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**Potassium Vapor Topping Cycle
Technical Progress Report for
April 1 to June 30, 1977**

R. S. Holcomb

OAK RIDGE NATIONAL LABORATORY
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POTASSIUM VAPOR TOPPING CYCLE[©]
TECHNICAL PROGRESS REPORT FOR
APRIL 1 TO JUNE 30, 1977

R. S. Holcomb

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POTASSIUM VAPOR TOPPING CYCLE
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R. S. Holcomb

ABSTRACT

The potassium vapor topping cycle is a concept for increasing the efficiency of the Rankine vapor cycle by raising the peak temperature by employing a potassium vapor cycle with a turbine inlet temperature of 1500 to 1600°F (815 to 870°C) in which the waste heat rejected from the condensing potassium vapor is transferred to boiling water and steam in a conventional steam cycle. An efficiency of about 50% is calculated for this cycle with a natural circulation potassium boiler fired by gas or oil.

An Energy Research and Development Administration (ERDA) program is under way at Oak Ridge National Laboratory (ORNL) to build a full-scale potassium boiler tube bundle and burner module and test it with water and then potassium. This is the third in a series of quarterly progress reports.

The design work necessary for the installation of the potassium system was completed during the quarter. Fabrication of the potassium system components was finished. Installation of the condenser enclosure was completed and the drain tank was installed. Construction work on the equipment tower was completed.

I. SCOPE

A. Introduction

One important step that can be taken to reduce the national fuel consumption is to increase the efficiency of thermodynamic cycles. Few realize that a major factor in keeping our consumption from increasing more rapidly than it has during the past century has been an increase in the thermal efficiency of steam plants by about a factor of 8. Unfortunately, there has been no further increase since about 1950 because at that time we reached the upper practicable temperature limit for the steam cycle; namely, about 1000°F (538°C). To reach higher thermal efficiencies, it will be necessary to go to higher temperatures, which in

turn implies the use of other working fluids. A leading candidate for an advanced thermodynamic cycle is a potassium or a cesium vapor cycle.

The approach proposed by Oak Ridge National Laboratory (ORNL) entails raising the peak temperature of the thermodynamic cycle by employing a potassium vapor Rankine topping cycle; this operates with a turbine inlet temperature of 1500 to 1600°F (815 to 870°C) superimposed on a conventional steam cycle with a turbine inlet temperature of about 1000°F (538°C) by transferring the waste heat rejected from the condensing potassium vapor to the boiling water of the steam cycle.¹ Design studies have indicated that a cycle efficiency of about 50% can be achieved² with a natural-circulation boiler fired by gas or oil in a potassium topping cycle.

The basic layout of the power plant envisioned is shown in Fig. 1. Three basic systems are coupled to form the power plant: a gas turbine that supercharges the combustion chamber for the potassium boiler, the potassium vapor topping cycle, and an essentially standard steam cycle. The most important components involving new technology are the furnace-potassium boiler unit and the potassium condenser-steam generator unit, both of which employ tube bundle modules as their basic unit of construction.

The ORNL gas- or oil-fired potassium boiler concept employs a basic tube bundle module that consists of two annular rows of 1 in.-diam stainless steel tubes arranged around a 22-in.-diam, 16-ft-long, vertical, cylindrical chamber. A full-scale test unit is shown in Fig. 2. The flame from the burner directs hot gas upward through this combustion chamber. The tubes are bent at the top to provide flow passages between them so that the hot gas from the top of the combustion chamber can flow radially outward and then downward through an outer annulus over the outer row of tubes. To reduce the amount of heat transfer surface area required, the furnace and combustion chambers would be operated at a pressure of 6 to 10 atm, which is substantially above the 2 atm which would be the design operating pressure of the potassium vapor system. Potassium would circulate under natural thermal convection from a header tank at the top of the tube bundle through two downcomers, one on either side, to two ring-shaped manifolds at the bottom and then vertically upward through

Fig. 1. Flow sheet for the proposed Potassium Vapor Topping Cycle System showing the relationships of the major components.

Fig. 2. Photo of the ORNL potassium boiler under construction.

the tubes back to a header drum and vapor separator at the top of the header tank.

Preliminary studies have also indicated that a particularly attractive system could be obtained by coupling a potassium or cesium vapor cycle to a fluidized-bed coal-combustion system. One very promising concept is a fluidized bed that would operate at a temperature of about 1700°F (927°C) and a pressure of about 5 atm. This pressure yields an acceptable pressure drop with a bed of sufficient depth to employ a vertical-tube natural-circulation boiler. To minimize the problems of turbine bucket erosion, corrosion, and deposits, the hot gases leaving the bed would be cooled to about 1000°F (538°C) before being admitted to a gas turbine to give a power output just sufficient to drive the compressor. The studies indicate that a cycle efficiency of about 48% can be achieved with this type of system.

