

Expanding Students' Imagination and Creative Thinking - from Blending Electro spraying to Coaxial Electro spraying

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Abstract—The problem of how to expand the college students' imagination and creative thinking in their courses is always an important issue puzzling their professional teachers a lot, particularly for those majoring in material science and engineering. In this paper, the history and development of electro spraying (from blending electro spraying to coaxial electro spraying, and to modify coaxial electro spraying) is explored as a useful teaching materials to explain how to provoke the students to imagine and to think in a creative manner about the materials processing engineering. Abundant teaching materials are disclosed from the single-fluid blending and modified coaxial electro spraying processes for expanding the college students' imagination and creative thinking, which include the technology itself, the reasonable selections of raw materials, the resultant nanoproducts produced during the electro spraying processes, as well as their formation mechanisms. The present article shows the method of feedback teaching for undergraduate students in higher education through scientific research by taking an example.

Keywords—Creative thinking; Modified coaxial electro spraying; College students; Engineering education; Nanomaterials

I. INTRODUCTION

During the engineering teaching in high school, it is very important that the students are taught to study from their practices. And during the practice processes, they should grasp the methods and form a fine habit about expanding their imagination and creative thinking. This is particularly important for those senior students, who will walk into the society. However, how to do this kind of self-learning is not an easy thing for them. The teachers should exhibit to them and share their owns experiences with the students about this kind of capability.

In this paper, with the development history of electro spraying as an excellent example, we explain how to promote the students to imagine and think in a vivid manner. Electro spraying, a word stemmed from electrostatic spraying, means that the energy applied to spray the working fluids is the electrostatic high voltage [1-4]. Thus, this technology is similar with electro spinning [5-13], and they similarly belong to the electrohydrodynamic atomization (EHDA) processes [14-19]. Today is a nano era, nanomaterials and the useful

methods for creating nanomaterials in a simple and cost manner are very popular [17-23]. Electro spraying, as a one-step straightforward fabrication process for creating nanoparticles, has abundant materials that can be refined for teaching in the high school for the undergraduate students.

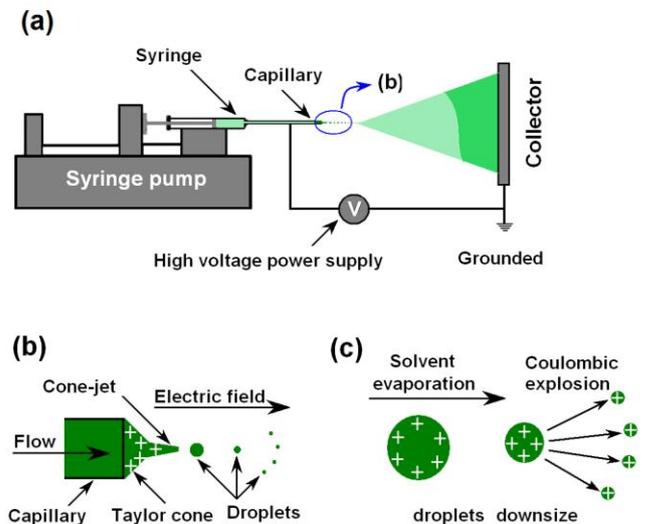


Fig.1 A diagram showing the blending electro spraying process and its working mechanism [8].

Shown in Fig. 1 is a diagram of a single-fluid blending electro spraying process and its working system. Just as single-fluid electro spinning system [20-27], it is composed of four parts: a syringe pump, a high voltage power supply, a collector, and a metal capillary as the spraying head (Fig. 1a). When the working fluid is guided to the electrical field, it will be subjected to a series of forces, such as the electrical drawing force, the repulsion force, the surface tension and the capillary force. Their balance will transfer the droplet of working fluid into a cone shape, which was first discovered by Taylor and named Taylor cone (Fig. 1b). After the Taylor core, often there is a straight fluid jet or a converging point, which will be followed by an atomization process (Fig. 1c). Within the atomization region, the solvent in the working fluid will fast

evaporate thanks to the rapid increase of surface area of the split tiny droplets. This is because of the Coulombic repulsions among the split droplets, and should take charge of the formation of fine solid nanoparticles [28-29].

