ANALYTICAL AND EXPERIMENTAL PROGRAM OF SUPERCRITICAL HEAT TRANSFER RESEARCH AT THE UNIVERSITY OF OTTAWA

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The present paper describes the preliminary compilation, assessment and examination of the supercritical heat transfer (SCHT) database. The availability and reliability of the SCHT data are discussed. Similarities in thermodynamic supercritical properties and SCHT behaviour of water, CO_2 and R-134a have been examined and some tentative conclusions are made. Finally, the future experimental and analytical program at the University of Ottawa is described.

KEYWORDS : Supercritical Heat Transfer, Supercritical Pressure Drop, Multi-fluid Loop

1. INTRODUCTION

A research team in the Department of Mechanical Engineering, University of Ottawa (UO) has been active in measuring various thermalhydraulic parameters and compiling heat transfer databases since 1975. It has compiled the world's largest databases for critical heat flux and film-boiling heat transfer obtained at forced convective conditions in directly heated tubes. Although film boiling does not occur at pressures higher than the critical pressure, Schmidt [1] and Herkenrath et al. [2] extended their subcritical databases for water by obtaining supercritical heat transfer (SCHT) measurements at film-boiling-like conditions. A comparison of the axial wall temperature profiles at subcritical and supercritical (SC) conditions reveals gradual, rather than drastic changes [1]. At the subcritical pressures of 22 MPa and below, there are sharp peaks in the wall temperature profiles, which are characteristic of CHF occurrence. Such peaks are less severe at the SC pressures of 23 MPa and above. Thus, a CHF-like phenomenon seems to occur at SC conditions and high heat fluxes (Jackson and Hall [3]). This phenomenon probably signifies a change from a liquid-like layer at the wall to a low-density, low-conductivity layer covering the wall and resembling a film-boiling-like state. At bulk coolant temperatures well above the critical temperature, the heat transfer starts to resemble the normal single-phase heat transfer to a gas, which can be predicted with conventional correlations of the form $Nu = a\ Re^b\ Pr^c$ where Nu is the Nusselt number, Re is the Reynolds number, Pr is the Prandtl number, and a,b and c are empirical constants.

A supercritical heat transfer investigation has recently commenced at the University of Ottawa. Its main objectives are: (i) to develop, assess and improve prediction methods for SCHT and pressure drop, (ii) to improve fluid-to-fluid modelling of SCHT, and (iii) to simulate SCHT in complex geometries using CFD. Details of the progress made are provided in this paper.

2. SC HEAT TRANSFER CORRELATIONS

Hall, Jackson and Watson [4] and Jackson and Hall [3] have presented overviews of SCHT correlations and assessments of SC heat transfer correlations against both SC water and SC CO_2 data. Pioro et al. [5] recently presented a more updated review of such correlations that have been applied to SC conditions. Hall, Jackson and Watson [4] considered a modified form of the Krashnochekov and Protopopov equation (based on a variation of the Dittus-Boelter equation),

$$Nu_b = 0.0183 Re_b^{0.82} Pr_b^{0.5} \left(\frac{\rho_w}{\rho_b}\right)^{0.3} \left(\frac{\overline{C}_p}{C_{p_b}}\right)^n \qquad (1)$$

$$\text{where } \overline{C}_p = \frac{h_w - h_b}{T_w - T_b}$$

In this expression, ρ is the density, h is the specific enthalpy, C_p is the specific heat, and the subscripts b and w denote bulk and wall properties, respectively. The exponent n varies in the range 0.4 to 0.6. Equation 1 was found to agree with a selection of SC water and CO_2 data and was therefore recommended. Recently, an analysis was performed by the present authors using the SC CO_2 data obtained at AECL by Pioro and Khartabil [6] and SC water data obtained by Dickinson and Welch [7] and Kirillov et al. [8] to assess their similarity in thermalhydraulic behaviour at SC conditions, using parameters similar to those used in Eqn. 1. Figure 1 shows similar trends of the SCHT water and CO_2 data when plotted as Nu_{exp}/Nu_{DB} vs H_b/H_{pc}, where $Nu_{DB} = 0.023\ Re^{0.8}\ Pr^{0.4}$ (Dittus-Boelter equation), H_b is the bulk enthalpy, and H_{pc} is the enthalpy at the pseudo-critical temperature, at which the specific heat reaches a maximum. The three data sets covered the ranges of conditions shown in Table 1. A more detailed examination of this similarity using additional SC data sets will be performed in the near future.

