# Electrical, thermal and optical characteristics of plasma torch

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## Abstract

　　Non thermal argon plasma needle at atmospheric pressure was constructed. The experimental set up was based on simple and low cost electric components that generate electrical field sufficiently high at the electrodes to ionize various gases which flow at atmospheric pressure. A high AC power supply was used with 9.6kV peak to peak and 33kHz frequency. The plasma was generated using two electrodes. The voltage and current discharge waveform were measured.  The temperature of Ar gas plasma jet at different gas flow rate and distances from the plasma electrode was also recorded. It was found that the temperature increased with increasing frequency to reach the maximum value at 15 kHz, and that the current leading the voltage, which demonstrates the capacitive character of the discharge. The electron temperature was measured at about 0.61 eV, and we calculated the electron number density to be $4.38\times10^{15}$ cm$^{-3}$.

## تشخيص شعلة البلازما كهربائيا وحراريا وبصريا

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### الخلاصة

　　تم توليد ابرة بلازما الاركون غير الحرارية وتحت الضغط الجوي. باستعمال مكونات الكترونية بسيطة وواطئة الكلفة. لها القدرة على توليد مجال كهربائي عالي عند الاقطاب يكفي لتباين الغازات المختلفة والمتدفقة عند الضغط الجوي. ولدت البلازما التي تم دراستها بفولتية متناوبة عند الاقطاب 9.6 كيلو فولت من القمة الى القمة، وتردد المجال المسلط 33 كيلو هرتز. قدم هذا العمل معلومات عن قياس الفولتية والتيار اللذان استعملا في توليد البلازما. كذلك تم قياس درجة حرارة الغاز (Ar) الاركون لابرة البلازما المتدفق بمستويات تدفق مختلفة من نهاية القطب الكهربائي. وجدت أن درجة الحرارة أرتفعت بأزدياد التردد  للوصول إلى القيمة القصوى15 كيلو هيرتز ويبدا بالانخفاض مرة اخرى، ويمكن ان نرى ان سلوك التيار والفولتية يدل على شكل التفريغ ذو خواص سعوية. كما تم حساب درجة حرارة الالكترون وكانت بحدود 0.61 الكترون فولت، وحساب كثافة عدد الالكترونات وكانت بحدود $4.38\times10^{15}$ سم$^{-3}$.

## Introduction

　　Atmospheric pressure plasma jet, non-thermal plasma, plasma propagation in plastic tube, cold atmospheric pressure plasma jets (APPJs) have attracted much attention due to their versatility, low-cost operation and also ability to produce reactive chemistry at room temperature[1].

These facts make the plasma jet very attractive for applications in the biomedical field. An interesting feature of APPJs is their ability to penetrate and propagate inside small holes and flexible dielectric tubes [2]. Delivery of cold plasma through flexible tube in a specific location can be very useful for endoscopic applications in medicine, such as treatment of colorectal, tooth, and pancreas cancers[3,4].

Therefore, the development of appropriate plasma sources for *in vivo* treatments has been subjected for intense research's. So-called plasma needle reported in [3] produced cold argon plasma on the tip of a thin electrode inserted into a 10-cm-long flexible catheter.

Non thermal (cold plasma), can be considered as medium with non-thermodynamic equilibrium, which means that the temperature of molecules, atoms and ions does not match the temperature of the electrons[5].
Several applications such as treatment of living cells [6], sterilization [7], blood coagulation, wound healing, bacteria in activation [8,9], tooth bleaching [10] and air purification [9] were conducted a wording to the characteristics of such plasma.

In this work, a plasma needle torch will be described and the characteristics of the torch discharge are explained on the basis of electrical and thermal diagnostic study.

**Experimental**
**a- Plasma torch**
Plasma torch consists of a hollow stainless steel pipe 100mm long with inner diameter 1mm and outer diameter 2.7mm inserted inside a glass pipe as shown in Fig.1. The stainless steel connected to a high voltage power supply. Teflon was put between glass pipe and stainless steel pipe.

