FLOWWEX®

SIMULATION ENVIRONMENT

CASE STUDY

FLOW & HEAT TRANSFER IN A PACKED BED – STEADY STATE

This case study demonstrates the steady-state simulation of the heat transfer through a packed pebble bed. Of particular importance for the reactor model is the prediction of the pebble temperatures obtained in the case of natural convection driven flows that will prevail if the forced cooling flow though a pebble bed reactor should stop.

NUCLEAR & SMR

CHALLENGE:

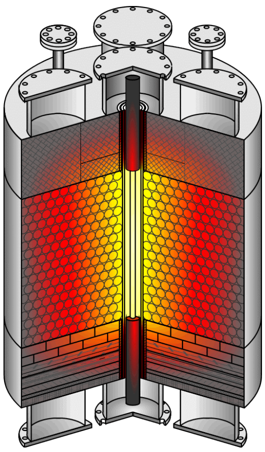
The thermal hydraulic conditions of a typical high temperature gas cooled pebble bed reactor core are simulated. Figure 1 shows a schematic of the pebble bed with a single central long heating element. The top and bottom of the bed is well-insulated while the outside of the furnace wall is open to atmospheric conditions. The heating is done with a graphite tube within a protection tube in the center of the bed.

BENEFITS:

This case study demonstrates the steady-state simulation of the heat transfer through a packed pebble bed. Of particular importance for the reactor model is the prediction of the pebble temperatures obtained in the case of natural convection driven flows that will prevail if the forced cooling flow though a pebble bed reactor should stop.

SOLUTION:

The steady-state simulation of the natural convection in a packed pebble bed was simulated. These simulations can be typically used for accident analysis of high temperature reactors when the forced cooling fluid flow is stopped abruptly, for example, if the pebble maximum temperatures and the bed's ability to remove the heat without forced convection are important.



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INTRODUCTION

This case study demonstrates the steady-state simulation of the heat transfer through a packed pebble bed. Of particular importance for the reactor model is the prediction of the pebble temperatures obtained in the case of natural convection driven flows that will prevail if the forced cooling flow though a pebble bed reactor should stop.

SYSTEM DESCRIPTION

The thermal hydraulic conditions of a typical high temperature gas cooled pebble bed reactor core are simulated. Figure 1 shows a schematic of the pebble bed with a single central long heating element. The top and bottom of the bed is well-insulated while the outside of the furnace wall is open to atmospheric conditions. The heating is done with a graphite tube within a protection tube in the centre of the bed.

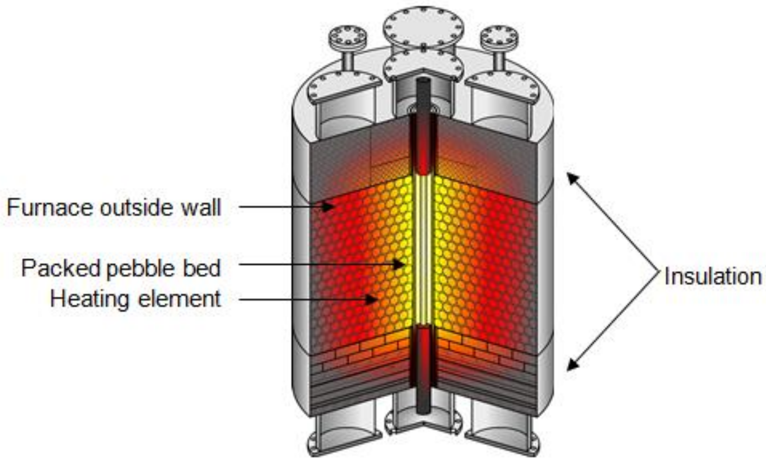

Figure 1: Schematic layout of SANA test facility taken from Nießen & Stöcker (1997).

The objective of the simulation is to simulate the natural convection in the pebble bed and predict the pebble surface temperature distribution.

OBJECTIVE OF SIMULATION

The objective of the simulation is to simulate the natural convection in the pebble bed and predict the pebble surface temperature distribution. A buoyancy force, due to the heating in the centre of the bed and the cooling on the outside of the bed, is responsible for the natural convection flow.

FLOWNEX MODEL

Flownex uses a distributed model equivalent to a 2D CFD method to solve the flow, pressure and temperature distribution inside the pebble bed reactor [2]. Figure 2 shows the network representation of the staggered CFD grid with nodes representing the control volume centers and the elements representing the convective fluxes across control volume boundaries.

