Original Article

Synthesizing cyclohexanone oxime

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ABSTRACT

Nylon 6 or polycaprolactam is the most widely used polymer, which is gained by the polymerization of monomer caprolactam resulting from the innovation of cyclohexanone oxime. Cyclohexanone-oxime is achieved by the reaction of hydroxyl-amine and cyclohexanone-oxime. This reaction is subject to parameters such as temperature, amount of raw materials, catalyst, and reaction time, which affect the reaction efficiency. We add an oxidizing agent, such as hydrogen peroxide, to the reaction medium through the reaction of ammonia and cyclohexane in the presence of an aluminum silicate catalyst, and oxidize the ammonia in the reaction environment after the progress of the reaction; so the reaction of cyclohexanone leads to the progress of the reaction, which is the formation of oxime. This research tried to increase the production efficiency of this material by investigating the factors of the catalytic production of cyclohexanone oxime. This reaction was investigated using different catalysts, including aluminum silicate and titanium oxide catalysts, in different reaction conditions for the production of cyclohexanone oxime. The results show the production of cyclohexanone oxime with an efficiency of 90.54% in the conditions of 0.294 moles of ammonia, 0.176 moles of hydrogen peroxide, 0.178 moles of cyclohexanone, at a temperature of 72 to 75 °C and 1% catalyst. Aluminum silicate catalyst showed the best efficiency in the production of cyclohexanone oxime.

Keywords: Ammonia, hydrogen peroxide, Hydroxylamine, Aluminum silicate catalyst, Titanium oxide catalyst, Cyclohexane, Cyclohexanone oxime.

Introduction

Cyclohexanone prepares oxime from the reaction and catalytic synthesis between cyclohexane and hydroxylamine derivative. The most famous commercial cyclohexanone oxime reaction is the Beckman rearrangement, which produces caprolactam. Indeed, cyclohexanone plays a mediating role in the production of caprolactam, about 90% of which is gained by cyclohexanone oxime retrieval. A new method of direct catalytic ammoxidation makes cyclohexane an oxime with H2O2 and NH3 in the presence of the aluminum silicate catalyst. Sulfuric acid is the most common acid for caprolactam production because of the formation of an ammonium sulfate byproduct when neutralized with ammonia. The most important use of cyclohexanone oxime is the use of its derivatives in the production of caprolactam (about 70%) as a raw material for the production of nylon 6, and the remaining 30% of cyclohexanone oxime was used in the industries of dyes, pesticides, solvents, and softeners. It is used generally as an intermediate in the production of nylon 6 and Nylon 6,6. Nylon 6 or polycaprolactam is a semi-crystalline polyamide, which is a compression polymer, unlike other nylons, which distinguishes it from other nylons.

Benson Richard Edward gained in 1950 a new method for the production of hydroxylamine. This method can increase hydroxylamine production by using a nitric oxide catalyst with hydrogen in moderate acid amount, under low pressure. This method cannot use the platinum catalyst because it is not economical [1]. Jockers Kurt and Wintersberger Karl (1952) used the method of reducing nitric oxide by hydrogen in the presence of a catalyst and in an acidic environment to produce hydroxylamine. A mixture of nitric oxide and hydrogen in a double amount was stirred in a solution of platinum catalyst suspension in three normal hydrochloric Acids at room temperature and the yield was 70% [2]. Seiji Hisama (1988) worked on the direct production of oxime using the reaction of a ketone or aldehyde with nitrogen monoxide and hydrogen in the presence of a platinum catalyst. An advantage of the direct method of oxime production compared to the indirect method is to prevent the production of side products [3].

