# 1 General Conservation Equations in STARS

A conservation equation is constructed for each componet of a set of identificable chemical components that completely describe all the fluids of interes.

The semi-spatially discretized conservation equation of fluwing component $i$ is

$$\begin{aligned} & V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_w S_w w_i+\rho_o S_o x_i+\rho_g S_g y_i\right)+\varphi_v A d_i\right] \qquad \text{(F5.1)} \\ = & \sum_{k=1}^{n_f}\left[T_w\rho_w w_i\Delta\Phi_w+T_o\rho_o x_i\Delta\Phi_o+T_g\rho_g y_i\Delta\Phi_g\right]+v\sum_{k=1}^{n_r}\left(s'_{ki}-s_{ki}\right)r_k \\ & +\sum_{k=1}^{n_f}\left[\phi D_{wi}\rho_w\Delta w_i+\phi D_{oi}\rho_o\Delta x_i+\phi D_{gi}\rho_g\Delta y_i\right]+\delta_{iw}\sum_{k=1}^{n_f}\rho_w qaq_{wk} \\ & +\rho_w q_{wk}w_i+\rho_o q_{ok}x_i+\rho_g q_{gk}y_i \qquad \text{[well layer } k] \end{aligned}$$

where $n_f$ is the number of neighboring regions or grid block faces.

The conservation equation of solid component $i$ is

$$V\frac{\partial}{\partial t}\left[\varphi_f c_i\right]=v\sum_{k=1}^{n_r}\left(s'_{ki}-s_{ki}\right)r_k \qquad \text{(F5.2)}$$

The conservation equation of energy is

$$\begin{aligned} & V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_w S_w U_w+\rho_o S_o U_o+\rho_g S_g U_g\right)+\rho_g c_s U_g+\left(1-\varphi_v\right)U_r\right] \qquad \text{(F5.3)} \\ & =\sum_{k=1}^{n_f}\left[T_w\rho_w H_w\Delta\Phi_w+T_o\rho_o H_o\Delta\Phi_o+T_g\rho_g H_g\Delta\Phi_g\right]+\sum_{k=1}^{n_f}K\Delta T \\ & \qquad +\rho_w q_{wk}H_w+\rho_o q_{ok}H_o+\rho_g q_{gk}H_g \qquad \text{[well layer } k] \\ & +\sum_{k=1}^{n_r}H_{rk}r_k+HL_o+HL_v+HL_c+\sum_{k=1}^{n_f}\left(HA_{CV}+HA_{CD}\right)_k \end{aligned}$$

The phase transmissibilities $T_j$ are

$$T_j=\underline{\underline{T}}\left(\frac{K_{ri}}{\mu_j r_j}\right) \qquad j=w,o,g \qquad \text{(F5.4)}$$

and for phase enthalpies

$$\begin{aligned}
U_w &= H_w - \frac{p_w}{\rho_w} \qquad \text{(D9.1)} \\
H_o &= \sum_{i=1}^{n_c} x_i H_{Li} \\
U_o &= H_o - \frac{p_o}{\rho_o} \\
H_g &= \sum_{i=1}^{n_c} y_i H_{gi} \\
U_g &= H_g - \frac{p_g}{\rho_g} \\
U_s &= C_{ps}\left(T - T_r\right) \\
U_r &= a\left(T - T_r\right) + \frac{1}{2} b\left(T^2 - T_r^2\right)
\end{aligned}$$

and for reactions

$$r_k = r_{rk} \cdot \exp\left(-E_{ak}/RT\right) \prod_{i=1}^{n_c} C_i^{e_k} \qquad \text{(D13.3)}$$

where

$$\begin{aligned}
C_i &= \varphi_f \rho_j S_j x_{ji} \qquad j = w, o, g \text{ For fluid componet} \qquad \text{(D13.4)} \\
C_i &= \varphi_v c_i \ \text{ For solid component} \\
C_i &= y_i p_g \ \text{ For gas component}
\end{aligned}$$

$c_i$ is the concentration of component $i$ in void volume
$s'_{ki}$ is the product stoichiometic coefficient of component $i$ in reaction $k$.
$s_{ki}$ is the reactant stoichiometric coefficient of component $i$ in reaction $k$.
$H_{rk}$ is the enthalpy of reaction $k$.
$E_{ak}$ is the activation energy.
$x_{ji}$ is the represents water, oil, or gas mole fractions.
$r_k$ is the volumetric rate of reaction $k$.
$r_{rk}$ is the constant part of $r_k$.
$n_c$ is the number of components

and finaly for well equations

$$q_{jk} = I_{jk} \cdot \left(p_{wfk} - p_k\right) \qquad j = w, o, g \qquad \text{(F2.16)}$$

- The subscrip $k$ refers to the fact that the region of interest contains layer no. $k$ of a well which may be completed also in other blocks or regions.

- $I_{jk}$ is the phase $j$ index for the well layer $k$ may contain the movilty factor $\left(k_{rj}/\mu_j\right)$, through which the well equations can be tightly coupled to the resorvoir conditions.

- $p_k$ is the node pressure of the region of interest which contains well layer $k$.

- $p_{wfk}$ is the flowing wellbore pressure in well layer $k$.

Constant presure

$$p_{wf} = p_{spec} \tag{F4.1}$$

the subscript "spec" indicates a quantity specified by the user. Of the $n_{lay}$ layers of a well, one is designated as the bottom-hole layer, its flowing wellbore presure is $p_{wf}$.

Constant Water Rate

$$\sum_{k=1}^{N_{lay}} q_{wk} = q_{soec} \tag{F4.2}$$

Constant Oil Rate

$$\sum_{k=1}^{N_{lay}} q_{ok} = q_{spec} \tag{F4.3}$$

Constant Gas Rate

$$\sum_{k=1}^{N_{lay}} q_{gk} = q_{spec} \tag{F4.4}$$

Constant Liquid Rate

$$\sum_{k=1}^{N_{lay}} (q_{wk} + q_{ok}) = q_{spec} \tag{F4.5}$$

Constant Steam Production Rate

$$\frac{1}{\rho_w^{ST}} \left\{ \sum_{k=1}^{N_{lay}} q_{gk} y_1 \rho_g \right\} = q_{spec} \tag{F4.6}$$

where $y_1$ and $\rho_g$ are values from the grid block containing well layer $k$.