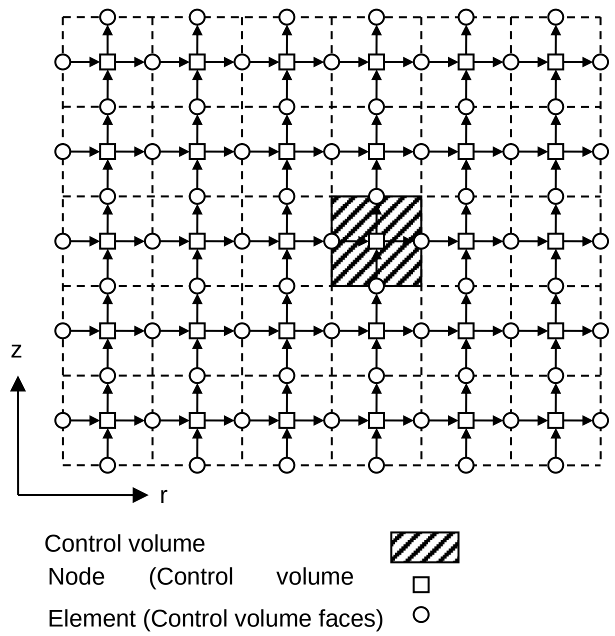

Figure 2: Flownex network representation of staggered CFD grid.

The fission heat released inside the pebbles is modeled with a point kinetics neutronics model [3]. The heat transfer inside the pebbles, heat transfer between the pebbles and heat transfer from the pebble surface to the gas is modeled through an additional network superimposed on the gas flow network as shown in Figure 3.

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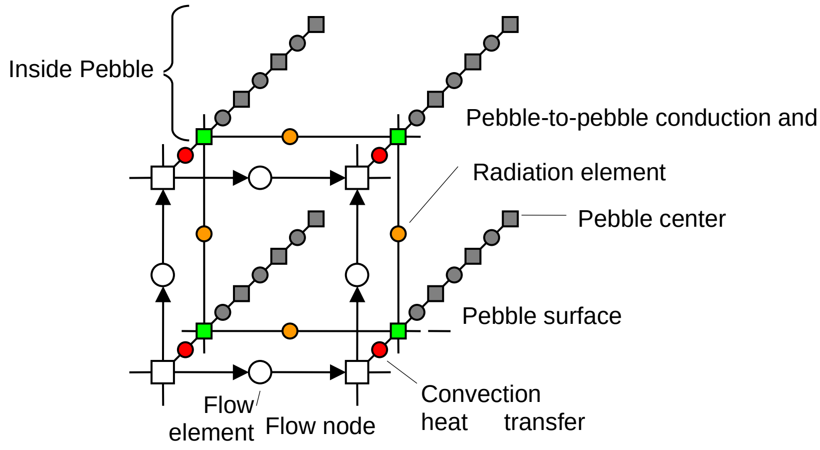

Figure 3: Network for calculating heat transfer inside the pebbles, between pebbles and between pebbles and gas.

A more detailed description of the reactor model can be found elsewhere [4].

DESCRIPTION OF SIMULATION

In this case the bed consisted of spherical graphite pebbles with 60 mm diameter. 5 kW nominal heating power along the full height of the pebble bed is modeled. The pebbles were first cooled with Nitrogen and then the simulation was repeated with Helium as the cooling fluid. The atmospheric conditions are at a pressure of 101 kPa and a temperature of 25.3 °C.

The Flownex simulation results are compared to experimental data from the SANA test facility (Nieβen & Stöcker, 1997) at different heights through the bed at certain radial positions.

