Paints and Coatings

1. Introduction

Paints are generally products of surface-coating for the preservation of all types of architectural structures, including factories, from ordinary attacks of weather. For example, uncoated wood and metal are particularly susceptible to deterioration, especially in cities where soot and sulfur dioxide accelerate such action. Aside from their purely protective action, paints, varnishes, and lacquers increase the attractiveness of manufactured goods, as well as the aesthetic appeal of a community of homes and their interiors. A varnish is a solution of oil and natural resin in an organic solvent. Synthetic resins may also be used. Lacquers are coatings in which the film dries or hardens entirely by evaporation of the solvent. Coatings that are used to cover buildings and furniture are referred to as "trade sales" or "architecture coatings" in contrast to industrial coatings, which are used on materials being manufactured. Industrial finishes are applied to a wide variety of materials, such as metal, textiles, rubber, paper, and plastics, as well as wood. Architectural coatings are usually applied to wood, gypsum wall-board, or plaster surfaces. The typical end uses of paints and coatings are showed in table 1.

Table 1. *Typical end uses for major categories of paints and coatings* [1]

Category	End Uses
Architectural coatings	• Exterior house and trim paints (including flat house paints and enamels) • Exterior masonry paints • Undercoaters, primers, and sealers (including flat wall paints, and gloss and semigloss enamels) • Varnishes • Stains
Product coatings for original equipment manufacturers	• Automobile, truck and bus finishes • Wood furniture and fixture finishes • Metal furniture and fixture finishes • Finishes for railroad equipment • Aircraft and missile coatings • Appliance finishes • Marine finishes • Plastic and film coatings • Pipe coatings
Special purpose coatings	• Specially formulated high-performance maintenance finishes • Automobile, truck, and bus refinish coatings • Marine refinish coatings • Other refinish coatings • Metallic finishes • Aerosol paints

2. The Raw Materials of Paints

The paints industry is a branch of the chemical industries sector. Paints are divided into:

- Solvent-based paints
- Water-based paints
- Varnishes; clear coatings
- Printing inks

Liquid paints are composites of a finely divided pigment dispersed in a vehicle, i.e. the liquid portion that is composed of binder (usually an oil or resin) and a thinner (or a volatile solvent). Vehicles are composed of nonvolatile and volatile parts as shown in Table 2. Other additives may be added to give the paints specific properties for specific purposes or applications.

Table 2. *Vehicle classification in liquid paints*

Paint Types	Vehicle classification	
	Nonvolatile	Volatile
Solvent-based paints	oils and/ or resins plus driers and additives	Ketones, esters, alcohol, aromatics, and aliphatics
Lacquers	celluloses, resins, plasticizers, and additives.	
Water-based paints	styrene-butadiene, polyvinyl acetate, acrylic, other polymers and emulsions, copolymers plus additives	

2.1 Main Raw Materials

The pigment is one of the main and most important constituents of the paint. In general, pigments should be opaque to ensure good covering power and chemically inert to secure stability, hence long life. Pigments should be nontoxic, or at least of very low toxicity, to both the painter and the inhabitants. Finally, pigments must be wet by the film-forming constituents and be of low cost. Different pigments possess different covering power per unit weight. Table 3 shows the different paints constituents.

Table 3. *Constitutions and their functions in paints*

Constituent	**Function**
Main constituents	
Pigments are usually: • An inorganic substance, such as titanium dioxide, chrome pigment, earths, lead pigments, zinc pigments. • A pure, insoluble organic dye known as a toner. • An organic dye precipitated on an inorganic carrier such as aluminum hydroxide, barium	The function of pigments and fillers is simply to provide a colored surface that is pleasing for its aesthetic appeal. The solid particles in paint reflect light rays, and thus help to prolong the life of the paints and to protect metals from corrosion.

sulfate or clay.	
Binders or vehicles. Those are resins or oils.	Its function is binding the pigment to the substrate.
Thinners and solvents; such as petroleum ether, toluene, xylene.	It is the volatile part of the vehicle. Its function is to dissolve the binders, adjust the paint viscosity, and give homogeneous, regular, and uniform thickness on the coated surface.
Fillers; such as clay, talc, gypsum, and calcium carbonate.	Pigment extender, or fillers, reduce the paint cost and control the rheorological properties (viscosity) of paints.
Other additives	
Driers, as cobalt, lead, zinc, zirconium, manganese, calcium, barium.	To accelerate the drying of the paints.
Anti-skinning agents	It is added to the paints (unsaturated), to prevent the solidification of paints surface during storage.
Anti-settling agents	To improve the dispersion efficiency of the pigments into the vehicle, to prevent the settling of pigments during storage.
Plasticizers; These materials are special types of oils, phthalate esters or chlorinated paraffins.	To improve the elasticity of paint films, and to minimize the paint films tendency for cracking.
Dispersants, wetting agents, fire retarding, anti-floating, anti-foaming, etc.	To give the paint specific property for specific purpose or application.

