# Development of Program for Generation of Thermodynamic Properties Tables in CUPID Code

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## 1. Introduction

Typical flow conditions in wide range of nuclear power plants includes water under high pressure and temperature in narrow channels. Designing proper experiments to investigate characteristics of this flow is essential for both, safety of nuclear reactors and validation of the CFD models. However, such conditions represent significant experimental challenges, in particular when high precision two phase measurements are needed. To overcome this, various refrigerant were frequently used as alternative to water. Advantages are this allow the use of test parameters which are more convenient for data measurements and visualization. The same vapor/liquid density ratio can be achieved at a much lower pressure and the same Reynold number can be used at bigger diameter of the heated pipe. Accordingly, codes that are used for nuclear safety and analysis should also be able to calculate the properties of these alternative fluids to validate its physical models.

CUPID is a three-dimensional thermal hydraulics code used for the transient analysis of two-phase flows in nuclear reactor component developed by the Korea Atomic Energy Research Institute (KAERI) [1]. In the CUPID code, full range steam tables for water were implemented at the first stage of the code development program. Later on, the fluid properties for various fluids were implemented by solving the FORTRAN properties functions provided by the National Institute of Standards and Technology (NIST) directly as a part of its solution algorithm. While this method is accurate it requires large computational resources and long simulation time. Motivated by this, a NIST based program for generation of properties tables of various fluids called CUPID_Prop is developed and verified in this work. DEBORA experiment is chosen as case study to demonstrate the effect of property tables on calculation time and accuracy.

## 2. CUPID _Prop

Currently, CUPID simulates light water properties using steam tables that contain full set of thermodynamics properties as a function of temperature and pressure for three phases; these thermodynamics properties are obtained from an equation of state at developer-specified pressures and temperatures. To achieve fast simulation, CUPID code obtains the water properties at any state point by interpolating the exact data at these specified points. This is the same approach used in the nuclear system code MARS [2]. In order to further extend its simulation capabilities to include other fluids, CUPID implemented the functions used in REFPROP program to calculate thermodynamic properties. REFPROP is an acronym for REFerence fluid PROPerties developed by NIST to calculate the thermodynamic and transport properties of industrially important fluids, it is based on the most accurate pure fluid and mixture models currently available [3]. Albeit being accurate this method calculates unnecessary properties when a certain function is being called which slow down the calculation process. To overcome this limitation, CUPID_Prop, a stand-alone FORTRAN program for generation of thermodynamic properties tables is developed. It utilizes NIST functions to generate properties tables of various fluids in a binary format that is compatible with CUPID/ MARS. The generated properties tables have the same structure and format used in the light water tables. For each fluid a full set of six thermodynamic properties are generated as a function of pressure and temperature for the three zones; saturation line, single-phase liquid and single-phase vapor. These properties are; specific volume, internal energy, thermal expansion coefficient, isothermal compressibility, specific heat and entropy. In order to generate tables for any fluid, user need to prepare input file that contains set of temperatures and pressures. It is advised to choose tight range of input data to increase accuracy of the calculation since CUPID code will interpolate the exact data generated at these points to obtain properties at any state point. Using properties tables reduces the calculation time significantly as will be shown later in this paper.

## 3. Verification

To confirm accuracy and consistency of the generated thermal hydraulics properties tables, the generated data by the CUPID_prop program are compared against data by NIST REFPROP (Version 10.0) for water. Verification against water is selected because it is the most widely used fluid in nuclear applications. Errors are calculated as follow

$$Error = \frac{ABS(CUPID_{prop} - REFPROP)}{CUPID_{prop}} \quad (1)$$

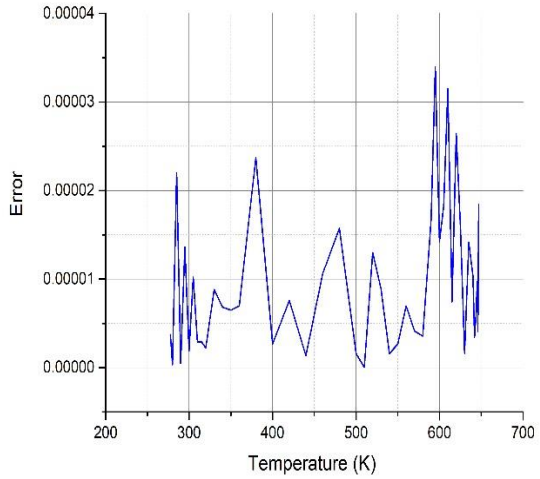


Fig. 1. Error in generated saturated pressures as a function of temperature.

