Homogeneous Equilibrium Model

Mass

\[ \frac{\partial \rho_m}{\partial t} - \nabla \cdot \rho_m \vec{v}_m = 0 \]

Energy

\[ \frac{\partial \rho_m e_m}{\partial t} + \nabla \cdot \rho_m e_m \vec{v}_m + P \nabla \cdot \vec{v}_m = q \]

Momentum

\[ \frac{\partial \vec{v}_m}{\partial t} + \vec{v}_m \cdot \nabla \vec{v}_m = - \frac{1}{\rho_m} \nabla P - K \vec{v}_m | \vec{v}_m | - g \sin \theta \]

or

\[ \frac{\partial \rho_m \vec{v}_m}{\partial t} + \nabla \cdot \rho_m \vec{v}_m \vec{v}_m = - \nabla \rho_m K \vec{v}_m | \vec{v}_m | - g \rho_m \sin \theta \]

where

\[ V_m = V_t = V_g \]

\[ \rho_m = \alpha \rho_g + (1 - \alpha) \rho_t \]

\[ \rho_m e_m = \alpha \rho_g e_g + (1 - \alpha) \rho_t e_t \]

and for \( 0 < \alpha < 1 \)

\[ T_t = T_g = T_{sat} \]
Non-Equilibrium Drift Flux Model

Mixture Mass Equation

\[ \frac{\partial}{\partial t} \rho_m + \frac{\partial}{\partial x} (\rho_m V_m) = 0 \]  

(1)

Vapor Mass Equation

\[ \frac{\partial}{\partial t} (\alpha \rho_g) + \frac{\partial}{\partial x} (\alpha \rho_g V_m) + \frac{\partial}{\partial x} \left[ \frac{\alpha \rho_g (1 - \alpha) \rho_v V_r}{\rho_m} \right] = -\Gamma \]  

(2)

Mixture Equation of Motion

\[ \frac{\partial}{\partial t} V_m + V_m \frac{\partial}{\partial x} V_m + \frac{1}{\rho_m} \frac{\partial}{\partial x} \left[ \frac{\alpha \rho_g (1 - \alpha) \rho_v V_r^2}{\rho_m} \right] = -\frac{1}{\rho_m} \frac{\partial p}{\partial x} - KV_m | V_m | + g \]  

(3)

Vapor Thermal Energy Equation

\[ \frac{\partial}{\partial t} (\alpha \rho_g e_g) + \frac{\partial}{\partial x} (\alpha \rho_g V_m e_g) + \frac{\partial}{\partial x} \left[ \frac{\alpha \rho_g (1 - \alpha) \rho_v V_r e_g}{\rho_m} \right] + p \frac{\partial}{\partial x} (\alpha V_m) \]

\[ + p \frac{\partial}{\partial x} \left[ \frac{\alpha (1 - \alpha) \rho_v}{\rho_m} V_r \right] = q_{wg} + q_g - p \frac{\partial \alpha}{\partial t} + \Gamma h_{sg} \]  

(4)

Mixture Thermal Energy Equation

\[ \frac{\partial}{\partial t} (\rho_m e_m) + \frac{\partial}{\partial x} (\rho_m e_m V_m) + \frac{\partial}{\partial x} \left[ \frac{(1 - \alpha) \rho_v \alpha \rho_g (e_g - e_i)}{\rho_m} V_r \right] + p \frac{\partial V_m}{\partial x} \]

\[ + p \frac{\partial}{\partial x} \left[ \frac{\alpha(1 - \alpha) (\rho_v - \rho_g)}{\rho_m} V_r \right] = q_{wg} - q_{wv} \]  

(5)

where

\[ \rho_m = \alpha \rho_g + (1 - \alpha) \rho_v \]  

(6)
\[ V_m = \frac{\alpha \rho_g V_g + (1 - \alpha) \rho_t V_t}{\rho_m}, \]  
(7)

and

\[ V_r = V_g - V_t, \]  
(8)

\[ \Gamma = \frac{-q_{ig} - q_{it}}{h_{sg} - h_{st}}, \]  
(9)

where

\[ q_{ig} = h_{ig} A_i \frac{(T_s - T_g)}{vol}, \]  
(10)

and

\[ q_{it} = h_{it} A_i \frac{(T_s - T_t)}{vol}, \]  
(11)

\[ q_{wg} = h_{wg} A_{wg} \frac{(T_w - T_g)}{vol}, \]  
(12)

and

\[ q_{wt} = h_{wt} A_{wt} \frac{(T_w - T_t)}{vol}. \]  
(13)
Two-Phase Two-Fluid Model
as implemented in TRAC-PF1

