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HIERARCHICAL ZEOLITE ZSM-5 FRAMEWORK ON THE SYNTHESIS AND CHARACTERIZATION FOR CATALYTIC CRACKING OF FLUID: A MINI REVIEW

(Kerangka Hierarki Zeolit ZSM-5 Terhadap Sintesis san Pencirian untuk Pemecahan Pemangkin Cecair: Sebuah Ulasan Ringkas)

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Abstract

This review discusses the modified hierarchical framework of zeolite ZSM-5 through top-down and bottom-up techniques, which progressed via a soft template through a combination of dealumination and desilication. Several experiments have been reviewed to increase the catalytic cracking performance of Z SM-5 zeolite, including fluid catalytic cracking (FCC) activity. Template-assisted or post-treatment procedures may be used to create hierarchical zeolites, with mesopores or macropores boosting the accessibility of acid sites in micropores and the hierarchical pore structure. The physiochemical characterization investigation revealed that the hierarchical catalysts had a substantial surface area and pore characteristics compared to the parent samples, making them an attractive alternative to be used in the FCC catalyst. It is important to develop a low-cost and effective process for manufacturing hierarchical zeolite.

Keywords: Zeolite Socony mobile five, modification of hierarchical framework, fluid catalytic cracking, catalytic activity

Abstrak

Ulasan ini membincangkan kerangka hierarki zeolite ZSM-5 yang diubah melalui teknik atas ke bawah dan bawah ke atas, yang berkembang melalui templat lembut melalui gabungan dealuminasi dan desilikasi. Beberapa eksperimen telah dikaji untuk meningkatkan prestasi pemecahan pemangkin zeolite ZSM-5, termasuk aktiviti pemecahan pemangkin cecair (FCC). Prosedur yang dibantu templat atau pasca rawatan boleh digunakan untuk menghasilkan zeolite hierarki, dengan mesopori atau makropora meningkatkan capaian asid di mikropori dan struktur pori hierarki. Penyelidikan pencirian fisiokimia menunjukkan bahawa pemangkin hierarki mempunyai ciri luas permukaan dan liang yang besar jika dibandingkan dengan sampel induk, menjadikannya alternatif yang menarik untuk digunakan dalam pemangkin FCC. Dalam penghasilan hierarki zeolite,proses kos yang rendah dan berkesan adalah menjadi keutamaan.

Kata kunci: Zeolite Socony Mobile five, modifikasi hierarki rangka-kerja, pemecahan pemangkin cecair, aktiviti katalitik

Introduction

Zeolites are microporous aluminosilicate minerals that serve as heterogeneous catalysts in a variety of applications including petroleum refining, oil refineries, fluid catalytic cracking (FCC), oligomerization, esterification, alkylation, and acylation [1]. Zeolite is a crystalline inorganic polymer that is mostly composed of tetrahedral [SiO_4] and [AlO_4] ions and water molecules [2]. Recently, scientists have paid close attention to Zeolite Socony Mobil 5 (ZSM-5) because of its outstanding chemical conversion in several industrial sectors [3]. A prior study confirmed that the ZSM-5 zeolite has been expanding zeolite application as a catalyst and adsorbent in many areas due to its molecular sieving properties, great surface acidity, strong hydrothermal stability, large Si/Al proportions (from tens to hundreds), and environmentally friendly synthesis [4, 5].

Nowadays, research on zeolite is focusing on customizing its acidity and porosity beyond mesoporous capability [6]. In fact, its high acid centre and structure selectivity make it as an interesting catalyst in organic synthesis, primarily for cracking reactions. Another research also stated that zeolite ZSM-5 has been applied as a catalyst in a wide variety of chemical activities such as cracking, isomerization, and alkylation [7]. Meanwhile, a study done by Widayat et al. [8] discovered that cracking is a process that is widely applied in research and industrial applications, primarily in fields especially involved hydrocarbons. Regrettably, the hydrocracking process is typically forced to involve relatively high temperatures, which can be hazardous to the environment. Thereby, transition metals, silica, zeolite-modified zeolite, mesoporous mixed oxide catalyst, and metal organic frameworks have been used in catalytic cracking. As it is an effective catalyst for oil cracking due to its high temperature stability, microcrystalline shape, and propensity to precipitate reactants trapped in pores, ZSM-5 zeolite is thus particularly important for the catalytic cracking process [8]. Thus, this review is intentionally to gather all information and related data to ZSM-5 in catalytic cracking. Zeolites are extremely useful as catalysts for several important reactions involving organic molecules. The most important are cracking, isomerisation and hydrocarbon synthesis. Zeolites can promote a diverse range of catalytic reactions including acid-base and metal induced reactions.

