HEAT TRANSFER AT SUPERCRITICAL PRESSURES (SURVEY)

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Objectives

The objectives are to assess the work that was done in the area of heat transfer at supercritical pressures, to understand the specifics of heat transfer at these conditions, to compare different prediction methods for supercritical heat transfer in tubes and bundles, and to choose the most reliable ones.

Preliminary Findings

The exhaustive literature search, which included hundreds of papers, showed that the majority of correlations were obtained in tubes and just few of them in other flow geometries including bundles.

The use of supercritical steam-water in nuclear reactors (Generation IV Nuclear Energy Systems Report 2001) will:

Significantly increase thermal efficiency up to 40–45% ;
Decrease reactor coolant pumping power;
Lower containment loadings during loss-of-coolant accidents;
Eliminate dryout; and
Eliminate steam dryers, steam separators, re-circulation pumps, and steam generators.

1 The presentation is based on the following papers:
THERMOPHYSICAL PROPERTIES AT CRITICAL AND SUPERCRITICAL PRESSURES

Temperature, °C

Density, kg/m³

- p=22.1 MPa
- p=25.0 MPa

Temperature, °C

Density, kg/m³
KRASNOSHCHEKOV AND PROTOPOPOV (1959, 1960) FOR TUBES

\[ Nu = Nu_0 \left( \frac{\mu_b}{\mu_w} \right)^{0.11} \left( \frac{k_b}{k_w} \right)^{-0.33} \left( \frac{c_p}{c_{pb}} \right)^{0.35} \]

\[ \xi = \frac{\xi}{8} \frac{Re_b}{Pr} \]

\[ Nu_0 = \frac{1}{12.7 \sqrt{\frac{\xi}{8}} \left( Pr^3 - 1 \right) + 1.07} \]

\[ \xi = \frac{1}{(1.82 \log_{10} Re_b - 1.64)^2} \]

\[ Pr = \frac{(H_w - H_b)}{(T_w - T_b)} \frac{\mu_b}{k_b} \]

\[ c_p = \frac{H_w - H_b}{T_w - T_b} \]
\[ Nu_x = 0.021 \text{Re}^{0.8} \text{Pr}^{-0.7} \left( \frac{\rho_w}{\rho_b} \right)_x^{0.45} \left( \frac{\mu_b}{\mu_{in}} \right)_x^{0.2} \times \left( \frac{\rho_b}{\rho_{in}} \right)_x^{0.1} \left( 1 + 2.5 \frac{D_{hy}}{x} \right) \]
Water, circular vertical tube, D=8 mm, L=1.5 m, P=23.3 MPa, q=1084 kW/m², G=1500 kg/m²s, \( t_{pc} = 378.6^\circ C \), \( H_{pc} = 2148 \text{ kJ/kg} \)
Heated Length, m

Sheath Wall Temperature, °C

CANDU-X
Pressure 25 MPa,
Mass flux 860 kg/m²s
Heat flux 670 kW/m²
Uniform axially and radially
Dₜₐ₉=7.71 mm
Heated length 5.772 m
43-element bundle
12 bundles in string

Gorban’ et al., 1990
Kondrat’ev, 1969
Krasnoshchekov-Protopopov, 1960
Dyadyakin-Popov, 1977
Bishop et al., 1964
Kitoh et al., 1999
Kirillov et al., 1990
**FINAL REMARKS AND CONCLUSIONS**

- A comparison of various correlations for supercritical heat transfer showed that several correlations can be used for preliminary estimations of heat transfer in tubes and bundles. However, no one correlation is able to describe deteriorated heat transfer in tubes.

- Preliminary calculations of heat transfer and temperature profiles in a CANDU-X supercritical water-cooled reactor operating conditions showed that the proposed concept of this reactor is feasible for future development.
CURRENT EXPERIMENTAL DATA FOR CO₂ LOOP
(NORMAL HEAT TRANSFER)

Carbon dioxide, $P_{\text{out}}=8.36$ MPa, $\Delta P=1.5$ kPa, $G=726$ kg/m²s, $Q=1.5$ kW, $q=26.8$ kW/m²
(uniform heat flux)

- $T_{\text{in}}, T_{\text{out}}, T_{\text{out mixer}}, T_{\text{w ext}}$ are measured values
- $T_{\text{pc}}^\text{cal} = 36.5°$ C
- $HTC$ (Krasnoshchekov-Protopopov, 1960)
Carbon dioxide, $P_{out}=8.37$ MPa, $\Delta P=1.7$ kPa,
$G=823$ kg/m$^2$s, $Q=12.0$ kW, $q=214.3$ kW/m$^2$
(uniform heat flux)

Fluid Bulk Enthalpy, kJ/kg

Heat transfer coefficient (calculated)

Inside wall temperature (recalculated from $T_{w ext}$)

$T_{in}$, $T_{out}$, $T_{out mixer}$, $T_{w ext}$ are measured values

$T_{cal} = 36.5^\circ C$

Heated length