THREE-SHAFT, PRE- AND INTER-COOLED RECUPERATIVE BRAYTON CYCLE

The PBMM (the world's first closed cycle multi–shaft gas turbine test rig) was developed to demonstrate the operation of a three-shaft, pre- and inter-cooled recuperative Brayton cycle in order to gain a better understanding of its dynamic behavior. The entire cycle was designed, simulated and commissioned with Flownex within 9 months at a cost saving of $48 million.

The system was also used to validate the control strategies of the PBMR namely, startup, load following and load rejection.

In this case study we will demonstrate Flownex's ability to simulate the startup of the PBMM.

NUCLEAR INDUSTRY

PBMM:

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CHALLENGE:

The design team was faced with the following challenges:

a) Construct a three-shaft recuperated Brayton cycle that should be able to operate at design conditions, and also be able to perform dynamics such as start-up, load following and load rejection.
b) A three-shaft recuperated Brayton cycle has never been built before and was only proven as a theoretical exercise in the past.
c) Therefore no validated and verified design or experience on similar Brayton cycles was available to guide the design.
d) No off the shelf components were available for this Brayton cycle.
e) The Pebble Bed Micro Model (PBMM) was to be designed, built, commissioned and proven to work within 9 months.
f) The successful operation of the PBMM was on the critical path to boost confidence and secure funding for a larger project.

SOLUTION:

Flownex proved to be accurate in the calculation of the bootstrap point.

The powerful Transient feature within Flownex allowed accurate simulation of the start-up events within the PBMM, and proved to be a tool capable of determining complex variables in seconds. The dynamics of the compressors, turbines and thermal storage in heat exchangers are all accounted for in Flownex.

""Flownex accurately predicted various plant parameters, providing a major boost of confidence in technical feasibility of the PBMR concept"

-David Nicholls, CEO of PBMR (February 2003)

PEBBLE BED MICRO MODEL (PBMM) START-UP

NORTH WEST UNIVERSITY (RSA)

INTRODUCTION

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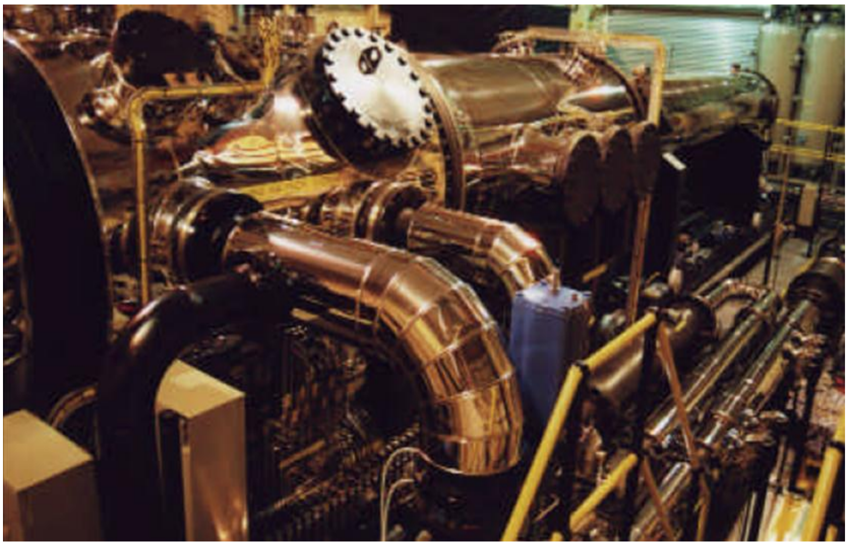
See the article "Comparison of the thermal-fluid analysis code Flownex with experimental data from the Pebble Bed Micro Model" by Van Niekerk et al.1 for a complete description of the PBMM cycle.



"… due to the successful demonstration of the PBMM and the resulting boost in confidence in the bigger PBMR project …the local economy stands to benefit on an unprecedented scale. If successful the PBMR could create more than 200 000 new jobs, add R8 billion to the country's annual gross domestic product and R10 Billion in exports."

