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HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

A Bimonthly Technical Progress Review

PREPARED UNDER THE AUSPICES OF SPECIAL TECHNOLOGY BRANCH,
DIVISION OF REACTOR DEVELOPMENT AND TECHNOLOGY, USAEC

VOLUME 7 • NUMBER 1 • FEBRUARY 1969

BROOKHAVEN NATIONAL LABORATORY
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UNITED STATES ATOMIC ENERGY COMMISSION

P1800

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FOREWORD

The purpose of the High-Temperature Liquid-Metal Technology Review is to provide up-to-date information on the various research and development programs in the United States in the field of high-temperature liquid-metal technology. The method is to publish reviews prepared by members of the Department of Applied Science of the Brookhaven National Laboratory on current topical and progress reports submitted by contracting organizations. When results and conclusions are reported, it is intended that the individual reviews become both summaries and critiques.

The organizations currently submitting reports are those operating under AEC, NASA, and Air Force contracts. A list of these organizations is given in the Appendix.

The Review covers all phases of high-temperature liquid-metal technology, including materials development, corrosion and mass transfer, heat transfer, fluid dynamics, instrumentation, purification, component development, physical properties, thermodynamics, chemical analysis, and power systems. This type of information is pertinent to the AEC's fast breeder development program and to the development of nuclear-Rankine power systems for space vehicles.

Monthly progress reports, owing to the usually small amount of new information contained in them, do not always receive individual treatment. The information in two or more such reports is usually combined into a single review.

Whenever an author feels that his report was not adequately or correctly represented in the Review, we would like to hear from him and would be happy to publish his letter in the next issue, if he so wishes.

Those organizations which regularly submit reports for coverage in the Review automatically receive courtesy copies of it directly from Brookhaven on date of issuance. All other organizations are required to follow the usual procedure of subscribing for them from the Clearinghouse for Federal Scientific and Technical Information, National Bureau of Standards, U. S. Department of Commerce, Springfield, Virginia.

O. E. Dwyer
Technical Editor

HIGH-TEMPERATURE LIQUID-METAL TECHNOLOGY REVIEW

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REVIEW NO. 797

ULTRASONIC INSTRUMENTATION FOR DETECTION
OF INCIPIENT BOILING IN LIQUID METALS

Sponsor: U. S. Atomic Energy Commission
Contractor: Aeroprojects Incorporated, West Chester, Penna.
Contract No.: AT(30-1)-3622
Report No.: NYO-3622-20
Report By: Herbert Kartluke
Report Date: July 1968
Reviews for Previous Two Years: 599,640,696,768,782

This report describes the development of an instrument, based on ultrasonic principles for indicating the proximity to boiling in liquid-metal systems. The method is based on the principle that the acoustic power required to produce cavitation in the liquid decreases as the boiling condition is approached. The instrument must therefore (a) deliver, through the liquid metal containment, ultrasonic power to the liquid, (b) measure this power, and (c) detect the start of cavitation.

The acoustic conductors are inserted through the walls of the containment vessel by means of a hermetically sealable flange-type acoustic isolation mount. This mount was apparently developed by the contractor as part of an earlier effort that involved the development of an ultrasonic device for the detection of incipient boiling in pressurized water systems.

Initial experimental work in a static potassium system was performed by the contractor at Oak Ridge. Subsequent work was done in both a static potassium cell and in a flowing sodium system at the Mine Safety Appliance Research Corporation. Results in all cases verified that the acoustic power required to produce cavitation decreased as the boiling condition was approached. However, tests in the flowing system exhibited less scatter, presumably because of improved thermal uniformity.

The ultrasonic generator and the associated instrumentation are fully described in the report.

The instrument described in this report measures the ultrasonic power required to initiate cavitation. It would seem that the device is just another means for measuring subcooling, but it will not measure the superheat required to initiate boiling in its absence. It would appear that the primary effect of its

presence in a system would be to minimize the superheat required to initiate boiling. In fact, it has been reported⁽¹⁾ that a similar instrument was used to initiate and maintain stable boiling in potassium under conditions that normally produced liquid superheating and unstable and explosive boiling. A device of this sort might also have utility as a safety feature in a non-boiling system in that if the boiling point were accidentally reached, boiling would be initiated with little or no superheat, thereby minimizing its effect.

In summing up, this reviewer feels that the device described in this report cannot fulfill the function it was designed for any better than a pressure gage and thermocouple. However, it appears that it might possibly be useful for the applications described above.

(S. Kalish)

REVIEW NO. 798

ARGONNE NATIONAL LABORATORY
REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT

Sponsor: U. S. Atomic Energy Commission
Contractor: Argonne National Laboratory, Argonne, Illinois
Contract No.: W-31-109-Eng-38
Report No.: ANL-7527
Report Coordinated By: L. B. Fosdick and A. Glassner
Report Date: December 1968
Reviews for Previous Two Years: 584, 585, 600, 601, 602, 623, 624, 644,
645, 662, 663, 681, 682, 697, 699, 700,
719, 720, 737, 738, 757, 758, 771, 772,
783

(1) M. M. Yarosh - An Experiment Employing Ultrasonic Energy to Promote Boiling in Liquid Metals, Paper IIB-2 in Proceedings of the International Conference on the Safety of Fast Reactors--Sept. 19-22, 1967. Edited by G. Denielou, Cadarache, France.

Influence of Dissolved Cesium, Antimony, Rubidium, and Gold in Sodium on the Corrosion Behavior of Austenitic Stainless Steel
p. 79)

Radioactive isotopes of these solute elements have been suggested for use in the bond sodium of fuel elements in a sodium-cooled reactor to enable rapid detection of a cladding rupture. Capsules of type 304L stainless steel were loaded with 5- and 10-mil-thick samples of the same material and reactor grade sodium containing 2% of either high-purity Cs, Sb, Rb, or Au. The samples were then held at 650°C (in a rotating assembly) for 500 hr.

After testing, analysis showed that the sodium contained <10 ppm oxygen. The weight gains of the specimens varied from 1 to 31 $\mu\text{g}/\text{cm}^2$, and metallographic examination showed a small amount of new phase formation just below the surface of each specimen. Preliminary electron-probe analysis showed that the new phase (in the form of particles of different shapes) was not directly associated with the special additives.

Oxygen Determination in Sodium (p. 101)

This investigation was carried out in connection with the measurement of the equilibrium distribution coefficients for oxygen between the Group-V refractory metals and liquid sodium, where very accurate analysis of oxygen is required. The method employed was that of vacuum distillation, followed by titration of the hydrolyzed residue with dilute hydrochloric acid. The oxygen concentration in the sodium was controlled by circulation through a cold trap, in which the temperature was varied from 103° to 240°C, corresponding to 0.30 to 30 ppm.

Fig. 1 shows the analytical results compared with those previously obtained by Rutkauskas.⁽¹⁾ The agreement is good. The ANL values in the figure are based on the assumption that all the sodium titrated to a pH of 4.7 was in the form of Na_2O . On the basis of careful analysis, it was concluded that the sodium did not contain a detectable amount of Na_2CO_3 .

Several of the hydrolyzed residues were also analyzed for sodium by flame photometry. The results consistently showed 3 ppm more sodium at each concentration than those obtained by

(1) V. J. Rutkauskas, LA-3524-MS, 1966.

titration, indicating that a sodium compound (unaffected by the variation in cold-trap temperature) was present in the residue which was not detectable by titration.

Corrosion Inhibition by Dissolved Getters in Liquid Sodium (p. 104)

Dissolved getters in sodium are being investigated as a means of controlling the oxygen activity. For example, CaO is more stable than Na₂O, and consequently the Na-O-Ca system is being studied to determine its equilibrium free energy relationships. The apparatus for this work is under construction.

Carbon Determination in Sodium (p. 104)

"A dry-combustion apparatus for the analysis of total carbon in sodium is being constructed. The method involves conversion of all the carbon in the sample to CO₂ and analyzing the evolved gas by chromatography."