During the electrospinning process, abundant teaching materials can be refined for expanding the students' imagination and creative thinking from a standing point of selection of raw materials, technology itself, resultant products and the working mechanisms, which are included in Fig. 2.

	Material Engineering	Real treating processes (Blending electrospaying)	Expanding potential creative thinkings (Coaxial electrospaying)
1	Raw materials	Polymers Solvents Additives	Matching material sets Compatible solvent/polymer Multiple-functions
2	Technologies	Applied voltage Flow rate Collected distance	Applied voltage Fluid flow rate ratio Working distance Organized formats
3	Products	Micro-/Nano-spheres Monolithic Amorphous Wet films	Size of nanoproducts Nanostructures Crystalline/Amorphous Wet films Heterogeneous
4	Mechanisms	One solidifiable fluid EHDA mechanism	Solidifiable/Un-solidifiable co-treatment EHDA mechanisms

Fig. 2 During the electrospinning process, abundant teaching materials can be refined to expand the students' imagination and creative thinking from a standing point of selection of raw materials, technology itself, resultant products and the working mechanisms.

First of all, the selection of started raw materials comprises a vivid lesson for the students to expand their imaginations and creative thinking, who major in material science and engineering. In the real single-fluid blending electrospinning process, the materials that can be selected for carrying out the working processes to fabricate the designed functional nanoparticles include polymer, solvent and also some other additives. Based on this simple one-fluid process and monolithic nanoparticles [3], the students can expand their thoughts on how to select the started raw materials for implementing a coaxial or modified coaxial electrospinning process. And beyond the traditional concept, some new creative thinking can be drawn out from this development processes, such as matching or not of the material sets, compatibility between the solvent of sheath fluid with the solutes of the core fluid or vice visa, and the potential multiple-functional performances.

II. EXPANDING STUDENTS' IMAGINATION AND CREATIVE THINKING THROUGH THE PROGRESSES OF ADVANCED TECHNOLOGY ITSELF

Advanced technologies always play a key role in the innovation teaching in high education about science and engineering. Just as the progress from one-fluid electrospinning to two-fluid coaxial and side-by-side electrospinning [12-17], the progress from the single-fluid

blending electrospinning to the coaxial electrospinning and modified coaxial electrospinning comprises interesting teaching materials for provoking the students' thinking and imaginations about the modern advanced nanotechnologies.

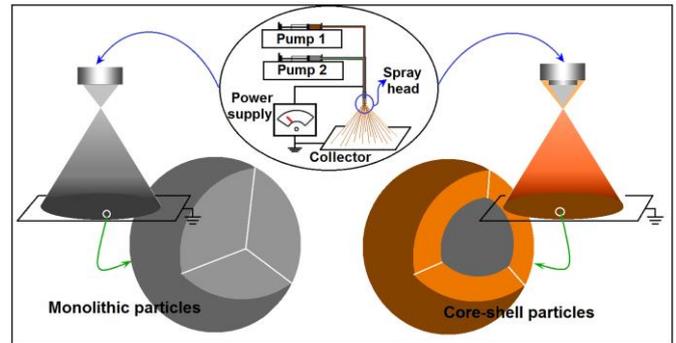


Fig. 3 Expanding the college students' imagination and creative thinking from a single-fluid blending electrospinning to the coaxial electrospinning and modified coaxial electrospinning [3].