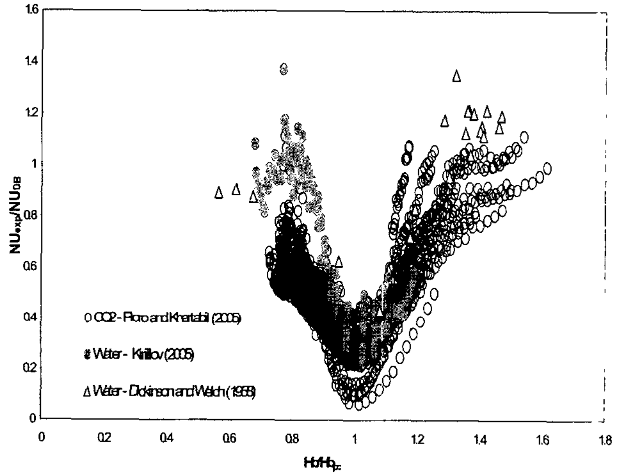

Fig. 1. Dimensionless Nusselt Number vs. Dimensionless Bulk Coolant Enthalpy

3. FLUID-TO-FLUID MODELLING OF SCHT

Fluid-to-fluid modelling is a technique to model a thermalhydraulic phenomenon in a working fluid (usually water) using a modelling fluid, which is usually a member of the Freon family. The two main reasons for using modelling fluids are the low testing costs and the convenience in performing more extensive tests because of less severe test conditions than using water. Fluid-to-fluid modelling of CHF has been applied successfully in many heat transfer laboratories using Freons as modelling fluids to simulate the CHF of water (e.g., Groeneveld et al. [9-10]). Reliable CHF predictions for water can be made based on CHF measurements in Freons at considerably lower pressures, temperatures and powers, resulting in cost savings of around 80% compared to equivalent experiments in water (Groeneveld et al. [11]). Fluid-to-fluid modelling techniques for film boiling are not as well established as for CHF, and have been considered by several researchers (e.g., Groeneveld et al. [11], Hammouda [12], El Nakla [13]). Successful fluid-to-fluid modelling or scaling of SCHT requires the use of appropriate similarity relationships. It is proposed to apply fluid-to-fluid modelling of SCHT using the following dimensionless groups:

(i) P/P_c *and* T/T_c: For the subcritical region, the saturation lines of CO_2, water and R-134a nearly coincide on a P/P_c vs. T/T_c (absolute temperatures) diagram, as can be seen in Figure 2. For SC conditions, we hypothesized that the dependence of the pseudocritical temperature T_{pc} on pressure might be similar to the dependence of the saturation temperature on pressure, because the enthalpy gradient dh/dT reaches a maximum at both

Table 1. Ranges of SC Water and CO_2 Data

Fluid	Water	Water	CO_2
Authors	Kirillov et al. [8]	Dickinson and Welch [7]	Pioro and Khartabil [6]
No. of data	156	21	2464
L, mm	4000	1600	2208
D, mm	10.0	7.62	8.06
T_b/T_c	0.92 - 1.03	0.84 - 1.16	0.97 - 1.31
P/P_c	1.09	1.09	1.026 - 1.2
Re	$(1.8-5.2)\times 10^5$	$(2.6-9.3)\times 10^5$	$(1.1-12.1)\times 10^5$
Pr	0.89 - 10.35	0.8 - 7.23	0.90 - 34.50