Prof. Gideon P. Greyvenstein, Dean of the faculty Engineering, Northwest University (March 2003).

[1] VAN NIEKERK, W., GREYVENSTEIN, G.P., VAN RAVENSWAAY, J.P., LABUSCHAGNE, J.T. and SWIFT, W.J., 2006 "Comparison of the Thermal-Fluid Analysis Code Flownex with Experimental Data From the Pebble Bed Micro Model", Proceedings HTR2006: 3rd International Topical Meeting on High Temperature Reactor Technology, October 1-4, 2006, Johannesburg, South Africa.

CHALLENGES

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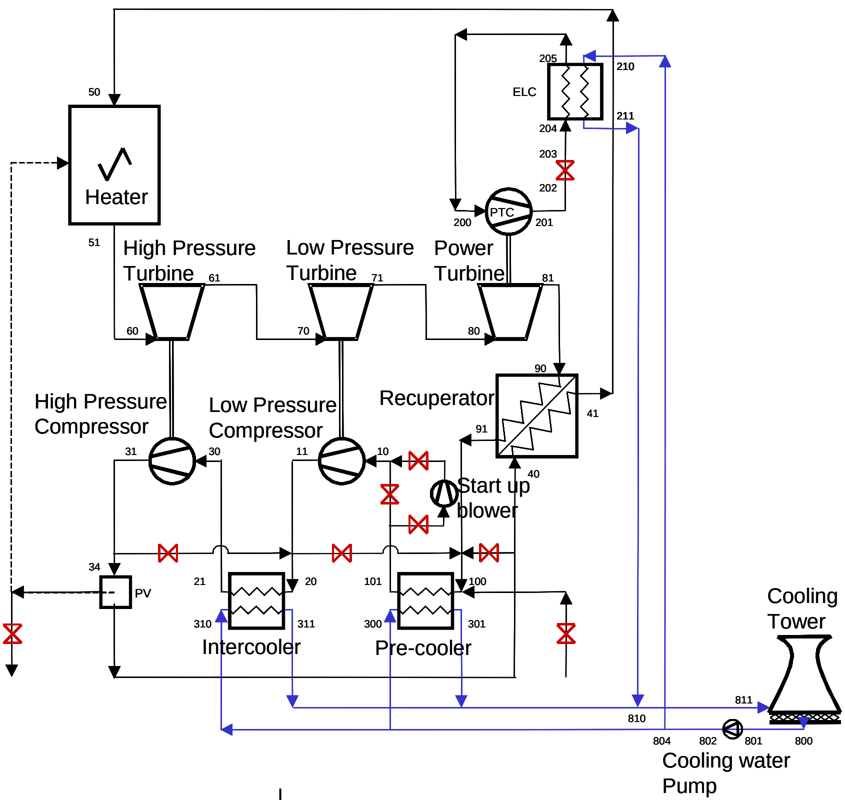
SOLUTION

Initial quotes received were in the order of $50 million and with a lead time of 3 years. This was not within the design requirements. The system as a whole was scrutinized and the turbo machines were found to be both critical for the cycle operation and having the longest lead times.



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The design team then investigated the option to buy off the shelf turbo machines and then design the rest of the cycle around the turbo-machines with the help of Flownex.

The other components in the cycle (Recuperator, Intercooler, Pre-cooler, Start-up blower etc.) were designed from the Flownex results using the off the shelf turbo machine performance characteristics as input.

The cycle was not only designed for the optimum operating point of the cycle but also for off design conditions as required and especially for start-up of the cycle. For start-up, the power to the heater is kept constant. As the system heats up, the outlet temperature of the heater rises as the inlet temperature rises. As a result the system pressure increases and the systems dependence on the start-up blower decreases. The cycle spirals towards self-sustained circulation and the Start-up Blower System is disengaged. At this condition the cycle is said to have bootstrapped.

