Maximizing Condenser Efficiency in Polypropylene Plant Using the Spheripol Process

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Abstract
This paper considered the performance of water condenser and coolers in the bulk section of polypropylene plants using the Spheripol Process. The condenser and coolers were installed to capture condensable from recycle steams. The efficiency of polypropylene condenser was least in all the coolers and condenser under the scope of this study. A model was developed to demonstrate how the catalyst activity or mileage could be enhanced. A computer simulation was carried out and the result obtained shows the effects of reactor density and residence time on catalyst mileage.

1. Introduction

For the last two decades, the considerable changes have been made in the chemical and petroleum industries, plants have been grown in capacity with process conditions such as pressure and temperature becoming more severe. Storage has been reduced and interlinking with other plants increased. Process hazards have equally increased and so has the area, which might be affected by such occurrences, Chanlelt, (1973). These factors have greatly increased the potential for loss both in human and economic terms. Improvement and prevention therefore will continue to be one of the available options in reducing economic losses and lowering environmental burden, Goyal, (1999). For polypropylene plants using the spheripol process, hydrocarbon such as propylene emitted from process equipment such as heat exchangers is not controlled as criteria pollutant because of any inherent toxicity. Generally, hydrocarbon such as propylene is controlled because any loss is hazardous when it exhibits any of the following properties or characterizes such as ignitability, reactivity, corrosivity and toxicity. Propylene is a slightly narcotic gas. It has anesthetic properties at high concentration, Keli, (1972).

Materials are consumed in manufacturing operation as they pass through various processes and unit operations. These losses either in the form of gases, liquids or solids depends on the particular process operation and material being handled. For the hydrocarbon processing industry, major loss area includes the following; losses from leaks, losses from plant start-up and shutdowns, losses due to sampling and losses from purging which tend to have a significant effect on the environment. Immediate environmental effects include changes in temperature which give rise to expansion and contraction of metals resulting to failures caused by fatigue.
Heat transfer is by three different mechanisms namely; conduction, convection and radiation. The principal mechanism by which heat is transferred into solid materials is conduction. Convection applies mainly to fluids. In radiant heat transfer, energy is transferred by means of electromagnetic waves, Calvert and Harold, (1999).

Combination of these heat transfer mechanisms is possible in many process operations especially where heat is transferred from one fluid to another through a metal tube or plate. A variety of devices are used and these include plate exchanger, fluidized or moving beds, fin tube banks, jacket coils etc. However, the most commonly used heat transfer equipment is the shell and tube heat exchanger.

A shell and tube exchanger utilizes tubes arranged within a shell in such a way that one fluid, known as the tube fluid, flows within the tubes while the other fluid known as the shell fluid flows outside the tubes but within the shell heat. Transfer is through the tube walls. The tube fluid enters one of the nozzles and leaves through the other tube nozzle. The shell fluid enters one of the shell nozzles, passes around the tubes, follows the path formed by shell baffles and finally through the other shell nozzle. The shell and tube heat exchanger also direct the shell side fluid in a path that promotes heat transfer by reducing the thickness of the stagnant fluid film developed near the tube walls Flory, (1985).

The spheripol process is a modular technology consisting of three main process steps-catalyst and raw material feeding, polymerization and finishing. The catalyst, liquid propylene and hydrogen for molecular weight control are continuously fed into the loop reactor. The main sections for the bulk polymerization of propylene using the spheripol process are as follows; the catalyst preparation and metering, polymerization section, polymer degassing and monomer recovery and steaming and drying, Eleme Petrochemical Company, (1991). All these sections serve as flow description of the spheripol process used in the polypropylene plant.
The objective of this work therefore was to identify the causes and reduce the quantity of hydrocarbon losses through maximization of heat exchanges' efficiency in the spheripol process to a level justified by economics and environmental considerations.

2. Model Development

This work on hydrocarbon loss reduction and source control of gaseous pollutants in polypropylene plant using the spheripol process was carried out using the following steps:

- Development of reactors performance models
- Testing of developed models using plant data
- Assessment of plant operations to determine areas of profitable improvement.

