MODELING OF U-TUBE STEAM GENERATOR

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Abstract
In this paper a numerical model for U-tube steam generator of a nuclear power station 700 MWe is evolved. The reactor analysis code RELAP5 is used as a tool for this purpose. The evolved model is benchmarked with the available experimental data from Bugey-4 steam generator. Subsequently, the results obtained for 540 MWe steam generator would be compared with the numerical data from BHEL. Finally, using this code, parametric trends would be generated for the proposed 700 MWe steam generator.

Keywords: U-tube steam generator, RELAP5

Introduction

Pressurized Heavy Water Reactors (PHWR) are horizontal pressure tube reactors using natural Uranium Oxide fuel in the form of clusters. The fuel is cooled by a high pressure, high temperature circulating heavy water. The Primary heat transport system circulates the high pressure coolant through the fuel channels to remove the heat generated in fuel. The heat from the reactor is carried away by the heavy water coolant in the PHT system and gives away to the secondary side in steam generators. The steam from steam generators is fed to the turbine to generate electricity.

In nuclear power plants the steam generator plays an important role. It is a crucial component of a nuclear power plant and provides the interface for heat exchange between high pressure primary and steam generating secondary fluids. It is a dynamic link between the reactor core and the turbo generator systems. Therefore, the behavior of the steam generator plays an essential role in determining the power plant response in the event of changes in the operating load or power.

The motivation for the present work is the result of a move by Nuclear Power Corporation of India Limited (NPCIL) to upgrade the existing 540 MWe design so that it can generate 700 MWe. This is proposed to be accomplished by allowing boiling in the core to a limited extent (3% quality). Similar concept was first introduced in Canadian reactors. The present work is aimed at generating a detailed thermal hydraulic code of the analysis of steam generator that will be integrated with the stability analysis code to be developed independently.

U-Tube Steam Generator (UTSG)

A geometric view of the U tube Steam generator is given in Fig.1. It consists of several inverted U-tubes connected to a tube sheet. The primary fluid's inlet and exit manifolds are connected to the bottom of the tube sheet. A shell is welded to the other side of the tube sheet. A partition plate divides the lower hemispherical head into an inlet plenum and an outlet plenum. The shell is expanded at the top to accommodate centrifugal steam separators and dryers. Since the tubes are fairly long, tube