The key factor in achieving the lower capital cost and higher thermal efficiency projected by the ORNL design lies in employing a vertical-tube natural-circulation boiler rather than a horizontal-tube forced-circulation one. Therefore, since this is a new design, it is very important that successful operation of the natural-circulation boiler be demonstrated. A program for testing a full-scale tube bundle and burner module on water and then on potassium was initiated to investigate the uncertainties that have become evident in the course of the design. These uncertainties fall into four major problem areas: burner performance; combustion gas heat transfer; flow distribution of the two-phase potassium liquid-vapor mixture and the tube bundle temperature distribution; and the vapor separator effectiveness. In many cases the cumulative uncertainties in the analysis are substantial and can be resolved only by obtaining test data. A section through the test module is shown in Fig. 3.

The water tests, which are being run with boiling at atmospheric pressure, are designed to provide as much insight into these problems as possible. In the first phase of the tests, the boiler drum top is open so that visual observation of the flow from the boiler tubes is possible. The open boiler drum will also make it much easier to install instrumentation that will provide a detailed picture of the flow distribution; this will not be the case in later tests with potassium.

Fig. 3. Section through the gas-fired potassium boiler tube bundle module, burner and furnace assembly.

The potassium test will provide a test of the boiler bundle and furnace at the design conditions of full pressure and temperature for potassium operation. Although visual observation and measurement of flows from each boiler tube cannot be done while operating with potassium, the tube bundle temperature distribution will provide an indication of the potassium two-phase flow distribution.

The results obtained from the test program will provide boiler design data that will be beneficial to both gas-fired and fluidized-bed coal-fired systems.

B. Objective

The overall objectives of the program are to complete the water tests; design, fabricate, and install the potassium system; and run the potassium test. These objectives are to be achieved in the following manner.

1. Water tests

- a. Check out the boiler and furnace.
- b. Check out combustion air seals.
- c. Measure tube bundle and flue gas temperature distribution.
- d. Observe argon distribution.
- e. Operate at a power level of 2×10^6 Btu/hr.
- f. Observe boiling stability.
- g. Establish minimum power level for stable boiling in outer tube bank.
- h. Measure heat load on individual boiler tubes.
- i. Observe vapor separator performance.

2. Potassium system

- a. Complete the design of components and modifications.
- b. Perform system modifications and fabrication of components, including tower extension, condenser, drain tank, piping, sample box, electrical system, instruments and controls.
- c. Install the components.

3. Potassium test

- a. Check out system.
- b. Measure tube bundle and flue gas temperature distribution.
- c. Monitor boiling nucleation problem.
- d. Operate at power levels up to 4×10^6 Btu/hr.
- e. Observe liquid level control.
- f. Observe vapor separator performance.
- g. Run 200-hr endurance test.
- h. Determine minimum argon flow required for nucleation.

II. PROGRESS TO DATE

A. Work Prior to FY 1976

Work on alkali metal vapor cycles at ORNL began with some design studies under the Aircraft Nuclear Propulsion Program in 1954 and was resumed in 1958 with studies of nuclear electric space power plants. This led to an extensive series of component and system tests resulting in ~200,000 hr of boiling potassium system operation in the early and middle sixties. When the pressing need for reductions in both fuel consumption and heat rejection to the environment became evident in 1970, a design study of a potassium vapor cycle plant sponsored by the National Science Foundation (NSF) was carried out.¹⁻³ This plant was designed to operate on clean gaseous fuel derived from coal, which was the preferred fuel of the future for central stations at that time. The study showed that the greatest uncertainties from both the design and cost standpoints were associated with the potassium boiler and that these could be resolved best by designing, building, and testing a full-scale tube bundle and burner module with water and then with potassium. Funds to begin this work were made available by NSF in July 1972 and NSF funding was continued in 1973. When ERDA was proposed in June 1973, the responsibility for the potassium vapor cycle work became uncertain, with NSF, AEC, OCR, and NASA all having claims in this area. As a consequence of these uncertainties, the program remained unfunded through 1974, when ERDA was formed; at this time some interim funds were made available from NSF and

funds from ERDA-FE finally became available at ORNL for the program in December 1975.

B. Accomplishments in FY 1976

The shakedown and performance tests of the burner operating outside the boiler in the open air were completed in May 1976. The water system installation was completed and the test begun in July 1976. Detailed design of the potassium system was resumed in April 1976 and much of the work was completed by the end of September. Fabrication of components for the potassium system, such as the condenser and drain tank, was initiated in August.