Hierarchical ZSM-5 is a type of zeolite catalyst that has been modified to contain both micro- and mesopores, which increases its surface area and enhances its catalytic activity. This modification is achieved by a post-synthesis treatment, which involves the removal of some of the material that fills the micropores of the zeolite. While hierarchical ZSM-5 has shown promising results in various catalytic reactions, including the conversion of biomass to fuels and chemicals, there are some concerns about the reproducibility and scalability of the synthesis method. Some studies have reported variations in the performance of hierarchical ZSM-5 catalysts depending on the synthesis conditions, which may limit their practical application. Furthermore, the precise mechanisms by which the hierarchical structure enhances the catalytic activity of ZSM-5 are not yet fully understood. This makes it challenging to design and optimize hierarchical ZSM-5 catalysts for specific catalytic reactions. Therefore, a review of the hierarchical ZSM-5 synthesis method is needed to evaluate the reproducibility and scalability of the method and to provide insights into the mechanisms underlying the enhanced catalytic activity of hierarchical ZSM-5. Such a review can help to identify areas for further research and development, ultimately leading to more effective and practical catalysts for various industrial applications.

Development of hierarchical zeolite ZSM-5 (HR-ZSM-5)

A research revealed that the conventional microporous ZSM-5 has limited pores and diffusion channels, hence limiting its use [9]. According to Jia et al. [10], the typical crystal size of standard ZSM-5 zeolites is in micrometre or submicrometer, which lengthens the retention time of macromolecular intermediates and products in the inter channel. Consequently, the small pores of such zeolites are susceptible to be clogged rapidly due to coke deposition, accelerating the deactivation process of zeolite catalysts. Nonetheless, Speight’s study discovered that catalytic cracking of gas oil can result in the production of coke because it is a heat-absorbing process, indicating that heat is absorbed by the process and the temperature of the reaction mixture decreases as the reaction progresses, necessitating the need for a heat source [11]. This heat is generated by the burning of coke produced throughout the operation. Coke is a significant, yet unfavourable, by product of cracking because it occurs on the surface and in the pores of the catalyst throughout the cracking process, blocking active sites and disabling them. In the meantime, diffusion issues come up within the zeolite crystals when large reactants or products are applied, causing in pore clogging in both conventional and non-traditional chemical reactions. Widayat et al. [8] concurred that the function of zeolite as a catalyst is confined by its minute pores, which impede the diffusion of bigger particles during the mass transfer process. Hence, ZSM-5 zeolite will be modified to maximize the surface porosity. Several strategies have been investigated to enhance the structure of ZSM-5 zeolite. According to a new finding by Talebian-Kiakalaieh and Tarighi [1] found that modified zeolites encompass mesoporous materials, large-cavity, nanosized zeolites, hierarchical zeolites, and ultra large-pore zeolites. Nanosized zeolite crystals have low product yields, and zeolites generated with only a mesoporous framework are pricy, hence their applicability are confined. They suggested that the zeolite ZSM-5 framework will be developed to include hierarchical zeolites with microporous and mesoporous structures, which will have a high economic value. Přech et al. [12] also agreed that micropores and mesopores coexist in hierarchical zeolites, helping reactants and products to diffuse more efficiently. This triggered to development of hierarchical zeolite ZSM-5 as mentioned below.

The development of hierarchical ZSM-5 zeolite can be done in a variety of ways. Again, Jia et al. [10] postulated that hierarchical zeolite ZSM-5 can be produced using both bottom-up and top-down methods. These methods include desilication (base leaching) and dealumination (acid leaching). According to Talebian-Kiakalaieh and Tarighi [1], it is ideal to add a post-synthesis treatment that includes desilication and dealumination, coupled with soft tessellation with surfactant and steaming, in order to produce a stable zeolite ZSM-5. Furthermore, Peron et al. [13] emphasized that combining desilication with dealumination may be the optimum way for generating hierarchical zeolites with the appropriate balance of mesoporosity, crystallinity, and acidity. On the other hand, soft templating seems to be more versatile owing to the ease with which it can be implemented and, more importantly, due to the fact that it can alter mesoporosity from inside the zeolite framework [1].

