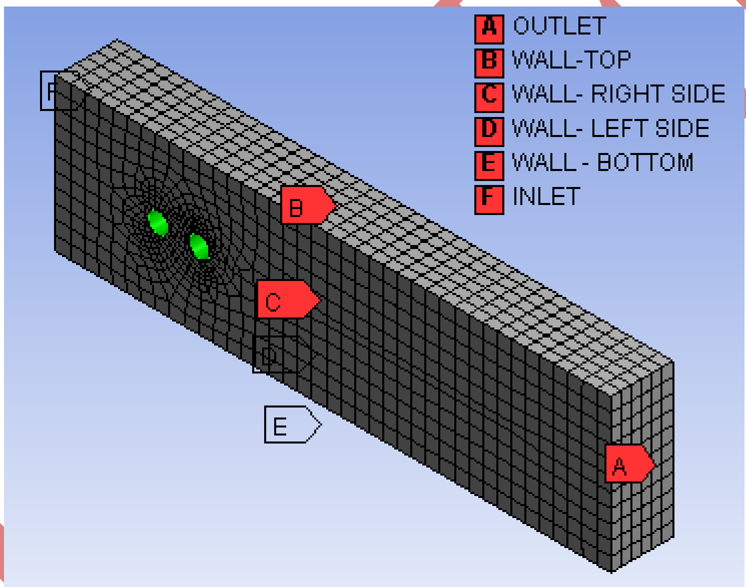


Fig.1: Fluid flow domain with two cylinders arranged in tandem and their mesh

IV. RESULTS AND DISCUSSIONS

Basically two situations are considered in this study. The first situation is when the flows from both cylinders are interacting and the second is when the flows are not interacting. Both cylinders, having the same diameter and length, are heated by certain heat source and the heat flux is maintained at 20000 Watt per square –meter.

The temperature of the water entering the channel where in two heated cylinders are placed at a location from the inlet is maintained at temperature that is 300 degree K.

During these two situations the phase change of the primary fluid (water) is observed. When water passes over the heated cylinders it shall absorb heat from the walls.

To arrive at such situations the numerical experiment is conducted by changing the spacing between the two cylinders. There could be many possibilities to know whether flow from one cylinder is interacting with that from the other. Here, one parameter, the spacing, is used to discern the flows and then the phase change is observed. The plots for these two situations are presented in this paper.

The buoyancy effect on the flow and heat transfer around the tandem arrangement is also observed investigated. If the force is in the same direction of incoming flow, the vortex street is always suppressed and no critical spacing seems to exist. However, if the force is in the opposite direction of the incoming flow, the vortex street can always be generated and the critical spacing always seems to exist.

Some of the results reported herein include the phase change and the corresponding volume fractions of two phases of the fluid. The spacing between the two heated cylinders of equal diameter is varied in terms of the diameter.

Three different spacings are considered. One is 1.5 times D . This spacing is taken when the two cylinders are deemed to be interacting through their flows and the intension is to observe how the phase changes when two are quite closer to each other.

One intermediate spacing is considered which is 3 times the diameter of the cylinder. This is considered to investigate a situation when the flows transition from a flow-interacting case to a non-interacting situation between the same two cylinders. The non-interacting case is taken at 6 times of the diameter when two flows approaching to two cylinders seem independent.The above cases are finalised and the results of phase change from water(liquid phase) to steam(vapour phase), isotherms and velocity vectors are plotted.

Fig.2 is about depiction of phase change from water (liquid)[a,c& e] to steam(vapor) [b,d& f] contours at time 0.05 for all the above-mentioned cases and Fig.3 is for the same output at a different time step 0.5. The difference between these two figures is quite evident as time progresses and when there is a change of spacing.