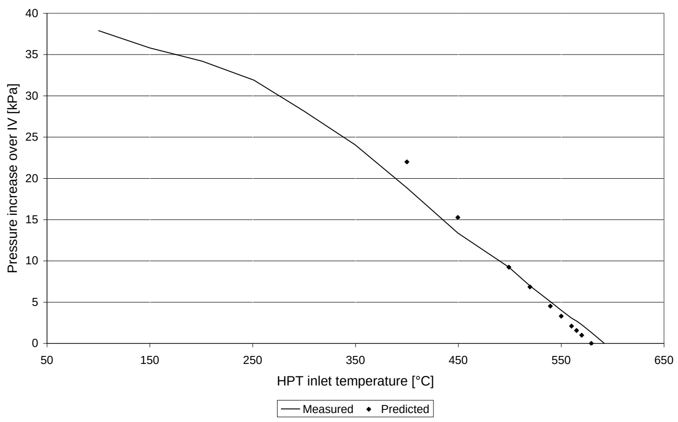
Using Flownex, the start-up procedure of the PBMM was simulated, and it could be determined beforehand where changes to the procedure were necessary. The temperature the system will bootstrap at was also determined with the help of Flownex simulations.

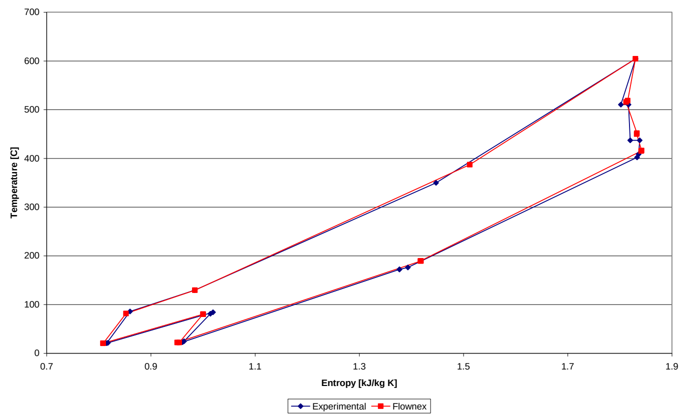
The exit temperature of the heater is probably the most important determinant of the bootstrap point as the energy that the turbines can deliver depends on the inlet gas temperature.

Flownex predicted the bootstrap temperature as shown below. In the figures a comparison between the calculated and measured variables can be seen.

"Flownex provides a suitable compromise between accuracy, complexity and speed while allowing integrated simulation of the entire plant within acceptable computer times"

Prof. Pieter G. Rousseau,
Professor of Mechanical Engineering and Director of Energy Systems Research at Northwest University,
South Africa (March 2004)





The heat loss to ambient conditions, the transient behaviour of the turbo machines, the thermal inertia of the heat exchangers and the system as a whole, the pressure drop and heat transfer through the piping and valves were integrated in Flownex to be able to design an operational plant from the selected turbo machines without any prior practical knowledge of a similar three shaft recuperated plant. Not only was the plant designed for a design point operating condition, the start-up of the plant from cold initial conditions, through the bootstrap point to the designed operating point was predicted with Flownex very accurately.

The powerful Transient feature within Flownex allowed accurate simulation of the start-up events within the PBMM, and proved to be a tool capable of determining complex variables in seconds. The dynamics of the compressors, turbines and thermal storage in heat exchangers are all accounted for in Flownex.

RESULTS

The initial cost estimates were in the order of $50 million and with a lead time of 3 years. The Pebble Bed Micro Model was designed, manufactured, constructed, commissioned and proved to be successful within 9 months as required and at a cost of only $2M. Flownex was instrumental throughout the design of the cycle and provided the design team with quick, accurate and integrated performance information. This performance information enabled the design team to make critical time saving decisions in terms of component selection and component interaction and still ensure cycle controllability at design and off design conditions.

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