Innovative Technologies in Mechatronics and Robotics

Edited by
Fang-Jung Shiou, Jeng-Ywan Jeng
and Liang-Kuang Chen

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Innovative Technologies in Mechatronics and Robotics

Selected, peer reviewed papers from the
18th International Conference on
Mechatronics Technology
(ICMT 2014),
October 21-24, 2014, Taipei, Taiwan

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Trans Tech Publications Ltd
Churerstrasse 20
CH-8808 Pfaffikon
Switzerland
http://www.ttp.net

Volume 649 of
Key Engineering Materials
ISSN print 1013-9826
ISSN cd 1662-9809
ISSN web 1662-9795

Full text available online at *http://www.scientific.net*

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Churerstrasse 20
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printed in Germany

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Preface

The ICMT is an annual international mechatronics and technology conference that has been successfully held for 17 years. ICMT offers a forum to discuss state-of-the-art technologies and emerging application trends, and provides great opportunities for professional interactions and networking in a friendly and hospitable setting. The first ICMT was convened in Santa Clara, USA, in 1996, and subsequently held in Yokohama, Hsinchu, Pusan, Singapore, Kitakyushu, Taipei, Hanoi, Kuala Lumpur, Mexico City, Ulsan, Sudbury, Cebu City, Osaka, Melbourne, Tianjin, Jeju Island, and this year in Taipei, Taiwan. The objective of ICMT is to facilitate close dialogues, networking and collaborations among experts on issues related to research and technological development in mechatronics. ICMT 2014 continues to follow the rich tradition of ICMT with this year's conference theme: Innovative Mechatronics Technology. The topics to be discussed under this theme include robotics, intelligent mechanisms, sensors, intelligent control and actuators, MEMS/NEMS, micro/nano-manufacturing, precision measurement technology, production systems, bioengineering and mechatronics applications in life sciences, 3D printing technologies.

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Key Engineering Materials Vol 649 (2015) pp 1-8
© (2015) Trans Tech Publications, Switzerland
doi:10.4028/www.scientific.net/KEM.649.1

Submitted: 2015-02-26
Accepted: 2015-03-27

Variation of Entrance Length effect on EHD Gas Pump performance

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Keywords: Entrance length, Electrohydrodynamics, corona wind, and gas pumping.

Abstract

The effects of entrance length on performance and flow characteristic of EHD gas pump has been experimentally examined in this study. A 61.8mm-in-diameter EHD gas pump with eight evenly spaced emitting electrodes and flush mounted on the tube inner wall is used for this investigation. The experiment is conducted for two applied voltages 19 kV and 20kV with positive polarity. Several (L/D) ratios are used aiming at picking the appropriate length to achieve highest ionic discharge and maximum pump performance. Results show that the lowest (L/D) ratio gives the best pump performance with highest discharge managed.

Introduction

Corona discharges are relatively low power electrical discharges that take place at or near atmospheric pressure. The corona is invariably generated by strong electric fields associated with small diameter wires, needles, or sharp edges on an electrode. Depending on the electrode geometrical configurations and polarity of an electric field several forms of a corona discharge can exist along with an increase in applied voltage. When a high voltage is applied between two electrodes of different radius of curvature in air, it leads to ions discharged from the electrode with a smaller one. Under the influence of Coulomb force, ions drift from the emitting electrode to the collecting electrode. While traversing down those ions exchange momentum with neutral air molecules and induce a bulk motion of fluid, which is commonly called *corona wind* or *ionic wind*. Corona discharges can be put to good use in many engineering applications such as electrostatic precipitation[1], and flow control[2, 3] enhancement of heat and mass transfer[4-7] and drying[8, 9]. Recently, the demand on thermal management of electronic components has prompted the use of EHD technique. Corona wind generated between the electrodes can be utilized for electronics cooling. Since the flow is generated by the direct interaction of electric and flow fields, the technique is termed electrohydrodynamic (EHD) gas pumping [10-13]. For this specific application, EHD can create a pressure difference (and thus a flow) between the inlet and outlet of a flow passage by means of electrical forces which act directly on the fluid volume present between the two electrodes without any moving part. This unique feature of EHD gas pumping has received enormous attention in recent years for its potential new applications in micro-electro-mechanical systems (MEMS). Compared to conventional fans EHD gas pump is becoming advantageous as such the power it requires is much less as the current is in micro scale or less besides having no moving components and optimum control of gas flow.

