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STEAM TEST PLAN

Techniques For Measuring The Quality Of High Temperature Potassium Vapor

(Contract No. AF-33(615)-2495)

MASTER

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INTRODUCTION

This document presents the Steam Test program plan for a steam check of the potassium calorimeter performance. The test program is divided into four parts.

The purpose of the steam test is to achieve the goals listed below using a fluid which is simpler to control than alkali metal vapor.

1. Design checkout and instrument performance.
2. Determination of modifications required to achieve the desired accuracy within 2% for a vapor quality range of 80 - 95%; and within 1/2% for a vapor quality range of 95 - 100%.
3. Determination of the effect of miniaturization on designs suitable for individual probes in confined spaces.
4. Gain test experience with the devices for application in the potassium tests to be performed at ORNL.

PART I. MODIFICATION OF PRESENT FACILITY

This part essentially is a work statement for the modifications to be made to the existing facilities at the Westinghouse Research and Development Center which will be used to perform the steam tests of the potassium calorimeter.

PART II. DESIGN AND INSTALLATION OF TEST ITEMS

This portion of the plan comprises the design of the test items and the installation of these items into the modified test facilities. Sketches of the various elements necessary to conduct the tests are also included.

PART III. INSTRUMENTATION

All instrumentation necessary for performing the tests is shown in this section of the plan.

PART IV. TEST SEQUENCE

This part is subdivided into two parts. Part IV (A) will comprise the initial investigation of the "large" calorimeter and form the basis for the calibration standard. Part IV (B) will comprise the calibration of the miniaturized calorimeter using Calorimeter No. 1 (large) as a standard.

PART I
MODIFICATION OF PRESENT FACILITY

TEST SET UP FOR STEAM CHECK OF POTASSIUM CALORIMETER PERFORMANCE

PLACE

Westinghouse Research and Development Center — test facility for steam injection into gas turbine burner. (Dr. W. Young)

AVAILABLE EQUIPMENT

The following equipment is suitable and available for the tests:

1. Steam boiler and separator.
2. Three-inch main line well lagged to test room.
3. One-inch tap from main line for initial blow off.
4. One and one-fourth inch tap to the steam line bypassing the separator.

STEAM CONDITIONS

Pressure at the boiler adjustable from 100 psi to 300 psi.

Steam into the separator is of approximately 90% quality.

Steam out of the separator is of approximately 99% quality. This steam enters the main test line.

REQUIRED PLUMBING

99% Steam Pipe

A tee from 1-inch below off tap can be used for the high quality source. The change from the present set up will involve the following steps:

1. Disconnect 1-inch line and valve at the elbow.
2. Insert 1 x 1 x 1 inch tee into the line.
3. Reattach blow line and the control valve downstream of the tee.
4. Attach 1-inch control valve at the vertical leg of tee.
5. Lag the tee and valve and side pipe.

Figure 1-1 shows the necessary changes at this point. Figure 1-1(A) shows the present configuration and Figure 1-1(B) shows the new configuration.

90% Steam Pipe

1. Tap the 1-1/4 inch line to the point of entry of steam from boiler to the separator and run 1-1/4 inch line to the vicinity of the 1-inch tap from the main steam line.
2. Reduce line size to 1-inch and install control valve into 1-inch line.
3. Lag the line to reduce heat loss to environment using the lagging thickness and material comparable to that of a 3-inch main line.

Mixing Points

The two 1-inch pipes (the 99% quality and the 90% quality) are joined together through a 45°-Y into a single 1-inch line leading downward. At the lower part, approximately 24-inches to 30-inches from the floor, a reducing ell changes the pipe from a 1-inch to a 2-inch diameter pipe which connects to a 2-inch tee equipped with a spray nozzle at the bottom. The flow then turns and flows upward through a 2-inch test section. (See Figure 1-2.) All piping construction will be well lagged through all of the 2-inch test pipe and sufficiently beyond (12-inches or more) the terminal of the 1-inch pipe.

The exhaust from the 1-inch pipe beyond the flow control valve may be vented directly to outside.

Test Pipe

The test pipe (or the pipe carrying the steam to be sampled) will be a 2-inch diameter pipe equipped with Swagelock or equivalent fittings as shown on Figure 1-3. The fittings will accept standard 1/4-inch sample tubing.

The cross-section of the sample tubing and its installation is shown on Figure 1-3.

(A) PRESENT CONFIGURATION

(B) MODIFIED CONFIGURATION

Figure 1-1. Main Line Modifications

606364A

606363A

Figure 1-2. Steam Test Plumbing

605003A

Figure 1-3. Test Section Details

Condenser Cooling Water

The condenser and cooling water requirements for this test will be limited to a flow of 2 gal/min. The system will include a flow meter and a control valve to regulate the flows.