The functions of paints are to hide the original surface, providing a certain color, resisting the weathering conditions, washability, gloss, and protecting surface from corrosion. In general, pigments should be opaque to ensure good covering power, and they should be chemically inert to secure stability as well as non-toxicity.

Traditional paints were under 70% solids with the remainder being predominantly solvents. Air pollution regulations limiting the amount of solvents that can be emitted into the atmosphere have resulted in the development of a wide variety of substitute paints with low or no organic solvents. These include: water-based latex paints; two-part catalysed paints (e.g., epoxy and urethane systems); high solids paints (over 70% solids), including plastisol paints consisting primarily of pigments and plasticizers; radiation-cured paints; and powder coatings.

To predict some properties of paints such as ease of painting, gloss, washability for a certain formulation, the pigment volume concentration (PVC) in paint is used as indicator.

$$\text{Pigment volume Concentration (PVC)} = \frac{\text{volume of pigment in paint}}{\text{(volume of pigment in paint + volume of nonvolatile vehicle constituents in paint)}}$$

PVC value in paints is shown in table 4, below.

Table 4*. Pigments volume concentration (PVC) of different paints*

Paint Type	Indicator values
Matt paints	50-75%
Semigloss paints	35-45%
Gloss paints	25-35%
Exterior household paints	27-36%
Metal primers	25-40%
Wood primers	35-40%

2.2 Other Raw Materials

There are some other chemicals that are utilized at the facility for different purposes:

- Chemicals used are organic solvents (ether, chloroform, ketones, esters, xylene, toluene, hexane, ethyl and methyl alcohol's), acids (acetic, boric, oxalic, benzoic, hydrochloric, sulfuric), alkalis (sodium, potassium and ammonium hydroxides), potassium chloride, sodium sulfate, sodium thiosulphate potassium iodide. These chemicals are used in the production processes, and in the quality control laboratories for raw materials and products.
- Biocides and antifouling agents are used in the manufacture of the antifouling and wood preservatives paints, and they are also used in the manufacture of water-based paints to prolong their life time.
- Water-alkali solutions and solvents for equipment cleaning and washing, between batches.
- Detergents and antiseptics for floor cleaning.

3. Manufacturing Processes

In general, the manufacture of paints and other coatings is a series of unit operations using batch processes. The most common method of manufacture involves dry blending of the powdered ingredients and extrusion melt-mixing. The dry resin or binder, pigment, filler and additives are weighed and transferred to a premixer. This process is similar to dry blending operations in rubber manufacture. After mixing, the material is placed in an extruder and heated until molten. The molten material is extruded onto a cooling conveyor belt and then transferred to a coarse granulator. The granulated material is passed through a fine grinder and then sieved to achieve the desired particle size. The powder coating is then packaged. The general manufacture procedures illustrated in Fig. 1.

