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''Ways forward to promote resources equity:
The role of cleaner production and circular economy as moderator.
Action or Reaction to Save the Planet''

INTERNATIONAL WORKSHOP ON ADVANCES IN CLEANER PRODUCTION

Oral Presentation

A STUDY OF MIXED PLASTIC WASTE PYROLYSIS UNDER LOW-PRESSURE

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Background

- South Africa produces in excess of 500 000 tons p.a. of unrecyclable waste plastic (DST, 2014)

- Generally, plastics cannot be easily recycled if they are constituted by **uncharacterized mixtures of different plastic types** or plastic-paper/metal combinations

- In this work we are developing and analyzing a catalytic pyrolysis technology that focuses on disposing of uncharacterized mixtures of different plastic types that is less impactful on landfill

Catalytic pyrolysis

•Pyrolysis is a thermal degradation process conducted in the absence of oxygen.

•Catalytic pyrolysis preferred over thermal (non-catalytic) pyrolysis as it produces a higher quality fuel oil at a lower temperature (from about 423 K), has faster reaction times and produces less volatile organic pollutants suggesting a less environmentally impactful process (Oh et al., 2018)

•Limitations include the energy cost to attain the pyrolysis temperature, catalyst cost and low catalyst reuse period depending on the reactor configuration.

•Optimization of catalytic pyrolysis involves selection of suitable inexpensive catalysts, catalyst regeneration, process variables and reactor type, condition and configuration optimization.

Literature

- Multiple reactor types have been reported on in literature at laboratory-scale and pilot-scale operations for the pyrolysis of waste plastic.

- The technology proposed in this work employs a unique lower pressure operation with a low-cost catalyst in a fluidized bed reactor (FBR) under vacuum.

- FBRs for catalytic cracking of plastic has been reported in the literature on the laboratory scale (0.42 kg/hr plastic pellets with reactor dimensions of 300 mm x 80mm ID) (Garforth et al., 1998; Lin et al., 2004; Lin and Yen, 2005; Liu et al., 1999; Marcilla et al., 2007; Mastral et al., 2001, 2006; Sharratt et al., 1997; Williams, 1998; Yan et al., 2005). However, research into the pyrolysis of mixed plastic waste using catalyst is limited.

- Advantages of FBR lies in the mixing which provides large surface area for the reaction to take place on the catalyst, higher efficiency of heat and mass transfer, high yield of pyrolysis oil (Gholizadeh et al., 2020), low capital and maintenance costs, and external heating makes the reactor body easier to clean and load (Al-Salem et al., 2017)

Methodology

- There are three parts/phases to the work presented. Phase 1: laboratory-scale vacuum pyrolysis experiments in a semi-batch reactor conducted for mixed plastic waste to perform catalyst screening and process temperature and pressure optimization.
- The permutations considered for optimization include:
  - Catalyst (none, zeolite, zinc oxide)
  - Temperatures in the range of 450-821 K
  - Pressures between 30 kPa vacuum to 101 kPa absolute
- Pyrolysis products characterized by Gas Chromatography–Mass Spectrometry (GCMS) analysis.
- Phase 2: A continuous pilot unit has been constructed and commissioned, with experimental conditions and design informed from the first phase. A series of experiments is ongoing to determine the operational limitations of the unit, char handling, emissions, product collection and testing. This will be presented in detail in future work.
- Phase 3: a techno-economic analysis of a 100 $kg.hr^{-1}$ to-scale fluidized bed vacuum reactor was designed using simulation software (Aspen Plus ®) to determine if the proposed technology is cost-effective.