Maria A. Mantegazza et al. (1991) investigated a direct catalytic process for the production of hydroxylamine using ammonia oxidation with hydrogen peroxide in the presence of the titanium silicon catalyst. Finally, they found that increasing the titanium silicate catalyst in the reaction decreases the production efficiency of hydroxylamine [4]. L. Dal Pozzo et al. (2001) converted cyclohexanone to oxime using ammonia and hydrogen peroxide in the presence of a TS-1 catalyst. The reaction is carried out in the presence of nitrogen at atmospheric pressure and an aqueous solution of Tetrapropylammonium hydroxide 20% by weight and the gradual addition of (Tetraethyl orthosilicate) TEOS and titanium isopropylate [5]. Song et al. (2006) used the titanium silicate catalyst to produce hydroxylamine. The results showed that the behavior of the catalyst in this system is under the influence of the way of adding hydrogen peroxide so the hydrogen peroxide needs to be added drop by drop and gradually in order to achieve a high conversion percentage. The optimal temperature of this process is 75 degrees Celsius. The yield decreases at higher temperatures because of the evaporation and decomposition of ammonia and hydrogen peroxide. Optimum conditions in this method include 1.4 weight percent of catalyst, 1.1 molar ratio of ammonia, and 1.2 molar ratio of hydrogen peroxide [6]. Jakkapan Sirijaraensre and Limetrakol (2013) investigated the catalytic performance of titanium species in TS-1 zeolite for the formation of hydroxylamine using density functional theory with the ONIOM scheme. The results show that H2O2 decomposition is kinetically and thermodynamically favorable on incomplete Ti species compared to suitable species [7].

Sadeghi (2019) was successful in producing cyclohexane oxime using TS-1 catalyst and titanium oxide as well as methyl ethyl ketone to produce oxime with a yield of 70%. This method produced hydroxylamine from the reaction of ammonia with hydrogen peroxide in the presence of the TS-1 catalyst and achieved cyclohexane oxime by using cyclohexanone with a yield of 70% [8]. Pouramini (2006) examined the performance of synthesis and purification of salicylaldoxime and determination of the formulation of copper transition extractant that uses 5-nonyl salicylaldoxime, 2-hydroxy, or 5-nonyl benzaldoxime, which has high copper extraction power in the copper extraction process. They used the synthesis of 5-nonyl salicylaldoxime and gained aldoxime and ketoxime extractants that compete with similar foreign samples [9].

The purpose of selecting "Catalytic synthesis of cyclohexanone oxime as a raw material for nylon 6 and its efficiency" for this research is to gain cyclohexane oxime directly from the reaction of cyclohexane and liquid hydroxylamine derivative so that we can produce the oxime of that reaction, and we can make hydroxylamine to react easily with any ketone or any aldehyde and produce the corresponding oxime of that material. For example: cyclohexane or 5-nonyl salicylaldoxime and acetone are supposedly ketone that can react with hydroxylamine.

Materials and Methods

Several modes have been investigated in the synthesis of cyclohexanone oxime. Ammonia, cyclohexanone, catalyst, and finally hydrogen peroxide were introduced into the system in the first mode. Ammonia, hydrogen peroxide, catalyst, and cyclohexanone were added, in the second mode, to the system. All materials including ammonia, hydrogen peroxide, aluminum silicate catalyst, and cyclohexanone were entered into the system simultaneously in the third mode.

Adding cyclohexane at the beginning of the synthesis

First, aluminum silicate catalyst, ammonia, and cyclohexane were added to the balloon and it was stirred for 1.5 to 2 hours at a temperature of 75 degrees Celsius with a magnet. Then, hydrogen peroxide was added drop by drop to the solution inside the balloon through the dropping funnel over 1.5 hours. The solution inside the balloon, after the hydrogen peroxide was finished, was mixed again for half an hour, and the evaporated ammonia was returned to the balloon by the condenser during this time. Then the heater was turned off and the solution was poured into Falcon tube and the organic and aqueous substances were separated by biphasing. Then we give the achieved solution time to form the oxime.

Adding cyclohexane at the end of the synthesis

First, aluminum silicate catalyst, ammonia, and hydrogen peroxide were added to the balloon in this method, and it was stirred for 1.5 to 2 hours at 75 degrees Celsius with a magnet; then cyclohexane was added drop by drop through a dropping funnel to the solution inside the balloon for 1 and half hour. The hydrogen peroxide solution inside the balloon was mixed again for half an hour. Then we turned off the heater and poured the solution into the Falcon tube; the organic and aqueous substances were separated by biphasing. We give the achieved solution time to form the oxime.