2.1 Performance Equations for Heat Exchangers

The simplest form of equation which represents this heat transfer operation can be written as (Goyal, 1999);

$$Q = UA\Delta T_M \quad (1)$$

The heat load or duty of the exchanger can be calculated from the following relationships

$$Q = WC_p(t_2 - t_1) \quad \text{for tube side} \quad (2)$$

$$Q = WsC_p(T_1 - T_2) \quad \text{for shell side} \quad (3)$$

Equation 2 and 3 apply where heat is transferred as sensible heat. If transfer is by latent heat as applicable to reboilers and condensers, then the heat load is given by

$$Q = W\lambda \quad (4)$$

From equation (1) ΔT_M is the log mean difference for either counter current or co-current flow heat exchangers and is given as

$$\Delta T_M = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln\left[{(T_1 - T_2)}/{(T_2 - t_1)}\right]} \quad (5)$$

And also from equation (1) A is the total heat transfer area for an exchanger given as

$$A = N_T A_S N_P \quad (6)$$

Putting equation (5) and (6) into equation gives

Q = $UN_T A_S N_P \frac{(T_1-t_2)-(T_2-t_1)}{\ln\left[\frac{(T_1-T_2)}{(T_2-t_1)}\right]}$ (7)

Where,

A_S = area of surface for one tube and is given as

A_S = $\pi d_o L$ (8)

Putting equation into equation (7) gives

Q = $UN_T \pi d_o L N_P \frac{(T_1-t_2)-(T_2-t_1)}{\ln\left[\frac{(T_1-T_2)}{(T_2-t_1)}\right]}$ (9)

Equation (9) becomes the general equation that represents heat transfer operation in polypropylene plant using the spheripol process.

1.2 Efficiency Equations

For counter current flow and R=1, the efficiency equation applicable is

P = $\frac{NTU}{1+NTU}$ (10)

P = $\frac{1-Z^{1-R}}{1+Z^{1-R}}$ (11)

For co-current flow, efficiency (P) is given by

P = $\frac{1-Z^{1-R}}{1+R}$ (12)

Where;

U = Overall heat transfer coefficient, $Kcal/m^2/hr/℃ \; or \; w/m^2k$

A = Area of heat transfer, m^2

ΔT_M = Corrected or actual mean temperature difference

Ws = Flow rate for hot or shell side fluid, kg/hr

W = Flow rate for cold or tube side fluid, kg/hr

Cp = Specific heat capacity for cold or tube side fluid, Kcal/kg ℃

Cps = Specific heat capacity for hot or shell side fluid, Kcal/kg℃

N_T = Number of tubes

A_S = Area of surface for one tube

N_P = Number of passes

R = Heat capacity ratio

1.3 Development Of Reactors Performance Model

In spheripol process, polymer produced is an enlarged for m of the catalyst particles. Therefore, for a continuous process, residence time for a given catalyst particle is given by;

Residence time = $\frac{polymer\ inventory\ in\ kg}{production\ rate\ in\ kg/hr}$ (13)

Polymer inventory (product leaving the reactor) is a function of reactor volume and concentration of materials inside the reactor. This is obtained as;

Pc = polymer concentration (kg/m^3) $\times$ $Reactor\ volume\ (m^3)$ (14)

The concentration of the polymer in the reactor at any given time will be the difference between the densities of the slurry and unreacted monomer i.e. propylene. Since fraction conversion is

0.5 and propylene and polypropylene densities at 70℃ (Reaction Temperature) have been determine as 400kg/m^3 and 900kg/m^3 respectively, the polymer concentration is obtained as;

$$Pc = \frac{slurry\ density - propylene\ density}{(1 - propylene\ density/900)} \quad (15)$$

1.4 Computation of Developed Model to Determine Areas of Profitable Improvement in Plant Operations

Using the developed model (i.e equations 13, 14 and 15), the following operating parameters were investigated to determine their relationship with catalyst activity or mileage:

- Polymer concentration
- Residence time
- Slurry density

The temperature –density profile of propylene shown in table 1.0 below was obtained when the reactors were filled with liquid propylene and put under circulation with no catalyst added. Heating of the reactors was carried out through reactors jacket water system. Propylene density at 70°C was used in the reactor performance model.