Experimental setup

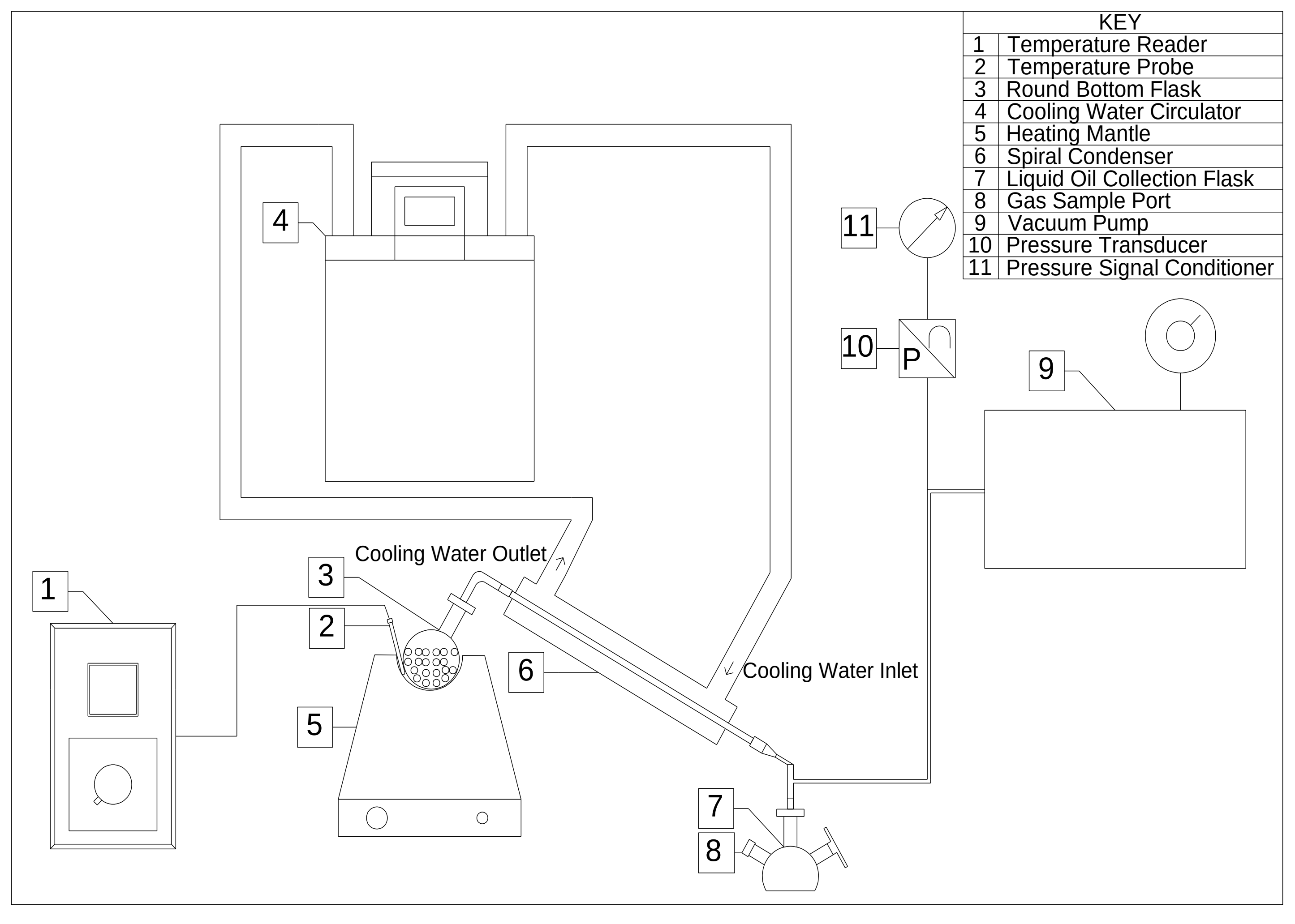

Figure 1: Experimental setup for lab-scale semi-batch pyrolysis measurements.

