Slurry and Shell Building Considerations, Best Practices and Documentation

Mike Hendricks
Business Unit Director
Ransom & Randolph
Maumee, Ohio

Introduction

- Purpose of this presentation is to focus more on the process than the materials or slurry control.
- Review various process in the shell room
- Will present
  - Process review
  - Best practice tips
  - Considerations
  - Items to include in documentation

Agenda – areas of Discussion

- Slurry Preparation
- Viscosity Measurement
- Shell Dipping
- Shell Draining
- Shell Drying Environment
- Measurement Equipment
- Discussion and Questions

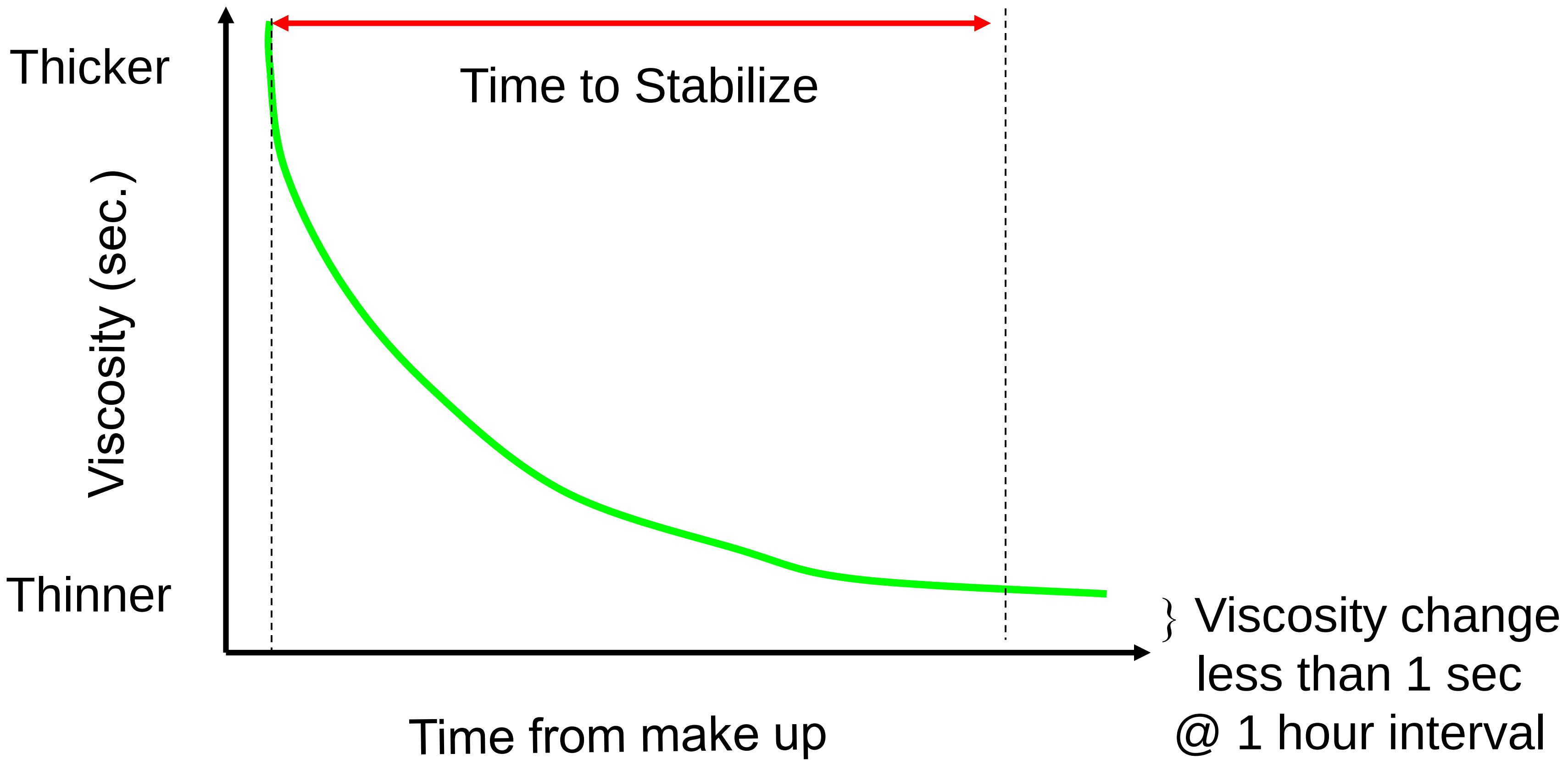
Slurry Preparation

- The process of building a slurry
- Slurry formula is chosen for a reason
- Good formula with bad preparation gives bad results
- A slurry is mixed when each refractory particle is completely wet with binder solution (no air between particles and binder)
- Key to good preparation technique is to achieve a stable (ready-to-use) slurry
- Stabilization can be determined by viscosity

