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OPERATIONAL UPSET TRANSIENTS IN A DUAL BOILING BINARY CYCLE GEOThermal POWER PLANT

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ABSTRACT

The effects of operational upsets (such as a valve or pump failure) on a dual boiling binary power plant with isobutane as the working fluid are discussed. These results are based on a mathematical simulation using vendor specifications of the existing components and materials in the 5MW(e) Raft River Pilot Plant. The major problems which can result are excessive heat-up or cool-down rates in the heat exchangers and reverse flow into lower pressure areas. Effects of upsets on plant operation are discussed and appropriate counteractive operator action is recommended.

INTRODUCTION

A method for utilizing a moderately low temperature (approximately 140°C) geothermal resource in the production of electrical power employs a two-boiler binary cycle with an organic as the working fluid. The geothermal fluid transfers its heat to the working fluid causing the working fluid to vaporize. Turbine, producing work which powers an electric generator.

The probability of a catastrophic operational failure is very low in a dual boiler binary cycle power plant, whereas the probability of an upset which is potentially damaging only to operating equipment (such as a pump or valve failure) is comparatively higher. Special care should be taken, therefore, to design and operate the system in a manner which will prevent or minimize damage to equipment.

In light of this, the purpose of this paper is to present results of a study on the effects of major upsets for a dual boiler binary system, so that the characteristics of unanticipated design and operational problems can be recognized and damage prevented. A mathematical model was used to simulate the effects of operational upsets on the system. The model used parameters of the 5MW(e) Raft River Pilot Plant, but similar results will be observed for other dual boiler binary systems.

This paper will include the most significant upsets of those which were studied:

- Sudden closure of the turbine bypass valve during thermal loop steady-state.
- Total loss of geothermal fluid flow during normal operational steady-state.
- Sudden opening of the isobutane heat exchanger bypass valve during normal operational steady-state.
- Total loss of cooling water flow during normal steady-state.

SYSTEM DESCRIPTION

We used a mathematical model to simulate the basic thermal loop for a dual boiling binary cycle. We analyzed the effects of the upset transients for a geofluid temperature of 140°C at a flow rate of 4.53 \times 10^6 kg/hr, at an ambient wet bulb temperature of 18°C and 10% of design fouling. The thermal loop is depicted in Figure 1. Design fouling resistance on the geothermal side of the heat exchangers is 2.64 \times 10^{-2} m^2°C/W, on the isobutane side is 8.81 \times 10^{-5} m^2°C/W, and on the cooling water side of the condenser is 1.76 \times 10^{-4} m^2°C/W.

As can be seen in Figure 1, the geofluid passes through two boilers and two preheaters (11, 12, 13, 14, 15) where it transfers its heat to a working fluid, isobutane. The isobutane pumps move the isobutane from the condensate storage tank at 3.07 \times 10^6 Pa in the low pressure preheater (1). The low pressure boiler feed valve then throttles approximately 34% of the isobutane (8) causing the pressure to drop to 1.32 \times 10^6 Pa. The geofluid further heats and vaporizes the isobutane to 78.3°C in the low pressure boiler (9). The other 66% of the isobutane from the low preheater enters the high pressure boiler to 113°C at 2.54 \times 10^6 Pa (3). The boiler feed valves automatically maintain the levels in the boilers. During start-up and thermal loop steady-state, isobutane vapor bypasses the turbine (4, 9). During normal operation, isobutane vapor expands through the turbine where some of its energy is transformed into mechanical work which powers the electric generator. At the Raft River Facility the 44MW of energy which are transferred from the geofluid to the isobutane in the heaters and boilers generate 5MW of electricity. After

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accounting for power usage by the plant, 3.1MW of power is actually transferred to the electrical grid.

The condensation in the condenser of the vapors exhausting from the turbine completes the isobutane cycle. The condensation takes place at 36°C and subcooling occurs to approximately 34°C, at which time the isobutane enters the condensate storage tank. The cooling water used to condense the isobutane is cooled in a wet cooling tower. If the boiler demand for isobutane flow is not sufficient to maintain the isobutane pump's capacity, part of the flow automatically bypasses the heat exchangers through the flow control bypass valve.

**MODEL DESCRIPTION**

We modeled the previously described dual boiling binary cycle mathematically. The INEL CDC Computer System using the Time and Frequency (TAF) Computer Simulation Code (Springer 1968) solved a set of representative mathematical equations with additional input appropriate to the modeled upset. The resulting transients represent the effects of the upsets on the system without operator intrusion. We modeled pumps, valves, and controllers using the Raft River Power Plant's vendor specifications. We modeled the turbines using manufacturer's values for stage flow coefficient as a function of pressure ratio, and stage isentropic efficiency as a function of velocity ratio. We modeled the cooling tower using Merkel's Theory for cooling tower performance along with manufacturer's supplied data, and we modeled the heat exchangers using appropriate correlations for convective and conductive heat transfer accounting for fouling resistance and thermal storage in fluids and tubes. More information on how we applied these specifications to the model can be obtained from a paper presented by Bliem (1980).

**RESULTS**

**Sudden Closure of High Turbine Bypass Valve**

The sudden closure of the high pressure turbine bypass valve has a negative impact on the plant operation only while the throttle valve to the respective turbine is closed, as it is in plant start-up or thermal loop steady-state. Immediately after this upset occurs, the boiler feed valve closes automatically in order to maintain the level in the boiler. The isobutane flow through the high pressure boiler drops to zero and the flow through the condenser drops to the flow through the other, still operable, turbine bypass valve. Since the isobutane is trapped in the boiler, the temperature of the isobutane increases. The temperature in the other boiler also increases slightly, since there is more heat in the geofluid which has not been transferred away.