Product yields from pure plastic pyrolysis

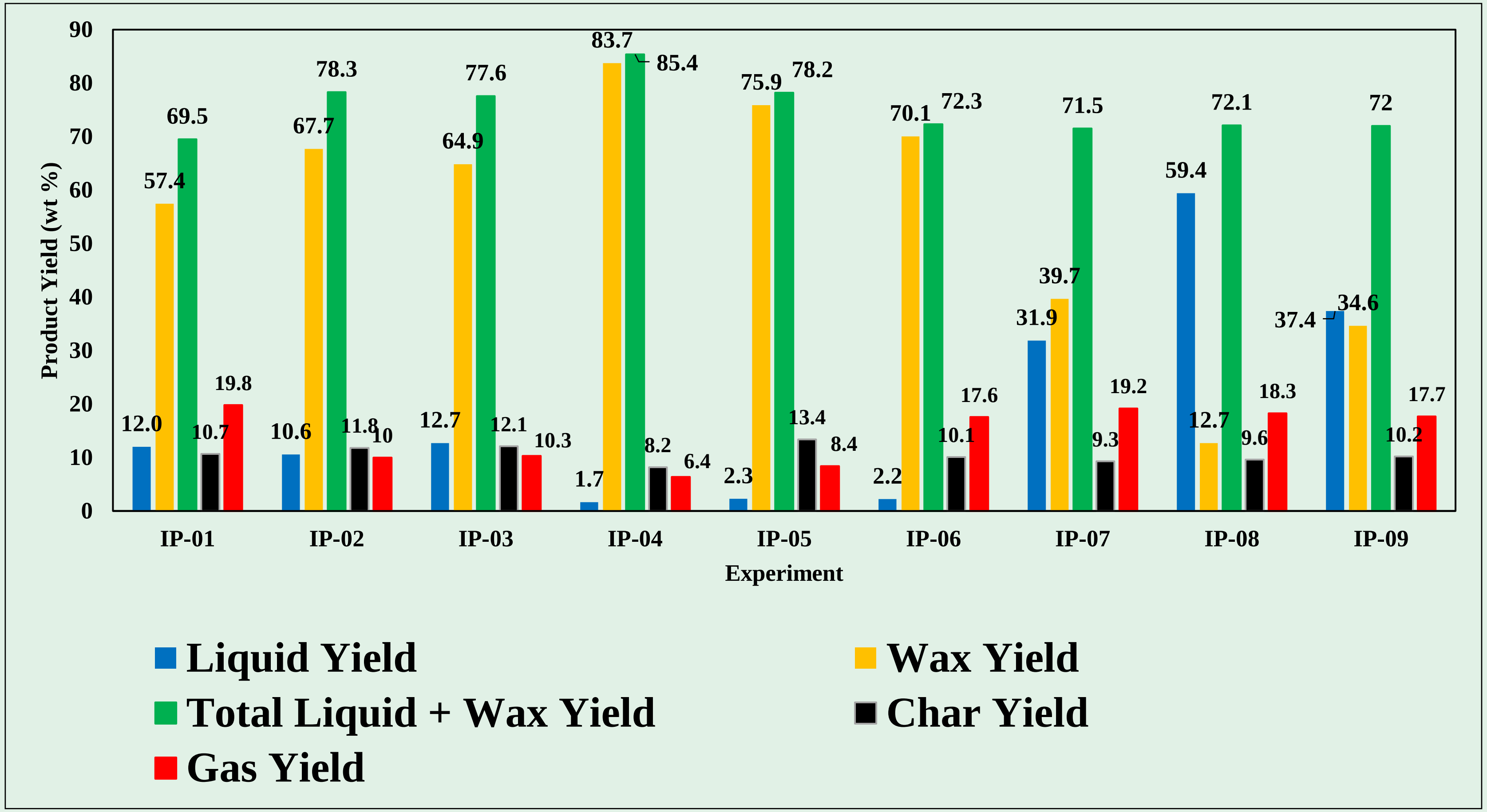

Figure 3: Comparison of low-density liquid, wax, total liquid + wax product, char and gas yields for uncatalyzed and catalyzed plastic pyrolysis experiments using feedstock of LDPE, HDPE, and PP pellets.