The plasma jet obtained by this method is cold enough to be put in direct contact with human skin without electric shock and can be used for medical treatment and decontamination.
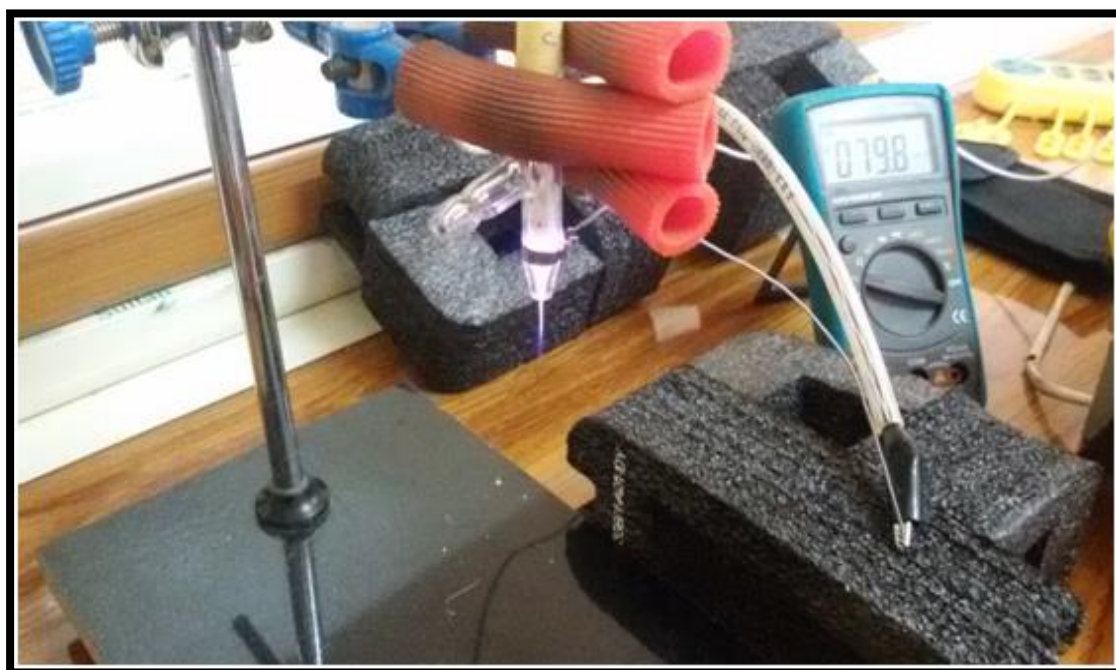


*Fig. 1: Plasma torch experiment setup.*

## b- Plasma needle system

Plasma system includes four main parts:

1. The source of alternating high voltages.
2. Plasma needle.
3. Argon gas.

4. Flow meter. Fig.2 shows the schematic diagram of plasma needle the system.

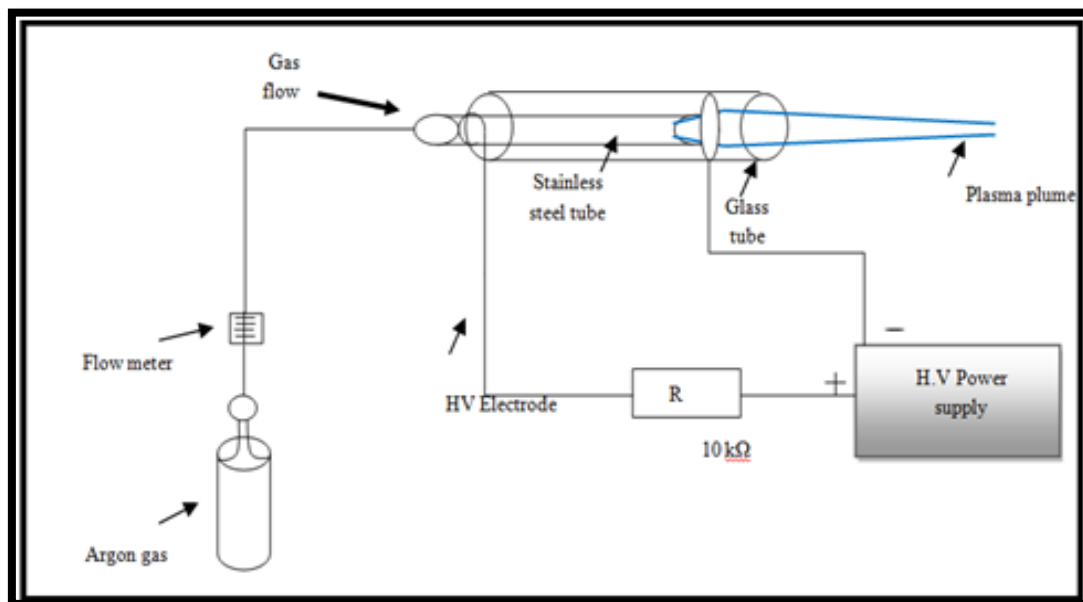Which conssast from high voltage source, plasma torch, Argon gas and gas flow meter.