Table 1: Temperature-Density Profile of Propylene

Temperature (°C)	Density (kg/m^3)
40	500
50	465
55	450
60	437
65	420
70	400
75	380

2.5 Computation of Teal/Donor Ratio

To calculate teal/donor ratio, can be calculated using the formula

Y = T/D (16)

Where

T = Teal/propylene ratio based on plant design i.e 0.2

Y = Teal/donor ratio required

D = Donor flow, it is unity for copolymer run but for homopolymer when donor is mixed with mineral oil, the value of 'D' is divided by the concentration of donor in oil.

2. Results and Discussion

The bulk plant has two (2) condensers

E-301 high pressure scrubber condenser

E-701 Stripper condensers

These condensers are installed to capture condensables from recycle stream but could also become large sources of hydrocarbon loss when their performance remains unmonitored. The efficiency obtained from computation for the two exchangers are 57.12% and 86.6% for E301and E701 respectively.

The log mean temperature difference for the exchangers also shows remarkable drop in E301 than in E701. This poor performance of E301 condenser is unconnected to the heavy polymer fines build-up on the shell side. Polymer fines in spheripol process are caused by low catalyst mileage. This exchanger is fixed head and has not been cleaned since plant commissioning in 1995. As condensable become uncondensable due to its poor heat duty, this exchanger has become large hydrocarbon loss source.

3.1 Catalyst Yield as a Function of Polymer Concentration, Residence Time and Slurry Density

Results of the various computations show that slurry density is the only variable in the spheripol process that influences residence time of the catalyst particles in the reactor.
The figure below shows the linear relationship that exists between reactor density and residence time at up to the reactors maximum residence time of 1hr 30mins at constant temperature.
Temperature is a critical factor and should be held constant because the stereospecifity of the Ziegler Natta catalyst lowers temperature. There is a slight increase from 20℃ to 60℃ and a rapid decline above 70℃. Temperature increase on stereospecifity may also be explained on the basis of the different activation energies of the propagation rate constant.

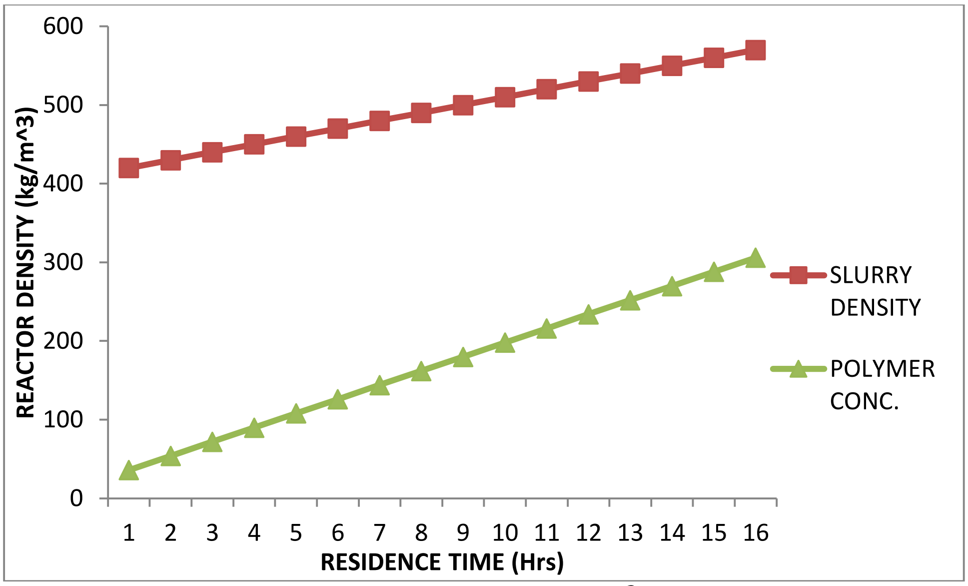

Fig 1: Plot of Reactor density (kg/m^3) against Residence time (Hrs).