As the pressure rises in the bottled up boiler, the liquid level drops. After 50 seconds, the valve which controls flow into the affected boiler
(boiler feed valve) opens to allow more isobutane to raise the boiler liquid level. This creates a problem in the case of the high turbine bypass valve failure. Since the pressure in the high pressure boiler is higher than in the low pressure boiler and the recirculation loop, isobutane flows into these lower pressure areas. This causes the liquid level to drop and the boiler feed valve to stay open.

During this upset, the operator should beware of excessive pressures and temperatures in the condenser which could result and cause damage to the condenser and the isobutane feed pump. Most systems will be designed to trip-off the isobutane pump before the higher temperatures cause extreme cavitation and loss of suction or pump damage. The condenser pressure will approach a maximum of 6.89 x 10^5 Pa at 49°C within 115 seconds of upset initiation. If the condenser is designed to handle only 6.89 x 10^5 Pa (20% above normal operating pressure), the condenser may not be able to contain the pressure. Unlike most systems, the Raft River condenser is designed to handle 1.59 x 10^6 Pa, which will never be approached during this upset, and therefore, does not constitute a problem. In systems which are not designed to handle higher pressures in the condenser, this problem can be averted by installing a check valve downstream of the high pressure boiler feed valve. In which case, appropriate action needs to be taken by the operator to shut down the plant before boiler pressure exceeds boiler design values. Procedures need to be developed where the operator manually shuts off the involved line and flow of isobutane, and bypasses the geofluid around the exchangers and turbines. The operator should immediately start the high turbine bypass valve upset. In these operator actions, pressures, heat-up, and cool-down rates which exceed design values should be avoided.

Sudden Opening of Isobutane Heat Exchanger Bypass Valve

Backflow would also occur in the event of an isobutane heat exchanger bypass valve's failure to close while the plant is in full operation with the turbines loaded. The isobutane would flow immediately from the high pressure boiler to low pressure areas elsewhere in the plant, such as the low pressure boiler and the isobutane bypass loop. After 8 seconds, the high pressure boiler isobutane would flow only into the low pressure boiler. The low pressure boiler would continue to operate normally with a slightly higher flowrate; whereas, the flow through the high pressure boiler would decrease and level off to a negative flow. The level of isobutane in the high pressure boiler would continue to fall as the isobutane flows out of the boiler. The valve which controls the high pressure boiler liquid level would open fully in response to demand for a higher liquid level and would stay open since the level cannot be increased. This process continues until there is no isobutane in the high pressure boiler. Excessive pressures and temperatures will not result in the condensate storage tank as they did for the high pressure turbine bypass valve failure, since backflow is not extensive. This upset can be corrected by closing the hand valve or remote valve which is also located on the isobutane heat exchanger bypass line.

Loss of Geofluid Flow

In the event that both geofluid boost pumps fail, the production well pumps fail, or the flow is suddenly diverted around the plant, the flow of geothermal fluid through the plant would cease. The amount of heat which is transferred to the isobutane working fluid would then decrease. This would cause the temperature of the isobutane to decrease in the boilers by as much as 15°C and the pressure by as much as 1.03 x 10^5 Pa in 100 seconds. The boiler feed valves respond automatically by closing, in an attempt to keep the level in the boilers constant. This temperature transient can create a problem if the system is not designed to handle a 20°C/min cool-down rate. Some systems are not designed to handle extreme temperature changes in normal operation because of limitations on the design of the exchangers, the piping, or the welded connections. If these design values are exceeded, thermal stress may cause the exchangers or piping to break apart at their weak points, thus allowing leakage of isobutane.

If the operator observes a sudden temperature transient which could be attributable to the flow of geofluid, he should immediately shut off the flow of isobutane and let the system cool down slowly. This will alleviate the thermal stress which could result from the ensuing temperature transient.

Cooling Water Upset

A cooling water pump failure could cause the flow of cooling water through the condenser to cease. The temperature of the isobutane which flows through the condenser would then increase from 35 to 53°C in 50 seconds or 22°C/min. In the first two minutes of this transient, the pressure would also increase to 1.59 x 10^6 Pa. The condenser pressure or turbine exhaust pressure would increase, causing the flow of isobutane through the turbine to decrease. The flow of isobutane through the pump would decrease until the recirculation loop is activated and then remain constant, whereas the flow of isobutane into the preheaters would continually decrease. Since the flow would decrease, the valve which controls the flow into the boiler would automatically close in an attempt to keep the level constant.

The major operational concern during this upset is the excessive temperature changes and condenser pressures which result: most systems are not designed to handle 22°C/min temperature changes and 1.59 x 10^6 Pa condenser pressures. If the operator observes system conditions which are characteristic of this upset (no cooling water flow, increase of isobutane temperatures and pressures), he should immediately shut off and isolate geofluid and isobutane flow.
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CONCLUSIONS

Based on a computer simulation of a dual boiling binary cycle, it was determined that the discussed operational upsets could cause system damage if appropriate action is not taken. In the case of a sudden closure of the turbine bypass valve or the sudden opening of the isobutane heat exchanger bypass valve, reverse flow into the lower pressure areas from the high pressure boiler would occur. Damage to the condensate storage tank and pump could result. This situation could be alleviated by developing operational procedures which direct the operator to manually shut off the involved line and, if necessary, the geofluid flow. In the case of a loss of geofluid flow or cooling water flow, excessive heat-up or cool-down rates would result. Operator action could avert this by shutting off the isobutane and geofluid flow through the plant and allowing it to cool down slowly.

REFERENCES


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