Aspects of rheology to consider for different application methods

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Paint application

- Transfer of a liquid paint from a container to a substrate at the desired thickness via contact or remote application technique

- Technique is dependent on many factors, outcome dependent on the human factor

- Post application, the paint film should develop the required attributes such as a/c performance, adhesion, flow and levelling for aesthetics

- Common theme across most application methods is the need for low viscosity at point of application, increased viscosity afterwards

- The rate at which this increase happens is critical
  - Too slow and paint sags on vertical surface or runs off horizontal ones
  - Too fast and excessive levels of defects such as orange peel and brush marks are trapped
Paint application

Paint properties and shear rate

Source: Elementis Specialities
 Application methods

- End user requirements - mechanics of paint application
  - Brushing
  - Hand roller
  - Machine roller coating
  - Air spray
    - General Principles
    - Conventional spray
    - Airless spray
Brushing

- Primarily used DIY but also used in many heavy duty applications even with paints formulated for spray application

- Useful for small areas and gives good penetration of pores and cracks

- Inexpensive equipment, can be used by inexperienced operators

- Paint can be Newtonian, shear thinning or thixotropic

- Application rates are slow – 8m²/hr

- Only low or medium build coatings can be applied - <100µm/coat
Brushing

- Pick up of paint dictated by viscosity at a shear rate of $\sim 15-30 \text{s}^{-1}$
- Viscosity at a shear rate of $\sim 5000-20,000 \text{s}^{-1}$ controls ease of brushing
- Paint viscosity at high shear typically 1-3 poise at 25°C
- Solvent balance important for levelling
- Formulate for application viscosity, build in desired hold up
- Dependent on end use – low build varnish, high build emulsion paint

![Image of brush speed and shear rate calculation]

*Figure 2: Simple brush application of a paint system already results in a shear rate of about 10,000 s$^{-1}$*

Source: BASF
Brush application

- On application, pressure forces the paint out from between the bristles
- Forward motion splits the layer of paint between brush and substrate
- Brush marks result from the paint film splitting between the brush and the substrate, not due to the bristles themselves
- Viscosity at high shear controls ease of brushing
- Applied film thickness also increases with increasing viscosity
- Low viscosity promotes levelling and also sagging – so high build and good flow not currently possible
Hand Roller application

- DIY and also industrial method
- Fastest method for hand application of paints
- Need good flow to level out roller texture
- Air entrapment can be a problem
- ‘Roll and tip’ used in some applications to remove defects
Hand Roller application

- Rheological requirements similar to those for brush application
- High, low shear viscosity to load the roller
- Low, high shear viscosity for application
- Low viscosity for flow and levelling
- High, low shear viscosity to prevent sagging

Assumption:

linear velocity \( (V) = 0.5 \text{ m/s} \)

d = 0.2 mm

shear rate = \( \frac{V}{d} = \frac{0.5 \text{ m/s}}{0.0002 \text{ m}} = 2500 \text{ 1/s} \)

Source: Elementis Specialities
Roller application

- As roller moves, film is split
- At the nip, the paint is under pressure and as the roller moves on, textured surface produced
- If there is not enough time at low viscosity for the paint to flow out, then some texture is left
- Only low/medium build possible without texturing
- Air entrapment can be a problem, as can ‘spatter’
Roller spatter

Source: Sherwin Williams
Roller moves forward
Pressure reduces
Cavitation occurs
Filaments formed
Filaments split in two places
Forms droplets

As filaments are drawn out, extensional flow takes place

Extensional viscosity rather than shear viscosity affects the development of filaments and spattering

Machine roller application – coil coating

- Continuous operation painting flat sheets or coils of steel or aluminium
- Paint is applied to either one or both faces of the sheet via rollers and then cured in an oven at air temperatures up to 400°C
- Many types of paint can be used
- Line speeds up to 200m/min

Source: National Coil Coating Association
**Machine roller application**

- Paint is transferred to the moving strip by two main techniques, direct and indirect.
- Film thickness controlled by gap adjustments or doctor blades to match line speed.
- Very high shear rates – $10^5$ – $10^6$ s$^{-1}$ due to line speed and film thickness.

Source: Guidance 7, Coil Coating, European Commission, 2009
Machine roller application

- Typical scheme shown below
- Solvent contents vary – 30-70% w/w

Source: Jörg Sander: Coil Coating, 2014 Vincentz Network, Hanover, Germany
Direct roller coating

- In direct roller coating—coated material comes out of the nip between the rollers and the wet layer of paint is split between the roller and the substrate.

- As coated stock comes out of the nip, cavitation occurs and walls between cavities become filaments.

- These filaments may break and fall back onto the surface giving a ribbed appearance.

- Coating should level quickly to avoid these marks so slow recovery of viscosity is needed.