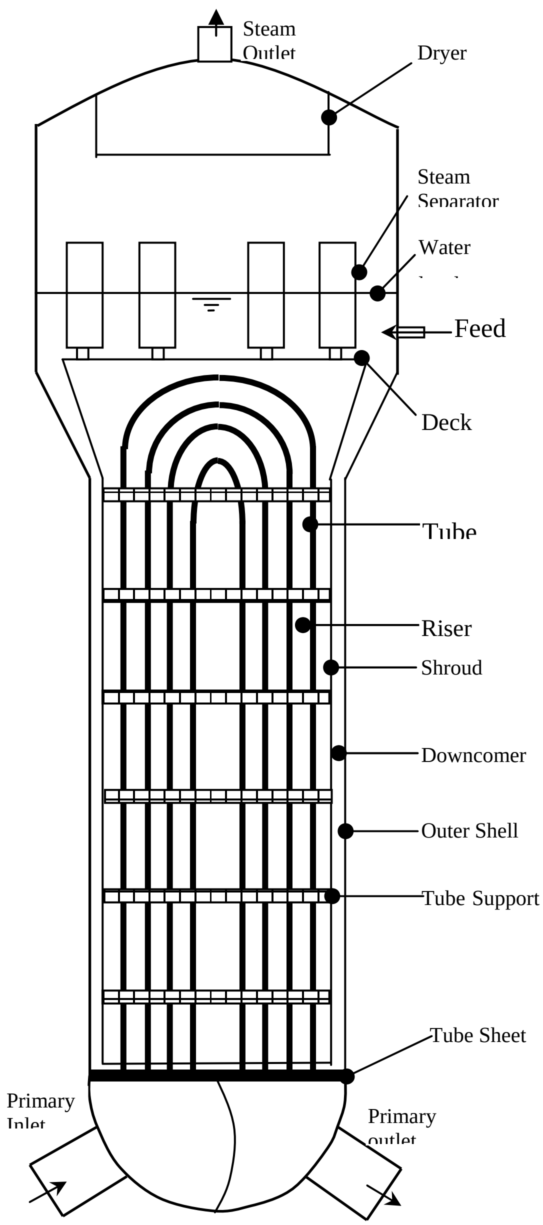

Figure 1: Schematic view of U tube steam generator (Iyer,2003)

supports are provided at several elevations to provide lateral rigidity and prevent excessive vibrations. A cylindrical shroud with a flare at its top covers the U-tubes.

The hot primary fluid enters the primary chamber through the inlet nozzle into the inlet manifold and the same exists through the exit manifold after transferring heat to the secondary fluid flowing outside the tubes. Since the fluid is forced through using primary coolant pumps, the mass flow rate is assumed to be a given design parameter. Relatively cooler primary fluid now leaves the steam generator through the outlet nozzle.

Feed water enters the steam generator through the feed water nozzles shown in Fig.1. The fluid is directed to flow in the downcomer, which is the passage formed in between the outer shell and the inner shroude. A passage provided at the bottom of the shroude allows water to be directed up in the passage formed in between the U tubes and the shroud, called the riser. The process of heat exchange occurs in this riser. The up-moving fluid in the riser receives heat from the primary fluid flowing inside tubes. Soon boiling ensues and continues all along the riser, thereby increasing the thermodynamic quality of the secondary fluid. The steam-water mixture exiting the riser is fed into centrifugal separators that are mounted on a deck plate. These steam separators separate water from steam and this steam is then passed on to the dryers. Dryers reduce the moisture content to less than 0.25 percent and this dry saturated steam leaves the steam generator through the steam nozzle. The separated water (recirculating water) mixes with feed water to flow down through the downcomer. If x_e is the amount of steam per unit mass of the secondary coolant at the inlet of separator, then it can be shown that $1/ x_e$ times the steaming rate
will be the amount of water circulating in the downcomer.

RELAP5 MOD3.2

The MOD3 version of RELAP5 has been developed jointly by the Nuclear Regulatory Commission (NRC) and a consortium consisting of several countries and domestic organizations that were members of the International Code Assessment and Applications Program (ICAP), and its successor organization, Code Applications and Maintenance Program (CAMP). Credit also needs to be given to various Department of Energy sponsors, including the INEL laboratory-directed discretionary funding program. The mission of the RELAP5/MOD3 development program was to develop a code version suitable for the analysis of all transients and postulated accidents in LWR systems, including both large and small break loss-of-coolant accidents (LOCAs) as well as the full range of operational transients.

The RELAP5/MOD3 code is based on a nonhomogeneous and nonequilibrium model for the two-phase system that is solved by a fast, partially implicit numerical scheme to permit economical calculation of system transients. The objective of the RELAP5 development effort from the outset was to produce a code that included important first-order effects necessary for accurate prediction of system transients but that was sufficiently simple and cost effective so that parametric or sensitivity studies are possible.

The code includes many generic component models from which general systems can be simulated. The component models include pumps, valves, pipes, heat releasing or absorbing structures, reactor point kinetics, electric heaters, jet pumps, turbines, separators, accumulators, and control system components. In addition, special process models are included for effects such as form loss, flow at an abrupt area change, branching, choked flow, boron tracking, and noncondensable gas transport.

For forced and natural convection mode calculations, Dittus Boelter[5] and Churchill-chu[3] correlations are used respectively. In the boiling region upto CHF Chen's Correlation[2] is used and modified Bromley's Correlation[1] is used in the film boiling region. In the condensation region Shah's Correlation[9] is used.