The wellbore presure $p_{wfk}$ at each layer is obtained by adding $p_{wf}$ (at $k = 1$) the accumulated fluid head

$$p_{wf} = p_{wf} + \int_{h_j}^{h_k} \gamma_{av} g dh \tag{F4.7}$$

where $h_k$ denotes the elevation of layer $k$, and $\gamma_{av}$ denotes an average mass density of the fluids in the wellbore.

## 2 Conservation Equations STARS for the problem 7

The semi-spatially discretized conservation equation of fluwing component aqua of Ec.(F5.1) is

$$V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_w S_w w_1\right)\right] = \sum_{k=1}^{n_f}\left[T_w\rho_w w_1\Delta\Phi_w\right] + V\left(s'_{11}-s_{11}\right)r_1 + \rho_w q_{wk} w_1 \quad \text{[well layer } k\text{]} \tag{1}$$

The semi-spatially discretized conservation equation of fluwing component oil of Ec.(F5.1) is

$$V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_o S_o x_1\right)\right] = \sum_{k=1}^{n_f}\left[T_o\rho_o x_1\Delta\Phi_o\right] + V\left(s'_{12}-s_{12}\right)r_1 + \rho_o q_{ok} x_1 \quad \text{[well layer } k\text{]} \tag{2}$$

The semi-spatially discretized conservation equation of fluwing component inert gas of Ec.(F5.1) is

$$V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_g S_g y_1\right)\right] = \sum_{k=1}^{n_f}\left[T_g\rho_g y_1\Delta\Phi_g\right] + V\left(s'_{13}-s_{13}\right)r_1 + \rho_g q_{gk} y_1 \quad \text{[well layer } k\text{]} \tag{3}$$

The semi-spatially discretized conservation equation of fluwing component oxygen of Ec.(F5.1) is

$$V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_g S_g y_2\right)\right] = \sum_{k=1}^{n_f}\left[T_g\rho_g y_2\Delta\Phi_g\right] + V\left(s'_{14}-s_{14}\right)r_1 + \rho_g q_{gk} y_2 \quad \text{[well layer } k\text{]} \tag{4}$$

where $n_f$ is the number of neighboring regions or grid block faces.

The conservation equation of energy is

$$\begin{aligned} & V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_w S_w U_w + \rho_o S_o U_o + \rho_g S_g U_g\right) + \left(1-\varphi_v\right)U_r\right] \\ = & \sum_{k=1}^{n_f}\left[T_w\rho_w H_w\Delta\Phi_w + T_o\rho_o H_o\Delta\Phi_o + T_g\rho_g H_g\Delta\Phi_g\right] + \sum_{k=1}^{n_f} K\Delta T \\ & +\rho_w q_{wk} H_w + \rho_o q_{ok} H_o + \rho_g q_{gk} H_g \qquad \text{[well layer } k\text{]} \\ & +V\left(H_{r1} r_1\right) \end{aligned} \tag{5}$$

and

$$\begin{aligned} r_1 &= r_{r1}\cdot\exp\left(-E_{a1}/RT\right)\prod_{i=1}^{n_c} C_i^{e_k} \\ \Phi_j &= p_j - \lambda_j g h \end{aligned} \tag{6}$$

## 3 Conservation Equations RESSIM for the problem 7

The semi-spatially discretized conservation equation of fluwing component aqua of RESSIM equation is

$$(\phi S_w \xi_w x_{3w})_t + \nabla \cdot \left( \underline{\underline{T}}_{3w} \cdot \nabla \Phi_w \right) = \frac{(g_e)_{3w}}{W_w} + \frac{(g_r)_{3w}}{W_w} \tag{7}$$

The semi-spatially discretized conservation equation of fluwing component oil of RESSIM equation is

$$(\phi S_o \xi_o x_{1o})_t + \nabla \cdot \left( \underline{\underline{T}}_{1o} \cdot \nabla \Phi_o \right) = \frac{(g_e)_{1o}}{W_o} + \frac{(g_r)_{1o}}{W_o} \tag{8}$$

The semi-spatially discretized conservation equation of fluwing component inert gas of RESSIM equation is

$$\left(\phi S_g \xi_g x_{7g}\right)_t + \nabla \cdot \left( \underline{\underline{T}}_{7g} \cdot \nabla \Phi_g \right) = \frac{(g_e)_{7g}}{W_g} + \frac{(gr)_{7g}}{W_g} \tag{9}$$

The semi-spatially discretized conservation equation of fluwing component oxygen of RESSIM equation is

$$\left(\phi S_g \xi_g x_{6g}\right)_t + \nabla \cdot \left( \underline{\underline{T}}_{6g} \cdot \nabla \Phi_g \right) = \frac{(g_e)_{6g}}{W_g} + \frac{(g_r)_{6g}}{W_g} \tag{10}$$