Incipient-Boiling Superheats in Na (p. 128)

Pool-boiling experiments have indicated that an increase in oxygen content of the sodium slightly decreases the incipient-boiling superheat. Also, a theoretical study has indicated that an increase in heat flux can produce either a decrease or increase in the incipient-boiling superheat, depending on the sequence of events between experimental runs as they affect inert-gas diffusion from the active cavities. No numbers are given, but a topical report will soon be issued on this work.

(O. E. Dwyer)

Figure 1 in the Review corresponds to Figure III.B.1 in the original report.

REVIEW NO. 799

ARGONNE NATIONAL LABORATORY
REACTOR DEVELOPMENT PROGRAM PROGRESS REPORT

Sponsor: U. S. Atomic Energy Commission
Contractor: Argonne National Laboratory, Argonne, Illinois
Contract No.: W-31-109-Eng-38

Report No.: ANL-7548

Report Coordinated By: L. B. Fosdick and A. Glassner

Report Date: January 1969

Reviews for Previous Two Years: 584,585,600,601,602,623,624,644,
645,662,663,681,682,697,699,700,
719,720,737,738,757,758,771,772,
783,798

Effect of Temperature and Strain Rate on the Fracture Mode of
Type 304 Stainless Steel (p. 78)

"The fracture surfaces of tensile specimens of Type 304 stainless steel were studied by means of optical microscopy to determine the effect of temperature and strain rate on the transition point from transgranular to intergranular failure. The specimen material came from the same heat as that used in the EBR-II control-rod thimble currently undergoing postirradiation examination at ANL. The tensile tests were conducted at temperatures of 22, 450, 550, 650, and 750°C and at strain rates of 1, 10, 100, and 1000%/min.

"Preliminary results indicate that specimen failure occurs by transgranular fracture at all strain rates up to 100%/min and at temperatures below 550°C. At these strain rates, evidence of intergranular fracture begins to appear at about 550°C, and at 750°C the failure is entirely due to intergranular fracture. At the highest strain rate of 1000%/min, evidence of failure by intergranular fracture does not appear until 650°C, and at 750°C failure is again entirely due to intergranular fracture. In all tests the specimen had sustained a true uniform strain of 15% at the start of the transition from transgranular to intergranular fracture.

"These results suggest that the intergranular-type fracture could occur at lower values of true uniform strain and at temperatures below 550°C: at strain rates in the creep range ($\dot{\epsilon} < 10^{-4}\%$ /min). This possibility will be investigated by a similar study of fractured creep-specimens of the same material."

"These studies are being conducted in cooperation with similar studies of specimens that have suffered radiation damage, and the results for the irradiated material will be reported at a future date."

Development of an Acoustic Detector for Boiling Inception (p. 98)

In this project, the major problem in developing a high-temperature sensor is that of bonding the lithium niobate ceramic crystal to stainless steel. During the report period, the surfaces of two Z-cut crystals were coated with an organic-vehicle metallizer and fired in an oxygen furnace. One of these was brazed with Au-Ni alloy to the container diaphragm on the front crystal face and to a stainless-steel acoustic backing on the rear crystal face. With it, an ultrasonic test signal was electrically detectable. However; alternative bonding methods are also being investigated.

Electron-Bombardment Heater Development (p. 101)

Fig. 2 shows the 7-pin electron-bombardment heater and the associated test section that is being tested. Its operation has been hindered by mechanical problems associated with the attachment of the thoriated-tungsten filaments to the electrodes, and steps are being taken that will presumably eliminate the problem.

A second type of heater arrangement is being designed in which the pins are 1/4 in. in diameter rather than 3/8 in. and 36 in. long rather than 24. Also, these new pins will have single filaments instead of double filaments.

Liquid Fraction in Two-Phase Flow of Na (p. 117)

Liquid-fraction measurements were made for adiabatic two-phase flow of Na produced in a Na-flashing facility. The average liquid velocity in the two-phase region was measured with an electromagnetic flowmeter. Fig. 3 shows that the measurements agreed very well with the Lockhart-Martinelli correlation based on air-water and steam-water data. The vapor quality, x , was calculated from the average liquid velocity data using a temperature obtained from the measured axial temperature profile. The agreement between the measured and predicted liquid volume fractions shows once again that the hydrodynamic behaviors of two-phase flows of liquid metals and ordinary liquids are essentially the same. Similar results were observed by Baroczy⁽¹⁾ with potassium.

(O. E. Dwyer)

Figs. 2 and 3 in the Review correspond to Figs. III.C.1 and IV.A.3 in the original report.

(1) C. J. Baroczy, Chem. Eng. Progr. Symp. Ser. 64 p. (1968).

REVIEW NO. 800

THE SOLUBILITY OF OXYGEN IN LIQUID SODIUM:
A RECOMMENDED EXPRESSION

Sponsor: U. S. Atomic Energy Commission
Contractor: Atomics International, Canoga Park, Calif.
Contract No.: AT(04-3)-701
Report No.: AI-AEC-12685
Report By: R. L. Eichelberger
Report Date: November 1, 1968
Reviews for Previous Two Years: none

The solubility of oxygen in sodium as reported in nine publications from eight laboratories was reviewed. A proposed set of criteria for inclusion of the data was developed, whereby half the points were excluded. Five of the laboratories had some data which met the criteria. A recommended mathematical expression from these data is given as

$$\log_{10} S = 6.239 - 2447/T(^{\circ}\text{K}) ,$$

where S is the solubility of oxygen in weight ppm.

Data from experiments where sodium was equilibrated or sampled in glass apparatus were excluded because of the possibility of a sodium-glass reaction. Data derived by amalgamation analysis from sodium equilibrated at temperatures below 250°C were also excluded because of a possibility of a high analytical blank. The result of the above criteria is that below 250°C the only data included are those obtained in one laboratory utilizing the distillation technique. Unfortunately, there was no distillation data above 340°C to compare with the amalgamation results obtained in that region.

Standard deviations of the constants for the above equation are not given but it does not appear justified to report the constants to more than three and possibly only two significant figures.

(L. Newman)

REVIEW NO. 801

SODIUM TO STEAM HEAT EXCHANGER ELEMENTS AND RESEARCH
Preliminary Steam Generator Concept Selection Study

Sponsor: U. S. Atomic Energy Commission
Contractor: The Babcock & Wilcox Co., Power Generation Division,
Barberton, Ohio
Contract No.: AEC--AT(11-1)-1280; B&W 596-3559-55
Report No.: BAW-1280-55
Report By: P. B. Probert, Project Manager
Report Period: Interim Report - Preliminary Steam Generator
Concept Selection Study
Report Date: August 5, 1968
Reviews for Previous Two Years: 590,603,649,705,724,759,774

The purpose of this project is to select the optimum steam generator design for the Liquid-Metal Fast Breeder Reactor Program. A total of 96 possible designs were considered, and they encompassed all feasible combinations of the following variables.

1. Large units and modular units.
2. Once-through, natural recirculation, and pumped recirculation.
3. Drainable and undrainable bundles.
4. Vertical and horizontal.
5. Straight tube, U-tube, return bend, and helical coil.

Each feasible design is discussed in the report and the reasons for the rejection of specific designs are presented. Outline drawings of several designs are also included in the report. As a result of the analysis, five alternatives and a reference design were selected for further study. The selected designs are:

1. Modular, forced-recirculation, drainable, vertical straight tube unit.
2. Modular, once-through, drainable, vertical and horizontal straight tube units.
3. Modular, once-through, drainable, horizontal, U-tube unit.
4. Large, once-through, drainable, vertical, return bend unit.
5. Large, once-through, drainable, vertical, helical-coil unit.
6. Large, once-through, undrainable, vertical, helical-coil unit (reference design).

The sixth concept was selected as the reference design because of the large amount of analysis that is available from the prototype and full-size steam generator designs of this concept that have been performed by B&W.

The planned analyses of these selected designs involve a preliminary analysis in which sizing calculations and preliminary arrangement drawings will be prepared and a design analysis that will cover the work necessary to resolve important problems in sufficient detail to serve as a basis for cost estimates and schedules. The program is outlined in the report.

