Electrospinning is a simple, economical and straightforward method of production of various nanostructures. Electrospun nanofibres have a wide range of potential applications in many fields, such as air filtration, water filtration, biomedicine, catalyst supports, drug delivery, tissue engineering, nanowires, just say few. This experiment shows that operating parameters affect much morphology and mechanical character of electrospun nanofibres. This paper studies theoretically and experimentally the scaling relationship between two main operating parameters-current and applied voltage.

Polyacrylonitrile (PAN) nanofibres are prepared by electrospinning of 12 wt% and 18 wt% PAN/DMF solution. In our experiment the volume flow rate keeps unchanged during the electrospinning process, and the voltage varies from 10 kV to 50 kV. The non-linear relationship between current and applied voltage is obtained by an allometrical approach. The theoretical prediction agrees very well with experimental data.

**ABSTRACT**

Experimental Verification of Scaling Law between Current and Applied Voltage in Electrospinning

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**Key Words:**
electrospinning; nanofibre; nanomaterial; PAN; scaling relationship.

**INTRODUCTION**

Electrospinning [1-12] of polymer nanofibres attracted significant attention during the last several years as a simple and straightforward method of production of nanostructures, which are of interest in many applications [11]. The procedure involves applying a very high voltage to a capillary and pumping a polymer solution through it. Superfine fibres of polymer collect as a nonwoven fabric on a grounded plate below the capillary. Nanostructures are studied by various methods
Electrospinning needs high voltage to pull the charged solution, the current in the charged jet is the key factor affecting the diameter, the length of the electrospun fibre (the jet length was measured from the tip of the spinning drop to the onset of waves in the fibre), surface character, and mechanical strength.

**Allometric Scaling Relationship between Current and Voltage**

The charged jet can be considered as a one-dimensional flow. Conservation of mass gives:

\[ \pi r^2 u \rho = Q \]  

where \( Q \) is the mass flow rate, \( r \) is radius of the jet, \( u \) is the velocity, and \( \rho \) is density.

The current (I) passing through the jet is composed of two parts: the Ohmic bulk conduction current (\( I_c \)) and surface convection current (\( I_s \)).

\[ I = I_c + I_s \]  

(2)

In electrospinning process, the current (I) was considered to consist of the Ohmic bulk conduction current and the surface convection current, leading to the following equation [2-6].

\[ 2\pi \sigma u + \pi r^2 kE = I \]  

(3)

Suppose that the allometric relation between current, \( I \) and voltage, \( E \), can be expressed as [2,3].

\[ I \propto E^b \]  

(4)

where \( b \) is the power exponent. When \( b=1 \) the relationship is isometric, and it corresponds to Ohm Law. In case \( b\neq1 \) the relationship is allometric.

Assume that the volume flow rate (Q) keeps unchanged during the electrospinning procedure, i.e. \( Q \propto r^0 \).

From eqn (1), we have the following scaling relation:

\[ u \propto r^{-2} \]  

(5)

From eqn (3), we have

\[ \pi \sigma u \propto I \]  

(6)

and

\[ r^2 E \propto I \]  

(7)

Assume that:

\[ I \propto r^a \]  

(8)

From (4), (5) and (6), we have:

\[ \sigma \propto r^{a+1} \]  

(9)

and

\[ I \propto E^{a/a-2} \]  

(10)

The unknown constant, \( a \), varies among different polymer solutions, it can be determined by experiment. The experimental data by Therona et al. show the scaling law between current and voltage for 10 wt% PCL in MC/DMF(75/25) in the form [9]:

\[ I \propto E^3 \]  

(10)

Demir et al. obtained a similar result \( I \propto E^{2.7} \) for PU solutions [1].

**EXPERIMENTAL VERIFICATION**

Experimental set-up device used for electrospinning process is shown in Figure 1. A variable high voltage power supply was used for the electrospinnings. It was used to produce voltages ranging from 10 to 50 kV. Polyacrylonitrile (PAN) solution, which is one of the most promising materials for multifunctionalized applications [18], was poured in a syringe attached with a capillary tip of 0.5 mm diameter, the applied voltage and flow rate were changed separately, and the distance between the capillary tip and collector is constant, 8 cm. A voltmeter was used to measure the voltage on resistance, and the voltages measured were then converted to currents.

**Materials**

Polyacrylonitrile (PAN) with a molecular weight of 70,000 was supplied with Sinopec Shanghai Petrochem-
ical Company Limited, and N,N-dimethylformamide (DMF) was purchased from Shanghai Chemical Co.

Solution Preparation
Amount of 12 wt% and 18 wt% PAN were separately added to DMF and the solution was stirred magnetically for one hour under 80°C.

RESULTS AND DISCUSSION
A PAN/DMF solution of respective 12 wt% and 18 wt% were spun separately under different flow rates. The experimental results are shown in Figure 2, where a and b are designates for the two solutions.

Figure 2 reveals that scaling exponent is approximately equal to 3 for 2 wt% PAN in pure DMF and 18 wt% PAN in pure DMF.

CONCLUSION
We have proposed an allometric law between current and voltage for polymer solution considered as an Ohmic conductor in electrospinning. Our experimental data agree well with our proposal.

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REFERENCES