Synthesis of cyclohexanone oxime in two steps

Ammonia, hydrogen peroxide, and aluminum silicate catalyst were added to the balloon and mixed with a magnet for 2-2.5 hours at 75 degrees Celsius. The catalyst was separated from the solution by a centrifuge after the reaction. Then cyclohexane was poured into the balloon alone and the achieved solution was gradually added to the cyclohexanone inside the balloon for one hour by means of a dropping funnel.

Synthesis of cyclohexanone oxime through aluminum silicate catalyst

First, aluminum silicate catalyst, ammonia, and cyclohexane were added to the balloon and it was stirred for 2 hours at 70-75 degrees Celsius with a magnet; then hydrogen peroxide was added drop by drop through a dropping funnel to the solution over 90 minutes. It was added inside the balloon. The solution inside the balloon was mixed again for 30 minutes after the completion of hydrogen peroxide. Then we turned off the heater and poured the solution into the Falcon tube; the organic and aqueous substances were separated by biphasing. We give the achieved solution time to form the oxime.

Effect of temperature on the efficiency of cyclohexanone oxime

This method used 1% aluminum silicate catalyst, 1.37 g/mol of ammonia, 1.56 g/mol of hydrogen peroxide, and 3.85 g/mol of cyclohexane. The reaction time was 5 hours and the temperature was changed between 65 and 85 degrees Celsius.

Effect of the amount of cyclohexane on the efficiency of cyclohexane oxime

This method used 1% aluminum silicate catalyst, 1.37 g/mol of ammonia, 1.56 g/mol of hydrogen peroxide, and 4.55 to 5.6 g/mol of cyclohexane. The reaction time was supposedly 5 hours and the temperature was fixed at 75°C.

Effect of hydrogen peroxide amount on the efficiency of cyclohexanone oxime

This method used 1% aluminum silicate catalyst, 1.375 g of ammonia, 1.5 to 1.2 g/mol of hydrogen peroxide, and 3.85 g/mol of cyclohexane. The reaction time was 5 hours and the temperature was changed to 75 degrees Celsius.

Effect of ammonia on the efficiency of cyclohexanone Oxime

This method used 1% aluminum silicate catalyst, 1.25 to 2 g/mol of ammonia, 1.56 g/mol of hydrogen peroxide, and 3.85 g/mol of cyclohexane. The reaction time was 5 hours and the temperature was changed to 75 degrees Celsius.

Effect of catalyst amount on the efficiency of cyclohexanone oxime

This method used 0.2 to 1% aluminum silicate catalyst, 1.375 g/mol of ammonia, 1.65 g/mol of hydrogen peroxide, and 3.85 g/mol of cyclohexane. The reaction time was 5 hours and the temperature was changed to 75 degrees Celsius.

Determining the optimal conditions for the synthesis of cyclohexanone oxime

The optimal conditions were determined in the amount of hydrogen peroxide, ammonia, cyclohexane, temperature, and the amount of catalyst after conducting the tests and analyzing their results. Then, the synthesis was carried out under optimal conditions using titanium oxide and aluminum silicate 3A and 5A catalysts to determine the best catalyst for the production of cyclohexanone oxime.

Addition of nonyl salicylaldoxime at the beginning of the synthesis

Aluminum silicate catalyst, ammonia, and nonyl salicylaldoxime were added to the balloon and it was stirred for 1.5 to 2 hours at 70 to 75 degrees Celsius using a magnet. Then, hydrogen peroxide was added drop by drop to the solution inside the balloon through the dropping funnel over 1.5 hours. As the hydrogen peroxide was finished, the solution inside the balloon was mixed again for half an hour, and the evaporated ammonia was returned during this time to the balloon by the condenser. Figure (1) describes fully the synthesis mechanism of nonyl salicylaldoxime. Then we turn off the heater and pour the achieved solution into the Falcon tube to separate the organic and aqueous phases. The produced oxime is diluted with toluene at a ratio of 1 to 10 after separating the organic and aqueous phases, and then a ratio of 1 1 of this material is mixed with copper sulfate II (blue cut). The amount of copper in the produced oxime is observable in diminishing the blue color of the blue cut [10].

