DETAILED ENERGY BALANCE

Data:

Heat capacity:

C_3H_6 : $2.85 + .23 \times 10^{-2} T - 1.2 \times 10^{-4} T^2 + 2.3 \times 10^{-8} T^3$ (kJ/kmol K)
C_3H_4O : $3.7957 + 4.4 \times 10^{-2} T - 0.1304 \times 10^{-4} T^2 - 0.2848 \times 10^{-8} T^3$ (cal / mol K)
$C_3H_4O_2$: $1.6828 + 6.9212 \times 10^{-2} T - 0.4475 \times 10^{-4} T^2 + 1.10186 \times 10^{-8} T^3$ (cal / mol K)
$C_2H_4O_2$: $2.0142 + 5.6065 \times 10^{-2} T - 0.3401 \times 10^{-4} T^2 + 0.802 \times 10^{-8} T^3$ (cal / mol K)

REACTOR I

Heat in:

Feed is preheated to 200˚C (molten salt coolant temperature)

Heat in with C_3H_6 = $m \Delta H_{f \text{ at } 25^\circ C} + m \int_{298}^{473} Cp \, dT$

= 148 .38 (20.27 x 10 3 + $\int_{298}^{473} Cp \, dT$)
= 4999350. 27 kJ / hr

Heat in with air = $m Cp \Delta T$
(Compressed to 5 bar) = 1149.94 x 1.015x 29x (200-25)
= 5923484.68 kJ / hr

Heat in with steam = $m \lambda + m Cp \Delta T$
= 556.42 x (2676 x 18 + 2.291 x 18) x (200-25)
= 30817126.95 kJ / hr

Total heat in = 41739961.9 kJ / hr

Heat Generated :

Heat generated by reaction 1 = 340.8 kJ / mol
Heat generated by reaction 2 = 254.1 kJ / mol
Heat generated by other side reactions are neglected.

Total heat generated = $340.8 \times 10^3 \times 103.866 + 254.1 \times 10^3 \times 16.32$
= 39544444.8 kJ / hr

Heat removed by Coolant :

The temperature in the reactor reaches an average peak temperature of 355˚C due to the exothermic reaction.
At the end of the catalyst bed, the temperature drops toward that of molten salt coolant (210˚C).

Heat with acrolein $= m\int_{628}^{483} Cp\ dT$

$= 103.866 \times \int_{628}^{483} Cp\ dT$

$= 1493068.88$ kJ / hr

Heat with Acrylic acid $= m\int_{628}^{483} Cp\ dT$

$= 16.32 \times \int_{628}^{483} Cp\ dT$

$= 278848.6$ kJ / hr

Heat with Acetic acid $= m\int_{628}^{483} Cp\ dT$

$= 14.096 \times \int_{628}^{483} Cp\ dT$

$= 205053.1$ kJ / hr

Heat with air $= m\ Cp\ \Delta T$

$=1001.55 \times 30.35 \times (628-483)$

$=4408195.62$ kJ / hr

Heat with CO_2 $= m\ Cp\ \Delta T$

$=14.096 \times 47.896 \times (628-483)$

$=97897.62$ kJ / hr

Heat with steam $= m\ Cp\ \Delta T$

$=660.286 \times 36.173 \times (628-483)$

$=3463347.34$ kJ / hr

Total heat removed by the Coolant = 9946411.17 kJ/hr

Heat out:

Heat out with Acrolein $= m \int_{483}^{298} Cp\ dT$

$=103.866\ m \int_{628}^{298} Cp\ dT$

$=1509276.32$

Heat with Acrylic acid $= m \int_{483}^{298} Cp\ dT$

$= 16.32 \times \int_{483}^{298} Cp\ dT$

$= 283613.82$ kJ/hr

Heat with Acetic acid $= m \int_{483}^{298} Cp\ dT$

$= 14.096 \times \int_{483}^{298} Cp\ dT$

$= 208578.2$ kJ / hr

Heat with air $= m\ Cp\ \Delta T$

$=1001.55 \times 30.35 \times (483-298)$

$=5624249.59$ kJ / hr

Heat with CO_2 $= m\ Cp\ \Delta T$

$=14.096 \times 42.37 \times (483-298)$

$=110490.79$ kJ / hr

Heat with steam $= m\ Cp\ \Delta T$

$=660.286 \times 33.913 \times (483-298)$

$=4142581.4$ kJ / hr

Total heat out = 11878790.12 kJ/hr

Heat to Waste heat boiler

=Heat in + Heat generated - Heat removed by coolant - Heat out
=59459205.41kJ/hr

Water required in boiler = m =59459205.41 / λ
=22219.43 kg/hr

REACTOR II

Heat in from reactor I = 11878790.12 kJ/hr

Heat generated:

