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Insights in Molybdenum Composite Catalysts for High Performance Hydrazine Monopropellant Decomposition in Thrusters, FOR Spacecraft, Satellites, Space Probes, Launch Vehicles' Technologies, and Beyond

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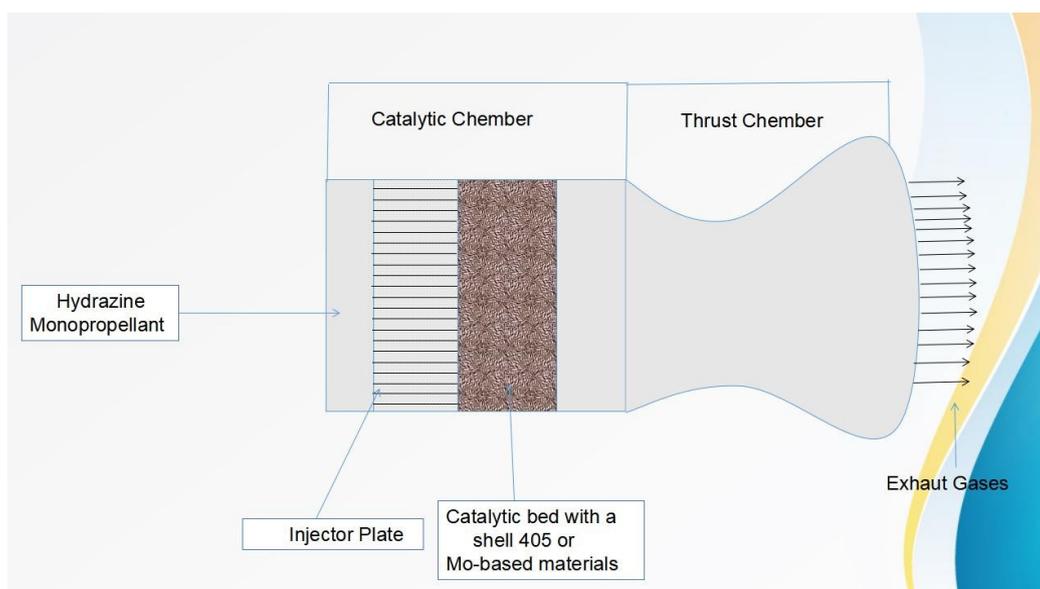
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Abstract

Launch Vehicles, satellites, Spacecraft, energy storage technologies constitute an important human endeavour, which requires big investment and highly crucial actions to fulfill the well being of our societies. So, hydrazine is largely used as a liquid propellant in the launch vehicles technologies, which is known to decompose over a shell 405 commercial catalyst to make done the space mission successful. Catalytic hydrazine decomposition over catalysts happens in two ways, indirect pathway which goes via (NH₃/N₂) intermediate to yield (H₂/N₂), and direct pathway to (N₂/H₂). This reaction products might be influenced by catalysts selectivity and reaction conditions such as temperature in the reactor room. Especially, in the satellite motor thruster, it is well known nowadays that metallic supported irridium catalyst plays a fantastic job to make this fuel decomposition, as the shell 405 case. Analysis shows that monometallic (Ir/Al₂O₃) and bimetallic (Ir-Ru/Al₂O₃) catalysts behave similarly as to shell 405 catalyst for hydrazine decomposition reaction (HzDR) in the satellite thruster. Also, forms of Ir composite catalysts have shown as powerful candidate for this special catalytic reaction. But, an effective and cheap catalysts based on molybdenum (Mo) catalysts revealed higher catalytic performances for this issue. Here, a significant ways of molybdenum catalysts engineering are fully shown, which exhibited advanced features of molybdenum based composites. In fact, allowing higher catalytic performance in the disintegration of hydrazine in satellite thrusters technologies. Also, these Mo-Catalysts showed a good hydrazine oxidation reaction (HzOR) activity in fuel cell technology, hydrogen evolution (HER) through water splitting, and act as environmental hydrazine sensing platform. Therefore, Mo-based materials could be suggested as the resolver of many catalytic and environmental issues via Mo-hybrid materials engineering technologies.