The conservation equation of energy is

$$\begin{aligned} &\left(\phi \left(S_w \rho_w c_{vw} + S_o \rho_o c_{vo} + S_g \rho_g c_{vg}\right) T + (1-\phi)\, \rho_r c_{vr} T\right)_t - \\ &\nabla \cdot \left( \underline{\underline{T}}_w \cdot \nabla \Phi_w c_{Pw} T + \underline{\underline{T}}_o \cdot \nabla \Phi_o c_{Po} T + \underline{\underline{T}}_g \cdot \nabla \Phi_g c_{Pg} T \right) \\ &= Q_I + Q_r + \nabla \cdot (\kappa_T \nabla T) \end{aligned} \tag{11}$$

and

$$(g_r)_i = \sum_{k=1}^{N_r} \left(s'_{ki} - s_{ki}\right) r_k \tag{12}$$

$$r_k = R_r \cdot \exp\left(-E_k/RT\right) \prod_{i=1}^{N_{R,k}} F_i^{e_{i,k}} \tag{13}$$

$$\Phi_\alpha = p_\alpha - \rho_\alpha g z \tag{14}$$

# 4 Interpretation of variables between STARS y RESSIM

In this case for the Ec. (1) of STARS

$$V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_w S_w w_1\right)\right]=\sum_{k=1}^{n_f}\left[T_w\rho_w w_1\Delta\Phi_w\right]+V\left(s_{11}'-s_{11}\right)r_1+\rho_w q_{wk}w_1 \quad (15)$$

replacing

$$T_j=\underline{\underline{T}}\left(\frac{k_{rj}}{\mu_j r_j}\right) \qquad j=w,o,g \quad (16)$$

then

$$V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_w S_w w_1\right)\right]=\sum_{k=1}^{n_f}\left[\underline{\underline{T}}\left(\frac{k_{rw}}{\mu_w r_w}\right)\rho_w w_1\Delta\Phi_w\right]+V\left(s_{11}'-s_{11}\right)r_1+\rho_w q_{wk}w_1 \quad (17)$$

where $r_j$, $j=w,o,g$ is the resistance factor are normally 1.0.

And in Ec. (7) of RESSIM

$$\left(\phi S_w\xi_w x_{3w}\right)_t+\nabla\cdot\left(\underline{\underline{T}}_{3w}\cdot\nabla\Phi_w\right)=\frac{(g_e)_{3w}}{W_w}+\frac{(g_r)_{3w}}{W_w} \quad (18)$$

now replacing the second tem $\underline{\underline{T}}_{i\alpha}=\frac{x_{i\alpha}\xi_\alpha k_{r\alpha}}{\mu_\alpha}$ and $\frac{(g_r)_{3w}}{W_w}$ by $\left(s_{11}'-s_{11}\right)r_1$, then

$$\frac{\partial}{\partial t}\left(\phi S_w\xi_w x_{3w}\right)+\nabla\cdot\left(\frac{x_{3w}\xi_w k_{rw}}{\mu_w}\underline{\underline{k}}\cdot\nabla\Phi_w\right)=\frac{(g_e)_{3w}}{W_w}+\left(s_{13}'-s_{13}\right)r_1. \quad (19)$$

Now comparing term by term for RESSIM Ec.(17) and STARS Ec.(19) for the componet water

$$\frac{\partial}{\partial t}\left(\phi S_w \xi_w x_{3w}\right) + \nabla \cdot \left(\frac{x_{3w}\xi_w k_{rw}}{\mu_w}\underline{\underline{k}} \cdot \nabla \Phi_w\right) = \frac{(g_e)_{3w}}{W_w} + \left(s'_{13} - s_{13}\right) r_1 \quad (20)$$

$$V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_w S_w w_1\right)\right] = \sum_{k=1}^{n_f}\left[\underline{\underline{T}}\left(\frac{k_{rw}}{\mu_w r_w}\right)\rho_w w_1 \Delta\Phi_w\right] + V\left(s'_{11} - s_{11}\right) r_1 + \rho_w q_{wk} w_1 \quad (21)$$

The first term $\phi S_w \xi_w x_{3w}$ and $\varphi_f\left(\rho_w S_w w_1\right)$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $(1-\sigma)\,\phi$ | $\varphi_f$ |
| $\phi$ | $\varphi_v$ |
| $S_w$ | $S_w$ |
| $\xi_w$ | $\rho_w$ |
| $x_{3w}$ | $w_1$ |

(22)

and for the term $\nabla \cdot \left(\frac{x_{3w}\xi_w k_{rw}}{\mu_w}\underline{\underline{k}} \cdot \nabla \Phi_w\right)$ and $\underline{\underline{T}}\left(\frac{k_{rw}}{\mu_w r_w}\right)\rho_w w_1 \Delta\Phi_w$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $k_{rw}$ | $k_{rw}$ |
| $\mu_w$ | $\mu_w$ |
| $\xi_w$ | $\rho_w$ |
| $\underline{\underline{k}}$ | $\underline{\underline{T}}$ |
| $x_{3w}$ | $w_1$ |
| $\Phi_w$ | $\Phi_w$ |
| $-$ | $r_w = 1.0$ |

(23)

and for the term $\left(s'_{13} - s_{13}\right) r_1$ and $\left(s'_{11} - s_{11}\right) r_1$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $s'_{13}$ | $s'_{11}$ |
| $s_{13}$ | $s_{11}$ |
| $r_1$ | $r_1$ |

(24)

for the $r_1$ then

$$\begin{array}{ll} RESSIM & r_1 = R_1 \cdot \exp\left(-E_1/RT\right)\prod_{i=1}^{N_{R,k}} F_i^{e_{i,k}} \\ STARS & r_1 = r_{r1} \cdot \exp\left(-E_{a1}/RT\right)\prod_{i=1}^{n_c} C_i^{e_k} \end{array} \quad (25)$$

where

| $RESSIM$ | $STARS$ |
|---|---|
| $r_1$ | $r_1$ |
| $R_1$ | $r_{r1}$ |
| $E_1$ | $E_{a1}$ |
| $R$ | $R$ |
| $T$ | $T$ |
| $F_i$ | $C_i$ |
| $e_{i,k}$ | $e_k$ |

