Polyethylene Terephthalate Recycling Facility

Background

Currently, there is considerable concern about materials "running out," and a renewed intent in conserving natural resources and increasing recycling. Also as landfill space runs out, recycling becomes increasingly attractive. This project concerns the recycling of polyethylene terephthalate (PET) bottles, typically used in the soda and bottle water industries.

PET is the main constituent in a variety of consumer and industrial products including plastic fibers, videotape, audiotape, film, engineered resin, food containers, and beverage bottles. In 1997, approximately 2.5 billion pounds of PET were available for recycling (1). Only 22.7%, or 580 million pounds, of the available PET is reclaimed yearly, thus allowing for potential market growth. This process is based on a patent for recycling of film consisting largely of PET (2). The goal was to determine if this process could be applied to PET bottles and be profitable.

Environmental Significance

Environmentally-friendly process that recycles a used product

Process Description

The BFD (Figure 1) and three PFDs (Figures 2-4) show a process to recycle PET.

<u>Unit 100</u> -- Production of TPA and Ethylene Glycol

The process flow diagram (PFD) for Unit 100 is presented in Figure 2. The purpose of Unit 100 is to reduce the size of the PET feed to that suitable for the following reaction to occur while recovering the products.

$$(C_{10}H_8O_4)_x + 2x\ KOH \rightarrow x\ K_2C_8H_4O_4 + xC_2H_6O_2$$

PET *Di-potassium terephthalate* *Ethylene Glycol*

Baled PET is crushed to loose scrap in bale breaker SR-101 at a rate of one to two bales per hour. The loose PET is shredded in SR-102, the PET shredder, to a size of approximately 76mm before passing through paramagnetic metal remover M-101, which eliminates any ferrous or non-ferrous metals from the feed. This protects the remaining size reduction equipment from excessive wear. The PET particles are then reduced to 3mm pieces in granulator SR-103, and then to 0.841 mm (20 mesh) in pulverizer SR-104 where they enter the process as Stream 1.

The feed to the remainder of Unit 100 is regulated by feed hopper HP-101 A/B and loaded to screw conveyor SF-101 to feed the rotary calciner reactor, R-101 (Stream 2). Additionally, potassium hydroxide is recycled from Unit 300 and combined with Stream 35 to feed to reactor, R-101. Ethylene glycol and water are vaporized in R-101 and forced out of R-101 as Stream 8, using a sweep gas consisting of air. The ethylene glycol and water are condensed in E-101 and separated from the sweep gas in air separator V-102. The vapor in Stream 9 consisting of air, carbon dioxide, and small amounts of ethylene glycol is vented to flare. The ethylene glycol bottoms is purified from the water in ethylene glycol column T-101 and recovered in Stream 11.

Unit 200 -- Potassium Hydroxide Recovery using Caustic Lime Process.

The PFD for Unit 200 is shown in Figure 3 (3). In Unit 200, the di-potassium terephthalate solution from Unit 100 (Stream 7) is fed to the di-potassium terephthalate reactor, R-201, along with the di-potassium terephthalate produced by R-202. Carbon dioxide, produced in R-203 and R-205, is bubbled through R-201 where the following reaction to convert di-potassium terephthalate into mono-potassium terephthalate and potassium bicarbonate,occurs,

$$C_8O_4K_2H_4 + CO_2 + H_2O \longrightarrow C_8O_4KH_5 + KHCO_3$$

Di-Potassium Terephthalate *Mono-Potassium Terephthalate* *Potassium Carbonate*

The mono-potassium terephthalate precipitates, is removed by F-201, and is recovered in Stream 15. The cake is then sent to R-202, the mono-potassium terephthalate reactor. In R-202, mono-potassium terephthalate is suspended in an 80-wt% water solution where it is hydrolyzed by the following reaction.

$$2\ C_8O_4KH_5 \longrightarrow C_8O_4K_2H_4 + C_8O_4H_6$$

Mono-potassium Tterephthalate *Potassium Terephthalate* *Terephthalic Acid*

Because of TPA's low solubility, it precipitates and is removed by filter F-202, and the potassium terephthalate is recycled to R-201.

The potassium bicarbonate and water solution leaving F-201 is pumped to a pressure of 2.31 bar and heated to 110^{o}C, via P-201 and E-201, respectively and fed to R-203. Potassium bicarbonate decomposes to potassium carbonate in the following reaction at temperatures above 100^{o}C, while the high pressure keeps the water from vaporizing and reduces the residence time for decomposition.

$$2\ KHCO_3 \xrightarrow{\text{heat}} H_2O + K_2CO_3 + CO_2$$

Potassium Bicarbonate *Potassium Carbonate*

The carbon dioxide produced in R-203 is recycled for use in R-201. The potassium carbonate solution is sent to R-204, the potassium carbonate reaction vessel, where it is reacted with hydrated lime to produce calcium carbonate and potassium hydroxide, via the following reaction:

$$K_2CO_3 + Ca(OH)_2 \longrightarrow CaCO_3 + 2\ KOH$$

Potassium Carbonate   *Hydrated Lime*   *Calcium Carbonate*   *Potassium Hydroxide*

