International Journal on Advances in Engineering Technology and Science
Volume: 2, Issue: 2, March-April 2016, e-ISSN: 2455-3131

Process Design for Hydrogenation of Palm Oil

Bhavika J. Parmar, Prof. S. M. Dutta, Prof. S. B. Thakore

Chemical Engineering Department, L D College of Engineering, Ahmedabad

Abstract— **This paper presented here is study about jet loop reactor technology for hydrogenation amination alkylation. A Jet Loop Reactor consists of a reaction autoclave, a circulation pump, a heat exchanger, a venturi type ejector similar to Stirred Tank Reactor but is arranged in a completely different way. Jet Loop Reactor gives excellent performance on a faster reaction scheme in the fully saturated hydrogenation process in palm oil refinery.**

***Keywords*— Jet Loop Reactor, Venturi Type Ejector, Hydrogenation Process, Palm Oil Recovery**

I. Introduction

The Loop Reactor consists of a reaction autoclave, a circulation pump, a heat exchanger and a venturi type ejector. This system requires the same number of elements as that of a stirred vessel system, but is arranged in a completely different way.

The reaction vessel of a Loop Reactor does not need baffles and is normally built with a larger L/D than the stirred vessel and is thus lower in cost, especially for high-pressure reactions.

The external heat exchanger are built as large as needed and is not limited by the reactor's working volume. The full heat exchanger area is available, also if the reactor is operated with reduced working volumes.

The circulation pump allows high power input per m3 working volume in those cases where high mass transfer rates have to be achieved.

Pump designs with mechanical seals that can be operated at pressures of up to 200 bar g. A unique impeller and a special hydrodynamic pump house profile allow pumping of liquids with a high solid content and high gas loads, without the aid of an inducer and thus avoiding abrasion problems where heterogeneous catalysts are used.

The down flow Jet Mixer is a high performance gassing tool. The ability to finely disperse very small gas bubbles to the liquid with a gas-liquid ratio between 0.5 and 2.0, or even more, makes this an ideal tool for gas-liquid reactions.

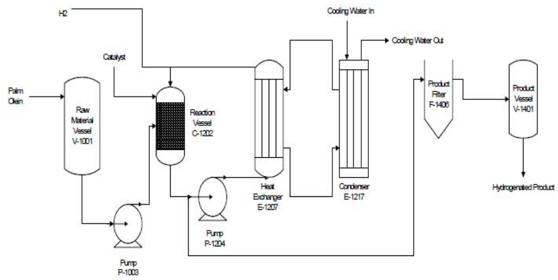

Fig. 1 Process flow design for Hydrogenation of Palm Oil

II. Applications of Jet Loop Reactor

The various industrial applications of Jet Loop Reactor are as follows:

- Hydrogenation of castor oil and fatty acids.
- Reduction of adiponitrile to hexamethylene diamine.
- Amination of aldehyde to amine.
- Low-pressure synthesis of methanol.
- Biological treatment of wastewaters.
- Reduction of carbonyl group and acid chlorides.
- Biodesulphurisation of petroleum

Advantages

Jet Loop Reactor possess several benefits which makes it substantial for various industrial applications, these benefits include; Firstly, it promotes a faster reaction rate by exerting its higher mass transfer rate & mixing intensity as compare to continuous stirred tank reactor (CSTR). Secondly, absence of moving parts in jet loop reactors eliminates the sealing problems and allows easier operation at elevated pressure. Third, Length to diameter ratio of jet reactor is higher than same of agitated vessel, thus it requires less cost particularly for high pressure reactions. Next, the external heat exchanger can be built as needed and can have accurate temperature control even if the reactor is operated with reduced working volumes. Moreover, the maximum power input per unit volume is often a limiting factor, especially for large reactors with an agitator. Since there is no agitator in the jet reactor, this limitation does not exist. Lastly, the circulation pump can provide very high power per m3 of working volumes if it is required to achieve the desired mass transfer rate.

III. Design for Hydrogenation of Palm Oil

Hydrogenation of palm oil is carried out to produce (hydrogenated fat) in the presence of nickel catalyst in batch reactor. In which iodine value of the mass is reduced from 64 to 10. The batch reactor has a jacket for heating the initial charge with circulating hot oil. Cooling requirements are met by passing cooling water in internal coils.

In a newly developed jet loop reactor, it is planned to complete the reaction in 3 hours by improving mass transfer in the reactor and cooling the mass in external heat exchanger, thereby maintaining near isothermal condition.

Palm oil, having iodine value (IV) of 64 is to be hydrogenated in the jet reactor at 5 bar g and 195° C. initially the charge is heated from 50°C to 160°C with the circulating hot oil external heat exchanger.