3.2 Catalyst Mileage and Teal Donor Ratio

There is an increase in polymerization rate upon increase in teal/donor ratio as in table 3 in Appendix A1 and figure 2. The rate increase is attributed to the progressive activation of the potential catalyst sites during the alkylation reaction.
The second phenomenon is the decrease of the overall rate often observed when the al-alkyl concentration increase beyond certain point relative to donor.
The figure below shows that catalyst mileage increases with increase in Teal/Donor ratio. The stereo-regulating function of the catalyst is performed by donor. When the concentration of the donor is high (i.e low teal/donor ratio), the complex structure will grow so big tending to overlap thereby reducing propylene admittance level and exposing the catalyst particles to less quantity of monomer that will be involved in the reaction. This is considered as catalyst poison. When Alkyl concentration increases above a certain limit as shown in the figure below, catalyst mileage begins to drop. This is explained by the absorption of metal alkyl on catalyst sites in competition with monomer.

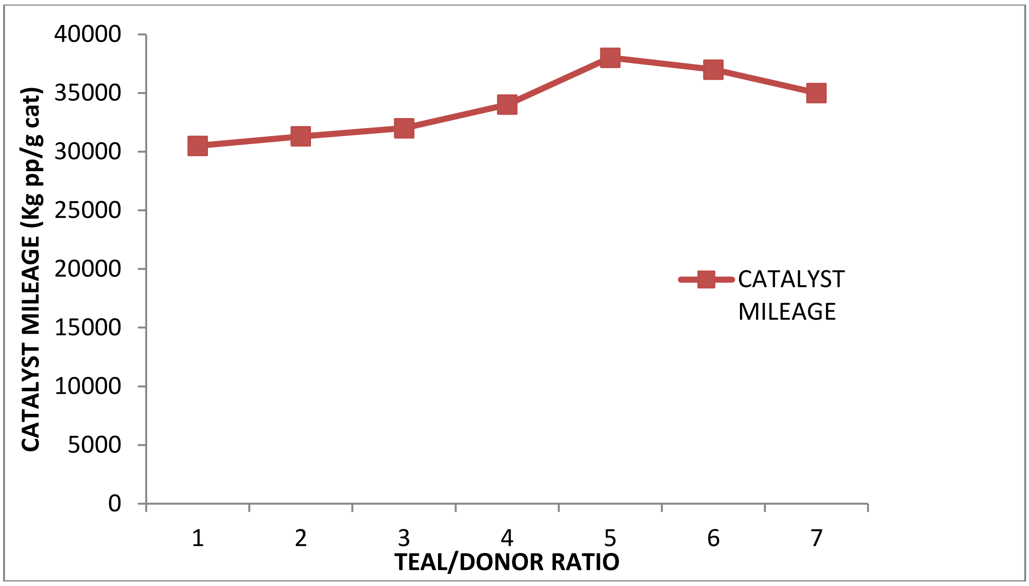

Fig. 2: Plot of Catalyst Mileage against Teal/Donor Ratio

3.3 Hydrogen Concentration, Melt Flow Rate and Catalyst Mileage

Hydrogen is used as a chain terminator in polypropylene production using the Spheripol process.

Its concentration varies inversely with polymer intrinsic viscosity. High melt flows are obtained with products of low intrinsic viscosity and vice versa. By varying the hydrogen concentration, the following melt flow and catalyst mileage values were obtained which shows a linear relationship as shown in Table 4 in Appendix A1 and Fig.3.

Result obtained shows that melt flow rate and catalyst mileage increases with hydrogen concentration in the reactor as shown in the figure below. Chain termination by molecular hydrogen involves hydrogenolysis of the metal-carbon centers with the formation of metal-hydrogen (M-H) group and an isopropyl end group as in the equation;

M-$CH_2CH_2CH_3 + H_2 \rightarrow M - H + C_3H_7$

This phenomenon explains how higher reactivity is achieved, when good concentration of hydrogen is used. When termination by hydrogen occurs, the polymer chain is saturated and complexing could not occur.

