# Numerical Study of Plasma Torch Performance Using LTE-Assumption

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**Abstract:** This study investigates the effects of $N_2$ flow rates on plasma properties in a 9MB plasma torch using CFD simulations under LTE assumptions. Increasing $N_2$ raises arc voltage due to higher plasma resistance and lowers outlet temperatures due to energy absorption. Reduced outlet velocity improves particle melting, enhancing coating quality.

## 1. Introduction

Gas composition plays a critical role in the performance of plasma torches used in thermal spray coatings. While traditional binary gas mixtures like Ar-$H_2$ are common [1], recent studies highlight the benefits of ternary mixtures with $N_2$, which enhance coating quality through unique thermal properties such as high specific heat and thermal conductivity. Despite these advantages, the effects of varying $N_2$ proportions on plasma properties, including voltage, temperature, and velocity, remain underexplored. This study uses computational fluid dynamics (CFD) simulations under local thermodynamic equilibrium (LTE) assumptions [2] to systematically analyze the influence of $N_2$ ratios on the performance of a 9MB plasma torch.

## 2. Methods

This study used CFD simulations under LTE assumptions to analyze the impact of varying $N_2$ flow rates in a 9MB plasma torch. The gas mixtures, with a total flow rate fixed at 102 SCFH, consisted of $H_2$ at 6 SCFH and $N_2$ at 0, 12, and 24 SCFH, with the remainder balanced by Ar. Thermophysical properties, including thermal conductivity and specific heat, were calculated using gas kinetic theory [3] and are shown in Figure 1. The results highlight how increasing $N_2$ proportions enhance these properties, influencing energy dissipation and plasma dynamics.

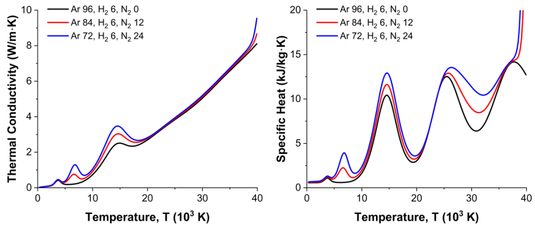


**Fig. 1**. Thermal conductivity and Specific heat for gas mixture

## 3. Results and Discussion

The simulation results showed that increasing the $N_2$ flow rate led to a noticeable rise in arc voltage. For the Ar 96, $H_2$ 6, $N_2$ 0 SCFH case, the arc voltage was the lowest, while the Ar 84, $H_2$ 6, $N_2$ 24 SCFH case exhibited the highest voltage. This increase is attributed to the higher thermal conductivity of $N_2$, which facilitates energy dissipation from the plasma, resulting in higher resistance and a greater energy requirement to sustain the arc.

The outlet temperature decreased as the proportion of $N_2$ increased. The N-rich cases exhibited lower peak temperatures, with a more uniform temperature distribution across the outlet radius. This behavior is due to $N_2$'s high specific heat capacity, which absorbs more energy and reduces the overall plasma temperature. For example, in the Ar 96, $H_2$ 6, $N_2$ 0 SCFH case, the peak temperature at the outlet was significantly higher compared to the Ar 84, $H_2$ 6, $N_2$ 24 SCFH case.

The addition of $N_2$ also influenced the velocity profiles at the outlet. For cases with higher $N_2$ flow rates, the velocity at the outlet decreased slightly, resulting in subsonic flows throughout the torch. This lower velocity increases particle residence time within the plasma, which can improve particle melting and enhance coating quality. The Mach number profiles confirmed this behavior, as no supersonic flow regions were observed in the analyzed cases, ensuring stable external injection.

## 4. Conclusion

This study utilized CFD simulations under LTE assumptions to analyze the effects of varying $N_2$ flow rates on plasma properties in a 9MB torch. Increasing $N_2$ enhanced thermal conductivity, leading to higher arc voltage and greater energy dissipation. Outlet temperature decreased due to energy absorption by $N_2$, resulting in a more uniform temperature distribution. Reduced outlet velocity extended particle residence time, improving melting potential and coating quality. These findings highlight the importance of optimizing $N_2$ flow rates for enhanced plasma properties and spray performance.

## References

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