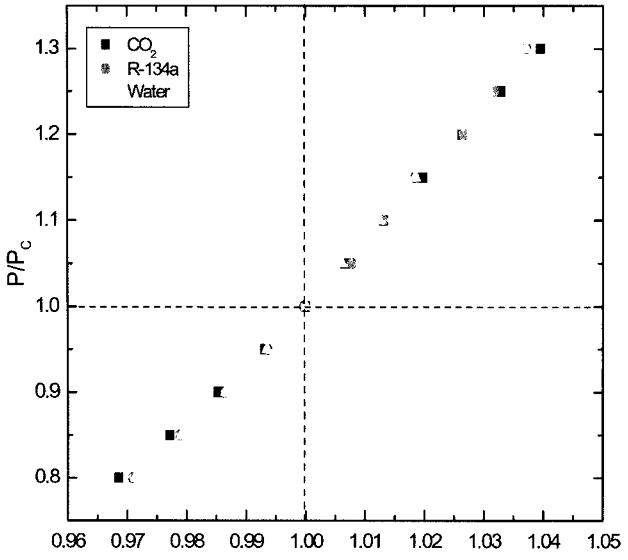

Fig. 2. Dimensionless Pressure vs. Dimensionless Temperature for Water, CO_2 and R-134a for Saturation and Pseudocritical Conditions

temperatures. This was confirmed in Figure 2 where a remarkable degree of similarity in the SC behaviours of these three fluids is noted. On a P/P_c vs. T/T_c plot, the pseudocritical lines for all three fluids nearly coincide and the pseudocritical line appears to be an extension of the saturation line.

(ii) *Reynolds number and Nusselt number*: At SC conditions that are well beyond the critical or pseudo critical points, single-phase-like flow characteristics prevail and the conventional Nu = f (Re, Pr) relationship is applicable for predicting the heat transfer. The heat transfer mode at these SC conditions is labeled as "normal" (Pioro and Duffey [14]). Thus, the product $Re \cdot Pr^{0.5}$ can be used as a first approximation to determine equivalent mass flux conditions, especially when the Prandtl number is not far from unity. Not surprisingly, for near-pseudocritical conditions, at which the fluid properties change drastically, the heat transfer also displays an anomalous behaviour, as shown in Figure 1. Because the anomalous behaviour appears to be similar for both CO_2 and water, when normalizing Nu by NuDB (Figure 1), this methodology will be used also in our preliminary fluid-to-fluid modelling approach. We will therefore scale test conditions for all three fluids by maintaining the same value of $Re \cdot Pr^{0.5}$. We also expect that the similarity would apply equally to heat transfer in the deteriorated heat transfer region, which, compared to the normal heat transfer mode, is characterized by lower values of the heat transfer coefficient (see again Figure 1) and hence higher values of wall temperature within parts of a test section at high heat fluxes and low mass fluxes. Mechanisms responsible for this deterioration in heat transfer have been described by various authors (e.g., Jackson and Hall [3]). This anomalous behaviour has been observed in various fluids operating at SC conditions. Additional confirmation that the fractional decrease in heat transfer (or the ratio Nu_{exp}/Nu_{DB}) is the same in all three fluids of interest is required for a wider range of fluids, and values of P/P_c and Re within the entire ranges of interest.

(iii) *Heat flux*: Jackson and Hall [3] examined the governing SC heat transfer equations and suggested that the values of the heat flux parameter $qD/(kT_b)$ should be kept the same in the prototype and modelling fluid; in this expression, D is the tube inside diameter, k is the thermal conductivity and T_b is the absolute bulk coolant temperature. Yang and Khartabil [15] found that the heat flux parameter $q/G\ H_b$, when included in a Nu = f(Re, Pr, T_b/Tc, P/Pc) type correlation, provided an improved prediction for the deteriorated heat transfer region for the AECL SC CO_2 data and the SC water data by Yamagata et al. [16]. We will therefore explore both heat flux parameters for SC fluid-to-fluid modelling.