= 254.1 x 10^3 kJ/kmol of Acrylic acid
=254.1 x 10^3 x 101.26
=25730166 kJ/hr

Heat removed by coolant:

The feed to the second reactor enters at temperature of 210˚C.
The temperature in the reactor reaches an average peak temperature of 300˚C due to the exothermic reaction.
At the end of the catalyst bed, the temperature drops toward that of molten salt coolant (210˚C).

$$\text{Heat with Acrylic acid} = m\int_{573}^{483} Cp\ dT$$

$$= 117.58 \times \int_{573}^{483} Cp\ dT$$

$$= 1211152.08 \text{ kJ / hr}$$

$$\text{Heat with Acetic acid} = m\int_{573}^{483} Cp\ dT$$

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$= 15.3942 \times \int_{573} Cp\ dT$
$= 134946.92$ kJ / hr

Heat with air $= m\ Cp\ \Delta T$
$=949.617 \times 30.35 \times (573-483)$
$=2588415.83$ kJ / hr

Heat with CO_2 $= m\ Cp\ \Delta T$
$=15.3942 \times 46.0548 \times (573-483)$
$=63807.91$ kJ / hr

Heat with steam $= m\ Cp\ \Delta T$
$=660.286 \times 35.42 \times (573-483)$
$=2104879.2$ kJ / hr

Total heat removed by the Coolant = 6103201.95 kJ/hr

Heat out:

Heat with Acrylic acid $= m \int_{483}^{298} Cp\ dT$

$= 117.58 \times \int_{483}^{298} Cp\ dT$
$= 2043343.9$ kJ / hr

Heat with Acetic acid $= m \int_{483}^{298} Cp\ dT$

$= 15.3942 \times \int_{483}^{298} Cp\ dT$
$= 54442.55$ kJ / hr

Heat with air $= m\ Cp\ \Delta T$
$=949.617 \times 30.35 \times (483-298)$
$=5332617.47$ kJ / hr

Heat with CO_2 $= m\ Cp\ \Delta T$
$=15.3942 \times 40.528 \times (483-298)$
$=115421.42$ kJ / hr

Heat with steam = m Cp ΔT
=660.286 x 36.913 x (483-298)
=4142581.4 kJ / hr

Total heat out = 11861751.85 kJ/hr.

Heat to Waste heat boiler

=Heat in + Heat generated - Heat removed by coolant - Heat out
=19644022.32 kJ/hr

Water required in boiler = m =19644022.32 / λ
=7340.8 kg/hr

ABSORBER:

Heat in:

Heat in from the second reactor = 11861751.85 kJ/hr

Absorbing solvent water enters at 30˚C.
Heat in with water = m Cp ΔT
=488.6 x 4.186 x 18 x (30-25)
=184075.1 kJ/hr

Total heat in = 10317508.86 kJ/hr

Heat out along with the offgas:

The off gas leave the column at 70˚C

Heat with Acrylic acid = $m\int_{343}^{298} Cp\ dT$

$= 1.1758 \times \int_{343}^{298} Cp\ dT$
= 4344.66 kJ / hr

Heat with Acetic acid = $m\int_{343}^{298} Cp\ dT$

$= 0\ .1539 \times \int_{343}^{298} Cp\ dT$

= 485.04kJ / hr

Heat with air = m Cp ΔT
=949.617 x 30.35 x (343-298)
=1297110.34 kJ / hr

Heat with CO_2 = m Cp ΔT
=15.3942 x 40.52 x (343-298)
=28075.48 kJ / hr

Heat with water = m Cp ΔT
=66.0286 x 33.913 x (343-298)
= 100764.5 kJ / hr

Total heat out with the off gas= 1430780.02 kJ/hr.

<u>Heat out along with the bottom product:</u>

The bottom products leave the column at 80˚C.

Heat with Acrylic acid = $m\int_{353}^{298} Cp\ dT$

$= 116.404 \times \int_{353}^{298} Cp\ dT$
= 531493.66 kJ / hr

Heat with Acetic acid = $m\int_{353}^{298} Cp\ dT$

$= 15.396 \times \int_{353}^{298} Cp\ dT$
= 61021.65 kJ / hr

Heat with water = m Cp ΔT
=1082.85 x 4.186 x 18x (343-298)
= 4487481.99 kJ / hr

Total heat out with the bottom product = 5079997.3 kJ/hr.

Heat to inter stage cooler (Minor equipment)

=Heat in - Heat out with off gas - Heat out at the bottom

= 5535049.54 kJ/hr