A Fluidized Bed Polymer Coating Experiment

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A unique experiment that can have a large impact on student learning and retention is the fluidized bed polymer coating process. This experiment, first developed for a NSF Novel Process Workshop, is a highly visual experiment in chemical engineering processes and experimentation. In addition it the coating process is environmentally benign because it has essentially no volatile emissions. The object of the experiment is to place a protective coating on a metal object. The metal object is coated by first heating in a hot air stream and then dipping the object into a fluidized bed of thermoplastic powder. The powder is contained within a clear plastic cylinder (acrylic) with allows the students to see and feel the fluidization. At the end of the experiment, students take home a metal object, of their choosing, covered with a brightly colored polymer.

This experiment can be used thoughout the curriculum. For recruitment at the precollege and freshman level the fluid motion of the gas and particles can be observed through the clear plastic walls of the fluidized bed. Using brightly colored particles gives the fluid bed the look of an executive desk amusement. Prospective students and freshman can also feel the water like quality of the bed using a rod or ruler. Freshman use the fluidized bed as an example of the engineering measurements of flowrate, temperature, pressure and coating thickness. They design an experiment to determine the desired coating thickness by varying the dipping time and temperature of the object. Simple excel plots are produced from their experiments. Sophomores measure pressure drop through the distributor plate to determine the relationship between flowrate and pressure drop. In an advanced fluids class the fluidization regimes can be identified from a pressure drop vs flowrate plot. For transport phenomena the combined heat and mass transport can be examined.

This experiment is compact and cost-effective, the cost of fabricating the equipment for this experiment is about $830. The colored polymer powder makes the experiment enjoyable to watch and collect data. Student feedback has been extremely positive.

Keywords: fluidization, fluid bed, coating, laboratory experiments, recrutiment, vertical integration, minimizatoin of volatile organic emission, environmental.

Introduction

The business of polymers is a major component of the process industry and represents a significant area of opportunity for the chemical engineering profession. The field encompasses many technologies, ranging from polymerization processes used for chemical production of materials, to fabrication processes needed to transform the materials into usable products.

The use of polymers continues to expand. Advanced polymers are being developed for use in emerging areas of technology such as medical devices, smart packaging systems, fuel cells, and electronic device fabrication. Conventional plastics find extensive use as a material of construction for many products common in daily life. Their low weight, resistance to weather and wear, and economical production, make them attractive alternatives to glass, metal, and wood for use in products ranging from food and beverage containers to recreational equipment to automobile components to building materials.

Coating processes fall in the area of polymer fabrication technologies along with molding, extrusion, casting, forming, and calendering. In parts that must be constructed of metal for structural reasons, a plastic coating may be applied for decorative and/or functional purposes such as electrical insulation, corrosion protection, and abrasion resistance.

Fluidized bed coating is a commercially important process which was developed for application of plastic coatings on metal substrates. It provided the basis for more advanced powder processes such as electrostatic coating and flame spraying. Dry powder coating processes use no solvents and thus provide an *environmentally friendly* alternative to older techniques such as dipping, brushing, and spraying. Fluidized bed coating is a novel process which offers the advantages of efficient utilization of materials (near 100%), the ability to coat irregular shapes, high coating rates, simple and inexpensive equipment requirements, process automation, and smooth and continuous coating applications.

Fluidization Fundamentals

Fluidization finds application in many important industrial processes. Examples of fluidization are given in the table below.

Table 1: Industrial Applications of Fluidized Beds

Polymeric Materials	gas phase polymerization of polyethylene production of silicon for the semi-conductor industry
Biochemical	cultivation of microorganisms for the food and pharmaceutical industries
Chemical Synthesis	Phthalic Anhydride, Fischer-Tropsch Synthesis of hydrocarbons, acrylonitrile, maleic anhydride, activated carbon, calcination, roasting of sulfide

	ores, chlorination, reduction,
Petroleum Processing	fluid catalytic cracking (FCC) for production of gasoline from oil coal gasification thermal cracking of naphtha petroleum fractions to produce ethylene and propylene Fluid Coking
Combustion	coal combustion solid waste incineration steam raising
Physical Operations	coating metal objects drying of solids Adsorption of solvents