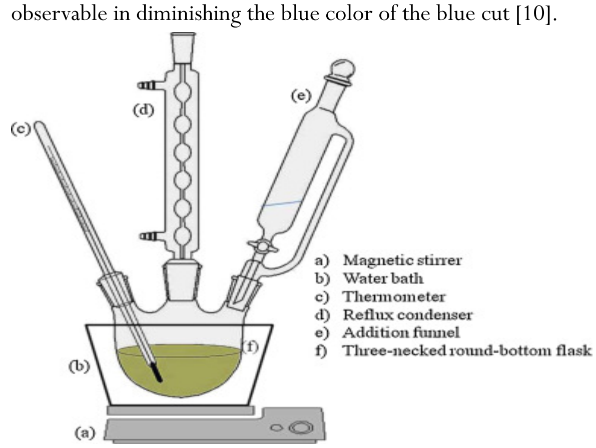

Figure 1. Synthesis of nonyl salicylaldoxime

Hydroxylamine sulfate

Aluminum silicate catalyst, ammonia, and hydrogen peroxide were added to the balloon and it was stirred by a magnet drop by drop for 1.5 to 2 hours at a temperature of 70 to 80 degrees Celsius. Sulfuric acid is added to the hydroxylamine in the environment outside the balloon, and then the reaction mixture of hydroxylamine and sulfuric acid is added to the balloon and placed in the balloon in the presence of the catalyst for 30 to 45 minutes until the reaction is complete. We remove the material from the balloon environment and place it at room temperature for 24 hours to settle the hydroxylamine sulfate. The precipitated hydroxylamine sulfate can be separated from its solution through a filter paper [11].

Results and Discussion

Figure (2) shows the result of FTIR analysis of cyclohexanone oxime adding cyclohexanone at the beginning of the synthesis without using water solvent. Peaks 2843 to 2977 are for the C-H bond, 3187 for the O-H bond, 1620 to 1690 for the C=N bond, and 700 to 1260 for the C-C bond.

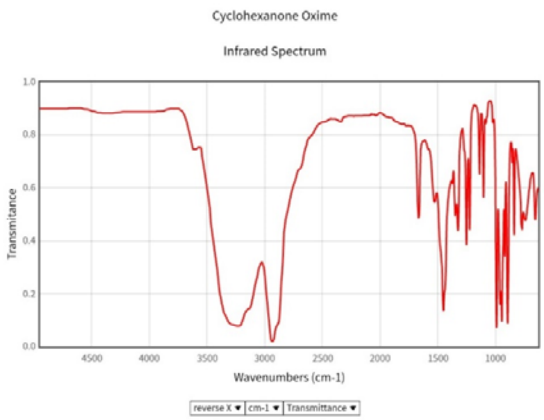

Figure 2. FTIR analysis of cyclohexanone oxime

FTIR analysis of cyclohexane oxime No. 1 is a formation of oxime at low temperature

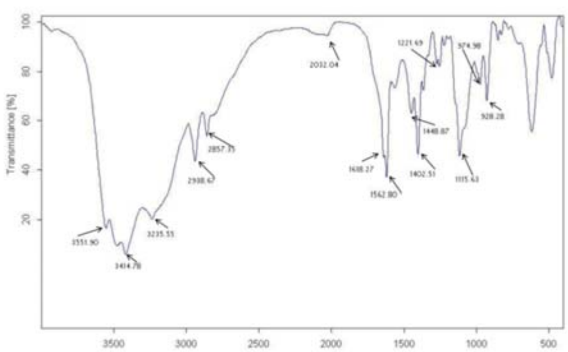

Figure 3. FTIR analysis of cyclohexane oxime No. 1

FTIR analysis of cyclohexane oxime No. 2 is a formation of oxime at ambient temperature.