Product yields from mixed plastic pyrolysis

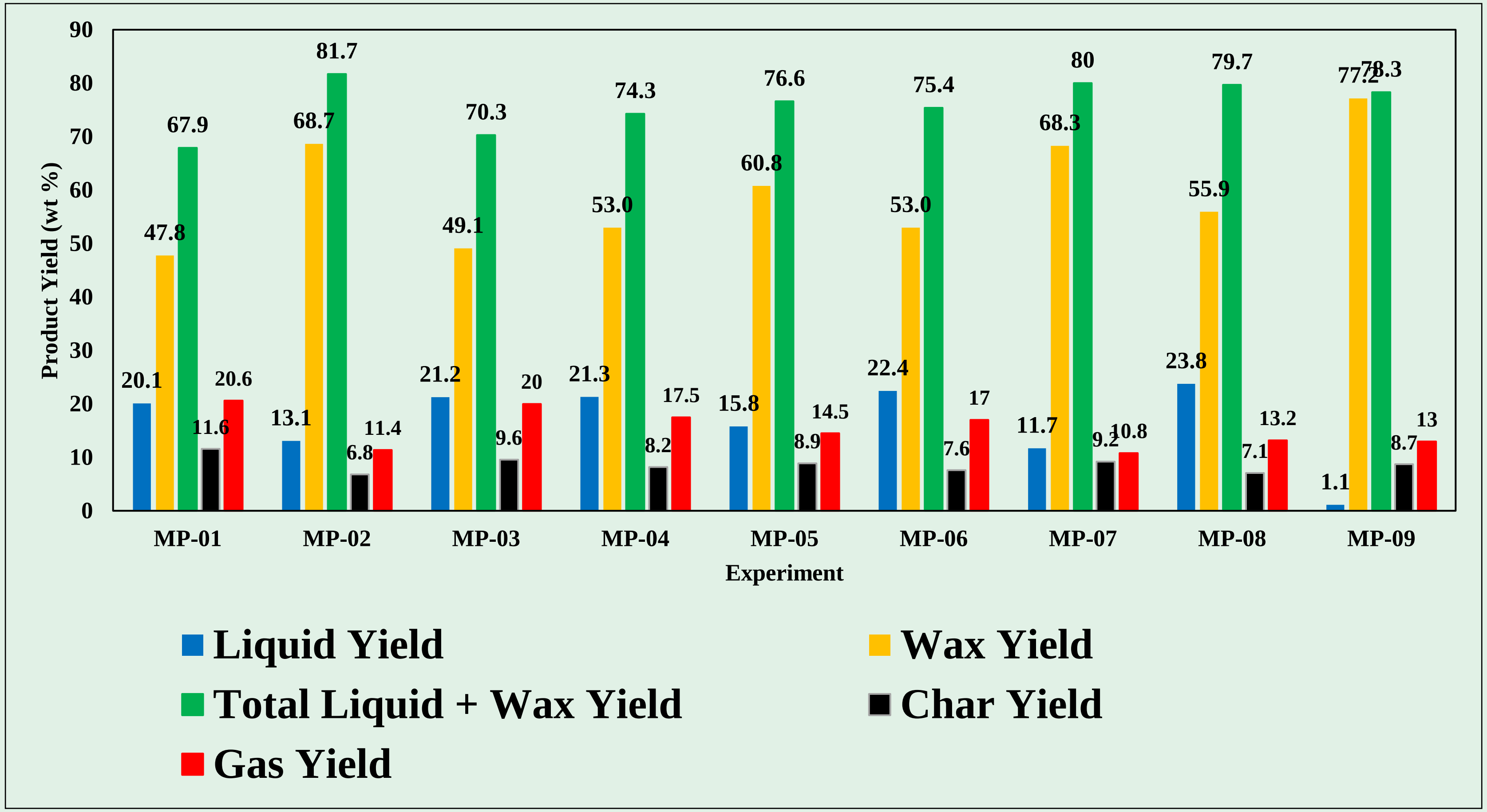

Figure 4: Comparison of low-density liquid, wax, total liquid + wax product, char and gas yields for uncatalyzed and catalyzed plastic pyrolysis experiments using mixed feedstock of LDPE, HDPE, and PP pellets.