Keywords: Mo-Catalysts, Hydrazine Monopropellant, Satellite-Thruster, Decomposition, Reactions, Space

Graphical Abstract

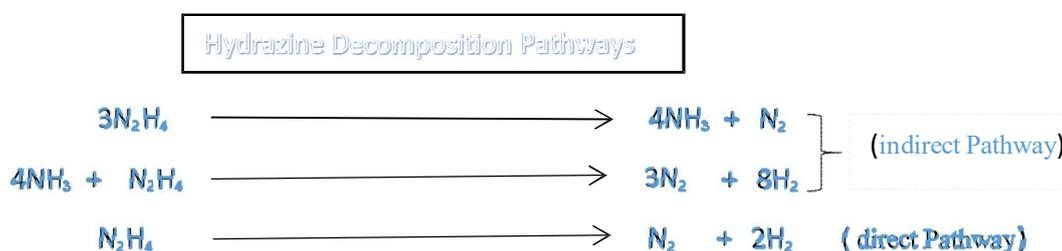


Introduction

Satellite launch vehicle technologies is an important field to explore as it brings tremendous advantages for the well establishment of our society, which can play a crucial role to boost nations economic business through Telecom technology, weather forecasts, military services, and scientific technologies explorations. So, hydrazine is well known as the fuel of the satellite vehicles, which is converted to (N₂/H₂) in the vehicle thrusters. Indeed, for the well travelling of the satellite vehicle from earth station to the space orbits, hydrazine is among the used fuels [1,2]. For this hydrazine catalytic decomposition in the thruster of the satellite vehicle, a commercial shell 405 catalyst is used [3]. for better purposes. So, since the development of shell 405 catalyst, a considerable work have been established to master this chemical reaction technology.

In the same way, in 2011, Soares Neto, T. G., et al [4]. prepared an Ir anchored on alumina support with only 30% of iridium charges, for monopropellant hydrazine decomposition in a 2 N satellite thruster technology. This particular study made an attention on catalysts textural evolution under the hydrazine decomposition reaction (HzDR). Another analysis reported by Jofre, J.B.F., et al [5]. described that both monometallic (Ir/Al₂O₃) and bimetallic (Ir-Ru/Al₂O₃) catalytic behaviour is similar to that of shell 405 commercial catalyst for hydrazine monopropellant decomposition reaction in the 5 N satellite thruster. However, the catalyst which does not contains iridium metal nanoparticles (Ru/Al₂O₃) shows lower catalytic performance for this particular reaction. And (Ru/Al₂O₃) catalyst shouldn't be advisable for uses in cold starts technology. This highlights that iridium materials and his related composites are interesting for this reaction. Vieira, R., et al [6]. demonstrated the use of carbon nanofibers as a support of the well known irridium for this chemical technology. In fact, the as prepared Ir/CNF catalyst reveal higher catalytic hydrazine decomposition performance than that of shell 405 catalyst under the studied conditions. The superior activity were attributed to the open structure of CNF with higher external surface area, and the lack of any closed porosity, which significantly boosted the contact between hydrazine and active sites. Also, the Ir/CNF catalyst exhibited strong catalytic stability.

Moreover, the decomposition of hydrazine is described to goes in two ways, the indirect pathway, which produces ammonia and nitrogen at low temperature, the produced NH₃ is further converted to (N₂/H₂), and the direct pathway, which yields (N₂/H₂) without any trace of NH₃ as described in [7,19]. The two pathways are shown below. Due the high cost, limited reserves, and as well as performances of noble metals for hydrazine decay related. The search of abundant earth metal materials with cost-effectiveness must be accelerated for affordable satellite thruster technologies. Therefore, in this research manuscript, it is focused on the recently developed molybdenum based catalysts for high performance hydrazine monopropellant Thrusters, for Satellites launch vehicle technologies. Also, it shows further catalytic applications of (Mo) based materials in interaction with hydrazine chemical fuel.