(iv) *Geometry*: Both Re and Nu contain an equivalent diameter, which should, in principle, account for differences in geometries in scaled tests. However, in previous CHF and film boiling modelling studies (e.g., Groeneveld et al. [11]), it was found that the accuracy of fluid-to-fluid modelling could be adversely affected by significant geometrical differences. To remove this uncertainty, SC fluid-to-fluid modelling experiments at the University of Ottawa will be based on identical test section geometries.

4. AVAILABILITY OF SCHT DATA

4.1 Water Data

Many heat transfer experiments on SC water have been reported during the past sixty years. Most of these SCHT data were obtained in support of the SC fossil fired plants, which have been constructed around the world since the early nineteen sixties. Pioro and Duffey [14] reviewed the literature of SCHT experiments in water and found more than a hundred data sets. Although these data should, in principle, be available to investigators worldwide, in practice data availability is a real problem for the following reasons.

- Many data sets have been lost, especially those data obtained prior to 1965, before computers were used in the laboratory. In some cases, investigators knowing the data storage locations have died or retired, in others the data were never properly archived, and in others laboratories where the data were obtained have since ceased to exist (e.g., UKAEA).

- The data are proprietary or commercial.
- The data may still be available, but it would require significant motivation, effort, and expense to retrieve them from archives and have them restored in a usable form.
- The data are only available in graphical form. Values can be extracted from the graphs using special software, but they would generally be less accurate than tabulated values, because of loss of resolution in small-size graphs, averaging of data on plots, and averaging of flow conditions for each graph.

It is estimated that about half of the reported SCHT data for water are no longer available and some duplication

Table 2. SCHT Water Data Sets Considered Accessible

Author(s)	P (MPa)	t (°C) / H_b (kJ/kg)	q (kW/m^2)	G (kg/m^{2}s)	Tube ID (mm)/ flow direction	Data availability
Alekseev et al. (1976) [17]	24.5	t_{in}=100-350	100-900	380-820	10.4 /vert.	Graph
Alferov et al. (1975) [18]	26.5	---	480	447	20 /vert.	Graph
Bazargan et al. (2005) [19]	23-27	t_w=405-670	Up to 310	330-1200	6.3 / hor.	Graph
Belyakov et al. (1971) [20]	24.5	H_b=1004-1800	232-1395	300-700	20 / vert. and hor.	Graph
Glushchenko et al. (1972) [21]	22.6-29.4	H_b=85-2400	Up to 3000	500-3000	3, 4, 6, 8 / vert.	Graph
Harrison and Watson (1976) [22]	24.5	t_b=50-350	1300,2300	940,1560	1.64, 3.1 /vert. and hor.	Graph
Herkenrath et al. (1967) [2]	14-25	$t_{b(min)}$= 345-370 $t_{b(max)}$= 374-437	60-1400	720-3620	10-20 / vert.	Graph/ Tables
Kamenetskii (1975) [23]	23.5-24.5	H_b=100-2300	Up to 1200	50-1700	21-22	Graph
Kamenetskii (1980) [24]	24.5	H_b=100-2200	Up to 1300	300-1700	21.1-21.9 /vert. and hor.	Graph
Kirillov et al. (2005) [8]	23-25	t_{in}=320-380	Up to 1400	200-2000	10 / vert.	Tables
Krasyakova et al. (1977) [25]	24.5	H_b=400-1900	100-1400	90-2000	20 / upward and downward	Graph
Ornatsky et al. (1970) [26]	22.6-29.4	H_{in}=420-1400	Up to 3000	450-3000	3 / vert.	Graph
Ornatskiy et al. (1971) [27]	22.6-29.4	H_{in}=800-1500	Up to 3000	500-3000	3 / vert.	Graph
Razumoviskiy (2005) [28]	23.5	t_{in}=20-380	Up to 515	250-500	6.28-9.5 / vert.	Graph/ tables
Schmidt (1959) [1]	17-30	t_b=200-700	290 – 820	700-1700	5 / vert. and hor.	Graph
Seo et al. (2005) [29]	23-24.5	H_b=1500-2500	210-933	430-1260	7.5-8 / vert.	Graph
Shitsman (1963) [30]	23-25	t_b=280-580	280-1100	300-1500	8 / vert.	Graph/ tables
Shitsman (1968) [31]	10-35	t_b=100-250	270-700	400	3, 8, 16 / vert.	Graph
Treshchev et al. (1977) [32]	23-25	t_{in}=300	815	750	---	Table
Vikhrev et al. (1967) [33]	24.5	H_b=230-2750	230-1250	500-1900	7.85 / vert.	Graph
Yamagata et al. (1972) [16]	22.6-29.4	t_b=230-540	1200-930	310-1830	7.5, 10 / upward, downward and hor.	Graph