In order to effectively synthesize hierarchical ZSM-5 zeolites with high mesoporous and hierarchy factors, a new soft template was developed and employed as a mesoporogen [14]. During the high-temperature hydrothermal crystallization process, the covalent link of Si-O-Si between the as-produced soft template and the mordenite framework inverted (MFI) frameworks maintains a constant connection. The structure of this soft-connection template's mode efficiently prevents the production of amorphous materials, and it may introduce several mesopores while using few micropores. The particles of as-synthesized hierarchical ZSM-5 zeolites about 1 µm in size and made of nanocrystals of 60-150 nm. These hierarchical samples exhibit excellent tolerance for hydrothermal treatment due to the nature of zeolite and it possesses a considerable microporosity. Additionally, the hierarchical structure exhibits excellent catalytic performance in the reactions of alkylation between benzene and benzyl alcohol, cracking of 1,3,5-tri-isopropylbenzenenzene, and thermal cracking of low-density polyethylene (LDPE), respectively, due to the intra-crystalline mesopores, large external surface areas, and abundantly accessible acid sites.

Acidity may be modified or rectified by the metal ion-exchange process and pre-treatment or post-synthesis treatment can be used to improve other structural properties. As an example, it can state unequivocally that alkali treatment is an efficient and straightforward way for creating mesoporous medium, which reduces channel length and corrects the diffusion restriction. As a result of this change, access to active sites has increased. Moreover, several attempts have been undertaken to optimize the Si/Al ratio or the synthesis working parameters, such as temperature and stirring duration [15].

By adding ZSM-5 zeolite with 65:1 SiO_2/Al_2O_3 ratio, HR-ZSM-5 zeolite was successfully created [1]. The mesoporous structure of the synthesized ZSM-5 zeolite was induced in the second step using the desilication, dealumination, and soft tessellation techniques. This method produces desilicated ZSM-5 by heating synthesized ZSM-5 for an hour at 80 °C with 50 wt.% NaOH solution in deionized water. Before being dried overnight, the mixture was properly cleaned and filtered. They dealuminized the ZSM-5 zeolite in their experiment by soft-templating with surfactant after three hours of acid leaching with H_2SO_4 solution at 80 °C cetrimonium bromide (CTAB). Each 20 g of desilicated or dealuminated ZSM-5 was dissolved in a 0.3 M NH_4OH solution containing CTAB, and then subjected to a hydrothermal procedure at 150 °C. They claimed that the final HR-ZSM-5 has undergone three successive phases of ion exchange with 1 M NH_4OH solution (80 °C, 2 h), and the powder has then been calcined at 550 °C for five hours before being applied to the fluid catalytic cracking (FCC) catalyst.

Effect of HR-ZSM-5 on the physiochemical properties

Due to their exceptional physical and chemical characteristics, zeolites such as ZSM-5 and ZSM-11 are frequently explored for catalytic cracking of big molecules. Distribution, strength of active sites, and acidity of zeolites are the most crucial elements for improving the catalytic performance of a process [16, 17]. In addition, the pore size and shape of zeolites are critical in influencing the selectivity and yield of the desired products. Consequently, it is vital to comprehend the structure-activity connection of zeolites in order to build effective catalysts for a variety of industrial processes.

Initially, the ICP-OES was used to determine the chemical composition of the parent and hierarchical zeolites that were produced (Table 1) [1]. The hierarchical HR-ZSM-5 (86.34) and parent ZSM-5 (65.55) SiO_2/Al_2O_3 ratios demonstrated that the hierarchical sample had a higher SiO_2/Al_2O_3 ratio than the parent ZSM-5. The increasing of SiO_2/Al_2O_3 ratio was due to the acid leaching by H_2SO_4 after base leaching with NaOH. Research done by Talebian-Kiakalaieh and Tarighi [1] reported that the specific surface area (S_{BET}) (Table 1) of parent ZSM-5 zeolite was 399 m^2/g which then increased to 462 m^2/g. In fact, the pore volume (V_p) showed an improvement in value from 0.20 to 0.59 cm^3. The average pore diameter (D_p) of parent formed when compared to hierarchical samples, showed a significant rise from 2.01 to 5.07 nm [1]. Large pores which might be attributed to the big holes in HR-ZSM-5 via framework dealumination/desilication processes and broad pores which could be generated from the transition of micropores to mesopores initiated by using surfactant for alteration. In their experiment, the mesoporous pore showed significant development when the parent ZSM-5 increased from 0.06 to 0.47 cm^3/g of HR-ZSM-5. These findings revealed that acid/base treatments of ZSM-5 zeolites, as well as the soft templating process, resulting in the development of outstanding hierarchical zeolites. Meanwhile, Wang et al. [15] experiment postulated that the N_2 adsorption–desorption isotherm of ZSM-5 zeolite sample obtained, has features of both type I and type IV(a) profiles with two steep uptake steps, one at $P/P_0 <0.02$ and the other at $0.45 <P/ P_0< 0.90$, which corresponded to micropore filling and mesopore capillary condensation, respectively. Unnikrishnan and Sabarish [18] agreed that the unaltered sample has the type I isotherm, which was the characteristic isotherm for microporous materials. The changed sample, on the other hand, has type IV isotherm. They added that BJH model was used to analyse the pore size distributions of the samples. Unmodified and adjusted sample pore diameters are predicted to be 2 and 10–20 nm, respectively. As a result, the increased mesoporosity in ZSM-5 zeolite was formed in their study. The porosity of ZSM-5 zeolite influences molecular adsorption, separation, and diffusion and among the dominating factors affecting its catalytic activity[19].