(K. Hoffman)

REVIEW NO. 802

BELLOWS SEALS FOR LIQUID METAL SYSTEMS--
LITERATURE SEARCH FOR FABRICATION
AND OPERATIONAL EXPERIENCE

Sponsor: U. S. Atomic Energy Commission
Contractor: Battelle Memorial Institute, Pacific Northwest
Laboratory, Richland, Washington
Report No.: BNWL-905
Report By: R. C. Aungst
Report Date: November 1968
Reviews for Previous Two Years: none

The control system for the Fast Test Reactor (FTR) will include bellows to isolate drive mechanisms from the sodium vapor-inert gas mixture which covers the 1200°F sodium pool in the reactor vessel.

To aid in the design of the bellows, a literature search was conducted by the Liquid Metals Information Center that yielded 136 references, of which 26 were relevant and were reviewed in detail. It was found that the design of the required bellows is within the "state-of-the-art." Tentative specifications have been written that specify the material, grain size, mechanical properties, dimensions, temper, surface conditions, welding configuration and procedure, leak testing and other testing, and certification.

This report is another example of the usefulness of the services offered by the Liquid Metals Information Center.

(S. Kalish)

REVIEW NO. 803

ANNUAL PROGRESS REPORT OF THE WORK SPONSORED
BY THE SODIUM TECHNOLOGY AND THE FUELS AND MATERIALS BRANCHES*

Sponsor: U. S. Atomic Energy Commission
Contractor: Brookhaven National Laboratory, Upton, N.Y.
Contract No.: AT30-2-Gen-16
Report No.: BNL 50161 (T-526)
Report Compiled By: John R. Weeks
Report Period: January 1 to December 31, 1968
Reviews for Previous Two Years: 684,741,742,760,787

The program includes studies of the 760° to 815°C corrosion behavior in sodium of materials for the LMFBR program, the mechanism of corrosion of materials in liquid sodium, and the chemistry of liquid sodium solutions.

Materials Testing Program

Thermal convection loops continue to be used to study the behavior of a wide range of possible fuel-cladding materials in sodium. Oxygen activity is controlled by one or more of the following techniques; cold-trapping, Zr hot-trapping, and Mg or Li-gettering. Carbon activity is varied by using both type 321 and type 316 stainless steels as loop piping. In the alloys tested, the corrosion rate increases with the Ni + Cr content of the alloy; the Co-base alloy S-1 corrodes the least, followed by stainless steel, and IN-800, which lost ~4 times the weight lost by S-1. The temperature dependence of the corrosion rates of all three alloys, however, is the same between 700° and 760°C, as shown in Fig. 4.

Co-base alloys are being studied as potential high temperature fuel-cladding materials for an LMFBR because of their increased strength at 750°C. A series of new alloys is being developed containing 2 to 3% Ti which have 800°C mechanical properties comparable to those of the stainless steels at 650°C.

*Division of Reactor Development and Technology
United States Atomic Energy Commission

Forced circulation loop tests have shown that the corrosion rates of the Co-base alloys HA-25 and UMC0-51 are much less affected by an increase in the oxygen level from 4 to 12 ppm than are the corrosion rates of stainless steels as seen in Figure 5. X-ray fluorescence and metallographic observations suggest deposition of iron occurs on the surface of the Co-base alloy specimens when the oxygen level in the Na is 12 ppm but not when it is 4 ppm as seen in Fig. 6. A comparison of the BNL corrosion data on the stainless steels with those from the UK RML and GEAP shows good agreement at comparable oxygen levels and velocities as seen in Fig. 7.

The corrosion of refractory metal alloys is being studied in a forced circulation loop with both hot- and cold-trap capabilities for controlling oxygen. A 2000 hr test was completed under Zr-hot-trapped conditions (<1 ppm oxygen) in which the V and Nb-base alloys all gained weight at a rate that leveled off at $\sim 0.5 \text{ mg/cm}^2\text{-mo}$ for 3 V-base alloys and $\sim 0.15 \text{ mg/cm}^2\text{-mo}$ for Nb - 1 Zr. The rate of weight gain was nearly independent of temperature between 700° and 760°C . Specimens of the Mo-base alloy TZM did not change in weight. After the oxygen level was raised to ~ 4 ppm, all the V and Nb-base alloys lost weight, but the Mo-TZM alloy was unaffected. The 321 SS specimens corroded at a rate comparable to the results obtained in FCL-1 at the same oxygen level.

Construction of a loop was completed to test high-flux heaters. Heat fluxes up to 10^6 Btu/hr-ft^2 were reached at a Na temperature of $\sim 600^\circ\text{C}$ using a NaK-cooled 50kW 10 KHz induction heater. The specimen holder in the heater area is a Permen-dur receptor. A long-term run has been started in which the maximum specimen temperature is $\sim 650^\circ\text{C}$ and the heat flux is 10^6 Btu/hr-ft^2 .

Sodium Solution Chemistry and Corrosion Mechanisms

Results of the solubility of Ni in Na is shown in Fig. 8. It has been shown to range from ~ 0.6 ppm at 450°C to ~ 1.4 ppm at 600°C . The solubility of Fe in Na has been shown to be ~ 0.3 ppm at 486°C and ~ 0.85 ppm at 550°C . It appears to be independent of oxygen in the Na below an oxygen activity of ~ 0.2 times its solubility. The apparent Fe solubility increases with the oxygen activities in Na above this value, as shown in Fig. 9. Combination of the present low-oxygen results with other recent determinations at higher temperatures yields the tentative solubility equation for Fe in Na:

$$\log_{10}(\text{ppm Fe}) \approx 7.05 - 5730/T(^{\circ}\text{K}) \quad .$$

The chemical activity of oxygen in Na held in a stainless-steel system is found to be buffered by one or more substances present in or on the stainless-steel surface. Further experiments in an oxidized Zr beaker containing 2 grams of a mixture of Cr and Cr_2O_3 powders confirmed that Cr is the probable buffering agent, and that, at 500°C , the buffered activity in the presence of Cr and Cr_2O_3 powders corresponds to that of a Na-17 ppm oxygen binary solution.

For this work, the Cu-Cu₂O reference electrodes in the commercial electrochemical oxygen meters are replaced by a liquid Na-Na₂O reference electrode, in which there is always excess solid Na₂O present to saturate the sodium. The measured potentials of this electrode at temperatures above 375°C against Na containing known amounts of oxygen yield the equation for the solubility of oxygen in Na:

$$\log_{10}(\text{ppm O}) = 6.55 - 2600/T(^{\circ}\text{K}) \quad .$$

There is an apparent inflection in the potential-temperature curve at 375°C , which is possibly due to a phase change in solid Na₂O at this temperature.

Work is complete on studies of the reaction of HCl with Na and Na-Ba solutions. The reaction occurs in two stages: the first produces H₂ and NaCl or BaCl₂ and is controlled by processes of a physical nature, and the second is the reaction of Na with the H₂ produced.

There is an interaction of hydrogen and oxygen in liquid Na at 400°C which reduces the oxygen activity at constant oxygen concentration, as observed by following the electrochemical potential of oxygen during reaction of the Na with H₂ gas. The reaction of CO with Na at 200°C occurs in three stages: an induction period in which a film forms on the Na, a rapid absorption stage in which the metal surface appears to be clear, and a second stage of negligible reaction rate in which the surface remains apparently clean.

Construction of the Na chemistry loop was completed in 1968. It is currently undergoing shakedown runs.

Electrochemical Techniques for Sodium Chemistry

The electrical conductivity of UNC $\text{ThO}_2\text{-Y}_2\text{O}_3$ meter tubes was determined over a range of oxygen pressure from air to very dry hydrogen and at temperatures from 200° to 800°C . The results are shown in Fig. 10. The predominant conduction mechanism was concluded to be ionic in the oxygen pressure range from air to 10^{-30} atm at temperatures from 300° to 850°C . To extend the measurements to oxygen pressures corresponding to <1 ppm in Na, studies with Si-SiO_2 are being made.

Tests of the commercial Cu, Cu_2O reference electrode in the UNC oxygen meter suggest that potentials closer to theoretical can be obtained if the operating temperature of the meter is raised from the recommended value of 320° to 350°C . Once the reference electrode is contaminated with air, it does not recover theoretical potentials.

