EXAMPLE 2-2 REDUCTION OF DISCHARGE IN A TIRE-TO-FUEL PLANT

This case study is adapted from El-Halwagi (1997) and Noureldin and El-Halwagi (1999). It involves a processing facility that converts scrap tires into fuel via pyrolysis. Figure 2-11 is a simplified flowsheet of the process. The discarded tires are fed to a high-temperature reactor where hydrocarbon content of the tires are broken down into oils and gaseous fuels. The oils are further processed and separated to yield transportation fuels. As a result of the pyrolysis reactions, water is formed. The amount of generated water is a function of the reaction temperature, T_{rxn}, through the following correlation:

$$W_{rxn} = 0.152 + (5.37 - 7.84 \times 10^{-3} T_{rxn}) e^{(27.4 - 0.04 T_{rxn})} \tag{2.10}$$

where W_{rxn} is in kg/s and T_{rxn} is in K. At present, the reactor is operated at 690 K which leads to the generation of 0.12 kg water/s. In order to maintain acceptable product quality, the reaction temperature should be maintained within the following range:

$$690 \leq T_{rxn}(\mathrm{K}) \leq 740 \tag{2.11}$$

The gases leaving the reactor are passed through a cooling/condensation system to recover some of the light oils. In order to separate the oils, a decanter is used to separate the mixture into two layers: aqueous and organic. The aqueous layer is a wastewater stream whose flowrate is designated as W_1

