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SIMULATION ENVIRONMENT

A CLOSED THREE-SHAFT, RECUPERATIVE BRAYTON CYCLE

The case study demonstrates a load following transient simulation of the Pebble Bed Micro model (PBMM). The PBMM is a closed three-shaft, recuperative Brayton cycle. It was designed and constructed in 2002 at the North-West University. Flownex was used extensively in the design of the PBMM and the prediction of its performance.

NUCLEAR POWER INDUSTRY

CUSTOMER PROFILE:

Pebble Bed Modular Reactor (Pty) Limited (PBMR) was established in 1999 with the intention to develop and market small-scale, high-temperature reactors both locally and internationally.

CHALLENGE:

The case study demonstrates a load following transient simulation of the Pebble Bed Micro model (PBMM).

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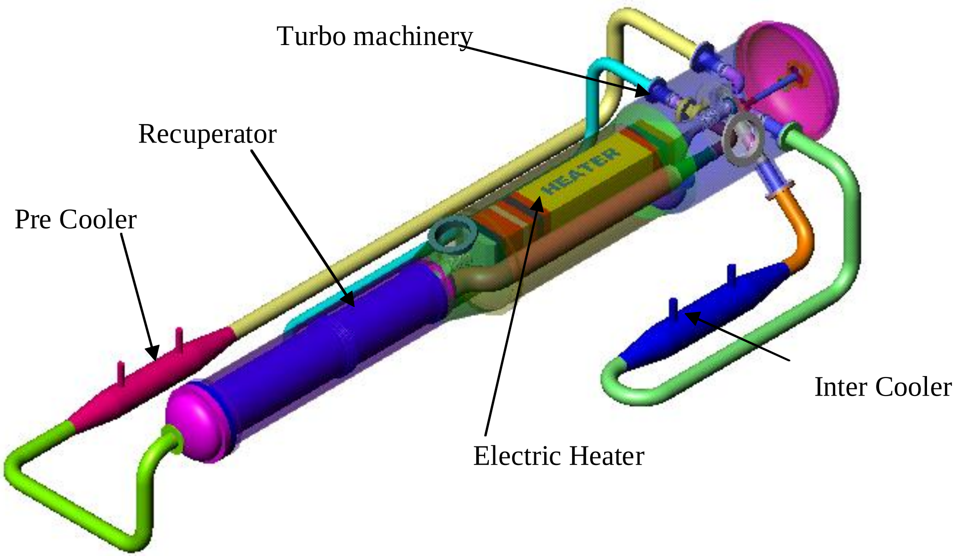
SOLUTION:

The simulation of a load following transient for the Pebble Bed Micro Model, with the thermal-fluid codes namely, Cathare and Flownex are presented in this case study. The overall results of the two codes agree quite well.



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LOAD FOLLOWING TRANSIENT SIMULATION FOR THE PEBBLE BED MICRO MODEL (PBMM)

SYSTEM DESCRIPTION

A solid model of the PBMM is shown in Figure 1 with a schematic layout of the PBMM power conversion cycle shown in Figure 2.

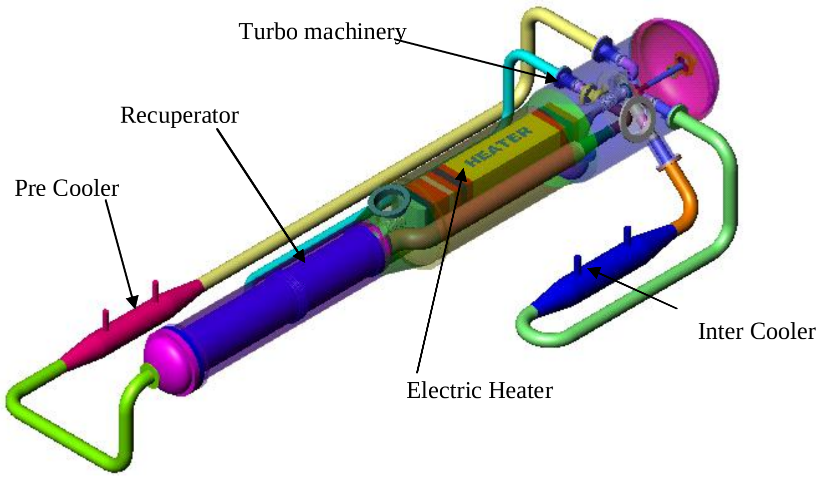

Figure 1: Solid model of the Pebble Bed Micro Model.