The PXRD patterns of parent ZSM-5, base/acid leached ZSM-5, and hierarchical HR-ZSM-5 samples, as shown in Figure 1a, were all identical to the standard ZSM-5 peaks, with no extra unexplained peaks, demonstrating that all of the synthesised samples were true MFI-type material [13]. There were no significant changes in the intensity, breadth, or location of the XRD peaks after dealumination and desilication of the ZSM-5 catalyst. Moreover, no specific peaks associated with the amorphous phase have been discovered. According to Ghrib et al. [20], the growth of ZSM-5 crystallizations were more difficult to detect owing to their tiny size. Earlier study found that both the parent ZSM-5 zeolite and the hierarchical sample had a decrease in reflection intensity [1]. The insertion of mesopores into parent zeolite results in a decrease in crystallinity and a broadening of peak width, confirming the scission of Al-O bonds and the formation of hydroxyl nests (cavities), which caused the unit cell sizes to expand with the desilication treatment because of selective silicon extraction, resulting in larger unit cell sizes. Yang et al [6] discovered a dense pore opening on the surface crystallite of the hierarchical zeolite. FESEM and HRTEM images (Figure 1b) further confirmed mesopores structures have been observed throughout the zeolite matrix.

Meanwhile, Jia et al. [21] shown in their experiment that the asymmetric stretching of SiO_4 and AlO_4 tetrahedra in the zeolite framework is believed to be due to vibrational modes around 547 and 1222 cm^{-1}, respectively. Another research discovered the distinctive bands in the FTIR spectra of parent ZSM-5 and hierarchical HR-ZSM-5 samples corresponded to internal and exterior symmetric and asymmetric stretching, double ring vibrations, and T-O bending, as shown in Figure 1c, demonstrating that the pure ZSM-5 phase was found in both samples [1]. In Sabarish and Unnikrishnan's work [18], NH_3-TPD analysis was used to investigate the acidity of the synthesized parent and hierarchical ZSM-5 zeolite. They claimed that the hierarchical sample had a 16.5% lower total acidity than the parent sample. When the framework Al atom was removed, the overall acidity of the hierarchical zeolite was reduced. Figure 1d shows the acidity profiles of synthesized ZSM-5 and HR-ZSM-5, with two peaks in the weak and medium regions. According to them, the strength of medium acidity fell dramatically following the base/acid washing and soft templating processes. The low-temperature peak indicated NH_3 molecule desorption from weak acid sites, while the high-temperature peak represented NH_3 molecule desorption from strong acid sites [18]. The formation of a mesoporous framework resulted in a little decrease in the intensity of the surfactant-modified sample.

As mentioned earlier, the acidity plays a major role in the fluid cracking process. In this type of reaction, the existence of a strong acid sites can significantly alter the catalyst's performance. Based on NH_3-TPD analysis done by Emori et al. [22], the standard zeolite had acid sites capable of adsorbing ammonia on its surface. Their result showed low Si/Al ratio which explained the elevated acidity (large amount of acid sites). High acidity prevails when the aluminium acid sites, one of the acidity sources on zeolitic materials, are separated in this structure. These aluminium atoms were more acidic than those closer together in the zeolite structure. Again, Talebian-Kiakalaieh and Tarighi [1] also postulated that the HR-ZSM-5 sample demonstrated a 36% drop in overall acidity when compared to the parent ZSM-5 which due to the removal of Si or Al atoms from the zeolite framework [1]. Desilication resulted in a decline in Brönsted acidity, as well as a minor rise in Lewis acid sites, which had similar consequences.

