SUPERCritical WATER NUCLEAR STEAM SUPPLY SYSTEM:
INNOVATIONS in MATERIALS, NEUTRONICS and THERMAL-HYDRAULICS

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SCWR Research Objectives:

- Design and fabrication of out-of-pile SCW test facilities for current & future utilization in R&D
- Fuel-cladding surface modification to improve clad-water compatibility, corrosion and wear
- Neutronics analyses of thermal SCWR core design with modified fuel-cladding materials
- Fundamental study of SCW heat transfer and stability under natural circulation conditions
SCWR Progress in FY 2002

• Cladding samples obtained and PSII surface modification underway
• SCW corrosion and thermal-hydraulics loop designed and under construction at UW.
• SCW simulant CO$_2$ loop designed and under construction at ANL
• Neutronics codes benchmarking begun
• Thermal-hydraulic and stability analyses begun
Temperature - Power Design Curve for Loop

P=25 Mpa (T_{psuedocritical}) = 657.9K
T_{coldwater}=657.1 K
T_{hot} varies from 658.1 to 661.1K for DB
T_{hot} varies from 657.1 to 659.6K for JM
L_{heater} = 2 m
Tube ID=4.29 cm
Tube OD=6.03 cm

\[ y = 541.44x - 358403 \quad R^2 = 1 \]
\[ y = -0.27x^2 + 734.05x - 365305 \quad R^2 = 1 \]
P=25 Mpa (T_pseudocritical) = 657.9K
T_{coldwater}=657.1 K
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Tube ID=4.29 cm
Tube OD=6.03 cm
Inconel 625, ID. 1.68”, OD 2.375” is used for the main 2m x 3m loop.
ANL Flow Loop

PIPE, 1/2" SCH. 80, SST
0.840" OD X 0.546" ID X 0.147" W

LOOP DESIGN PRESSURE:
100 BAR (1470 psi)

COPPER CONNECTION
SILVER SOLDERED TO PIPE

TC'S ON OUTSIDE
OF PIPE

1/4" SST TUBE

0-60 VAC
5000 A

440 VAC
770 A

440 VAC
770 A

PUMP

He

CO₂

2" SCH 80 PIPE

1 m

2 m

COLD SIDE

PRESSURIZER

RELIEF

LEVEL DETECTOR

EXHAUST

GRAYLOC FITTING

25 kW CHILLER

RELIEF

EXHAUST

EXTERNAL ULTRASONIC
FLOW METER

1/4" SST TUBE

1 m

DRAWING: CO2 LOOP
CONCEPTUAL DESIGN
DRAWING NO.: CO2L2
DRAWN BY: D. KILSDONK
DATE: 4/11/02
FILE: CO2_LOOP_2.DWG(AC70)
SCWR Progress in FY 2002

- Cladding samples obtained and PSII surface modification underway
- SCW corrosion and thermal-hydraulics loop designed and under construction at UW.
- SCW simulant CO₂ loop designed and under construction at ANL
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Corrosion/oxidation resistance of materials in supercritical water flow-loop

- **Substrates:**
  - Inconel 718
  - Zircaloy-2
  - 316 stainless steel

- **Plasma Surface Treatments (PSII):**
  - Room temperature and elevated temperature ion implantation
  - Energetic ion bombardment for modification of microstructure and composition
  - Non-equilibrium surface alloying for a more tenacious and protective oxide
Research Considerations in Current Work

- Properties of the oxide film (density, oxygen diffusivity, thickness vs stress-accumulation characteristics)
- How will plasma surface treatments alter the mechanisms of the corrosion product (i.e., growth of the oxide film)?
- Adherence of oxide film to the substrate
- Role of mass transport in supercritical water and substrate materials on oxidation rate
Aqueous corrosion & wear-corrosion tests underway

- ASTM standard aqueous potentiodynamic corrosion tests and wear-corrosion tests are underway (at boiling temp. & low press.)

- Since surface erosion and wear are related to surface mechanical properties, low-load micro-hardness tests are also being performed

- Following these low temperature tests, coupons will be placed in the natural convection loop
Past studies have demonstrated the effect of flow-rate (erosion) on corrosion rate

Oxide-metal interface strength can be determined theoretically, experimentally or using existing data bases.

For example, Zhou et al (Corrosion Science, vol. 44, No. 4, April, 2002) demonstrated the effect of flow rate on corrosion rate for water in the 150 to 390 deg. C range at 25 MPa at flow rates ranging from 0.375 to 1.00 ml/min.

A result demonstrating the effect of flow rate of alumina dispersed water (Chacon et al, J. Mater. Engr. Performance, vol. 10, No. 6, December 2001) is shown below
Potential for collaboration with SCWR researchers

- Wisconsin performs plasma surface treatment of samples and supercritical water flow tests
- Michigan performs irradiation of samples and stress-corrosion cracking (SCC) tests and MIT corrosion tests

If this collaboration can be successfully implemented, a comprehensive picture of the individual and synergistic effects of surface treatments, irradiation damage, SCC and flow velocity on the synergistic effects of erosion and corrosion on materials degradation in supercritical water environment could emerge.
Stability of a Natural Circulation Loop

Instabilities

Single Phase (Subcooled)
- Temperature oscillations
- Flow oscillations
- Flow reversals

Two-Phase
- Density wave oscillations
- Pressure drop oscillations
- Thermal oscillations

Single phase (Supercritical)
- Not yet fully explored. Expecting both single phase and two-phase instabilities
Natural Circulation Loop Analysis

Power (kW)

G (kg/m²s)

Mass Velocity
• ANL can achieve large property variations over a large $\Delta T$ with CO$_2$ as the working fluid.

• UW can obtain small property variations over small $\Delta T$’s with H$_2$O as the working fluid.
Stability References

Single Phase

Two-Phase Flow

Supercritical Fluids
• Harden G H, *Transient behavior of a natural-circulation loop operating near the thermodynamic critical point*, ANL-6710 (1963)
Synergistic effects of erosion and oxidation/corrosion on material removal

How does the shear stress generated at the materials’ surface due to supercritical water flow compare with the oxide-metal interface strength as the oxide film grows in thickness?

\[ Wt. \text{ loss} = 52.1 (Re)^{0.54} \left[ (0.96 t + 0.31)^{0.5} - 0.56 \right] \]

Wt. Loss is in units of gm\(^{-2}\)d\(^{-1}\) and t is in hours