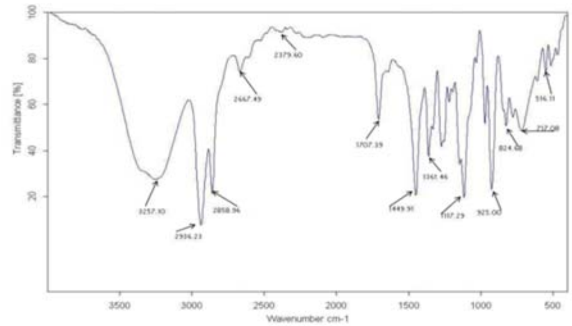

Figure 4: FTIR analysis of cyclohexane oxime No. 2

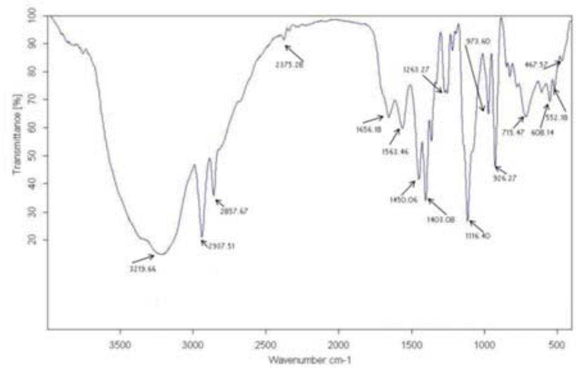

Figure 5. FTIR analysis of red oxime cyclohexane

The results show that adding cyclohexanone at the beginning of the reaction with ammonia has the highest efficiency in oxime production according to the type of catalyst.

Table 1. Results of Cyclohexanone oxime efficiency of adding cyclohexane at the beginning of the synthesis

Row	Aluminum silicate catalyst (percent)	Ammonia (g/mole)	Hydrogen peroxide (g/mol)	Cyclohexane (g/mol)	Temperature (°C)	Time (hours)	Efficiency (percent)
1	1	5	6	5.10	75	5	45
2	1	5	6	9.11	75	5	50
3	1	5	6	6.12	75	5	55
4	1	5	6	14	75	5	62
5	1	5	6	4.15	75	5	2.83
6	1	5	6	5.17	75	5	54.90

As the available studies show, if ammonia and hydrogen peroxide form hydroxylamine at the beginning of the reaction, this reaction must take place in the presence of a suitable catalyst, but the overall reaction does not take place because of the lack of a suitable catalyst, and this causes no formation of oxime at the end of the reaction.

Table 2. Results of the efficiency of adding cyclohexane at the end of the synthesis

Row	Aluminum silicate catalyst (percent)	Ammonia (g/mole)	Hydrogen peroxide (g/mol)	Cyclohexane (g/mol)	Temperature (°C)	Time (hours)	Efficiency (percent)
1	1	5	6	14	75	5	8.20
2	1	5	6	4.15	75	5	9.20
3	1	5	6	5.17	75	5	30

If we add cyclohexanone at the end of the reaction, oxime formation does not take place because of the non-formation of stable hydroxylamine at the beginning of the reaction, and the inappropriateness of the catalyst.

Table 3. Results of the efficiency of cyclohexanone oxime synthesis during two stages

Row	Aluminum silicate catalyst (percent)	Ammonia (g/mole)	Hydrogen peroxide (g/mol)	Cyclohexane (g/mol)	Temperature (°C)	Time (hours)	Efficiency (percent)
1	1	5	6	14	75	5	0
2	1	5	6	4.15	75	5	0
3	1	5	6	5.17	75	5	0

The cyclohexanone oxime was used in the amount of 3.5 to 4.9 g/mol in the synthesis in order to investigate the effect of hydrogen peroxide on the production efficiency of cyclohexanone oxime. The oxime production reaction, by adding hydrogen peroxide to the reaction medium, which contains ammonia and cyclohexanone, causes ammonia oxide. The addition of hydrogen peroxide in the reaction medium will not affect the reaction.