A complete schematic drawing of the test set-up is shown in Figure 1-4. The solid lines show the part of equipment and plumbing supplied by the test facilities, and dotted lines indicate the equipment supplied by WANL.

In addition to the equipment shown in Figure 1-4, some peripheral instrumentation may be supplied by R&D facilities.

606599A

Figure 1-4. Overall Test Arrangement

PART II
DESIGN AND INSTALLATION OF TEST ITEMS

Figure 2-1. Steam Test Set-Up

Figure 2-1 shows the installation of the test and the checking units. Two methods of measuring the quality of vapor will be used. The first method utilizes a throttling calorimeter suitable for measurement of vapor quality between 95% and 100%. The second method involves measurement of condensate mass flow. This latter method is suitable for vapor qualities ranging from that covered by the throttling calorimeter down to the lowest quality required by the contract (80%).

The test units shown in Figure 2-1 are arranged so that the positions of the test calorimeter and the throttle calorimeter are interchangeable. This is accomplished by having identical sample tubes and identical Swagelock connectors at each of the two test locations. This approach will reduce the possibility of error due to the sample tube affecting the flow geometry and, therefore, the measurements.

This arrangement also permits using either location to investigate the effect of miniaturization, by replacing the throttling calorimeter with the No. 2 Calorimeter (small).

The design of the large calorimeter has been completed and is shown in Figure 2-2.

A second calorimeter of a reduced size will be designed and tested in steam to study the effects of the size reduction of the flow channels and to evaluate these effects on calorimeters sufficiently small to be used as interstage turbine probes. The physical design of the calorimeter will permit installation using the same 1/4-inch Swagelock fitting that is presently used for both the large calorimeter and the throttling calorimeter. The test with this miniaturized calorimeter will be run using the large calorimeter set up as the basic unit.

The thermal evaluation procedure for the proposed design has been completed. However, the actual layout of the calorimeter is not scheduled till later in April, and therefore, is not shown in this test plan. In general, its configuration will be similar to that shown in Figure 2-3. The major change from the drawing will be incorporation of the full return jacket, rather than the coil shown in the drawing.

605002B

Figure 2-2. Large Calorimeter

563980

Figure 2-3. Conceptual Calorimeter for Vacuum Test

PART III
INSTRUMENTATION

The instrumentation necessary to conduct the test may be divided into three classes. Class I is instrumentation necessary to evaluate vapor quality in the manner described in the proposal. Class II instrumentation will be used to check vapor quality by other means and to determine heat losses. Class III comprises peripheral instrumentation necessary for satisfactory running of the tests.

CLASS I

Class I instrumentation will be used to acquire readings of primary data including the following:

Temperature

1. Inlet temperature (T_1)
2. Inter-coil temperature (T_2)
3. Superheat temperature (T_3)

To achieve a greater accuracy, a secondary temperature hook-up is contemplated to read temperature differences.

4. $\Delta T_1 = T_2 - T_1$
5. $\Delta T_2 = T_3 - T_2$

The temperature instrumentation will consist of chromel-alumel thermocouples and a potentiometer for each thermocouple.

Power Inputs

The power inputs into the coils will be read by two wattmeters, one for each coil.

1. Power input into the drier (P_1)
2. Power input into the superheater (P_2)

CLASS II

Class II instrumentation will be designed primarily for checking vapor quality. This instrumentation will include the following items:

Throttling Calorimeter

Readings with this instrument will be made by measuring two parameters:

1. Pressure in the calorimeter measured by a mercury manometer
2. Temperature in the calorimeter measured by a laboratory type thermometer

The readings of the pressure manometer will be corrected to the reading of local atmospheric pressure as established by a barometer and checked against local U.S. Weather Bureau readings. Vapor quality will be determined by use of an expanded Mollier Chart available at our facility.

Condensate Measurement

In addition to the readings of the throttling calorimeter (limited to approximately 5% moisture), the evaluation of the condensate efflux from the calorimeter will be used to check two values: (1) flow rate; and (2) thermal losses.

Flow Rate

The flow rates will be established by collecting the subcooled condensate in a container and measuring the time intervals necessary to collect a predetermined weight of condensate. The instrumentation for these measurements will include an accurate laboratory balance and a stop watch or a laboratory type electric clock with a sweeping second hand and having instantaneous starting and stopping capability.

The magnitude of the weight measurement for the efflux will limit the scale to 1 kilogram full-load to permit accurate evaluation of condensate for a period of 5 minutes. (Approximately 1/2 kilogram for 5 minutes with start at approximately 1/4 kilogram and stop at approximately 3/4 kilogram.)