The calcium carbonate and potassium hydroxide solution from R-204 is sent to F-203, where calcium carbonate is filtered from the potassium hydroxide solution. The potassium hydroxide solution is then fed to Unit 300 via Stream 24, while the calcium carbonate is fed to R-204, the calcium carbonate calciner (Stream 25). Reactor R-204, decomposes the calcium carbonate to calcium oxide, or quicklime, and carbon dioxide in the reaction below. (R-204 operates at a temperature of 1100°C to reduce the residence time required to decompose the calcium carbonate, which decomposes at temperatures above 825°C.)

$$CaCO_3 \xrightarrow{heat} CaO + CO_2$$

Calcium Carbonate   *Calcium Oxide*

The carbon dioxide produced in R-205 is separated from water in V-201 before being recycled to R-201. The calcium oxide produced in Stream 25 is sent to slaker unit R-206 where the calcium oxide is hydrated with water to produce calcium hydroxide (hydrated lime) to be used in the potassium carbonate reaction of R-204. The slaking reaction is as follows:

$$CaO + H_2O \longrightarrow Ca(OH)_2$$

Calcium Oxide *Hydrated Lime*

Unit 300 -- Potassium Hydroxide Concentration.

The PFD for Unit 300 is shown in Figure 4. Unit 300 utilizes a process known as multiple-effect evaporation to capitalize on the benefits of heat integration in lowering the high cost of utilities. An effect is a series of units consisting of a pump, a vaporizer, and a vapor/liquid separator. Unit 300 is a five-effect system in which potassium hydroxide enters the unit at 2-wt% and leaves at 63-wt% or 30M. Upon entering the system, the dilute potassium hydroxide is heated and partially vaporized in E-301 using the steam from V-302. Vessel V-301 then flashes the vapor-liquid mixture. The vapor leaves the vessel in Stream 31 and is later condensed after combining with other condensed steam streams in E-307. The more concentrated liquid exits V-301 as the bottom product and is pressurized 2.0 bar through pump P-301 before again being partially vaporized in E-302. This vaporizer utilizes heat integration by condensing the steam leaving the following vessel V-303. The process of “recycling” the steam into the heat exchanger of the prior effect to vaporize partially the liquid effluent is employed four consecutive times before high-pressure steam is utilized to vaporize the exiting liquid of V-304. The combined condensed steam stream is cooled in E-307 then separated and into three effluents. The three streams exit Unit 300 and are utilized as a recycle stream in both Units 100 and 200 and as a filter cake wash throughout the process. The concentrated 30M potassium hydroxide is cooled in E-306 to 195°C then recycled to the front end of the process to be employed in the reactor

Necessary Information and Simulation Hints

PET is hydrolyzed via potassium hydroxide or sodium hydroxide to form ethylene glycol and the corresponding terephthalic salt. The design of the reactor was based on the following kinetic expression (4):

$$-r_A = k[OH]^{1.1}\,[PET]^0 \quad \frac{\text{moles}}{\text{Ls}}$$

The reaction occurs on the surface of the PET particles, necessitating a small particle size of 0.841 mm (20 mesh). At 20 mesh, the PET possesses a large surface area to volume ratio allowing for the reaction to approach 100% conversion. (2).

The final and recommended reactor option is a rotary calciner. The rotary calciner requires high temperatures due to its heating inefficiency from poor heat transfer. The low heat transfer results from only 10% of the inner surface of the calciner contacting the solid/liquid flow, while the remaining 90% contacts vapor.

Accurate mathematical modeling of rotary calciners is difficult and not to be relied on for detailed design. A pilot plant would be required prior to constructing a full size rotary calciner. The goal of the design with the pilot plant is to determine the residence time necessary for the desired conversion and product dryness.

Theoretical modeling was approximated by assuming that the calciner approaches plug flow longitudinally. It was also assumed that there was no heat transfer resistance across the wall and that the inner surface of the calciner was at the temperature of the heating coil. All resistance was assumed to occur at the inner surface of R-101. In addition, the temperature inside the reactor was assumed to be constant radially. In a calciner, the heat transfer coefficient changes with length; however, for preliminary design it's recommended that a coefficient of 22.7 W/m^2 K (5) be used throughout.

Reference:

1. Internet address: **http://www.napcor.com/report.html**

2. Schwartz, J. A., "Process for Recycling Polyester," U.S. Patent #5,395,858, 1995.

3. Schütt, H., "Recovery of Alkalies and Terephthalic Acid from Aqueous Solutions Containing Alkali Salts of Terephthalic Acid," U.S. Patent #2,927,130, 1960.

4. Ramsden, M. John and Julia A. Phillips, "Factors Influencing the Kinetics of the Alkaline Depolymerization of Poly(ethylene terephthalate), I: The Effect of Solvent," *J. Chem. Tech. Biotechnology*, **67**, 131-136 (1996).