Shown in Fig. 3 is a diagram about both the single-fluid blending electrospinning and the coaxial or modified coaxial electrospinning processes. For a single-fluid electrospinning process, the key operational parameters include applied voltage to overcome the surface tension of working fluid for initiating the Taylor core and atomization, the matching fluid flow rate with the applied voltage, and the collected distance for the depositions of electrospayed solid nanoparticles. Based on these knowledge, the students can more effectively to be taught about the coaxial/modified coaxial processes. Not only the above-mentioned parameters, but also some new parameters will provoke the students to do simple creative thinking and imagination. For example, one student asked about a strange question about how to organize the two fluids in a systematic manner. This question can draw a series of potential new double-fluid electrospinning processes, such as side-by-side electrospinning and parallel multiple-needle electrospinning. Certainly, many student can imagine that the core-ti-sheath fluid flow rate should be an important parameter during the modified coaxial electrospinning process.

III. EXPANDING STUDENTS' IMAGINATION AND CREATIVE THINKING THROUGH THE NANOMATERIALS' STRUCTURES

About three decades before, nanomaterials with a size under 100 nanometers were very popular within the scientific researches. With the development of moder science and technology, the nanoscience and nanoengineering are now focusing on three aspects: the further downsize of nanomaterials (i.e. picotechnology), the preparation and application of complicated nanostructures and nanodevices, and the alignment of nanomaterials. Correspondingly, the single-fluid electrospinning process is famous for its capability of generating monolithic nanoparticles in a single step and a straightforward manner. Later, the coaxial electrospinning processes are drawing ever increasing attention because that this material treatment process hold the unique ability of duplicating nanostructures directly from the shapes of spray

heading at macroscale. Shown in Fig. 4 are typical single-fluid blending electro spraying and double-fluid modified coaxial electro spraying processes. From Fig. 4a, it is clear that all the components were dissolved into one fluid and highlighted in blue color with blue marker. Needless to say, the resultant nanoparticles were monolithic, shown as Fig. 5a and 5b. In sharp contrast, two different fluids were organized in a core-sheath manner in Fig. 5b, where the sheath working fluid was a pure organic solvent without any solute. Although the final products were still monolithic nanoparticles (Fig. 5c and 5d), these particles showed totally different morphology and inner structure. They had a smaller size but a rounder and more compact cross-section topography. Thus, this strange situations greatly puzzled the students and promoted them to think more broadly and deeply about the materials formation mechanisms.

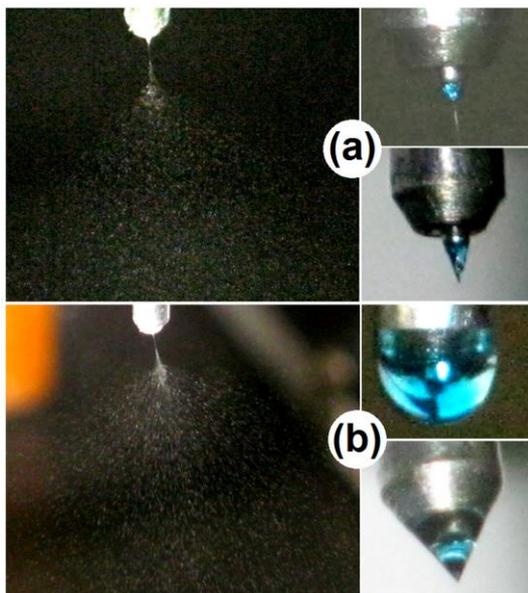


Fig. 4 Digital pictures about (a) the single-fluid blending electro spraying and (b) the double-fluid modified coaxial electro spraying [28].

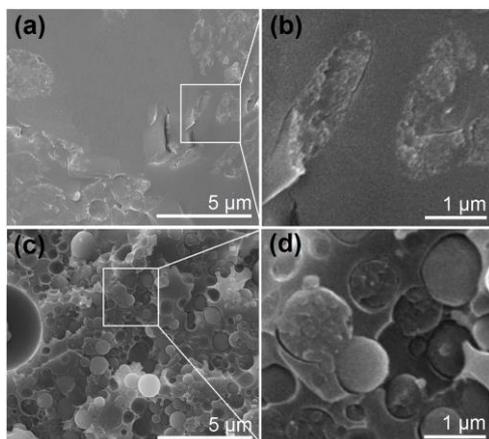


Fig. 5 SEM images of the inner structures of nanoparticles resulting from (a and b) the single-fluid blending electro spraying, and (c and d) the modified coaxial electro spraying [28].

