Intelligent Materials such as Rare Earth Elements on High-tech Materials Engineering for Catalysis and Environmental Applications

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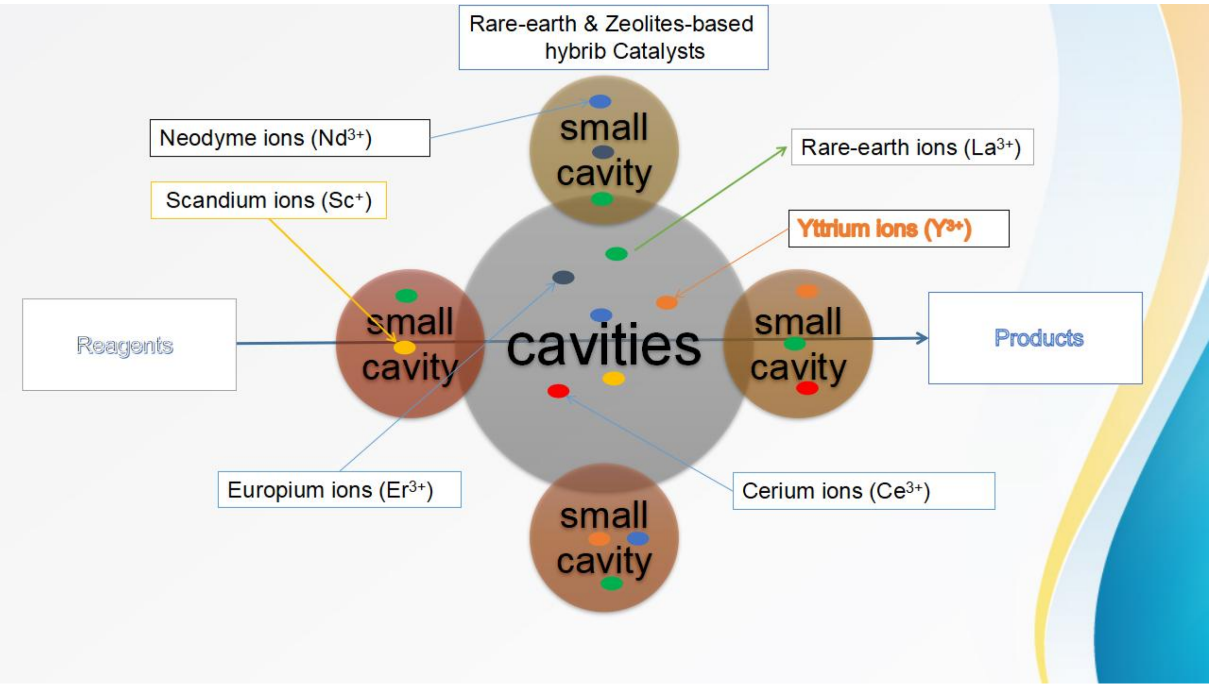
Abstract

Materials engineering and catalysis are known as central sciences, which can deeply contribute to the technological development of our nations, and as well as ensure the environmental protection and cleaning from both organic and inorganic contaminants. So, the generation of the most wanted chemical and fuels such as (CH_4) or to carbon monoxide (CO/H_2), methanol (CH_3OH) or even to hydrogen (H_2) and ammonia (NH_3) requires strongly active, selective, stable, and as well as reusable materials (catalysis) to fulfill the mankind needs. The determination and removing both inorganic and organic are highly regarded special issue in healthcare. So that, all these areas strong materials for the complete transformation of these chemical products. Indeed, zeolite materials are very explored in the recent years as they present advanced properties in both catalysis and environmental concerns. Also, its combination with transition noble and non-noble metals are also considered in order to boost the catalytic yields. In fact, here, it is ascribed the role of transition rare-earth (RE) elements in the hybrid materials engineering for advanced technological applications. It demonstrated that rare earth oxides might enhance catalytic features and avoid the loss of acid sites under the fluid catalytic craking (FCC) unit operation. Moreover, It is shown that (RE) elements might be used for materials engineering for high-tech uses such as in hydrogen evolution reaction (HER), methanol oxidation reaction (MOR), oxygen evolution reaction (OER), and oxygen reduction reaction (ORR). Many other reactions can be realized over hybrid materials made via the use of rare earth (RE) elements with improved catalytic performances. Therefore, due to the large properties of transition rare-earth (RE) metals, more possible superb materials will be engineered in upcoming generation.