In fluidization, a gas or liquid is passed through a bed of solid particles which is supported on a perforated or porous plate. In the case of fluidized bed coating, air is passed through a bed of polymer particles. When the frictional force acting on the particles, or pressure drop, of the flowing air through the bed equals or exceeds the weight of the bed, the powder particles become suspended and the bed exhibits liquid-like behavior. As shown in the figure below, at gas flowrates less than the fluidization velocity, the bed is a fixed bed and there is no movement of particles. At flowrates above minimum fluidization the bed expands and bubbles appear.

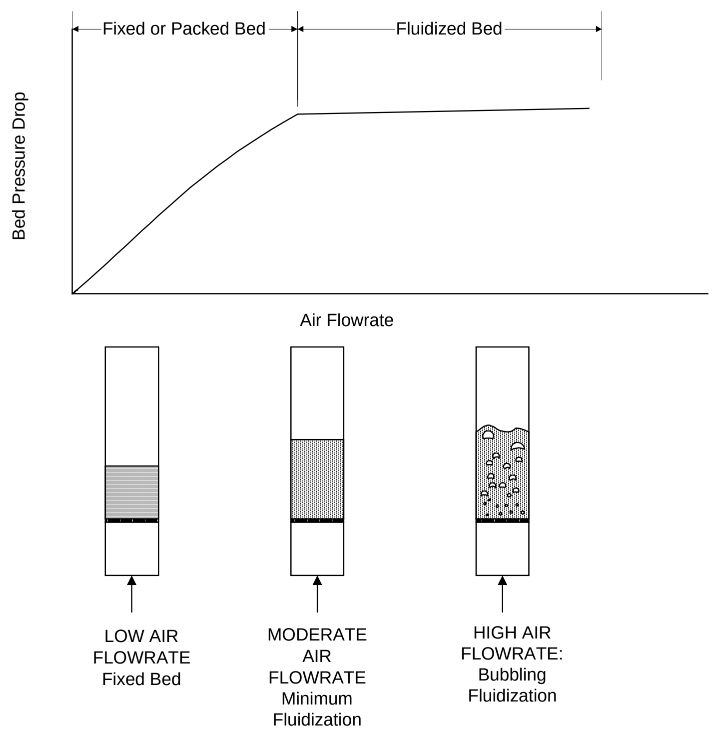

Figure 1: Fluidization Regimes

The air velocity corresponding to a pressure drop that just equals the weight of the bed is referred to as the minimum fluidization velocity. At this air velocity or flowrate all of the bed particles are completely suspended by the air stream. For a given system, minimum fluidization velocity can be determined from a pressure drop vs. air velocity diagram.

As air flow is increased above the minimum fluidization velocity, the bed may exhibit behaviors ranging from smooth fluidization to bubbling fluidization to dilute fluidization in which powder can be transported by the air stream. Smooth fluidization is desirable for optimal performance in the powder coating process. The liquid-like nature of the fluidized powder bed allows a metal object to easily be dipped into it. The metal object is preheated to a temperature above the melting point of the polymer prior to being dipped. Powder particles contact and fuse to the hot surface of the object when it enters the bed. Heat is transferred from the object to the polymer, causing the polymer to melt and flow to form a continuous layer. It is then allowed to cool. The coating may be reheated to achieve a smoother finish. For a given object, the thickness of the coating is dependent on two process variables, preheat temperature of the object, and the amount of time for which it is submersed in the powder bed.

Scope & Objectives

The purpose of this experiment is to introduce students to basic measurements of temperature, pressure, flowrate, film thickness using a fluidized bed coating unit. By conducting this experiment you will also be introduced to the chemical engineering operation of fluidization. The experiment is broken into two parts. The first is a demonstration of the basic fluidization regimes. You will operate a laboratory fluidized bed and take measurements to generate a classical pressure drop vs. flowrate diagram to determine the minimum fluidization flowrate for the system. During this part of the exercise, you will get a chance to observe the behavior of the fluidized bed over a wide range of air flowrates. In the second part of the experiment, the participants will be charged with conducting coating trials to determine process conditions (preheat temperature & dip time) necessary to achieve a specified coating thickness on sample objects.