Solution Procedure

For modeling of UTSG the input data files have been generated in RELAP5. Deferent input data file has to be generated for any respective change in input (e.g. pressure, temperature etc.)

Benchmark runs

The input data file generated for RELAP5 was first tested with the data obtained from commercial U-tube steam generator. The full details of the steam generator are presented in the EPRI report[10] .Some important dimensions are presented in Table 2.The value of from loss coefficients are summarized in Table 2.

Table 1

Geometric details of Bugey 4 steam generator

Component	**Dimension**
Lower shell inner diameter (m)	3.286
Upper shell inner diameter (m)	4.280
Starting elevation of shell expansion (m)	9.014
Ending elevation of shell expansion(m)	10.099
Lower shroud internal diameter (m)	3.137
Upper shroud internal diameter (m)	3.432
Starting elevation of shroud expansion (m	10.099
Ending elevation of shroud expansion (m)	10.587
Shroud thickness (m)	6.4 e-3
Shroud clearance above the tube sheet (m)	0.254
Tube outer diameter (m)	0.022
Tube inner diameter (m)	0.0197
Tube pitch – square (m)	0.0325
Number of tubes	3,388
Height at the start of the U bend (m)	9.063
Height at the end of the U bend (m	10.594
Number of support plates	8

Table 2
Form loss coefficients

Device	**Bugey 4**
Tube support plates	3.5
Downcomer	1.25
Steam separators	35

The results obtained for the variation of total power generated and the circulation ratio as a function of the fractional load for the case of Bugey 4 are shown in Fig. 2 and 3 respectively. It may be observed that the predicted values are quite satisfactory.

Table 3
Geometric details of NPC-540 steam generator

Component	Dimension
Lower shell inner diameter (m)	2458
Upper shell inner diameter (m)	3350
Starting elevation of shell expansion (m)	10.278
Ending elevation of shell expansion(m)	11.870
Lower shroud internal diameter (m)	2.197
Lower shroud external diameter (m)	2.233
Starting elevation of shroud expansion (m	11.870
Ending elevation of shroud expansion (m)	12.670
Shroud thickness (m)	1.8 e-3
Tube outer diameter (m)	0.019
Tube inner diameter (m)	0.0167
Number of tubes	2,489
Height at the start of the U bend (m)	10.278
Number of support plates	13

Table 4
Form loss coefficients

Device	NPC-540
Tube support plates	1.5
Downcomer	1.25
Steam separators	22.8
Flow distribution plate	818.5

To carry out the parametric studies of 700 MWe steam generator first of all the code is benchmarked with the result available on the 540 MWe steam generator. Because these two steam generators are geometrically identical. The results are compared with the numerical estimates provided by BHEL[11].The geometric details for the 540 MWe steam generator are shown in table 4. The form loss coefficients based on fluid flow area in the bundle region are summarized in table 5. Using these data, the results obtained by BHEL report and RELAP5 are compared in Fig 4 and 5. It may be observed that the predicted values are quite satisfactory.

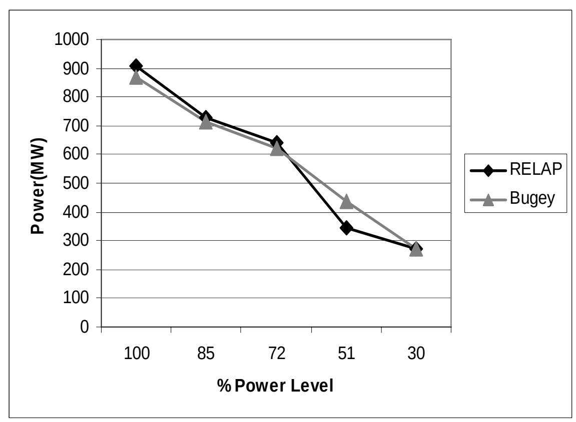

Fig.2: Comparison of Bugey and RELAP results (Power v/s Fractional load)