of previously performed experiments may be required. An international cooperative effort, such as Generation IV International Forum (GIF), could assist in uncovering these inaccessible data. It is recommended that member countries initiate searches of archives of participating national institutes and university libraries for relevant SCHT data sets. Doctoral theses related to SCHT are expected to provide useful data to augment the SCHT data bank.

A condensed version of the SCHT water database of Duffey and Pioro [34], showing only the data sets currently available to UO, is presented in Table 2. Figure 3 shows the range of water data on a P/Pc vs. T/Tc plot.

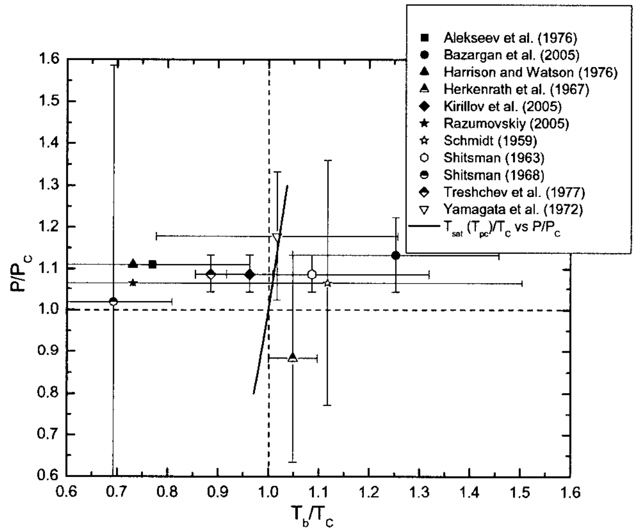

Fig. 3. Ranges of Available SCHT Data for Water

4.2 Carbon Dioxide Data

SC CO_2 has been used as a surrogate fluid for SC water to investigate the SCHT phenomena but at less severe test conditions permitting lower pressures, temperatures and heating powers (see Section 2). As shown in Sections 2 and 3, the SC behaviours of water and CO_2 are similar. Except for the Bringer et al. [34] experiments, the CO_2 data are more recent than the water data. However, the concerns expressed in Section 4.1 regarding SC water data availability also apply to CO_2 data, although to a lesser extent. Duffey and Pioro [35] provided a review of available CO_2 data and tabulated all reported SC CO_2 experiments. The CO_2 data provide the second largest bank of SCHT data after that for water.

Figure 4 shows the range of available SC CO_2 data. Recent data obtained at the University of Wisconsin and at the Korea Atomic Energy Research Institute (KAERI) are being reviewed and will be incorporated into the database.