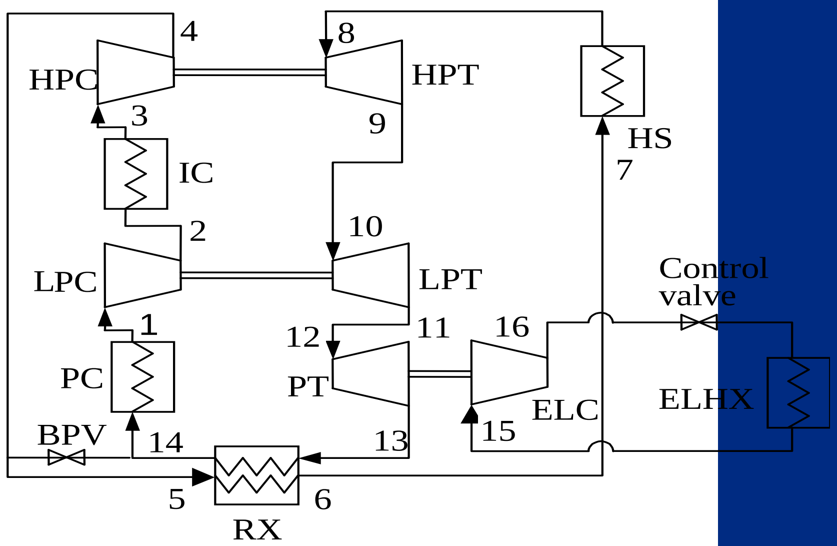

Figure 2: Schematic layout of the Pebble Bed Micro Model.

The output of the plant can be controlled by changing the nitrogen inventory of the system or by opening and closing the bypass valve.

Starting at 1 (in Figure 2), nitrogen at a relatively low pressure and temperature is compressed by a low-pressure compressor (LPC) to an intermediate pressure 2 where after it is cooled in an intercooler (IC) to state 3. A high-pressure compressor (HPC) then compresses the nitrogen to state 4. From 5 to 6 the nitrogen is preheated in the recuperator (RX) before entering the electric resistance heater (HS), which heats the nitrogen to state 8. After the electric heater the hot, high-pressure nitrogen is expanded in a high-pressure turbine (HPT) to state 9 after which it is further expanded in a low-pressure turbine (LPT) to state 11. The high-pressure turbine drives the high-pressure compressor while the low-pressure turbine drives the low-pressure compressor. After the low pressure turbine the nitrogen is further expanded in the power turbine (PT) to pressure 13. From 13 to 14 the still hot nitrogen is cooled in the recuperator after which it is further cooled in the pre-cooler (PC) to state 1. This completes the cycle. The heat rejected from 13 to 14 is equal to the heat transferred to the nitrogen from 5 to 6.

From 15 to 16 a generator is emulated by a load compressor (ELC) connected to a power dissipation loop consisting of a flow control valve and a heat exchanger (ELHX) as shown in Figure 2. Variations in load can be affected by increasing or decreasing the pressure level in the load rejection loop.

The output of the plant can be controlled by changing the nitrogen inventory of the system or by opening and closing of the bypass valve (BPV). Changing of the nitrogen inventory is a relatively slow process and is used for load following while the faster bypass control is used for load rejection.