(26)

and for the last term $\frac{(g_e)_{3w}}{W_w}$ and $\rho_w q_{wk} w_1$, first is necesary defined $\frac{(g_e)_{3w}}{W_w}$???, and for the second term remplacing

$$q_{jk} = I_{jk} \cdot (p_{wfk} - p_k) \qquad j = w, o, g \tag{27}$$

in $\rho_w q_{wk} w_1$ then

$$\rho_w I_{wk} \cdot (p_{wfk} - p_k)\, w_1 \tag{28}$$

where [see Ec.(F4.1) to Ec.(F4.7)]

$$\begin{array}{c} I_{wk} = (k_{rw}/\mu_w) \\ p_{wfk} = p_{wf} + \int_{h_1}^{h_k} \gamma_{av} g dh \end{array} \tag{29}$$

By analogy, for the Ec.(8) and Ec.(2) for componet oil, then the first term $\phi S_o \xi_o x_{1o}$ and $\varphi_f (\rho_o S_o x_1)$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $(1-\sigma)\,\phi$ | $\varphi_f$ |
| $\phi$ | $\varphi_v$ |
| $S_o$ | $S_o$ |
| $\xi_o$ | $\rho_o$ |
| $x_{1o}$ | $x_1$ |

(30)

and for the second term $\nabla \cdot \left( \frac{x_{1o}\xi_o k_{ro}}{\mu_o} \underline{\underline{k}} \cdot \nabla \Phi_o \right)$ and $\underline{\underline{T}} \left( \frac{k_{ro}}{\mu_o r_o} \right) \rho_o x_1 \Delta \Phi_o$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $k_{ro}$ | $k_{ro}$ |
| $\mu_o$ | $\mu_o$ |
| $\xi_o$ | $\rho_o$ |
| $\underline{\underline{k}}$ | $\underline{\underline{T}}$ |
| $x_{1o}$ | $x_1$ |
| $\Phi_o$ | $\Phi_o$ |
| $-$ | $r_o = 1.0$ |

(31)

and for the term $(s'_{11} - s_{11})\, r_1$ and $(s'_{12} - s_{12})\, r_1$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $s'_{11}$ | $s'_{12}$ |
| $s_{11}$ | $s_{12}$ |
| $r_1$ | $r_1$ |

(32)

and for the last term $\frac{(g_e)_{1o}}{W_o}$ and $\rho_o q_{ok} x_1$, first is necesary defined $\frac{(g_e)_{1o}}{W_o}$???, and for the second term remplacing

$$q_{jk} = I_{jk} \cdot (p_{wfk} - p_k) \qquad j = w, o, g \tag{33}$$

in $\rho_o q_{ok} x_1$ then

$$\rho_o I_{ok} \cdot (p_{wfk} - p_k)\, x_1 \tag{34}$$

where [see Ec.(F4.1) to Ec.(F4.7)]

$$\begin{array}{c} I_{ok} = (k_{ro}/\mu_o) \\ p_{wfk} = p_{wf} + \int_{h1}^{h_k} \gamma_{av} g dh \end{array} \tag{35}$$

By analogy, for the Ec.(9) and Ec.(3) for componet gas inert, then the first term $\phi S_g \xi_g x_{7g}$ and $\varphi_f \left(\rho_g S_g y_1\right)$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $(1-\sigma)\,\phi$ | $\varphi_f$ |
| $\phi$ | $\varphi_v$ |
| $S_g$ | $S_g$ |
| $\xi_g$ | $\rho_g$ |
| $x_{7g}$ | $y_1$ |

(36)

and for the second term $\nabla \cdot \left(\frac{x_{7g}\xi_g k_{rg}}{\mu_g} \underline{\underline{k}} \cdot \nabla \Phi_g\right)$ and $\underline{\underline{T}} \left(\frac{k_{rg}}{\mu_g r_g}\right) \rho_g y_1 \Delta \Phi_g$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $k_{rg}$ | $k_{rg}$ |
| $\mu_g$ | $\mu_g$ |
| $\xi_g$ | $\rho_g$ |
| $\underline{\underline{k}}$ | $\underline{\underline{T}}$ |
| $x_{7g}$ | $y_1$ |
| $\Phi_g$ | $\Phi_g$ |
| $-$ | $r_g = 1.0$ |

(37)

and for the term $(s'_{17} - s_{17})\, r_1$ and $(s'_{13} - s_{13})\, r_1$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $s'_{17}$ | $s'_{13}$ |
| $s_{17}$ | $s_{13}$ |
| $r_1$ | $r_1$ |

(38)

and for the last term $\frac{(g_e)_{7g}}{W_g}$ and $\rho_g q_{gk} y_1$, first is necesary defined $\frac{(g_e)_{7g}}{W_g}$???, and for the second term remplacing

$$q_{jk} = I_{jk} \cdot (p_{wfk} - p_k) \qquad j = w, o, g \tag{39}$$

in $\rho_g q_{gk} y_1$ then

$$\rho_g I_{gk} \cdot (p_{wfk} - p_k)\, y_1 \tag{40}$$

where [see Ec.(F4.1) to Ec.(F4.7)]

$$\begin{array}{c} I_{gk} = \left(k_{rg}/\mu_g\right) \\ p_{wfk} = p_{wf} + \int_{h1}^{h_k} \gamma_{av} g dh \end{array} \tag{41}$$

By analogy, for the Ec.(10) and Ec.(4) then for componet oil, then the first term $\phi S_g \xi_g x_{6g}$ and $\varphi_f \left(\rho_g S_g y_2\right)$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $(1-\sigma)\,\phi$ | $\varphi_f$ |
| $\phi$ | $\varphi_v$ |
| $S_g$ | $S_g$ |
| $\xi_g$ | $\rho_g$ |
| $x_{6g}$ | $y_2$ |

(42)

and for the second term $\nabla \cdot \left(\frac{x_{6g}\xi_g k_{rg}}{\mu_g} \underline{\underline{k}} \cdot \nabla \Phi_g\right)$ and $\underline{\underline{T}} \left(\frac{k_{rg}}{\mu_g r_g}\right) \rho_g y_2 \Delta \Phi_g$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $k_{rg}$ | $k_{rg}$ |
| $\mu_g$ | $\mu_g$ |
| $\xi_g$ | $\rho_g$ |
| $\underline{\underline{k}}$ | $\underline{\underline{T}}$ |
| $x_{6g}$ | $y_2$ |
| $\Phi_g$ | $\Phi_g$ |
| $-$ | $r_g = 1.0$ |