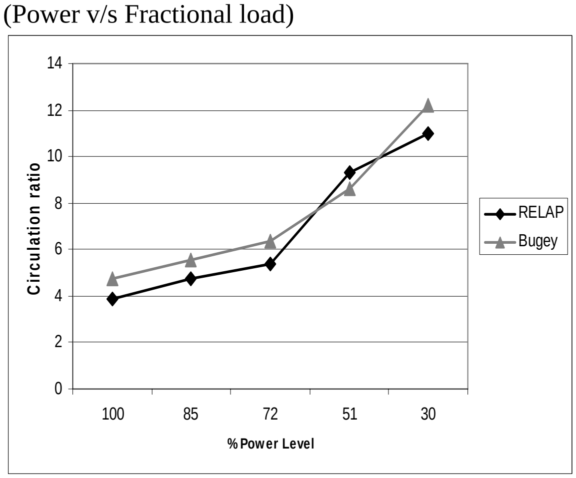

Fig.3: Comparison of Bugey and RELAP results (Circulation ratio v/s Fractional load)

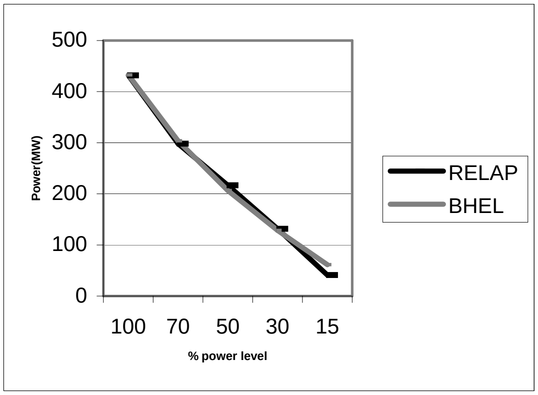

Fig. 4: Comparison of BHEL and RELAP results (Power v/s Fractional load: NPC-540)

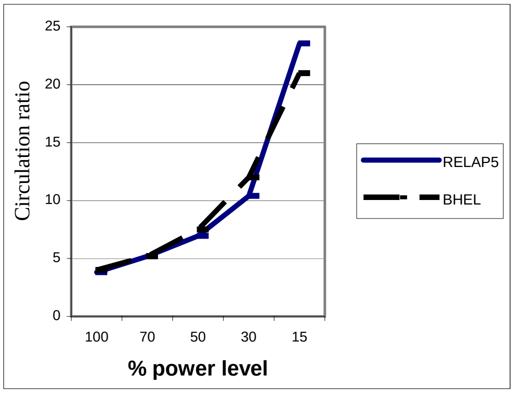

Fig. 5: Comparison of BHEL and RELAP results (Power v/s Fractional load :NPC-540)

Parametric studies of 700 MWe Steam Generator

After the satisfactory results for NPC-540 UTSG the prediction for 600 MWe steam generator has been done using the operating conditions summerised in Table 6

Operating conditions:

Table 6
Operational details of NPC-700 steam generator

Primary water flow rate	2109 kg/s
Primary inlet quality	0.03
Feed water temperature	180 °C
Primary water temperature	308.02 °C
Steam dome pressure	4.412 MPa
Drum water level	0.73 m above deck plate

Using the above data, calculations have done to estimate the power and circulation ratio. These were computed to be 539.6 and 3.1 respectively. The variation of the primary coolant temperature and the secondary coolant's quality are shown in Fig. 6 and 7 respectively.