Hydrogen is introduced in hot palm oil and pressure is maintained in the reactor at 5 bar g. reaction is exothermic and the temperature of mass increases. Cold oil flow in the external heat exchanger controls the temperature at 195°C as per the requirement; IV reduction is desired up to 10 when the reaction is considered over.

Thereafter hydrogenated mass is cooled to 110° C in about 1.5 h before it is discharged to filter. 150 kg spent nickel catalyst is charged with palm oil while fresh 5 to 10 kg nickel catalyst is charged at intervals in the reactor under pressure. A bleed is maintained from the system to purge out water vapour and non-condensable.

IV. Input Parameters for the Design

The presented design of jet reactor incorporates charge of 1t palm oil 64 IV for a product specification of 10 IV, 24℃ melting point (max).

The following data is taken into consideration:

- Average molar mass of soybean oil is 270
- Average chain length of fatty acids is 16.98
- Average exothermic heat of reaction is 0.942 kcal /kg or 3.941 kJ /kg
- Hydrogen feed rate is from 110 to 125 Nm^3/h
- Bleed rate is 1 to 2 Nm^3/h

Thermic fluid or oil is used as both, heating medium in starting of reaction and cooling medium in running of reaction.

Cooling water is available at 2 bar g and 32°C. A rise of 5° C is permitted over here. Cooling water is used for cooling the oil from 80°C to 70°C in oil cooler (HE-2) of oil cycle.

The following average properties of fluids for the design are taken:

Properties	**Palm oil or hardened fat**	**Circulating oil (thermic fluid)**
Density, kg / L	0.856	0.71
Specific heat, kJ /(kg°C)	2.56	2.95
Viscosity, mPa s	2.387	0.5
Thermal conductivity, W/(m°C)	0.1664	0.1

V. Design of Jet Loop Reactor

S.No	**Properties**	**Design Equation**	**Results**
1	Volume of inside the jet reactor	$V_L = \pi/4\ D_i^{\,2}\ h_i$ + inside volume of torispherical head $h_L = 1.5\ D_i$	11.682 m^3
2	Diameter of Reactor	$V_L = \pi/4\ D_i^{\,2}\ h_i + 0.084672\ D_i^3 + \pi/4\ D_i^{\,2}\ S_F$	2.1 m
3	Total height of reactor	$H = 2*D_i$	4.2 m
Design of Shell and Tube Heat Exchanger used for cooling of Palm Oil (HE – 1)			
4	Heat Duty Required	$Ø_c$ = average heat of reaction× IV reduction× kg of reaction / mass reaction time	196.99 kW or 425628 kJ/h
5	Mean temp. difference	$\Delta T = \Delta T_{lm} \times F_t$ $F_t = 1$	117.1459°C
6	Tube side mass velocity ($kg/m^2 \cdot s$)	$G_t = u_t \rho$ $u_t = 1.5$ m / s	1284 kg / $m^2 s$
7	Tube side flow area (m^2)	$a_t = \mathring{m} / G_t$	0.0126719m^2
8	Total number of tube	$a_t = N_t / N_P \times \pi/4.\ D_i^2$ Number of tube side passes = 1	34
9	Tube side Reynold's Number	$Re_t = d_t\ G_t / \mu$	11886
10	Tube side Prandtl's Number	$P_r = C_p \mu / k$	36
11	Tube side heat transfer coefficient	$h_i d_i / k_f = 0.023\ R_e^{0.8} Pr^{0.33} (\mu/\mu_w)^{0.14}$	1028.339 $W/m^2 {}^\circ C$
25.4 mm (1 in) OD and 31.75 (1.25 in) triangular pitch; Type of baffle =25 % cut segmental Baffle spacing , B_s =150mm			
12	Shell side flow area	$A_s = (P_t - do)/P_t \times D_s \times B_s$	$7.62 \times 10^{-3}\ m^2$