5. Personal communication with Heyl & Patterson, maker of the calciner.

Equipment Descriptions

SR-101	PET Bale Breaker
HP-101 A/B	PET Hopper
SF-101	PET Screw Conveyor
R-101	PET Reactor
SR-102	PET Shredder
HP-102 A/B	K_2TPA Hopper
SF-102	K_2TPA Screw Conveyor
V-101	Dipotassium Terephthalate Reaction Vessel
M-101	Ferrous/Nonferrous Metal Remover
E-101	EG/Water Condenser
F-101	Unreacted PET Filter
SR-103	PET Granulator
V-102	Water/EG Flash
SR-104	PET Pulverizer
T-101	Ethylene Glycol Column

E-102	Water Condenser
E-103	EG Reboiler
P-101 A/B	Water Reflux Pump
V-103	Water Reflux Drum
R-201	Dipotassium Terephthalate Reaction Vessel
R-202	Monopotassium Terephthalate Reaction Vessel
F-201	Monopotassium Terephthalate Vessel
F-202	TPA Filter
R-203	$KHCO_3$ Reaction Vessel
P-201 A/B	System Pump
E-201	Preheater
P-202 A/B	System
R-204	K_2CO_3 Reaction Vessel
F-203	$CaCO_3$ Filter
R-205	$CaCO_3$ Calciner
R-206	Slaker
E-301	First Effect Evaporator
V-301	First Effect Flash Vessel
P-301	Second Effect Pump
E-302	Second Effect Evaporator
V-302	Second Effect Flash Vessel
P-302	Third Effect Pump
E-303	Third Effect Evaporator

V-303	Third Effect Flash Vessel
P-303	Fourth Effect Pump
E-304	Fourth Effect Evaporator
V-304	Fourth Effect Flash Vessel
P-304	Fifth Effect Pump
E-305	Fifth Effect Evaporator
V-305	Fifth Effect Flash Vessel
E-306	KOH Cooler
E-307	H_2O Cooler

Stream Table for PET Degradation with KOH

	1	2	3	4	5
Temperature (°C)	25.00	25.00	180.00	134.00	45.00
Pressure (bar)	1.01	1.01	1.01	1.01	1.01
Vapor Fraction	Solid	Solid	0	Solid	Solid
Total Mass Flow (kg/hr)	1,124.67	1,124.67	1,025.91	1,389.67	6,949.76
Total Molar Flow (kmol/hr)	5.87	5.87	32.69	5.74	314.23
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	5.74	5.74	--	--	--
Terephthalic Acid (TPA)	--	--	--	--	--
Potassium Hydroxide (KOH)	--	--	11.47	--	--
Ethylene Glycol	--	--	--	--	0.02
Dipotassium Terephthalate	--	--	--	5.74	5.74
Monopotassium Terephthalate	--	--	--	--	--
Potassium Bicarbonate	--	--	--	--	--
Potassium Carbonate	--	--	--	--	--
Carbon Dioxide	--	--	--	--	--
Calcium Carbonate	--	--	--	--	--
Calcium Hydroxide	--	--	--	--	--
Calcium Oxide	0.14	0.14	--	--	--
Water	--	--	21.22	--	308.47

	6	7	8	9	10
Temperature (°C)	45.00	45.00	180.00	35.00	35.00
Pressure (bar)	1.01	1.01	1.5	1.4	1.4
Vapor Fraction	Solid	0	1	1	0
Total Mass Flow (kg/hr)	69.40	7,436.22	3,113.46	2,476.18	637.29
Total Molar Flow (kmol/hr)	3.14	341.94	108.69	87.33	21.36
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	--	--	--	--	--
Terephthalic Acid (TPA)	--	--	--	--	--
Potassium Hydroxide (KOH)	--	--	--	--	--
Ethylene Glycol	--	0.02	5.74	0.01	5.73
Dipotassium Terephthalate	0.06	5.68	--	--	--
Monopotassium Terephthalate	--	--	--	--	--
Potassium Bicarbonate	--	--	--	--	--
Potassium Carbonate	--	--	--	--	--
Carbon Dioxide	--	--	0.83	0.83	--
Calcium Carbonate	--	--	--	--	--
Calcium Hydroxide	--	--	--	--	--
Calcium Oxide	--	--	80.21	80.21	--
Water	3.09	336.23	21.91	6.28	15.63

Stream Table for PET Degradation with KOH (cont.)

	11	12	13	14	15
Temperature (°C)	205.12	104.83	104.83	45.00	45.00
Pressure (bar)	1.30	1.20	1.20	2.01	1.51
Vapor Fraction	0	0	0	0	Solid
Total Mass Flow (kg/hr)	354.26	310.52	283.03	31,836.73	2,594.36
Total Molar Flow (kmol/hr)	5.71	17.17	15.65	1,598.79	27.23
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	--	--	--	--	--
Terephthalic Acid (TPA)	--	--	--	--	--
Potassium Hydroxide (KOH)	--	--	--	--	--
Ethylene Glycol	5.71	0.03	0.02	--	--
Dipotassium Terephthalate	--	--	--	--	--
Monopotassium Terephthalate	--	--	--	11.24	11.24
Potassium Bicarbonate	--	--	--	11.36	0.11
Potassium Carbonate	--	--	--	--	--
Carbon Dioxide	--	--	--	--	--
Calcium Carbonate	--	--	--	--	--
Calcium Hydroxide	--	--	--	--	--
Calcium Oxide	--	--	--	--	--
Water	0.002	17.15	15.63	1,576.19	15.87

