FLOWNEX®
SIMULATION ENVIRONMENT

REACTOR CAVITY COOLING

This case study demonstrates the investigation into the operating characteristics of a Reactor Cavity Cooling System (RCCS) during passive operation.

The RCCS is a heat removal system designed to remove heat that is radiated from the Reactor Pressure Vessel (RPV) wall. The RCCS is able to operate during active operation where the flow is driven by a pumping system or during passive operation where flow is induced by means of buoyancy forces.

NUCLEAR INDUSTRY

CHALLENGE:

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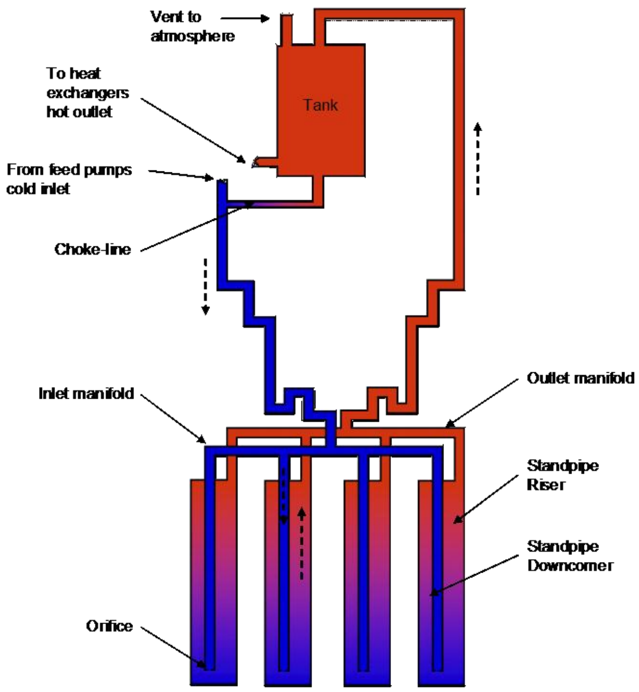
BENEFITS:

- Thorough Sensitivity Analysis on system.
- Ambient conditions taken into account.
- Flashing behavior of the system modeled.
- Thermal inertia.
- Buoyancy forces taken into account.

SOLUTION:

The sensitivity investigations revealed that the RCCS is insensitive to change in ambient pressure when the tank is at 15 °C. The effect of ambient pressure becomes more evident when the tank is at saturation temperature. This is ascribed to the change in saturation temperature with ambient pressure, which in turn affects the flashing behavior of the system.



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CHARACTERIZATION OF A REACTOR CAVITY COOLING SYSTEM

INTRODUCTION

This case study demonstrates the investigation into the operating characteristics of a Reactor Cavity Cooling System (RCCS) during passive operation.

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SYSTEM DESCRIPTION

The configuration considered in this example consists of one sub-system of the RCCS. That is one tank and four standpipes. Figure 1 shows a schematic representation of one sub-system of the RCCS.