Hydrazine is also described as a potential hydrogen carrier through its hydrolysis, hydrogen gas can be acquired as shown in Wang, Y., et al's research paper [8]. Where, in-situ melt-quenching method is used to prepare Mo doped Ni-based catalysts for both decomposition of ammonia borane (AB) and hydrazine to generate hydrogen. Specially, the introduction of Mo was found to enhance the reducibility of Ni, which significantly boosts the performance of Mo-Ni catalyst. So, the Mo-Ni catalyst revealed more than 6 times higher TOF value as compared to that of unmodified Ni in both AB and N₂H₄ hydrolysis. A group of researchers [9]. showed some ways of liquid-phase chemical generation and storage of hydrogen. Among these chemicals hydrous hydrazine is listed and they are considered as a fortunate hydrogen storage material based on their comparatively higher hydrogen content. Moreover, a series of prepared Rh-MoO_x NPs is reported from Yao, Q., et al's research team [10]. as a powerful catalyst for hydrogen release from both hydrous (8 wt%) and borane (15.4 wt%) hydrazine. Under 323 K in alkaline nature, with the action of the optimized Rh_{0.5}MoO_{0.5} NPs (1:1) catalyst, a highest catalytic performances was achieved with 100% selectivity of H₂ release from both chemical reactants. So, a turnover frequency of 750 and 2000 h⁻¹ are reached from hydrazine borane and hydrous hydrazine hydrolysis respectively. So, as known, noble metals possess good catalytic features but some issues hindered their large technological applications. Consequently, a large need on engineering of actively earth abundant and cost-effective catalysts is on the cutting edges of scientific and engineering fields. Therefore, due the advisable catalytic performance and low price of molybdenum based materials for hydrazine monopropellant satellite thrusters applications as compared to iridium or other noble metals, here a brief review on this intelligent (Mo) based composite materials are introduced for satellites launch vehicles technologies and beyond.

New Trends on Molybdenum Functionalized Materials for High Catalytic Decomposition of Hydrazine Monopropellant in the Thrusters, Space Vehicles' Applications and Beyond