*Fig. 2: Schematic diagram of plasma needle system.*

## c- Plasma characterization

Working gas temperature was measured by using a digital thermometer (-40$^{o}$C to 232$^{o}$C) of type (DFP 450 W, Waterproof).

The temperature was measured at different distances of the needle end (10, 20, 30 and 40)mm.

The high voltages were measured by using the high voltage probe with conversion ratio (1/1000) and voltage range (0-40) kV.

The current was measured by using voltage divider. It linked the resistance 10kΩ in the way of the anode and measured the voltage at both ends by using a digital multimeter Model victor Vc 97.

## Results and discussion
## a- Thermal properties

A non-equilibrium atmospheric pressure plasma needle operated with Ar gas was developed successfully. The gas temperature was determined by mercury thermometer at various distances from the end of the plasma needle electrode, for various Argon gas flow rate.

Fig.3 shows the relationship between the temperature of the gas as a function of frequency for different flow rates (1, 2, 3, 4 and 5) l/min. It was measured the temperature at a distance of (10mm) from the nozzle needle.

Fig.3 it can see that all curves behavior by same manner, also it found that the where the temperature increased with increasing frequency to reach the maximum value when the frequency 15 kHz almost and then temperature begins to decline with increasing frequency.
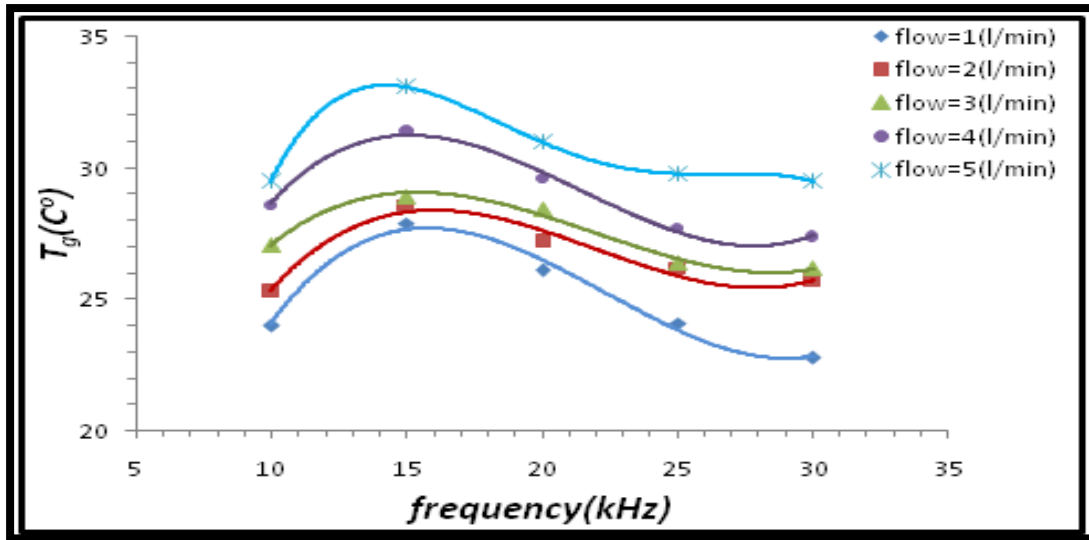
*Fig.3: Working gas temperature as a function of frequency for different gas flow rates.*

The optimum flow rate that gives maximum gas temperature at different distances are shown in Fig. 4, it is found to be around 3 l/min for all distance.