The PBMM is based on the Brayton power cycle (as used in aircraft engines) but with the following distinguishing features:

- It uses nitrogen as the working fluid.
- The gas moves around in a closed circuit, which implies that no nitrogen is consumed in the power generation process – it merely acts as an energy carrier.
- The PBMM uses single stage centrifugal compressors and turbines. It makes use of three separate shafts, one for the high-pressure (HP) compressor/turbine pair, one for the low-pressure (LP) compressor/turbine pair and one for the power turbine (PT) and generator. This allows the HP and LP compressor/turbine pairs to run at high speeds thereby reducing the size and therefore also the cost of the machines.

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- It makes use of a recuperator to recover heat that would otherwise have been rejected to atmosphere. The recovered heat is transferred elsewhere in the system thereby reducing the heat required from the heat source and ultimately increasing the thermal efficiency of the plant.

The objective of the simulation is to model a transient operation of the PBMM where nitrogen is injected into the cycle just upstream of the Pre-Cooler (low pressure) in order to increase the inventory of nitrogen in the cycle.

OBJECTIVE OF SIMULATION

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FLOWNEX MODEL

The Flownex model of the system is shown in Figure 3.

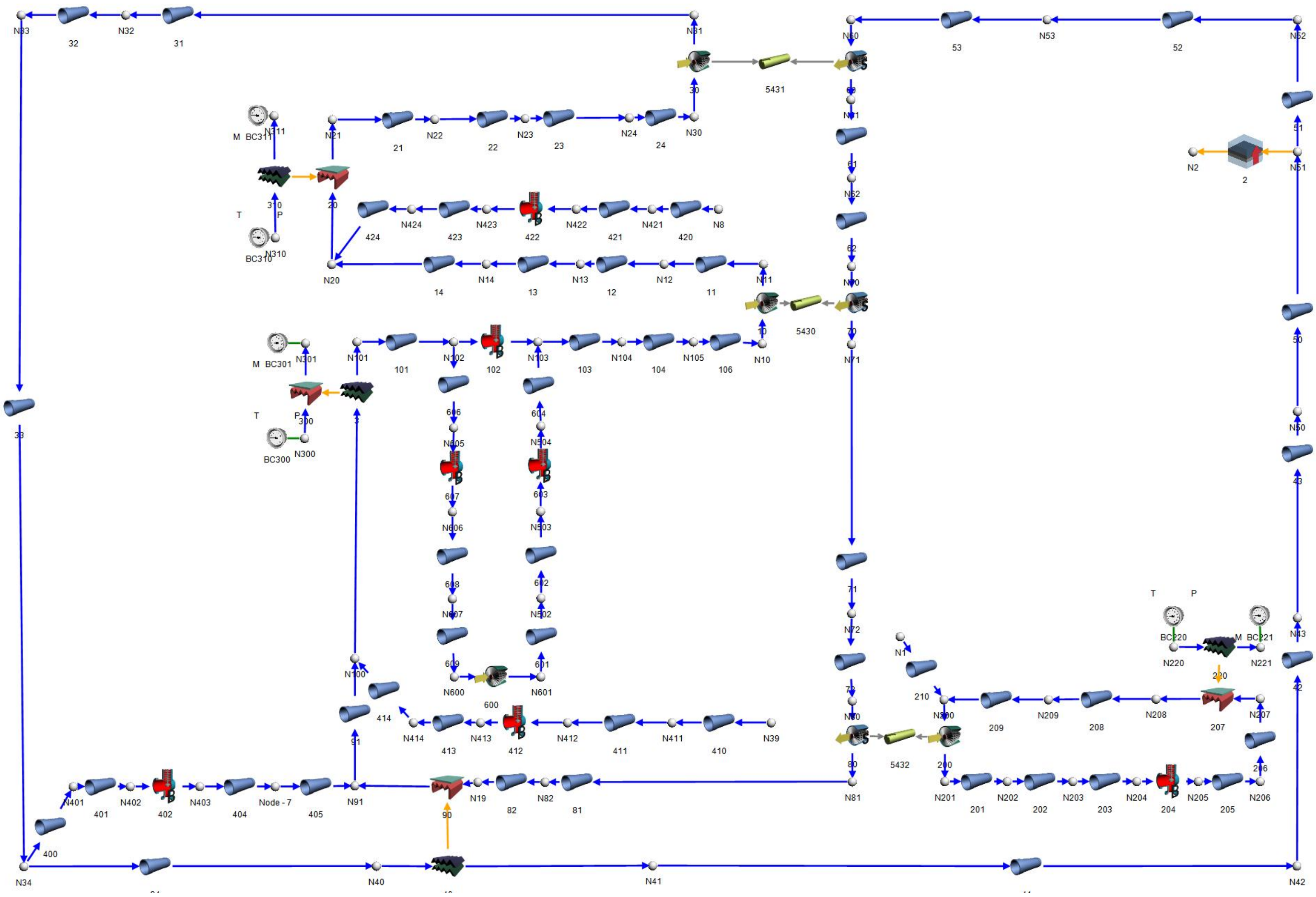

Figure 3: Flownex model of the Pebble Bed Micro Model.

DESCRIPTION OF SIMULATION

In this case, mass is injected at a low pressure point. As the mass of nitrogen in the cycle increases, the power output of the power turbine also increases. Before injection commences, the plant is run at steady state with a LPC suction pressure of 95 kPa. Nitrogen is now injected into the cycle at a rate of 0.02 kg/s until the LPC suction pressure rises to 120 kPa. The injection is then stopped. The rest of the variables remain the same. The simulation results are compared with another thermal-fluid simulation code Cathare [3], [4].

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RESULTS

The Flownex (FNX) and Cathare (CAT) [5] results for different plant parameters are shown in the next few figures for the load following transient model. Figure 4 shows the suction pressure for the LP compressor during the injection transient at the LPC suction point. It is clear that the two codes compare very well.

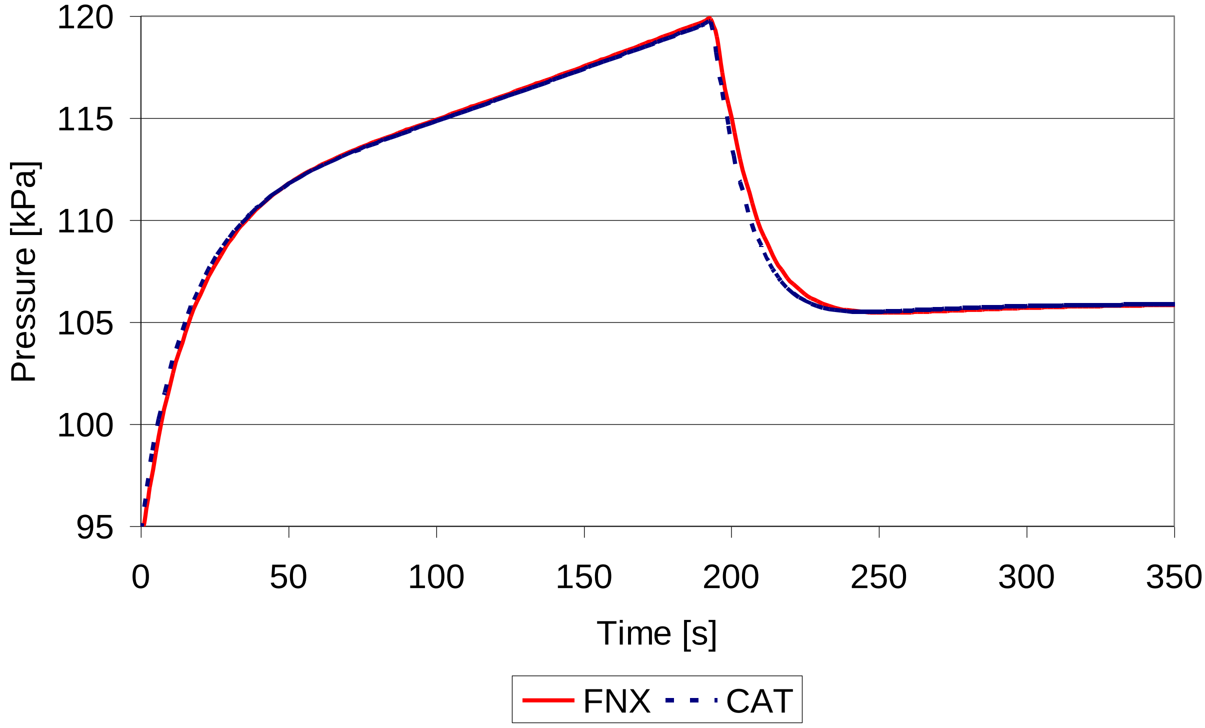

Figure 4: LPC suction pressure.

