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Editorial

Energy and Environment—Towards Greenhouse Gas Mitigation: Novelty in Heterogeneous Catalysis

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Climate change, a consequence of global warming, is a global issue resulting due to greenhouse gas (GHG) emissions. The main GHGs of concern are carbon dioxide (CO_2), methane, and nitrogen oxide. Scientists have utilized technologies in recent decades to mitigate GHGs. Among the proposed technological solutions, catalysis—and in particular heterogeneous catalysis—has played a vital role in the abatement of GHGs.

One of the strategies to combat methane emissions is combustion, and catalytic combustion offers economic benefits due to the fact that the lower methane concentration in combustion emissions is less harmful than by-products such as formaldehyde. Nanotechnological advancement in heterogeneous catalysis for combustion has significantly reformed the process. The catalytic conversion of carbon dioxide is carried out via different routes, hence suggesting the economic development of energy-efficient catalytic CO_2 conversion to useful products. Some of the well-known catalytic routes to convert methane and CO_2 include steam methane reforming, dry reforming of methane, partial oxidation of methane, methane decomposition, reverse water gas shift, CO_2 hydrogenation to methanol, and CO_2 hydrogenation to higher alcohols.

The investigation of metal/metal oxide nanoparticles anchored onto an oxide support in a heterogeneous catalysis is significantly important for understanding the nature and extent of the metal–support interaction which affects the catalytic activity and product selectivity. The preparation of a heterogeneous catalyst involves different elevated temperature steps, including oxidation and reduction, which influence the morphology of the catalyst. The metal–support interaction also causes morphological changes such as alloy formation, sintering of metal particles, inter-diffusion, and encapsulation. Therefore, the preparation steps need to be optimized to obtain well-dispersed metal nanoparticles anchored onto the oxide support. The recent developments in spectroscopic and microscopic characterization techniques, as well as density functional theory, have facilitated scientists in predicting the performance of the catalysts and proposing hypotheses before the reactions. Later, the suggested hypotheses are validated by characterizing the catalysts after the reactions.

Considering the above-mentioned developments in heterogeneous catalysis for GHG abatement, this Special Issue is mainly focused on the novel advancements in heterogeneous catalysis for the mitigation of GHGs. Potential topics include, but were not limited to the following:

- Heterogeneous catalysts for steam methane reforming;
- Dry methane reforming, partial oxidation of methane;
- Methane decomposition;
- Reverse water–gas shift;
- CO_2 hydrogenation to methanol;
- CO_2 hydrogenation to higher alcohols.

Considering the COVID-19 crisis, the response to our call was excellent, with the following statistics:

- Submissions: (8);
- Publications: (7);
- Rejections/withdrawals: (1);
- Article types: review article (1); research articles (6).

A brief overview of the contributions in this Special Issue:

Abasaeed et al. [1] submitted the very first article to the SI and demonstrated the modification of support materials such as alumina (Al_2O_3) and zirconia (ZrO_2) by doping lanthanum oxide (La_2O_3) in the range from 0 to 20 wt%. These modified support-based nickel catalysts were further investigated for a dry methane reforming reaction. The catalytic performance tests revealed that lanthanum oxide modification positively influenced the conversions and, depending upon the base support, modified catalysts outperformed the unmodified catalysts. The improvement in surface basic properties, specific surface area, metal dispersion, and lower reduction temperatures of modified catalysts were the major factors behind their superior performance during the dry reforming reaction.

The role of strontium (Sr) and cerium (Ce) in nickel-based perovskite catalysts during methane reforming using carbon dioxide was studied by Ahmed et al. [2]. The catalyst characterization results showed that a $CeNiO_3$ perovskite catalyst exhibited a higher number of reducible species, BET surface area, pore volume, and nickel dispersion as compared to a $SrNiO_3$ catalyst. These factors had a significant impact on catalytic activity results and the $CeNiO_3$ catalyst obviously outperformed the $SrNiO_3$ catalyst. The catalyst stability tests also followed the same trend and $SrNiO_3$ deactivated more than $CeNiO_3$, which was assigned to carbon deposition.

Singh et al. [3] investigated the photocatalytic performance of BiF_3 and Bi_2O_3 and found that BiF_3 presented superior activity. Considering the relatively better photocatalytic performance of BiF_3, they incorporated it in plaster of Paris (POP) with varying amounts of BiF_3 between 0 and 10 wt%. The photocatalytic activity of BiF_3-modified POP evaluated using Resazurin (Rz) ink under ultraviolet (UV) light irradiation demonstrated that an increase in the amount of BiF_3 improved ink removal and, hence, enhanced photocatalytic activity. This was further substantiated with UV visible spectroscopy which quantified the rate of de-coloration of modified POP samples.

Khan et al. [4] evaluated the performance of various supports for nickel-based catalysts during the dry reforming of methane. The exploration of supports, such as H-ZSM-5 zeolite, Y-zeolite, and alumina (Al_2O_3), under dry reforming conditions indicated that an alumina-supported nickel catalyst exhibited higher catalytic activity than that of zeolite-supported catalysts. On the contrary, the alumina-supported nickel catalyst deactivated more than the zeolite-supported catalysts and, hence, zeolite-supported catalysts showed more stability, especially with just 2% deactivation, and the H-ZSM-5-supported nickel catalyst remained the most stable catalyst.

Taira and Murao [5] studied the role of ceria (CeO_2) dispersion in CeO_2/MgO synthesized under a dry condition and its improved redox properties during a methane dry reforming reaction. The impregnation of ceria over MgO under a dry condition maintained the ceria particle diameter at approximately 3 nm, even at 800 °C, and a slight agglomeration of ceria particles (~5 nm) was noted when impregnated under ambient conditions. The catalyst characterization results identified that dry condition impregnation imparted a higher number of mobile oxygen species than the ambient condition counterpart, which played its positive role during the dry reforming reaction.

This SI also witnessed a review article by Lach and his teammates [6] focused on comparing the perspectives regarding carbon dioxide as a crisis or an opportunity and working towards useful utilization. The review highlighted the carbon dioxide emissions contributing to global warming and a possible solution for its abatement by using carbon dioxide as a raw material, such as in carbon dioxide methanation, which is one of the starting points for successive projects such as synthesis, polymers, and/or fuels, and power-to-gas applications. Hence, the review article discussed the carbon dioxide methanation reaction and development and progress in catalyst design for this reaction.

Finally, an article was published by Kapkowski et al. [7] to demonstrate the role of zinc oxide (ZnO) and titania (TiO_2) nanorods supported on ceramic foam (using alumina, silicon carbide, and zirconia substrates) during catalytic NOx removal. They also explored the ornaments of ceramic foam containing ZnO and TiO_2 nanofilaments with oxides of vanadium (V) and tungsten (W). The catalytic activity results revealed that among alumina-based form-supported TiO_2 nanorods ornamented with oxides of V and W, 1% $W/TiO_2/Al_2O_3$ outperformed the rest of the catalysts, whereas in the case of ZnO nanorods, 1% V,W(3:7)/ZnO/Al_2O_3 exhibited the highest activity. Using 1% loading of V and/or W as optimum, ZrO_2-supported ZnO nanorods (1% W,V/ZnO/ZrO_2) were found to have the highest conversion.

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