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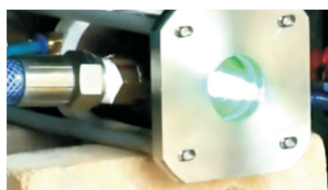
Design and Development of Indigenous 100 kW Plasma Torch

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High power plasma torch

ABSTRACT

Plasma technology is a vital tool in municipal and nuclear waste processing. The high temperature and high reactivity of free ions and radicals of the plasma make it a powerful medium to promote high heat transfer and chemical reactions, thereby enabling gasification of organic materials. Beam Technology Development Group is developing a 100kW thermal plasma torch indigenously. This article gives a brief overview of design basis and the progress of work towards the development of the plasma torch.

KEYWORDS: Plasma torch, 100 kW plasma torch, HC torch, Electrode.

Introduction

Hollow Cathode (HC) air plasma torches are generally used in high power applications. They are advantageous compared to pin type torches at higher power. A typical hollow cathode plasma torch is shown in Fig.1. It consists of two hollow electrodes made of copper and separated by a narrow gap of 2 mm.

Air as plasma gas is injected through a vortex chamber to achieve swirl action. Arc root attachments in both the electrodes moves continuously. This movement is both in longitudinal and radial direction. Longitudinal movement of arc attachment occurs by achieving dynamic equilibrium between Lorentz force and drag force. Lorentz force is a function of arc current while drag force is a function of gas flow rate. These two forces act in opposite direction and due to their dynamic behaviour generates voltage fluctuations in saw-tooth form. The frequencies of the fluctuation are linked to arc current, anode design and nature of plasma gas. The location of arc attachment and erosion rate of the electrode material determines the lifespan of the electrodes.

In this article, we discuss briefly the design and performance parameters of HC torch like variation of arc voltage, thermal efficiency of torch and oscillation frequency of voltage using similarity criteria given in literature [1-4]. These parameters were calculated for the range of utility limits available at site. A preliminary aerodynamic study was also conducted to characterize the air flow and the temperature distribution due to the air, considering plasma as a heat source.

Design basis

Following are the design criteria for thermal plasma torch intended to use for treatment of organic wastes:

- High thermal efficiency for economical treatment.
- Large volume of high temperature region for easy decomposition of organic wastes.
- Abundant oxygen quantity sufficient for transforming the decomposed wastes into stable and innocuous elements.
- Low electrode erosion rate for long lifetime of the torch.

Power source and utilities for plasma torch

The power source for a thermal plasma torch consists of a main arc power supply and a trigger power supply (Fig.2). The trigger power supply initiates the arc and main arc power supply gives energy to maintain it. A high voltage and frequency trigger power supply is used for igniting the arc discharge whilst using Argon as the plasma gas. Once a breakdown is initiated, the plasma gas is changed to air. The main arc power supply has a capacity of 100kW (500V and 200A).

Design by similarity criteria

Zhukov had developed similarity criteria on the basis of dimensionless equations, describing physical phenomena

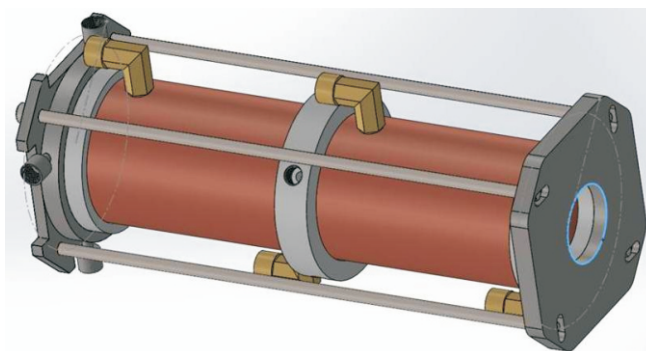


Fig.1: Model of a HC torch.

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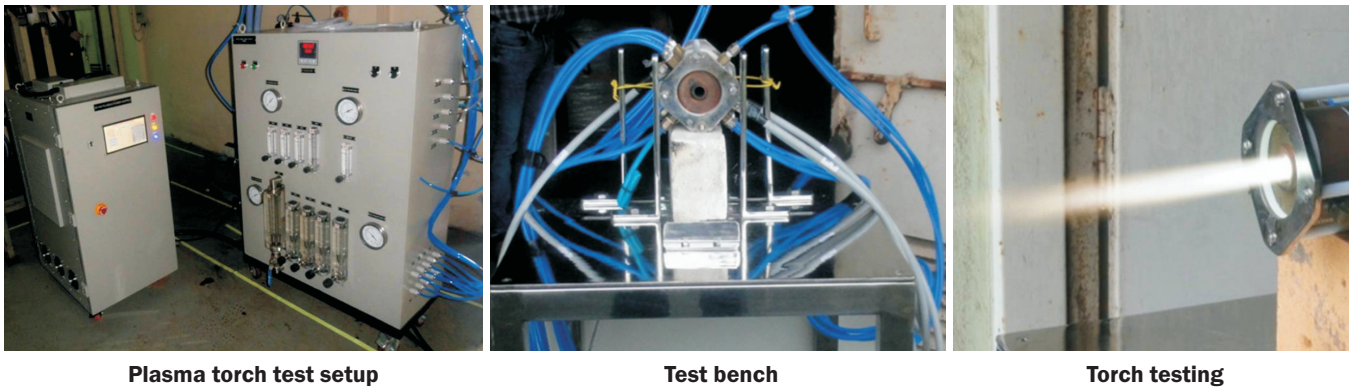