	16	17	18	19	20
Temperature (°C)	45.00	45.00	45.00	45.00	110.00
Pressure (bar)	1.51	1.01	1.01	1.31	1.90
Vapor Fraction	0	solid	0	0	1
Total Mass Flow (kg/hr)	22,980.16	1,155.26	23,892.17	32,083.91	247.38
Total Molar Flow (kmol/hr)	1,158.57	17.21	1,256.09	1,729.20	5.62
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	--	--	--	--	--
Terephthalic Acid (TPA)	5.62	5.62	--	--	--
Potassium Hydroxide (KOH)	--	--	--	--	--
Ethylene Glycol	--	--	--	0.02	--
Dipotassium Terephthalate	5.62	0.06	5.57	--	--
Monopotassium Terephthalate	--	--	--	--	--
Potassium Bicarbonate	0.11	0.001	0.11	11.24	--
Potassium Carbonate	--	--	--	--	--
Carbon Dioxide	--	--	--	--	5.62
Calcium Carbonate	--	--	--	--	--
Calcium Hydroxide	--	--	--	--	--
Calcium Oxide	--	--	--	--	--
Water	1,147.22	11.53	1,250.41	1,717.93	--

Stream Table for PET Degradation with KOH (cont.)

	21	22	23	24	25
Temperature (°C)	110.00	110.00	95.00	95.00	95.00
Pressure (bar)	1.90	1.90	1.40	1.40	1.30
Vapor Fraction	0	0	Solid	0	Solid
Total Mass Flow (kg/hr)	31,836.64	32,267.79	879.78	34,494.65	321.74
Total Molar Flow (kmol/hr)	1,729.20	1,741.00	22.98	1,890.43	5.74
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	--	--	--	--	--
Terephthalic Acid (TPA)	--	--	--	--	--
Potassium Hydroxide (KOH)	--	11.36	0.11	11.24	0.11
Ethylene Glycol	0.02	0.02	--	0.02	--
Dipotassium Terephthalate	--	--	--	--	--
Monopotassium Terephthalate	--	--	--	--	--
Potassium Bicarbonate	--	--	--	--	--
Potassium Carbonate	5.62	--	--	--	--
Carbon Dioxide	--	--	--	--	--
Calcium Carbonate	--	5.62	5.62	--	--
Calcium Hydroxide	--	--	--	--	--
Calcium Oxide	--	--	--	--	5.62
Water	1,723.55	1,724.00	17.24	1,879.16	--

	26	27	28	29	30
Temperature (°C)	95.00	50.00	95.00	95.00	105.00
Pressure (bar)	1.30	1.30	1.30	1.30	1.30
Vapor Fraction	0.70	Slurry	1	0	1
Total Mass Flow (kg/hr)	558.05	429.86	261.48	296.52	508.82
Total Molar Flow (kmol/hr)	22.86	6.11	6.21	16.65	12.03
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	--	--	--	--	--
Terephthalic Acid (TPA)	--	--	--	--	--
Potassium Hydroxide (KOH)	--	0.11	--	--	--
Ethylene Glycol	--	--	--	--	--
Dipotassium Terephthalate	--	--	--	--	--
Monopotassium Terephthalate	--	--	--	--	--
Potassium Bicarbonate	--	--	--	--	--
Potassium Carbonate	--	--	--	--	--
Carbon Dioxide	5.62	--	5.62	--	11.24
Calcium Carbonate	--	--	--	--	--
Calcium Hydroxide	--	5.62	--	--	--
Calcium Oxide	--	--	--	--	--
Water	17.24	0.38	0.59	16.65	0.79

Stream Table for PET Degradation with KOH (cont.)

	31	32	33	34	35
Temperature (°C)	100.27	100.27	134.21	134.21	152.79
Pressure (bar)	1.01	1.01	3.01	3.01	5.01
Vapor Fraction	1	0	1	0	1
Total Mass Flow (kg/hr)	4,549.65	29,943.63	5,093.97	24,857.08	7,221.89
Total Molar Flow (kmol/hr)	252.48	1,637.93	282.68	1,355.65	400.77
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	--	--	--	--	--
Terephthalic Acid (TPA)	--	--	--	--	--
Potassium Hydroxide (KOH)	--	11.24	--	11.24	--
Ethylene Glycol	--	--	--	--	--
Dipotassium Terephthalate	--	--	--	--	--
Monopotassium Terephthalate	--	--	--	--	--
Potassium Bicarbonate	--	--	--	--	--
Potassium Carbonate	--	--	--	--	--
Carbon Dioxide	--	--	--	--	--
Calcium Carbonate	--	--	--	--	--
Calcium Hydroxide	--	--	--	--	--
Calcium Oxide	--	--	--	--	--
Water	252.48	1,626.68	282.68	1,344.41	400.77

	36	37	38	39	40
Temperature (°C)	152.79	166.85	166.85	248.46	248.46
Pressure (bar)	5.01	7.01	7.01	9.01	9.01
Vapor Fraction	0	1	0	1	0
Total Mass Flow (kg/hr)	17,635.18	8,285.97	9,349.21	8,343.80	1,005.52
Total Molar Flow (kmol/hr)	954.88	459.82	495.06	463.03	32.04
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	--	--	--	--	--
Terephthalic Acid (TPA)	--	--	--	--	--
Potassium Hydroxide (KOH)	11.24	--	11.24	--	11.24
Ethylene Glycol	--	--	--	--	--
Dipotassium Terephthalate	--	--	--	--	--
Monopotassium Terephthalate	--	--	--	--	--
Potassium Bicarbonate	--	--	--	--	--
Potassium Carbonate	--	--	--	--	--
Carbon Dioxide	--	--	--	--	--
Calcium Carbonate	--	--	--	--	--
Calcium Hydroxide	--	--	--	--	--
Calcium Oxide	--	--	--	--	--
Water	943.64	459.82	483.82	463.03	20.80

Stream Table for PET Degradation with KOH (cont.)

