

Effect of impeller types on saponification reaction using stirred tank reactor

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Abstract

The choice of impeller type is an important factor in maximizing the performance of a stirred tank reactor in saponification process. This study aims to determine the type of impeller that can produce the highest reaction rate by taking into account changes in alkali concentration in saponification reactions so as to obtain a shorter residence time. The saponification process was carried out by reacting 30% oil with alkali (KOH) at operating conditions 70°C, stirring speed of 400 rpm for 45 minutes using 4 types of impellers namely paddle-2 blades, pitch blade turbine 45°-2 blades, paddle-4 blades, pitch blade turbine 45°-4 blades. Testing of alkali concentration was carried out every 5 minutes until the reaction was complete. Alkali concentration was obtained at the end of the reaction using a paddle-2 blades impeller of 0.182 M with a conversion of 97.35%, a pitch blade turbine 45°-2 blades of 0.142 M with a conversion of 97.93%, paddle-2 blades of 0.106 M with conversion of 98.46%, pitch blade turbine 45°-4 blades of 0.100 M with conversion of 98.54%.

Keyword: Tank reactor, Saponification reaction

1. INTRODUCTION

Along with the development of science and technology various ways are carried out to optimize a chemical reaction, both in terms of the economy and the quality of the products produced. To optimize a chemical reaction, it can be done by optimizing operating conditions, using catalysts and improving the design of the reactor being used. The reactor is the main component used to convert reactants into products in a chemical industry.

The main component in a stirred tank flow reactor is a tank and impeller. Impeller is a device used to induce motion in a stirred tank reactor. Impeller that rotate in the liquid will lift the liquid or immerse the liquid to the bottom, so that the two substances become homogeneous (Walas, 1990). Stirring also serves to increase the mass transfer rate in stirred tank reactor systems (Kokate *et al.*, 2015). The impeller performance in the stirred tank reactor is influenced by several factors, namely the impeller diameter, impeller width, tank shape, distance from the bottom of the tank, and the slope of impeller (Zhang *et al.*, 2017).

In soap production, stirred tank reactor is one of the commonly used operating units. Soap is made by the saponification process using raw materials of oil and alkali. The saponification reaction is the hydrolysis of carboxylic acid esters using a base medium. In the saponification reaction the alkaline serves to break up the ester chain to obtain fatty acid salts (soap) and glycerol. In oil, esters are generally in form of triglycerides (Mukhtar *et al.*, 2015).

To understand the chemical reactions that occur in saponification reactions, it must be reviewed based on reaction kinetics. The reaction kinetics is a translation of our understanding of the chemical process which is expressed in the mathematical model used to design the reactor.

Reaction kinetics is a part of chemistry-physics that studies the rate of reaction. The reaction rate for reactants or products in a particular reaction is defined as how fast a reaction occurs. The reaction rate is a molecular change in the reaction of the unit volume per unit time. The reaction

constants are the speed constants of a chemical reaction. The reaction rate is influenced by several factors such as surface area for solid reactants, reactant concentration, pressure for reactants in the gas phase, catalyst use, reaction temperature and stirring. (Mukhtar Al *et al.*, 2017) This study evaluates the effect of impeller type on reaction kinetics in saponification reaction.

2. METHODS

The main equipment used consisted of a stirred flow tank reactor in the form of a beaker glass with a size of 2000 ml equipped with a driving motor (IKA®RW 20 digital) with a stirring speed of 1-500 rpm. Hot plate (Cimarec™ Stirring Hot Plates SP131325) with a maximum temperature of 540°C and variation of impeller ie namely paddle-2 blades, pitch blade turbine 45°-2 blades, paddle-4 blades, pitch blade turbine 45°-4 blades (shown in Figure 2.1)

The materials used in this study were coconut oil and palm oil with a ratio of 1:1 (v/v), and alkali Potassium Hydroxide (KOH) 30% (w/w).

The operating conditions of the saponification reaction at a temperature of 70 °C, stirring rotation speed of 400 rpm, and reaction time for 45 minutes. The concentration analysis was carried out every 5 minutes interval with the alkalimetry titration method.