Liquid Mass Equation

\[
\frac{\partial}{\partial t} [(1 - \alpha) \rho_L] + \nabla \cdot [(1 - \alpha) \rho_L \vec{v}_L] = - \Gamma
\]  \hfill (22)

Combined-Gas Mass Equation

\[
\frac{\partial}{\partial t} (\alpha \rho_g) + \nabla \cdot (\alpha \rho_g \vec{v}_g) = \Gamma
\]  \hfill (23)

Total Energy Equation

\[
\frac{\partial}{\partial t} [(1 - \alpha) \rho_t \delta_t + \alpha \rho_g \delta_g] + \nabla \cdot [(1 - \alpha) \rho_t \delta_t \vec{v}_t + \alpha \rho_g \delta_g \vec{v}_g] = - p \nabla \cdot [(1 - \alpha) \vec{v}_t + \alpha \vec{v}_g]
\]
\[+ q_{wt} + q_{wg}
\]  \hfill (24)

Combined-Gas Energy Equation

\[
\frac{\partial}{\partial t} (\alpha \rho_g \delta_g) + \nabla \cdot (\alpha \rho_g \delta_g \vec{v}_g) = - p \frac{\partial \alpha}{\partial t} - p \nabla \cdot (\alpha \vec{v}_g)
\]
\[+ q_{wg} = + q_{ig} + \Gamma \vec{h}_i
\]  \hfill (25)
Liquid Equation of Motion

\[ \frac{\partial \vec{v}_i}{\partial t} + \vec{v}_i \cdot \nabla \vec{v}_i = -\frac{1}{\rho_i} \nabla p + \frac{c_i}{(1 - \alpha) \rho_i} (\vec{v}_s - \vec{v}_i) |\vec{v}_s - \vec{v}_i| \\
\] \[ - \frac{\Gamma^*}{(1 - \alpha) \rho_i} (\vec{v}_s - \vec{v}_i) - \frac{c_{wg}}{(1 - \alpha) \rho_i} \vec{v}_i |\vec{v}_i| - g \]

Combined-Gas Equation of Motion

\[ \frac{\partial \vec{v}_g}{\partial t} + \vec{v}_g \cdot \nabla \vec{v}_g = -\frac{1}{\rho_g} \nabla p - \frac{c_i}{\alpha \rho_g} (\vec{v}_s - \vec{v}_g) |\vec{v}_s - \vec{v}_g| \\
\] \[ - \frac{\Gamma^*}{\alpha \rho_g} (\vec{v}_g - \vec{v}_s) - \frac{c_{wg}}{\alpha \rho_g} \vec{v}_s |\vec{v}_s| + g \]

where

\[ \Gamma = \frac{- (q_{ig} - q_{ig})}{\bar{h}'_v - \bar{h}'_t} \]  \hspace{2cm} (28)

\[ q_{ig} = h_{ig} A_i \frac{(T_{sv} - T_g)}{vol} \]  \hspace{2cm} (29)

\[ q_{it} = h_{it} A_i \frac{(T_{sv} - T_t)}{vol} \]  \hspace{2cm} (30)

\[ q_{wg} = h_{wg} A_w \frac{(T_w - T_g)}{vol} \]  \hspace{2cm} (31)
\[ q_{w_1} = h_{w_1} A_w \frac{(T_w - T_v)}{\text{vol}} \]  \hspace{1cm} (32)

**Total Mass Equation**

\[
\frac{\partial}{\partial t} \left[ (1 - \alpha) \rho_t + \alpha \rho_g \right] + \nabla \cdot \left[ (1 - \alpha) \rho_t \vec{v}_t + \alpha \rho_g \vec{v}_g \right] = 0
\]  \hspace{1cm} (33)

**Air Mass Equation**

\[
\frac{\partial (\alpha \rho_a)}{\partial t} + \nabla \cdot (\alpha \rho_a \vec{v}_a) = 0
\]  \hspace{1cm} (34)

where

\[ \rho_g = \rho_v + \rho_a \]  \hspace{1cm} (35)

\[ \rho_g e_g = \rho_v e_v + \rho_a e_a \]  \hspace{1cm} (36)

\[ p = \rho_v + \rho_a \]  \hspace{1cm} (37)

**Liquid-Solute Concentration Equation**

\[
\frac{\partial [(1 - \alpha) m_p]}{\partial t} + \nabla \cdot [(1 - \alpha) m_p \vec{v}_l] = S_m,
\]  \hspace{1cm} (38)
Two-Phase Two-Fluid Model

\[ \frac{d \rho_m}{dt} + \mathbf{\nabla} \cdot (\alpha_g \rho_g \mathbf{V}_g + \alpha_v \rho_v \mathbf{V}_v) = 0. \]  \hfill (2.1-1)