C. Progress During the Past Quarter

1. Water tests

The vapor separator test was completed; an exit steam quality of greater than 99.9% was obtained, which was better than the design goal of 99%. The vapor separator performance data were taken over a range of burner power output from 1.7 to 3×10^6 Btu/hr. This test completed the water test program.^{4, 5}

Additional tests were run using argon as a tracer gas to determine the relative magnitude of the air leakage rate across the seal around the burner.

A test was run to determine if the empty boiler tube bundle could be heated with the burner prior to filling with potassium and if the temperature distribution could be held uniform enough to avoid excessive thermal stresses. Runs with the main burner at its minimum stable power level resulted in excessive temperature differences across the tube bundle. The pilot flame operating at its maximum power was not satisfactory for preheating. It was concluded that an external air preheater will be required for preheating the boiler before filling with potassium.

2. Potassium system

The last group of drawings for the mechanical design of the potassium system components was completed during the past quarter. An elevation

drawing of the potassium test system is shown in Fig. 4. The tower extension drawings were completed and released in January. The drawings for the potassium vapor and liquid return piping and the last of the drawings for the sample box were completed. Design drawings for a propane supply system were prepared.

The design work on the electrical supply and heaters and instruments and controls progressed well during the quarter. The drawings for installation of the heater control cabinets, for the tower light fixtures, and for the heater and wiring for the sample box were completed. Instrument and control drawings completed include the instrument application drawing, condenser thermocouple details, and instrument cabinet panel and wiring drawings.

Fabrication was completed for all the potassium system components except for the sample box and final modifications of the vapor separator for potassium operation. The condenser and its enclosure were completed. The fill-and-drain tank was fabricated, and electric heaters and insulation were installed on it. The fabrication of the structural steel for the tower extension was finished.

Installation of the potassium components on the equipment tower was nearly completed. The condenser and its enclosure along with the inlet and outlet air plenums were installed, and erection of the structural steel for the tower extension was begun.

The interruption of the supply of natural gas because of the fuel shortage brought about by the unusually cold weather in January led to the decision to install a 3000-gal propane supply system. The installation of this system was completed in March.

III. TECHNICAL PROGRESS

A. Summary of Progress This Quarter

1. Potassium system

The design work for the installation of the potassium system was completed in June. The instrument and control construction drawings, including 8 new drawings and 23 revised drawings, have been completed.

Additional drawings will be made for operation and maintenance and drawings will be revised to incorporate as-built changes and design modifications.

An electric air preheater for startup was selected instead of a gas-fired preheater because it will cost less and can be supplied in about one-third of the time required for delivery of a gas-fired unit. Bids were invited and received for the electric air preheater and the purchase order was placed. Delivery is expected in early August.

Fabrication work completed during the quarter includes completion of the sample box and sampling manifold, installation of heaters, thermocouples and insulation on the sample box, modification of the vapor separator and fabrication of the boiler drum liquid-level-indicator elements, installation of the vapor separator and liquid-level indicator in the boiler, welding on the top head of the boiler drum, and fabrication and checkout of control panels 6 and 7. Installation of the condenser enclosure was completed and the drain tank was installed. Construction work on the equipment tower was completed on June 10, six weeks later than had been estimated by the contractor. Installation of the metal siding was delayed by the unusually long periods of rainy weather in April and May. Installation of piping and electrical wiring and conduit was begun in June. This work was late getting started because of the construction delay, but it is expected that it can be put back on schedule with the use of more personnel.

Control panels 6 and 7 were installed in the control room and the metrascope and smoke detectors were installed in panel 5.

B. Progress by Task

R. H. Guymon D. B. Lloyd

1. Potassium system design

The design work for the potassium system was completed during the previous quarter except for the electrical and instrument and controls drawings which have been completed this quarter.

a. Electrical. The electrical drawings were completed; these include the heater and thermocouple schedule and locations and the conduit

routing drawings. Design was also completed on the sprinkler interlock equipment and revised drawings were issued.

b. Instruments and controls. The drawings necessary for construction of the instrument and control system have been completed. A total of 8 new drawings and 23 revised drawings were prepared during this quarter. These include 2 instrument application drawings, 6 control and annunciator maintenance elementary drawings, 5 field wiring and instrument piping drawings, and 18 cabinet wiring drawings. Additional drawings will be made for operation and maintenance, and drawings will be revised.

c. Air preheater. The results of tests of heating the empty boiler with the module burner had indicated that an external air preheater would be required for startup to avoid excessive temperature differences between the inner and outer tube rows. A gas-fired preheater was first considered, but contacts with suppliers indicated that it would be rather expensive and would take too long for delivery. An electric preheater was investigated that would cost only about half as much as the gas-fired unit and would require only about one-third the time for delivery. Bids were invited for the electric unit and received in June. The purchase order was placed and delivery is expected in early August.