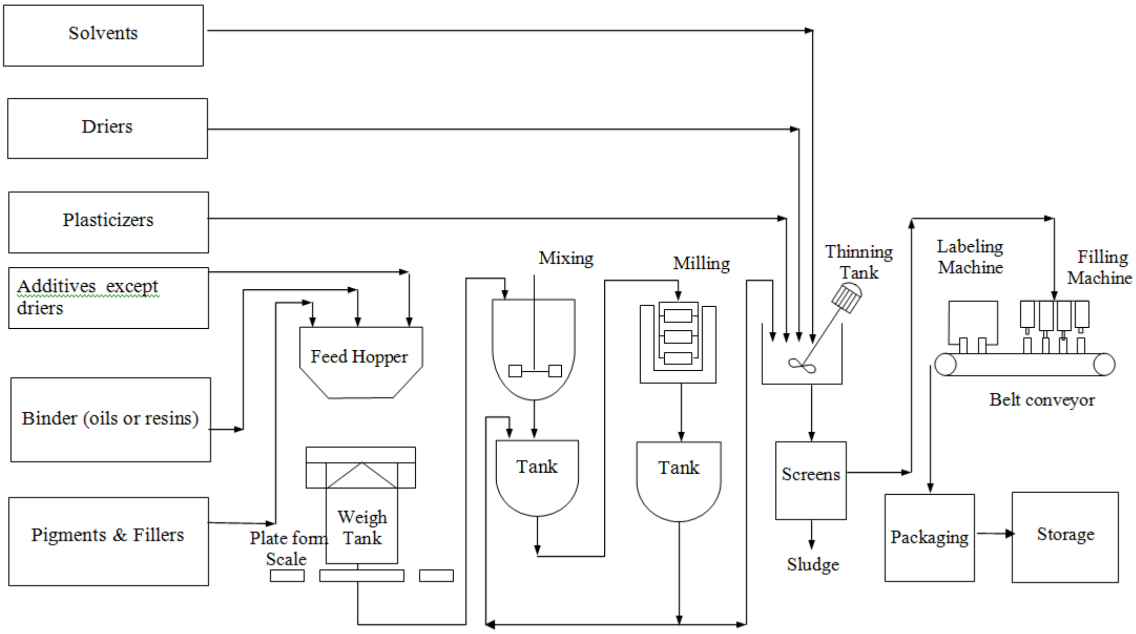

Figure 1. *Flowchart of paints Manufacturing Steps*

3.1 Desirable Paint Properties

Particle size and rheological properties govern many key properties that are important to the coatings industry. For example, flocculation, hue/tint strength, hiding/transparency, dispersability, stability, gloss/flatting and film appearance, viscosity, and weather resistance are some examples. Actually, the rheological properties are also directly related to particle size. As particles are below 20 microns in size, colloidal forces become important, and the adhesion forces increase rapidly. The pigment dispersability therefore diminishes, and there is an increased likelihood of aggregate formation.

In order to yield the correct optical properties, pigment particle size needs to be controlled. Usually, the finer the particle size, the more opacity possible. For example, TiO_2 is specifically processed to a particle size of 0.20 to 0.35 micron, or approximately equal to one-half the wavelength of light. By dispersing this pigment to its optimum size, ultimate hiding is obtained.

In order to achieve the highest scattering power, the pigment particle size should be less than one micron (Figure 1), if not below 0.5 micron, although this does depend on whether high or low refractive index pigments are used. Maximizing the scattering power then allows other properties of the pigment dispersion to be controlled [2].

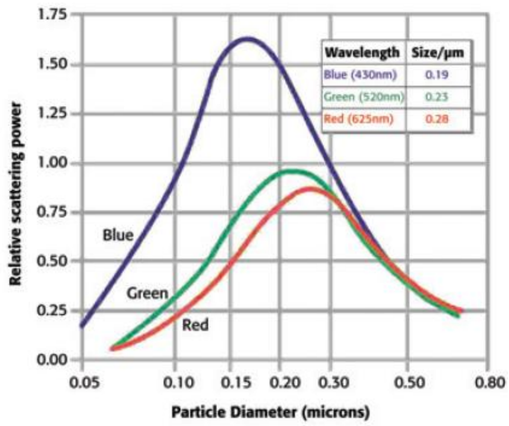

Figure 2. *Scattering power of titanium dioxide as a function of particle size and wavelength.*

When the synthetic iron oxide pigment is dispersed to a 6 $^{1}/_{2}$ NS Hegman (20 microns), the intended dark-red oxide or maroon-like shade is obtained. However, upon further dispersing these grades, not only is there a definite improvement in hiding power, but there is also a shift in both mass tone and tint to a medium-red iron oxide shade. The dramatic hue shift is due to the destruction of individual pigment crystals, except that in this case the pigment particles have been reduced to the size of the next finer stage of red iron oxide production.
The stability of pigment dispersion is improved through particle size reduction in three ways:

1. *Rheology and/or viscosity.* Reducing pigment particle size increases pigment surface area, which usually results in increased viscosity. Also, many organic and even inorganic pigment systems develop a thixotropic state. Higher viscosity or induced thixotrophy prevents pigment mobility, preventing both settling and reflocculation.
2. *Prevention of flocculation.* In flocculation, pigment particles tend to reagglomerate, resulting in a loss of color intensity and poor color uniformity. Reducing the particle size will prevent reagglomeration. Reducing the particle size increases the viscosity of the system; it further reduces the possibility of migration.
3. *Settling.* One of the main stability concerns of most coating manufacturers is settling. Differences in particle size can show widely varied results in the settling of a spherical object in a liquid medium, and apply it to the rate or settling of a pigment particle in a dispersion or coating system. We can see the value gained in stability due to simple particle size reduction.