Fig.2: Plasma torch testing facility.

occurring in plasma torches. These dimensionless equations and validated our simulation results using literature values [2].

The maximum capacity of the main arc power supply (U, I), maximum plasma gas (G'), cooling water (g') determines the range of electrode dimensions.

Based on the following limiting conditions $0 < I < 200A$, $0 < U < 520V$, $0 < G' < 300slm$ @, $g' = 50-60lpm$, anode length (l_a) = 120mm and cathode (l_c) = 110mm and vertex diameter $D = 45mm$ have been taken and the following combination of anode (d_a)-cathode (d_c) diameters were used for study of electrode diameter effect on performance parameters

1. $d_a=14mm$ & $d_c=16mm$
2. $d_a=14mm$ & $d_c=18mm$
3. $d_a=16mm$ & $d_c=18mm$
4. $d_a=16mm$ & $d_c=20mm$

The variation of voltage (Fig.3a), efficiency (Fig.3b), and oscillation frequency of voltage were calculated w.r.t. the variation in current and gas flow rate based on similarity criteria. Following are the observations made:

- a) The arc voltage decreases with rise in the arc current and concurs with a typical V/I characteristic of arc. It is clear from the graph (Fig.3a) that arc voltage decreases with increase in electrode diameter, however its change with cathode diameter is much more dominant than change in anode diameter.

- b) Arc voltage increases with corresponding increase in the gas flow rate. The change in anode diameter is less dominant than the change in cathode diameter.
- c) Efficiency of torch decreases with corresponding increase in the current. With increase in electrode diameter efficiency increases this is due to decrease in heat transfer from arc to electrode wall because the gap between these two increases however causing increase in gas flow rate requirement.
- d) Frequency of oscillation of voltage increases with corresponding increase in arc current and is inversely proportional to square of anode diameter. The effect of change in cathode diameter is less dominant than that in anode diameter. However it does not varies much with variation in gas flow.
- e) With increase in electrode diameter higher temperature zone in the plume spreads, which is an important performance characteristic. However axial velocity of plasma gas decreases with increase in electrode diameter leading to decrease in available oxygen flux for waste treatment. So, there should be an optimization among efficiency, high temperature zone and axial velocity.

Preliminary flow simulations

In order to optimize the flow rate of air for a particular diameter of torch, a typical distribution of temperature and

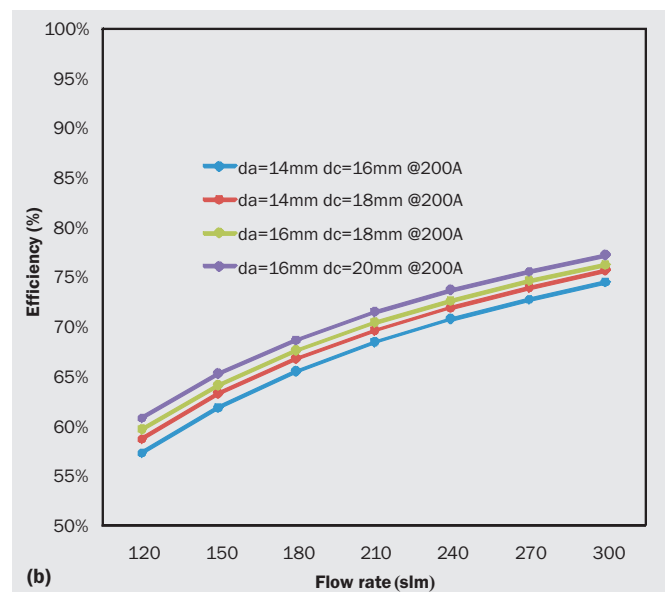
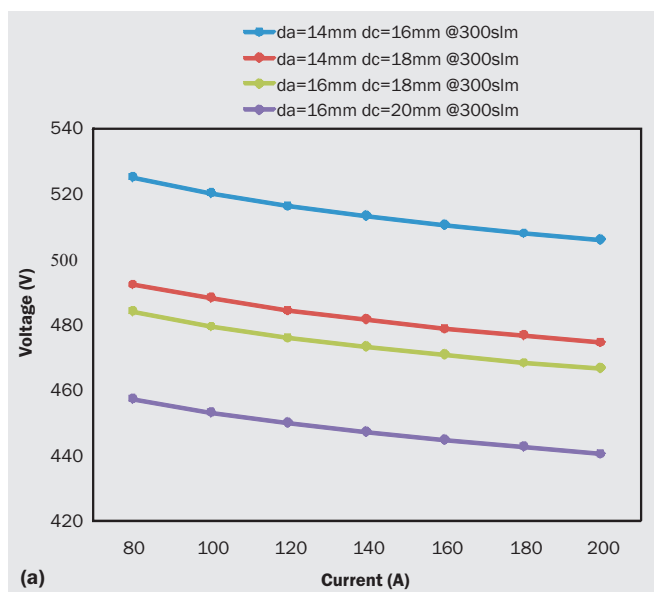