Difference between saturated pressure values for water as a function of temperature generated by the two programs is shown in Fig.1. Errors in generated liquid and vapor for six thermodynamic properties as a function of temperatures at saturation pressures are shown in Fig.2 and Fig.3 respectively. As can be seen, the difference between the properties generated by both programs are very small with the maximum value reach to 0.005 %. This small difference is because in the REFPROP, the properties are limited to 5 digits while in the CUPID_prop the properties are calculated up to 32 digits accuracy.

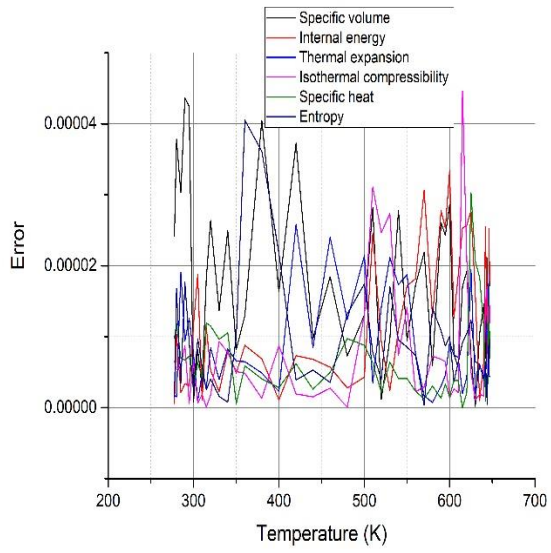


Fig. 2. Error in generated liquid water properties as a function of temperature.

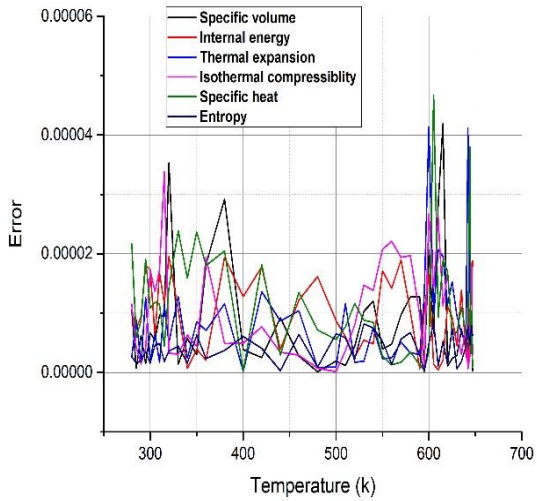


Fig. 3. Error in generated vapor water properties as a function of temperature.

## 4. DEBORA experiment

DEBORA experimental data was selected in the past to validate the implemented property functions in CUPID as well as its subcooled boiling model. Since the old simulation was performed using the direct implementation of the fluid properties functions and not by property tables [4]. This simulation results are chosen as a case study to demonstrate that by using property tables, CUPID shows same accuracy with a significant reduction in simulation time. Fluid used in DEBORA is Freon (R12). Details about DEBORA experiment can be found in literature [5].

Fig. 4. Shows comparison between the two simulation results for radial void fraction. In Fig.5. calculated radial gas velocity distributions are compared. Results shown in the figures are at elevation of 3.5 m. The height at which radial profiles were measured in DEBORA experiment.

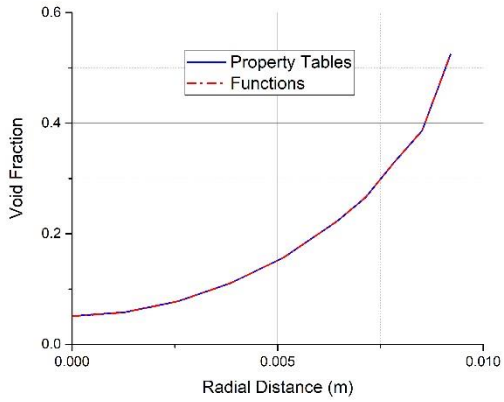


Fig. 4. Radial gas void fraction distribution calculated by both methods.