The use of electrochemical oxygen meter electrodes is being studied as a means of making coulometric additions or subtraction of oxygen to or from sodium. No net transfer of oxygen through $\text{ThO}_2\text{-Y}_2\text{O}_3$ from saturated to unsaturated solutions of oxygen in Na was observed at 500°C and 0.1 to 5 milliamps of current, possibly because the applied voltage caused the electrolyte to become an electronic conductor.

An electrochemical carbon meter is being studied; CaC_2 appears to be a suitable electrolyte reversible to carbon. The emf developed by the experimental cell, graphite || CaC_2 || Zr,ZrC was within 10% of the theoretical value between 250° and 400°C .

Analytical Development

Contributions of stainless-steel tube surfaces to the oxygen analyzed by the amalgamation method were found to range from 1 to 2 μg per linear inch of 1/2-in. o.d. tubing. This problem arises when loop by-pass samples are analyzed without extrusion of the Na. The U-gettering method for O in Na has been shown to be applicable up to 30 ppm O in Na at 500° as seen in Fig. 11. The gettering rate is proportional to the mass transfer coefficient of oxygen in Na.

(J. R. Weeks)

Figs. 4 to 11 in the Review correspond to Figs. 2, 4, 7, 6, 14, 15, 18, and 19, respectively, in the original report.

REVIEW NO. 804

Space Programs Summary 37-54, Vol. III
SUPPORTING RESEARCH AND ADVANCED DEVELOPMENT

Sponsor: National Aeronautics and Space Administration
Contractor: Jet Propulsion Laboratory, Pasadena, Calif.
Contract No.: NAS 7-100
Report No.: 37-54, Vol. III
Report Section By: D. G. Elliott, D. J. Cerini, and L. G. Hays
Report Period: For the Period October 1 to November 30, 1968
Report Date: December 31, 1968
Reviews for Previous Two Years: 606,628,629,706,727,744,761,789,790

Liquid-Metal MHD Power Conversion

The NaK-N₂ model induction generator was checked in the no-flow mode. Core losses were greater than those anticipated; otherwise, the generator performed as expected.

The theory of the separation probe that will measure the lithium level in the separator was checked against experimental values obtained with Dow-Therm as a stand-in.

(J. Powell)

REVIEW NO. 805

LIQUID METAL ENGINEERING CENTER
SEMIANNUAL TECHNICAL PROGRESS REPORT

Sponsor: U. S. Atomic Energy Commission
Contractor: Liquid Metal Engineering Center, Canoga Park, Calif.
Contract No.: AT(04-3)-700
Report No.: LMEC-69-1
Report By: O. J. Foust et al.
Report Period: July to December 1968
Reviews for Previous Two Years: 607,631,677,691,729,730,748,762

This report summarizes the activities of the Liquid Metal Engineering Center during the first half of fiscal year 1969. There are 16 major projects. Summaries on the following four are taken from the SUMMARY portion of the report and are considered appropriate for inclusion here.

Sodium Pump Seal Test Program

"Preliminary System Design Descriptions for both oil-type and gas-type seal test facilities were approved after their revision. The described facilities can subject seals to operational and environmental conditions within the ranges expected to be encountered in actual LMFBF pump service. Means are provided to determine operating characteristics of seals under various controlled and measured levels of these conditions.

Project plans currently anticipate facility usage in the test of five seals: two for proposed 60,000-gpm LMFBR prototype pump designs, a third as-yet-unspecified design for a 60,000-gpm size pump, the PNL/FFTF pump, and a proposed one from an existing pump design.

"Facility design modifications were resolved that resulted from new seal design information received from the pump study contractors. These included addition of supplemental cooling for the drive motor of one test rig and replacement of torque transducers with another type to improve accuracy. A bearing spindle and support housing reinforcement assembly will be added to eliminate flexibility revealed by load deflection measurements. Discrepancies of the test vessels were corrected by rework; the vessels were received and installed. Assembly of the test rigs was continued. Negotiations for the procurement of test seals were also continued.

Sodium Pump Bearing Test Program

"A two-step program for development of radial bearings for LMFBR sodium pumps was instituted. The first part of the program involves testing of a prototype bearing for the FFTF primary sodium pump followed by tests of bearing designs developed by the Large Sodium Pump Study contractors. Use of existing surplus equipment to compress the schedule and reduce costs is planned.

Precision Mechanisms in Sodium

"A detailed technical management plan to ensure meeting program objectives was developed. A literature search documenting information published since 1950 on mechanical devices operating in sodium environments was compiled and published. A similar document pertaining to operational experience with mechanical devices at various sodium-cooled reactor installations is being prepared.

"Sliding wear tests were conducted with 82 material combinations in high-temperature liquid and sodium vapor. The resultant wear rates are presented with some correlations in terms of a "dimensionless wear coefficient" and the square of the hardness ratio for the particular material combinations.

The cobalt base - nickel base alloy combinations appear to be the best performers on the basis of tests completed. For the material and test parameters under investigation, frictional heating effects appear to have a minimal contribution to the wear process.

"A journal bearing test plan has been prepared outlining a comprehensive test program to evaluate bearing performance characteristics in 900 to 1200°F liquid sodium and sodium vapor. Materials selected for these tests include Hastelloy-C, Stellite-1 and -6B, Star-J, TZM, Inconel-718, K-95, and K-801.

Steam Generator and Intermediate Heat Exchanger Performance Evaluation

"Test conditions are being established for a 2000-hr steady-state run of the Alco IHX and the Alco/BLH steam generator. This extended-run test is to be performed under reduced load and less-than-rated temperature and pressure conditions.

"The capability of available computer codes to evaluate detailed pressure and thermal stresses in the region of a tube-sheet has been demonstrated. Only steady-state conditions have been programmed to date, but the codes are capable of obtaining transient solutions as well.

"Additional studies have been performed to define the tube vibration problem in the Alco IHX. There is evidence of vibrational impacting over an incompletely defined primary sodium flow range. The severity and potential effect of this problem have not yet been fully evaluated."

(Authors)

REVIEW NO. 806

AN ANALYTICAL AND EXPERIMENTAL INVESTIGATION OF TURBULENT FLOW IN BEARING FILMS, INCLUDING CONVECTIVE FLUID INERTIA FORCES

Sponsor: U. S. Atomic Energy Commission
Contractor: Mechanical Technology Inc., Latham, New York
Contract No.: AT(30-1)-3930
Report No.: NYO-3930-2 and MTI-68TR80

Report By: A. J. Smalley, J. H. Vohr, V. Castelli and
C. Wachmann

Report Date: December 1968

Reviews for Previous Two Years: 732

This is the first topical report of the program on "Liquid Metal Bearings Technology for Large, High Temperature, Sodium Rotating Machinery." A major aim is to extend the developed turbulent lubrication theory to include fluid inertia effects and to verify by test the resultant analytical techniques. An analysis was developed that involves the direct numerical solution of the simultaneous equations representing conservation of momentum and fluid continuity. It was incorporated into a computer program and applied to pad bearings. The results were then compared with experimental measurements made on a 12-in.-diam, four-pad, shrouded step bearing using silicone fluids as a lubricant. A comprehensive description of the analysis, as well as graphically depicted comparisons between program and test data are presented.

Tests were run with the bearing operating in the viscous and turbulent-inertial flow regimes at eccentricities of 0 and 0.5. The mean discrepancies between predicted and measured values of bearing peak pressure and integrated pressure profiles were found to be 8% or less. This is considered to be within tolerable limits, thereby verifying the analysis. An investigation of inertial and turbulent effects on pressure profile, peak pressure, and pressure-recovery factor was made and is reported herein.

(K. Hoffman)

REVIEW NO. 807

LIQUID METAL BEARINGS TECHNOLOGY FOR LARGE,
HIGH TEMPERATURE, SODIUM ROTATING MACHINERY

Sponsor: U. S. Atomic Energy Commission

Contractor: Mechanical Technology Inc., Latham, N. Y.

Contract No.: AT(30-1)-3930

Report No.: NYO 3930-3 and MTI-69TR1

Report By: E. B. Arwas, L. Hoogenboom, C. Kissinger, F. K.
Orcutt, and W. D. Waldron

Report Date: January 1969
Previous Reviews: 792

The progress made in the various tasks of this program, for the period August to October 1968, is reported.