Fig.3: (a) Typical variation of arc voltage for different arc current for air flow rate = 300 slm (b) Typical variation of efficiency for different gas flow rate.

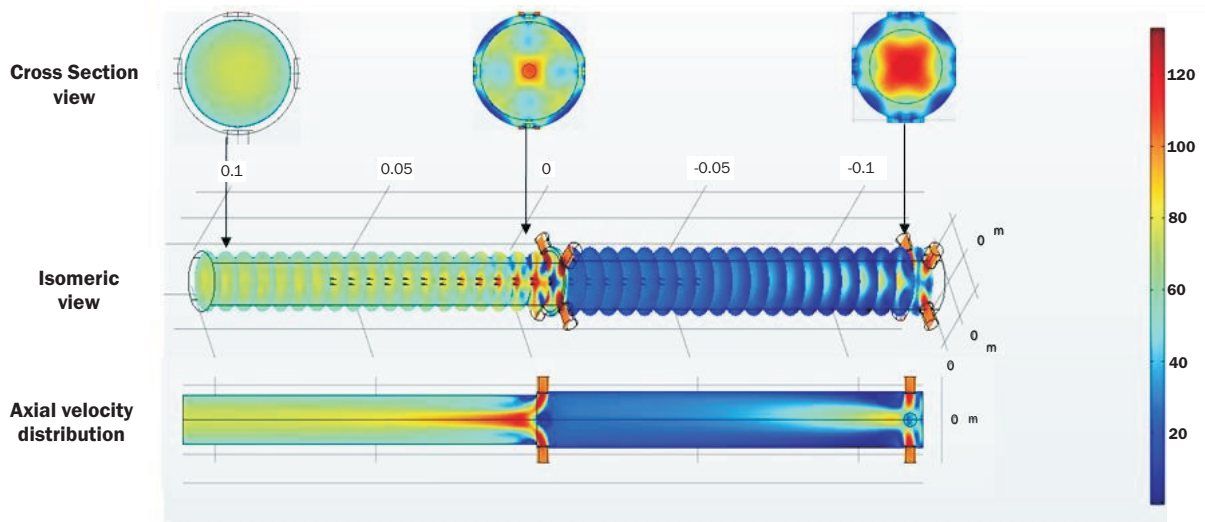


Fig.4: Typical velocity distribution (in m/s) of a 14 mm anode 16 mm cathode torch.

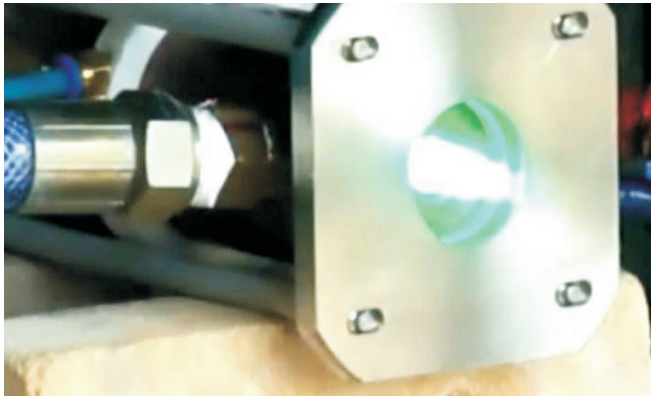


Fig.5: High power plasma torch testing at Hall-6 in BARC.

velocity (Fig.4) was simulated in commercial multiphysics simulation software, using the plasma as an extended heat source. Various combinations of nozzle geometry and flow rate variations were simulated and validated using data from literature [2].

Testing of the plasma torch

Based on the electrical and aerodynamic calculations, a plasma torch has been fabricated. It is being tested to achieve the optimum operating conditions, as shown in Fig.5.

Conclusion

Plasma torches act as high enthalpy sources that can be used in cutting, welding, spraying, machining, plasma metallurgy, underwater cutting and space simulations. Beam Technology Development Group is developing expertise in design, development and testing of high power plasma torches. In view of the widespread high power industrial and nuclear applications, the development of the 100 kW plasma torch by BARC will pave way for wider deployment of the technology in the near future.

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