The temperature behavior for gas flow rate lower than 3 l/min is due to high transfer efficiency of the energy from the plasma needle generator to the plasma. For flow rate rather than 3 l/min the temperature decreases because the gas cooling is higher at high gas flow rates [11].
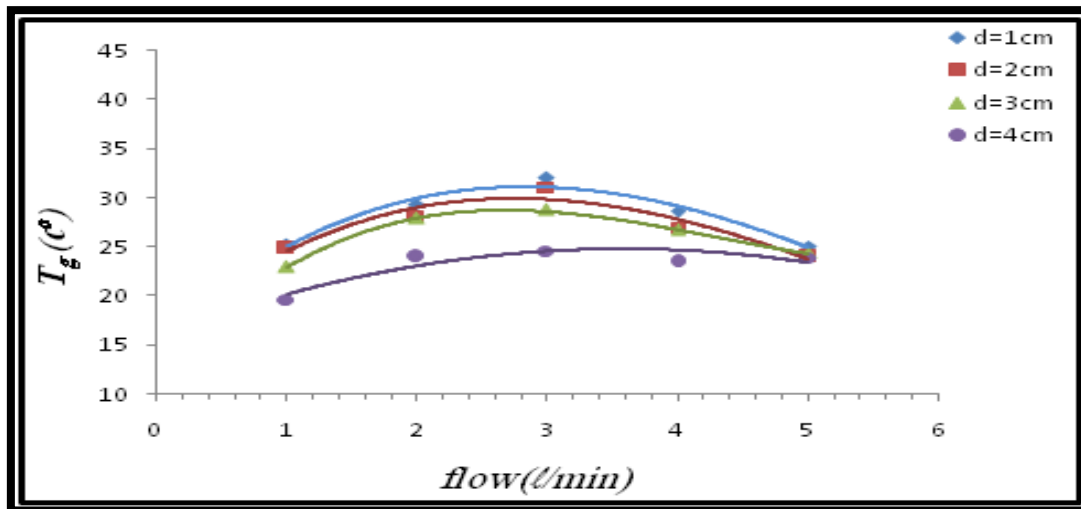


*Fig.4: Dependence of the gas temperature on the gas flow rate at various distances.*

**b- Electrical properties**

The voltage and current waveform are shown in Fig. 5. The voltage was measured at the ends of the secondary coil of the flyback transformer, from the figure we can see that the voltage have sinusoidal waveform with frequency of 33kHz.

This frequency is near the resonant frequency of the secondary circuit of the flyback transformer which calculated from the RLC values for the secondary coil. The measured voltage at the ends of the secondary coil is 9.6kV peak to peak. The current waveform has four damped oscillations

for one applied voltage, oscillation with 30µs cycle. This behavior may be due to the capacitive coupling of the circuits with the discharged gas [12].

The voltage and the current show no spiky lines which indicates that the discharges are homogenous glow, also note that the current leading the voltage, which demonstrates the capacitive character of the discharge[13].
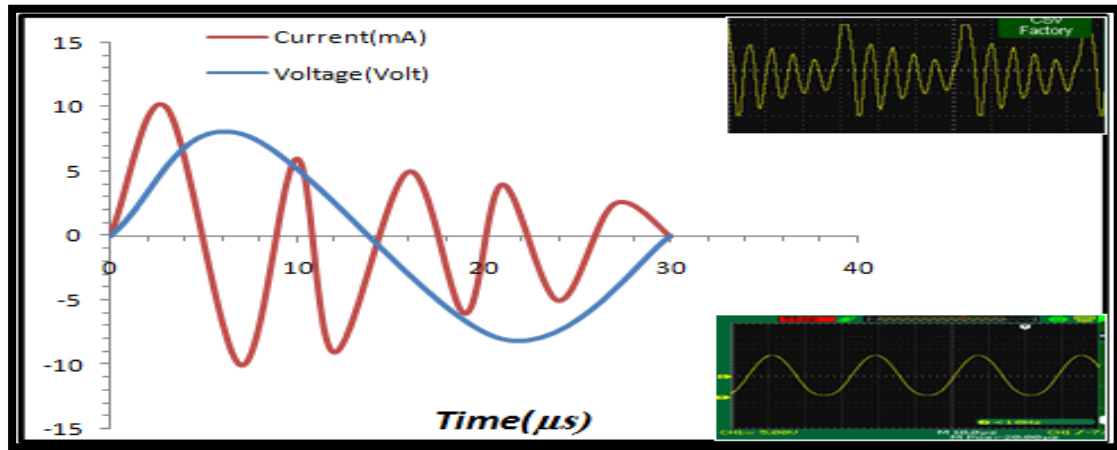