Keywords: Rare-Earth-modified-Materials, Catalysis, Environments, Zeolites, Engineering, Technologies

Graphical Abstract



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1. Introduction

Materials engineering and catalysis are known as central sciences, which can deeply contribute to the technological development of our nations, and as well as ensure the environmental protection and cleaning from both organic and inorganic contaminants. So, the design and synthesis of powerfully performance materials are required for many technologies, such as in conversion of higher hydrocarbons to lower hydrocarbon as methane (CH_4) or to carbon monoxide (CO/CO_2), methanol (CH_3OH) or even to hydrogen (H_2) [1,2]. Also, performance hybrid materials are also so wanted for recycling waste products such harmless (CO_2), and harmful (CO/NO_x) to value-added products, because it should be considered as an alternative fuels, which limit the use of feedstock fuels from natural gas reforming or higher hydrocarbons cracking [3,4]. Hybrid materials elaborations and characterizations allow also the detection and quantification of organic compound in our food products, to limit our exposure in some diseases such as cancer, diabetes, and so fourth [5,6]. In fact, in the past few decades, many engineering routes have been suggested and and thoroughly discussed in order to find superb materials for considerable technological applications. So that, these ways include : the exploration of metal oxides materials such Alumina, ceria, silica,Manganese oxides [7,9], they can be used as a matrix of metallic nanoparticles or as an active catalyst. The development and characterization of many forms of carbons such as nanotubes, nanofibers, polymers, heteroatoms-incorporated carbons, black carbons, and so on, have severely discussed to boost the performance of composite materials [10,14]. The use of cost-effective metals such as transition cobalt, zinc, nickel, copper, molybdenum hybrid materials, and so fourth have been extensively considered [15-17] in both catalysis and environmental technologies. Porous materials, such as intelligent as zeolite materials recently are fully regarded as powerfully active catalysts in a wide range of catalysis technologies. Indeed, as explained in Zhang-a's work [18], It covering a deep range of pore sizes starting from micropores ($D < 2$ nm), mesopores ($2 < D < 50$ nm) to macropores ($D > 50$ nm), so zeolite materials are versatile and essential in applications such as gas separators, ion exchangers technology, catalysts, for energy holding, in sensor, and beyond. Also, the use of zeolites on multicomponent reactions is introduced in Lima's work [19]. So, it is notified that an increased materials features such as efficiency, catalytic selectivity and activity, along with their beneficial environmental benign, elaboration routes, and material reusability, it gets so distinct the union of heterogeneous catalysis and MCRs exhibits an open framework of opportunities. Moreover, Wang's report [20] showed the synthesis and uses of core-shell, hollow, yolk-shell multifunctional architecture zeolites materials. In fact, the authors deeply discussed the new design strategies for large zeolite-related <<core-shell concept>> and costly affiliated with their preparation and the need for deeper research into their uses exhibit significant challenges. Another important class of materials is also introduced due to their advanced properties such as magnetic (Neodymium), lighting (Lanthanum), Catalytic at high temperature (Cerium/Lanthanum), component of a exceptional sort of glass (Praseodymium), visual displays in devices (Yttrium, terbium, europium), and (Gadolinium) is used in MRI, and X-ray scanning method, and as well as television screens. In addition, as shown here, this class of elements named as rare-earth materials might possess advanced features which would be exploitable for future catalysis/technological composite materials engineering. Therefore, in this review article one focus is dedicated to the novel development and application of hybrid materials made of rare-earth in union with other materials.