When the gap is smaller, the phase change seems to be quite prominent meaning the, after the crossing the heated cylinder surface , the steam phase is clearly visible and water is diminishing (or almost not visible) in the mixture model. While the gap is widening (and has almost become not interacting or independent of each other) the phase of water is visible(not so prominent though) after crossing the heated surfaces of the cylinder. The reason could be the heat transfer to the mixture (when two cylinders quite closer to each other) is playing a role in defining a sharper phase change from water to steam. Although complete phase is not happening in this case. The same is observed from the plots in Fig. 4 & 5. In these two figures one thing is quite evident that is sharper drop(volume fraction of water) or rise(volume fraction of steam) as the position, x of the mixture moves towards the outlet of the flow domain. The larger spacing between the cylinders is having weaker phase change for the same situation.

The closure model used for solving the turbulent quantities in the momentum equations is two-equation model. The problem shall also highlight a comparison of the wake dynamics and vortex shedding when there is single and multiphase of the working fluid. This will target to bring forth an understanding of the fundamental heat transfer and mass transfer study in the wake zone of two-,four- and six-cylinder arrangement.

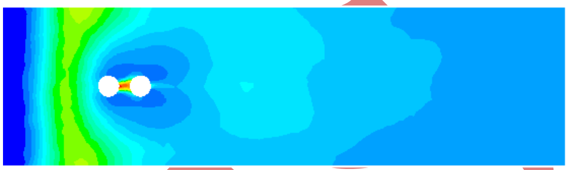
The future scope of the project involves but not limited to studying the multiphase flow over heated cylinders for different Reynolds numbers that is when the flow moves from a laminar to turbulent, the array of cylinders is conceived to have 4 or 6 cylinders in certain relevant arrangement.

Gap:

1.5D, 3D and 6D (Centre to Centre), D is the diameter of cylinder. Two heated cylinders immerged in flowing water

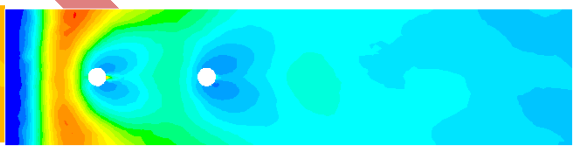
Phases:

Water (liquid) **Steam(vapor)**

(a) (b)


(c) (d)

(e) (f)

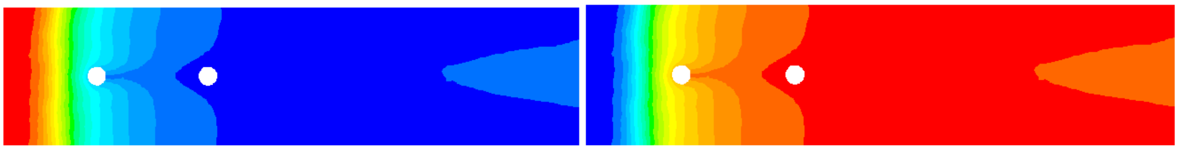
Fig. 2 : Phase change from water(liquid)[a,c & e] to steam(vapor) [b,d& f] contours at time 0.05 and at different spacings(1.5D,3D and 6D) in terms of diameter of cylinder(D).

Phases:

Water (Liquid) **Steam (vapor)**


(a) (b)


(c) (d)



(e) (f)

Fig. 3 :Phase change from water(liquid)[a,c&e] to steam(vapor) [b,d& f] contours at time 0.5 and at different spacings (1.5D,3D and 6D) in terms of diameter of cylinder(D).