(43)

and for the term $(s'_{16} - s_{16})\, r_1$ and $(s'_{14} - s_{14})\, r_1$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $s'_{16}$ | $s'_{14}$ |
| $s_{16}$ | $s_{14}$ |
| $r_1$ | $r_1$ |

(44)

and for the last term $\frac{(g_e)_{6g}}{W_g}$ and $\rho_g q_{gk} y_2$, first is necesary defined $\frac{(g_e)_{6g}}{W_g}$???, and for the second term remplacing

$$q_{jk} = I_{jk} \cdot (p_{wfk} - p_k) \qquad j = w, o, g \tag{45}$$

in $\rho_g q_{gk} y_2$ then

$$\rho_g I_{gk} \cdot (p_{wfk} - p_k)\, y_2 \tag{46}$$

where [see Ec.(F4.1) to Ec.(F4.7)]

$$\begin{gathered} I_{gk} = \left(k_{rg}/\mu_g\right) \\ p_{wfk} = p_{wf} + \int_{h1}^{h_k} \gamma_{av} g dh \end{gathered} \tag{47}$$

The conservation equation of energy is for STARS

$$
\begin{aligned}
& V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_w S_w U_w+\rho_o S_o U_o+\rho_g S_g U_g\right)+\left(1-\varphi_v\right)U_r\right] \qquad (48)\\
= \; & \sum_{k=1}^{n_f}\left[T_w\rho_w H_w\Delta\Phi_w+T_o\rho_o H_o\Delta\Phi_o+T_g\rho_g H_g\Delta\Phi_g\right]+\sum_{k=1}^{n_f}K\Delta T\\
& +\rho_w q_{wk}H_w+\rho_o q_{ok}H_o+\rho_g q_{gk}H_g \qquad \text{[well layer } k\text{]}\\
& +V\left(H_{r1}r_1\right)
\end{aligned}
$$

remplacing $U_j$, $H_j$, and $T_j$ using

$$
\begin{aligned}
U_w &= H_w-\frac{p_w}{\rho_w} \qquad (49)\\
H_o &= \sum_{i=1}^{n_c}x_i H_{Li}\\
U_o &= H_o-\frac{p_o}{\rho_o}\\
H_g &= \sum_{i=1}^{n_c}y_i H_{gi}\\
U_g &= H_g-\frac{p_g}{\rho_g}\\
U_r &= a\left(T-T_r\right)+\frac{1}{2}b\left(T^2-T_r^2\right)\\
T_j &= \underline{\underline{T}}\left(\frac{k_{rj}}{\mu_j r_j}\right) \qquad j=w,o,g
\end{aligned}
$$

then

$$
\begin{aligned}
& V\frac{\partial}{\partial t}\left[\varphi_f\left(\rho_w S_w\left(H_w-\frac{p_w}{\rho_w}\right)+\rho_o S_o\left(x_1 H_{L1}-\frac{p_o}{\rho_o}\right)+\right.\right. \qquad (50)\\
& \left.\rho_g S_g\left(y_1 H_{g1}+y_2 H_{g2}-\frac{p_g}{\rho_g}\right)\right)+\\
& \left.\left(1-\varphi_v\right)\left(a\left(T-T_r\right)+\frac{1}{2}b\left(T^2-T_r^2\right)\right)\right]\\
= \; & \sum_{k=1}^{n_f}\left[\underline{\underline{T}}\left(\frac{k_{rw}}{\mu_w r_w}\right)\rho_w H_w\Delta\Phi_w+\underline{\underline{T}}\left(\frac{k_{ro}}{\mu_o r_o}\right)\rho_o\left(x_1 H_{L1}\right)\Delta\Phi_o\right.\\
& \left.+\underline{\underline{T}}\left(\frac{k_{rg}}{\mu_g r_g}\right)\rho_g\left(y_1 H_{g1}+y_2 H_{g2}\right)\Delta\Phi_g\right]\\
& +\sum_{k=1}^{n_f}K\Delta T+\rho_w q_{wk}H_w+\rho_o q_{ok}\left(x_1 H_{L1}\right)+\\
& \rho_g q_{gk}\left(y_1 H_{g1}+y_2 H_{g2}\right) \qquad \text{[well layer } k\text{]} \qquad +V\left(H_{r1}r_1\right)
\end{aligned}
$$

And for RESSIM

$$\begin{aligned}
&\left(\phi\left(S_w\rho_w c_{vw}+S_o\rho_o c_{vo}+S_g\rho_g c_{vg}\right)T+(1-\phi)\rho_r c_{vr}T\right)_t- \\
&\nabla\cdot\left(\underline{\underline{T}}_w\cdot\nabla\Phi_w c_{Pw}T+\underline{\underline{T}}_o\cdot\nabla\Phi_o c_{Po}T+\underline{\underline{T}}_g\cdot\nabla\Phi_g c_{Pg}T\right) \\
&=Q_I+Q_r+\nabla\cdot(\kappa_T\nabla T)
\end{aligned} \tag{51}$$

remplacing $\underline{\underline{T}}_\alpha=\frac{\rho_\alpha k_{r\alpha}}{\mu_\alpha}\underline{\underline{k}}$ and $Q_r=\sum_k^{Nr}H_{rk}r_k$, then

$$\begin{aligned}
&\left(\phi\left(S_w\rho_w c_{vw}+S_o\rho_o c_{vo}+S_g\rho_g c_{vg}\right)T+(1-\phi)\rho_r c_{vr}T\right)_t- \\
&\nabla\cdot\left(\frac{\rho_w k_{rw}}{\mu_w}\underline{\underline{k}}\cdot\nabla\Phi_w c_{Pw}T+\frac{\rho_o k_{ro}}{\mu_o}\underline{\underline{k}}\cdot\nabla\Phi_o c_{Po}T+\frac{\rho_g k_{rg}}{\mu_g}\underline{\underline{k}}\cdot\nabla\Phi_g c_{Pg}T\right) \\
&=Q_I+H_{r1}r_1+\nabla\cdot(\kappa_T\nabla T)
\end{aligned} \tag{52}$$