(a) The theoretical analysis of turbulent-flow lubrication, including the effects of fluid convective inertia, was completed. A comprehensive description of this work is presented in NYO 3930-2.

(b) The preparation of a bearing design handbook was begun, with calculations to optimize shrouded step bearing configurations for operation with low-viscosity lubricants under high levels of turbulence.

(c) An in-house development of an inductance-type proximity transducer was initiated when it became apparent that commercially available units could not withstand elevated temperature testing. The development of a capacitance-type, film-pressure transducer for operation in high-temperature sodium was completed. A sample probe is being subjected to fatigue testing.

(d) The design of the bearing test rig is proceeding with the preparation of component detailed drawings now under way.

Specifications for the two probes and the bearing test rig, as well as a flowsheet of test rig, are included.

(P. Bezler)

REVIEW NO. 808

STUDY OF THERMO-HYDRAULIC OSCILLATIONS IN BOILING
SYSTEMS EMPLOYING LIQUID METAL WORKING FLUIDS

Sponsor: National Aeronautics and Space Administration
Contractor: Mechanical Technology Incorporated, Latham, N. Y.
Contract No.: NASW-1705
Report Nos.: Tenth, Eleventh, and Twelfth Monthly Letter
Progress Reports
Reports By: J. H. Vohr and S. V. Manson
Report Dates: November, December, and January
Reports for Previous Two Years: 750, 763, 791

This is primarily an analytical study and the main objective is to investigate the thermal-hydraulic behavior of forced flow of liquid metals in once-through boilers. Expressions are being developed for net-vaporization rates in bubbly-, annular-, and fog-flow regimes. In the bubbly-flow regime, the rapid rate of growth of the bubbles in superheated liquid calls for a nonequilibrium treatment, and for this the expression of Theofanous et al.⁽¹⁾ for the growth rate of vapor bubbles is being used. In addition, the number and size distributions of the bubbles must yet be considered. The net vaporization rate in annular flow is assumed to take place under equilibrium conditions, which makes the analysis straightforward; and the governing differential equation is presented. The net vaporization rate in fog flow is another nonequilibrium phenomenon, and little work has yet been done on it.

In the case of large incipient-boiling superheats, the bubbly-, annular-, fog-flow sequence is replaced by the generation of a large vapor void, which grows in all available directions. In this situation, a "shock-wave" model of void propagation is being analyzed, and some of the basic momentum and heat transfer equations are given. Eventually it is hoped to be able to predict the probability of a vapor void and its rates of growth in the upstream and downstream directions.

(O. E. Dwyer)

REVIEW NO. 809

EVALUATION OF THE RESULTS OF A ROUND ROBIN
ANALYSIS FOR OXYGEN IN POTASSIUM AND SODIUM

Sponsor: National Aeronautics and Space Administration
Contractor: Lewis Research Center, Cleveland, Ohio
Report No.: NASA TN D-4971
Report By: Glenn R. Zellars and Charles A. Barrett
Report Date: December 1968
Reviews for Previous Two Years: none

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- (1) "A Theoretical Study of Bubble Growth in Constant and Time-Dependent Pressure Fields," by T. Theofanous, L. Biasi, H. S. Ishin, and H. Fauske, to be published in Chemical Engineering Science.

This is a report on the results of a round robin analysis of the determination of oxygen in sodium and potassium which was conducted in mid-1965. Each of 17 participating laboratories utilized their own method of analysis, in most cases the amalgamation technique, in some the vacuum distillation, and in one a neutron activation method.

The mean value obtained for oxygen in sodium was 10.7 ppm with a standard deviation of 4.70 ppm; the value in potassium was 14.7 with a standard deviation of 5.08. The data showed significant variance in addition to experimental error. Analysis of variance performed on a selected set of results for the same nominal experimental conditions indicated that the major source of variation was a lack of reproducibility among laboratories for sodium, and within laboratories for potassium. The results were not consistent enough to come to any conclusions as to other possible sources of error.

This round robin was conducted nearly four years ago. Much has been learned since that time, and consequently the delayed publication of these results is mainly of historical interest. As an outcome of this round robin, a second one was planned and has already been conducted whereby the participating laboratories were all required to use a prescribed amalgamation technique.

(L. Newman)

REVIEW NO. 810

SUMMARY OF IN-HOUSE LIQUID-METALS INVESTIGATIONS
(A special summary report to the editor)

Sponsor: National Aeronautics and Space Administration
Contractor: Lewis Research Center, 21000 Brookpark Road,
Cleveland, Ohio
Forwarded By: Joseph P. Joyce
Report Period: January 1968 to March 1969
Reviews for Previous Two Years: 708,728

The report is reproduced below in its entirety:

A. Accelerated Cavitation Damage Facility

A vibratory apparatus was used to subject the cobalt-base alloy, L-605, to cavitation damage in sodium at 400°, 800° and 1200° F. Cover gas pressures were varied from 1 to 4 atmospheres at each temperature. Increasing pressure increased the cavitation damage at each test temperature. Damage was greatest at the 800° F test temperature for all pressures. A volume loss rate contour diagram was constructed to show cavitation damage in terms of the combined temperature and pressure of the sodium.

This information was covered in the following published paper:

1. Young, Stanley G.; and Johnston, James R.: Effect of Temperature and Pressure on Cavitation Damage to a Cobalt-Base Alloy in Sodium. NASA TM X-52555. (To be presented at 72nd Annual Meeting of the American Society for Testing and Materials, Atlantic City, New Jersey, June 22-26, 1969.)

Other recent published papers utilizing the same equipment included:

2. Young, Stanley G.: Cavitation Damage of Stainless Steel, Nickel, and an Aluminum Alloy in Water for ASTM Round Robin Tests. NASA TM X-1670, October 1968.
3. Young, Stanley G.; and Leonard, L.: Effect of Ultrasonic Vibration on Precipitation Hardening of Steels and Superalloys. NASA TN (in final stages of printing).

B. Alkali-Metal Heat-Transfer Facility

The 600 kW, refractory-metal, boiling test facility is presently deactivated. Data from over 800 hours of operation are included in a forthcoming NASA Technical Note entitled "Tests of Sodium Boiling in a Single-Tube-in-Shell Heat Exchanger Over the Range 1720° to 1980° F (1210° to 1360° K)."

C. Space Radiator and Condenser Facility

The 150 kW facility is presently deactivated. The final test, for which a Technical Note is being written, determined the extent of liquid superheat (or liquid tension) that occurs in the throat of an adiabatic venturi to be used as a boiler tube inlet device for flow stabilization and vapor initiation. The test was run with potassium over the range 1190° to 1470° F (915° to 1070° K).

D. Seal Studies

Experimental and theoretical studies continue at a low level of effort. There is no reportable new progress at this time.

E. Bearing Studies

Stability tests were conducted with 1.5 inch diameter, 1.5 inch long hydrodynamic journal bearings in water at 80° F (300° K), at speeds to 12,000 rpm. It was possible to use water instead of sodium because of

the viscosity and density similarities between the two fluids. Good agreement existed between stability data obtained in water and in sodium for the same herringbone configuration on the journal, indicating that water can be used instead of sodium for bearing stability investigations. Plain bearings were run at various clearances with three different journals: (1) a partially grooved herringbone journal having 20 groove-ridge pairs; (2) a fully grooved herringbone journal having 20 groove-ridge pairs; and (3) a partially grooved herringbone journal having 40 groove-ridge pairs. No significant differences in the zero load threshold of stability were measured among the three different configurations of herringbone grooved journal bearings tested. Theoretical analysis for herringbone-groove journals predicts a larger range of stable operation than was observed experimentally.

The following NASA report has been published describing these tests in detail:

1. Schuller, F. T.; Fleming, D. P.; and Anderson, J. A.: Experiments On The Stability of Water Fabricated Herringbone Groove Journal Bearings.

Part I - Theoretical Considerations and Clearance Effects.
NASA TN D-4883, Nov. 1968.

Part II - covers the effect of configuration and groove to ridge clearance ratio of herringbone-groove bearings on stability (should be available June 1969).