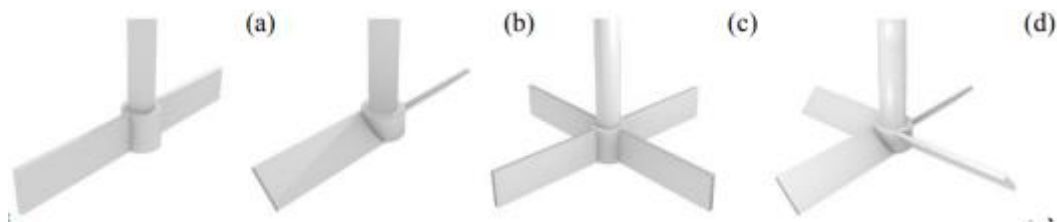


Figure 2.1. a) paddle-2 blades, b) pitch blade turbine 45°-2 blades, c) paddle-4 blades, d) pitch blade turbine 45°-4 blades

The schematic of a stirred tank reactor is shown in Figure 2.2.

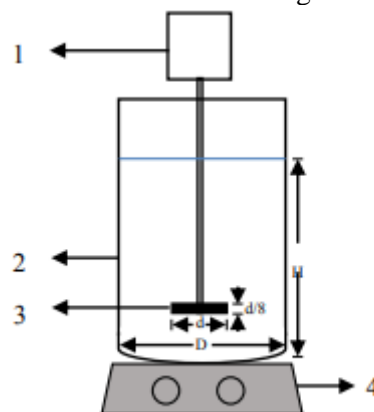


Figure 2.2. Equipment series

Captions:

1. Motor (rotation speed 1-500 rpm)
2. Tank ($D = H = 13$ cm)
3. Impeller
4. Hot plate (maximum temperature of 540 °C)

Note: D = tank diameter
 H = liquid height
 d = impeller diameter

3. RESULT AND DISCUSSION

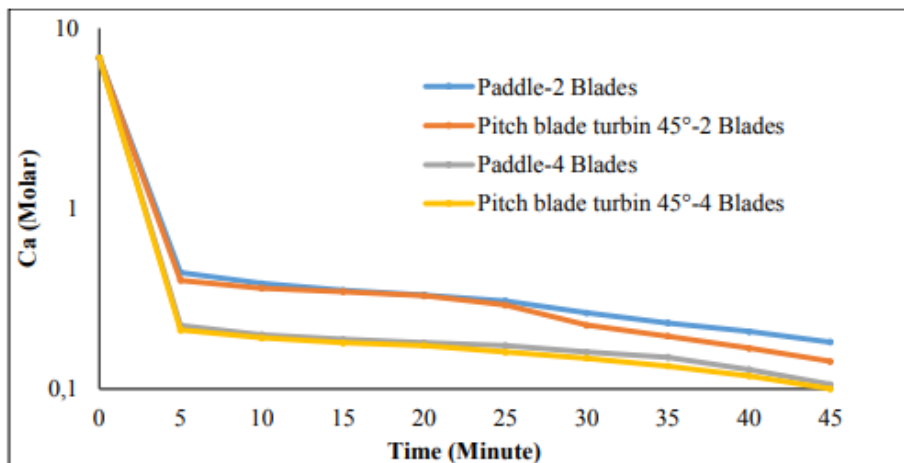


Figure 3.1. Decreasing Alkali Concentration Against Time with Different Impeller Types

From Figure 3.1, it can be seen that the longer the reaction time, the lower the overall alkali concentration. The initial concentration of alkali (KOH) 30% (v/v) was 6.86 M. In the 5th minute there was a significant decrease in alkali concentration using paddle-2 blades, pitch blade turbine 45°-2 blades, paddle-4 blades, pitch blade turbine 45°-4 blades with concentrations of 0.44 M, 0.22 M, 0.40 M and 0.21 M, respectively. Concentration of alkali at the end of the reaction for paddle-2 blades, pitch blade turbine 45°-2 blades, paddle-4 blades, pitch blade turbine 45°-4 blades impeller are 0.18 M, 0.11 M, 0.14 M, and 0.10 M, respectively. Alkali concentrations in the use of pitch blade turbine 45°-4 blades impeller are better than other types of impellers, this is due to the better stirring effect of pitch blade turbine 45°-4 blades impeller than other types of impellers. Good stirring causes more effective collisions between reactant particles so that the reaction occurs more perfectly. In accordance with the quality of soap according to SNI No. 06-3532-1994 (BSN, 1994) it is expected that the remaining alkali concentration of the reaction is small, which is 0.1% (w/w).