RESULTS

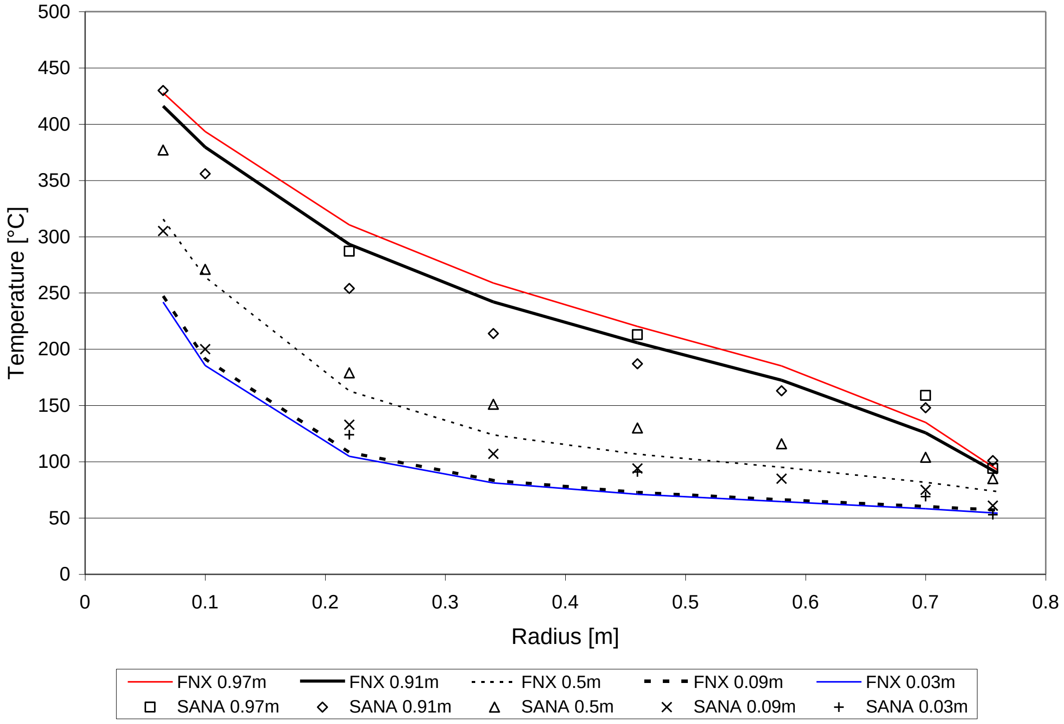

Figure 4: Flownex and SANA comparison for 5 kW heat added to a bed with Nitrogen.

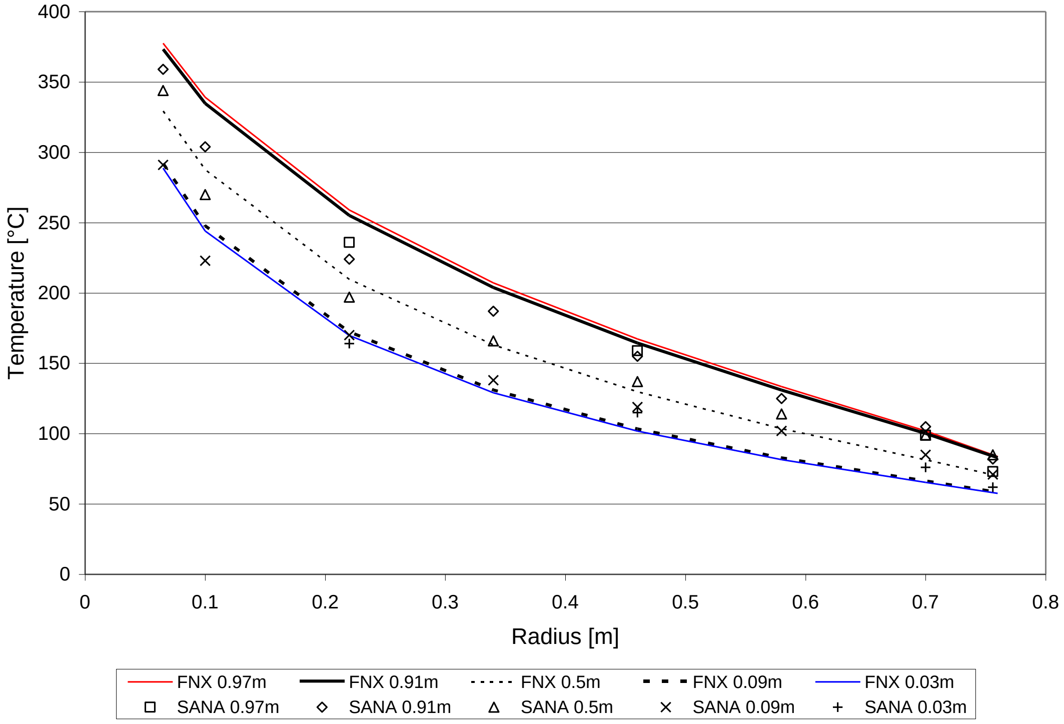

Figure 5: Flownex and SANA comparison for 5 kW heat added to a bed with Helium.

The Flownex simulation results are compared to experimental data from the SANA test facility (Nieβen & Stöcker, 1997) at different heights through the bed at certain radial positions. In Figure 4 the results for the natural convection with Nitrogen as cooling fluid is shown and in Figure 5 helium was used as cooling fluid. In the graphs "FNX" indicates the Flownex results at different heights in the bed and "SANA" indicates the experimental results at corresponding heights.

CONCLUSION

The steady-state simulation of the natural convection in a packed pebble bed was simulated. It can be seen from the results that there is more temperature stratification with Nitrogen than with Helium as cooling fluid. These simulations can be typically used for accident analysis of high temperature reactors when the forced cooling fluid flow is stopped abruptly, for example, if the pebble maximum temperatures and the bed's ability to remove the heat without forced convection are important.

REFERENCES

[1] NIEβEN, H.F. & STöCKER, B., 1997. "Data Sets of the SANA Experiment 1994-1996" JüL-3409, Forschungszentrum Jülich.

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[3] Rousseau, P.G., and Greyvenstein, G.P., 2003, "One-dimensional reactor model for the integrated simulation of the PBMR power plant", Proc. 1st Int. Conf. on Heat Transfer, Fluid Mechanics and Thermodynamics, Kruger Park, South Africa, April 8-10, 2002.

[4] Du Toit, C.G., Rousseau, P.G., Greyvenstein, G.P., and Landman, W.A., 2005, "A systems CFD model of a packed bed high temperature gas-cooled nuclear reactor", Int. J. of Thermal Sciences 45, pp 70–85.

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