F. SNAP-8 Test System

Following completion of the boiler endurance test in November 1967, the Lewis SNAP-8 test facility was shut down for extensive modifications in preparation for a system dynamic test program. The following components were replaced: electric NaK heater, boiler, and turbine alternator. In addition, the NaK-cooled parasitic load resistor was removed and a large amount of primary NaK-loop and mercury-loop piping was replaced. A change was also made in the routing of the auxiliary start-loop piping in order to keep pace with the current SNAP-8 design. Extensive changes were made in the instrumentation and recording system in order to improve its accuracy and dynamic response.

Operation of the system was resumed in October 1968. Steady-state mapping of the NaK-to-NaK auxiliary start-loop heat exchanger was accomplished and performance mapping of the mercury boiler was initiated. However, the compact electric NaK heater being used as a reactor simulator electrically failed in January 1969. This heater has been replaced with a larger, more conservatively designed electric heater. Also, a NaK leak through the shell of the auxiliary start-loop heat exchanger was observed. The shell was replaced with one having a thicker wall. Test operations are once again being resumed. The dynamics program will mainly investigate startup and shutdown transients.

Reports published between January 1, 1968 and March 1969 are as follows:

1. Thollot, P. A.; Block, H. B.; and Jefferies, K. S.: Experimental Investigation of Reactor-Loop Transients During Startup of a Simulated SNAP-8 System. NASA TN D-4546, May 1968.

2. Soeder, R. H.; Curreri, J. S.; and Macosko, R. P.: Performance of a Multitube Single-Pass Counterflow NaK-Cooled Mercury Rankine-Cycle Condenser. NASA TM X-1548, April 1968.
3. Albers, J. A.; Soeder, R. H.; and Thollot, P. A.: Design-Point Performance of a Double-Containment Tantalum- and Stainless-Steel Mercury Boiler for SNAP-8. NASA TN D-4926, Dec. 1968.
4. Valerino, A. S.; Wood, J. C.; and Reznik, J. F.: SNAP-8 Simulator Loop Mechanical Design. NASA TM X-1515, 1968.
5. Deyo, J. N.; and Wintucky, W. T.: Instrumentation of a SNAP-8 Simulator Facility. NASA TM X-1525, 1968.
6. Block, H. B.; Kruchowy, R.; and Gallagher, J. D.: Performance of the SNAP-8 Fabrication and Coolant Subsystem. NASA TM X-1731, 1968.
7. Macosko, R. P.; Hanna, W. T.; Gorland, S.; and Jefferies, K. S.: Performance of An Experimental SNAP-8 Power Conversion System. NASA TM X-1732, 1968.
8. Asadourian, A. S.; Frye, R. J.; Macosko, R. P.; and Vernon, R. W.: Results on Endurance Tests of a SNAP-8 Turbine Alternator Assembly. NASA TM X-1741, 1968.
9. Gorland, S.; Hecker, T. P.; and Lottig, R. A.: Performance and Evaluation of Two Liquid-Metal Pumps for NaK Service. NASA TM X-1765, 1968.
10. Gorland, S.; Lottig, R. A.; and Hecker, T. P.: Performance and Evaluation of a Liquid-Metal Pump for Mercury Service. NASA TM X-1766, 1968.

G, Liquid-Metal Instrumentation

Analytical studies and development work in the areas of quality, flow-rate, pressure, and temperature measurements in liquid-metals have been undertaken.

1. Quality Measurement

Studies of quality measurement included analysis of calorimetric techniques, a two-phase flow measurement technique, and a sonic velocity measurement technique. These studies are reported in the following publication:

- a. Nyland, Ted W.: Analysis of Three Liquid-Metal Quality Measuring Techniques. NASA TN D-4038, June 1967.

2. Flowrate Measurement

The effort in the study of liquid-metal flowrate measurements consists of an analytical study of a d.c. electromagnetic flowmeter with a static transverse magnetic field. The purpose of this study is to improve the accuracy of flowrate measurements by considering

such effects as distortion of the velocity profile by the static magnetic field and the entrance and exit effects at the edges of the magnetic field. A numerical analysis of the velocity profile distortion effect is nearly complete. It covers a range of Hartmann numbers up to 200, wall-to-fluid conductivity ratios from zero (the insulated pipe wall case) to 2.0 and outside-to-inside diameter ratios from 1.05 to 1.35. Results indicate that the velocity profile distortion effect is greatest at the higher Hartmann numbers and at the lower values of conductivity and diameter ratios, and may be as much as 7 percent.

3. Pressure Measurement

The development of a liquid-metal pressure transducer has been based on the requirements of a flat frequency response up to 200 Hz and operation in 1500° F sodium. A bellows is used as the pressure element and a miniature quartz load cell is used for readout. A concentric tube system, 6 inches long, connects the load cell to the bellows. Testing on this transducer is complete and a report is in preparation.

The performance of commercial strain gage pressure transducers suitable for use with liquid-metal has been measured for 1300 hours at 260° C (533° K). The most significant effect of the time and temperature was a zero drift of approximately 2 percent of full scale. This work is reported in a technical note which will be released soon:

- a. Lewis, Ralph D.: Performance of Commercial Unbonded Strain Gage-Type Absolute Pressure Transducers at 260° C. (Final stages of printing.)

4. Temperature Measurement

An experiment to determine the thermoelectric drift of some noble and refractory metal thermocouples at 2400° F (1590° K) and for times up to 10,000 hours has been conducted in air, argon, and vacuum environments. Photomicrographs and solids mass spectrometer analysis are being prepared on selected thermocouple samples.

A second test involving noble metal thermocouples at 2350° F (1563° K) in a vacuum environment for 3700 hours has also been completed. Spark emission spectroscopy, photomicrograph, and electrical resistivity measurements are being made on sample wire specimens.

H. Materials Support Programs

1. Alkali-Metal Purification and Analysis

A procedure was devised for the isolation and recovery of alkali-metal reaction products in an uncontaminated state. Separation of the reaction product from excess alkali metal is accomplished by vacuum distillation. All recovery operations are carried out in high-vacuum or inert gas atmospheres. Two typical examples of the

application of this method are: (a) the recovery of potassium tantalate (K_2TaO_4) from the potassium-tantalum-oxygen reaction, and (b) the recovery of potassium monoxide (K_2O) from the potassium-oxygen reaction. Reaction products were identified by both X-ray diffraction and chemical analyses. This work is reported in:

- a. Gahn, Randall F.: Technique for Recovery of Alkali-Metal Reaction Products. NASA TN D-4310, January 1968.

2. Effects of Environment on Interstitial Contamination of Refractory Metals

Sticking probabilities for oxygen on columbium and dilute columbium-zirconium alloys were derived from ratios of oxygen absorption rates to their corresponding oxygen fluxes. Oxygen test pressures were varied from 10^{-7} to 10^{-5} torr over temperatures between 1158° and 1373° K. Absorption rates were derived from a pressure-drop technique and fluxes were derived from constant pressure measurements. Reaction kinetics, as well as test method characteristics, were considered. This work is reported in:

- a. Barrett, Charles A.: Absorption Rate Sticking Probabilities for Oxygen on Columbium and Dilute Columbium-Zirconium Alloys. NASA TN D-4885, November 1968.

3. List of Publications since January 1, 1968

The following is a complete listing of reports from the Liquid Metals Section that have been published since January 1, 1968:

- a. Gahn, Randall F.: Technique for Recovery of Alkali-Metal Reaction Products. NASA TN D-4310, January 1968.
- b. Rosenblum, Louis; Scheuermann, Coulson; Barrett, Charles; and Lowdermilk, Warren: Mechanism and Kinetics of Corrosion of Selected Iron and Cobalt Alloys in Refluxing Mercury, NASA TN D-4450, April 1968.
- c. Bowles, Kenneth J.: Vapor Pressure of Potassium to 2170° K. NASA TN D-4535, May 1968.
- d. Vary, Alex: A Radiator Concept Based on Capillary Retention of Liquid. NASA TN D-4370, July 1968.
- e. Sinclair, John H.: Compatibility of Several Iron-, Cobalt-, and Nickel-Base Alloys with Refluxing Potassium at 1800° F. NASA TM X-1617, Aug. 1968.
- f. Barrett, Charles A.: Absorption Rate Sticking Probabilities for Oxygen on Columbium and Dilute Columbium-Zirconium Alloys. NASA TN D-4885, Nov. 1968.
- g. Zellars, Glenn R.; and Barrett, Charles A.: Evaluation of the Results of a Round Robin Analysis for Oxygen in Potassium and Sodium. NASA TN D-4971, Dec. 1968.