*Fig.5: Voltage and current waveform for measured the power.*

## C- Optical emission spectroscopy (OES)

The electron temperature is determined from the slope of Boltzmann's plot that uses the intensity of several spectral lines versus their corresponding excitation energies as shown in Fig. 6. The electron number density is determined from the Stark broadening of well-isolated Ar-I (696.54 nm). It is observed that electron temperature and electron number density is higher when optical emission is recorded in axial direction in comparison with radial direction.
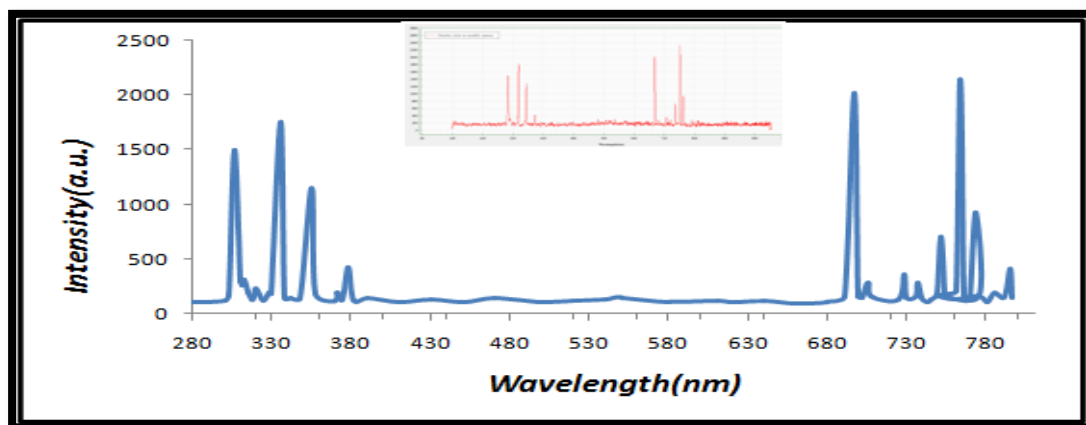


*Fig. 6: Spectra of Ar plasma operated in open air.*

The prominent spectral lines in the spectrum are identified and labeled using NIST data.

The electron temperature was measured by using spectroscopy. We selected four spectrums (wavelengths: 696.54nm, 706.72nm, 763.51nm, and 772.37 nm), these spectrums were clearly distinguished. We calculated the electron temperature to be 0.61 eV by using the Boltzmann plot

method[14]. The equation used for the calculation was as follows:

$$ln\frac{I\lambda}{Ag} = \frac{-E}{KT} + lnC$$

The electron density was measured by using spectroscopy. We selected one spectrum (wavelengths: 696.54nm), the electron number density were calculated to be $4.38\times10^{15}$ cm$^{-3}$ by using the Stark broadening method [15]. The equation used for the calculation was as follows:

$lnn_e=1.20ln[\Delta\lambda_{1/2}] +44.2476-0.60ln[T_e]$

This fact may be ascribed to energy loss of electromagnetic wave as it propagates along the plasma column, which makes the plasma parameters to vary continuously along the discharge region.

## Conclusions

The plasma generator was constructed using low-cost available component. It is easy to set up and operate. The increasing in frequency of electric field leads to increasing in the value of discharge current.

The small increasing of obtained discharge current with the increasing of the applied voltage at a certain value of flow rate (that called breakdown voltage), this value (the breakdown voltage) is decreasing with the increasing of flow rate.

A non-thermal plasma torch was built to operate at atmospheric pressure. At distances longer than 3cm from the tip of the needle the plasma is thermally non aggressive, its temperature being lower than 32$^o$C, therefore can be used in medical applications.

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