13	Shell side mass velocity	$G_s = \dot{m}_s / A_s$	876.350 kg/m^{2}s
14	Shell side velocity	$u_s = G_S / \rho_0$	1.2342 m/s
15	Shell side equivalent diameter	$d_e = 1.1 / d_o (p_t^2 - 0.907 d_o^2)$	18.3147 mm
16	Shell side Reynold's numbers	$R_e = d_e G_s / \mu_o$	32100.175
17	Shell side Prandtl's numbers	$P_r = C_{Po} \mu_0 / k_0$	14.75
18	Shell side heat transfer coefficient	$h_o d_e / k_0 = 0.36 R_e^{0.55} P_r^{0.33} (\mu/\mu_w)^{0.14}$	1438.080 W / m^2 °C
Thermic fluid (oil) side fouling coefficients, h_{od}=5000 W/m^2 ^{0}C Palm oil side fouling coefficients, h_{id}=3000 W/m^2 ^{0}C Tube material = SS 316 Thermal conductivity of tube material k_w = 16.26 W/m^2 ^{0}C			
19	Overall heat transfer coefficient	$1/U_0 = 1/h_0 + 1/h_{od} + d_o \ln (d_o/d_i)) /2 \times k_w + (d_o/ d_i) \times 1 / h_{od} + (d_o / d_i) \times 1/h_i$	399.2075 W/m^2 °C
20	Heat transfer area required	$A = U_0 \O_c / \Delta T_m$	4.21248 m^2
21	Length of tube	$L_t = A_r / n_t \ \pi \ d_o$	1.5526 m
22	Heat Transfer Area Provided	$A = N_t \pi d_o L$ Taking Length of tube = 3m	5.4261 m^2
23	% excess heat transfer area	$(A / A_r - 1) \times 100$	28.81 %
R_e = 11886 and 25 % cur segmental baffles J_f = 0.047			
24	Tube side pressure drop	$\Delta p_r = N_p [8 J_f (L / d_i) (\mu / \mu_w)^{-m} + 2.5] \rho u_t^2 / 2$	7.323 kPa
25	Shell side pressure drop	$\Delta p_s = 8 J_f (D_S / d_e) (L / B_s) (\rho u_s^2 / 2) (\mu/\mu_w)^{-m}$	53.97 kPa
Parameters of Shell and Tube Heat Exchanger used for preheating of Palm Oil before Reaction (HE -1)			
26	Time required for heating the palm oil from 50 to 160		7600 s
27	K_2 Constant	$U_A / \dot{m}C_{LH} = 0.04530$ $K_2 = e^{(UA/\dot{m}C_{LH})}$	1.0463
28	Temperature of heating medium inlet, t_1	$\ln [(t_1 - t_1')/(t_1 - t_2')] = \dot{m}C_{LH} / \dot{m}C_{LC} (K_2 - 1 / K_2) \Theta$	321.605477°C
Design of cooler of oil cycle (HE – 2)			
BEM type fixed tube sheet Tube side fluid : cooling water Shell side fluid oil : (Thermic oil) Cooling water inlet temp. = 32°C Cooling water outlet temp. = 37°C			
29	Cooling water flow rate	$\phi_c = \dot{m} C_L \Delta t$	33877.73 kg/h
30	Mean Temperature Difference	$\Delta T_m = \Delta T_{lm} \times F_t$ $R = [(t_1 - t_2')/(t_2 - t_1')] = 2$ $S = [(t_2 - t_1) / (t_1 - t_1')] = 0.1042$ $F_t = 0.99$	40.04°C
31	Volumetric flow rate of water	Density of water at 34.5 ^{0}C =994.202 kg/m^3 $V = \dot{m}/\rho$	9.465 × 10^{-3} m^3/h
32	Tube side flow area	$a_t = V / u_t$	6.3102 × 10^{-3} m^2
33	Number of tubes	$a_t = (N_t / N_p) \times (\Pi /4) d_i^2$ N_p = 2 (selected) d_i = 15.748 mm d_o = 19.05 mm	66
For 25.4 mm triangular pitch , N_p= 2 , shell ID = 305mm			
34	Tube side Reynold's numbers	$R_e = d_i u_t \rho/\mu$	32171.3
35	Tube Side Prandtl's numbers	$P_r = C_L \mu / k$	4.867
36	Heat Transfer Coefficient of Tube Side	$h_i d_i /k = 0.023 R_e^{0.8} Pr^{0.33} (\mu/\mu_w)^{0.14}$ Viscosity of water, μ = 0.73 cp, thermal conductivity of water, k = 0.626 W/m°C	6340.7 W/m^2 °C
37	Shell side flow area	$A_s = [(P_t - d_o)/P_t] \times D_s \times B_s$ P_t = 25.4, d_o = 19.05 D_s = 305 mm B_s = 125	9.5312 × 10^{-3}
38	Shell side mass velocity	$G_s = \dot{m}_o / A_s$	700.62 kg/m^{2}s
39	Shell side velocity	$u_s = G_s / \rho_o$	0.9867 m/s
40	Shell side equivalent diameter	$d_e = 1.1 / d_o (p_t^2 - 0.907 d_o^2)$	18.25 mm