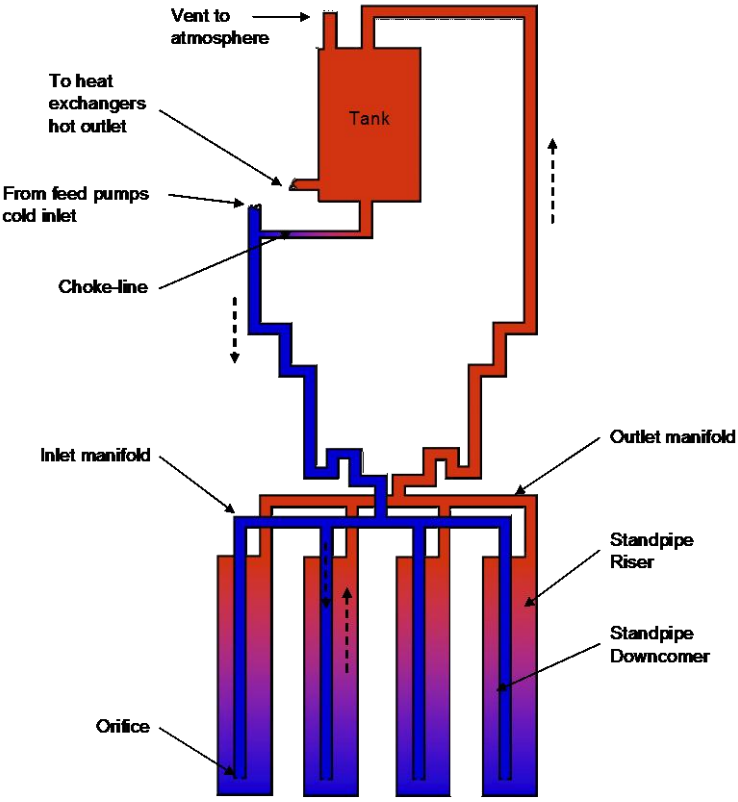

Figure 1: Schematic layout of one RCCS subsystem.

Cold water from the feed pumps enters the system just above the choke-line. A small amount of water bypass the system and flows directly back to the tank. The purpose of the choke-line is to limit the bypass flow to the tank in active operation. The water flows down in the piping network where it distributes to four standpipes in the inlet manifold. The annular geometry of the standpipes is depicted in Figure 2 as well as the standpipes relation to the reactor cavity, Reactor Pressure Vessel (RPV) and concrete wall. From the inlet manifold, the water moves downwards in the downcomer pipes, through an orifice at the bottom into the heated section of the riser pipes. The water rises while being heated (due to radiated heat from the reactor) into the outlet manifold where the water is collected and flows back to the tank. From the tank the water flows to a heat exchanger where it is cooled and pumped back to the RCCS.

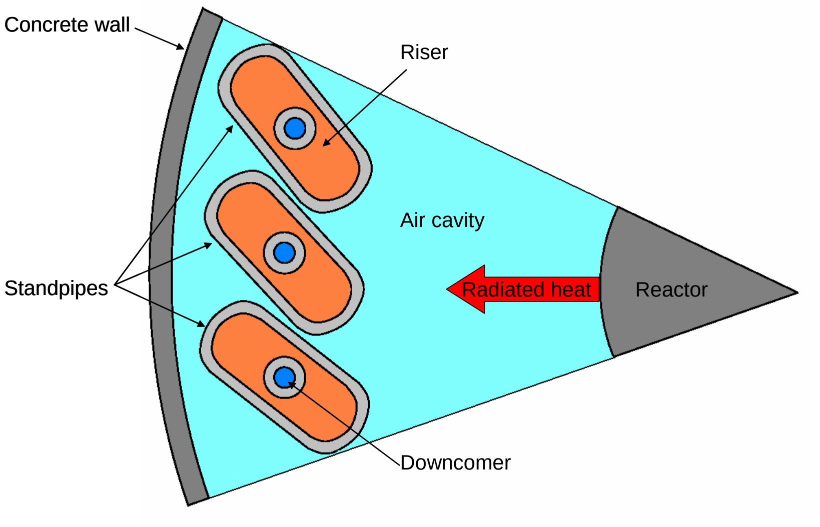

Figure 2: Top view cutout of the RCCS-Reactor configuration.

OBJECTIVE OF SIMULATION

The objective of the simulation is to investigate the operating characteristics of the RCCS for various orifice and choke-line diameters. The influence of the ambient pressure and RPV temperature on the RCCS is also investigated.

