Gold nanoparticles on manganese oxides with different crystalline structures: enhancing low-temperature air pollutants abatement

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Significance and Relevance
Removing pollutants in confined spaces is essential for improving air quality and well-being. This study investigated gold-functionalized manganese oxides with different crystalline phases to oxidize CO and VOC at low temperatures. The results revealed that gold nanoparticles (AuNPs) enhanced catalytic activity toward all the molecules. Moreover, a relationship between nanoparticle size and catalytic performance was determined, identifying a "critical radius" below which the catalytic efficiency increased substantially and highlighting the importance of optimizing AuNPs for pollutant abatement.

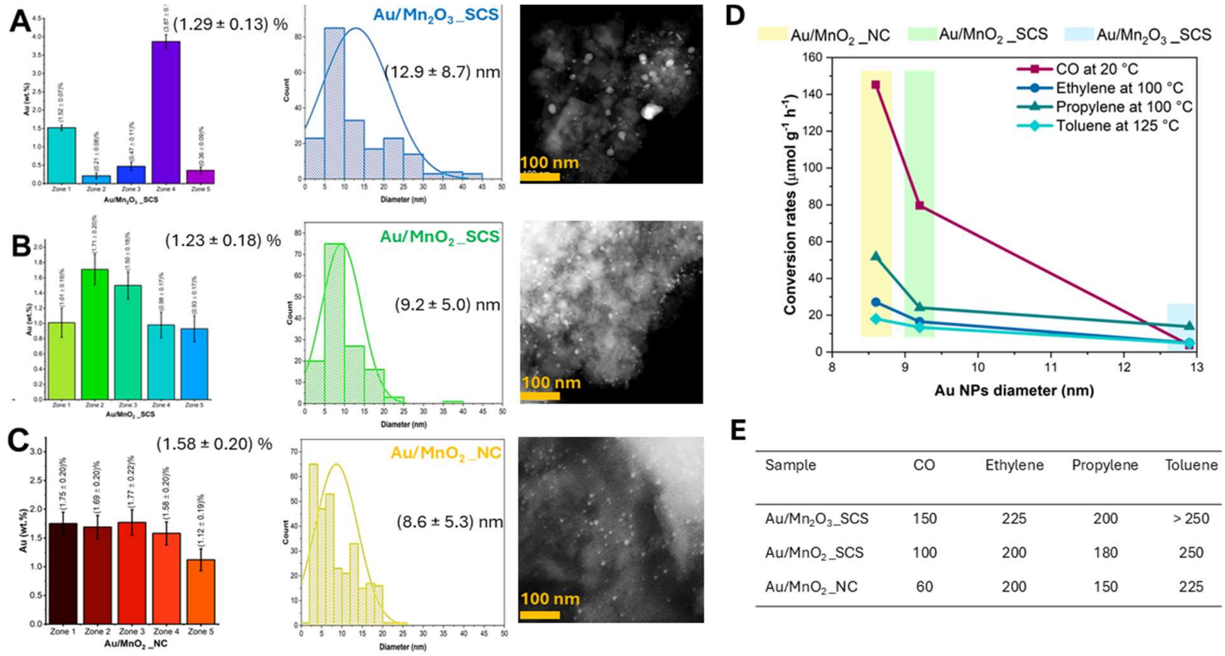
Preferred and 2nd choice for the topic: Air cleaning and combustion; 2nd: Automotive and stationary emission control
Preferred presentation: Oral preferred or Short Oral

Introduction and Motivations
In recent decades, air purification has gained significant attention, particularly regarding indoor pollution, which can be more hazardous than outdoor pollution. Among the main atmospheric pollutants, Volatile Organic Compounds (VOCs), commonly found in paints and household products, are the most common ones[1]. A promising technology for removing these pollutants is catalytic oxidation at low temperatures. In this context, manganese oxides have proven to be effective catalysts for CO and VOC oxidation due to their activity, durability, and low cost[2]. Different crystalline phases of manganese oxides (such as MnO_2 and Mn_2O_3) exhibit varying catalytic properties, influenced by their redox behavior and structural defects, thus making them effective in oxidizing pollutants like CO, ethylene, and propylene at moderate temperatures[3]. Introducing AuNPs on the surface of these catalysts could further enhance their catalytic activity, improving catalytic performance at even lower temperatures. This approach holds great promise for improving indoor air quality to ensure the health and well-being of people in confined environments.

Materials and Methods
Manganese oxides with two different crystalline structures (MnO_2 and Mn_2O_3) were synthesized through the Solution Combustion Synthesis and Nanocasting methods, by following the procedures reported in our previous work[3]. Gold nanoparticles (1 wt.%) were deposited through a sol-immobilization method with the aim of enhancing the catalytic performance at low temperatures. These materials were extensively characterized by different physicochemical techniques, i.e., N_2-physisorption at -196 °C, XRD, XPS, H_2-TPR, O_2-TPD, and STEM-EDX analyses. The catalytic activity was investigated by simulating a real polluted atmosphere containing CO, ethylene propylene, or toluene as target molecules in a concentration of 100 ppm over 50 mg of catalyst. These molecules were chosen since they are common indoor pollutants (e.g., CO) and are difficult to oxidize at low temperatures (e.g., VOCs). Finally, cyclic tests and time on stream (TOS) analyses were carried out on the best-performing catalyst to better investigate the performance and stability of this sample.

Results and Discussion
The catalytic tests revealed highly promising results, particularly in the case of CO conversion. The most striking achievement is its complete conversion at a remarkably low temperature of 60 °C and more than 50 % of conversion at room temperature.

The results obtained in this study highlight the positive impact of AuNPs on the oxidation of VOCs, especially when compared to the unfunctionalized supports. While CO showed a more pronounced response to the presence of AuNPs, with a significant decrease in oxidation temperature of 90 °C for the NC sample compared to the gold-free support (60 °C from 150 °C, respectively), a notable temperature decrease of ~50 °C was also observed for the tested VOCs, highlighting the major potential of AuNPs in promoting oxidation of gaseous pollutants. Another crucial aspect was the effect of the different crystalline structures of MnOx, which influenced the deposition and distribution of NPs. In particular, the MnO_2 phase emerged as the most promising, ensuring optimal NP distribution. The SCS and NC samples showed a more homogeneous NP distribution and a narrower size distribution, with average diameters of 9.2 nm and 8.6 nm, respectively, hinting at a correlation between nanoparticle size and catalytic performance (Figure 1). The best performance was achieved with the higher-surface-area NC sample, indicating that a greater surface area favors better NP distribution and interaction with the reagents. Furthermore, the results led to the identification of a "critical radius", below which catalytic performance significantly increases, particularly for CO, suggesting a pronounced structural sensitivity for this molecule.



Sample	CO	Ethylene	Propylene	Toluene
Au/Mn_2O_3_SCS	150	225	200	> 250
Au/MnO_2_SCS	100	200	180	250
Au/MnO_2_NC	60	200	150	225

Figure 1 AuNPs distribution, average diameter, and STEM images (A-C), the relationship between Au diameter and catalytic performance (D), the temperature at which the conversion is complete (E) for all the pollutants

The ability to achieve full conversion at such low temperatures not only reduces energy consumption but also opens up new possibilities for cleaner technologies. These findings open new perspectives for the optimization of catalysts for air purification, where both the composition and morphology of the catalysts play a decisive role.

References

1. Guo, Y., Appl Catal B, **2021**, 281.
2. Zhou, H., et al., Fuel, **2024**, 366.
3. Grifasi, N., et al., Appl Catal B, **2025**, 362.

Acknowledgements

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