Although various EHD gas pumps have been developed for specific applications, currently there is no general rule in design an EHD gas pump. Apparently the pump geometry, charge polarity, electrode spacing, and electrode arrangement have all played an important role in the performance of an EHD gas pump. To address the need for a design methodology, several studies have been conducted to explore the role played by each parameter mentioned above [10, 11, 14, 15] . A further study on the matter which is an experimental investigation on the effects of inlet pipe variation vis a vis EHD gas pump flow characteristics is presented in this paper.

Experimental Procedure

The schematic of the experimental setup used for this study is shown in Fig. 1. The pump has an inner diameter of 61.8 mm. It consists of three major parts: an inlet section, a test section (EHD gas pump) and an outlet section. A clear acrylic pipe is used to manufacture these parts. Different entrance length sizes such as 1D, 2D, 3D, 4D, 5D, 6D as shown in fig.3 are manufactured for this experiment. Further sizes can be put to use using the available pipes and joining different sizes, such that 8D entrance length can be formed by joining 2D and 6D sizes.

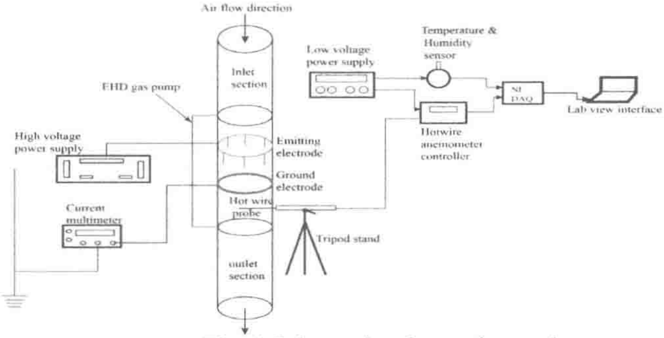
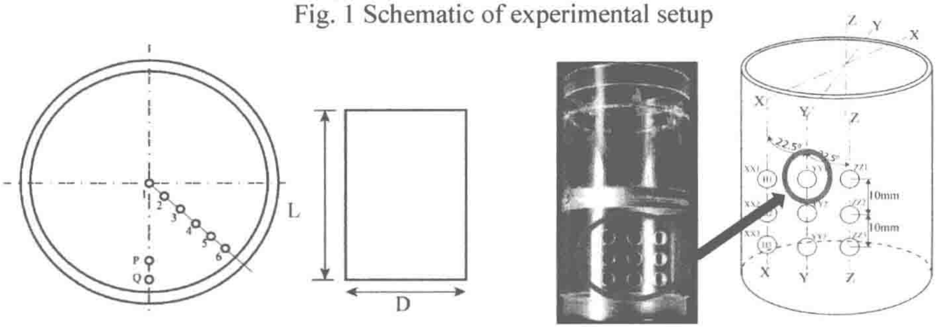


Fig. 1 Schematic of experimental setup



(a) (b) (c)

Fig.2 (a) Near wall and radial measuring positions (b) inlet pipe parameters
(c) EHD gas pump and testing position