Example Experimental Objectives for a Freshman Engineering Laboratory

1) Using a calibration curve, convert the rotameter readings in mm’s to a flowrate in mL/min.
2) Measure the temperature of an object using a bare wire thermocouple.
3) Measure the pressure of the inlet air stream using a Bourdon gauge.
4) Measure the pressure difference across a fixed and fluidized bed using a liquid filled manometer.
5) Estimate the thickness of a polymer coating from a knowledge of the surface area of an object and the masses of the coated and uncoated objects.
6) Determine the optimum temperature, dipping time and fluidization regime to obtain an average coating of 0.025 inches.
7) Explain the effect of temperature and dipping time on the coating thickness of an object.

Experiment - Safety

1. Specific hazards of this lab include the heating of metal objects to very high temperatures. Wear appropriate gloves and use tongs where possible when handling these hot objects. Exercise extreme caution in the use of heat guns.
2. Safety goggles or glasses are required since there is a possibility of fine powder, hot objects or line breakages entering the eyes of the participants.
3. The polymer powder used in the coating process is very fine and will produce dust. Loading of the fluid bed column should be done in a hood. A paper towel should be secured over the top of the column when operating at high air flow rates where entrainment of the powder can occur.
4. Observe normal laboratory safety practices.

Relevant Data

Coating Material: Functionalized polyethylene copolymer based powder

Polymer Density = ρ = 0.934 g/cm^3

Polymer Melting Point = 221°F or 105°C

Metal Substrate: Steel Washer from Sears Hillman Brand 1/2 inch nominal size. Item 270067

(OD 1.376 in, ID 0.563 in, thickness 0.117 in)

Substrate Surface Area = 3.19 in^2 = 20.6 cm^2

Required Equipment:

The fluidized bed can be fabricated from clear plastic (acrylic) tubing and sheets. The clear plastic tube is glued to a flat sheet flange and a rubber gasket material is used to seal the distributor plate to the unit. The distributor plate is a polyethylene porous sheet manufactured specifically for heat treating fluidized beds. This plate can be obtained from POREX Technologies. The drop mechanism for the metal samples was fabricated by bending stainless steel tubing into a U-shape and running a thin metal cable through the center of the tubing. An attachment device is placed at one end to hook a wire loop to it and the other end has an adjustable stop. The wire is weighted using washers to obtain a fast drop into the fluidbed. The remaining components shown in Figure 2 are standard laboratory units given in the table below.