Since august 1973, a kinetics analysis of monopropellant hydrazine decomposition over both iridium (Ir) anchored on Alumina and unsupported one (Ir) has been discussed in smith's work [11]. So, catalyst material attrition chemical change in hydrazine monopropellant locomotive are analyzed in the light of this kinetic activeness. Also, suggestions are made regarding further interpretation of basic processes taking place in monopropellant motor cold starts. So, as well known catalysts-based on noble metals and related composites have been advisable and demonstrated as highly potential catalysts for a wide range of catalysis, environmental applications. But the issues of those noble materials are the high costs, limited reserves resources, stability and durability, and as well as effect of poisoning species. Hence, in the case of space self-propelled vehicle technologies, iridium catalysts have demonstrated powerful performance in the decomposition of the monopropellant hydrazine. So, due to its noble features and catalytic limits, molybdenum (Mo) materials are among the recently introduced catalysts for this interesting reaction for the space explorations. Specially, in this research article, it is summarized the newly developed molybdenum (Mo)-based catalysts for hydrazine monopropellant self-propelled vehicle applications. In this Perspectives, Hinckel, J., et al [12]. have established a work on the cost-effective catalysts for monopropellant hydrazine thrusters, for space vehicles' mission. In 1997, it is demonstrated from Rodrigues, J.A.J., et al [13]. that both molybdenum nitride (MoN_x) and carbides (MoC_s), and as well as tungsten (W) catalysts behave as noble metal catalysts in a wide range of catalysis reactions. Indeed, these materials were tested in a 2 newton hydrazine microthruster. It is notified that their catalytic performance was analogous to that of the conventional catalyst (Ir/Al₂O₃), with respect to combustion delay and thrust. Particularly, it found that their mechanical resistance is far beyond to that of iridium based catalysts. Indeed, this discovery further helped to accelerate the program of affordable catalysts synthesis and utilization in monopropellant hydrazine thrusters applications. In the same trends, in a monopropellant thruster (10 N), a series of supported molybdenum nitride (MoN_x/γ-Al₂O₃) catalysts was fully analyzed with a discussion of Mo charges, as shown in Chen's research article [14]. In fact, the proposed catalysts with specially about 23 wt% Mo (1.5 monolayers) exhibited the best catalytic features of monopropellant fuel decomposition. So, this boosted catalytic activities of (MoN_x/γ-Al₂O₃) catalyst was very closed to the state-of-the-art (Ir/γ-Al₂O₃) catalyst. Therefore, it is thought that the improved performance of (MoN_x/γ-Al₂O₃) might be coming from to the reduction of the oxide layer formed in the passivation process. A recently published article from Cheng's group [15]. discussed the production of hydrogen gas from hydrous hydrazine (N₂H₄*H₂O) by catalytic decomposition reaction. As (N₂H₄*H₂O) is a potential H₂ storage material for fuel cells owing to its higher H₂ content, easy storage, and as well as facial transportation. This review analysis fully shows the numerous designed and characterized catalysts for this issue, and considerably describes the routes of which catalysts performance might be boosted for hydrous hydrazine decomposition to yield hydrogen and nitrogen gases (H₂/N₂) through the direct pathway. Furthermore, it is described from Chen's research group [16]. that Al₂O₃-supported molybdenum carbides catalyst (Mo₂C/γ-Al₂O₃) is powerfully active like an Ir/γ-Al₂O₃ catalyst for the catalytic decomposition of hydrazine in monopropellant thruster. In fact, it is found that pure phases of γ-Mo₂N, W₂N, NbN, and W₂C could be suggested as a possible substitutes of the costly catalyst (Ir/γ-Al₂O₃) for monopropellant hydrazine decomposition in space technology. These materials performances is almost the same to that of Ir/γ-Al₂O₃ catalyst or inferior. Moreover, both Al₂O₃-supported and unsupported molybdenum phosphide (MoP) were designed and used as potential candidate catalyst for hydrazine decomposition in comparison with Mo₂N catalysts performance previously reported as shown in Cheng's work [17].

The MoP charges was found to boost the catalytic activity of MoP/Al₂O₃ materials, and was very stable N₂H₄ decomposition when compared to the supported Mo₂N catalysts' performance. It is introduced from Chen's work [18]. that the reaction path of N₂H₄ disintegration over molybdenum nitride catalysts seems to be identical as that of Ir/γ-Al₂O₃ catalyst. So, it is notified that below 673 K, N₂H₄ decomposes into N₂ and NH₃. However, above this value, N₂H₄ decomposes into N₂ and NH₃ first, and then the produced ammonia further dissociates into the syngas (N₂/H₂).

therefore, according to in situ FT-IR spectroscopy analysis, the Mo site of the Mo₂N/γ-Al₂O₃ catalyst constitutes major place for both the hydrazine adsorption and decay. Moreover, it is proved also from the above author's research article [19]. which articulate that the fresh α-Mo₂C/γ-Al₂O₃ hydrazine decay catalytic activity is far beyond to that of passivated α-Mo₂C/γ-Al₂O₃ catalyst. Particularly, catalyst deactivation occurs due to the strongly adsorbed NH_x species, then yielding to decrease in the catalytic performances under the reaction time at 303 K. So, the produced NH₃ under the low temperature process was found to further dissociates into N₂ and H₂ at higher temperatures. A microwave-assisted the synthesis of Mo₂C and WC supported on carbon nanocatalysts have been made and studied by Mnatsakanyan, R., et al's research team [20]. as an active catalysts for N₂H₄ decomposition reaction. Many parameters were analyzed such as irradiation time, gas surroundings, architecture, and as well as formation mechanism of the carbide phases. So, the generated catalysts displayed good catalytic behaviour for the hydrazine disintegration reaction (HzDR) at relatively low temperatures (30-70)°C. Then, the catalytic performance was discovered to be boosted by the assisted-microwave irradiation effect under the decomposition process. Therefore, it is ended that such conditions allow full conversion of N₂H₄ to NH₃ and N₂ within minutes. This could be attributed to the synergistic effect of catalysts' components and as well as microwave absorbing carbon. Molybdenum based catalysts might be also extended to hydrazine fuel cells applications, as it presents good catalytic behaviour in the monopropellant hydrazine thrusters technologies. So, in this special ways, more recently, a novel catalyst materials based molybdenum carbides anchored on nitrogen doped carbon composites is reported by Deng, J., et al [21].