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FLOWNEX MODEL

The Flownex model of the system is shown in Figure 3. The tank is modeled with a node with a fixed volume, with the tank inlet and outlet volume fractions specified, in order to model steam separation in the tank. CHT elements are used to model the heat transfer through the solid walls of the standpipes. Radiation is activated for the outside wall CHT's in order to model the heat radiated from the reactor. The heat is radiated form a constant RVP temperature. The riser pipes are incremented to account for flashing phenomena which is expected high up in the standpipes near the tank. RD elements (Restrictor with Discharge Coefficient) are used to model the orifices at the bottom of the standpipes. It is also used to model the exit of the piping system into the tank. This is done to account for choking in the flashing region (if it exists).

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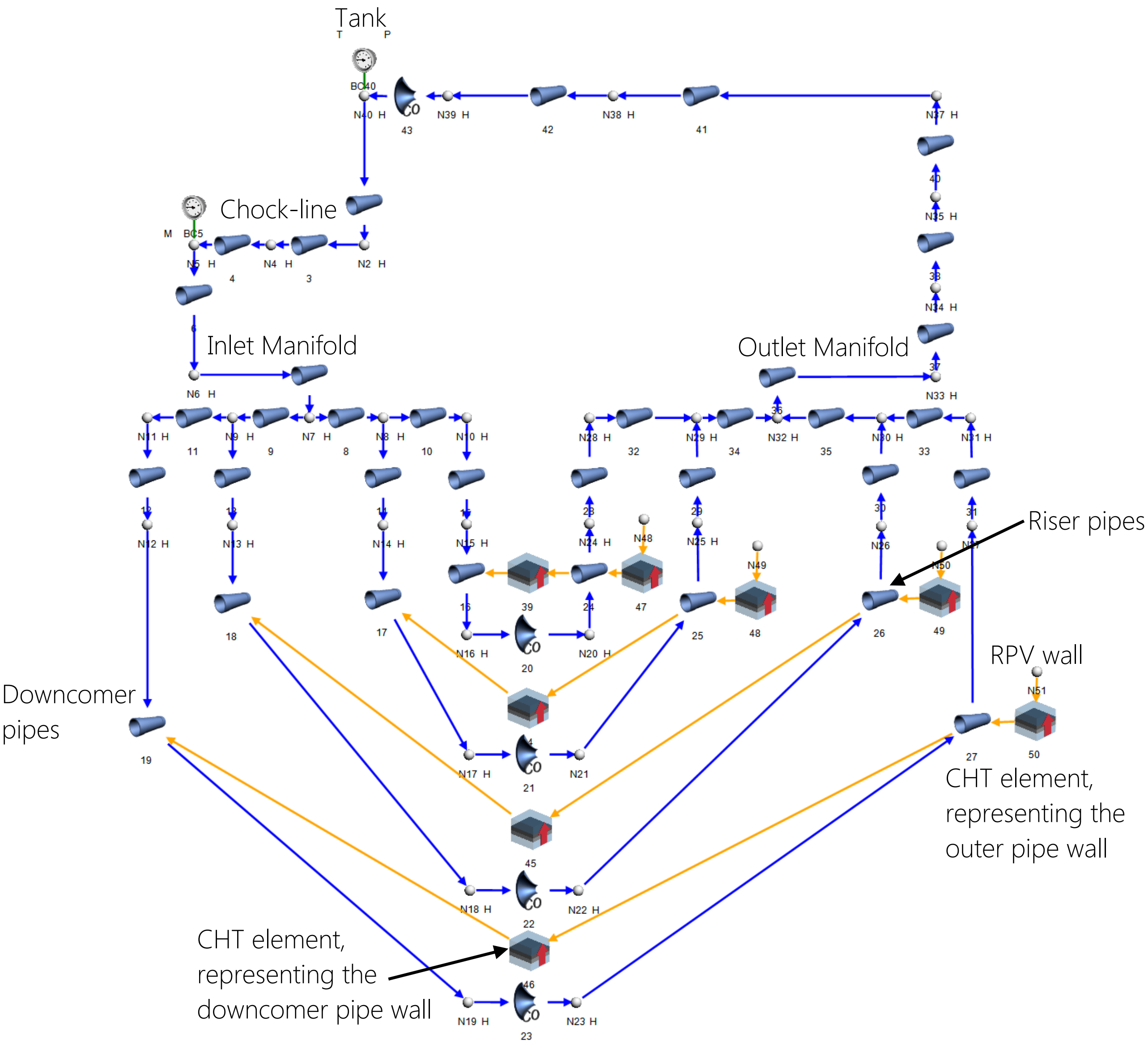

Figure 3: Flownex network of the RCCS with radiation from the RPV.

