2-Phase Property Table Development Methods

NPSS consortium thermal working meeting

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Task

- Update NPSS - FPT tables for 2-phase properties

Plan

- Utilize methods developed by NASA Marshal to develop system for two phase property lookup near the dome.

Nguyen, Martin, “AN INTERPOLATION METHOD FOR OBTAINING THERMODYNAMIC PROPERTIES NEAR SATURATED LIQUID AND SATURATED VAPOR LINES”, 52nd JANNAF Propulsion Meeting, NASA ID-20040075672, Feb. 2004.

- Make use of CoolProp for thermophysical properties
  - Does not handle mixtures
- Create a suite of variables needed for 2-phase heat transfer.

Grid development

- 2 table system : pressure (P) to enthalpy (H)
  - Table 1 : Saturation lines
  - Table 2 : all other data

- Create grid minimizing number of points, Set minimum error tolerance, reduce points until this error tolerance is hit.

Grid development

Table 1

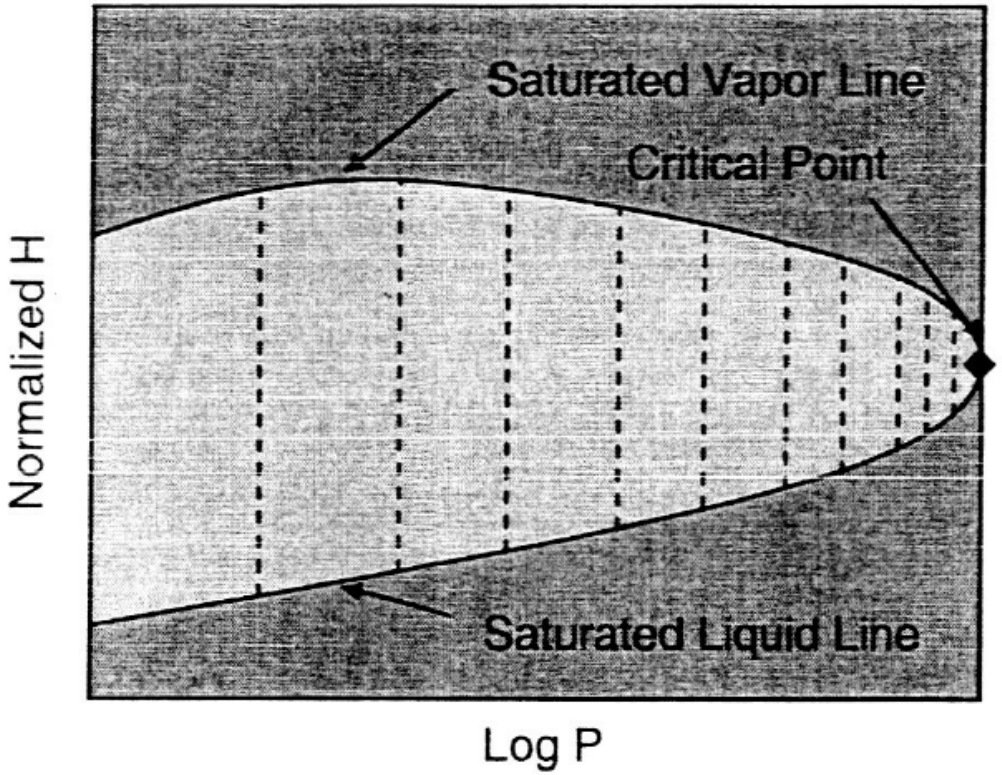


Figure 4. Pressure Grid for Saturation Lines

Table 2

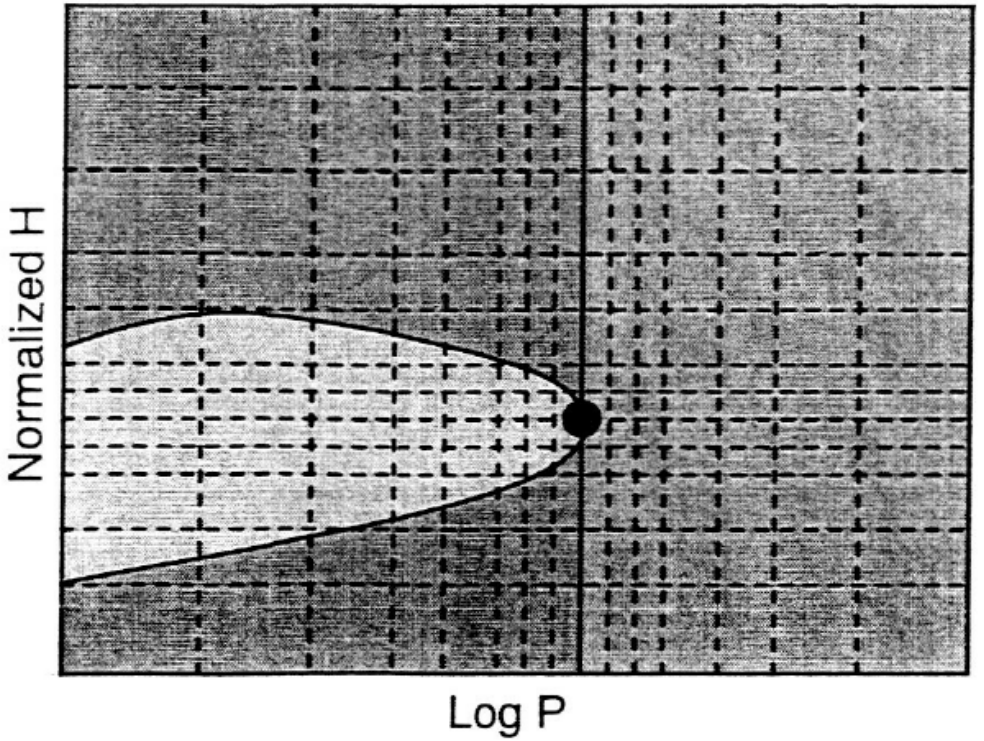


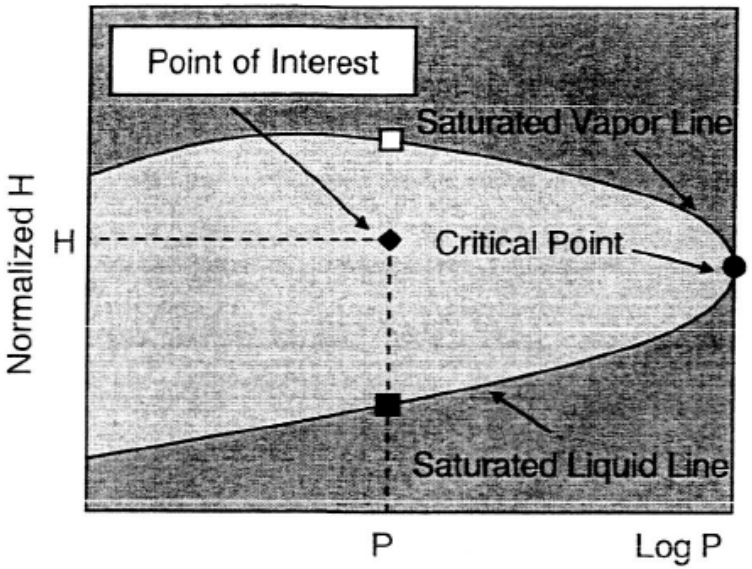
Figure 8. Pressure-Enthalpy Grid for the Entire Region

Finer grid in both P and H near critical point.

Interpolation method

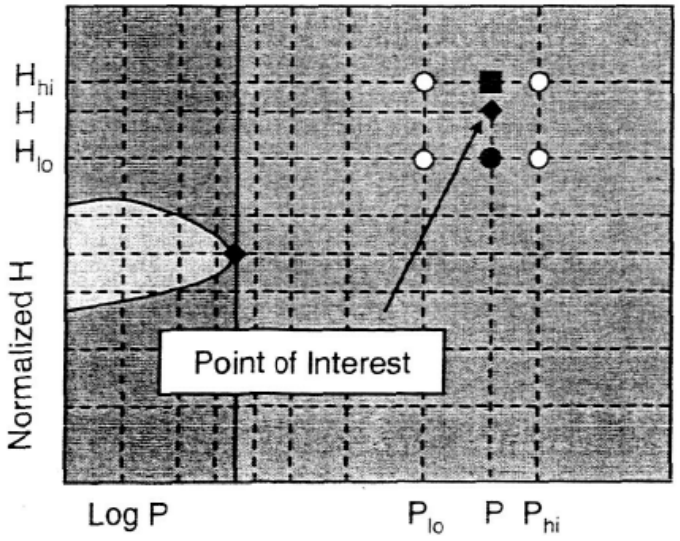
Inside Dome :

Calculate Quality then use linear interpolation between the saturation lines.