Table 4. Effect of the amount of hydrogen peroxide on the efficiency of cyclohexanone oxime

Row	Aluminum silicate catalyst (percent)	Ammonia (g/mole)	Hydrogen peroxide (g/mol)	Cyclohexane (g/mol)	Temperature (°C)	Time (hours)	Efficiency (percent)
1	1	375.1	5.1	85.3	75	5	65
2	1	375.1	65.1	85.3	75	5	67
3	1	375.1	8.1	85.3	75	5	68
4	1	375.1	95.1	85.3	75	5	70
5	1	375.1	1.2	85.3	75	5	75

The cyclohexanone oxime was used in the amount of 1.25 to 1.75 g/mol in the synthesis in order to investigate the effect of ammonia on the production efficiency of cyclohexanone oxime. Ammonia and cyclohexane have a direct mutual relationship in the reaction; so, the more ammonia is added to the environment, the production efficiency of oxime decreases. The reason is that the additional amount of ammonia does not react completely with cyclohexane and ammonia remains unreacted in the product and pollutes the environment, and this causes a decrease or non-formation of oxime at the end of the reaction.

Table 5. Effect of the amount of ammonia on the efficiency of cyclohexanone oxime

Row	Aluminum silicate catalyst (percent)	Ammonia (g/mole)	Hydrogen peroxide (g/mol)	Cyclohexane (g/mol)	Temperature (°C)	Time (hours)	Efficiency (percent)
1	1	25.1	56.1	85.3	75	5	5.70
2	1	375.1	56.1	85.3	75	5	9.67
3	1	5.1	56.1	85.3	75	5	8.65
4	1	87.1	56.1	85.3	75	5	6.63
5	1	2	56.1	85.3	75	5	5.62

The temperature was changed between 65 and 85 degrees Celsius in the synthesis in order to investigate the effect of temperature on the production efficiency of cyclohexanone oxime. The results showed that an increase in temperature between 65 and 75 degrees Celsius increases the formation of oxime and efficiency. The reaction does not proceed in the right direction at a temperature of 80 to 85 degrees, because of the greater condensation of ammonia and the destruction of the structure of cyclohexane. This causes the complete formation of oxime and decreases efficiency.

Table 6. Effect of temperature on the efficiency of cyclohexanone oxime

Row	Aluminum silicate catalyst (percent)	Ammonia (g/mole)	Hydrogen peroxide (g/mol)	Cyclohexane (g/mol)	Temperature (°C)	Time (hours)	Efficiency (percent)
1	1	1.375	1.56	3.85	65	5	9.67
2	1	1.375	1.56	3.85	70	5	8.68
3	1	1.375	1.56	3.85	75	5	5.70
4	1	1.375	1.56	3.85	80	5	4.69
5	1	1.375	1.56	3.85	85	5	67

The cyclohexanone oxime was used in the amount of 4.2 to 5.6 g/mol in the synthesis in order to investigate the effect of cyclohexane on the production efficiency of cyclohexanone oxime. As the results reveal, an increase in cyclohexane increases the efficiency of the reaction and oxime formation. The efficiency increases with the increase of cyclohexane. The reason is that the purity ratio is lower than the ideal value calculated for the reaction because of the industrial nature of the cyclohexane material and the presence of impurities; so increasing the amount of cyclohexane according to the purity percentage compensates for the complete lack of oxime formation.