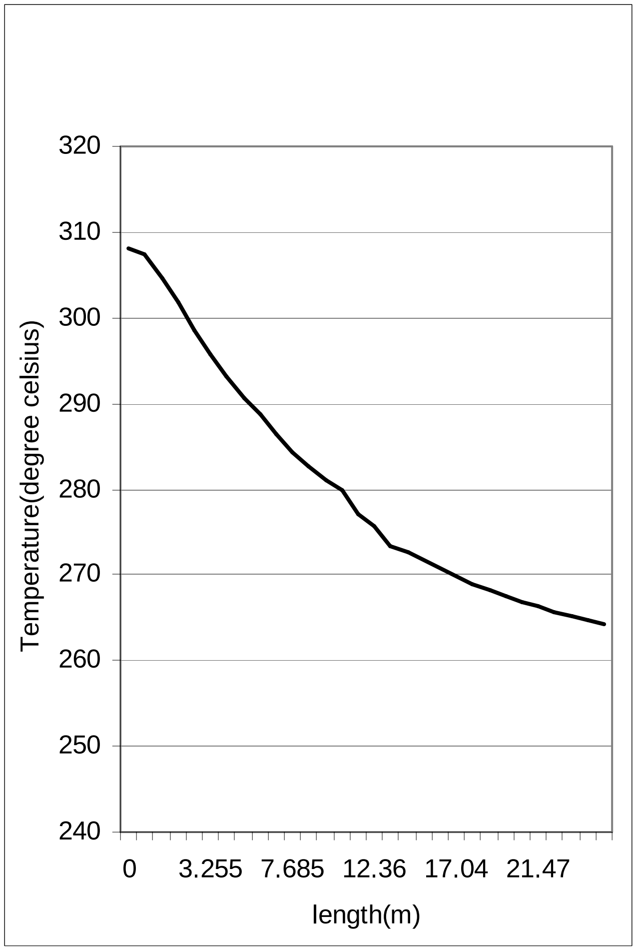

Fig. 6: Primary temperature variation (NPC-700)

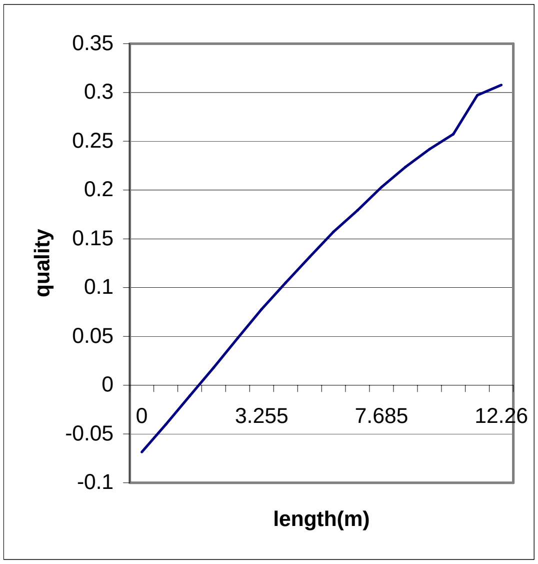

Fig. 7: Secondary quality variation (NPC-700)

Several parametric studies conducted to study the UTSG behavior .The results of these studies are summerised as follows.

Change in Inlet Primary Quality

As primary inlet temperature increases it has been found that the power output increases because of the respective increment in steaming rate. The results are presented in Fig. 8 and 9. The amount of circulating fluid decreases accordingly due to friction enhancement because of increase in steaming rate. Therefore circulation ratio decreases as quality increases.

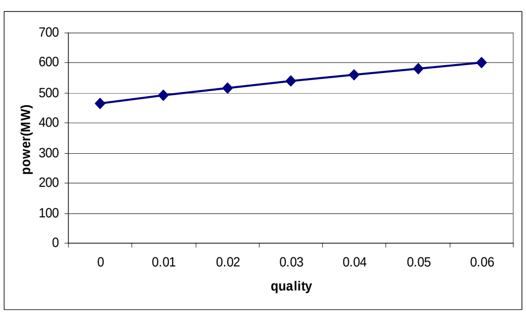

Fig. 8: Variation of Power output with primary inlet quality (NPC-700)