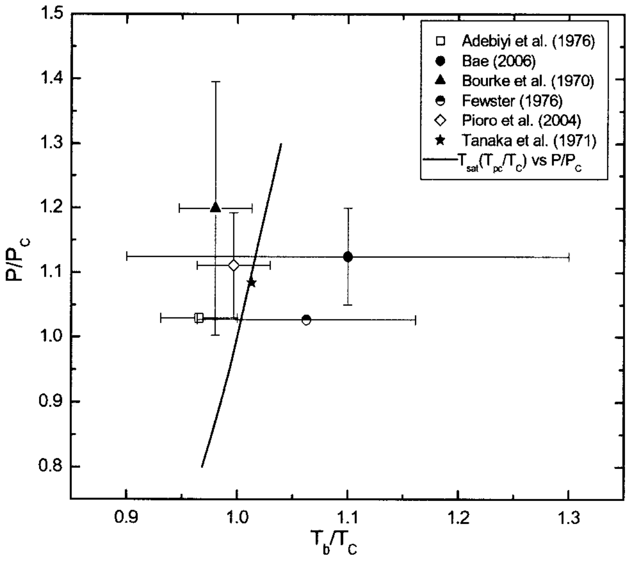

Fig. 4. Ranges of Available SCHT Data for CO_2

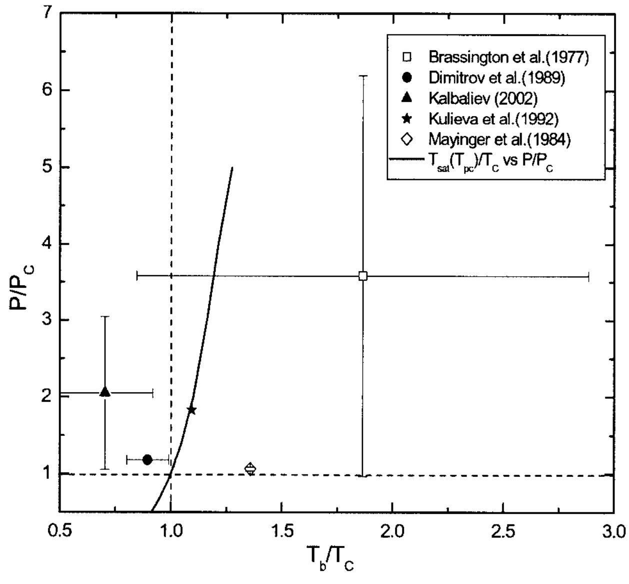

Fig. 5. Ranges of Available SCHT Data Obtained in Fluids Other than Water or CO_2

4.3 SCHT in Other Fluids

The SCHT database has recently been augmented by experiments performed on refrigerants, hydrocarbons and a few other fluids. These data sets are being compiled at UO. Figure 5 shows the range of the available SCHT data on a P/P_c vs. T/T_c plot.

4.4 Discussion

Table 2 lists data obtained in horizontal and vertical tubes. A limited number of SCHT measurements have also been obtained in annular geometries (Hong [36], Sergeev et al. [37], McAdams et al. [38], Anderson et al. [39], Kim et al. [40]) or bundle geometries (Grabezhnaya and Kirillov [41]). These data have been reviewed by Pioro et al. [5, 14] and will not be discussed here.

Once the SCHT data compilation has been completed, all data will be carefully screened using the same process used for the screening of CHF and film boiling data in the UO data banks (Groeneveld et al. [42-43]). The screening process will remove the duplicates and outliers, and will identify those data that are affected by entrance effects and data sets that are considered less reliable because of high heat balance errors and/or large scatter. Note that some data, especially those extracted from graphs, are only available in a processed form and their accuracy depends on the accuracy of the property subroutines used in processing the measurements.

5. SCHT RESEARCH PROGRAM AT THE UNIVERSITY OF OTTAWA

5.1 Experimental studies

Measurements of surface temperature and pressure drop at SC water conditions and geometries relevant to a SCWR core are very expensive to obtain. Few SC facilities for testing the thermalhydraulic behaviour of geometries simulating fuel bundles for SCWR are available. To complement the available SCHT data for water, it is proposed to investigate the thermalhydraulic behaviour of fuel bundle simulators by using Freon R-134a and CO_2 as modeling fluids. The advantage of using these modelling fluids is that they reach SC conditions at much lower pressures and temperatures, compared to water: the critical pressures and temperatures of water, CO_2 and R-134a are, respectively, 22.1 MPa and 374°C, 7.38 MPa and 31°C, and 4.06 MPa and 101°C. Because of the much lower specific heats of CO_2 and R-134a (typically 25% of those of water), the power requirements are also much lower.