Table 7. Effect of the amount of cyclohexane on the efficiency of cyclohexanone oxime

Row	Aluminum silicate catalyst (percent)	Ammonia (g/mole)	Hydrogen peroxide (g/mol)	Cyclohexane (g/mol)	Temperature (°C)	Time (hours)	Efficiency (percent)
1	1	1.375	1.56	2.4	75	5	5.63
2	1	1.375	1.56	55.4	75	5	8.65
3	1	1.375	1.56	9.4	75	5	3.67
4	1	1.375	1.56	25.5	75	5	8.69
5	1	1.375	1.56	6.5	75	5	7.70

An efficiency of about 70% was gained as a result of the formation of cyclohexane oxime with an aluminum silicate catalyst. This efficiency is because of the addition of the amount of catalyst for the type of catalyst and the type of synthesis because the catalyst becomes inactive according to time and temperature. Thus, adding the amount of catalyst up to one gram can solve this problem during synthesis.

Table 8. Effect of catalyst on the efficiency of cyclohexanone oxime

Row	Aluminum silicate catalyst (percent)	Ammonia (g/mole)	Hydrogen peroxide (g/mol)	Cyclohexane (g/mol)	Temperature (°C)	Time (hours)	Efficiency (percent)
1	2.0	1.375	1.56	3.85	75	5	9.49
2	4.0	1.375	1.56	3.85	75	5	8.54
3	6.0	1.375	1.56	3.85	75	5	3.61
4	8.0	1.375	1.56	3.85	75	5	8.65
5	1	1.375	1.56	3.85	75	5	5.69

The results determined the optimal conditions for the production of cyclohexanone oxime in efficiency. Table (9) gives these conditions.

Table 9. Optimal conditions for producing cyclohexanone oxime

Material	Amount (g/mol)
Hydrogen peroxide	6
Ammonia	5
Cyclohexanone	5.17
temperature	75

The effect of the type and amount of catalyst on the reaction efficiency of cyclohexanone oxime production was investigated after determining the optimal conditions of the reaction in the amount of raw materials and temperature. The results showed that increasing the amount of catalyst increased the reaction efficiency. At first, the effect of increasing the catalyst on the efficiency was noticeable, but this parameter did not affect the increase in efficiency at higher amounts of the catalyst. This research used an aluminum silicate catalyst because of the lack of the TS-1 catalyst (for the lack of this catalyst and the high price of the catalyst). A gradual increase in the amount of catalyst can increase the speed of the reaction and can advance the reaction in a better direction. Tables 5-10 give the results of this section.

Table 10. Diagram of the effect of catalyst type and amount on the reaction efficiency

Amount of catalyst (g/mol)	Titanium oxide	ZSM-5	Aluminum silicate 3A	Aluminum silicate 5A

2.0	12	14	16	27
4.0	30	33	40	53
6.0	38	43	53	70
8.0	41	53	64	84
1	45	60	73	91

4 syntheses were carried out with titanium oxide catalysts, ZSM-5 catalysts, and aluminum silicate catalysts 3A and 5A after determining the optimal conditions for the production of cyclohexanone oxime in order to determine the most effective catalyst for the production of this material. As the results showed, the type of catalyst has a great effect on the reaction efficiency of producing cyclohexanone oxime. Thus, the lowest efficiency was gained in the presence of titanium oxide catalyst, and the highest efficiency through aluminum silicate catalyst. Table (11) gives the full results of this section.

Table 11. Results of the effect of the type of catalyst on the reaction efficiency

Type of Catalyst	Efficiency (percent)
Titanium oxide	%45
Aluminum silicate 3A	%84
Aluminum silicate 5A	%91

Figure (6) shows the result of FTIR analysis of cyclohexanone oxime, adding cyclohexanone at the beginning of the synthesis without using water solvent. Peaks 2843 to 2977 correspond to the C-H bond, 3187 to the O-H bond, 1620 to 1690 of bond C=N, and 700 to 1260 correspond to the C-C bond.