	41	42	43	44	45
Temperature (°C)	99.91	99.91	99.91	99.91	50.00
Pressure (bar)	1.01	1.01	1.01	1.01	1.01
Vapor Fraction	0.56	0.33	0.26	0.23	0
Total Mass Flow (kg/hr)	9,636.21	16,858.11	25,144.08	33,487.77	5,277.07
Total Molar Flow (kmol/hr)	534.75	935.52	1,395.34	1,858.37	292.85
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	--	--	--	--	--
Terephthalic Acid (TPA)	--	--	--	--	--
Potassium Hydroxide (KOH)	--	--	--	--	--
Ethylene Glycol	--	--	--	--	--
Dipotassium Terephthalate	--	--	--	--	--
Monopotassium Terephthalate	--	--	--	--	--
Potassium Bicarbonate	--	--	--	--	--
Potassium Carbonate	--	--	--	--	--
Carbon Dioxide	--	--	--	--	--
Calcium Carbonate	--	--	--	--	--
Calcium Hydroxide	--	--	--	--	--
Calcium Oxide	--	--	--	--	--
Water	534.75	935.52	1,395.34	1,858.37	292.85

	46	47	48	49	50
Temperature (°C)	50.00	50.00	50.00	50.00	50.00
Pressure (bar)	1.01	1.01	1.01	1.01	1.01
Vapor Fraction	0	0	0	0	0
Total Mass Flow (kg/hr)	19,640.63	8,570.10	20,494.90	108.12	20,386.78
Total Molar Flow (kmol/hr)	1,089.94	475.59	1,137.34	6.00	1,131.34
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	--	--	--	--	--
Terephthalic Acid (TPA)	--	--	--	--	--
Potassium Hydroxide (KOH)	--	--	--	--	--
Ethylene Glycol	--	--	--	--	--
Dipotassium Terephthalate	--	--	--	--	--
Monopotassium Terephthalate	--	--	--	--	--
Potassium Bicarbonate	--	--	--	--	--
Potassium Carbonate	--	--	--	--	--
Carbon Dioxide	--	--	--	--	--
Calcium Carbonate	--	--	--	--	--
Calcium Hydroxide	--	--	--	--	--
Calcium Oxide	--	--	--	--	--
Water	1,089.94	475.59	1,137.34	6.00	1,131.34

Stream Table for PET Degradation with KOH (cont.)

	51	52	53	54	55
Temperature (°C)	50.00	50.00	50.00	50.00	50.00
Pressure (bar)	1.01	1.01	1.01	1.01	1.01
Vapor Fraction	0	0	0	0	0
Total Mass Flow (kg/hr)	555.86	8,014.23	2,840.29	2,067.29	3,106.65
Total Molar Flow (kmol/hr)	30.85	444.74	157.62	114.72	172.40
Component Molar Flowrate (kmol/hr)					
Polyethylene Terephthalate (PET)	--	--	--	--	--
Terephthalic Acid (TPA)	--	--	--	--	--
Potassium Hydroxide (KOH)	--	--	--	--	--
Ethylene Glycol	--	--	--	--	--
Dipotassium Terephthalate	--	--	--	--	--
Monopotassium Terephthalate	--	--	--	--	--
Potassium Bicarbonate	--	--	--	--	--
Potassium Carbonate	--	--	--	--	--
Carbon Dioxide	--	--	--	--	--
Calcium Carbonate	--	--	--	--	--
Calcium Hydroxide	--	--	--	--	--
Calcium Oxide	--	--	--	--	--
Water	30.85	444.74	157.62	114.72	172.40

	56	57	58	59
Temperature (°C)	25.00	25.00	25.0	25.00
Pressure (bar)	1.01	1.01	1.01	1.01
Vapor Fraction	0	0	1	1
Total Mass Flow (kg/hr)	20.40	554.30	0.09	2,353.00
Total Molar Flow (kmol/hr)	0.65	30.76	0.002	81.14
Component Molar Flowrate (kmol/hr)				
Polyethylene Terephthalate (PET)	--	--	--	--
Terephthalic Acid (TPA)	--	--	--	--
Potassium Hydroxide (KOH)	0.23	--	--	--
Ethylene Glycol	--	--	--	--
Dipotassium Terephthalate	--	--	--	--
Monopotassium Terephthalate	--	--	--	--
Potassium Bicarbonate	--	--	--	--
Potassium Carbonate	--	--	--	--
Carbon Dioxide	--	--	0.002	--
Calcium Carbonate	--	--	--	--
Calcium Hydroxide	--	--	--	--
Calcium Oxide	--	--	--	--
Air	--	--	--	81.14
Water	0.42	30.76	--	--

