



## Solventless polymer coating of microparticles

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### ABSTRACT

Solventless coating technologies have recently emerged to improve upon the processing inefficiencies and practical limitations of solvent-based polymer film coating. The purpose of this study was to introduce a dry-coating methodology by which microparticles can be coated with polymers without the use of solvents, plasticizers, or heat treatments and is applicable to particles including those <100  $\mu\text{m}$ , noted as major improvements upon solvent-based and current dry-polymer coating technologies. Using a vibratory mixing device, the dry-polymer-coating method developed here first forms an ordered mixture consisting of a particulate substrate, ascorbic acid, ranging in size from 50  $\mu\text{m}$  to 500  $\mu\text{m}$  coated with a micronized polymer, polyethylene (PE) wax. Surface energy measurements accurately predicted that PE wax particles would strongly adhere to ascorbic acid through van der Waals induced attractive forces indicating a simple approach for predicting substrate-polymer compatibility. Due to vibration, subsequent particle-particle collisions between constituents of the ordered mixture deform the polymer layer into a continuous film resulting in encapsulation of the ascorbic acid. Discrete and continuous polymer coating could be discriminated based on SEM imaging, dissolution testing, or dispersive particle size measurements. Furthermore, polymer coatings were able to prolong the dissolution time of ascorbic acid from seconds to hours depending on the coating thickness. This novel dry-polymer-coating technique, operating in dry state without solvents, plasticizers, or heat treatments while also avoiding particle breakage and agglomeration, can reasonably be extended to a wide variety of applications ranging from the control release of pharmaceutical microparticles to protective coatings for metal powders.

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### 1. Introduction

Coating of solids is an essential process for a diverse group of industries including the chemical, pharmaceutical, agricultural, cosmetic, electronic, and food [1]. Coatings are applied for a variety of purposes in order to control the release or dissolution of active ingredients, to improve powder flowability, to protect reactive substances susceptible to oxidation, light, air, or humidity, to enhance mechanical properties (e.g. abrasion resistance and compressibility), or to improve aesthetic appeal (e.g. texture, appearance, odor and taste masking). Regardless of the objective, the coating layer is usually applied as a film resulting from the spraying and subsequent drying of solutions or dispersions. A significant portion of film coating literature has focused on pan coaters or fluidized bed coaters/granulators due to its scalability, automation, and batch-to-batch uniformity [2,3]. The preferred coating materials are usually polymers due to their versatility and range of physiochemical properties. While liquid-based coating is frequently used in industry, many disadvantages have motivated research in the emerging field of solventless film coating.

Solventless coating, as the name suggests, avoids the use of solvents and is very attractive for several reasons. Toxic or flammable organic

solvents pose many environmental and safety concerns. Exposure, recovery, and disposal of organic solvents must be carefully monitored and add to manufacturing cost and time as well as increased operator risk. Although many organic-based coating techniques have been put aside in favor of aqueous-based formulations, substantial disadvantages are still present. Water has an exceptionally high latent heat of vaporization which increases energy costs associated with solvent evaporation and drying. Additionally, low polymer concentrations must be used to avoid overly viscous solutions adding to the processing time. Furthermore, water-sensitive materials make processing with aqueous solutions very difficult and residual moisture may affect product stability. In contrast, solventless coating is inherently environmentally friendly and cost- and time-effective making it highly desirable [4,5].

Several solventless coating technologies have been introduced to replace many organic- or aqueous-based film coating processes. These include, but are not limited to, hot-melt, compression, supercritical fluid, electrostatic powder, or dry-polymer coating [4,5]. While each process has its own advantages, dry-polymer coating has the most applicability to the widest ranges of products. Dry-polymer coating techniques have been used to coat polymer films onto materials varying from metal powders to pharmaceuticals dosage forms ranging in sizes from <100  $\mu\text{m}$  to >1 mm [6–20]. The applications of the coating studies have included flowability improvement, controlled drug release, and oxidative protection to name only a few.

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The two main approaches to dry-polymer coating found in literature may be referred to as plasticizer-dry-polymer-coating and mechanical-dry-polymer-coating. The first technology has gained a significant amount of attention in pharmaceutical literature due to its success in taste-masking and control release formulations [6–13]. Plasticizer-dry-polymer-coating is a rather simple process which entails the layering of a film-forming polymer, usually micronized to 5–50  $\mu\text{m}$ , onto a host material which may include granules, pellets, or tablets ranging in size from ~500  $\mu\text{m}$  to several millimeters. Once the micronized polymer is layered onto the host material, a thermal treatment (e.g. curing) is performed to coalesce the polymer and to form a continuous film. This process has been achieved in pan coaters and fluidized bed coaters where plasticizers and the micronized polymers are simultaneously sprayed onto or mixed with host materials. Plasticizers are necessary in order for the micronized polymer to adhere to the host material, soften the polymer thereby increasing deformation during drying, and to lower the minimum film formation temperature for the curing step. An assortment of polymers such as ethylcellulose, hydroxypropyl methylcellulose acetate succinate, shellac, and various acrylic based polymers have been used to successfully control the release of several pharmaceutical active ingredients [6–13].

Plasticizer-dry-polymer-coating has attracted some criticism because despite the name, these processes are not truly dry. In addition to the large amounts of liquid plasticizers used in the formulations, including water, some processes required small volumes of polymer solutions to be sprayed prior to the curing step. Moreover, difficulty with “stickiness” was reported requiring the use of talc. Absence of studies involving particles/granules smaller than 500  $\mu\text{m}$  is more than likely due to the potential of uncontrolled agglomeration and is noted here as a serious limitation. In addition, the curing step requires elevated temperatures anywhere from hours to days to achieve proper film formation, which adds to process time and cost.