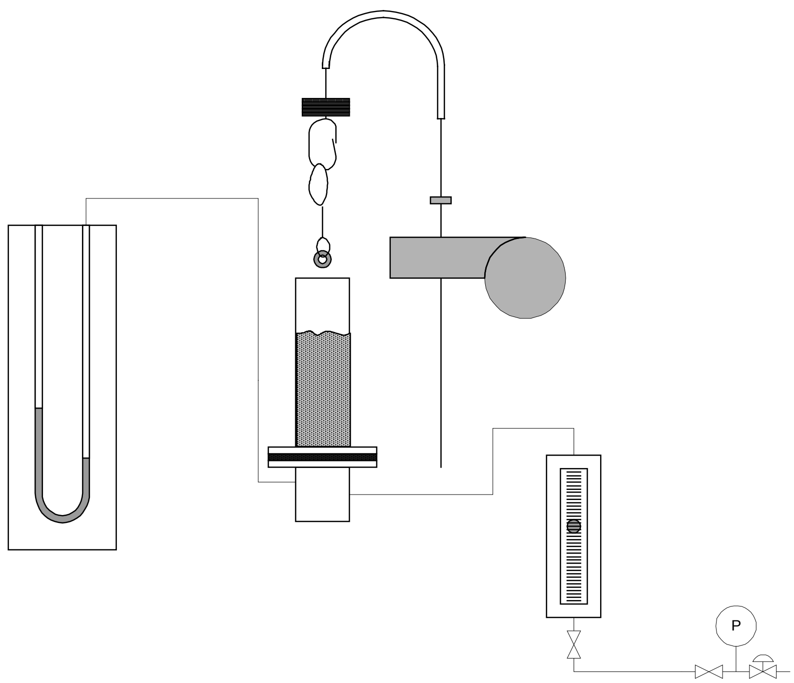

Figure 2: Experimental Apparatus

Table 2: Parts List for Fluidized Bed

Fluidized Bed Unit: Fabricated by Pemm Corp., Chelsea Industrial Park, Brockway Road, Wappingers Falls, NY 12590. Phone: (914) 831-5828 Polyethylene Porous Distributor Plate was obtained from POREX Technologies, 800-565-8777, www.porex.com	$140
Rotameter	$220
Heat Gun	$139
Handheld Thermometer	$99
Ring Stand	$47.32
Polyarmor Powder (3 lb Sample)- PFS Thermoplastic Powder Coatings, 3400 West 7th, Big spring, TX 79720. www.powder-coating.com or email pfs-a@xroadstx.com. Telephone 800-753-5263	$40
Three-Prong Extension Clamps (Two)	$20.18 (each)
Tilt Stand (for thermometer)	$15
Stopwatch	$11.95
U-Tube Manometer,	$40.46
Castaloy Clamp Regular Holder	$9.72
Plastic Tubing for air lines	$25.36
Electronic Balance	
Metal samples and disposable hanging wire	

Experimental Procedure - Part I: Investigation of Fluidization Regimes

The first experiment in the freshman laboratory is to have the students investigate the flow regimes of the fluidized bed. In these experiment they identify the equipment and identify the point of incipient fluidization. They are asked to place a ruler into the fluidized bed and feel the difference between a slumped bed (no air flow) and a fully fluidized bed. Students always marvel at the fluid like behaviour of particles. The next step is to obtain a fluidization curve of bed pressure drop as a function of air flowrate shown below. In addition, they make a plot of bed height as afunction of air velocity. In this experiment the freshman uses several measurement devices: air pressure gauge, rotameter, ruler, and a U-tube manometer.

At the end of the laboratory the students submit the following:

1. Fluidization chart (graph). (This includes bed pressure and height vs. flowrate.)
2. Show the value of the minimum fluidization velocity that you have determined on your graph.
3. Laboratory notebook yellow sheets containing data and a sample calculation of the flowrate.
4. Sample calculation of step 2 in the next experiment.