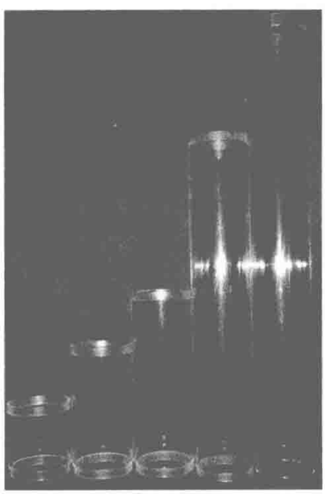


Fig.3 Entrance length photos

A groove of 1.2 mm wide and 1.2 mm deep, which is located 10 mm away from the top of the test section, is machined around the inner wall of the pipe to house a copper ring which serves as a common bus for emitting electrodes. Eight emitting electrodes which are made from copper wire of 0.4 mm diameter are welded to the copper ring. They are evenly spaced at an angle of 45° around the pipe and are flushed with the pipe wall. Another groove of 10 mm wide and 0.5 mm deep has been machined to mount the ground electrode. The electrode spacing, which is measured between the tip of the emitting electrode and the ground electrode, is fixed at 25 mm for the present study. The copper ring is connected to a high voltage power supply while the ground electrode is maintained at the same level as that of the power supply. The high voltage power supply is custom made by You-Shang Technical Corp. in Taiwan with dual polarity and a maximum output of 30 kV. It has an accuracy of ± 1V in voltage and 2% in current.
For flow measurement, nine sampling holes (each of 6.5-mm-diameter) are drilled circumferentially around the pipe (Fig. 2). They are arranged in three rows and three columns. The first row of holes is 15 mm below the ground electrode and the rest are equally spaced in a vertical distance of 10 mm center-to-center. Similarly, each column of holes is evenly spaced at an angle of 22.5°. In this arrangement, the first and third columns of sampling holes (labeled here as axes XX and ZZ) are aligned with the emitting pins and the second column (labeled as YY axis) is midway between two neighboring emitting pins. A hot wire anemometer (TSI 8465) has been used along with a tripod for flow measurements. Since the diameter of the hot wire probe is much smaller than that of the pipe, flow blockage by the probe stem is considered minimal. The hotwire anemometer has an accuracy of ± 0.05% of the full scale with minimum resolution of 0.07 m/s. The sensitivity of the anemometer is 0.07% of the full scale which translates to 0.035 m/s. The hotwire anemometer is connected to a data acquisition system (NI 9207) that has 16 channels with ±20 mA and 24 bit resolution. A sampling rate of 5 Hz has been used for all measurements reported in this study. It has been determined by a systematic trial that this sampling rate is sufficient to capture the variations of electric and flow fields. At each measuring point, data are recorded for a minimum of three times and an average value is taken for all cases conducted in the experiment. Before each experimental run, the setup is carefully cleaned and tightly assembled. The emitting electrode pins are connected to the high voltage power supply while the ground electrode is grounded to the same level as that of the power supply and multimeter. After the hot wire probe is placed at the sampling position and carefully aligned, the high-voltage power supply is set to the positive polarity and turned on. The voltage is gradually increased until it reaches a threshold value, at which point a hissing sound can be heard. This threshold voltage marks the onset of corona discharge. Corona current collected from the ground electrode is recorded using a multimeter (FLUKE 287). Ambient conditions (temperature and humidity) are also recorded for reference.

Since corona discharge is greatly affected by the ambient condition, the present study has been conducted under tightly control of room temperature and humidity. The ambient condition has been recorded during the course of experiment to substantiate any variation due to ambient condition. The uncertainty associated with the measurements was calculated by the method proposed by Steele et al. [16]. The velocity measured by the hotwire anemometer had an uncertainty of 0.03535 m/s while the average current collected on the ground electrode using a multimeter has an uncertainty of 0.965 μA.

Results and discussion

Variation of entrance lengths have significant influence on the flow generated from the EHD gas pump studied here. Previous studies reported EHD pump cases with less attention regarding the entrance length effects. Since recent interests of EHD gas pumps is much on electronics cooling, attaining high discharge from EHD gas pump is the vital. Therefore, prior to further experimental investigations identifying the appropriate entrance length is essential. In this study several entrance length to EHD gas pump diameter ratio (L/D) are examined to investigate the flow characteristics such as pump volume flow rate, pump performance and pump flow velocity. Based on this the following results that will be discussed in the subsequent sections are obtained and several important practical implications for engineering applications are obtained.