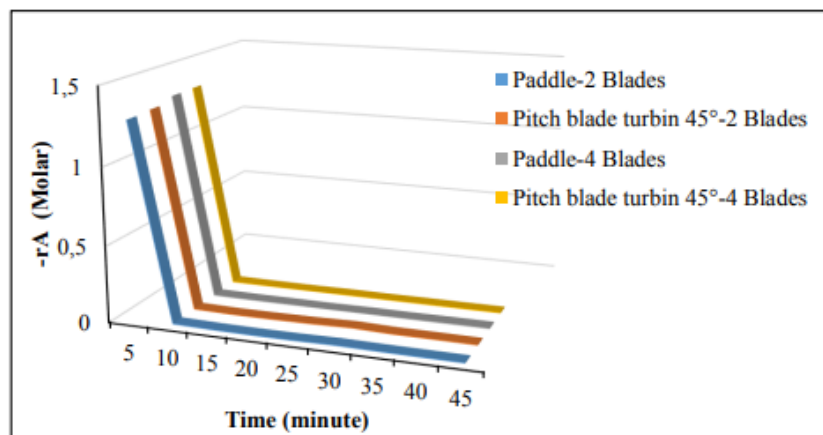


Figure 3.2. Effect of Impeller Types on the Reaction Rate with Different Impellers

Figure 3.2 shows that the reaction rate tends to decrease with time. The reaction rate in the 5th minute for all types of impellers decreased very significantly. Furthermore, the reaction rate after the 5th minute has almost no significant changes for all types of impellers used. This indicates that the reaction that occurred has approached equilibrium.

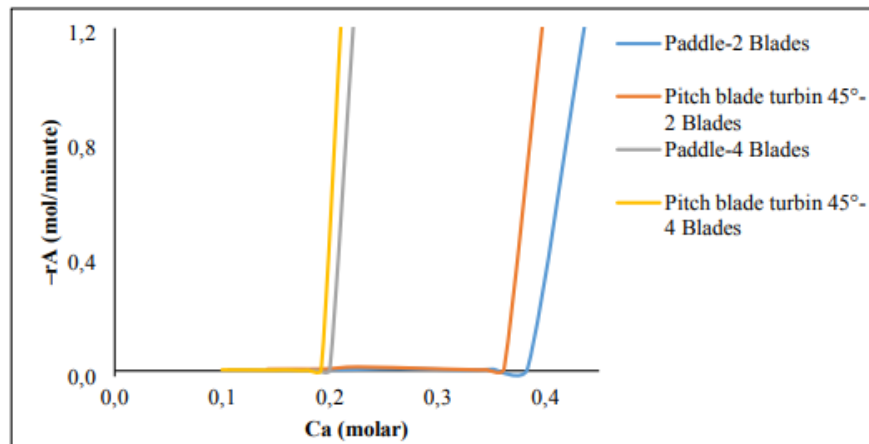


Figure 3.3. Effect of Impeller Types on Alkali Conversion

Figure 3.3 shows that the reaction rate decreases with decreasing concentration. The initial high reaction rate then decreases as the reactant concentration decreases. With the increase in reaction time and reactant concentration, there was almost no significant decrease. This indicates that the reaction that occurred has approached equilibrium.

Effect of impeller types on the reaction rate constants. To determine the reaction rate constant and the reaction order in the saponification reaction, the reaction that occurs is expressed by the following equation (Levenspiel, 1999)