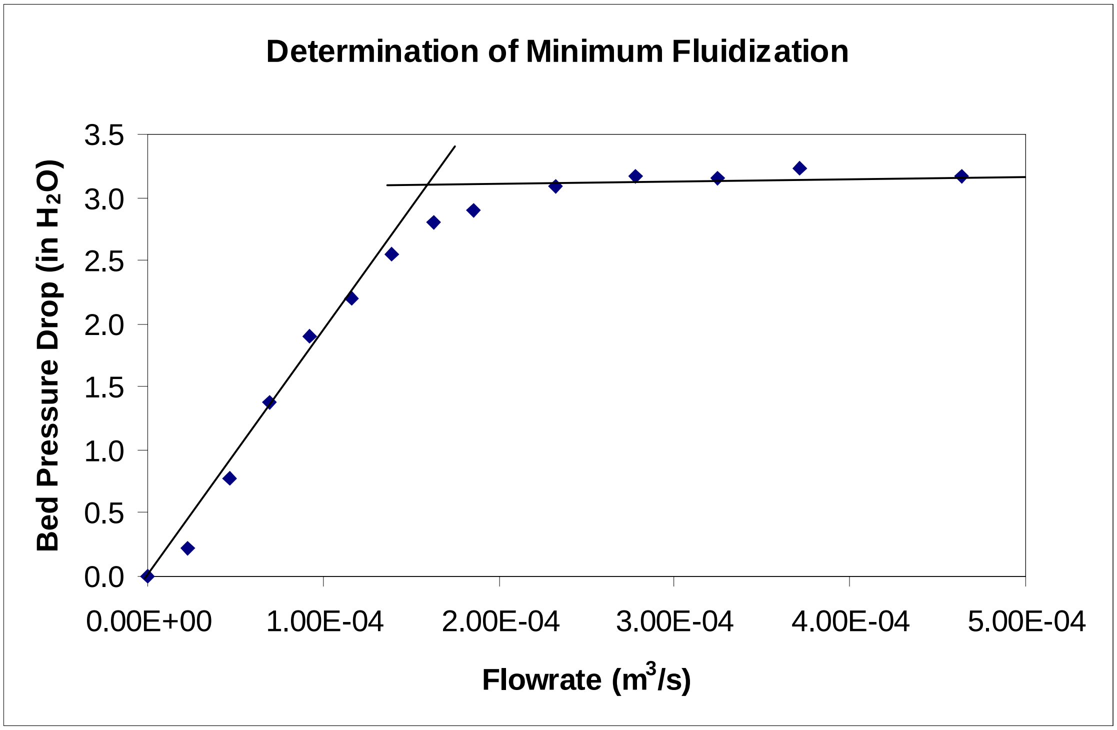

Figure 3: Determination of Minimum Fluidization

Experiment - Part II : Polymer Coating

The next part of the experiment is where the students coat the metal samples. The students are told that a metal part is to be used in an application where the rate of heat transfer through the part is critical. The environment to which the part is exposed requires that the part be coated with polyethylene to protect against corrosion. Increasing the coating thickness increases corrosion protection, but decreases heat transfer

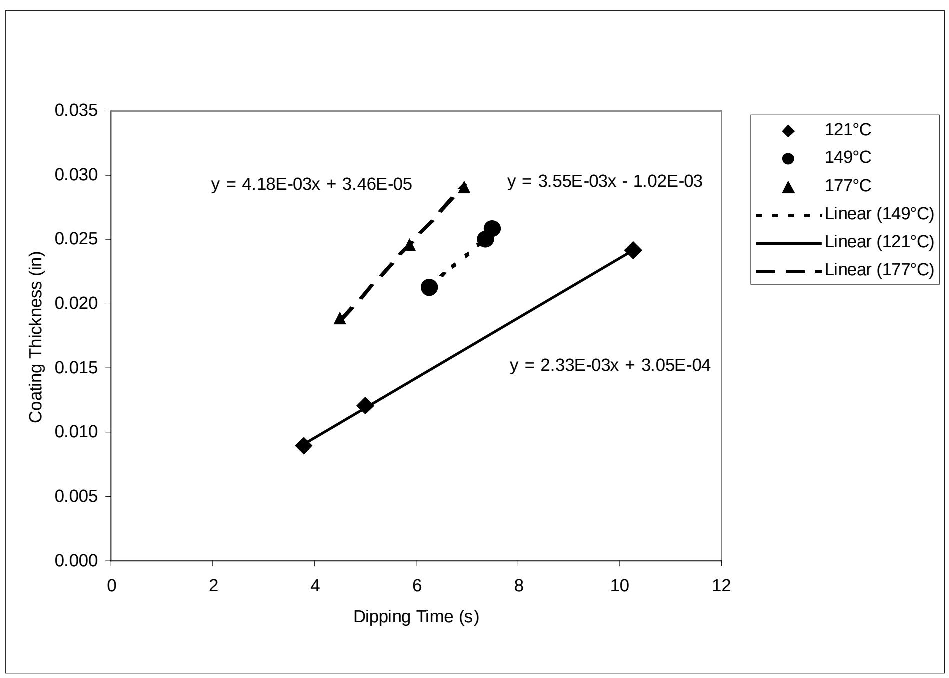

Figure 4: Example of Student Coating Thickness Results

rate. Initial calculations indicate that a coating thickness of 0.025 inches $\pm$ .001 inches will maximize corrosion protection while allowing for an adequate heat transfer rate.

Based on this problem statement the students conduct a series of pilot runs in the fluidized bed coating system to determine values for the process variables (pre-heat temperature and dip time) which will produce the desired coating thickness. To examine the behaviour of the coating process they conduct runs of constant temperature and constant time. They are given a range of temperatures that start below the melting point of the polymer (221°F) and extend to 450°F. The dip time ranges between 2 and 10 s.