Table 1. ICP-OES analysis and result of N_2 adsorption-desorption for the ZSM-5 and HR-ZSM-5[1]

Sample	**SiO_2**	**Al_2O_3**	**SiO_2/Al_2O_3**	**S_{BET} (m^2/g)**
ZSM-5	72.11	1.10	65.55	399
HR-ZSM-5	87.20	1.00	87.20	462

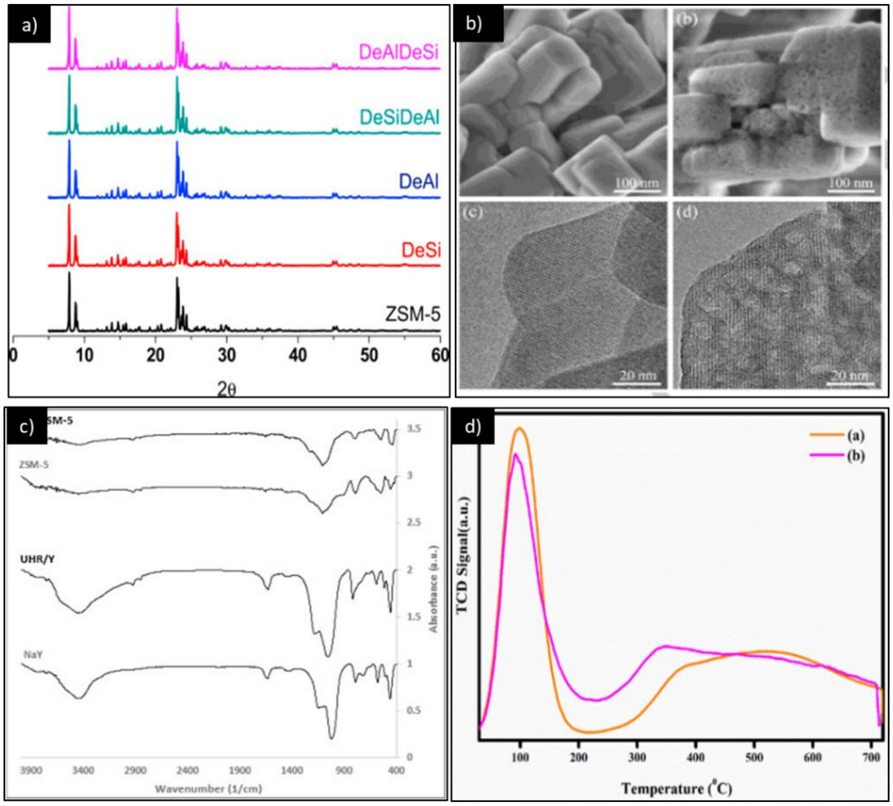

Figure 1. a) PXRD pattern for ZSM-5 [13], b) FESEM and HRTEM images of hierarchical zeolites [6], c) FTIR spectra for ZSM-5 and HR-ZSM-5 [1] and d) NH_3-TPD analysis of a) ZSM-5 b) HR-ZSM-5 [18]

According to Kantarelis et al. [23], the hydrothermal stability of the zeolite was critical for cleaning up coked catalysts. Moreover, they noted that post-treatment procedures increased the thermal stability of hierarchical samples by transforming the original zeolites' microporosity to a structure containing mesopores. Figure 2a depicted the impact of desilication on zeolite thermal stability, which they indicated had no influence on thermal stability as tested [23]. This is shown by the comparability of the mass and DSC curves following heating in an oxidative atmosphere. The observed differences in the two samples' actual thermal deterioration were linked to physiosorbed water, which happened when the samples were exposed to the atmosphere before being tested. Another study proposed that the synthesized parent and hierarchical zeolites in Figure 2b exhibited a single small weight loss in the 80-200 ℃ range, corresponding to physically adsorbed water and demonstrating the strong heat thermal of the catalysts [1]. Additionally, no weight loss was observed at temperatures beyond 200 °C, indicating that the catalysts were thermally stable. The high crystallinity explains the remarkable thermal stability of HR-ZSM-5. In contrast to the first assertion, Widayat and Annisa [8] proposed that the morphology of synthesized ZSM-5 was amorphous (Figure 2c-2d). The surface structure of the catalyst clustered together, while commercial ZSM-5 exhibited a separated structure owing to its very high crystallinity. However, as shown in Figure 2e-f, SEM pictures corroborated the hexagonal shape of ZSM-5 crystals with a size of that generated larger agglomerates [1].