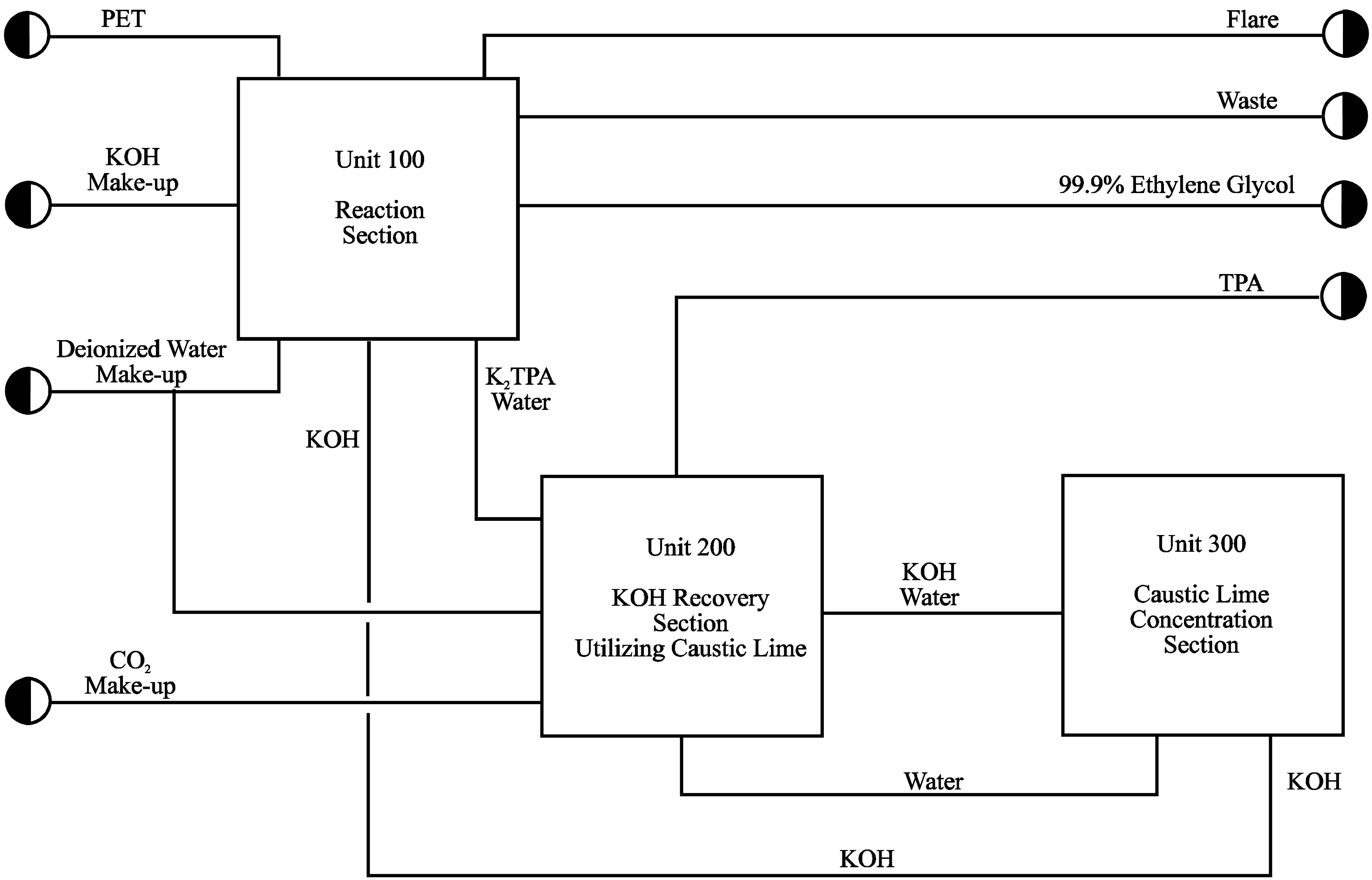

Figure 1: Block Flow Diagram for the Recycling of Polyethylene Terephthalate via Hydrolysis with Caustic Lime