A. Entrance length variation and flow velocity

Previously; Brown and Lai [11] considered entrance length for EHD gas pump in a vertical tube of their specific design. They used eight times of the diameter assuming the flow is developed at the inlet of EHD gas pump, yet the method to pic this size is not stated. Moreover since flow is initiated at the emitting electrodes flow development at the inlet of the pump has not much significant used for such investigations rather picking the appropriate size that will enhance the discharge is found critical. Here, radial flow velocity profile development for different (L/D) ratios is depicted in figures below. Experiments are conducted for two applied voltages 19kV and 20kV. The onset applied voltage for this experiment is marked at 17kV. As EHD experiments are highly affected by humidity the onset value is slightly elevated. The average humidity in this experiment is recorded and due to its fluctuation from time to time different humidity values are observed, for applied voltage 19kV the humidity was averaged 62 while for 20kV the humidity recorded was averaged to 48. The current collected on the ground as a result is lower for 19kV compared to that of 20kV beyond the natural phenomena that it should be lower for lower applied voltages compared to the current generated for higher applied voltages [11, 17]. Yet since the objective of this study is on entrance length, the overall trend for flow velocity profile and subsequent results is quite uniform and reasonable. To avoid wadded sketches, plots are performed separately as shown below in Fig.4 and Fig.5. Fig.4 shows flow velocity profile for L/D ratio of 1, 4 and 8 for the applied voltages 19kV and 20kV respectively. From the figures it is visible that for a fixed diameter, as the entrance length increases flow velocity magnitude reduces. As stated above the pump is uniquely designed to study near wall flow influence so that special attention is given to this region. Apparently, pronounced effect of entrance length is observed near wall and velocity values for different L/D ratios does not show significant difference in the central region as shown in figures 4(a) and 5(a), except that in fig.4(b) the lowest entrance length gives uniformly higher velocity at all radial sampling points. Again, at fixed radial positions the lower entrance length marks the highest velocity and the trend follows successively disregarding slight discrepancies that might occur due to ambient conditions variation.