REVIEW NO. 811

NIOBIUM - 1% ZIRCONIUM BOILING-POTASSIUM
FORCED-CIRCULATION LOOP TEST

Sponsor: U. S. Atomic Energy Commission
Contractor: Oak Ridge National Laboratory, Oak Ridge, Tenn.
Contract No.: W-7405-eng-26
Report No.: ORNL-4301
Report By: D. H. Jansen et al.
Report Date: December 1968
Reviews for Previous Two Years: none

This report gives a carefully documented account of the construction of, and operating experience with, a forced-circulation boiling-potassium loop. The loop, built of niobium - 1% zirconium alloy, was designed to test simulated turbine blade specimens for possible use in potassium Rankine systems. The report gives clear descriptions of loop design, loop operating characteristics, and test results.

Fig. 12 presents a schematic diagram of the test system. The test section consisted of three stages of nozzles and simulated turbine blades. The nozzles were designed to provide potassium vapor over the quality range of 83 to 97% and temperature range of 1860° to 1260°F. The simulated turbine blade specimens were of niobium - 1% zirconium alloy. The preheater, boiler, and dryer sections of the primary loop were heated with radiant clam-shell furnaces using tantalum resistors.

The authors report that loop operation was characterized by periods of complete stability followed by periods of severe temperature and pressure fluctuations associated with unstable boiling. During unstable periods, the test section outlet temperature underwent rapid changes of as much as 500°F, with corresponding boiler pressure fluctuations of as much as 70 psi. The authors state that the cause of this instability was most likely associated with the problem of high nucleation superheat that has been found to be characteristic of the alkali metals. Because unstable operating conditions prevailed for ≈40% of the operating time, it was not possible to obtain an unequivocal analysis of the corrosion and erosion results. One of the major uncertainties was the extent of liquid carry-over from the boiler to the test section specimens during unstable flow conditions. It was reasoned that this subjected the blade specimens to wet vapor conditions that were more severe than design conditions, but were not quantitatively definable. The report does give

tables and figures illustrating results of metallographic and chemical analyses of various portions of the loop and of the test blade specimens. From this evidence, the authors note the following qualitative conclusions:

(a) Evidence of a chrome-rich layer on the second-stage blade specimen indicated that the presence of a few stainless-steel components was sufficient to provide chromium transport, even though the components presented only limited surface area at relatively low temperatures. The test specimens generally indicated only minor damage, in spite of the rather severe operating conditions.

(b) Some oxygen transfer from the potassium to the niobium - 1% zirconium alloy was observed, with the greatest transfer in the hotter loop regions.

(c) An excessive increase in tubing diameter at the drier section indicated that the creep characteristics of the test alloy may be a problem for operation near 2000°F.

(J. C. Chen)

Fig. 12 in the Review corresponds to Fig. 1 in the original report.

REVIEW NO. 812

ULTRASONIC THERMOMETRY FOR LMFBR SYSTEMS
Phase I Report

Sponsor: U. S. Atomic Energy Commission
Contractor: Panametrics, 221 Crescent Street, Waltham, Mass.
Contract No.: AT(30-1)-3906
Report No.: NYO-3906-4
Report By: S. S. Fam, L. C. Lynnworth, and E. H. Carnevale
Report Date: September 1968
Reviews for Previous Two Years: 795

This report summarizes the results of the first phase of a program whose ultimate aim is the development of thermometers, based on ultrasonic principles, for use in liquid-metal-cooled reactor systems. The intent is to develop a system for monitoring fuel, cladding, and coolant temperatures.

The proposed system is similar to that of a previous NASA program⁽¹⁾ in which an ultrasonic system was developed for measuring local temperatures up to 4800°F (to an accuracy of $\pm 50^\circ\text{F}$) for one hour in the core of a nuclear rocket engine (see Figure 13).

"This system exploits the temperature dependence of sound velocity in refractory metal wires. The system is basically comprised of four parts: transducer, lead-in, sensor, and an electronic instrument. The transducer consists of a coil wound around a suitable magnetostrictive wire (usually a nickel alloy). The coil is pulsed, thus producing an elastic strain in the wire...which is reflected and/or transmitted according to the geometry and materials used in the line... Of particular interest are the reflections emanating from the beginning and end of the sensor element, the time interval between which is a measure of its average temperature. This time interval is automatically measured and digitally displayed... Since extensional and torsional waves propagate at speeds proportional to the square root of Young's modulus, E , and to the modulus of rigidity, G , respectively, it is necessary to consider all the possible mechanisms by which the environment may affect these moduli."

The authors mention the advantages that thin-wire ultrasonic thermometers have over other temperature-measuring systems. The ultrasonic sensor consists of a single wire, such as pure Re, and is therefore not subject to the calibration shifts, which in thermocouples are due to diffusion of one leg into another. In addition, the small thermal mass of wire sensors results in less error due to internal heat generation from radiation.

The sensor materials that have been found suitable are, Re for the fuel ($\approx 5000^\circ\text{F}$) and type 304 SS for the coolant and cladding ($\approx 1200^\circ\text{F}$). Lead-in wire is of 304 SS and will be placed in protective sheaths (304 SS) for acoustic isolation. In the reactor core the Re sensor will be placed in a suitable protective sheath. Ta or W/Re may be used with UO_2 fuels and W/Re may be used with UO_2/PuO_2 fuels.

A complete system was successfully tested under simulated conditions which included: sensor temperatures up to $\approx 5000^\circ\text{F}$; lead length of 50 ft, 20 ft of which were at temperatures up to

(1) Lynnworth, L. C. and Carnevale, E. H. "Ultrasonic Temperature Measuring Device," Final Report NASA CR-72339, Aug. 1967.

$\approx 1200^{\circ}\text{F}$; lead wire transmission through feedthroughs capable of containing vapor pressures of 100 psi; and operation with the lead wire containing typical bends.

Recommendations for Phase II of the program include the installation of the system constructed for Phase I in a selected liquid-metal nuclear reactor facility to measure in-core temperatures. Radiation effects, if any, could then be checked.

(S. Kalish)

Fig. 13 in the Review corresponds to Fig. 1 in the original report.

REVIEW NO. 813

ULTRASONIC THERMOMETRY IN LMFBR SYSTEMS

Sponsor: U. S. Atomic Energy Commission
Contractor: Panametrics, 221 Crescent Street, Waltham, Mass.
Contract No.: AT(30-1)-3906
Report No.: NYO-3906-5
Report By: S. Fam, L. C. Lynnworth, and E. H. Carnevale
Report Period: September to December 1968
Report Date: December 1968
Reviews for Previous Two Years: 795, 812

(See Review No. 812)

This is the first quarterly progress report in Phase II of a program whose purpose is to develop an ultrasonic thermometry system for use in liquid-metal fast-breeder-reactor cores. The topical report covering Phase I of the program is reviewed in this issue.

The objective of Phase II of the program is to test the system developed in Phase I in a liquid-metal-reactor facility.

During this report period, arrangements were made for system testing at the Oak Ridge Research Reactor, where temperatures up to $\approx 5000^{\circ}\text{F}$ can be maintained in a radiation field of 10^{13} n/cm²sec (fast) and $\approx 10^{14}$ n/cm²-sec (thermal). Apparently, the test will be run in conjunction with a GE experiment whose

purpose is to test the compatibility of W/Re sheaths with UO_2 - PuO_2 mixed oxide fuel. The tests are scheduled for mid-March 1969.

Room-temperature sound-velocity measurements were made on three Re-Os alloy samples. However, further tests involving thermal cycling and annealing are required in order to determine the effect of composition on sound velocity.