2. New insights on the use of rare earth elements on advanced materials engineering for catalysis and environmental technologies

So, in a review established by Akah, A.[21], it is described that rare earth oxides might enhance catalytic features and avoid the loss of acid sites under the fluid catalytic craking (FCC) unit operation, particularly when heavy residue with higher metal content is used as feed. Indeed, this review shows the effects of rare earth materials on the structure, stability, and as well as activity of FCC catalysts. Also, other looks of rare earth metals was taken within this article. Furthermore, in 2019, a review discussed on the use of rare earth elements with transition metal-based materials for ecatalysts design, synthesis, and applications were exhaustively analyzed in Gao's research work [22]. It shows that these rare earth metals could be used for materials engineering for high-tech applications as hydrogen evolution reaction (HER), methanol oxidation reaction (MOR), oxygen evolution reaction (OER), and oxygen reduction reaction (ORR). Many benefits and challenges of hybrid materials made via the use of rare earth elements are considered in the study. An alumina (Al_2O_3) supported nickel catalysts (Ni/Al_2O_3) modified by rare earth elements was demonstrated as a highly active catalyst for the decomposition of NH_3 as described in Okura's paper [23]. Analysis results displays that the Lanthanum (La) modified catalysts reaches the highest ammonia conversion. To boost the catalytic performance of this (La)-modified Ni/Al_2O_3 catalyst a pretreatment step was required. Hence, 400 °C and 600 °C as calcination, and reduction temperature respectively shows the highest NH_3 conversion as high as 94% at 550 °C. Moreover, it is notified from Li's work [24] that lanthanum (La) is the best choice for improving the nickel dispersion and the ratio of metallic to acid functions among rare earth elements. Indeed, due to this fact, high catalytic activity and isomerization selectivity was reached when this (La) modified Ni/HY is used. While other rare earth modified nickel catalysts shows poor catalytic performance due to the reduction of acidity feature and Ni dispersion, only a lower ratio of metallic to acid functions displayed. In 2019, a FeK/Al_2O_3 and rare earth elements as (La, Ce, and Y) were combined to construct a FeK/M-Al_2O_3 catalysts for direct CO_2 hydrogenation to liquid hydrocarbons as shown by Zhang's team [25]. So, the incorporation of M (La, Ce, and Y) was found to boost the selectivity of C_{5+} hydrocarbon formation and decrease the selectivity for CH_4 generation. Hence, at above 20% of carbon dioxide (CO_2) conversion, C_{5+} selectivity could be enhance about 60% with around 11% CH_4 selectivity. Particularly, it discovers that the addition of rare earth element on the catalysts minify the H_2 adsorption and support the adsorbed CO_2 species, therefore, leading to boost the liquid hydrocarbons (C_{5+}) selectivity over to gas hydrocarbons. Moreover, three rare-earth based composite materials (La, Ce, and Y) zeolite performances were compared by Lemos' group [26] in terms of acidity feature and catalytic properties. Indeed, it discovers that LaHY possesses the strongest bronsted acid sites than those of essential HY and CeHY. So, it proved that LaHY catalyst present the best activity for n-heptane cracking with very low coke generation. Hence, it shows that the exchange of HY by Ce^{3+} or La^{3+} boosted the thermal stability, which probably due to the formation of stable oxygen complexes between lattice oxygen atoms and rare-earth cations. The thermal stability was more marked with La^{3+} as compared to Ce^{3+}. In addition, Du, X., et al [27] examined three rare-earth oxides namely (La_2O_3, CeO_2, and $LaPO_4$) for the properties improvement of the USY zeolite catalyst as vanadium traps. In fact, it found that rare-earth oxides is thoroughly distributed on the zeolites surfaces, and some of rare-earth ions moved to cages of the zeolites under calcination and hydrothermal process. Therefore, the catalytic activity and as well as hydrothermal stability of the modified-zeolites were boosted. While in $LaPO_4$-USYzeolite, $LaPO_4$ was only distributed on the zeolite surface and did not impact the properties of catalyst. In order to rise light olefins yield and selectivity under catalytic cracking of propane one method was used by Pouria, R., et al [28] to introduce (La) on ZSM-5 zeolite catalyst via wet impregnation followed by calcination step. Indeed, analysis results shows that as the temperature increased, the number of bronsted acid sites reduces and which consequently intensify light olefins generation as well as catalyst stability. Particularly, the La-ZSM-5 treated under (N_2) atmosphere was largely stable than La-ZSM-5 calcined under air stream. A La/SAPO-11 catalyst was design and synthesized by Liu's group [29] via one-pot method. It discovers that La ions raise the depolymerization of phosphorus species and interaction with aluminum and phosphorus species. It found that the presence both silicon and La ions, does not allow La ions to incorporate into zeolite framework. Then, $LaPO_4$ conserves framework structure under steam attack. Specially, it notified that $[La(OH)_2]^+$ ions compensate structure tensions and improve the bond strength of Al-O inhibiting the desilication reaction under thermal handling. Therefore, La/SAPO-11 increased isomerization reaction (about 9.5% enhance of iso-paraffin) and inhibit cracking. Du's group [30] investigated ions location and migration in La-exchanged NaY zeolite, through calcination of LaNH4Y, LaY is prepared. So, analysis insights shows that La cations initially are located in supercages, and their hydration covering are stripped off and they move to small SI'positions of sodalite cages under heating and dehydration. Hence, it is noted that rare-earth species secure the hydrothermal stability of the zeolite to power the acid site density and catalytic features. Wang, X., et al [31] established a consistency review on rare-earth hybrid materials engineering for further technological applications such electrocatalysis.Both development and advantages of rare-earth materials discussed, future investigation ways addressed to help scientist for rapid technological development. So, it is highlighted from Liu, P., et al's work [32] that rare-earth (RE)-exchanged zeolite-Y is the principal active constituent of fluid catalytic cracking (FCC) catalysts. In this sense, a series of Yttrium (Y^{3+})-exchanged zeolite-Y was elaborated and characterized by physicochemical methods. As lanthanum (La^{3+}) exchanged zeolite-Y, Y^{3+} cations were mainly located inside sodalite units near the double six-membered rings. It is notified that the exchange of Y^{3+} cations by Na^+ causes a noticeable decrease of the unit cell due to the comparatively small ionic radius and high charge density of Y^{3+} cations. Hence, Y^{3+}-exchanged HY-based FCC catalyst exhibited better steam stability, superior selectivity for high-value products such as (C_{5+} gasoline and liquefied petroleum gas) under n-docosane cracking as compared with La^{3+}-exchanged HY-based catalysts. Via liquid phase ion exchanged, a series of CeY zeolites were designed and synthesized by Zu, Y., et al's team [33]. the fabricated materials showed adsorptive and active species sites in CeY zeolite toward ultradeep desulfurization in a fixed-bed column and as well model fuels. It is suggested that this route should play an instructive role for the development of the directive design of effective adsorption active sites for advanced desulfurization adsorbents. More recently, the investigation of $LaNi_5$-type alloy electrocatalysts were discussed in Tamura's work [34] for H_2 evolution reaction. It is demonstrated that the synthesized catalysts ($LaNi_5$-type alloy) displayed high catalytic compared with the constituent metals, and their activities were nearly competitive with those of Pt, and Pd catalysts. The control of temperature, and current density, avoid the catalysts ($LaNi_5$-type alloy) surface alteration. Furthermore, a supposed cost-effective catalyst