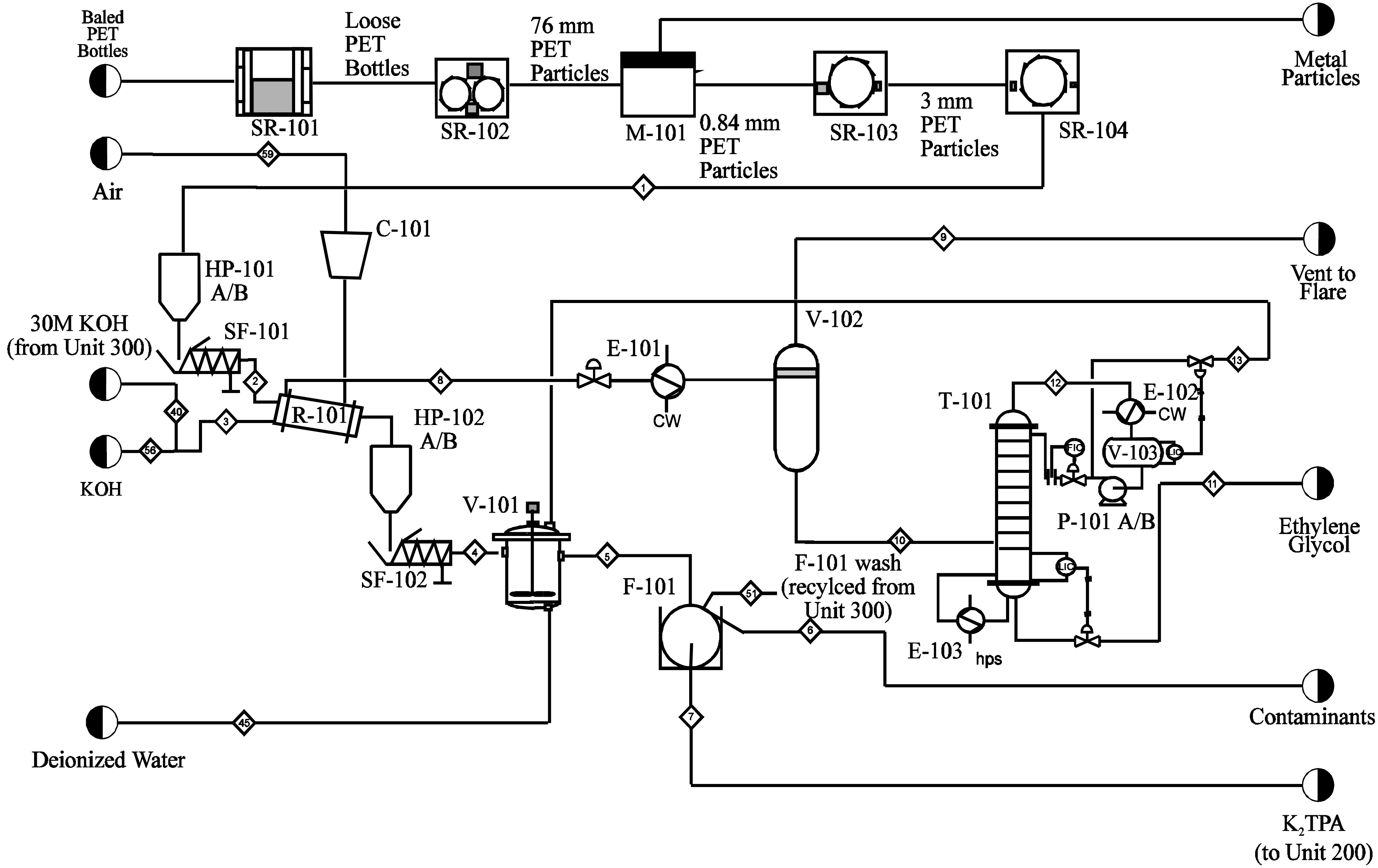

Figure 2: Unit 100 Process Flow Diagram for Production of TPA and Ethylene Glycol from PET and KOH