The UO team has recently completed a design for a SC multi-fluid loop suitable for performing experiments in R-134a and CO_2 and is in the process of acquiring the loop components. The ranges of similarity parameters used to scale the tests are listed in Table 3. The range of pressure ($0.95 < P/P_c < 1.2$) covers the range of interest for the SC CANDU reactor, but the range of temperature ($0.9 < T/T_c < 1.1$) does not extend to temperatures as high as those of CANDU interest ($T/T_c \approx 1.4$); this is done in order to keep the need for electrical power within acceptable levels and is justified by the fact that, at high temperatures, SCHT becomes similar to single phase heat transfer, so that conventional heat transfer correlations can be used (see discussion in Section 3.0 (ii)). The ranges of inlet Reynolds number and dimensionless heat flux will be kept the same for all

Table 3. Ranges of Similarity Parameters Used for Scaling Tests

Similarity parameter	Range
P/P_c	0.95 – 1.20
T_b/T_c	0.9 – 1.1
Re (at inlet)	$0.5 \times 10^5 - 4 \times 10^5$
$q/(GH_b)$	$3.5 \times 10^{-5} - 5 \times 10^{-3}$

Table 4. Summary of Test Conditions

Parameter	Unit	CO_2	R-134a	Equivalent range in water
Pressure	MPa	7.0 - 8.9	3.9 - 4.9	21 - 26
Mass flux	$kg\ m^{-2}\ s^{-1}$	500 - 3900	540 - 4200	500 - 3900
Inlet temperature	°C	5 - 30	60 - 100	300 - 370
Bulk temperature	°C	5 – 60	60 - 140	300 - 440
Heat flux	$kW\ m^{-2}$	65 - 930	70 - 800	400 - 3500

fluids. The following experiments are planned for this facility.

Reference heat transfer and pressure drop measurements: Surface temperature and pressure drop of CO_2 flow in a 2 m long, 8 mm ID, vertical tube will be measured for the conditions listed in Table 4. These measurements will serve as reference and will be compared to CO_2 measurements from the literature. Heating will be applied such as to generate conditions for both normal and deteriorated heat transfer. Yang and Khartabil [15] proposed a criterion for the onset of deteriorated heat transfer for CO_2 in 8 mm ID tubes as $q > 0.27\ G^{0.94}$, where q is the heat flux in kW/m^2 and G is the mass flux in kg/m^2s. This is analogous to the condition $q > 0.20\ G^{1.2}$, suggested by Yamagata et al. [16] for water in 10 mm tubes. Cheng and Schulenberg [44] have reviewed additional criteria for deteriorated heat transfer and demonstrated that they provide vastly different estimates. This issue will be examined in detail in the future. For planning purposes, the range of heat fluxes for the present tests was estimated to extend from one order of magnitude lower to one order of magnitude higher than the value given by the criterion of Yang and Khartabil.

Effect of fluid type: Tests similar to those in CO_2 will be performed in Freon R-134a to facilitate the development and validation of fluid-to-fluid scaling laws for SC heat transfer and pressure drop (see also Table 4).

Effect of orientation: The proposed Canadian Generation IV reactor design uses horizontal fuel channels. Although some SCHT tests have been performed in horizontal channels (see Table 2), no systematic investigation of the orientation effect has yet been performed. It is proposed to conduct heat transfer and pressure drop measurements in horizontal tubes over the complete range of conditions of interest and in both fluids. These results will be compared to corresponding measurements in vertical tubes for an assessment of the orientation effect.

Effect of flow geometry: Upon the completion of the circular-tube tests, rod-bundle subassemblies will be tested as part of a systematic study of the effects of equivalent diameter, heater curvature, inter-element gap size, and rod-wall gap size. A three-rod subassembly is already available for these tests.

Effect of flow obstructions: Nuclear fuel bundles require spacers between fuel rods and between fuel rods and pressure tubes or containment channels. Spacers affect both pressure drop and heat transfer significantly (Yao et al. [45], Groeneveld et al. [11]), depending on the flow blockage ratio, their shape and their axial pitch. Spacer effects will be investigated initially by inserting simple obstructions in a heated tube and will be extended later to include more realistic obstructions in the rod-bundle subassembly.