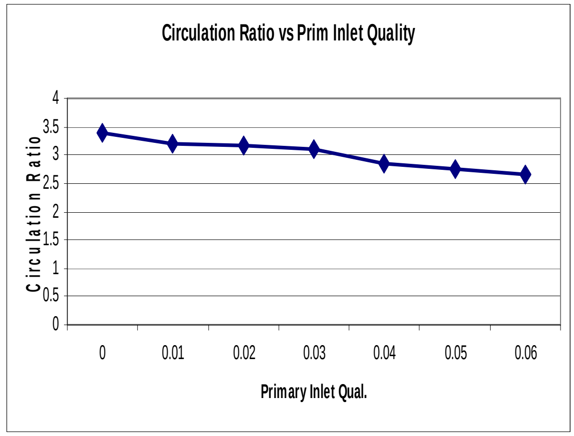

Fig. 9: Variation of circulation ratio with primary inlet quality (NPC-700)

Change in Primary Mass flow Rate

The primary mass flow rate has been varied from 80% to 120% of the reference value (i.e. 2109 kg/s) in the steps of 10%.It has been found that as primary mass flow rate increases the power output increases and there is a corresponding degradation in circulation ratio. The results are presented in Fig. 10.

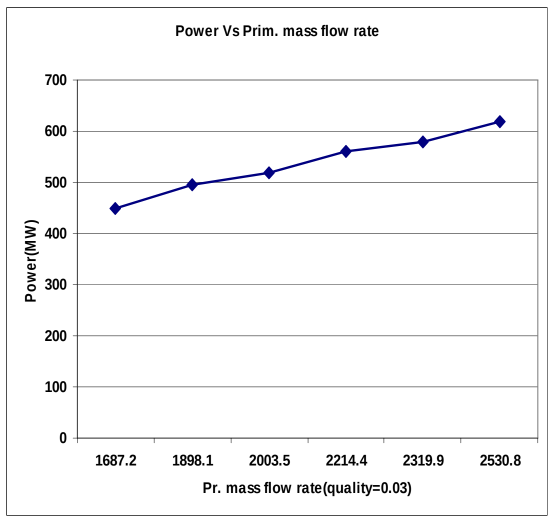

Fig. 10: Variation of Power output with primary mass flow rate (NPC-700)

Change in Distributor Plate Resistance

The resistance of distributor plate has been varied from 0% to 100% of reference value in the steps of 25%.It has been found that as plate resistance increases the circulation ratio decreases. The results are presented in Fig. 11.

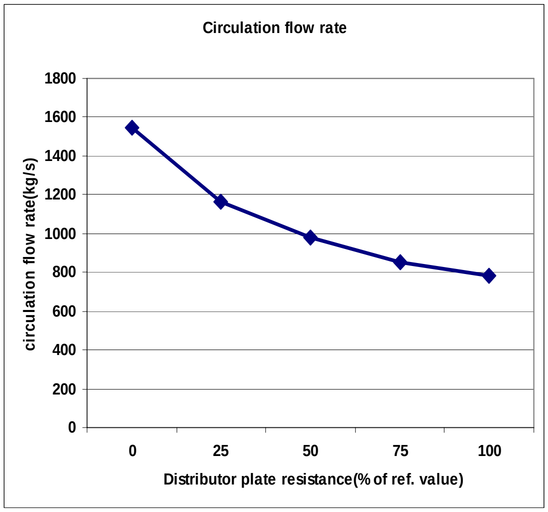

Fig. 11: Variation of Circulation ratio with distributor plate resistance (NPC-700)

Conclusion:

One dimensional analysis of U-Tube steam generator used in nuclear power plants has been done using RELAP5 MOD 3.2. First of all it was benchmarked with results available from commercial full scale generator. After that analysis was carried out for the 540 MWe UTSG and the results were compared with the data provided by BHEL. Having verified the results, 700 MWe design modeled and parametric studies were carried out.

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