Mo_x-NC electrocatalyst prepared through pyrolysis is applied as a potential catalyst for hydrazine fuel cell technology. Particularly, the Mo_x-NC (900°C, 5%) discovers to be the optimal catalyst, which exhibits superior catalytic performance of 3.56 mA/cm² and advisable cycling stability of 86.13% for hydrazine oxidation reaction. Also, under 12 h long-term operation stability, the Mo_x-NC (900°C, 5%) delivers 0.96 V (80°C) an open circuit voltage with a maximum power density of 158.26 mW/cm². Hence, it is suggested that Mo_x-NC might be applied as a powerful catalyst for direct hydrazine fuel cells in future. In 2019, a prepared Ni₂P@Ni₁₀Mo/Ni-Mo-O/NF catalyst is described from Wen's research group [22]. as an efficiently active material, which under hydrazine oxidation operation shows fantastic high activity, considerable durability and as well as nearly 100% selectivity toward this targeted reaction. The phosphorization step of the synthesized catalyst was necessary to circumvent the problem happen with unphosphorilated material. Also, NiMo supported over carbon was investigated as an active oxidation catalyst for hydrazine decay as reported in Asset's work [23].

Particularly, NiMo(9:1)/C is highly represented as amongst potential catalyst. So, small molybdenum charges (<15%) but non-negligible content shows superb catalytic activity, as it stabilizes the N₂H₄ (N-N) bond, thereby avoiding the chemical disintegration of hydrazine to NH₃, and the catalysts selectivity toward the complete N₂H₄ oxidation to N₂ gas is enhanced. More recently, an oxygen-doped MoS₂ nanoflowers with sulfur vacancy (O-rich MoS₂) is synthesized for the hydrazine oxidation reaction as shown in Song's research article [24]. Especially, the sulfur vacancy and doping were discovered to be the mainly active site for the hydrazine oxidation reaction (HzOR). The hydrazine oxidation onset potential was as high as 0.5 V vs RHE. Hence, this doping strategy may furnish new ideas for boosting the design of future hydrazine oxidation catalysts. Furthermore, a powerful Ni_{1-x}Fe_x anchored on polyethyleneimine (PEI)-functionalized molybdenum disulfide (MoS₂) material is reported by Li, J., et al's research team [25]. as an active catalyst for hydrazine fuel cell technology. Analysis revealed that Ni₈₅Fe₁₅ NPs with 2.25 nm average size are uniformly distributed on the PEI- MoS₂ sheets. So, the Ni_{1-x}Fe_x/PEI-MoS₂ material shows unexpectedly superior performance towards the N₂H₄ oxidation reaction (HzOR). Due to the structural of PEI-MoS₂, the Ni₈₅Fe₁₅/PEI-MoS₂ catalyst exhibited higher stability than that of Ni₉₀Fe₁₀/PEI-MoS₂ and as well as Ni₈₅Fe₁₅/MoS₂ catalysts under HzOR conditions. Hence, this highlights the importance features of the alloy composition and as well as the conducting polymer additions. In addition, a Co(OH)₂/MoS₂/CC has been recently demonstrated from Cheng's work [26]. To possess superior Bifunctional performances for HzOR/HER under alkaline media. In fact, due to the abundant active sites, and boosted reaction kinetics, the Co(OH)₂/MoS₂/CC catalyst delivers 100 mA/cm² at low potentials of 177 and - 134 mV for HzOR and HER respectively. Especially, in hydrazine-assisted overall water electrolyser system (OH₂S), the catalyst (Co(OH)₂/MoS₂/CC) shows low potential to reach 10, 50, and 100 mA/cm². Therefore, this highlight that Co(OH)₂/MoS₂/CC is a potential candidate material for large-scale preparation hydrogen fuel. A molybdenum metallo-organic precursor (MoO₂(acac)₂) has been used in Guo's work [27]. To create defect-rich crystalline MoP NPs uniformly distributed over reduced graphene oxide (rGO) as highly active catalyst for Bifunctional hydrogen evolution and hydrazine oxidation reactions.

