Optimization of Flow Distribution in the Feed Sparger of a Steam Drum

P. Goyal, Anu Dutta, A. K. Ghosh
Reactor Safety Division
Bhabha Atomic Research Centre
Mumbai
pgoyal10@rediffmail.com

Abstract:

Steam drums of a nuclear power plant separate steam from the steam water mixture and sub cooled incoming feed water returns to the reactor. The entire feed water flow is delivered to the steam drum through the feed water sparger. The feed water sparger is provided with number of inverted 'j' type lateral tubes to distribute the feed water in the drum for proper mixing with the separated saturated water in the steam drum of a nuclear reactor. The flow distribution through these lateral branches is an important aspect of the design of steam drum internal. Non-uniformity in the flow distribution of feed water along the steam drum can cause different enthalpy (different density and hence) of fluid entering into different down-comers. This may lead to thermal hydraulic instability in the Primary Heat Transport (PHT) system of the nuclear reactor due to variation in the driving head in the down comers which is not desirable from reactor control point of view. Thus an accurate design of feed sparger is required to ensure uniform flow distribution in the steam drum. This paper presents a computer model which has been developed to study the flow distribution in the lateral branches of dividing flow system analytically for accurate prediction of the no. of "j" type tube (lateral branches), spacing between the each lateral branch and the diameter of the lateral branches. Predictions for the flow rates and pressure in the feed sparger are obtained from the solution of two first order differential equations (pressure-flow equation set) which are formulated by using the continuity and momentum equations involving the flow rate and the pressure difference across the feed pipe and a discharge equation for the lateral flows. The approach has been generalized in terms of dimensionless equations and flow coefficient. Dimensionless parameters which affect feed water distribution such as lateral/header area ratio, lateral flow resistances, and length/diameter ratios are identified to select the appropriate design for feed sparger. The flow and pressure distribution obtained through the feed sparger was then compared with the result that obtained by using a commercial CFD analysis code COMSOL.

Nomenclature

Ar	area of header
a	area of lateral pipe
Cd	coefficient of discharge for lateral branches
CT	turning loss coefficient
D	diameter of header
d	diameter of lateral pipe
f	friction factor
Keq	loss coefficient for orifice in lateral pipe
L	distance between successive lateral branches
l	lateral pipe length
n	number of lateral branches
P	perimeter of header
p	pressure
q	flow through lateral branch
u	longitudinal velocity
v	transverse velocity
ρ	density of fluid
μ	viscosity of fluid

Introduction

Steam drum in a nuclear power plant is one of the important components of PHT system where steam is separated from the steam water mixture. Steam water mixture emanating from the reactor core is separated in a steam drum. Separated steam goes to the turbine whereas separated water after mixing with incoming feed water returns to the reactor. The entire feed water flow is delivered through the feed sparger which is running along the length of the steam drum. The feed sparger (Fig. 1) is provided with no. of inverted "J" to distribute the feed water in the drum for proper mixing with the separated saturated water.

Non-uniformity in the flow distribution of feed water along the steam drum can cause different

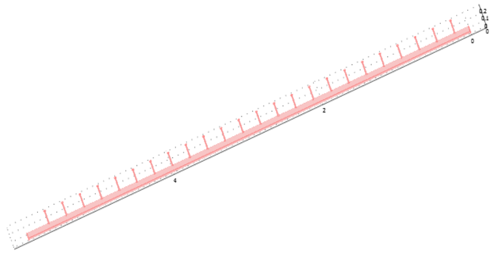

Fig. 1 Schematic of feed sparger

enthalpy (different density and hence) of fluid entering into different down-comers. This may lead to thermal hydraulic instability in the PHT system of the reactor due to variation in the driving head in the down-comers connected to the common steam drum. Steam to the turbine should have as low moisture content as possible to ensure high turbine efficiency and low risk of corrosion of turbine blades. In order to ensure uniform feed flow distribution along the steam drum, the design of the feed sparger need to be optimized. The variation of flow rates and pressure distribution along the sparger are predicted from the solution of two first order differential equations (pressure-flow equation set).Commercially available software COMSOL has been considered to evaluate the flow distribution in the feed sparger. The CFD model has been earlier validated with literature quoted experimental data [1]. This papers deals with the COMSOL model utilized for optimization of feed sparger design. The effect of the parameter on designing the feed sparger like ratio of header diameter to lateral pipe diameter (D/d) has been studied.

Governing equations

The equation of motion governing the flows in dividing and combining flow manifold systems can be written as [2]

Momentum:

$$\frac{d}{dx}\left(C_T \frac{\rho u^2}{2}\right) = \frac{dp}{dx} - \frac{f\rho u^2 P}{8A} \qquad (1)$$

Continuity:

$$\frac{d}{dx}(\rho u A_r) = -\frac{q_x}{l} \qquad (2)$$

Where

$$q_x = \rho v a \qquad (3)$$

and

$$v = C_D \sqrt{2\Delta p / \rho} \qquad (4)$$

where the discharge coefficient, C_D is given by

$$C_D = \frac{1}{\sqrt{1 + K_{eq} + \left(\frac{f.l}{d}\right)_{eq}}} \qquad (5)$$

Keq and (fl /d) eq represent the loss coefficient for sudden expansion and skin friction respectively in the lateral pipe.
Pressure drop in the lateral pipe can be given as:

Δp = pi - ps (for dividing flow manifold) (6)
= ps – pi (for combining flow manifold)

Boundary conditions

The boundary conditions at x = 0 and x = L are given as:

Dividing Manifold
x = 0, u = u inlet = Q/ ρAr (7)
and at:
x=L, u = 0 (8)

Combining Manifold
x = 0, u = 0 (9)
x=L, u exit = Q/ ρAr

3.0 Results and Discussion

Experimental data from Acrivos et al [1] has been used for validating the COMSOL model. The agreement (Fig. 2) has been found to be good. After successfully validation of the model, COMSOL was used for optimization of feed sparger design.