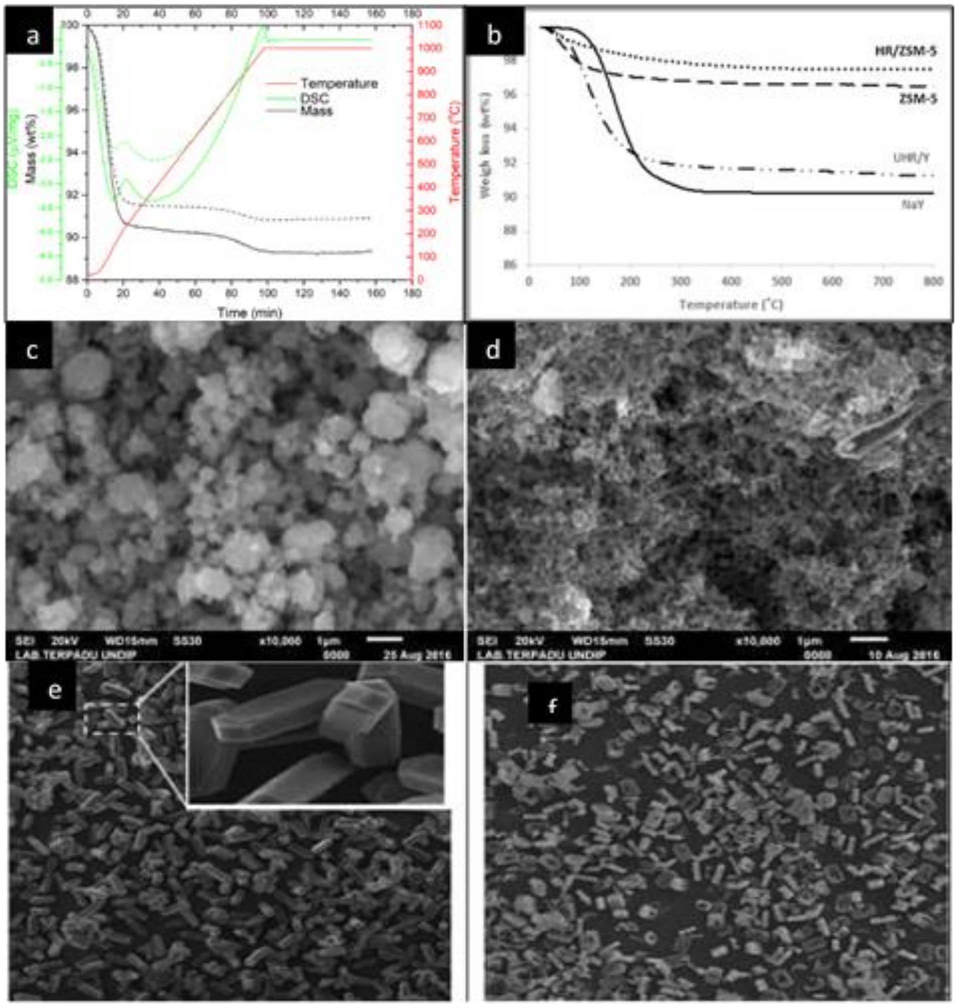

Figure 2. a) The effect of desilication on zeolite thermal stability [23], b) The result of TG-DTA plots for parent ZSM-5 and HR-ZSM-5 [1], c) SEM images of a HR-ZSM-5 and d) SEM images of ZSM-5 [8], e) SEM image of ZSM-5 and f) SEM image of HR-ZSM-5 from different source [1]

Fluid catalytic cracking of gas oil

Fluid catalytic cracking (FCC) has emerged as the primary force behind oil refining performance improvement since its inception in 1942 [16, 24]. It has been discovered over time that FCC is a flexible process that can transform feeds of various origins, including vacuum oils, residual oils, crude oil, scrap tires, pyrolysis oil, polyethylene plastic waste, and biomass derived oils, into high value transportation fuels and light olefin feeds for the petrochemical industry [25, 26]. The feedstock quality has the greatest influence on the performance of the FCC unit (FCCU) across all independent factors [27]. The processing of secondary gas oils (from cokers, visbreakers, and residual hydrocrackers) is more difficult than the processing of straight run vacuum gas oils (SRVGOs) in the FCCU [16]. Secondary gas oils do in fact have larger levels of refractory condensed aromatic compounds and basic nitrogen [28]. Hence, the quantity and quality of the secondary gas oil fraction present in the FCC feed mix are directly associated to the performance of the FCCU [29, 30].