(S. Kalish)

Figure 1

Vacuum Distillation Analysis of Oxygen
in Sodium as a Function of Cold-Trap Temperature

(Review No. 798)

Electron-bombardment-heated Simulated Fuel Test Section

Figure 2
(Review No. 799)

Figure 3

Sonic-Velocity Test Apparatus. The pressures at the four points above the test section are measured by quartz transducers.

(Review No. 799)

Figure 4
(Review No. 803)

EFFECT OF OXYGEN
ON CORROSION RATE OF HAYNES 25 AND 304 S.S.
 (VELOCITY = 22 fps)

Figure 5
 (Review No. 803)

(Review No. 803)

Figure 6 - X-ray Fluorescence Results
FCL-1

Figure 7
(Review No. 803)

Figure 8 - Solubility of Nickel in Sodium as a Function of Temperature

(Review No. 803)

(Review No. 803)

Figure 9 - A Logarithmic Plot of the Solubility of Iron in Sodium as a Function of Oxygen Activity. The Extrapolations to Zero Oxygen are 0.3 ppm Fe at 486° and 0.58 ppm Fe at 550°C.

(Review No. 803)

Figure 10 - The Resistance of ThO₂-
15 wt % Y₂O₃ as a
Function of Temperature and
Oxygen Pressure

(Review No. 803)

Figure 11 - The Variation of the Rate
of Oxygen Uptake by
Uranium With Oxygen
Concentration

Figure 12
Schematic of Loop Test System.

(Review No. 811)

Figure 13
Schematic of automatic measurement of pulse transit time in sensor.

(Review No. 812)

APPENDIX A

ORGANIZATIONS HAVING REPORTS AS INDICATED BY REVIEW NUMBERS
COVERED IN THIS AND PREVIOUS ISSUES OF THE REVIEW

Aerojet-General Corporation 82, 94, 143, 144, 212, 213, 214, 229, 275, 299, 335, 358, 359, 389, 410, 448, 464, 486, 509, 510, 511, 558, 559, 560, 615, 616, 637, 638, 639, 661, 695, 715, 736, 756, 767, 780, 781	Argonne National Laboratory (cont.) 413, 414, 415, 427, 428, 429, 430, 451, 452, 468, 469, 489, 490, 491, 513, 514, 515, 537, 538, 561, 562, 582, 583, 584, 585, 600, 601, 602, 623, 624, 643, 644, 645, 662, 663, 681, 682, 697, 698, 699, 700, 717, 718, 719, 720, 737, 738, 757, 758, 769, 770, 771, 772, 783, 784, 798, 799
Aeroprojects Inc. 465, 487, 536, 599, 640, 696, 768, 782 797	
Aerospace Research Laboratory 716	Atomic Power Development Assoc. Inc. 36, 65, 106, 133, 172, 211, 238, 239, 247, 276, 320, 321, 322, 340, 364, 393, 394, 416, 432, 433, 470, 516, 517, 586, 664, 665, 666, 701, 702
Air Force Aero Propulsion Laboratory (Wright Patterson AFB) 300	
AiResearch Mfg. Company (A Division of Garrett Corp.) 12, 64, 88, 102, 103, 150, 151, 152, 173, 243, 312, 313, 336, 360, 361, 390, 411, 412, 449, 450, 466, 467, 488, 512, 579, 580, 581, 617, 618, 619, 620, 621, 622, 641, 642	Atomics International 33, 92, 301, 341, 365, 395, 431, 492, 493, 539, 540, 541, 563, 564, 587, 588, 589, 625, 646, 647, 648, 667, 668, 669, 683, 703, 704, 721, 722, 739, 740, 773, 785, 786, 800
Alleghany Ballistics Lab., Hercules Powder Company 259	The Babcock & Wilcox Co. 56, 61, 115, 116, 123, 124, 163, 194, 195, 237, 248, 249, 277, 302, 342, 417, 453, 454, 494, 518, 542, 565, 590, 603, 649, 705, 723, 724, 759, 774, 801
Allison Division, General Motors Corp. 96, 145	Baldwin-Lima-Hamilton Corp. 57, 122, 147, 174, 208
Ames Laboratory 314, 315, 316	
Argonne National Laboratory 29, 30, 41, 42, 66, 67, 83, 117, 118, 141, 142, 168, 169, 170, 202, 203, 240, 241, 244, 245, 246, 289, 296, 297, 317, 318, 319, 337, 338, 339, 362, 363, 391, 392,	Battelle Memorial Institute 37, 93, 125, 126, 127, 128, 129, 130, 131, 197, 198, 199, 343, 396, 434, 802
	Bendix Corp. 471

Brookhaven National Laboratory
9,16,32,49,79,180,366,472,684,
741,742,760,787,803

Columbia University
73,344,519

Consolidated Controls Corporation
250,278,323,367,397,435,473,
495,520

Electro-Optical Systems, Inc.
1,85

Fairchild Stratos Corp., Stratos
Division
167

General Electric Company
3,11,22,26,27,50,51,52,72,73,74
75,98,100,101,158,159,160,161,
162,187,188,189,190,191,192,219,
220,221,222,223,224,233,234,235,
251,252,253,254,255,256,257,291,
292,293,294,295,303,304,324,325,
345,346,347,348,368,398,418,436,
437,438,439,474,475,476,477,478,
496,497,498,543,544,545,566,591,
604,605,650,651,652,670,671,672,
685,686,725,726,775,788

Geoscience Ltd.
8,23,165,166,225,258,326,349,369,
399,479,626,673

Hydronautics Inc.
107,132,164,260,370,419,546,567,
593,653,743

Jet Propulsion Laboratory
80,97,547,568,606,627,628,629,
674,687,706,707,727,744,761,789,
790,804

Liquid Metal Engineering Center
607,630,631,676,677,688,689,690,
691,709,729,730,745,746,747,748,
762,776,777,805

Los Alamos Scientific Laboratory
2,15,20,99,155,156,201,262,279,
305,327,372,400,441,480,499,
550,569,570

Marquardt Corporation
521,551

Massachusetts Institute of Tech.
6,25,39,40,86,119,171,228,
263,328,522,552,608,731,749

Mechanical Technology Inc.
329,373,374,401,592,710,732,
763,791,792,806,807,808

MSA Research Corporation
21,53,54,55,68,69,81,89,109,
110,153,154,184,185,186,204,
205,206,207,227,264,265,266,
267,280,281,282,283,306,330,
331,332,350,351,375,376,402,
403,420,421,422,455,456,457,
500,501,523,524,525,553,594,
609,610,632,654,678,679,692,
711

NASA-Lewis Research Center
17,60,84,157,261,371,502,548,
549,675,708,728,809,810

Oak Ridge National Laboratory
58,90,91,95,284,298,377,378,
404,423,526,633,655,656,712,
733,751,752,764,765,778,793,
794,811

Panametrics
795,812,813

Philco Corporation
527,595,611,634

Pratt and Whitney Aircraft
14,28,47,48,62,148,149,175,
285,286,333,352,379,380,405,
406,458,459,460,461,481,482,
503,528

Rocketdyne (A Division of North
American Aviation)
7,24,59,76,196,236,270,353,381

San Fernando Laboratory
382,422,504,529,530,554,713

Southwest Research Institute
38,271,307,334,383,424,443,571

Stanford Research Institute
753

Sundstrand Aviation
34,63,108,134,193,242,287

Tapco (A Division of Thompson
Ramo Wooldridge)
5,121

Temple University (Research Inst.)
596

Thermo Electron Engineering Corp.
181

Thompson Ramo Wooldridge, Inc.
4,13

United Nuclear
78,290,462,483,505,531,555,556,
572,573,597,635,657,658,680,
693,714,734,754,766,779,796

U. S. Naval Research Laboratory
35,104,105,226,268,269,354,
463

University of Michigan
18,19,31,43,44,45,46,70,71,87,
120,135,136,146,176,177,178,
179,215,216,217,218,230,231,
232,272,288,308,309,310,355,
356,357,384,385,386,387,407,
408,409,425,444,445,484,506,
532,533,534,557,574,575,576,
598,659,745

University of Washington
200

Westinghouse Electric Corp.
10,111,112,113,114,137,138,
139,140,182,183,209,210,273,
274,311,388,426,446,447,485,
507,508,535,577,578,612,613,
614,636,660,694,755