($Pt_{1.5}La_{1.5}Ni_{12}$/NPC) was reported by Zheng, L, et al's team [35] for the hydrogen generation through hydrogen evolution reaction (HER) in alkaline media (1.0 M KOH). Indeed, due to the synergistic effect between element as Pt, La, Ni, and as well as nanocarbon support, the designed ($Pt_{1.5}La_{1.5}Ni_{12}$/NPC) displays highest catalytic performances for the HER which outperforms all the considered material catalysts in this study and even commercial Pt/C catalyst. It needs ultralow overpotential of 20 mV and 132 mV to achieve 10 and 100 mA under the HER respectively. In 2020, it is reported from Zou, H.-H., et al's work [36] a photoelectrochemical (PEC) water splitting under the action of novel LTO/LaOCl@N-C microspheres heterostructures (MH) for hydrogen generation. The hold hybrid photocatalyst LTO/LaOCl@N-C (MH) exhibited outstanding PEC hydrogen evolution feature and as well as better durability when compared to the pure LTO material. So, at 0.7 V vs RHE, under simulated solar irradiation, the designed photoecatalyst shows higher performance of photoecatalytic hydrogen evolution rate, which was as high as 26.43 µmol/h*cm. Therefore, it is mentioned that LTO/LaOCl@N-C (MH) photoecatalyst surpasses many previously suggested materials based on LTO composite catalysts. Recently, Ye, X., et al [37] suggested a bifunctional metastable LaOCl@hcp-Ni nanocomposite photoecatalyst and photocatalytic activities via Schottky effect engineering for environmental remediation and electrocatalysis applications. So, it is thought that this material (LaOCl@hcp-Ni) might be a potential rare-earth based Schottky catalyst for both photoelectrocatalytic oxygen evolution and as well as photocatalytic degradation of organic pollutants. In addition, in 2022, Gogoi's team [38] reported a BiOCl-LaOCl-1 composite catalyst for organic compound removal such Rhodamine B in aqueous media. So, under sunlight, the proposed catalyst (BiOCl-LaOCl-1) delivers the highest catalytic activity of Rhodamine removal, thus allowing it to outperform all the considered catalyst materials in the study, such as BiOCl and LaOCl semiconductors. A N-regulated lanthanum phosphate (N-$LaPO_4$/C) was adopted by Zhao's team [39] as a model catalyst for alkaline oxygen reduction reaction (ORR), as it is an important electrochemical energy conversion devices. Indeed, it is experimentally demonstrated that the N-$LaPO_4$/C exhibits superior ORR activity and stability, which outperforms the commercial Pt/C catalyst. So, the N-doped $LaPO_4$ in the N-$LaPO_4$/C is identified to be the active sites, and the N regulation function on lanthanum is believed to ensure enhance the catalytic activity of N-$LaPO_4$/C under the ORR. Also, it is provided that N-$LaPO_4$/C plus Ru_2O demonstrated higher power density and as well as long life cycle, which lets to suggest these materials as potential candidate in rechargeable Zn-air batteries as an air cathode. Moreover, Liu, C., et al [40] constructed a bifunctional LaN_xC_{4-x}-doped graphene in acidic-alkaline omnipotent electrocatalyst for oxygen electrode reaction. Indeed, the developed material (LaN_xC_{4-x}-Gra) with an appropriate composition of LaN_2C_2hex-Gra exhibits potential bifunctional performance with the original oxygen evolution reaction (OER) and oxygen reduction reaction (ORR) overpotentials of 0.68 V and 0.56 V respectively accompanied by OH ligands modification. Therefore, as fully shown here materials engineering of advanced hybrid materials through the use of rare-earth (RE) materials such Lanthanum (La), Cerium (Ce), Yttrium (Y), Neodymium, Samarium, Europium, and so fourth should be considered to design and synthesized powerfully active composite materials for high-tech applications such as environmental, catalysis, electrochemical sensors, Biosensors, water managements, beyond technologies. Rare-earth (RE) will be highly considered as platinum group metal-based materials is not cost-effective than (RE).

