Material Properties

Properties of Materials to be defined in CFD Simulation

- Most of the CFD softwares have in-built materials database such "Air as Ideal Gas", Water, Hydrogen, Steam. However, they also provide users an option to define their own material characteristics such as Molecular Weight, Viscosity / Thermal Conductivity / Specific Heat Capacity as a function of temperature, Radiation properties, etc.
- All the liquids are considered incompressible w.r.t. pressure changes. However, they are still compressible w.r.t. temperature changes.
- All the gases can be considered incompressible provided flow Mach number is < 0.3
- In case there is significant variation in temperature, the gases cannot be assumed to be incompressible. For example, $p = \rho.R.T \rightarrow \Delta\rho \propto 1/\Delta T$. Thus, if $\Delta T > \pm 10$ [K], one should treat them compressible with equation of state governed by "Ideal Gas Law".
- Typically, viscosity of air is defined by Sutherlands "2-Coefficient" and "3-Coefficient" formula.
- It should be noted that "Compressible" flow cases are sometimes difficult to converge. Hence, the approach typically adopted is to "Start with incompressible)

flow conditions (that is turn-off energy and define flow media as incompressible fluid)" → Let the flow field develop (u, v, w, k, ε) except temperature → Switch on the temperature (the energy equation and "Compressible properties" of the flowing media.

- There is a common misunderstanding (which has come from FEA Analysis) community that the solver does not need to know the units of the variables required for CFD simulation. This is true in case of FEA simulation but is quite irrelevant in CFD world. In case of FEA, there are no non-dimensional numbers which need to be calculated. In case of CFD, there are many non-dimensional numbers which need to be estimated such as Y+, Peclet Number, Reynolds Number. These numbers will not be realistic unless they are explicitly recorded by the solver and suitable conversion made internally.

Specification of Temperature Dependent Properties - CFX

CFX: Following 3 expressions are to set Ideal Gas properties in CFX and Fluent equivalent.

CpAir = 1030.33 [J/kg/K] - 0.196044 [J kg^-1 K^-2] * T + 3.93365E-4 [J kg^-1 K^-3] * T * T

kAir = 6.24978E-6 [W m^-1 K^-1] + 9.73517E-5 [W m^-1 K^-2] * T - 3.31177E-8 [W m^-1 K^-3] * T * T

muAir = 1.458E-6 [Pa s K^-0.5] * T^1.5 / (110.4 [K] + T)

Fluent: In Fluent, all the properties can be set by GUI or following TUI command that can be read from a Journal File:

Heat Capacity of Water (Stephan and Mayinger):

CpAq = 3.17599E-6 [J kg^-1 K^-5] * T^4 - 4.25155E-2 [J kg^-1 K^-4]* T^3 + 2.1382 [J kg^-1 K^-3] * T^2 – 4.7836 [J kg^-1 K^-2] * T + 44.310 [J kg^-1 K^1]

Density of Water (Kuchling 1988):

rhoAq = 0.0036 [kg m^-3 K^-2] * T^2 - 1.8843 [kg m^-3 K^-1] * T + 752.61 [kg m^-3]

Specification of Temperature Dependent Properties - CFX

Engine Oil - HDC 15W40: Heat Capacity (Große 1962)

$\mathbf{C_{oil}(T)}$ = 4459.05 [0.414824 + (T-273.15)/1037.34]

$\boldsymbol{\rho_{oil}}\mathbf{(T)}$ = [ρ_{15} - (T-288.15) x 0.64] [kg/m^3] ρ_{15} = 885 [kg/m^3]

Kinematic Viscosity: $\nu(T) = \nu_{20[C]} (20\ [C] / T\ [C])^n$, 250 [K] ~ 420 [K]

$\nu_{20[C]} = 3.6 \times 10^{-4}$ [m^2/s], n = 2.0257