DESCRIPTION OF SIMULATION

CASE 1:

The boundary conditions for the RCCS network are as follows for the case where the effects of the orifice and choke-line diameters are investigated:

- For the tank (Node 40) the pressure and the temperature is fixed.
- For active operation, the mass flow is fixed at Node 5.
- The RPV wall temperature is fixed on the outside CHT elements.

A transient simulation is performed to investigate the operating characteristics of the RCCS in passive mode of operation for various orifice and choke-line diameters. The RCCS will only switch to passive mode of operation if the pumps trip. A transient event is specified to simulate the pump trip.

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CASE 2:

The boundary conditions for the RCCS network are as follows for the cases where the sensitivity of the system to ambient pressure and RPV temperature are investigated:

Ambient Pressure:

- The pressure is varied between 100 kPa and 60 kPa at a tank temperature of 15 °C and at saturation temperature.
- The RPV wall temperature is fixed at 325 °C.

RPV wall temperature:

- The RPV wall temperature is varied between 200 °C and 600 [°C] at a tank temperature of 15 °C and at saturation temperature.
- The pressure is fixed at 100 kPa on the tank (Node 40).

For case 2, quasi steady-state simulations are performed to investigate the influences of these system parameters.

CASE 1: RESULTS

Figure 4 shows the transient mass flow rate of one standpipe for various orifice sizes and a choke-line diameter of 0.01 [m]. The negative mass flow rates show that recirculation occurs in the standpipes.

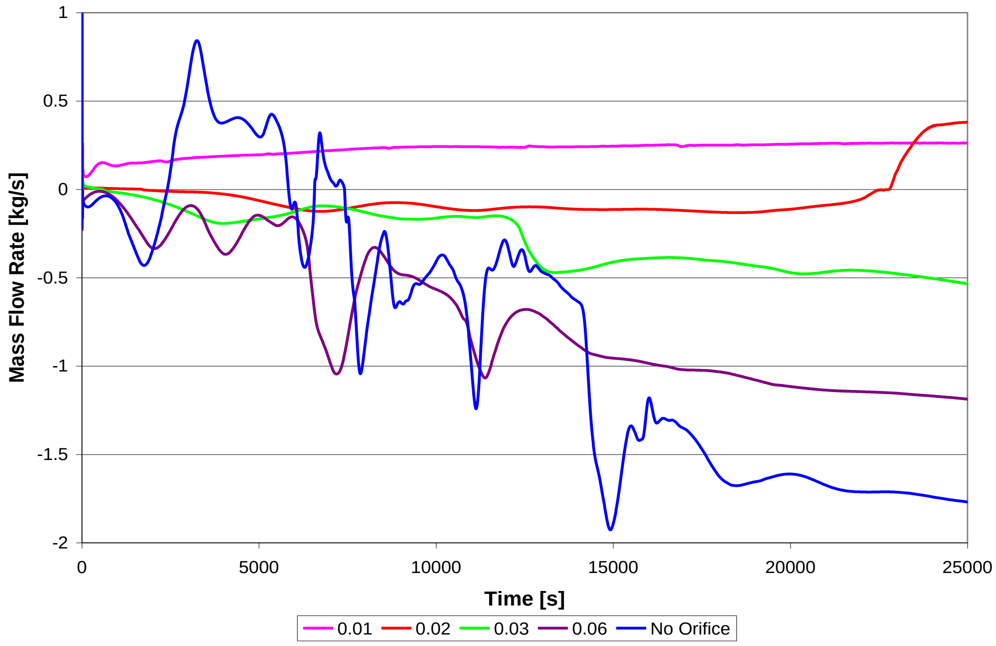

Figure 4: Passive mode: Standpipe mass flow rate for a 0.01 [m] choke-line.