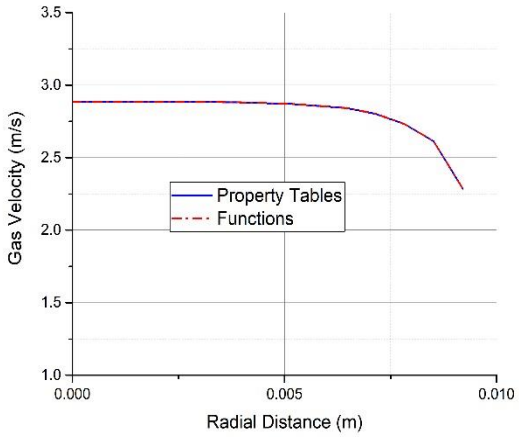


Fig. 5. Radial gas velocity distribution calculated by both methods.

Fig.6. shows error between the calculated radial profiles for void fraction and gas velocity using the two approaches. Error is calculated as follow

$$Error = \frac{ABS(Tables - Functions)}{Tables} \quad (2)$$

Comparison between densities of liquid for the whole computational grid is shown in Fig.7.

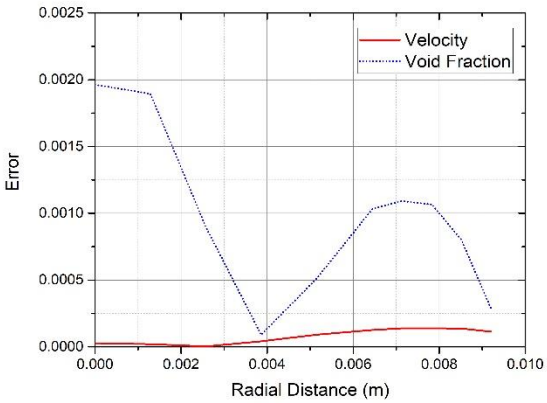


Fig. 6 Errors in calculated radial profiles using the two methods.

As can be seen from Figs 4-7. Results obtained using the two approaches are very similar for all parameters which demonstrates the accuracy of the data generated by the proposed program. Regarding the calculation time, using property tables is 10 times faster than the old method using same time step and grid size.

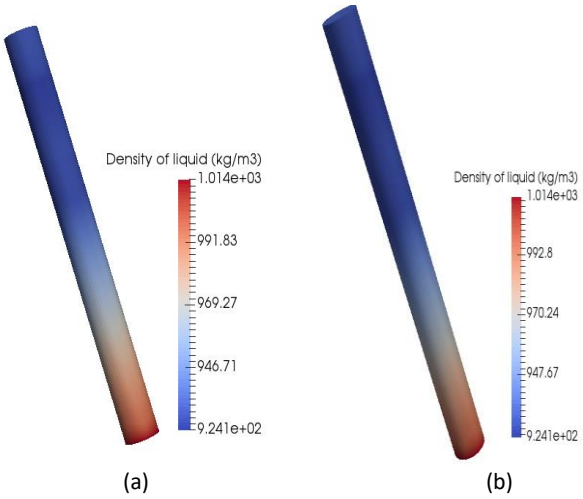


Fig. 7. (a) Liquid density calculated using property tables (b) liquid density using property functions.

## 5. Conclusion

FORTRAN program based on NIST property functions was developed motivated by the need to decrease the calculation time for cases when water is not the working fluid. The developed program is able to generate full set of thermodynamics properties tables for various fluids in a binary format that can be read directly by CUPID or system analysis codes such as RELAP/MARS. Accuracy and consistency of the generated tables for light water were confirmed against property tables generated by NIST REFPROP. DEBORA experiment was selected as a case study and confirmed the validity of the program. Comparison also showed that using property tables are approximately 10 times faster than the old method. Various refrigerants will be implemented in the future based on user needs.

## REFERENCES

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