Source: Werner Blank et al, King Industries and Ray Fernando, Air Products
Direct roller coating

- As coated stock comes out of the nip, cavitation occurs and walls between cavities become filaments
- Filaments grow quite long and may break in more than one place producing droplets – this is called misting
- Extended filaments result when extensional viscosity is high

Machine roller application

200 ppm POLY(ETHYLENE OXIDE) (Mw=7 million g/mol) IN 60/40 (wt. %) GLYCERINE/WATER

SPEED = 0.5 m/s
VISCOSITY = 14 mPa-s
ROLL DIAM. = 10 cm
SURF. TEN. = 65 mN/m

Source: Pranannarao Dontulata, Doctoral thesis, University of Minnesota, 1999
Reverse roller coating

- In reverse roller coating the rollers rotate in the same direction so the material to be coated must be pulled through the nip

- Used for coating coil stock

- Paint film is applied by wiping rather than film splitting

- Gives a smoother film and levelling problems are minimised

Source: Werner Blank et al, King Industries and Ray Fernando, Air Products
Machine roller coating

- Coatings formulated for Newtonian flow
- Reduces tracking defects
- Encourages uniformity of film across the painted area
- High shear viscosity important
- Slow evaporating solvents to keep viscosity low and to promote levelling
- Long pot life needed for two pack paints
Spray application

- Fast method for wide range of paints, both one and two packs, surfaces,

- Used in industrial and architectural applications

- Many different types of equipment, all atomize paint into droplets by various means

- High shear application – 20,000s\(^{-1}\)

- Good for irregular shapes – ships and yachts
Air spray – general principles

- Sheet or jet of liquid paint broken up by air
- As paint moves away from the orifice, thickness decreases and perforations are formed in the sheet, these expand to form filaments
- Filaments break up producing drops of varying sizes
- **Conventional spray** – air injection
- **Airless spray** – no air injection

Source: Werner Blank et al, King Industries and Ray Fernando, Air Products
Air spray – general principles

- For good atomisation, surface tension forces must be overcome

- Viscosity of the liquid acts to delay growth of instabilities and delays atomisation

- Initial instabilities augmented by aerodynamic disturbances – air injection

- Droplet size important:
  - Too small <15µm, overspray
  - Too large >70µm, affect aesthetics in finishes

Solvent loss on application

- Solvent loss in transit from gun to substrate

- Amount lost depends on:
  - Surface area to volume ratio of droplets
  - Air flow over droplets
  - Air/paint temperature

- Loss is greater from conventional spray than airless spray
  - Produces a cooling effect
  - Increases viscosity and surface tension

- May affect flow and levelling
  - Careful formulation of solvent blend required
  - Fast and slow reducers for cold and hot climates
  - Brush and spray reducers
Air spray – conventional

- Typically used to apply low viscosity paints such as cosmetic finishes
- Paint delivered to gun in a variety of ways

Source: International Paint Application Guide (air atomised spraying)
Air spray – conventional

Figure 2-1—Parts of a Typical Air Spray Gun

Source: IBPAT Joint Apprenticeship and Training Fund Study Guide
Air spray – conventional

- Stream of paint exits tip at 10-20psi
- Atomised by compressed air at 40-80psi

- Degree of atomisation controlled by:
  - Paint viscosity – higher, larger droplets
  - Air pressure – higher, smaller droplets
  - Tip size – smaller tip, smaller droplets
  - Paint pressure – higher, smaller droplets
  - Surface tension – lower, smaller droplets

- Typical droplet size – 20-50µm
  - Larger drops - >70µm affect aesthetics
  - Orange peel

- Entrained air causes large volumes of paint / air mixture to rebound resulting in 'over-spray'

Source: IBPAT Joint Apprenticeship and Training Fund Study Guide
Air spray – conventional

- Typical paint viscosity is low –
  14 seconds on Din 4 flow cup ~ 0.2 poise

- High build not compatible with good flow and aesthetics
  Hold up is low – 50µm wft

- Target of 60 µm dft achieved by multiple coats wet on tacky

- Solvent is lost in the turbulence which can lead to 'dry' films being applied with poor flow-out.

- Complex solvent blends to aid flow and levelling

Source: IBPAT Joint Apprenticeship and Training Fund Study Guide
Orange peel
Orange peel
Orange peel

Source: Schneider et al, Fraunhofer institute, April 2013

2-4\mu m
Flow and levelling

- Orchard proposed that surface tension is the driving force for levelling.

- Patton derived the following equation:

\[
\ln \frac{a_0}{a_t} = \frac{5.3\gamma x^3 dt}{\lambda^4 \eta}
\]  

(24.1)

where \(a_0\) is the initial amplitude (cm), \(a_t\) is the amplitude at time \(t\) (cm), \(x\) is the average coating thickness (cm), \(\lambda\) is the wavelength (cm), \(\gamma\) is the surface tension (mN m\(^{-1}\)), \(\eta\) is the viscosity (Pa·s), and \(t\) is the time (s).