Thermal Evaluation

The evaluation of thermal losses will be made by thermal measurements of the return flow from the exit of the calorimeter to the temperature of the flow leaving the sub-cooler, balancing this against the temperature gain of the cooling water circulated through the condenser and the subcooler. These thermal measurements require taking the following readings:

Flow Rates

1. Condensate flow rates as described previously.
2. Cooling water flow rates as measured by the flow meter. The flow meter will be calibrated by using the weighing system. The maximum flow anticipated is 2 gpm, requiring the 5-minute weighing interval on the scale rated at approximately 50 kg capacity.

Temperature Measurements

The following temperature measurements will be required in order to determine thermal losses:

1. Temperature of the vapor leaving the calorimeter.
2. Temperature of the condensate leaving the subcooler.

These two temperatures will be determined by chromel-alumel thermocouples with the latter being checked by laboratory type thermometers.

The temperature of cooling water also will be measured at two points:

1. Entry into the subcooler.
2. Exit from the condenser.

The system of measurements from the calorimeter exit to the subcooler exit will be lagged with suitable insulating material (minimum - 2 inches of asbestos) to prevent large heat losses to the environment. An evaluation of these losses will be made using surface temperatures of insulating material as measured by laboratory thermometers.

CLASS III

Class III instrumentation consists of two basic types: (1) supporting instrumentation; and (2) peripheral data instrumentation.

Supporting Instrumentation

This category comprises electrical and pressure instrumentation necessary to establish and monitor the environmental conditions and to control the test conditions.

Electrical Instrumentation

1. Constant voltage controls
2. Power input controls (Variac)

Pressure Instrumentation

1. Vacuum system (vacuum pump)
2. Vacuum gage
3. Differential pressure manometer across the calorimeter
4. Flow control valve to maintain the pressure differential

Peripheral Data Instrumentation

This instrumentation is used primarily to evaluate the performance of secondary system equipment such as the condenser and subcooler. This includes temperature measurements between the condenser and the subcooler as well as surface temperatures to evaluate heat insulation.

Data Recording

Data sheets will be used to record information compiled during test. Initially, emphasis will be placed on the compilation of the more important data. All efforts will be made to have the primary information recorded automatically with a printer or a strip chart where applicable.

PART IV
TEST SEQUENCE

This section is divided into two parts. Part IV(A) comprises the initial investigation of Calorimeter No. 1 (large) and will form the basis for the calibration standard. Part IV(B) will comprise the calibration of the miniaturized calorimeter using Calorimeter No. 1 as a standard.

PART IV(A). LARGE CALORIMETER INVESTIGATION

Purpose

The purpose of this first test is to establish the ground rules for the design of an additive heat calorimeter whose performance will fall within the accuracy envelope desired for the program.

The design of the test set-up and that of the calorimeter reflect the fundamental nature of the instrument in that the physical size and arrangement of the component elements are predicated on establishing fundamental parameters at the cost of physical convenience.

Three major goals of this effort are determination of: (1) fundamental calorimeter parameters; (2) test set-up accuracy limits; and (3) calorimeter accuracy.

Fundamental Calorimeter Parameters

The fundamental calorimeter parameters to be established include:

1. The influence of the vapor quality on the coexistence of superheated vapor and liquid droplets.
2. The effect of Reynolds numbers on the performance of the calorimeter.
3. Evaluation of the heat loss to the environment.

Test Set-Up Accuracy Limits

In addition to the fundamental parameters enumerated above, the actual test set-up will be evaluated with regard to its accuracy limits. This data will be used for test set-up modifications which may be required to achieve desired measurement accuracies in later tests.

Calorimeter Accuracy

The accuracy band of the calorimeter will be determined in relation to the accuracy limits of the test set-up to establish an acceptable confidence level.

Anticipated Procedure

Preparatory Steps

1. After the boiler is brought up to satisfactory pressure and temperature conditions, steam is blown through the lines via the by-pass system until the system reaches a temperature equilibrium.
2. The test system plumbing is then opened and again steam is passed through until the system reaches a temperature equilibrium.
3. The 99% quality steam (from the separator) is used throughout while temperature equilibrium is being achieved. A throttling calorimeter will be used to indicate when equilibrium is obtained.
4. The calorimeter valve is then opened to permit steam to enter and warm up the test system. This should take approximately 15 minutes.