It has been reported that Microactivity Test (MAT) apparatus was used to catalyze the catalytic cracking of gas oil [12]. The catalyst activity test was conducted in the MAT unit (ASTM-D3907), which was a plug flow reactor (PFR) for cracking vacuum gas oil (VGO). The principal constituents of the cracking products, were hydrocarbons, oxygenated chemicals (mostly water, CO, and CO_2), and coke [12]. The gaseous hydrocarbon component was divided into dry gas (hydrogen, methane, ethane, and ethene) and liquefied petroleum gas fractions (LPG; propane, propene, butenes, and butanes). There are three different liquid hydrocarbons; C_{5+} gasoline (212 °C), light cycle oil (LCO; 221-360 °C), and heavy cycle oil (HCO; >360 °C), and these cracking products were examined using specific analytical tools including the MAT unit. The formula for the typical MAT conversion is $(Y_{HCO} + Y_{LCO}) = 100\%$. The selectivity of propene has been calculated as a proportion of all C_3 hydrocarbons (C_3 olefinicity). The selectivity of butenes in total C_4 hydrocarbons is expressed as a percentage (C_4 olefinicity).

Meanwhile, according to Ibarra et al. [13], the catalytic cracking of the VGO was carried out in riser simulator. The product stream was collected from the reaction chamber using a fast-triggered vacuum pump attached to an auxiliary chamber (30 cm^3), and then evaluated online using gas chromatography (GC). They stated that the mass loss after burning of spent catalysts in a TGA-Q 5000 TA Instruments thermobalance, from 300°C to 550°C at a 3°C min^{-1} heating rate, was used to determine the amount of coke. Meanwhile, in literature experiment, they highlighted that VGO has been injected into the catalyst bed at a rate of 55 ml/h using a syringe pump in the presence of N_2 as the inert carrier gas (5–10 ml/min) at the correct temperature [1].

Equation. (1) and (2) have been used to determine the reaction conversion product yields:

$$Conversion(\%) = \frac{W_f - \frac{R \times W_i}{100} - W_Q}{W_f} \times 100 \quad (1)$$

$$Yield(\%) = \frac{W_i - X_i}{W_F} \times 100 \quad (2)$$

W_f is injected feed weight (g), W_L is liquid product weight (g), R is weight percentage (wt%) linked to the product evaporated up to 216℃, W_Q is liquid held up at reactor outflow (g) and W_i is each product's mass fraction [1].

Effect of HR-ZSM-5 mesoporous on the FCC activity

This section explored the effect of mesoporosity of synthesised hierarchical zeolites (HR-ZSM-5) on FCC catalyst activity and stability for the transformation of VGO to value-added chemicals such as gasoline, propylene, and olefins. It has been reported that zeolites with a mesoporous structure were able to boost the interaction between catalyst active sites and bulky molecules of feedstock (VGO) and ultimately increase the production of value-added chemicals such as gasoline, propylene, and olefins [1]. The reaction conversion (99.2%) and propylene yield (16.41 wt.%) obtained in their study were the highest than those obtained in the previous studies as shown in Figure 3, indicating that the synthesized FCC-4 catalyst had significant activity. Besides, García et al. [31] agreed that large molecules can be cracked more easily with hierarchical zeolites, which also provided selectivity for bulky intermediates. Furthermore, it was obvious that coke was formed at a faster rate for hierarchical catalysts but due to the presence of more saturated hydrocarbon molecules that resist in a hierarchical catalyst, coke that forms in a mesoporous structure would be easier to burn in the regenerator.