Figure 5 shows the transient mass flow rate of one standpipe for various orifice sizes and a choke-line diameter of 0.02 m. No negative mass flow rates are observed, thus the RCCS is stable for any orifice size used in conjunction with a 0.02 m choke-line diameter.

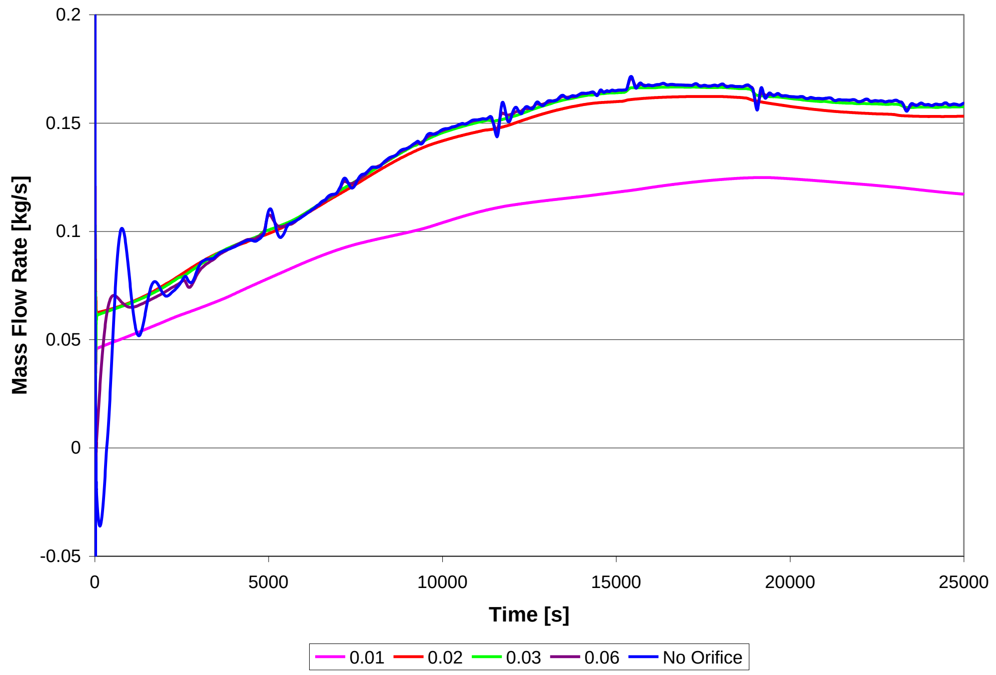

Figure 5: Passive mode: Standpipe mass flow rate for a 0.02 [m] choke-line.

Case 2: Results

Ambient Pressure Sensitivity:

Figure 6 shows the effect of ambient pressure on the system mass flow rate at a tank temperature of 15 °C and saturation temperature.