Figure 5 shows the power and speed of the power turbine in the two simulations.

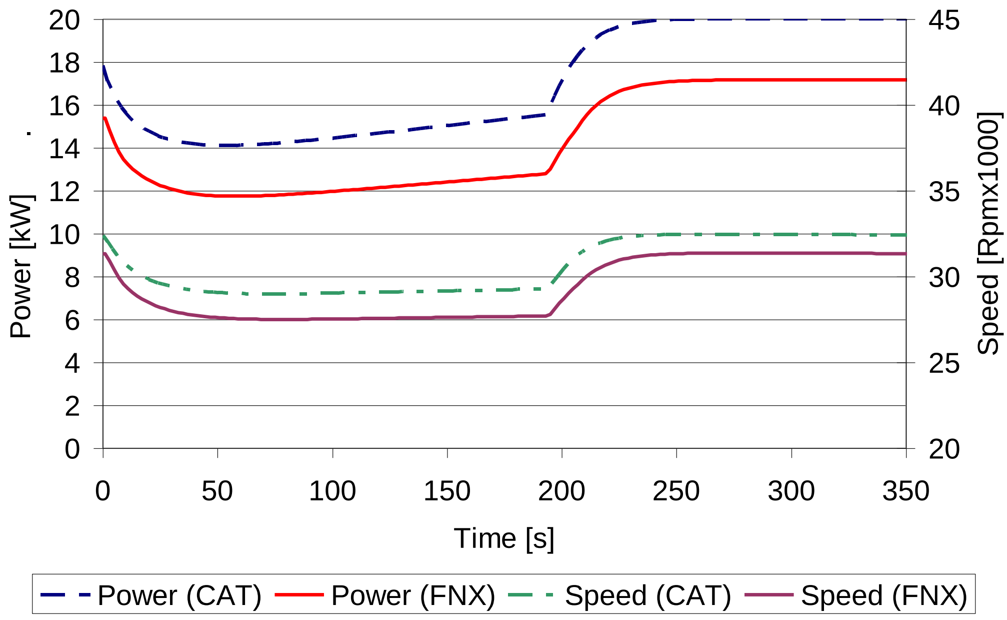

Figure 5: Power turbine power and speed.

Figure 6 shows the comparison between Cathare and Flownex for temperature and pressure at the recuperator high pressure inlet. The pressures and temperatures are within 6 and 2 percent from each other, respectively.

Figure 7 shows the heat loads of the recuperator and inter cooler. Again, the results of the two codes compare very well.