Now comparing term by term for RESSIM Ec.(50) and STARS Ec.(52) of conservation equations of energy, then

$$\begin{aligned}
&\left(\phi\left(S_w\rho_w c_{vw}+S_o\rho_o c_{vo}+S_g\rho_g c_{vg}\right)T+(1-\phi)\rho_r c_{vr}T\right)_t- \\
&\nabla\cdot\left(\frac{\rho_w k_{rw}}{\mu_w}\underline{\underline{k}}\cdot\nabla\Phi_w c_{Pw}T+\frac{\rho_o k_{ro}}{\mu_o}\underline{\underline{k}}\cdot\nabla\Phi_o c_{Po}T+\frac{\rho_g k_{rg}}{\mu_g}\underline{\underline{k}}\cdot\nabla\Phi_g c_{Pg}T\right) \\
&=Q_I+H_{r1}r_1+\nabla\cdot(\kappa_T\nabla T)
\end{aligned} \tag{53}$$

$$\begin{aligned}
&V\frac{\partial}{\partial t}\Bigg[\varphi_f\left(\rho_w S_w\left(H_w-\frac{p_w}{\rho_w}\right)+\rho_o S_o\left(x_1H_{L1}-\frac{p_o}{\rho_o}\right)+\right. \\
&\left.\rho_g S_g\left(y_1H_{g1}+y_2H_{g2}-\frac{p_g}{\rho_g}\right)\right)+ \\
&(1-\varphi_v)\left(a\left(T-T_r\right)+\frac{1}{2}b\left(T^2-T_r^2\right)\right)\Bigg] \\
=\ &\sum_{k=1}^{n_f}\Bigg[\underline{\underline{T}}\left(\frac{k_{rw}}{\mu_w r_w}\right)\rho_w H_w\Delta\Phi_w+\underline{\underline{T}}\left(\frac{k_{ro}}{\mu_o r_o}\right)\rho_o\left(x_1H_{L1}\right)\Delta\Phi_o \\
&+\underline{\underline{T}}\left(\frac{k_{rg}}{\mu_g r_g}\right)\rho_g\left(y_1H_{g1}+y_2H_{g2}\right)\Delta\Phi_g\Bigg] \\
&+\sum_{k=1}^{n_f}K\Delta T+\rho_w q_{wk}H_w+\rho_o q_{ok}\left(x_1H_{L1}\right)+ \\
&\rho_g q_{gk}\left(y_1H_{g1}+y_2H_{g2}\right)\qquad[\text{well layer }k]\qquad+V\left(H_{r1}r_1\right)
\end{aligned} \tag{54}$$

For the first term $\phi S_w \rho_w c_{vw} T$ and $\varphi_f \rho_w S_w \left(H_w - \frac{p_w}{\rho_w}\right)$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $(1-\sigma)\phi$ | $\varphi_f$ |
| $\phi$ | $\varphi_v$ |
| $S_w$ | $S_w$ |
| $\rho_w$ | $\rho_w$ |
| $c_{vw}T$ | $U_w = H_w - \frac{p_w}{\rho_w}$ |

(55)

for the term $\phi S_o \rho_o c_{vo} T$ and $\varphi_f \rho_o S_o \left(x_1 H_{L1} - \frac{p_o}{\rho_o}\right)$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $(1-\sigma)\phi$ | $\varphi_f$ |
| $S_o$ | $S_o$ |
| $\rho_o$ | $\rho_o$ |
| $c_{vo}T$ | $U_o = x_1 H_{L1} - \frac{p_o}{\rho_o}$ |

(56)

for the term $\phi S_g \rho_g c_{vg} T$ and $\varphi_f \rho_g S_g \left(y_1 H_{g1} + y_2 H_{g2} - \frac{p_g}{\rho_g}\right)$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $S_g$ | $S_g$ |
| $\rho_g$ | $\rho_g$ |
| $c_{vg}T$ | $U_g = y_1 H_{g1} + y_2 H_{g2} - \frac{p_g}{\rho_g}$ |

(57)

for the term $(1-\phi)\rho_r c_{vr} T$ and $(1-\varphi_v)\left(a(T-T_r) + \frac{1}{2}b\left(T^2 - T_r^2\right)\right)$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $\phi$ | $\varphi_v$ |
| $\rho_r c_{vr} T$ | $U_r = a(T-T_r) + \frac{1}{2}b\left(T^2 - T_r^2\right)$ |

(58)

for the term $\nabla \cdot \left(\frac{\rho_w k_{rw}}{\mu_w} \underline{\underline{k}} \cdot \nabla \Phi_w C_{Pw} T\right)$ and $\underline{\underline{T}} \left(\frac{k_{rw}}{\mu_w r_w}\right) \rho_w H_w \Delta \Phi_w$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $\rho_w$ | $\rho_w$ |
| $k_{rw}$ | $k_{rw}$ |
| $\mu_w$ | $\mu_w$ |
| $\underline{\underline{k}}$ | $\underline{\underline{T}}$ |
| $\Phi_w$ | $\Phi_w$ |
| $C_{Pw}T$ | $H_w$ |
| $-$ | $r_w = 1.0$ |

