King Fahd University of Petroleum and Minerals

Two Steps Reactor Catalytic Pyrolysis

Coach. Dr Yasser Adel Almoghathawi

Cluster 1/Team 90

Department (Industrial Engineering) Hadi Aldhaen, Emad Kanfar, Mohammad Alsulaimani

Department (Chemical Engineering) Abdulmajeed sheha, Adel Fallatah

Introduction

The Danger of Plastic Waste

The global plastic waste crisis, marked by an annual production of over 350 million tons, results in approximately 8 million tons of plastic entering the seas annually, causing severe harm to marine life and ecosystems. The persistent nature of plastics, taking hundreds or thousands of years to decompose, poses environmental and health risks, impacting both wildlife and human populations. To effectively address this crisis and secure a sustainable future, a global shift in attitudes, infrastructure, and consumer behavior is crucial, complementing ongoing efforts such as the development of biodegradable polymers and legislation to reduce single-use plastics.

Plastic Pyrolysis

Plastic pyrolysis offers a transformative solution to the plastic waste problem by converting it into valuable products through a process involving shredding, pyrolysis, and further refining. The resulting pyrolysis oil can be processed into diesel fuel, gasoline, or other products, contributing to a circular life cycle for materials and reducing pollution. Despite challenges like high initial investment costs, the market for pyrolysis oil is expected to grow due to increasing environmental consciousness and evolving waste management regulations.

Problem Statement

Helping the environment to reduce the Plastic pollution using the pyrolysis process by recycling the plastic waste to useful fuels

Constraints

Technological Challenges:
- High temperatures
- Advanced technologies and expertise
- Optimizing pyrolysis conditions

Feedstock Variability:
- Managing feedstock variability
- Ensuring consistent product quality.

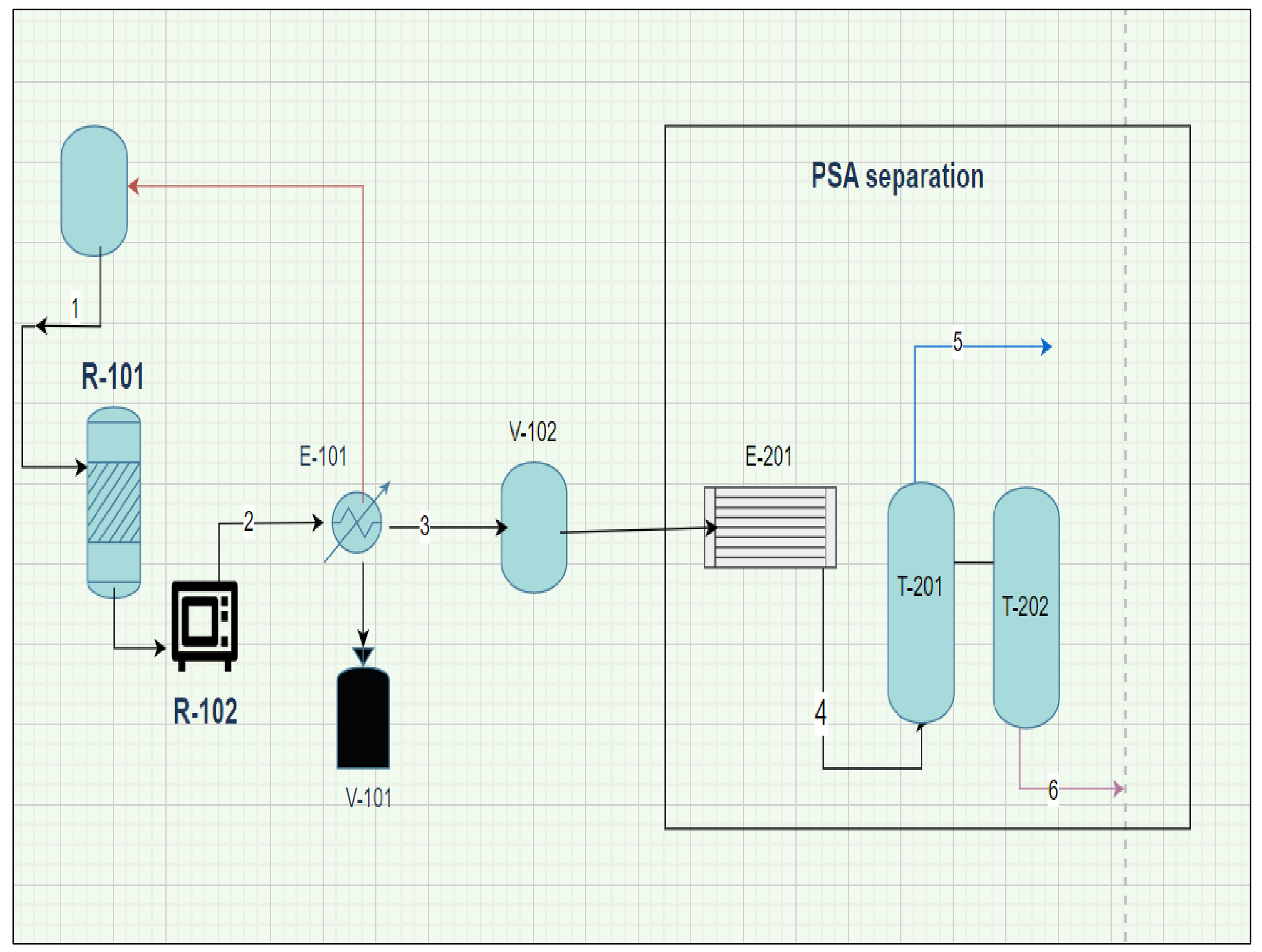
Economic Viability:
- The initial investment required for setting up pyrolysis plants,
- Operational expenses
- Market demand for the resulting products