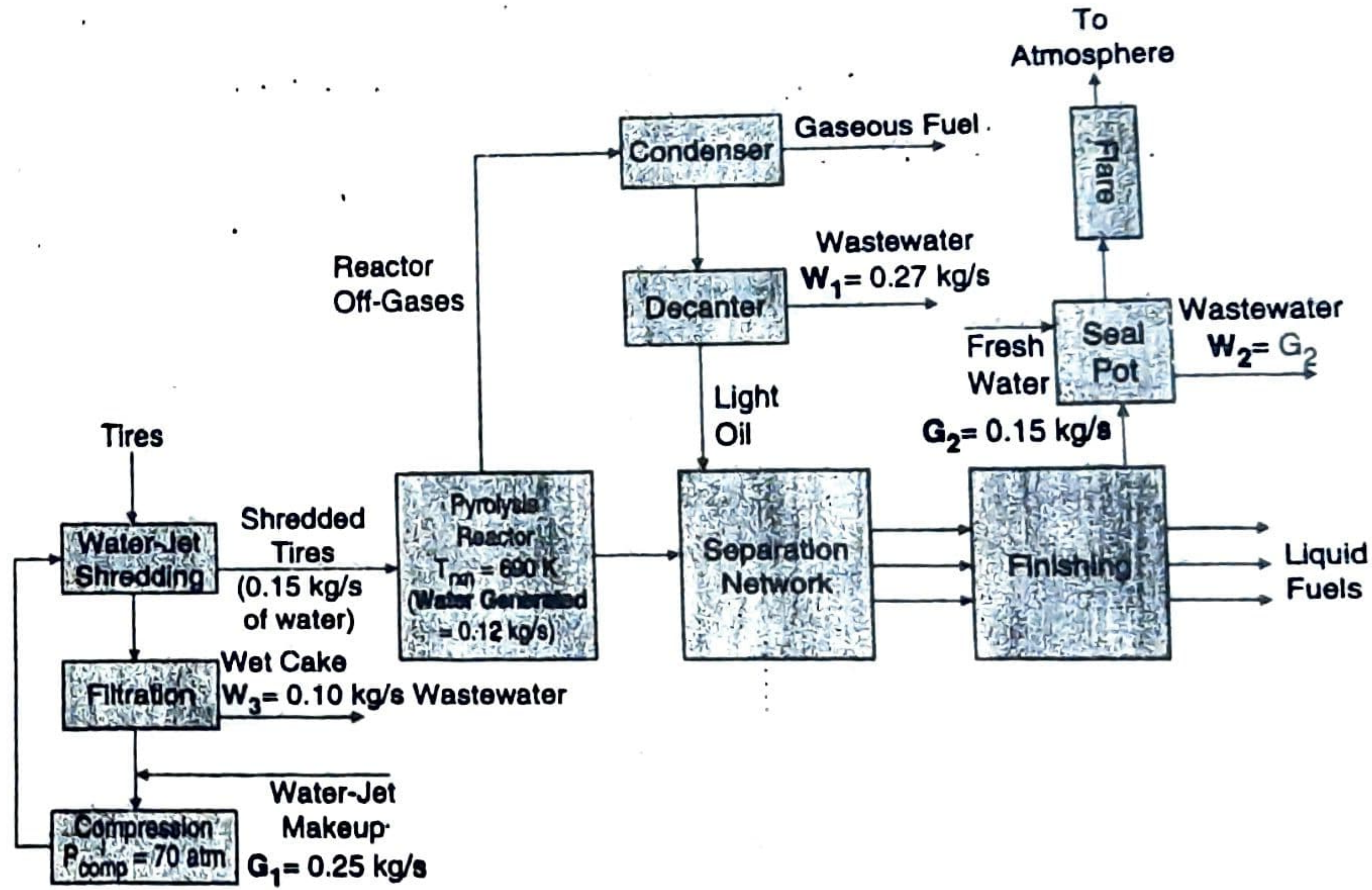


FIGURE 2-11 SIMPLIFIED FLOWSHEET OF TIRE-TO-FUEL PLANT

and it contains phenol as the primary pollutant. The organic layer is mixed with the liquid products of the reactor and fed to finishing. As a result of fuel finishing, a gaseous waste is produced and flared. As a safety precaution to prevent the back-propagation of fire from the flare, a seal pot (or a water valve) is placed before the flare to provide a buffer zone between the fire and the flare gas. The flowrate of the water stream passing through the seal pot is referred to as G_2 and an equivalent flowrate of wastewater stream, $W_2 = G_2$, is withdrawn from the seal pot.

Tire shredding is achieved by using high-pressure water jets. The shredded tires are fed to the process while the spent water is filtered. The wet cake collected from the filtration system is forwarded to solid waste handling. The filtrate is mixed with fresh water-jet makeup "G_1" to compensate for water losses with the wet cake "W_3" and the shredded tires. The mixture of the filtrate and the water makeup is fed to a high-pressure compression station for recycle to the shredding unit. The flowrate of water-jet makeup depends on the applied pressure coming out of the compression stage "P_{comp}" via the following expression:

$$G_1 = 0.47\, e^{-0.009 P_{comp}} \tag{2.12}$$

where G_1 is in kg/s and P_{comp} is in atm. In order to achieve acceptable shredding, the jet pressure may be varied within the following range:

$$70 \le P_{comp}(\text{atm}) \le 95 \tag{2.13}$$

At present, P_{comp} is 70 atm which requires a water-jet makeup flowrate of 0.25 kg/s.

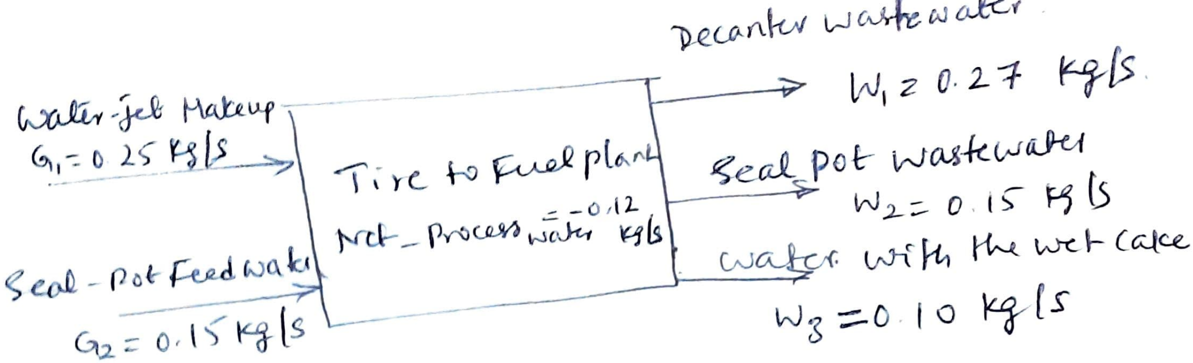
The water lost in the cake is related to the mass flowrate of the water-jet makeup through:

$$W_3 = 0.4\, G_1 \tag{2.14}$$

In addition to the water in the wet cake, the plant has two primary sources for wastewater; from the decanter (W_1) and from the seal pot (W_2). At present, the values of W_1, W_2, and W_3 are 0.27, 0.15, and 0.10 kg/s, respectively. The wastewater from the decanter contains about 500 ppm of phenol. Within the range of allowable operating changes, this concentration can be assumed to remain constant. At present, the wastewater from the seal pot contains no phenol. The plant has been shipping the wastewater streams W_1 and W_2 for off-site treatment. The cost of wastewater transportation and treatment is \$0.10/kg leading to a wastewater treatment cost of approximately \$1.33 million/year. W_3 has been processed on site. Because of the characteristics of W_3, the plant does not allow its recycle back to the process even after waste-handling processing. The plant wishes to reduce off-site treatment of wastewater streams W_1 and W_2 to avoid cost of off-site treatment and alleviate legal-liability concerns in case of transportation accidents or inadequate treatment of the wastewater. The objective of this problem is to determine a target for reduction in flowrate of terminal discharges W_1 and W_2.

W_1 and W_2.

Soln: Overall water balance for the process before mass integration



1st step.

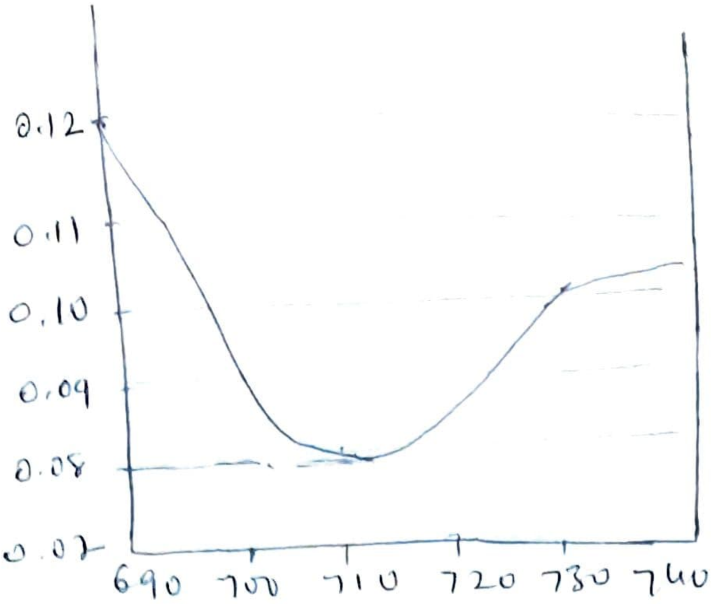
To reduce terminal discharge reduce net generation of water

$$W_{rxn} = \left[0.152 + (5.37 - 7.84\times10^{-3}\,T_{rxn})\,e^{(27.4-0.04T_{rxn})}\right]$$

and $690 \le T_{rxn}(K) \le 740$

$e = 2.7182$

T_{rxn}	W_{rxn}
690	0.11957
700	0.0872
710	0.079
720	0.084
730	
740	



Rate of water consumption as a function of reaction temperature.

From graph, the minimum generation of water is 0.08 kg/s and is attained at a reaction temperature of 710 K.

2nd step:

Adjust design and operating parameters to minimize fresh water consumption

Fresh water used for shredding in a function of pressure

$G_1 = 0.47\, e^{-0.009\, P_{comp}}$

where Pcomp should be maintained at 70 – 95 atm.

∴ In order to minimize the fresh water needed for shredding, the value of Pcomp should be set to maximum

$G_1 = 0.47\, e^{-0.009 \times 95}$

$= 0.20$ kg/s.