Indeed, the as (D-MoP/rGO) prepared catalyst revealed greater electrochemical active surface area as high as 8 times to that of bulk MoP. Especially, only small overpotentials were required in order to reach 10 mA/cm² when D-MoP/rGO catalyst is applied in the system HER/HzOR. So, under 12 h operation stability at a small cell voltage as low as 0.74 V vs RHE, the catalyst (D-MoP/rGO) in the system (HER/HzOR) water-splitting reached high current density as high as 100 mA/cm². Therefore, such ways can be used to design and synthesized relatively active and stable supported metal phosphide for this complex system and beyond. Recently, a ternary complex base on hematin (HM), Al³⁺ salt, and two dimensional molybdenum disulfide (2D-MoS₂) is applied to modify the screen-printed graphene electrodes (SPGrEs). So, this modified (HM-Al³⁺-2D-MoS₂/SPGrEs) electrodes are used as an effective catalyst for sensing hydrazine chemical compound as described in Villa-Manso's research work [28]. Indeed, it is notified that, the hematin anchored on the electrode surface can act as a redox mediator and exhibit tremendous catalytic performance towards the hydrazine oxidation reaction. Particularly, the sulfur presence in 2D-MoS₂ structure shows very important features

to boost the catalyst properties. Therefore, the catalyst displays interesting charge transfer kinetic between hematin mediator and electrode surface, thus, offering an advanced capabilities in the design of functionalized electrode surfaces for environmental sensing technologies and beyond. This research article have shown the importance properties of molybdenum based composite materials, which shows higher catalytic performance of hydrazine decomposition in satellite thrusters technology, good hydrazine oxidation reaction (HzOR) in fuel cell technology, hydrogen production via (HER), and as well as environmental hydrazine sensing platform. So, as it presents advanced features for technological applications, its composite design, functionalization, synthesis routes, reaction mechanism could be major factors that researchers can be deeply focused on, and it will then create fantastic catalysis and environment problem solving.

Conclusion

Space exploration, satellites, Spacecraft, energy genesis and storage systems constitutes an important focus and need, which requires enormous investment and highly decisive works to satisfy the well being of our nations. So, since many decades ago, the monopropellant hydrazine is utilized in the satellite lunch vehicles technology, specially, in the satellite motor thruster, where a well known metallic supported irridium catalyst plays a fantastic job to make this fuel decomposition. Experimental analysis shows that both monometallic (Ir/Al₂O₃) and bimetallic (Ir-Ru/Al₂O₃) catalytic behaviour is similar to that of shell 405 commercial catalyst for hydrazine monopropellant decomposition reaction in the satellite thruster. Also, diverse forms of Ir composite catalysts have been described as potential candidate for this catalytic decay reaction. But, the cost-effective catalysts is based on transition molybdenum metal materials, as it achieved higher catalytic performances for this special reaction. Here, a appreciable ways of molybdenum catalysts engineering are fully shown, which shows advanced properties of molybdenum based composite materials. Thus, allowing higher catalytic performance in the disintegration of hydrazine monopropellant in thruster technology. Also, good hydrazine oxidation reaction (HzOR) activity in fuel cell technology, efficient catalysts for hydrogen evolution (HER) through water splitting, and as well as environmental hydrazine sensing platform. Therefore, this Mo-based materials maybe the solver of many catalytic and environment issues via hybrid materials engineering.

Conflict of Interest

Author declares that these insights on Mo-based nanocomposite materials (paper) was led in the absence of any bankable or marketable relationships that could be interpreted as a achievable conflict of interest.

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