**Vapor Mass Equation**

\[ \frac{d (\alpha_g \rho_g)}{dt} + \nabla \cdot (\alpha_g \rho_g \mathbf{V}_g) = \Gamma_g. \]  \hfill (2.1-2)

**Noncondensable (Air) Mass Equation**

\[ \frac{d (\alpha_{NC} \rho_{NC})}{dt} + \mathbf{\nabla} \cdot (\alpha_{NC} \rho_{NC} \mathbf{V}_{NC}) = \Gamma_{NC}. \]  \hfill (2.1-3)

**Boron Mass Equation**

\[ \frac{d (\alpha \rho_{NC})}{dt} + \mathbf{\nabla} \cdot (\alpha \rho_{NC} \mathbf{V}_{NC}) = \Gamma_B. \]  \hfill (2.2-4)

**Vapor Equation of Motion**

\[ \frac{d \mathbf{V}_g}{dt} + k_{vm} \left( \frac{\rho_c}{\alpha_g \rho_g} \right) \frac{\partial}{\partial t} \left[ (\mathbf{\nabla} - \mathbf{V}_g) + \mathbf{V}_g \cdot \mathbf{\nabla} \mathbf{V}_g \right] \]

\[ = - \frac{f_i}{\alpha_g \rho_g} - \frac{1}{\rho_g} \mathbf{\nabla} \mathbf{P} - \frac{C_{ng}}{\alpha_g \rho_g} \mathbf{V}_g |\mathbf{V}_g| + \mathbf{g} - k_{vm} \frac{\rho_c}{\alpha_g \rho_g} \mathbf{V}_D |\mathbf{V}_D| \cdot \mathbf{\nabla} (\mathbf{V}_g - \mathbf{V}_g). \]  \hfill (2.1-5)

**Liquid Equation of Motion**

\[ \frac{d \mathbf{V}_l}{dt} + k_{vm} \left( \frac{\rho_c}{\alpha_l \rho_l} \right) \frac{\partial}{\partial t} \left[ (\mathbf{\nabla} - \mathbf{V}_l) + \mathbf{V}_l \cdot \mathbf{\nabla} \mathbf{V}_l \right] \]

\[ = - \frac{f_i}{\alpha_l \rho_l} - \frac{1}{\rho_l} \mathbf{\nabla} \mathbf{P} - \frac{C_{wl}}{\alpha_l \rho_l} \mathbf{V}_l |\mathbf{V}_l| + \mathbf{g} - k_{vm} \frac{\rho_c}{\alpha_l \rho_l} \mathbf{V}_D |\mathbf{V}_D| \cdot \mathbf{\nabla} (\mathbf{V}_l - \mathbf{V}_l). \]  \hfill (2.2-6)
Mixture Energy Equation
\[
\frac{\partial (\alpha_i \rho_i e_i + \alpha_g \rho_g e_g)}{\partial t} + \nabla \cdot (\alpha_i \rho_i \vec{V}_i - \alpha_g \rho_g \vec{V}_g) = -P \nabla \cdot (\alpha_i \vec{V}_i - \alpha_g \vec{V}_g) + Q_{wg} + Q_{w} + Q_{d g} + Q_{d}.
\] (2.1-7)

Vapor Energy Equation
\[
\frac{\partial (\alpha_g \rho_g e_g)}{\partial t} + \nabla \cdot (\alpha_g \rho_g \vec{V}_g) = -P \frac{\partial \alpha}{\partial t} - P \nabla \cdot \alpha \vec{V}_g + Q_{wg} + Q_{i g} - \Gamma_g h_{sg} + Q_{dg}.
\] (2.1-8)

In the above equations, \( k_{vm} \) is the virtual mass coefficient, and the subscripts \( C \) and \( D \) refer to the continuous and dispersed phases, respectively, and \( P \) refers to the continuous and dispersed phases, respectively.

\( \Gamma_g \) refers to the interfacial mass continuity
\[
\Gamma_g = \frac{Q_{ig} - Q_{d}}{h_{ig} - h_{i}}.
\] (2.1-9)

Interfacial Energy Continuity
\[
\Gamma_g = \frac{Q_{ig}}{h_{ig}}. \quad \text{(2.1-10)}
\]

where
\[
Q_{ig} = h_{ig} \frac{A_i}{Vol} (T_s - T_g)
\] (2.1-11)

and
\[
Q_{d} = h_{d} \frac{A_i}{Vol} (T_s - T_d).
\] (2.1-12)