So, the reaction rate equation can be expressed by equality

$$-r_A = -\frac{dC_A}{dt} = KC_A^a C_B^b \quad (2)$$

If we follow the stoichiometric equation, CB: CA = 3: 1 at any time, so CA = 1/3 CB and the reaction equation can be written

$$-r_A = -\frac{dC_A}{dt} = KC_A^a \left(\frac{1}{3}C_B\right)^b \quad (3)$$

$$-r_A = KC_B^a \left(\frac{1}{3}\right)^b C_B^b \quad (4)$$

$$-r_A = K \left(\frac{1}{3}\right)^b C_B^{a+b} \quad (5)$$

Considered that

$$a + b = n \quad (6)$$

$$k(1/3)^b = k \quad (7)$$

Then the equation above can be illustrated by the equation

$$-r_A = KC_B^n \quad (8)$$

$$\ln -r_A = n \ln C_B + \ln k \quad (9)$$

Based on the results of the saponification reaction constants experiments carried out, the relationship between the type of impellers and the reaction rate constants is expressed in the graph below:

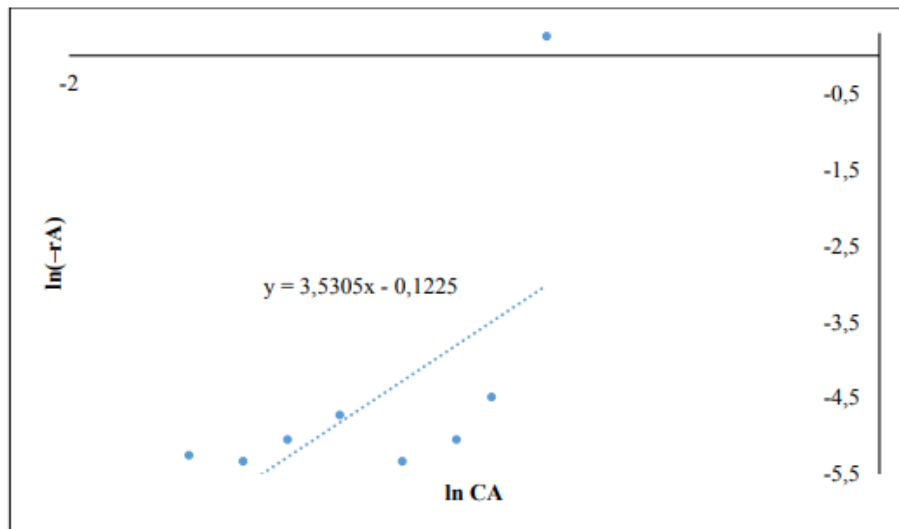


Figure 3.4. Relationship of $\ln(-r_A)$ and $\ln C_A$ for paddle-2 blade

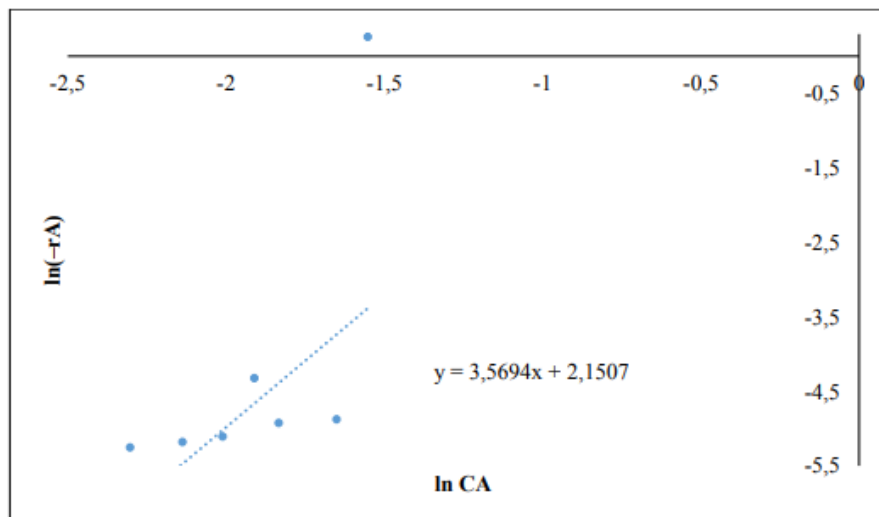


Figure 3.5. Relationship of $\ln(-r_A)$ and $\ln C_A$ for pitch blade turbine 45°-4 blades