3.2 Dispersion Equipment and Grinding Condition

From the above discussion, a good quality paint needs homogenous pigment dispersion and suitable particle size. Agglomerated pigment particles must be reduced to the original pigment size, and the particles must be wet with the binder to ensure dispersion in the liquid matrix. This dispersion process, called grinding, is done with a variety of types of equipment, including high-speed shaft-impeller dispersers, dough mixers, ball mills, sand mills, triple roll mills, pug mills and so forth.

Figure 2 shows three-roller mills in which each roller rotates in the opposite direction of the others and with different speeds with ratio 1:3:9. The clearance between each two rollers must be controlled accurately to maintain the desired finesse of dyes. These types of mills lead to the desired homogeneity as the dye is dispersed into its particles. These types of mills are open, and therefore cannot be used in grinding of paints which contain high volatility solvents, as solvent emissions to the atmosphere could occur [3]. Figure 3 gives the rough pigment particle size during three roll mill. The three roll mill is only used for high viscosity paints.

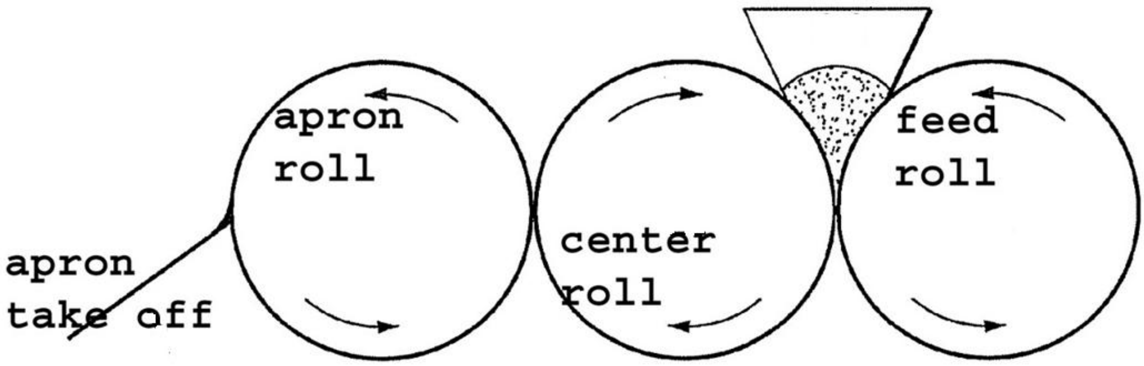

Figure 2. *Three roll mill diagram*

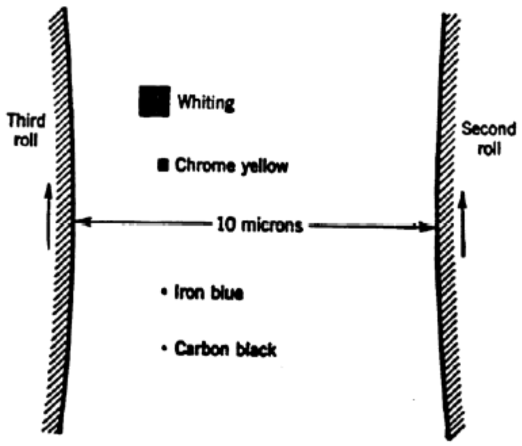

Figure 3. *Diagram comparing clearance between rolls and size of primary pigment particles as approximated for three-roll mill during operation.*

Another type of mill is the ball mill (Figure 4). As the mill is rotated, the viscosity of the formulation causes the media to be lifted around the perimeter of the mill. When the forces of gravity overcome the lifting action of the formulation, the media cascades down upon itself, creating compression and shearing forces on the pigment. This results in the eventual dispersion of the pigment. The grinding efficiency and fineness of particle depends on the dimensions of the cylinder, speed of rotation, ball size, and ball density. In some mills the length of the cylinder is equal to its diameter, but to maintain higher degree of fineness, mills with a length larger than diameter are used. The limitation of the ball mill is that the proper viscosity in the mill base is required. During operation, the paste is difficult to empty, cool, and vent.