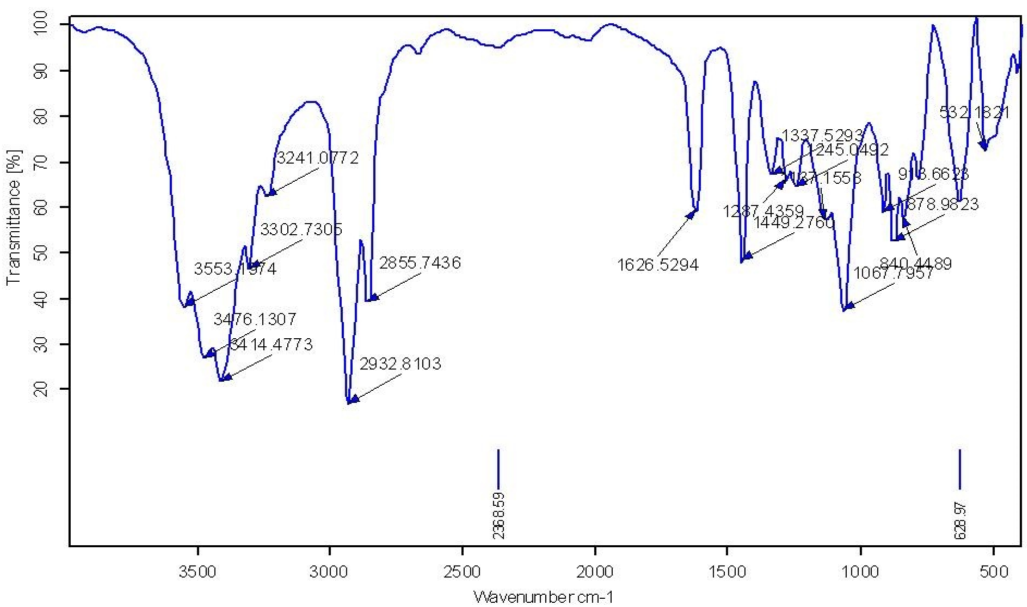

Figure 6. FTIR analysis of cyclohexanone oxime synthesized by aluminum silicate catalyst

Conclusion

As the results showed, if cyclohexanone is purer, the amount of cyclohexane in this reaction is, according to the molecular mass, almost half of ammonia and we have economically a more optimal production. Increasing the temperature on the production efficiency of cyclohexanone oxime is effective up to a certain temperature range and thereafter it has no effect. As for this reaction, increasing the temperature up to 75 degrees helps the reaction efficiency, and it is almost ineffective from 75 to 85 degrees. The effect of ammonia on the efficiency of the reaction is such that if the amount of ammonia is more than the specified value, the complete reaction will not take place and it will not react. It remains at the end of the reaction and prevents the formation of the true oxime.

We investigated the effect of hydrogen peroxide on the efficiency of the reaction. As long as ammonia is present in the environment, increasing its amount leads to an increase in the efficiency of cyclohexane oxime, and its additional amount has no effect on the reaction; only an additional material is added to the reaction medium and causes waste of raw materials. Because hydrogen peroxide enters the environment for oxidation with ammonia, which later reacts with cyclohexanone as hydroxylamine. If the effect of increasing cyclohexanone in the reaction of oxime formation, according to the purity and molecular mass, is added to the reaction, the reaction with higher efficiency is progressing in the direction of product efficiency, otherwise, we will have additional cyclohexanone in the reaction medium, which prevents the formation of oxime. We investigated the effect of different catalysts on the production efficiency of cyclohexanone oxime, and we slightly ground the catalysts so that the contact surface of the catalyst with the materials during the reaction was done faster. We evaluated also the use of catalysts for greater efficiency. The results show that as long as the amount of the catalyst is not reduced, i.e. the catalyst is still in the reaction environment, it will not affect the reaction efficiency negatively, and the use of the aluminum silicate catalyst 3A and 5A has the highest efficiency in oxime production up to 91%.

As the results reveal, it is recommendable to use the aluminum silicate catalyst, investigate its effect on the production efficiency of cyclohexanone oxime, recycle the catalyst, and use it to produce cyclohexanone oxime.

Conflict of interest: None

Financial support: None

Ethics statement: None

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