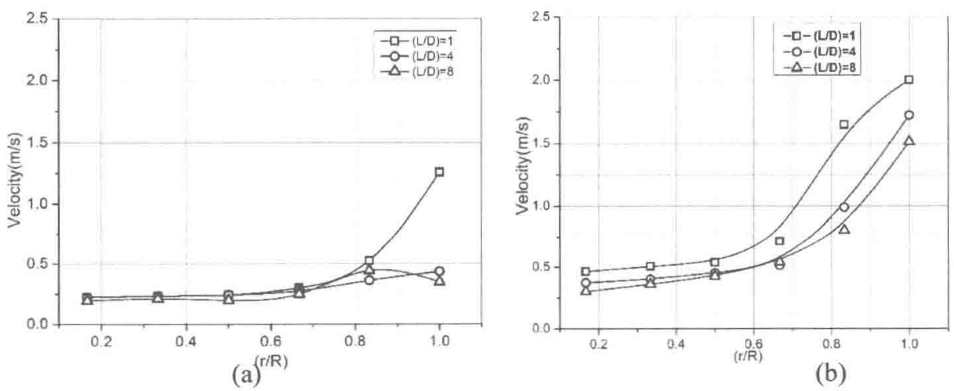


Fig.4 Entrance length variation (1, 4, 8) (a) 19kV (b) 20kV

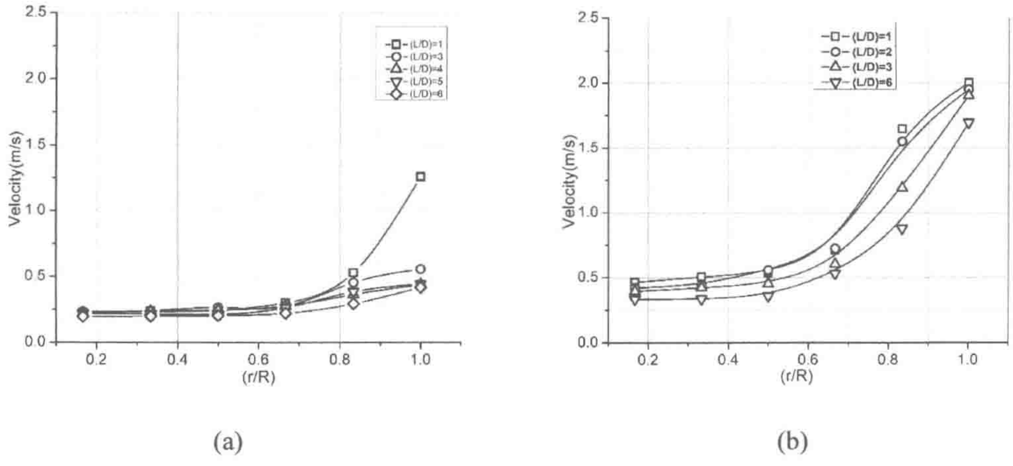


Fig.5 Entrance length variation with radial flow velocity
(a) L/D of 1, 3, 4, 5, 6 at Vo = 19kV
(b) L/D of 1, 2, 3, 6 at Vo = 20kV

B. Near wall flow velocity and Entrance length variation

Fig.6 shows plot of velocity at two positions Q and P, for L/D ratios of 1, 2, 3,4,5,6 and 8 at applied voltages of 19kV and 20kV. Close examination of the near wall effect due to the nature of EHD gas pump design is found necessary to better decide on the outcome of the entrance length. For this two points *P* and *Q* are taken in to account as shown in fig 2(a) labeled as near wall region. In terms of boundary layer thickness (δ) points *Q* and *P* are nearly 15 and 30% of δ.

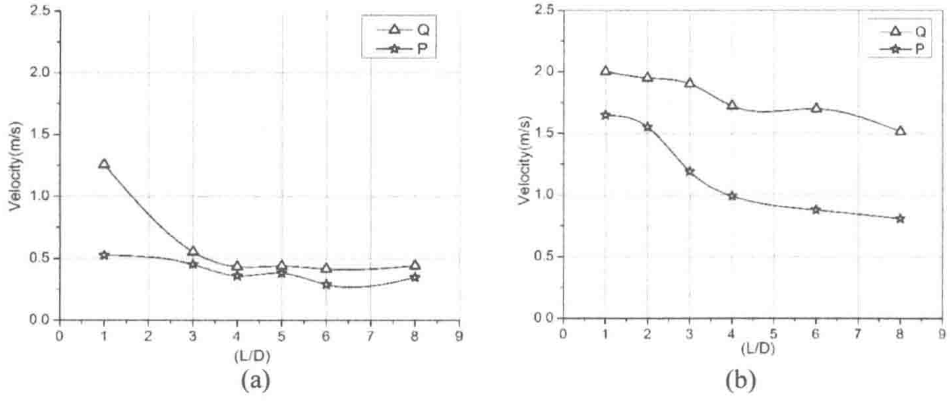
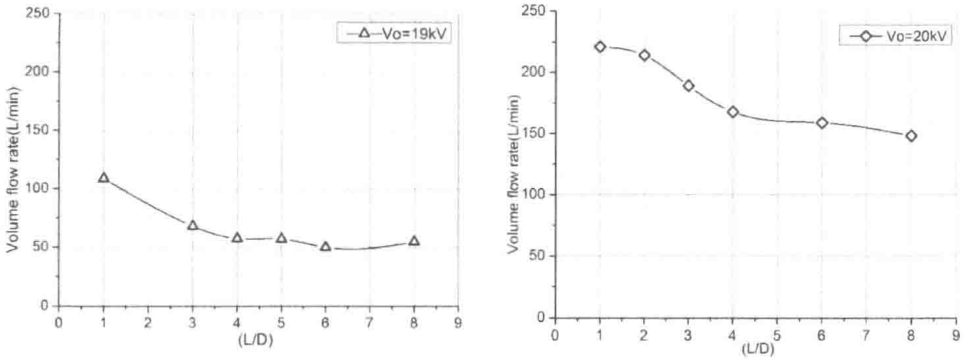