3. Conclusion

Material science related areas are known as key, which can deeply contribute to the technological evolution, which can control the environmental pollution from both organic and inorganic harmful products. Indeed, in order to satisfy these needs, powerfully hybrid materials with cost-effectiveness are fully desired for high-tech applications. So that, owing to this interests, numerous zeolite materials in recent years have been fully developed and characterized, and it found that they exhibit advanced features in catalysis and environmental concerns. Furthermore, its combination with transition noble and non-noble metals are also fully depicted to boost the catalytic yields of the designed materials. Here, it is shown that transition rare-earth (RE) elements might be adopted in the hybrid materials engineering for advanced technological applications. As rare earth oxides might enhance catalytic features and avoid the loss of acid sites under the fluid catalytic craking (FCC) unit operation. Moreover, It is shown that (RE) elements such as lanthanum (La^{3+}), (Ce^{3+}), (Y^{3+}), and so on might be used for materials engineering for high-tech utilizations such as in hydrogen evolution reaction (HER), methanol oxidation reaction (MOR), oxygen evolution reaction (OER), and oxygen reduction reaction (ORR), organic/inorganic pollutants removal. Other reactions can be realized over rare-earth-based catalysts with enhanced catalytic features. Hence, due to the sophisticated properties of transition rare-earth (RE) metals, more possible brilliant materials could be designed in upcoming period of time.

4. Conflict of Interest

The Author declares that this review article on rare earth modified materials was led in the absence of any profitable or marketable relationships that could be interpreted as a possible conflict of interest.

5. References

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