The students determine an average coating thickness from the following formula $m_c = \rho A t$. Where m_c is the mass of the polymer coating, ρ is the density of the coating, A is the area and t is the desired thickness. The mass of the coating is determined by difference using the electronic balance. A wire is attached to the sample and place on the hook to dip and remove the sample from the fluidized bed. The sample is heated using the heat gun, to a temperature approximately 10-15 °F above the desired temperature. Then the sample is dropped in to the fluidized bed and then removed. After the sample has cooled the wire is removed and the coated sample is weighed using the electronic balance. To give the sample a more attractive finish it can be reheated to obtain a smooth finish.

An example of the student data is shown in the figure below. The find that the coating thickness can be increased by increasing either the coating temperature and time. Many students also find out that if they use a temperature near or below the melting point of the polymer that the polymer particles do not coat the metal object!

At the end of this laboratory the students are asked to submit the following:
1. Summary graph of data from coating experiment. (See step 14).
2. Summary paragraph on the effect of temperature and dipping time on the coating thickness. Include in this paragraph the prediction of a time and temperature that would result in a coating thickness of 0.05 inches.
3. Laboratory Notebook yellow sheets containing data, and sample calculations (showing units).

This laboratory is both a meaningful and fun activity. Students practice principles of measurement and learn about fluidization, coating and environmental principles. The students also have a lot of fun coating objects. In addition to the standard samples, students have coated their keys and flashlights made in an earlier lab.

References

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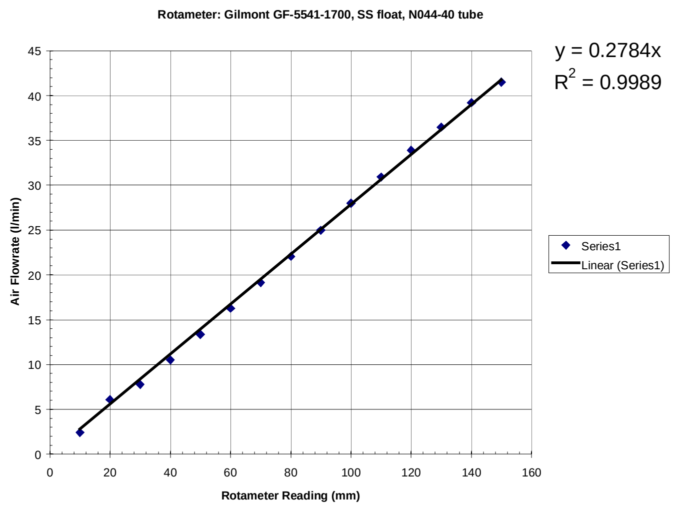
<u>Rotameter Calibration Data</u> Gilmont: GF-5541-1700, SS float, N044-40 tube



Scale Reading	Flow (L/min)
10	2.397
20	6.095
30	7.772
40	10.495
50	13.353
60	16.263
70	19.139
80	22.059
90	24.96
100	28.001
110	30.923
120	33.904
130	36.48
140	39.213
150	41.512

Example Laboratory Notebook Setup

Date **Freshman Engineering Clinic Section X** **Group Member Names**

Title: Fluidized Bed Powder Coating Experiment

Experiment - Part I: Investigation of Fluidization Regimes

Flowmeter Reading (scale reading)	Plate + Bed Pressure Drop (in H_2O)	Bed Expansion (from air flow) (inches)	Observations of Bubbles
100			
80			
70			
60			
50			
40			
35			
30			
25			
20			
15			
10			
5			
0			

(Leave space here for sample calculations. See first page for instructions on using the laboratory notebook. Start the table below on a new page.)

Experiment - Part II : Polymer Coating

Sample #	Pre-heat Temperature (C)	Dip Time (s)	Un-Coated Weight (g)	Coated Weight (g)	Net Weight of Coating (g)	Calculated Thickness (in)
1						
2						
3						
4						
5						
6						
7						
8						
9						