2. Potassium system fabrication

a. Vapor separator. Modification of the vapor separator was completed. Figure 5 shows the inner cylinder with the enlarged openings between the outer annulus and center which water tests indicated were needed for startup. Figure 6 shows the bottom of the top hat assembly with the downcomer, level element, and thermocouple well. Figure 7 shows the top of the top hat with the condensate return tee, the thermocouple disconnect, and the level element signal connections.

b. Sample box. Fabrication of the sample box has been completed, the heaters and thermocouples have been installed, and the sample box has been insulated. Insulation of the bottom chamber will be done in place after the interconnection piping is complete. Figure 8 is a view of the front of the sampler with the top door open and the bottom containment access cover removed. Figure 9 is a view inside the top section. The work on the sample box is about 95% complete.

PHOTO 6474-77

Fig. 5. Vapor separator inner cylinder.

PHOTO 6477-77

Fig. 6. Vapor separator top and flow level element.

Fig. 7. Top view of vapor separator top section showing condensate return tee and level element connections.

Fig. 8. Sample box.

PHOTO 6472-77

Fig. 9. View inside top section of the sample box.

c. Piping. Prefabrication of piping has proceeded as far as possible. Figure 10 shows some of the drain and argon lines which must be contained. The top two pipes have been bent to the required shape and have the containment installed. The bottom four have been bent to shape and the containment is laid out ready for installation. Figure 11 shows the magnetic flow element ready for installation in the condensate return line. The piping work is about 80% complete.

d. Panel fabrication and modification. The checkout of control cabinets 6 and 7 was completed in the panel shop. The cabinets were moved to the job site and installed in the control room. Figure 12 shows the cabinets after installation. The cable trays have been extended to accommodate the external wiring to these cabinets.

3. Potassium system installation

Installation of the condenser enclosure was completed and the fill-and-drain tank was installed. The structural steel for the tower extension was completed and the metal siding was installed on the equipment tower. Installation of the siding required considerably more time than had been expected because of the unusually long periods of rainy weather in April and May. Figures 13 and 14 show the tower after completion. Construction work on the tower was completed on June 10, about six weeks later than had been estimated by the contractor.

Installation of electrical wiring and conduit and potassium piping was begun after the tower construction was completed. This work was started later than planned because of the delay in completing installation of the siding, but it is expected that it can be put back on schedule with the use of more personnel.

The vapor separator was installed in the boiler, and the upper head was welded on. The vapor line between the boiler and condenser was fitted, and the first weld pass was made on the 45° elbow that is located on the top of the boiler. Figure 15 shows the top of the boiler after the head was welded on, and Fig. 16 shows the relative positions of the boiler and the condenser enclosure.

PHOTO 6475-77

Fig. 10. Sections of prefabricated sections of drain and argon lines.

Fig. 11. Electromagnetic flow meter for measuring potassium liquid flow.

Fig. 12. Control console with cabinets 6 and 7 in place.

Fig. 13. Support structure after completion of construction.

Fig. 14. Support structure after completion of construction.

Fig. 15. Top of boiler after installation of upper head.

Fig. 16. Upper level of support structure showing top of boiler and the lower part of the condenser enclosure.

REFERENCES

1. A. P. Fraas, Preliminary Assessment of a Potassium-Steam-Gas Vapor Cycle for a Better Fuel Economy and Reduced Thermal Pollution, ORNL-NSF-EP-6 (August 1971).
2. M. E. Lackey, Second Iteration Analysis of a Fossil Fuel-Fired Gas Turbine-Potassium-Steam Combined Cycle, ORNL-NSF-EP-39 (July 1973).
3. A. P. Fraas, Operational, Maintenance and Environmental Problems Associated with a Fossil-Fuel-Fired Potassium-Steam Binary Vapor Cycle, ORNL-NSF-EP-30 (August 1974).
4. R. S. Holcomb, Potassium Vapor Topping Cycle, First Quarterly Technical Progress Report for October 1 to December 31, 1976, ORNL/TM-5954.
5. R. S. Holcomb, Potassium Vapor Topping Cycle, Second Quarterly Technical Progress Report for January 1 to March 31, 1977, ORNL/TM-6042, to be published.

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