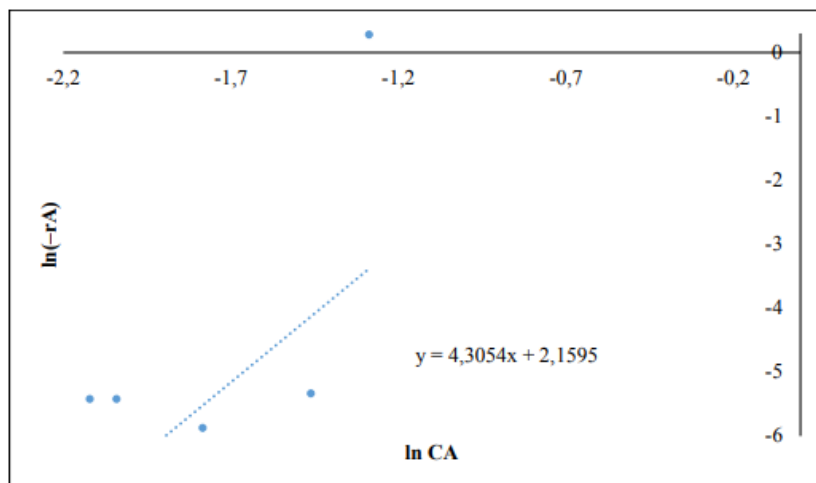


Figure 3.6. Relationship of $\ln(-r_A)$ and $\ln C_A$ for paddle-4 blade

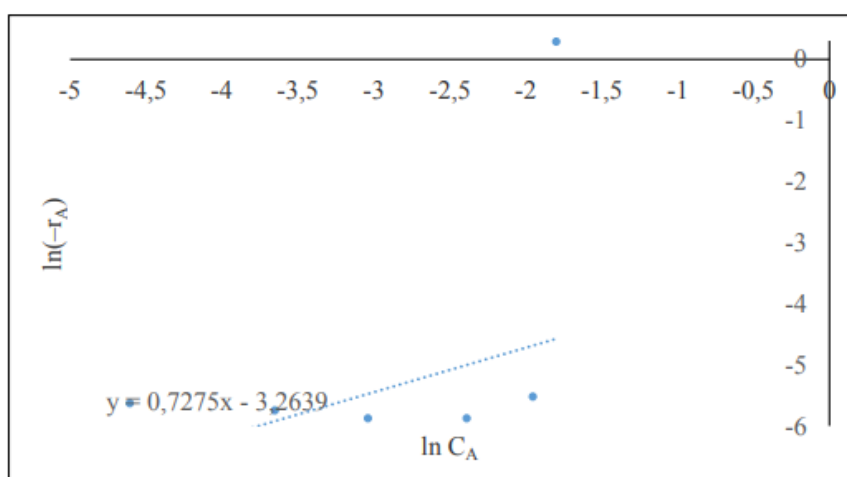


Figure 3.7. Relationship of $\ln(-r_A)$ and $\ln C_A$ for pitch blade turbine 45°-4 blades

The reaction order and reaction rate constants in various types of impellers used in this study can be seen from Table 3.1 below:

Impeller Types	N	ln k	k
paddle-2 blades	3.531	-0.123	0.885
pitch blade turbine 45°-2 blades	3.569	2.151	8.591
paddle-4 blades	4.305	2.160	8.667
pitch blade turbine 45°-4 blades	0.728	3.264	26.151

Table 3.1. Reaction orders and reaction rate constants in various types of impellers

Table 3.1 shows the reaction order values and reaction rate constants in various types of impellers used. The reaction order and reaction rate constants are different for each impeller used.

4. CONCLUSION

The alkali concentration at the end of the saponification reaction carried out for the two-blade paddle, four-blade paddle, 45° two-blade pitched-turbine, and 45° four-blade pitched-turbine were 0.182 M, 0.142 M, 0.106 M, and 0.100 M, respectively. The kinetic reaction equation for each type of blade is obtained, namely: for paddle-2 blades $-r_A=0,885 C_A^{3,531}$, pitch blade turbine 45°-2 blades $-r_A=8,591 C_A^{3,569}$, paddle-4 blades $-r_A=8,667 C_A^{4,305}$, pitch blade turbine 45°-4 blades $-r_A=26,151 C_A^{0,728}$.

5. ACKNOWLEDGMENTS

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