Lowest energy and CO_2 usage pyrolysis runs

Table 1. Energy usage for the plastic pyrolysis step for plastic pyrolysis experiments.

Experiment	Mass of liquid + wax (g)	Process Duration (h)	Energy Usage (kWh)				Energy Usage per gram of product (kWh per gram of liquid + wax)-A	Indirect CO_2 emissions per gram of liquid + wax product obtained (kg CO_2 per gram)-B
			Heating (0.3 kW)	Vacuum (0.3 kW)	Cooling (0.3 kW)	Total		
PP with 10:100 catalyst	10.81	2.33	0.70	0.70	0.70	2.10	0.19	0.31
LDPE/HDPE/PP 15/45/40 with 5:100 catalyst	12.32	7.83	2.35	2.35	2.35	7.05	0.57	0.92

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VOC content from emissions

Table 2. VOC content of emissions in the individual plastic pyrolysis experiments.

Plastic	Catalyst to Feed Ratio	VOC Emissions (%)
LDPE	Uncatalyzed	72.3
	5:100	67.2
	10:100	32.6
HDPE	Uncatalyzed	82.1
	5:100	69.2
	10:100	74.0
PP	Uncatalyzed	83.3
	5:100	35.6
	10:100	61.1

Table 3. VOC content of emissions in the mixed plastic pyrolysis experiments.

Plastic Composition (wt %)			Catalyst to Feed Ratio	VOC Emissions (%)
LDPE	HDPE	PP		
15	45	40	Uncatalyzed	66.1
			5:100	79.4
			10:100	89.6
32	35	33	Uncatalyzed	65.8
			5:100	76.5
			10:100	73.2
65	20	15	Uncatalyzed	76.9
			5:100	73.5
			10:100	74.5