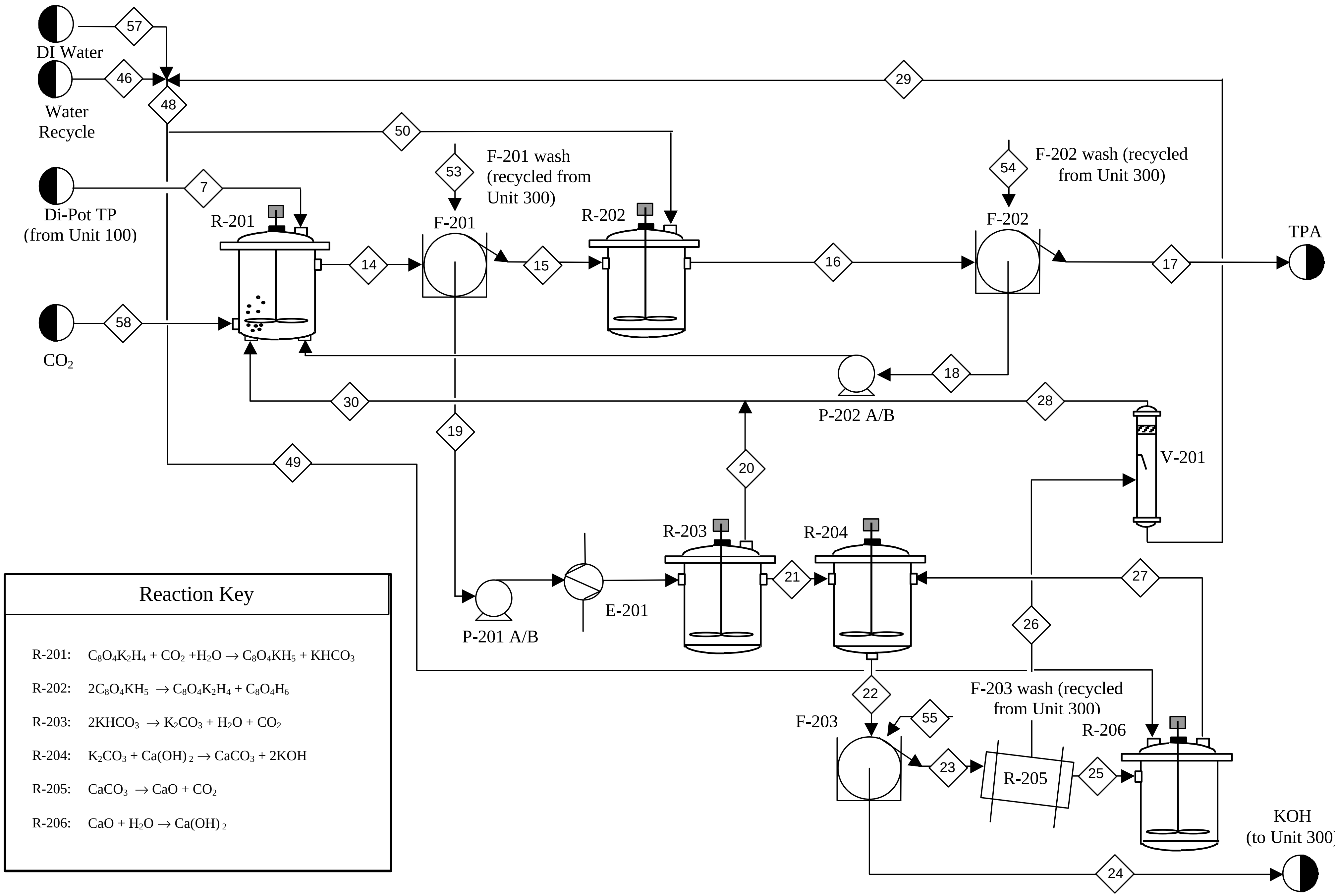

Figure 3: Unit 200 Process Flow Diagram for Production of TPA and Ethylene Glycol from PET and KOH

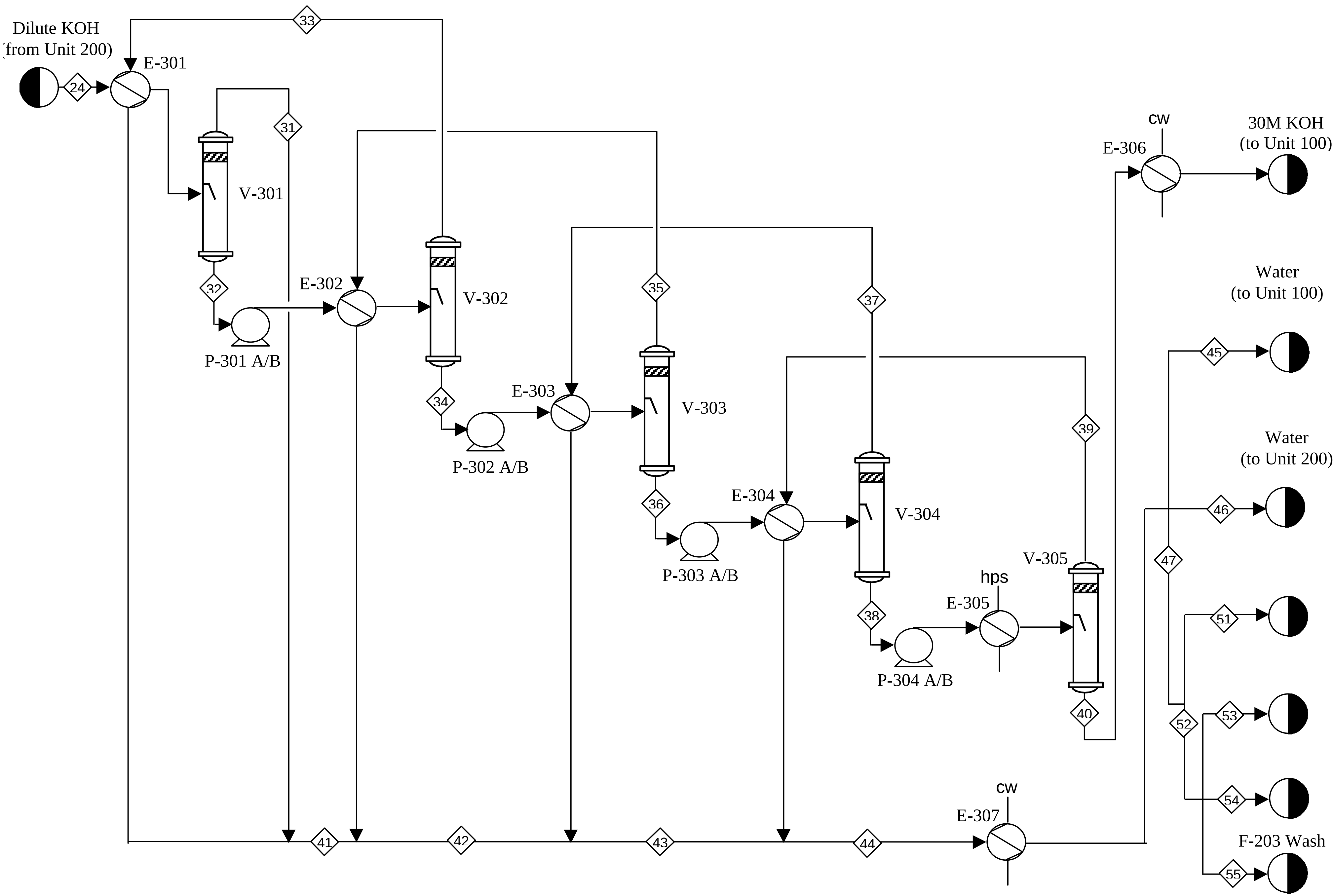

Figure 4: Unit 300 Process Flow Diagram for Production of TPA and Ethylene Glycol from PET and KOH