Fig.6 Near wall velocity profile (a) 19kV (b) 20kV

For both applied voltages the velocity nearest to wall is higher at all L/D rations and comparing the velocity magnitudes for the two applied voltages, the velocity at applied voltage of 20kV is higher at both (P and Q) locations of each corresponding sampling points. Again, the lower entrance length gives the highest velocity while the larger entrance length gives the lowest velocity for both applied voltages and locations *P* and *Q*.

C. Volume flow rate and Entrance length variation

The volume flow rate with entrance length variation as shown in the fig.7 is analyzed for the two applied voltages. A similar trend is observed as such highest volume flow is achieved for the lower entrance length. In Fig.7 (a) for L/D of one the volume flow rate is more than 100L/min whereas for the higher ratios such as L/D of eight the volume flow rate is slightly higher from 50L/min. Similarly for the 20kV applied voltage in fig.7 (b) the volume flow rate for lowest L/D ratio is as high as 225L/min and the deviation form the highest L/D ratio is nearly 100L/min. Similarly, at higher applied voltages a large amount of current is collected on the ground gives the better discharge compared to the lower applied voltage, this latter influences the pump performance owing to big deviation from the lower applied voltage. Besides, from the figures depicted; one can also observe that, using lowest entrance length for higher applied voltage is more valuable compared to that of lower applied voltage. This is because, comparing the discharge between L/D of one and L/D of eight for smaller applied voltage, the value is nearly 54L/min and while that of the corresponding magnitude for the higher applied voltage is nearly 74L/min. This however, should be supported by more applied voltages data which is part of future study.

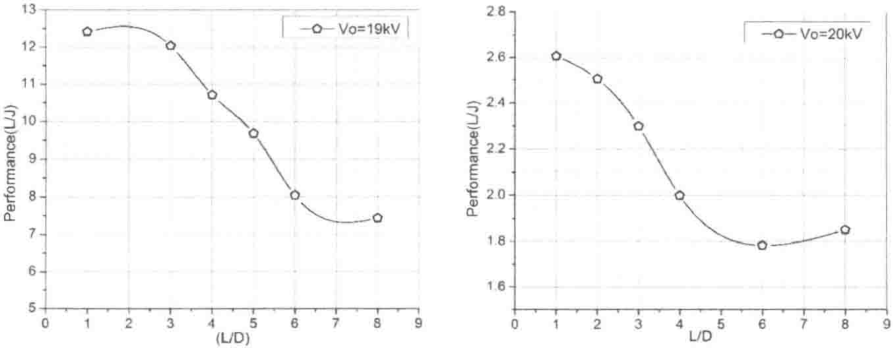


(a) (b)

Fig.7 Volume flow rate with entrance length (a) 19kV and (b) 20kV

D. Pump performance and Entrance length variation

Performance of the EHD gas pump is also investigated as shown in the figures below fig.8 (a) and (b). Again the entrance length variation with performance tested show that the lowest entrance length for both options of applied voltages used 19kV and 20kV gives the best performance and the highest entrance length gives the lowest performance for all aspects of the parameters tested. So far it is clearly shown that using the lowest entrance length for the specific EHD gas pump design used here is appealing. Apparently, the pump performance for an applied voltage of 19kV is higher than that of 20kV. This is due to the power consumption from the high voltage supply which is higher applied voltages consume more power than the lower once additionally the higher humid that was recorded as mentioned above gave the 19kV pump slight advantage due to the low current recorded, as such the low current also boosts the performance of the pump by reducing the power consumption.



(a) (b)

Fig.8 Performance of the EHD gas pump with entrance length