IV. EXPANDING STUDENTS' IMAGINATION AND CREATIVE THINKING THROUGH THE WORKING MECHANISMS

All the electro spraying processes, regardless of one-fluid blending or double-fluid coaxial/side-by-side, the material formation mechanisms are around the interactions between the working fluids and the electrostatic energy. During these processes, a wide variety of phenomena will happen, but the most important phenomena are the conversions of working liquids to solid nanoparticles in an extremely fast speed, often within one second.

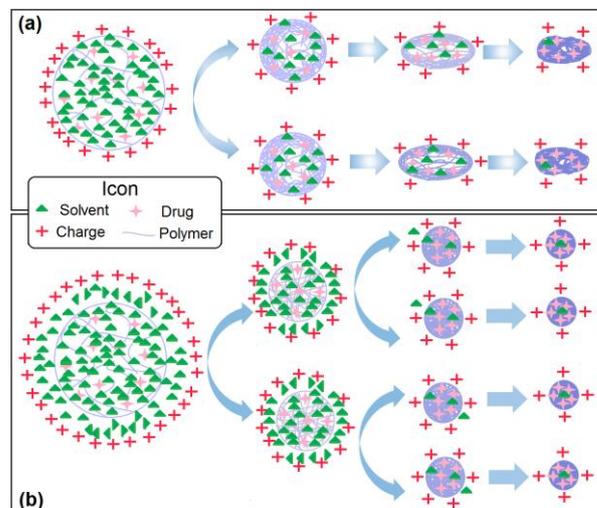


Fig. 6 Working mechanisms of (a and b) the single-fluid blending electro spraying, and (c and d) the modified coaxial electro spraying [4].

The “similar” formations of monolithic particles from the single-fluid electro spraying and the modified coaxial electro spraying are concluded in Fig. 6. In the traditional single-fluid blending electro spraying process (Fig. 6a), the small droplets after the Columbic explosion rapidly split and shrunk due to the accumulation of surface charges and the fast evaporation of solvents. The fast evaporation of solvent from the surface of droplets can result in a premature formation of semi-solid substance on their surfaces. This, in turn, can stop the active diffusion of solvent and entrap some solvents within the final particles, which should takes charge of the flat outer morphology and loose inner structures.

In the modified coaxial electro spraying process, an additional sheath solvent is applied on the core fluid, an air-solvent interface replaces the previous air-solution interface. Thus, the formation of Taylor cones and the droplet atomization would be profoundly modified. A small viscosity and surface tension of the sheath solvent results in an easy formation of Taylor cone. Furthermore, the Columbic splitting should occur more times in the coaxial process than in the blending process besides keeping a stable, longer time period and robust atomization process (Fig. 6b).

These mechanisms are the fundamental knowledge and theories that determine the quality of produced nanoparticles from different working processes. Combined with the technology processes and their resultant nanoproducts, these theoretical contents are excellent teaching materials that can

be exploited to enhance the students' study interests, to promote them to do more self-learning and to expand their imagination and creative thinking.

V. SUMMARY

The development of electrospaying from a single-fluid blending process to a double-fluid coaxial process and a modified coaxial electrospaying contains many useful teaching materials for expanding the college students' imagination and creative thinking. Here, we carefully analyze the reasonable selections of raw materials, the important working parameters, the properties of final resultant nanoproducts, the micro-formation mechanisms, and their meanings both on a standpoint of scientific researches and also from an angle of feeding back on high engineering education. The present job exhibit an example for excavating meanings of advanced nanotechnologies and advanced nanomaterials for fostering the college students' innovation capability.

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