Calibration Steps

The following steps will be taken for the initial conditions and for each change in vapor quality:

1. With the heaters shut off and the cooling water on, temperatures T_1 , T_2 , T_3 and T_4 will be taken. The calorimeter valve will be open to allow a 5-inch Hg pressure drop through the calorimeter.
2. The heater for the drying coil will be heated up to 500 watts, and the flow valve will be adjusted to stabilize at a slight superheat (approximately 5°) in thermocouple T_2 . All of the temperature, pressure, and flow rate readings will be recorded beginning at this point.
3. The heater for the drying coil will be brought up to increase superheat by 10° intervals and the readings of all thermocouples recorded. A value of $\Delta T_2 = T_3 - T_2$ will be monitored and the point at which $\Delta T_2 = 0$ will be established. This will

be done because it is possible to have liquid droplets coexisting with superheated steam at T_2 . The additional mixing in the channel between T_3 and T_2 will be used to establish the level of superheat necessary for initial dry condition at T_2 when $T_3 - T_2 = 0$.

4. Additional heat increments of 10° above that of step (3) will be used as a basis for determination of calorimeter performance. The heat input and the T_2 temperature for this base will be specially recorded for future reference. The throttling calorimeter reading will be taken at this time.
5. Heat will then be added to the drier coil to result in 20° increments until an additional 100° superheat is reached or the input limit of 750 watts is reached. A second reading of the throttling calorimeter will be taken at this point.

Test Steps

1. The drier coil input will be reduced to the base point as established in step (4), and the calorimeter will be allowed to reach initial equilibrium.
2. The heat in the superheater coil then will be brought up to the level necessary to achieve 20° superheat as recorded by $T_3 - T_2$.
3. An additional heat input in 20° increments will be imposed on the superheater coil until additional 120° superheat is reached. A third throttle calorimeter reading will be taken at this point.

The above steps are repeated for each change in vapor quality which may be achieved by mixing 99% steam and 90% steam (approximately 4 steps) and then by water injection in approximately 4 additional steps.

SUMMARY OF TEST IV(A)

The above procedure will determine the relationship between the vapor quality and the required superheat at the end of the drier coil and reliable base points will be established.

The repetition of the superheat investigations, first with the drier coil and then with both the drier and superheat coils, will give us a correlation of the internal working of the calorimeter for essentially the same end conditions but using different heating elements. This will point out any discrepancies in the calorimeter operation and will help to identify any remedial steps which may be required.

It should be noted that the condensate measurements for the evaluation of the quality data and the heat losses will be taken throughout the tests beginning at step (4).

PART IV(B). SMALL CALORIMETER TEST

Purpose

The purpose of the test of the small calorimeter, which is made of the same material as the large calorimeter and is of a similar construction, is to evaluate the effect of miniaturization. Miniaturization is desirable because it makes it possible to probe flow patterns in otherwise restricted areas, e.g., an alkali metal turbine. A series of such probes can be used to establish the axial and radial distribution of liquid droplets in a stream and thus point out ways to alleviate such problems as blade erosion.

Anticipated Procedure

The series of steps described in Part IV(A) will be taken with the small calorimeter replacing the throttling calorimeter. The readings of T_1 , T_2 and T_3 temperatures and P_1 and P_2 power inputs will be taken for each test step described in Part IV(A).

Table I shows the format proposed for a test data sheet for Part IV(A) and Table II shows a proposed test data sheet for Part IV(B). (See Figure 4-1).

TABLE I.
Steam Test - Part IVa. - Evaluation of Large Calorimeter

Test No. _____
Date _____
Observer _____

RUN NO.	ITEM	THROTTLING CALORIMETER			LARGE CALORIMETER								CONDENSATE					COOLING WATER						VOLTAGE		REMARKS
		T ₅	P ₃	Barom "Hg	T ₁	T ₂	T ₃	P ₁	P ₂	H ₁	H ₂	T ₄	T ₆	T ₇	W ₁	TIME	T ₈	T ₉	T ₁₀	W ₂	TIME	Meter GPM	V ₁	V ₂		

TABLE II
Steam Test - Part IVb. - Evaluation of Miniaturized Calorimeter

Test No. _____
Date _____
Observer _____

RUN NO.	ITEM	LARGE CALORIMETER							SMALL CALORIMETER							CONDENSATE				COOLING WATER				VOLTAGE				REMARKS
		T ₁	T ₂	T ₃	P ₁	P ₂	H ₁	H ₂	T' ₁	T' ₂	T' ₃	P' ₁	P' ₂	H' ₁	H' ₂	T ₄	T ₇	W ₁	TIME	T ₈	T ₁₀	W ₂	TIME	V ₁	V ₂	V' ₁	V' ₂	

LEGEND

T - Temperature, °Rankine
P - Pressure, Hg
H - Watts
V - Volts

Figure 4-1. Sample Test Data Sheets