(59)

for the term $\nabla\cdot\left(\frac{\rho_o k_{ro}}{\mu_o}\underline{\underline{k}}\cdot\nabla\Phi_o c_{Po}T\right)$ and $\underline{\underline{T}}\left(\frac{k_{ro}}{\mu_o r_o}\right)\rho_o\left(x_1 H_{L1}\right)\Delta\Phi_o$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $\rho_o$ | $\rho_o$ |
| $k_{ro}$ | $k_{ro}$ |
| $\mu_o$ | $\mu_o$ |
| $\underline{\underline{k}}$ | $\underline{\underline{T}}$ |
| $\Phi_o$ | $\Phi_o$ |
| $c_{P0}T$ | $H_o = x_1 H_{L1}$ |
| $-$ | $r_o = 1.0$ |

(60)

for the term $\nabla\cdot\left(\frac{\rho_g k_{rg}}{\mu_g}\underline{\underline{k}}\cdot\nabla\Phi_g c_{Pg}T\right)$ and $\underline{\underline{T}}\left(\frac{k_{rg}}{\mu_g r_g}\right)\rho_g\left(y_1 H_{g1}+y_2 H_{g2}\right)\Delta\Phi_g$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $\rho_g$ | $\rho_g$ |
| $k_{rg}$ | $k_{rg}$ |
| $\mu_g$ | $\mu_g$ |
| $\underline{\underline{k}}$ | $\underline{\underline{T}}$ |
| $\Phi_g$ | $\Phi_g$ |
| $c_{Pg}T$ | $H_g = y_1 H_{g1} + y_2 H_{g2}$ |
| $-$ | $r_g = 1.0$ |

(61)

for the term $\nabla\cdot\left(\kappa_T\nabla T\right)$ and $K\Delta T$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $\kappa_T$ | $K$ |
| $T$ | $T$ |

(62)

where

$$\begin{array}{ll} RESSIM & \kappa_T = (1-\sigma)\,\phi\left(S_w\kappa_w + S_o\kappa_o + S_g\kappa_g\right) + (1-\phi)\,\kappa_r \\ STARS & \kappa_{mix} = \varphi_f\left(thconw\cdot S_w + thcono\cdot S_o + thcong\cdot S_g\right) + \\ & (1-\varphi_v)\cdot thconr + \left(\varphi_v - \varphi_f\right)\cdot thcons \end{array} \tag{63}$$

for the term $H_{r1}r_1$ and $H_{r1}r_1$ then

| $RESSIM$ | $STARS$ |
|---|---|
| $H_{r1}$ | $H_{r1}$ |
| $r_1$ | $r_1$ |

(64)

for the term $Q_I$ and $\rho_w q_{wk} H_w + \rho_o q_{ok}\left(x_1 H_{L1}\right) + \rho_g q_{gk}\left(y_1 H_{g1} + y_2 H_{g2}\right)$, first is necesary defined $Q_I$???, and for the second term remplacing $q_{jk}$ where [see Ec.(F4.1) to Ec.(F4.7)]

$$q_{jk} = I_{jk}\cdot\left(p_{wfk} - p_k\right) \qquad j = w, o, g \tag{65}$$

$$p_{wf} = p_{wf} + \int_{h_j}^{h_k}\gamma_{av} g dh \tag{66}$$

then

$$\rho_w I_{wk} \cdot (p_{wfk} - p_k) \, H_w + \rho_o I_{ok} \cdot (p_{wfk} - p_k) \, (x_1 H_{L1}) + \tag{67}$$
$$\rho_g I_{gk} \cdot (p_{wfk} - p_k) \, (y_1 H_{g1} + y_2 H_{g2})$$

# 5 Data for the reduced problem 7

- Porosity *POR CON

$$\varphi_f = 0.25 \tag{68}$$

- Permeability *PERMI CON

$$k = 6.908e-1 \qquad \mu m^2 \tag{69}$$

- Thermal conductivity

$$\begin{aligned} \kappa_{mix} &= \varphi_f \left( thconw \cdot S_w + thcono \cdot S_o + thcong \cdot S_g \right) + \\ & \quad (1-\varphi_v) \cdot thconr + \left( \varphi_v - \varphi_f \right) \cdot thcons \end{aligned} \tag{70}$$

where use with *THCONR=4.4861e+5, *THCONW=4.4861e+5, *THCONO=4.4861e+5, *THCONG=4.4861e+5.

- Molecular mass component *CMM

$$0.018, 0.5089, 0.038, 0.032$$

- Critical Pressure *PCRIT

$$p_{c_j} = 22110, 349.6, 5171.1, 5033.2 \tag{71}$$

- Critical temperature *TCRIT

$$T_{cj} = 647.4, 887.8, 194.4, 154.4 \tag{72}$$

- K Value Correlations *KV1=0, *KV4=0 (defaults values)

$$K = \left( kv1/p + kv2 * p + kv3 \right) * \exp\left( kv4/\left( T - kv5 \right) \right) \tag{73}$$

by omision $K_w$ is a table data.

- Reference pressure *PRSR

$$p_r = 5620 \tag{74}$$

- Reference temperature *TERM

$$T_r = 322.2 \tag{75}$$

- Coefficent in liquid Heat Capacities*CPL1

$$CPL1 = 0, 1278.1, 30.27, 32.15$$

Liquid Heat Capacities
Condensable component:

$CPL(T) = cpl1 + cpl2 * T + cpl3 * T^2 + cpl4 * T^3.$
$HVAP(T) = hvr * (TCRIT - T)^{ev}.$
$HG(T) = HL(T) + HVAP(T).$

Non-Condensable component:

$$CPG = cpl1 + cpl2 * T + cpl3 * T^2 + cpl4 * T^3.$$

Vaporu Heat Capacities
Condensable component:

$CPG(T) = cpg1 + cpg2 * T + cpg3 * T^2 + cpg4 * T^3.$
$HVAP(T) = hvr * (TCRIT - T)^{ev}.$
$HL(T) = HG(T) - HVAP(T).$

Non-Condensable component:

$$CPG = cpl1 + cpl2 * T + cpl3 * T^2 + cpl4 * T^3.$$

Liquid and Vapour Heat Capacities
Condensable component:

$CPG(T) = cpg1 + cpg2 * T + cpg3 * T^2 + cpg4 * T^3.$
$CPL(T) = cpl1 + cpl2 * T + cpl3 * T^2 + cpl4 * T^3.$

where

$CPG$ Heat capacity in a liquid phase
$CPG$ Heat capacity in the gas phase
$HVAP$ Enthalpy of vapourization

Non-Condensable component:

$$CPG(T) = cpg1 + cpg2 * T + cpg3 * T^2 + cpg4 * T^3.$$

- The density of component $k$ in the solid phase at pressure $p$ and temperature $T$ is given by

$$\rho_{sk} = \rho_{ko} \cdot \exp \left[ \begin{array}{c} cp \cdot (p - PRSR) - ct \cdot (T - TEMR) + \\ cpt \cdot (p - PRSR) \cdot (T - TEMR) \end{array} \right] \tag{76}$$

  where use *TEMR=322.2 and *PRSR=5620.

- Mass density at reference pressure *MOLDEN=55500 1924.8
- Liquid Compresibility at constant temperature *CP

$$CP = 1.45e - 6$$

- Thermal expansion coefficient *CT1 $CT1 = 06.8e-4$, then

$$\rho_{wi} = \rho_{wi}^0 \cdot \exp\left[a\left(p-p_r\right) - b\left(T-Tr\right) - \frac{1}{2}c\left(T^2-T_r^2\right)\right] \quad (77)$$

$$\rho_{oi} = \rho_{oi}^0 \cdot \exp\left[a\left(p-p_r\right) - b\left(T-Tr\right) - \frac{1}{2}c\left(T^2-T_r^2\right)\right] \quad (78)$$

  where

  $a$ is the compressibility at constant temperature *CP
  $b+cT$ is the termal expansion coefficient
  $\rho_{wi}^0$ is the density at reference conditions $p_r$ and $T_r$
  $\rho_{oi}^0$ is the density at reference conditions $p_r$ and $T_r$

- Liquid densities are obtained by ideal mixing of pure-component densities whit pahse composition

$$\frac{1}{\rho_w} = \sum_{i=1}^{nc} \frac{w_i}{\rho_{wi}} \quad \text{(D4.1)}$$

$$\frac{1}{\rho_o} = \sum_{i=1}^{nc} \frac{w_i}{\rho_{oi}} \quad \text{(D4.2)}$$

$$\rho_g = 1 - \rho_w + \rho_o \quad (79)$$

- Stone's Model II, liquid does not contains $S_{wc}$ (*NOSWC) pag. 368

$$k_{ro} = k_{rocw}\left(\begin{array}{c}(k_{\text{row}}/k_{rocw} + k_{rw})* \\ (k_{rog}/k_{rocw} + k_{rg}) - k_{rw} - k_{rg}\end{array}\right) \quad (80)$$

$$k_{rocw} = k_{\text{row}}\left(S_w = 0\right) = k_{rog}\left(S_g = 0\right) \quad (81)$$

where $S_w, k_{rw}$ and $k_{\text{row}}$ are datum of *SWT, and $S1, k_{rg}$ and $k_{rog}$ are datum of *SLT *NOSWC. Then

$$S_w = \text{Interpolation} \quad (82)$$

$$S_1 = S_o. \quad (83)$$

then

$$S_g = 1 - S_w + S_o \quad (84)$$

- The gas viscosity correlation is

$$\mu_g = AVG(i) * (T * *BVG(i)) \quad (85)$$

  where *AVIG= $2.435e{-16}, 0, 3.719e{-15}, 3.883e{-15}$ is the first coefficients of the correlation for temperature dependence, *BVG= $1.075, 0, 0.702, 0.721$ is the second coefficients of the correlation for temperature dependence.

- The liquid viscosity correlation is

$$\mu_f = AVISC(i) * \exp(BVISC(i)/T) \tag{86}$$

where *AVISC= $0, 1.157e-3$ is the first coefficients of the correlation for temperature dependence of component viscosity, *BVISC= $0, 2726.7$ is the second coefficients of the correlation for temperature dependence of component viscosity.

- Crital chemical reaction data, $s_{ki}$ =*STOREAC= $0, 1, 0, 45.2915$, $S'_{ki}$ =*STOPROD= $29.71, 0, 37.46, 0$, $r_k$ =*FREQFAC= $3.0837e+5$ are stoichiometric coefficient of reacting component, produced component and reaction frequenci factor, are use in the critical chemical reaction data to use in Ec.(F5.1 and F5.2).

- Noncritical chemical reaction data, *RENTH= $5e$+7, *RORDER= $0, 2, 0, 1$

  and *EACT= 50000 are Reaction enthalpy, Order of reaction whit respect to echc reacting component and Activation energy respectively. The expresion for the volumetric reaction rate is

$$\begin{aligned} r_r &= rrf * \exp\left(-eact/\left(T * R\right)\right) * c(1) * *enrr(1) * \quad (87) \\ &\quad ... * c(n_c) * *enrr(n_c) \quad (88) \\ c(i) &= \varphi_f * den(iphas(i)) * sat(iphas(i)) * x(iphase(i), i) \\ \varphi_f &= \varphi_v * \left[1 - \sum C_{sk}/\rho_{sk}\right] \end{aligned}$$

where

$rrf$ constant part of the expresion $(r_{rk})$
$eact$ activation energe *EACT
$T$ Temperature
$R$ Universal gas constant
$c(i)$ Concentration factor contributed by reactan component $i$
$enrr$ Order of reaction with respect to component $i$ *RORDER

Initial values

- Presure $p = 5620$ kPa
- Water saturation $S_w = 0.3$
- Temperature $T = 322$ K
- Gas mole fraction inert gas 0.71
- Gas mole fraction Oxygen 0.29
- Oil mole fraction 1.0