Rethinking the Design of Catalysts for Plasma-Catalysis Systems

D. B. Go[1,2], F. Herrera[1], G. Brown[1], N. Turan[1], P. Barboun[2], P. Mehta[2], W. F. Schneider[2], and J. C. Hicks[2]

[1] *Department of Aerospace and Mechanical Engineering, University of Notre Dame, Notre Dame, Indiana 46556 USA*
[2] *Department of Chemical and Biomolecular Engineering, University of Notre Dame, Notre Dame, Indiana 46556 USA*

Abstract: Plasma-catalysis is an exciting branch of plasma science and engineering where non-equilibrium plasmas are used with catalytic systems to more effectively drive reactions. Generally, design of plasma-catalysis systems have adopted thermal catalysis strategies and modified them based on trial-and-error findings. Recently, we have shown that the non-equilibrium state of the plasma fundamentally changes how we should think about designing catalysts for plasma-catalysis. This work will summarize our efforts in this area.

Keywords: plasma-catalysis, catalyst, volcano plot

For well over a decade, a number of studies have shown that low-temperature, non-equilibrium plasmas can interact synergistically with catalytic materials to drive reactions more effectively than either the plasma or catalyst alone [1,2]. Understanding this synergy is the key to designing effective plasma-catalyst systems, but historically, this is has been accomplished using mostly heuristic approaches.

In our recent work, we have shown that the non-equilibrium state of the plasma may fundamentally change the interaction at a catalyst surface [3]. Specifically, when we consider the formation of ammonia (NH_3) from N_2 and H_2 via

$$N_2 + 3H_2 \rightarrow 2NH_3, \tag{1}$$

the rate limiting step is the dissociation of N_2. In thermal catalysis, a scaling between the rate and activation energy leads to a so-called volcano plot that illustrates the optimal catalyst for this chemical system. However, a non-equilibrium plasma vibrationally excites N_2, effectively lowering the energy barrier for dissociation at the catalyst surface. This behaviour shifts the volcano plot such that there is a different optimal catalyst than one might use for thermal catalysis.

Experiments using a plasma reactor confirm this behaviour, as cobalt has a larger reaction rate than other transition metal catalysts such as ruthenium, consistent with the new theory. Furthermore, detailed optical and electrical analyses show that different catalytic materials do not affect the macroscopic plasma properties, confirming that the synergy in this plasma-catalysis system is derived from the unique interaction at the catalyst surface rather than from the catalyst modifying the plasma to increase NH_3 production.

References

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