Target Specifications

- **Heat= 100-115 kwh**
- **Heat Consumption cost = 18 - 21 $/g**
- **Recovery = 88%-92%**
- **Production time = 55-70 min**
- **Mean time to repair = 6-12 months**
- **Pressure = 0.4-1 atm**
- **Average Product price = 12 - 18 $/g**

Sekar, M., Ponnusamy, V. K., Pugazhendhi, A., Nižetić, S., & Praveenkumar, T. R. (2022). Production and utilization of pyrolysis oil from solidplastic wastes: A review on pyrolysis process and influence of reactors design. *Journal of environmental management*, *302*, 114046.

Prototype Design



		|	m(ZSM-5) = 10mf			
		|				
X(PP)	0.5	|				
X(HDPE)	0.5	PROCESS				
mf	kg			mf	kg	
---------------------->				------------------------->		
				X(Gas)	0.32	
				X(liquid)	0.41	
				X(solid)	0.27	

$$Q_m = m_{pp}Cp_{pp}(T_f - T_i) + m_{HDPE}Cp_{HDPE}(T_f - T_i) \quad (1)$$

Qm: Heat transfer rate of microwave (W).

Mpp: Mass flowrate of polypropylene kg/s.

CPpp: Specific heat capacity of polypropylene J/kg.C

M(HDPE): Mass flowrate of high-density polyethylene kg/s

CP(HDPE): Specific heat capacity of high-density polyethylene J/kg.C

Tf: Final temperature of plastic which has been set as 500C.