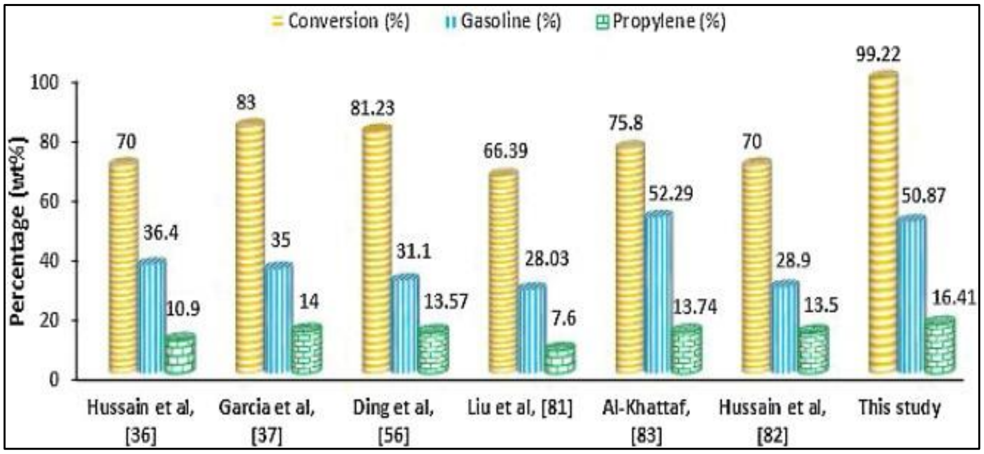

Figure 3. The analysis efficiency of FCC catalysts to other publications. The conversion, gasoline, and propylene yields were shown in comparison [1].

A recent study has discovered four different forms of fluid catalytic cracking (FCC) using HR-ZSM-5 zeolite, that was created by mixing the basic components, which include P_2O_5@ZSM-5, kaolin, Al_2O_3, $Ce(NO_3)_3.7H_2O$, and a binder [1]. Cerium has been used to control zeolite acidity while increasing catalyst acidity in the FCC catalyst framework. The FCC catalyst in a specific form was generated by placing the slurries in a spray dryer with an initial temperature of 210 °C and a mixing speed of 300 rpm. The catalyst was calcined for 4 hours at 650 °C. In another work, diammonium phosphate ($H_9N_2O_4P$) was immersed in distilled water to infuse with P_2O_5, then HR-ZSM-5 zeolite was added and refluxed for 2 hours [1]. The mixture was then dried for 12 hours at 70 °C before being calcined for 3 hours at 500 °C. Three distinct binders were employed in the manufacturing of FCC catalysts: alumina sol, a colloidal silica dispersion with an alkaline 40% aqueous dispersion (LUDOX-40), and alumina silica sol. It has been reported that the alumina sol binder was created by preparing 10 mL $Al(NO_3)_3.9H_2O$ solution (1 M), and 2.3 mL NH_4OH (25 wt.%) one drop at a time, and eventually adjusting the pH up to 4. Additionally, 1 g of aluminium sulphate was dissolved in 50 mL of water and the pH was adjusted to 2.5 by adding 20% H_2SO_4 dropwise. The physical and chemical characteristics of the FCC catalysts varied according to the use of various binders, with the alumina sol binder yielding the maximum activity and selectivity. The researchers also discovered that the calcination temperature had a substantial influence on catalyst performance, with higher temperatures leading to a lower activity and selectivity. This agglomeration in a meso and macroporous matrix results in the development of a hierarchical porous structure in the catalyst particle, which allows for sequential reactant dispersion and partial cracking of larger feedstock molecules, followed by cracking of the resulting chains within the catalyst's micropore structure.

Conclusion

Ultimately, the modified hierarchical framework of zeolite ZSM-5 through top-down and bottom-up techniques, which progressed via soft template through a combination of dealumination and desilication, has been comprehensively explained. Several experiments have been undertaken to increase the catalytic cracking performance of ZSM-5 zeolite, including catalytic cracking activity. Factors influencing ZSM-5 zeolite catalytic performance were reviewed from the viewpoints of ZSM-5 zeolite with particular shape, hierarchical ZSM-5 zeolite, and acid characteristics. By incorporating ZSM-5 zeolite with hierarchical structure, the diffusion length of a molecule may be lowered and the diffusion efficiency of a molecule can be raised. Template-assisted or post-treatment procedures may be used to create hierarchical ZSM-5 zeolites. The inclusion of mesopores or macropores boosted the accessibility of acid sites in micropores, resulting in ZSM-5 zeolite with a hierarchical pore structure, which is particularly advantageous for post-treatment procedures that improve catalytic cracking efficiency. Characterization investigation revealed that the hierarchical catalysts had a substantial surface area and pore characteristics compared to parent samples. Moreover, the hierarchical zeolites demonstrated exceptional hydrothermal stability, making them an attractive alternativeto be used in FCC catalyst. Above all, options to increase catalytic cracking performance are still being evaluated in the laboratory, and it is critical to develop a low-cost and effective process for manufacturing hierarchical ZSM-5 zeolite. Hence, the catalytic cracking performance may be increased by inserting hierarchical ZSM-5 zeolite.

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