Aside from plasticizer-dry-polymer-coating, mechanical-dry-polymer-coating has shown to be a promising technique to encapsulate a host material in a polymer film or layer without the use of solvents or a curing step [14–20]. In this technique a host material is blended with a deformable polymer, usually a type of wax and subjected to mechanical forces (e.g. shear or impaction). Due to mechanical forces, the waxy polymer deforms and spreads over the surface of the host material effectively coating it with a continuous film. Typical processing equipment include various milling devices such as hybridizers [17], ball-mills [14,15], and fluid-energy mills [16,18]. Interestingly, mechanical methods used for dry-polymer-coating has been able to coat particle sizes less than 100  $\mu\text{m}$  which are noted as being particularly difficult to coat with conventional methods such as fluidized bed film coating or plasticizer-dry-polymer-coating methods. Magnesium powder (75  $\mu\text{m}$ ) [17], lactose powder (20  $\mu\text{m}$ ) [19], Sn/Zn/Bi alloy (40.5  $\mu\text{m}$ ) [14], copper powder (69  $\mu\text{m}$ ) [15], potassium chloride (~10  $\mu\text{m}$ ) [18], and ascorbic acid (~10  $\mu\text{m}$ ) [20] have all been coated to various extents. The coating materials have mainly consisted of waxy type polymers which have been micronized (2–50  $\mu\text{m}$ ) including carnauba, polyethylene, castor, and polyamide wax. While this process may be limited to these highly deformable polymers, waxes have a multitude of applications in coating processes such as oxidation [14], humidity [17], and abrasion resistance and control release [21].

Despite the ability to coat particles <100  $\mu\text{m}$ , these processes have been restricted to rather robust materials such as metal powders where breakage or deformation of the host material can be easily avoided while still imparting the necessary forces needed to spread the polymer over the surface of the host. In studies using less robust materials such as potassium chloride or ascorbic acid, the coarse host material was ground to a fine powder during the coating process [16, 20]. Breakage of the host material is not preferred as this will introduce new surfaces which may be difficult to coat. Additionally, change in particle size may adversely affect downstream processes, powder properties such as flowability, or product functionality.

This paper presents an innovative dry-coating methodology for polymer coating microparticles under consideration of fundamental and engineering perspectives. As a *major novelty*, the dry-coating method avoids the use of solvents, plasticizers, or heat treatments and is applicable to organic substrates including those <100  $\mu\text{m}$  which is noted as being a major improvement upon solvent-based polymer coating and current dry-polymer coating techniques. The proposed dry-coating method entails the creation of an ordered mixture between a host material layered with a micronized polymer and subsequent deformation of the polymer layer by mechanical stressing resulting in encapsulation of the host in a continuous polymer layer. As a practical example, a highly water soluble organic material, ascorbic acid, ranging in size from 50  $\mu\text{m}$  to 500  $\mu\text{m}$  was coated with micronized polyethylene (PE) wax. Surface energy measurements accurately predicted that PE wax particles would strongly adhere to ascorbic acid through van der Waals forces resulting in ordered mixtures indicating a simple approach to preselect suitable coating materials. A high intensity vibratory mixer was used to form the ordered mixture and cause subsequent particle-particle collisions of the ordered mixture's constituents in order to deform the PE wax on the surface of ascorbic acid thus forming a continuous polymer layer. Discrete and continuous (i.e. deformed) coatings were differentiated by SEM, dissolution, and particle size analysis. Results of the dry-coating process showed that polymer films of various thicknesses could increase the dissolution time of the ascorbic acid core from seconds to hours. As will be shown, continuous polymer films can be coated onto microparticles in the dry state by virtue of mechanical stressing of the polymer without solvents, plasticizers, or heat treatments while also avoiding particle breakage and agglomeration. It is expected that this novel dry-polymer coating technique can ultimately be used for the polymer encapsulation of microparticles in applications ranging from control release for pharmaceuticals to protective coatings for non-pharmaceuticals.

## 2. A general methodology for dry polymer coating

Here, we introduce a methodology by which a host particle may be layered with a micronized polymer without the aid of plasticizers or polymer solutions and deformed into a continuous film by mechanical forces alone without breakage of the host, and can be applied to particle sizes ranging from about 50  $\mu\text{m}$  to 500  $\mu\text{m}$ . The method is divided into two main parts. First, an ordered mixture is created between a host material and a coating material, which is followed by mechanical deformation of the coating layer into a continuous film. Since this coating methodology is intended for a wide applicability, each part is discussed in detail in order to introduce fundamental considerations and engineering perspectives which may aid in the design and implementation of dry-polymer coating for various applications.

### 2.1. Formation of an ordered mixture

In the theory of mixing, obtaining a random mixture of various constituents is a statistical process for particles that do not interact except under the force of gravity. The mechanisms of random mixing simply include shear, diffusion, or convection. More often is the case that particles do interact by forces other than gravity when brought into contact by either capillary, electrostatic, or van der Waals forces. In fact, these three latter forces may come to dominate the force of gravity when particle mass is small as is the case with micron- or nano-sized materials. In the case when particles do interact as with cohesive powders, mixtures tend to be non-random and in some cases may be arranged into structured or ordered mixtures that are often composed of fine particles adhered to the surface of a coarser component [22,23]. Plasticizer-dry-polymer-coating effectively creates an ordered mixture by making use of capillary forces in order to adhere one or more layers of polymer microparticles onto the host material through addition of liquid plasticizers. Similarly, electrostatic forces can be utilized in electrostatic

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