Steady State Analysis of Car Cabin Heating using Exhaust Gases

Nakka Rao, Shivshankar Prjapati, Harsh Punamiya, Aman Raghani

Abstract---The Purpose of this research is to study and analyze the parameters required for designing of a natural circulation loop, which can also be applied inside an automobile to transfer heat from the exhaust gases to the car cabin. The study involves steady flow analysis and formulation of output based on heat flux conditions..

Keywords: — Natural Circulation loop, Exhaust gases, Car Cabin, Steady Flow analysis, Heat Flux Conditions.

1. INTRODUCTION

Most of the car heaters are conventional blowers with electrical heating coil drawing electricity from battery, which in turn charges by consuming energy directly from engine. We want to achieve this heating by utilizing the heat released by the car in the form of exhaust, which is waste, hence improves the efficiency of the car substantially**.**

The heat from the exhaust of the car is being stored in molten salt which has a high temperature range thermal storage capability and use of two phase flow to transfer heat from exhaust gases to car cabin and its circulation without pump, hence no additional power requirement from engine.
The principle of natural circulation, i.e. flow of fluid caused by density difference, is employed in diverse engineering Applications. As no pumping power is used, these loops are particularly suitable for harnessing nonconventional energy and utilizing waste heat. Natural Circulation Loops (NCLs) are employed in light water reactors and vertical thermo-syphon boilers. The analysis of such phenomenon is also necessary for an appraisal of the emergency cooling of nuclear reactor cores after a loss of coolant accident. NCLs involving evaporation and condensation of the working fluid is especially lucrative due to the large density difference of the vapor liquid phase. Numerous investigations, both theoretical and experimental have been conducted to study the behavior of NCLs.

Prof. Nakka Rao, Department of Mechanical Engineering, Thakur college of Engineering and Technology, Kandivali (east),Mumbai-400 101.

Harsh Punamiya, Final Year Mechanical Engineering student,
Thakur college of Engineering and Technology, Kandivali (east),Mumbai-400 101.

Shivshankar Prjapati, Final Year Mechanical Engineering student
Thakur College of Engineering and Technology, Kandivali(east), Mumbai-400 101.

Aman Raghani, Final Year Mechanical Engineering studen
Thakur College of Engineering and Technology, Kandivali(east), Mumbai-400 101.

2. Objective:

To make mathematical model of two phase natural circulation loop by generating continuity, momentum and energy equation.

To solve the differential equation by using suitable tools like FORTRAN, C ,C++,FEM

To apply it in the fields of application related to two phase flow like nuclear power plant, geothermal energy extraction.

3. METHODOLOGY:

3.1 BLOCK DIAGRAM:

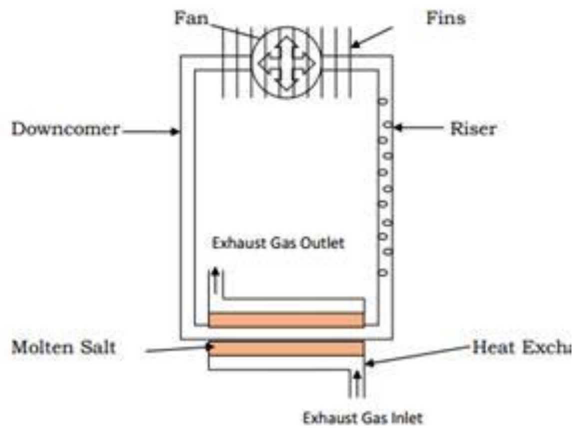

Fig 1: Conceptual Diagram of Car Cabin Heating with Exhaust Gases

3.2 Assumptions:

- Cross section of the loop is uniform.
- Uniform heating in the riser and uniform cooling in the down comer.
- Vertical limbs are adiabatic.
- Overall coefficient of heat transfer and the surface area per unit length are constant.
- No variation in temperature and velocity in the cross sectional plane.
- Thermal Properties of all the fluid streams are uniform and constant.

3.3 Mathematical Model:

For the steady-state operation of NCL (Fig. 1), following conservation equations may be written. For uniform cross section and in the absence of density variation the conservation of mass becomes:

du/dz= 0

The loop momentum equation may be written in a generalized form by considering frictional, gravitational and Acceleration pressure drops as follows.

$$\oint\left(\frac{dp}{dz}\right)_f dz+\oint\left(\frac{dp}{dz}\right)_g dz+\oint\left(\frac{dp}{dz}\right)_a dz=0$$

Energy Equation:

$$\frac{\partial T}{\partial t}+\frac{W}{\rho_r A_h}\frac{\partial T}{\partial s}=\frac{q_h P_h}{A_h \rho_r Cp} \qquad \text{Heater}$$

$$\frac{\partial T}{\partial t}+\frac{W}{\rho_r A_c}\frac{\partial T}{\partial s}=-\frac{UP_c(T-T_s)}{A_c \rho_r Cp} \qquad \text{Cooler}$$

$$\frac{\partial T}{\partial t}+\frac{W}{\rho_r A_p}\frac{\partial T}{\partial s}=0 \qquad \text{Pipe}$$

The acceleration pressure drop and compressibility of the gaseous phase has been neglected. Binomial series is used for the expansion of function and higher order terms are neglected.