- To increase levelling:
  - Reduce viscosity
  - Increase surface tension
  - Increase film thickness
  - Reduce wavelength

- Formulator has little control over variables – human factor

- Limitations due to cross linking, solvent evaporation and thixotropy

The applicator’s dilemma

Increasing wet film thickness

Target wet film thickness

Levelling:
Improved by reduced viscosity, high surface tension, increased film thickness
Hindered by solvent loss, thixotropy, reaction in convertible coatings
In PUs, RH range important in developing acceptable aesthetics
Airless spray paint application

- Used where a fine finish is not required for one and two pack paints
- High volume application method
- Long fluid lines often used
- Outdoor application
Airless spray paint application

- Paint is pumped at very high pressure (>3000psi) through a narrow orifice 300-800µm diameter which breaks the jet into droplets ~ 70-150µm in diameter.

- These coalesce into a continuous film.

- Film thickness is built up by repeat passes of the spray gun.

- Wft limited only by the thixotrope level.

- Need to formulate for high shear viscosity and hold up - may be 3x target thickness.

- Bounce back and solvent loss lower than conventional spray.
Airless spray – single packs

- Single pack paints are generally relatively low solids – 40-50% volume solids

- Target high shear viscosity typically 6 poise maximum at the application temperature

- Hold up built in using thixotropes

- Hold up should take into account the overlapping nature of the application process - maybe 2-3 times target scheme thickness
Airless spray - two pack systems

- Reactive, two pack systems such as epoxies, polyurethanes and polyureas present different challenges.

- Pot life considerations are important, especially if they are solvent free and highly reactive.

- Reactivity and viscosity of the components dictate the precise application method.

- Atomisation principle remains the same, but the way in which the paint is delivered differs, primarily in where the paint is mixed and its temperature.
Pot life

- Upon mixing a two pack paint, crosslinking begins and viscosity rises

- After a certain time – the pot life - it will be impossible to apply

- Various other approaches have been tried – 50% rise in viscosity, but not appropriate

- Makes applicators creative
Airless spray - two pack systems

- Paint 1: Low reactivity, relatively long pot life (>1hr), low mixed viscosity
  – mix components and use single feed

- Paint 2: Solvent free, short pot life (30 mins), high viscosity
  – heat individual components separately and mix close to gun

- Paint 3: High reactivity, no workable pot life (seconds)
  – heat individual components separately, mix in the gun (impingement mixing)
Airless spray - two packs: Paint 1

- Typical low or high solids (80% VS) amine cured epoxy with relatively long pot life 1-2 hrs or more

- Mix components and apply by single feed airless spray

- Rheology: High shear application viscosity at desired temperature (<6 poise) and hold up to 3x target wft

Note:
- Practical pot life should be determined by application trials
- Long fluid lines often used leading to pressure drops
Two pack systems: Paint 2

- Solvent free two pack amine cured epoxy

- Base and curing agent too viscous to apply (>10 poise)

- Pot life not practical (<30 mins) due to high concentration of reactive groups

- Use twin feed, heat the individual components, possibly lines trace heated and use an in-line static mixer close to the gun

- Use heat to reduce viscosity to an acceptable level, use thixotropes that are not heat sensitive, hold up 3x target wft

- Generally need a minimum substrate temperature to enable better wetting of surface (adhesion can be compromised)
Two pack systems

- Solvent free two pack amine cured epoxy separating the components
- Graco XP50™ Plural Component Component Sprayer
Two pack systems

- Static mixers

Source: Plural Component Spray presentation 2005
Heated Spray Application

- Increasing temperature reduces viscosity
- Reduction in viscosity greater for high solids coatings
- Significant temperature loss in transit between gun and substrate
  - 60°C at gun, 20°C within 30cm
- Increases viscosity of coating
- Helps build
- Adverse effects on coalescence, wetting of irregular surfaces, adhesion, flow and levelling
Two pack systems: Paint 3

- Polyurea – very reactive systems – effectively zero pot life
- Components separated, may be heated
- Fed to the gun and mixed in a small volume chamber within the gun – impingement mixing
- Guns designed to purge the chamber to prevent build up and blockage
- Heat used to reduce viscosity and combination of pressure and temperature adjusted for good atomisation
- Hold up not too much of an issue due to the very thick films and extreme reactivity of the system
Two pack systems

Source: Madison Chemical Industries Inc.
Two pack systems

- Gusmer GX-7 spray gun, mechanical purge
Summary

- The rheological requirements of a paint are complex and can be contradictory.
- Formulation is therefore often an optimisation exercise.
- Generally formulate for application viscosity for the technique initially, and then build in the hold up required for the end use.
- Effective product development requires:
  - A detailed understanding of the end user requirements.
  - A detailed understanding of thixotrope technology – how they work, incorporation, limitation, interactions.
  - Relevant test methods and protocols.
- Combine all of these maximises the chances of success (see Post Script).
Post script

- Don’t let Sales sell an existing product designed for one application, for a different application, unless cleared by Technical

- Don’t let Sales sell an existing product designed for one substrate, for a different substrate, unless cleared by Technical

- Don’t let Sales sell an existing product designed for one country, for a different country, unless cleared by Technical

- Don’t accept a project without application information

- If the Rep hasn’t got it, send him away to get it, or better get it yourself
THANK YOU

Any questions?