Ti: initial temperature of plastic coming from the furnace 250C.

$$Q_m = Q_c = m_w Cp_w (T_{w,out} - T_{w,in}) \quad (2)$$

$$\frac{1}{U} = \frac{1}{h_{plastic}} + \frac{1}{h_{water}} \quad (3)$$

$$Q_C = UA_S \Delta T_{lm} \quad (4)$$

$$\Delta T_{lm} = \frac{(T_{oil.in} - T_{w,out}) - (T_{oil,out} - T_{w,in})}{\ln\left(\frac{(T_{oil.in} - T_{w,out})}{(T_{oil,out} - T_{w,in})}\right)} \quad (5)$$

$$Q_w = m_w Cp_w (T_{w,out} - T_{w,in}) \quad (6)$$

$$Q_w = Q_{pre-heater} = m_{plastic} Cp_{plastic} (T_{w,out} - T_{plastic}) \quad (7)$$

$$Q = Pt \quad (8)$$

$$(Heat\ transfer\ rate\ (kW)) \times (time\ of\ residency\ (h)) \quad (9)$$

$$energy\ consumption\ (kWh) \times energy\ price\ (SAR/kWh) \quad (10)$$

Testing / Validation

Mathematical Model

Decision variable :
- Hj: the actual heat supplied in system j
- Mp: mass of plastic in kg
- Mc: mass of catalyst in kg
- Mw mass of water in kg/s
- Tij: initial temperature in system j in c
- Tfj: final temperature in system j in c
- Tco: water temperature out the condenser in c
- Tci: water temperature inlet the condenser in c
- Tho: temperature of oil exits the condenser in c
- Thi: temperature of oil entering the condenser In c

Parameter:
- Cp: specific heat capacity for plastic =1.8
- Cpc: specific heat capacity for coolant = 1
- Cph: specific heat capacity for oil =2.8

Objective function:
- Max (Q1/1400) × (Q2/1550) × (Q3/700)

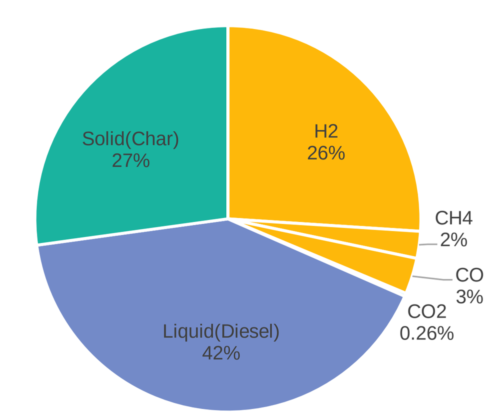
H1
- Subject to :
  - H1 = Mp ×2.2×(Tf1-Ti1)
  - Mp=Mf
  - Tf1=Ti2
  - 0≤H1≤1400
  - 0≤mp≤3
  - 20≤Ti1≤25
  - 180≤Tf1≤250

H2
- Subject to :
  - H2=Mf×2.2×(Tf2-ti2) + mc×2.2×(Tf2-Ti2)
  - Tf1=Ti2
  - Mm= Mf+Mc
  - 0≤H2≤1550
  - 0.005≤mc≤0.01
  - 180≤Ti2≤250
  - 450≤Tf2≤500

H3
- Subject to :
  - H3=Cc×(Tco-Tci) = Ch×(Thi-Tho)
  - Cc=2.2×Mw
  - Ch=2.2×Mm
  - 0≤H3≤700
  - 0≤mw≤2
  - 0≤Tco≤94
  - 0≤Tci≤10
  - 0≤Tho≤182
  - 0≤Thi≤500

"We built out the mathematical model aiming to increase the total efficiency of our process through increasing the efficiency of the furnace, the microwave and the condenser. Our total efficiency we could get from what we have was 0.591 due to the limitations in our budget "