Following simplified loop momentum equation is obtained by integrating the pressure drops over different sections of the loop

$$\oint \frac{2C_f\rho_{cf}u_{cf}^2}{D}ds+\sum_{i=1}^{n}\frac{2C_f\rho_{cf}u_{cf}^2}{D}L_{ei}+\oint \rho_{cfboo}g\,ds=0$$

ρ_{cf} in first and second terms designates the constant density, whereas ρ_{cfboo} in the third term represents variable density, used to determine frictional pressure drop and buoyancy head, respectively. D, L_{ei}, and C_f are loop diameter, equivalent length of various fittings, and friction factor, respectively.

Equation (2) can further be expressed considering the Boussinesq approximation as

$$\frac{32}{\pi^2}\frac{C_f\dot{m}^2}{\rho_0 D^5}\left[2(L_1+L_2)+\sum_{i=1}^{n}L_{ei}\right]=\rho_0 g\beta L_2(T_{cf2}-T_{cf1})$$

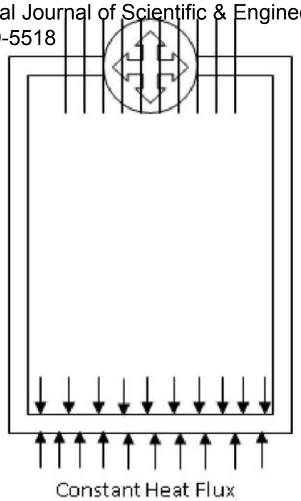

Fig 2: Schematic Diagram of idealized loop with Constant Heat Flux heating.

where $\dot{m}$, L_1, and L_2 are loop mass flow rate, and horizontal loop length and height, respectively. T_{cf2} and T_{cf1} are loop fluid temperatures in adiabatic riser and downcomer, respectively. ρ_0 and β are reference density at its corresponding temperature T_0 and thermal expansion coefficient of coupling fluid, respectively.

The friction factor C_f can be expressed as $C_f = a\,\mathrm{Re}^{-b}$, and substituting into Eq. (3) and neglecting the minor losses yield the following simplified loop momentum equation in terms of coupling fluid heat capacity rate, C_{cf}:

$$C_{cf}^{2-b} = \frac{\pi^{2-b}}{2^{6-2b}a}\frac{\rho_0^2 g \beta D^{5-b} c_{cf}^{2-b}}{\mu_{cf}^{b}}\frac{L_2}{(L_1+L_2)}[T_{cf2} - T_{cf1}] \qquad (4)$$

4. CONCLUSION

Theoretical investigation of one-dimensional steady state-analysis of the two-phase Natural Circulation Loop with heat exchangers at hot and cold end has been presented. Homogeneous equilibrium model has been used to predict the two-phase friction factor. The relevant non-dimensional numbers for the loop performance have been identified and the loop momentum equation and energy equations have been written in non-dimensional form. The mathematical model developed has been used for parameter study to determine the circulation rate of the loop and the exit quality of hot end heat exchanger as a function of the non dimensional parameters.

7. REFERENCES:

[1] N.M. Rao, B. Maiti, P.K. Das. “Dynamic performance of a natural circulation Loop with end heat exchangers under different excitations” International Journal of Heat and Mass Transfer 48 (2005) 3185–3196

[2] Steady State Performance of a Single Phase Natural Circulation Loop with End Heat Exchangers. By N. M. Rao B. Maiti P. K. Das International Communications in Heat and Mass Transfer 33 (2006) 1042 – 1052

[3] Stability Behavior of a Natural Circulation Loop with End Heat Exchangers. N. M. Rao B. Maiti P. K. Das JULY 2005, Vol. 127 / 749

[4] Steady - state performance of a two - phase natural circulation loop N.M. Rao, Ch. Chandra Sekhar b, B. Maiti b, P.K. Das b Journal of Heat Transfer and AUGUST 2008, Vol. 130 / 084506-1

[5] Scaling of the steady state and stability behaviour ofsingle and two-phase natural circulation systems P.K. Vijayan, A.K. Nayak, M.H. Bade, N. Kumar, D. Saha, R.K. Sinha