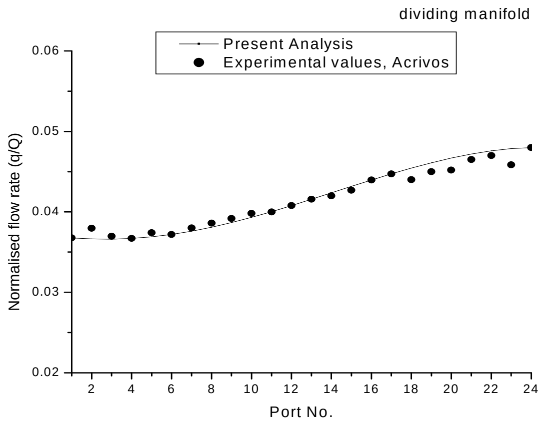

Fig. 2: Comparison between experimental values and numerical prediction of lateral flow distribution in dividing manifold

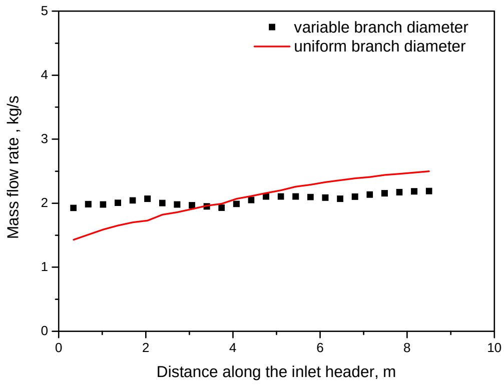

Fig. 3: Flow distribution comparison between lateral branches of uniform and variable diameter in a dividing flow manifold

At first, constant (d/D) ratio was considered and mass flow rate in different branches were predicted.. From the results (shown in Fig. 3), it is observed that the mass flow distribution along the lateral branches is highly non-uniform with more flow coming from the branches away from the inlet. Non-uniformity in the flow distribution of feed water along the steam drum can cause different enthalpy (different density and hence) of fluid entering into different down-comers. To obtain the uniform flow distribution, lateral pipe diameters were varied along the length of the header pipe. The result shows (Fig. 3) that ratio of header diameter to lateral pipe diameter (D/d) is one of the main parameters for manipulating the flow distribution through the feed sparger. The velocity and pressure contour plots for this case are shown in Fig. 4 and Fig. 5

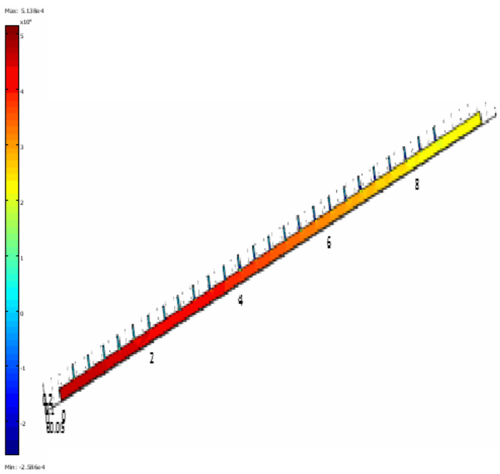

Fig. 4: Pressure (Pa) contour plot in the feed sparger

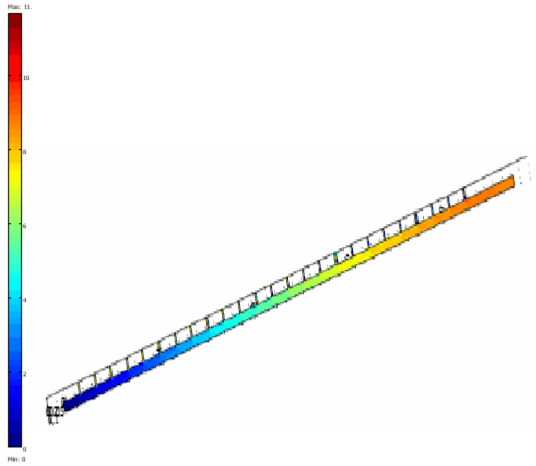

Fig. 5: Velocity (m/s) contour in the feed sparger

4.0 References

[1] Acrivos, A. et al. Chem. Eng. Sci. 1959

[2] A.K.Majumdar, Appl. Math. Modelling, 1980, Vol 4,

[3] Bajura, R.A. Journal of Engg. Power, Trams ASME 1971.

[4] Patankar S.V., Numerical Heat Transfer and Fluid Flow, McGraw-Hill Publications, 1980