Measurements of mean and turbulent velocity and temperature: Traverses of Pitot-tubes and micro thermocouples will be made across different test sections to measure the average velocity and temperature profiles. In addition, cold-wire/hot-wire probe combinations will be used to measure simultaneously the velocity and temperature fluctuations at selected locations, including narrow gaps. These results will be valuable in understanding SCHT phenomena, for developing phenomenological models and for validating SC subchannel analysis codes and CFD studies.

5.2 Analytical Studies

5.2.1 CFD Work

Numerical simulations will be performed for SC water, CO_2 and Freon flows in heated circular tubes and rod bundles to develop reliable procedures for the prediction of the turbulence structure, heat transfer and mixing processes in SCWR cores.

Effect of large property variations: Time-dependent simulations at extremely high spatial resolution and with variable thermophysical and thermodynamic properties will be conducted in heated laminar and turbulent flows in circular tubes, and will focus on the near-pseudocritical range. These simulations will attempt to predict possible heat transfer deterioration and flow instability caused by buoyancy.

Assessment of turbulence models: Fully-developed, SC turbulent flows in circular tubes will be simulated by solving the Reynolds-averaged, compressible continuity, momentum, energy and state equations with variable properties, using turbulence models. Initial simulations will be performed using mixing-length models, to provide a basis for comparison with previous studies. In addition, simulations using the classical and RNG k-ϵ models, the k-ω model and the Reynolds stress model will be performed and their predictions will be compared with each other and with the experimental results.

Intersubchannel mixing: Unsteady simulations (URANS) will be conducted for SC flows in eccentric annuli and simplified rod bundles to investigate the generation of flow pulsations across the gap and their effect on cross channel mixing. Comparison with flows in circular tubes will resolve whether heat transfer deterioration is eliminated by the stronger mixing in rod bundles or is due to other causes.

Large eddy simulations and direct numerical simulations: If time and resources permit, these types of simulations will also be attempted, starting with circular tubes and proceeding to rod bundles.

5.2.2 Data Analysis

The new data will be combined with ones from the literature to construct dimensionless look-up tables for SCHT and pressure drop applicable to many fluids. These tables will be in terms of dimensionless temperature, pressure, mass flux and heat flux, using suitable modelling parameters as discussed in Section 3. In addition, the more prominent SCHT correlations will be assessed by means of a comparison against the data, and modifications to some of the correlations may be suggested. A dimensional look-up table of wall temperature in tubes with SC water flow for a limited range of conditions has recently been constructed by Lowenberg et al. [46].

6. SUMMARY

It is estimated that approximately half of the SCHT data for water, measured during the past 60 years, are no longer available. An international cooperative effort such as GIF could assist in uncovering previously inaccessible data. It is recommended that countries participating in the Generation IV initiative undertake searches of archives of participating national institutes and university libraries. A possible source of information is doctoral theses, which usually include a detailed database.

Successful fluid-to-fluid modelling or scaling of SCHT requires choosing appropriate similarity relationships. For the subcritical region, the saturation lines of CO_2, water and R-134a nearly coincide on a P/Pc vs. T/Tc diagram. For SC conditions, the reduced pseudo-critical temperature vs. reduced pressure line appears to be an extension of the saturation line and, on a P/P_c vs. T_{pc}/T_c plot, the pseudocritical lines for all three fluids also nearly coincide.

A recent analysis using available SC CO_2 and water data showed a noticeable similarity between SCHT in these two fluids when the data were plotted as Nu_{exp}/Nu_{DB} vs. H_b/H_{pc}.

Mechanisms responsible for the deterioration in heat transfer have been described by previous authors for various fluids operating at SC conditions. Additional confirmation that the fractional decrease in heat transfer (or Nu_{exp}/Nu_{DB}) is also the same in all three fluids of interest is required for the range of P/P_c of interest.

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