Gate-to-gate analysis of lab-scale process

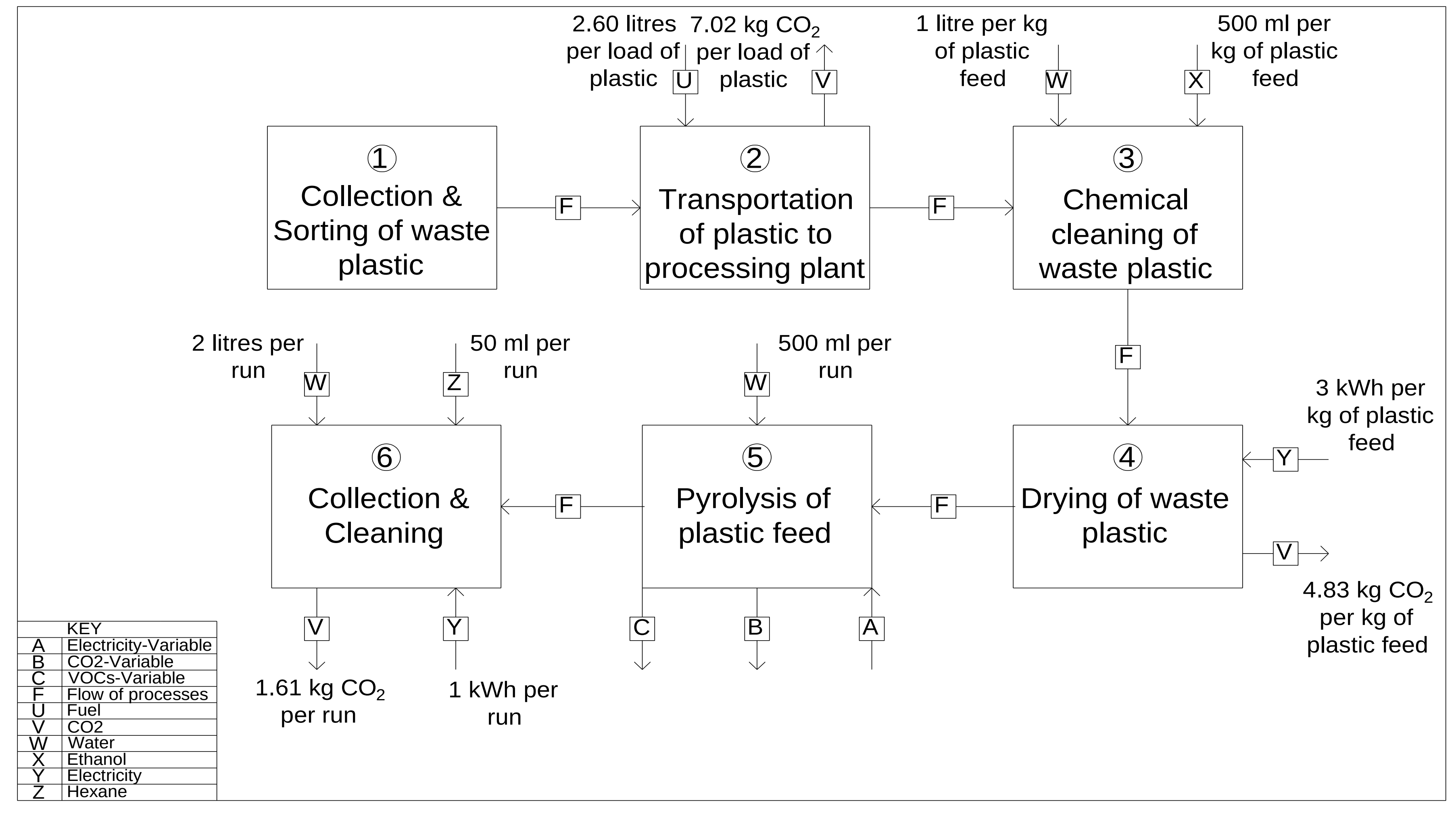

Figure 5. Analysis for the Laboratory-Scale Plastic Pyrolysis Process.