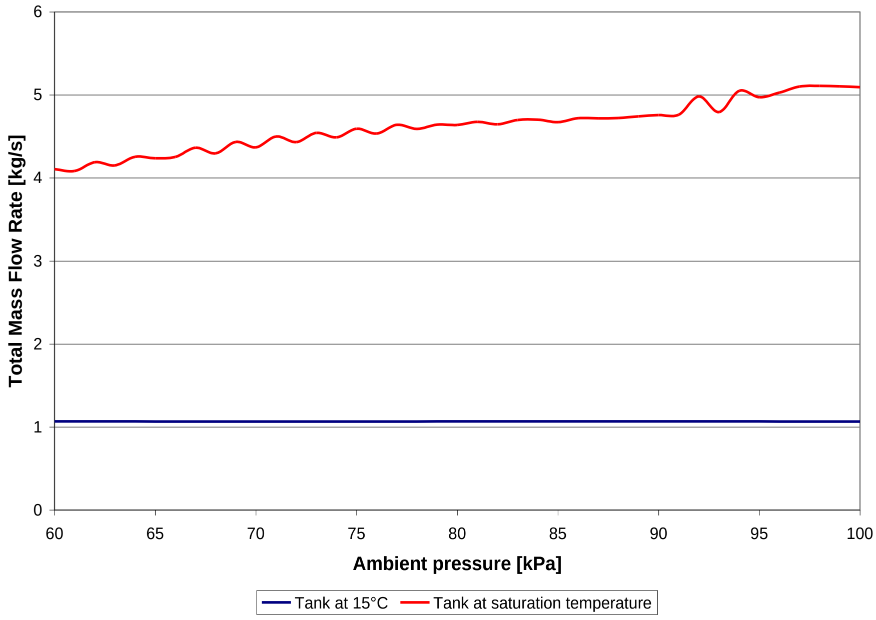

Figure 6: Total system mass flow rate vs. ambient pressure.

RPV Temperature Sensitivity:

Figure 7 shows the effect of the RPV wall temperature on the total system mass flow rate, with the tank at 15 °C and at saturation temperature.

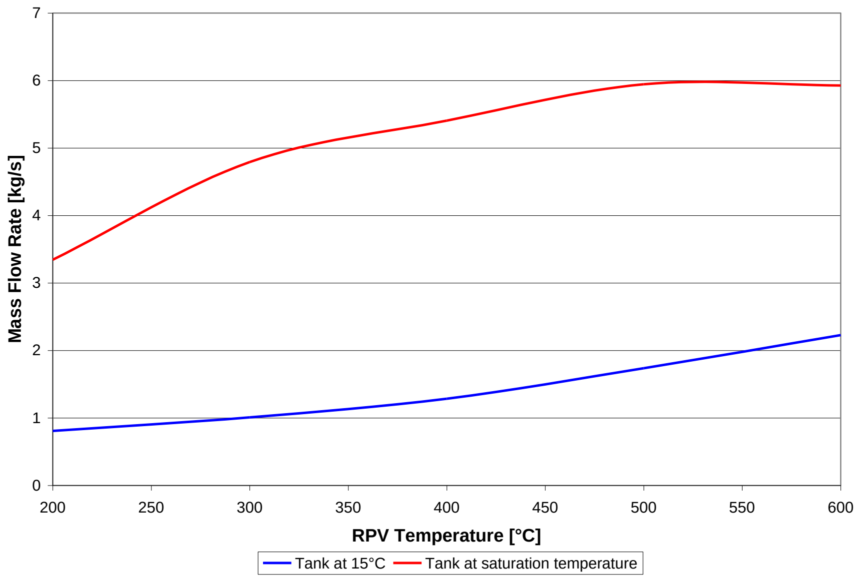

Figure 7: Total system mass flow rate vs. RPV temperature.

CONCLUSION

In Case 1, it is seen that recirculation occurs when a 0.01 m choke-line is used for all orifice sizes except for a 0.01 m orifice. It is clear that no recirculation occurs when a 0.02 m choke-line is used. Recirculation has a negative impact on the system, for it lowers the cooling capacity of the RCCS and adds uncertainty.

The sensitivity investigations revealed that the RCCS is insensitive to change in ambient pressure when the tank is at 15 °C. The effect of ambient pressure becomes more evident when the tank is at saturation temperature. This is ascribed to the change in saturation temperature with ambient pressure, which in turn affects the flashing behavior of the system.

As expected the mass flow rate increases with RPV temperature, regardless of the tank temperature.