41	Shell side Reynolds numbers	$R_e = d_e G_s / \mu$	25572.63
42	Shell side Prandtl's number	$P_r = C_P \mu / k$	14.75
43	Shell side heat transfer coefficient	$h_o d_e / k_0 = 0.36 R_e^{0.55} P_r^{0.33} (\mu/\mu_w)^{0.14}$	
44	Overall heat transfer coefficient	Thermic fluid (oil) side fouling coefficient, h_{od}= 5000 W / m^2 °C Tube material = mild steel k_W = 50 w / m^2 °C $1/U_0 = 1/h_0 + 1/h_{od} + d_o \ln(d_o/d_i)) /2 \times k_w + (d_o/d_i) \times 1 / h_{od} + (d_o / d_i) \times 1/h_i$	682.2290 W/ m^2 °C
45	Heat transfer area required	$A = U_0 Ø_c / \Delta T_m$	7.2110 m^2
46	Tube length	$L_r = A_r / n_t \ \pi d_o$	1.82560 m
47	Area Available	$A = N_t \pi d_o L$ tube length L = 2 m	7.89984 m^2
48	% excess heat transfer area	$(A / A_r - 1) \times 100$	9.5598 %
49	Tube side pressure drop	For R_e = 32171.3 and 25 % cut segmental baffles J_f = 0.0035 $\Delta p_r = N_p [8 J_f (L / d_i) (\mu / \mu_w)^{-m} + 2.5] \rho u_t^2/2$	13547 kPa
50	Shell side pressure drop	$\Delta p_s = 8 J_f (D_S / d_e)(L / B_s)(\rho u_s^2 / 2)(\mu/\mu_w)^{-m}$	31.791 kPa

VI. DISCUSSION

The time required for hydrogenation of Palm Oil with Continuous Stirred Tank Reactor takes 8 to 10 hours, while it takes 3 hours with Jet Loop Reactor. The design parameters for two heat exchangers in the process are well calculated citing their benefits over Conventional method of Jacket or coil Heat transfer methods. The use of external heat exchangers eliminates the disadvantage of limited reactor volume. Furthermore, the ease of recycle of product in the reactor loop increases the product consistency and purity. The formation of smaller bubbles in the reaction increases the surface area for reaction hence, promoting better reaction rates. The design calculations show a venturi type compact jet reactor with Diameter of 2.1 m and having Length 4.2 m, i.e., L/D ratio as 2, is sufficient for the hydrogenation reaction of 1 ton of Palm Oil. The reactor volume thus obtained is 11.682 m3.

Further calculation shows that, two BEM type fixed tube Shell and Tube Heat Exchanger used for cooling and preheating of Palm Oil and for cooling of thermic fuel. The dimensions of first being, 34 tubes of 25.4 mm (1 in) OD, 3m long and 31.75mm (1.25 in) triangular pitch, 25 % cut segmental type baffle with 150mm and spacing, 1 pass.

The dimensions of second heat exchanger being, 66 tubes of 25.4 mm (1 in) OD, 2m long and 15.048mm (1 in) ID and 19.04 OD triangular pitch, 25 % cut segmental type baffle with 150mm and spacing, 2 pass, 305mm Shell Inner Diameter.

The results of calculations meet the TEMA standards, thus giving most suitable process design.

REFERENCES

[1] R.J.Malone, Herzog-Hart Corp., (1980). "Loop reactor technology improves catalytic hydrogenation", Boston, Mass.

[2] Ogawa.s,h.yamaguchi,s.tone and t.otake (1983). "Gas liquid mass transfer in the jet reactor with liquid jet ejector", J. H. Chemical Engineering, Japan.

[3] N. N. Dutta And K. V. Raghavan, Chemical Engineering Division, Regional Research Laboratory, 1986, Jorhat-785 006 (India)

[4] Dirix and van der wiele, (1990). "Mass transfer in jet loop reactor", Akzo research laboratories Arnhem corporation research, process technology department, Netherlands.

[5] M. Velan, T. K. Ramanuj, (1992), "Gas - liquid mass transfer in a down flow jet loop reactor", Department of chemical Engineering, Indian Institute of Technology, Madras, India.

[6] Ch. Viala, B. S. Poncina, G. Wilda, N. Midouxa, "Experimental and theoretical analysis of the hydrodynamics in the riser of an external loop airlift reactor", A Laboratoire des Sciences du Genie Chimique, CNRS-ENSIC-INPL 1, rue Grandville, BP 451, F-54001 Nancy Cedex, France

[7] W. Ludwig A, R. G. Szafran, A. Kmiec, J. Dziak, "Measurements of flow hydrodynamics in a jet-loop reactor using PIV method", Wroclaw University of Technology, Faculty of Chemistry, Department of Chemical Engg., Wybrzeze Wyspianskiego St. 27,50-370 Wroclaw, Poland

[8] Thakore S. B., Bhatt. B. I., "Introduction To Process Engineering And Design", 2nd Ed., Tata McGraw Hill, 2010

[9] Pangarkar, Vishwas, Govind, "Design Of Multiphase Reactors"