Total % yield



Sensitivity Analysis

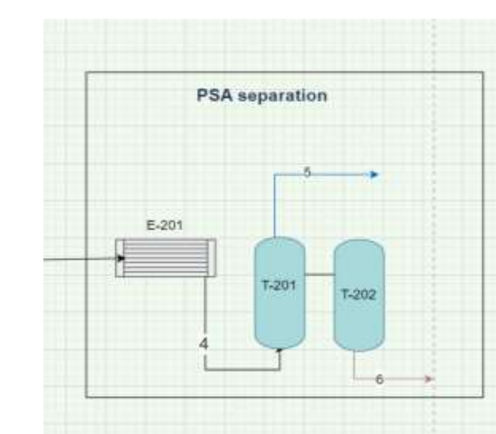
Inputs		TF	Efficiency	TI	Efficiency	MP	Efficiency	H1	Efficiency
Mass of Plastic (MP)	2.89 kg	180	53.5%	20	59.3%	1	7.1%	700	29.5%
Final Temperature for The Furnace (TF)	240.65 c	190	55.0%	21	59.0%	2	28.3%	800	33.8%
Initial Temperature for The Furnace (TI)	20.67 c	200	56.2%	22	58.7%	3	63.5%	900	38.0%
Energy for The Furnace (H1)	1400 W	210	57.3%	23	58.5%			1000	42.2%
Mass in The Furnace (MF)	2.89 kg	220	58.1%	24	58.2%			1100	46.4%
Mass of The Catalyst (MC)	0.009 kg	230	58.7%	25	57.9%			1200	50.6%
Final Temperature of The Microwave (TF2)	483.48 c	240	59.1%					1300	54.9%
Energy for The Microwave (H2)	1550 W	250	59.2%					1400	59.1%
		TF2	Efficiency	MC	Efficiency	MF	Efficiency	H2	Efficiency
		450	50.9%	0.005	59.0%	1	20.5%	1050	40.0%
Output		460	53.4%	0.006	59.0%	2	40.9%	1150	43.8%
Maximum Total Efficiency for The Process	59.1%	470	55.8%	0.007	59.1%	3	61.3%	1250	47.6%
Formulas		480	58.2%	0.008	59.1%			1350	51.5%
H1=MP*2.2*(TF-TI)		490	60.7%	0.009	59.1%			1450	55.3%
H2=MF*2.2*(TF2-TF)+MC*2.2*(TF2-TF)		500	63.1%	0.01	59.1%			1550	59.1%
Objective Function: MAX=(H1/1400)*(H2/1550)*(H3/700)									
Note: since H3=C*(TCO-TCI), also H3=CH*(THI-THO) as showed in the model									
H3 will have only one optimal inside ranges of its variables which equal to 413.6. So, we will consider H3 as constant									

For all parameters regarding the efficiency with the increasing for each parameter the efficiency will increase until it exceed the available range except in TI where the efficiency will decrease with its increasing. Also, since H3=C*(TCO-TCI), also H3=CH*(THI-THO) as shown in the model, H3 will have only one optimal inside ranges of its variables which equal to 413.6. So, we will consider H3 as constant.

Separation

$$Purity = 97.28 + 1.29\times10^{-3}\times t_{AD} + 0.015\times t_{PE} + 9.23\times r_{P/F} + 0.063\times(t_{AD}\times r_{P/F}) - 0.116\times(t_{PE}\times r_{P/F}) - 2.79\times10^{-4}\times(t_{PE})^2 - 80.94\times(r_{P/F})^2$$

$$Recovery = 49.97 + 0.2004\times t_{AD} + 1.16\times t_{PE} - 240.64\times r_{P/F} - 1.21\times(t_{PE}\times r_{P/F}) - 2.68\times10^{-4}\times(t_{AD})^2 - 0.01\times(t_{PE})^2 + 147.43\times(r_{P/F})^2$$



The results are Purity = 98.4% , Recovery = 85.7%

Conclusion

Plastic pyrolysis is a comprehensive solution to plastic waste, delivering economic, social, and environmental benefits. It creates jobs, generates revenue by converting plastic into valuable byproducts, and decreases reliance on fossil fuels. Socially, it improves waste management, lowers health and environmental risks, and promotes clean energy like hydrogen. Environmentally, it cuts greenhouse gas emissions, offers an alternative to fossil fuels, and combats water and land pollution. This process aligns with a circular economy, blending economic growth with environmental and social well-being, emphasizing the need for careful planning and efficient operation for success.