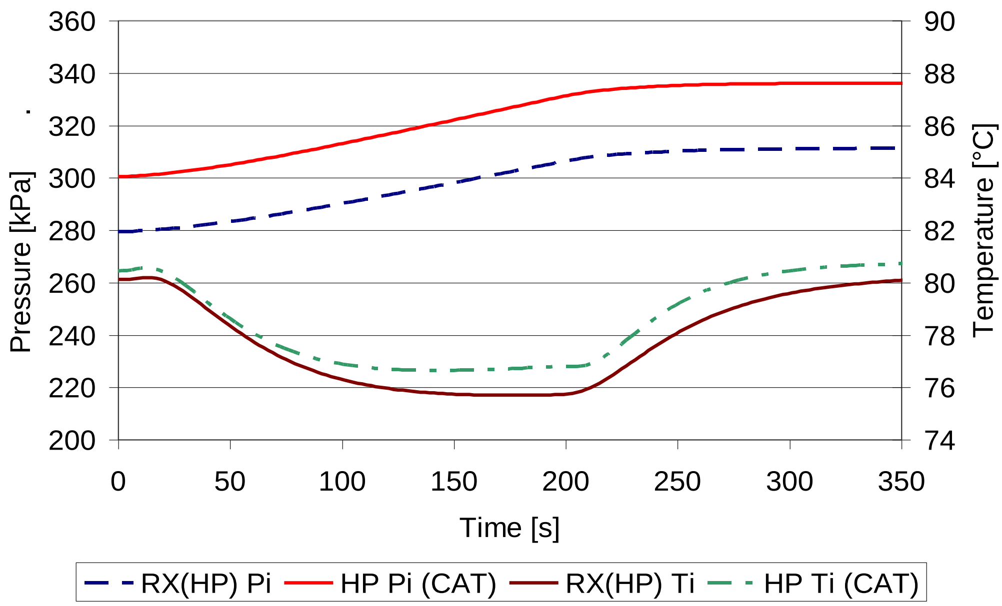

Figure 6: Recuperator high pressure side.

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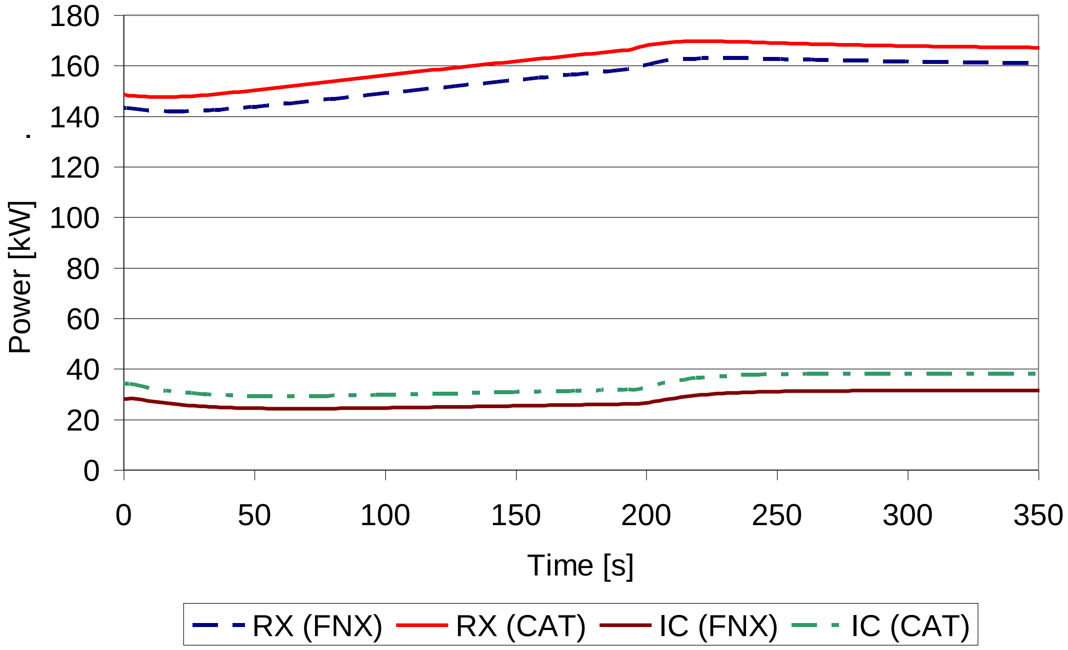

Figure 7: RX and IC power.

CONCLUSION

The simulation of a load following transient for the Pebble Bed Micro Model, with the thermal-fluid codes Cathare and Flownex, are presented in this case study. Overall the results of the two codes agree quite well.

REFERENCES

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[4] Widlund, O., Geffraye, G., Bentivoglio, F., Messié, A., Ruby, A., Saez, M., Tauveron, N. and Bassi, C., 2005, "Overview of gas-cooled reactor applications with Cathare", 11th International Topical Meeting on Nuclear Reactor Thermal-hydraulics (NURETh-11), Oct. 2-6, Avignon, France.

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