Current work

Model development

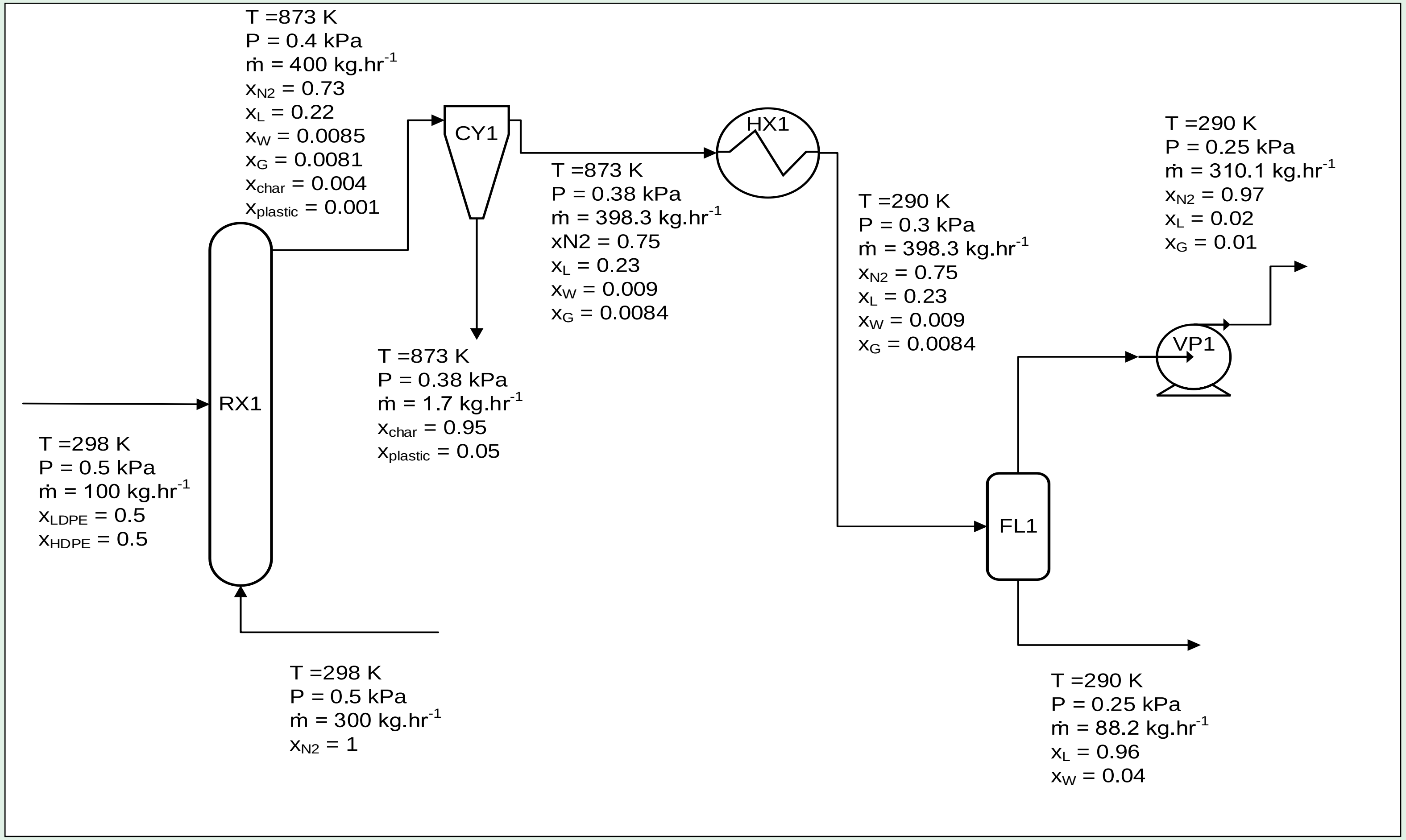

Figure 2: Model of the proposed pyrolysis process with reactor run at 723-873 K.

T- temperature, P- pressure, ṁ- mass flow rate, x_i- mass fraction. RX1- Fluidized bed reaction, CY1- cyclone, HX1- Heat exchanger, FL1- Flash vessel, VP1- vacuum pump.

Conclusions

- HDPE pyrolysis yields 85.4 wt % liquid + wax, while a 5:100 catalyst to feed ratio reduces gaseous yields in mixed HDPE plastic experiments.
- PP pyrolysis (<3 hours) trades liquid + wax yield, process duration, and gas yield, with a catalyst slightly altering the liquid and wax composition.
- Mixed plastic pyrolysis with a 5:100 catalyst to feed ratio resembles pure plastic pyrolysis, enhancing reaction times and liquid + wax yields.
- High LDPE feedstock extends process durations, with the catalyst reducing LDPE pyrolysis time but minimally impacting liquid + wax yields.
- Catalyzed PP reactions yield >98% C12 to C27 components, making high PP plastic valuable for significant liquid + wax yields suitable for fuel blends.
- Mixed plastic pyrolysis runs show lower total VOCs with a catalyst increasing condensation efficiency for higher boiling point VOCs.
- Conditions with a 5:100 catalyst to feed ratio for 32/35/33 LDPE/HDPE/PP achieve an efficient balance in liquid + wax yield (76.6 wt %), gas yield (14.5 wt %), VOC content (76.5 wt %), and process duration (12 h 45 min), with average energy usage and CO_2 emissions.

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