∴ water lost in the cake $W_8 = 0.4 \times G_1$

$= 0.4 \times 0.2$

$= 0.08$ kg/s

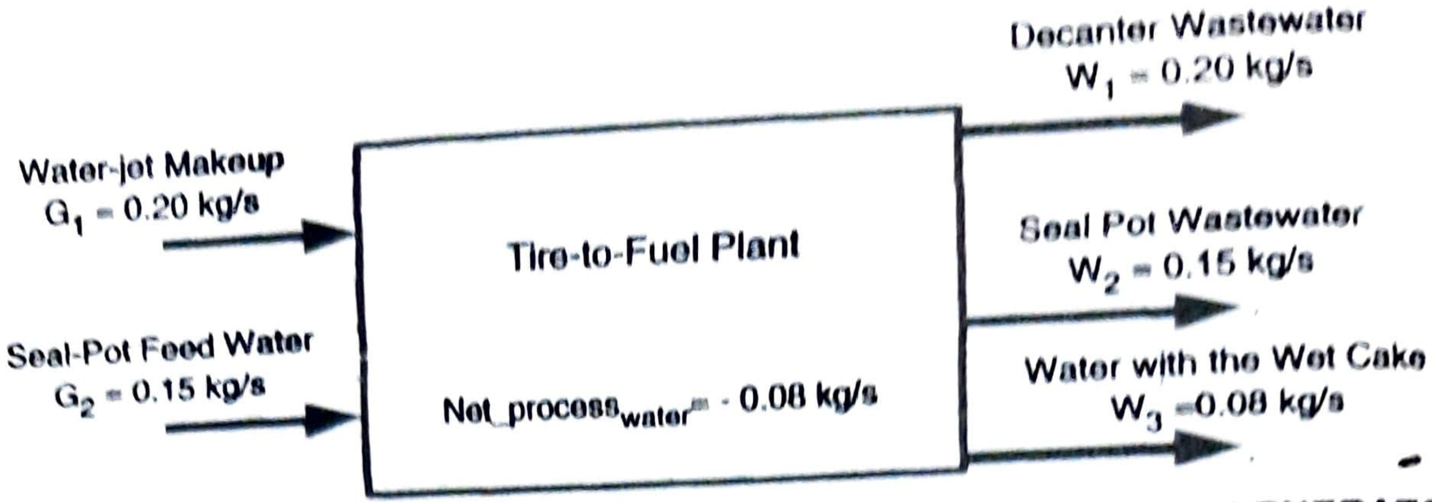


FIGURE 2-14 OVERALL WATER BALANCE AFTER SINK/GENERATOR MANIPULATION

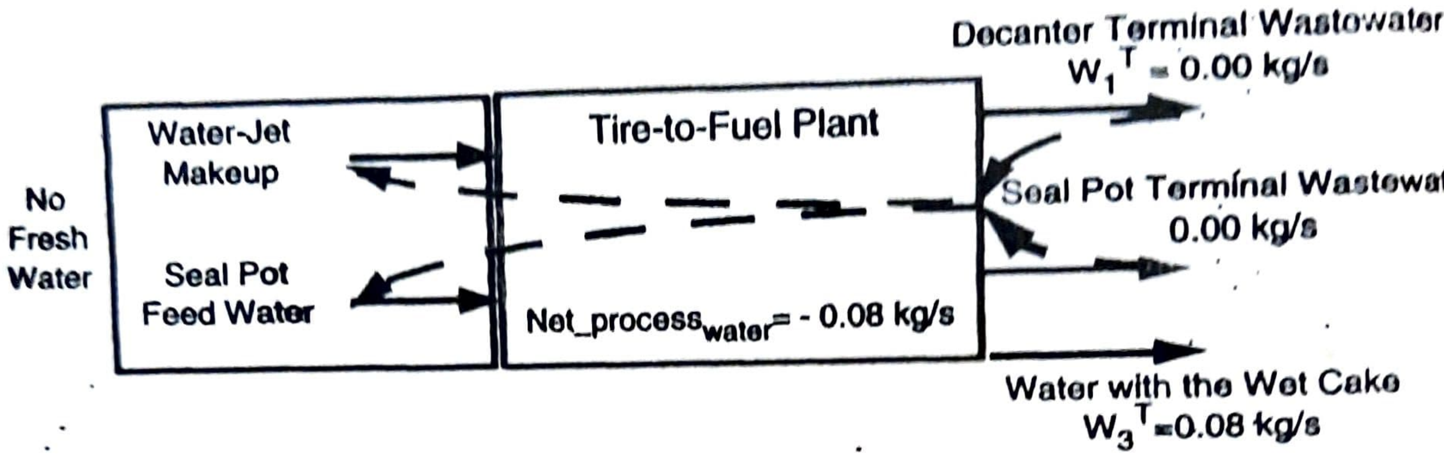


FIGURE 2-15 TARGETING FOR MINIMUM WATER USAGE AND DISCHARGE

Consequently, G_1 is reduced to 0.20 kg/s. According to equation (2.14), the new value of W_3 is given by:

$$W_3 = 0.4 \times 0.20 = 0.08 \text{ kg/s} \tag{2.15}$$

With the new values of G_1 and W_3 and with the water generation minimized to 0.08 kg/s, an overall water balance provides the value of W_2 to be 0.15 kg/s. These results are shown in Figure 2-14 and represent the overall water balance after sink/generator manipulation with existing units and current process configuration. Next, we calculate the target for water usage and discharge using interception (cleaning up of recycled water) and recycle. This targeting analysis is shown in Figure 2-15 and it yields a target of zero fresh water and 0.08 kg/s for wastewater discharge.