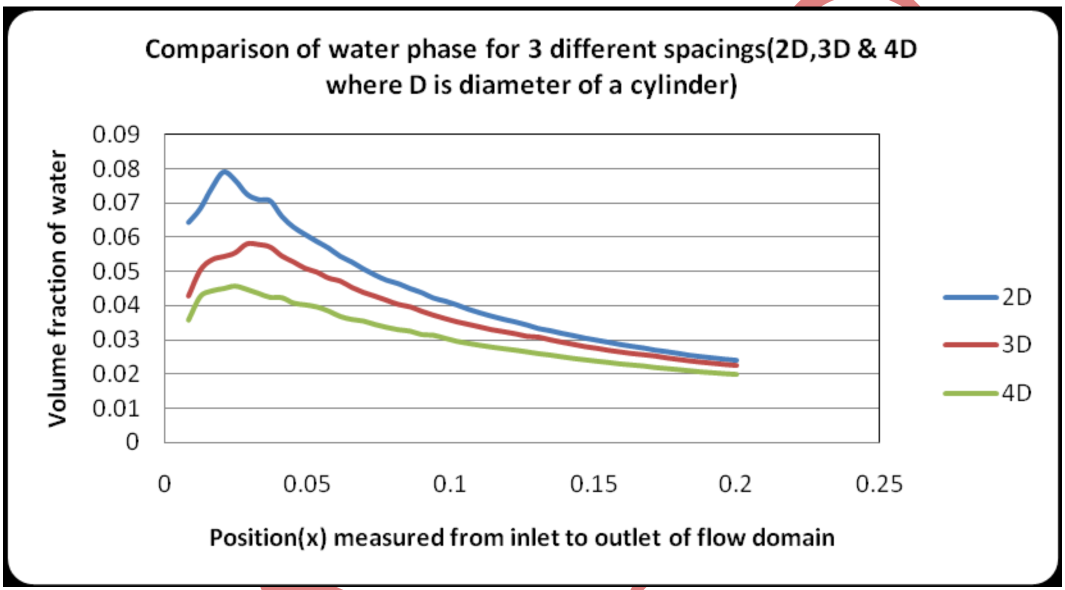


Fig.4 Volume fraction of Phase 1 (Water) from inlet to outlet of flow domain

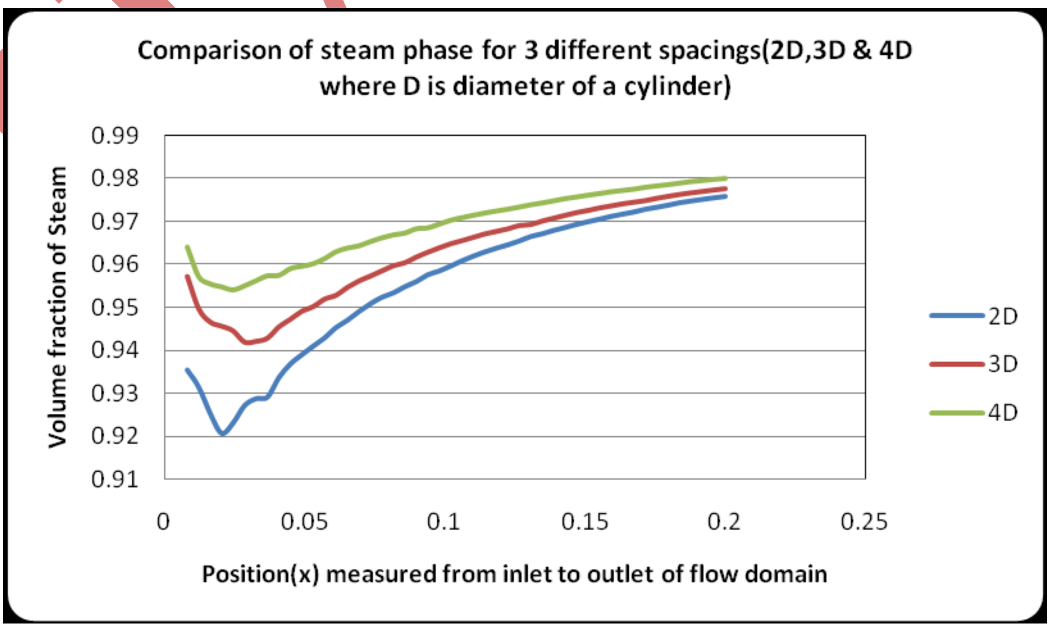


Fig.5 Volume fraction of Phase 2 (Steam) from inlet to outlet

V. CONCLUSION

The results obtained have demonstrated the effect of change of spacing on the phase change process from water to steam. The convective heat transfer from the surface of the cylinder to the water is also affected by the spacing , which in return, shows it impact on the values of volume fraction over a length spanning from the inlet to the outlet of flow domain. Another conclusive remark that is drawn from the research outcome is that the time of flow and Reynolds number have also made impact on the phase change. This is being studied by the authors as a future scope of this problem.

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