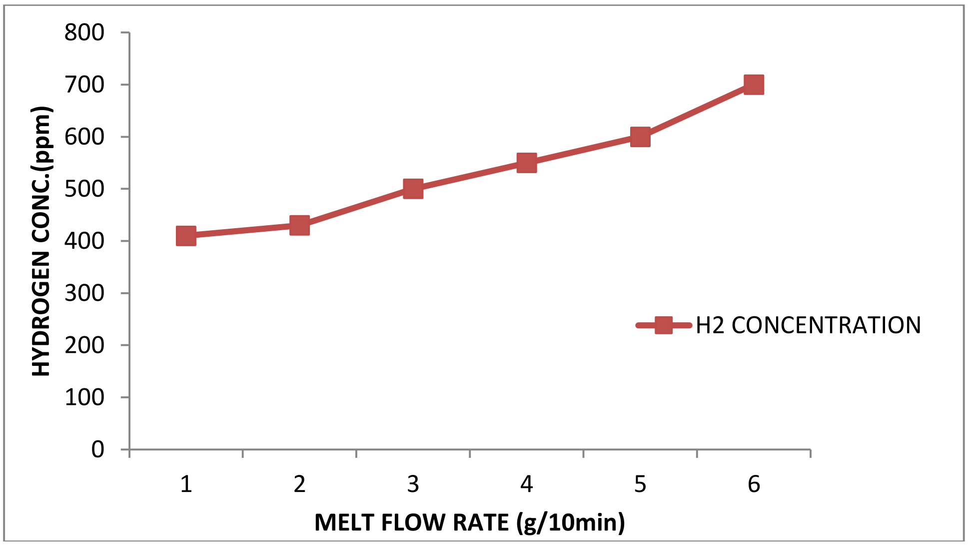

Fig. 3: Plot of Hydrogen Concentration against Melt Flow Rate

3. Conclusion

Results obtained from this work have shown that condenser efficiency polypropylene plant using the spheripol process could be maximized by increasing the catalyst mileage. The model developed shows the relationship between catalyst activities with reactor density, residence time. Maximizing condenser efficiency is therefore, is one of the tools to reduce economic losses and mitigate environmental burdens. This work would be contributory to other available studies on maximizing heat exchangers efficiency in the hydrocarbon processing industry. It is expected that the various approaches and recommendations made in this research will produce improved solution to problems associated with exchanger fouling.

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APPENDIX A1

Table 2.0: Result of computer simulated model showing catalyst yield as a function of polymer concentration, residence time and slurry density.

Slurry density Kg/m3	Polymer conc. Kg/m3	Polymer inventory Kg	Residence Time Hrs
420	36	1728	0.1728
430	54	2592	0.2592
440	72	3456	0.3456
450	90	4320	0.4320
460	108	5184	0.5184
470	126	6048	0.6048
480	144	6912	0.612
490	162	7776	0.776
500	180	8640	0.8640
510	198	9504	0.9504
520	216	10368	1.0368
530	234	11232	1.1232
540	252	12096	1.2096
550	270	12960	1.2960
560	288	13824	1.3824
570	306	14688	1.4688

Table 3.0: Catalyst mileage and teal donor

CATALYST MILEAGE (Kg pp/ G cat.)	TEAL/ DONOR RATIO
30,500	20.0
31,300	21.5
32,000	23.0
34,000	30.0
38,000	35.0
37,000	38.0
35,000	40.0

Table 4.0: Hydrogen Concentration, Melt Flow Rate and Catalyst Mileage

H_2 CONCENTRATION (PPM)	MELT FLOW RATE (g/10min.)	CATALYST MILEAGE (kg pp/kg catalyst)
410	2.70	28,000
430	2.90	29,500
500	3.60	30,100
550	3.80	32,000
600	4.00	32,300
700	5.55	34,500