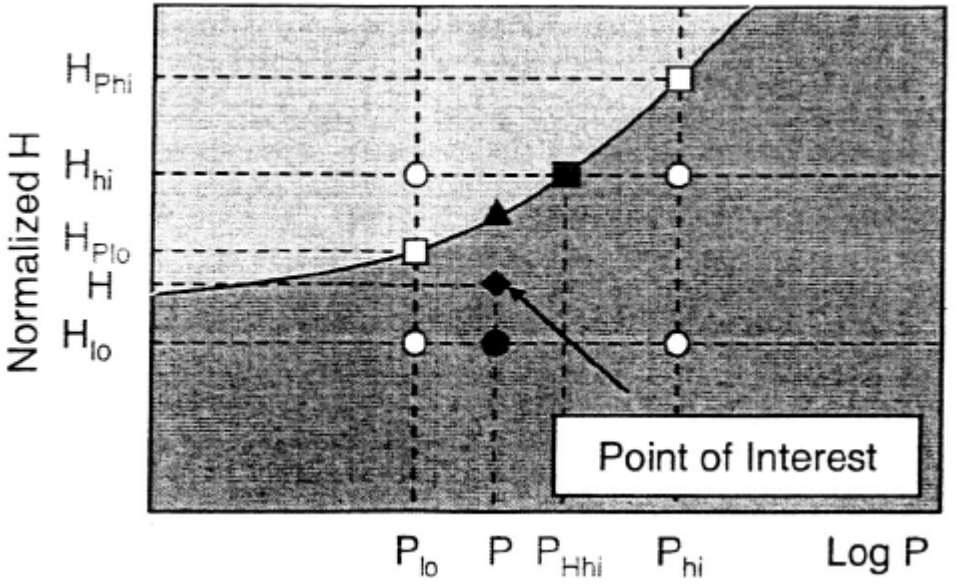
Outside Dome :

linear interpolation between the 4 surrounding points



Outside Dome, near saturation line :

linear interpolation replacing points within the dome with saturation line numbers



Parameter List : [High-Level Interface — CoolProp 6.6.0 documentation]

Parameter	Units	Input/Output	Trivial	Description
DELTA, Delta		IO	False	Reduced density (rho/rhoc)
DMOLAR, Dmolar	mol/m^3	IO	False	Molar density
D, DMASS, Dmass	kg/m^3	IO	False	Mass density
HMOLAR, Hmolar	J/mol	IO	False	Molar specific enthalpy
H, HMASS, Hmass	J/kg	IO	False	Mass specific enthalpy
P	Pa	IO	False	Pressure
Q	mol/mol	IO	False	Molar vapor quality
SMOLAR, Smolar	J/mol/K	IO	False	Molar specific entropy
S, SMASS, Smass	J/kg/K	IO	False	Mass specific entropy
TAU, Tau		IO	False	Reciprocal reduced temperature (Tc/T)
T	K	IO	False	Temperature
UMOLAR, Umolar	J/mol	IO	False	Molar specific internal energy
U, UMASS, Umass	J/kg	IO	False	Mass specific internal energy
ACENTRIC, acentric		O	True	Acentric factor
ALPHA0, alpha0		O	False	Ideal Helmholtz energy
ALPHAR, alphar		O	False	Residual Helmholtz energy
A, SPEED_OF_SOUND, speed_of_sound	m/s	O	False	Speed of sound
BVIRIAL, Bvirial		O	False	Second virial coefficient
CONDUCTIVITY, L, conductivity	W/m/K	O	False	Thermal conductivity
CP0MASS, Cp0mass	J/kg/K	O	False	Ideal gas mass specific constant pressure specific heat
CP0MOLAR, Cp0molar	J/mol/K	O	False	Ideal gas molar specific constant pressure specific heat
CPMOLAR, Cpmolar	J/mol/K	O	False	Molar specific constant pressure specific heat
CVIRIAL, Cvirial		O	False	Third virial coefficient
CVMASS, Cvmass, O	J/kg/K	O	False	Mass specific constant volume specific heat
CVMOLAR, Cvmolar	J/mol/K	O	False	Molar specific constant volume specific heat
C, CPMASS, Cpmass	J/kg/K	O	False	Mass specific constant pressure specific heat
D2ALPHA0_DDELTA2_CONSTTAU, d2alpha0_ddelta2_consttau		O	False	Second derivative of ideal Helmholtz energy with delta
D3ALPHA0_DDELTA3_CONSTTAU, d3alpha0_ddelta3_consttau		O	False	Third derivative of ideal Helmholtz energy with delta
DALPHA0_DDELTA_CONSTTAU, dalpha0_ddelta_consttau		O	False	Derivative of ideal Helmholtz energy with delta
DALPHA0_DTAU_CONSTDELTA, dalpha0_dtau_constdelta		O	False	Derivative of ideal Helmholtz energy with tau
DALPHAR_DDELTA_CONSTTAU, dalphar_ddelta_consttau		O	False	Derivative of residual Helmholtz energy with delta
DALPHAR_DTAU_CONSTDELTA, dalphar_dtau_constdelta		O	False	Derivative of residual Helmholtz energy with tau
DBVIRIAL_DT, dBvirial_dT		O	False	Derivative of second virial coefficient with respect to T
DCVIRIAL_DT, dCvirial_dT		O	False	Derivative of third virial coefficient with respect to T
DIPOLE_MOMENT, dipole_moment	C m	O	True	Dipole moment
FH		O	True	Flammability hazard
FRACTION_MAX, fraction_max		O	True	Fraction (mole, mass, volume) maximum value for incompressible solutions
FRACTION_MIN, fraction_min		O	True	Fraction (mole, mass, volume) minimum value for incompressible solutions
FUNDAMENTAL_DERIVATIVE_OF_GAS_DYNAMICS, fundamental_derivative_of_gas_dynamics		O	False	Fundamental derivative of gas dynamics
GAS_CONSTANT, gas_constant	J/mol/K	O	True	Molar gas constant
GMOLAR_RESIDUAL, Gmolar_residual	J/mol/K	O	False	Residual molar Gibbs energy
GMOLAR, Gmolar	J/mol	O	False	Molar specific Gibbs energy
GWP100		O	True	100-year global warming potential
GWP20		O	True	20-year global warming potential
GWP500		O	True	500-year global warming potential
G, GMASS, Gmass	J/kg	O	False	Mass specific Gibbs energy
HELMHOLTZMASS, Helmholtzmass	J/kg	O	False	Mass specific Helmholtz energy
HELMHOLTZMOLAR, Helmholtzmolar	J/mol	O	False	Molar specific Helmholtz energy
HH		O	True	Health hazard
HMOLAR_RESIDUAL, Hmolar_residual	J/mol/K	O	False	Residual molar enthalpy
ISENTROPIC_EXPANSION_COEFFICIENT, isentropic_expansion_coefficient		O	False	Isentropic expansion coefficient
ISOBARIC_EXPANSION_COEFFICIENT, isobaric_expansion_coefficient	1/K	O	False	Isobaric expansion coefficient