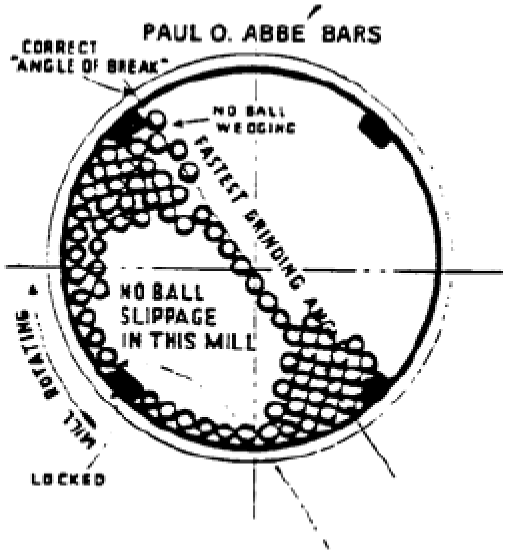

Figure 4. *Ball mill*

An attritor is essentially a ball mill set on end that replaces the rotation of the vessel with a rotating vertical shaft having pins arranged perpendicular to the shaft (Figure 5). The pins serve to agitate a ball charge as they pass through the batch. The attritor has been shown to reduce the time required to achieve full dispersion considerably as compared to a ball mill. Attritors have similar rheological requirements to ball mills. Due to this, formulations that work well in a ball mill will require little adjustment to work in an attritor. The disadvantages of attritor are that the small particles are deformed rather than broken, and the fine particles may coat the grinding medium.

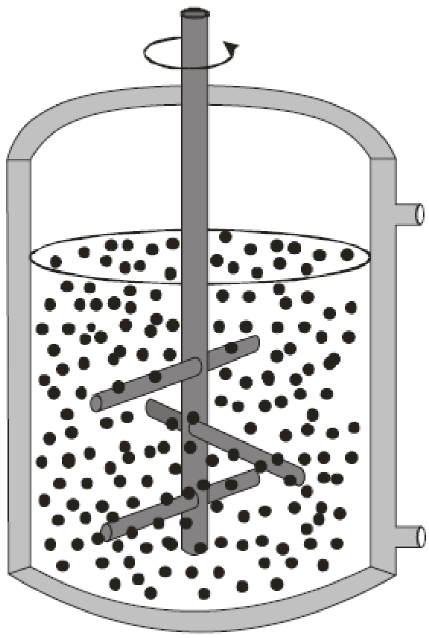

Figure 5. *Diagram of attritor*

Media mills can be considered as an extension of ball mill technology using smaller media. The dispersion process of a media mill is similar to a ball mill in that dispersion is achieved through forces imparted by the media upon the pigment. However, a media mill depends on centrifugal forces applied to the media by flat disk impellers rotating at high velocity to achieve dispersion, whereas a ball mill relies on gravitational forces to provide the cascading action of the media. Typically, dispersion in media mills can be enhanced by using smaller media to increase the number of potential points of impact and maintaining the volume of media corresponding to 80-90% of the internal mill volume. A disadvantage of the media mill is that it usually requires premixing of the ingredients in the formula to be efficient.

3.3 Grinding Condition

Generally, the pigment is initially ground for 48 hrs and then resin is added to be ground for a shorter period.

3.4 Dispersion Measurement

The paint and coating industry uses a variety of tools, such as the Hegman and PC grind gages, to characterize the dispersion level achieved.

Grind gages rely on a simple principle. When a dispersion sample is drawn down from the deep end of the gage toward the shallow end, the undispersed agglomerates will protrude from the surface of the paint and coating in the channel if the agglomerates are larger than the depth of the gage. These protrusions are seen as specks on the surface of the paint and coating path on the gage.

A Hegman gage, with a channel ranging from 100µ to 0µ deep, is used to determine the "grind" or the point at which no further increase in the frequency of specks can be observed. The depth of the channel at the "grind," measured in microns, is noted. The Hegman gage scale ranges from 0 at the 100µ depth to 8 at the 0µ depth. An 8 Hegman grind rating is ideal. A 0 Hegman grind rating is poor.

The grind gage is only a basic tool for describing the relative dispersion performance of paint while still in liquid form. Other tools like gloss measurements, light microscopy, and electron microscopy combined with automated image analysis are used to complement the grind gage ratings and to evaluate dispersion.

Conclusion

Homogenous dispersion of pigment is very important for paint's quality. The three roll mill is an effective grinding machine for paint dispersion, especially for high load paints. In the past, the low volume throughput of three roll mill limits it application in paints industry [4]. However, large size three roll mill has been developed to mass production for paint and coating. It is believed that the three roll mill will continuously play an important role in the paint industry.

References:

1) www.cdc.gov/niosh/pdfs/84-115b.pdf
2) Alison Vines, Why particle size in coating industry?, Malvern Instruments Ltd
3) Paints Industry- Self-Monitoring Manual
4) Robert B. McKay, Technological applications of dispersion, CRC Press, 1994