Parameter List : [High-Level Interface — CoolProp 6.6.0 documentation]

ISOTHERMAL_COMPRESSIBILITY, isothermal_compressibility	1/Pa	O	False	Isothermal compressibility
I, SURFACE_TENSION, surface_tension	N/m	O	False	Surface tension
M, MOLARMASS, MOLAR_MASS, MOLEMASS, molar_mass, molarmass, molemass	kg/mol	O	True	Molar mass
ODP		O	True	Ozone depletion potential
PCRIT, P_CRITICAL, Pcrit, p_critical, pcrit	Pa	O	True	Pressure at the critical point
PHASE, Phase		O	False	Phase index as a float
PH		O	True	Physical hazard
PIP		O	False	Phase identification parameter
PMAX, P_MAX, P_max, pmax	Pa	O	True	Maximum pressure limit
PMIN, P_MIN, P_min, pmin	Pa	O	True	Minimum pressure limit
PRANDTL, Prandtl		O	False	Prandtl number
PTRIPLE, P_TRIPLE, p_triple, ptriple	Pa	O	True	Pressure at the triple point (pure only)
P_REDUCING, p_reducing	Pa	O	True	Pressure at the reducing point
RHOCRIT, RHOMASS_CRITICAL, rhocrit, rhomass_critical	kg/m^3	O	True	Mass density at critical point
RHOMASS_REDUCING, rhomass_reducing	kg/m^3	O	True	Mass density at reducing point
RHOMOLAR_CRITICAL, rhomolar_critical	mol/m^3	O	True	Molar density at critical point
RHOMOLAR_REDUCING, rhomolar_reducing	mol/m^3	O	True	Molar density at reducing point
SMOLAR_RESIDUAL, Smolar_residual	J/mol/K	O	False	Residual molar entropy (sr/R = s(T,rho) - s^0(T,rho))
TCRIT, T_CRITICAL, T_critical, Tcrit	K	O	True	Temperature at the critical point
TMAX, T_MAX, T_max, Tmax	K	O	True	Maximum temperature limit
TMIN, T_MIN, T_min, Tmin	K	O	True	Minimum temperature limit
TTRIPLE, T_TRIPLE, T_triple, Ttriple	K	O	True	Temperature at the triple point
T_FREEZE, T_freeze	K	O	True	Freezing temperature for incompressible solutions
T_REDUCING, T_reducing	K	O	True	Temperature at the reducing point
V, VISCOSITY, viscosity	Pa s	O	False	Viscosity
Z		O	False	Compressibility factor

Coolprop can also obtain derivatives using its syntax : what derivatives are needed?

$$c_p = \left.\frac{\partial h}{\partial T}\right|_p$$

and called through python

```
In [23]: import CoolProp.CoolProp as CP

# c_p using c_p
In [24]: CP.PropsSI('C','P',101325,'T',300,'Water')
Out[24]: 4180.6357765560715

# c_p using derivative
In [25]: CP.PropsSI('d(Hmass)/d(T)|P','P',101325,'T',300,'Water')
Out[25]: 4180.6357765560715
```

$\frac{\partial \rho}{\partial P}$ and $\frac{\partial \rho}{\partial h}$ Needed in energy balance equations for finite-volume methods