Slurry Preparation
Viscosity Stabilization Time

- The time it takes for the viscosity of a slurry to become stable, after makeup or an addition to the slurry
- Slurry is stable when viscosity changes less than 1 second when measured at 1 hour interval
- Once viscosity is stable, it is OK to use slurry

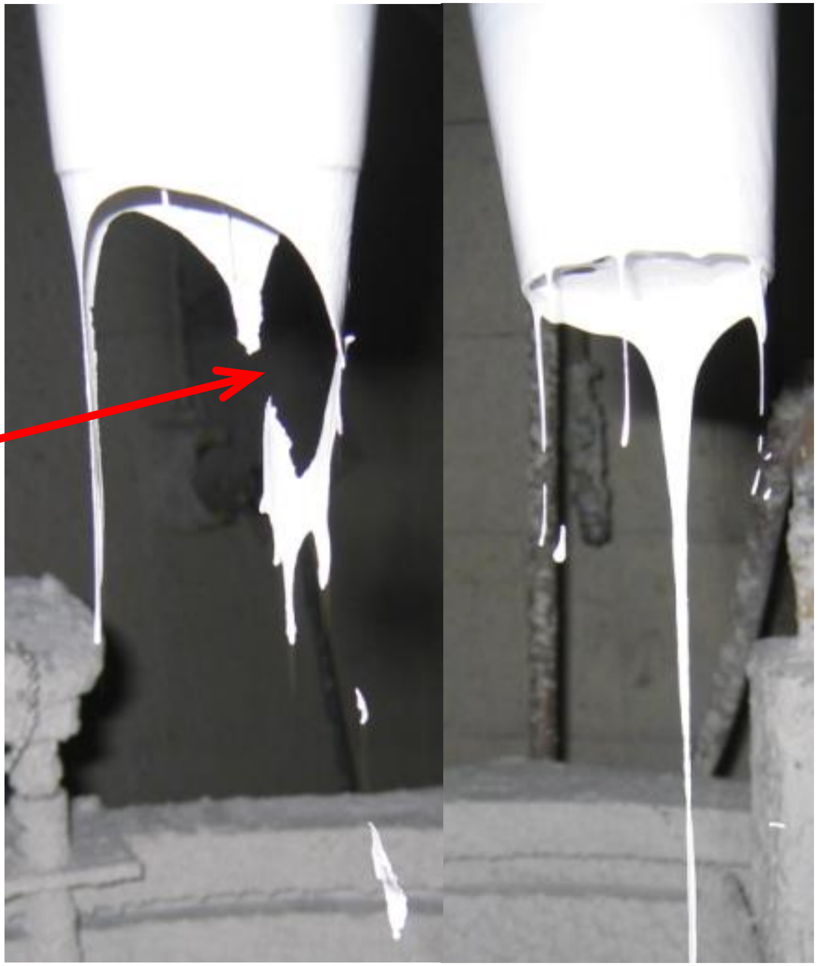
Slurry Preparation
Slurry Viscosity Stabilization



Slurry Preparation

Visual Check on Slurry Mixing

Slurry not
creamed in
(tears during
draining)



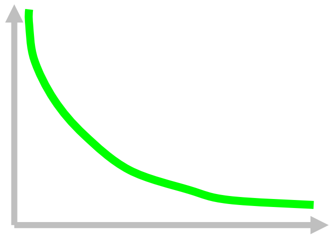
Slurry
creamed in

Slurry Preparation
Stabilization Time

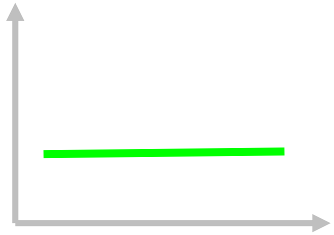
- Factors affecting stabilization time
  - Mixing equipment
  - Amount of addition
  - Slurry formula
  - Makeup procedures

Slurry Preparation
Slurry Tanks

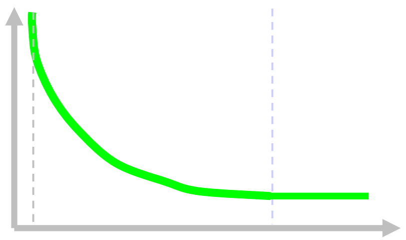
- Makeup Tank
  - The tank that slurry is made up in and allowed to cream in
  - Once creamed in (stable), slurry can be transferred to a working tank



- Working Tank
  - Contains only stable viscosity slurry
  - The tank that you dip parts into

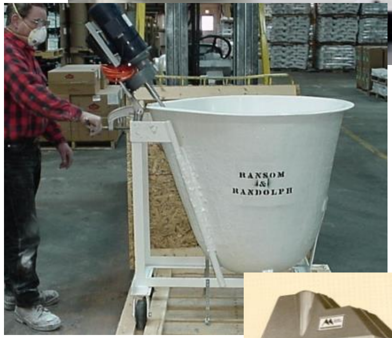


- Can use one tank for both, but do not dip in it until viscosity is stable



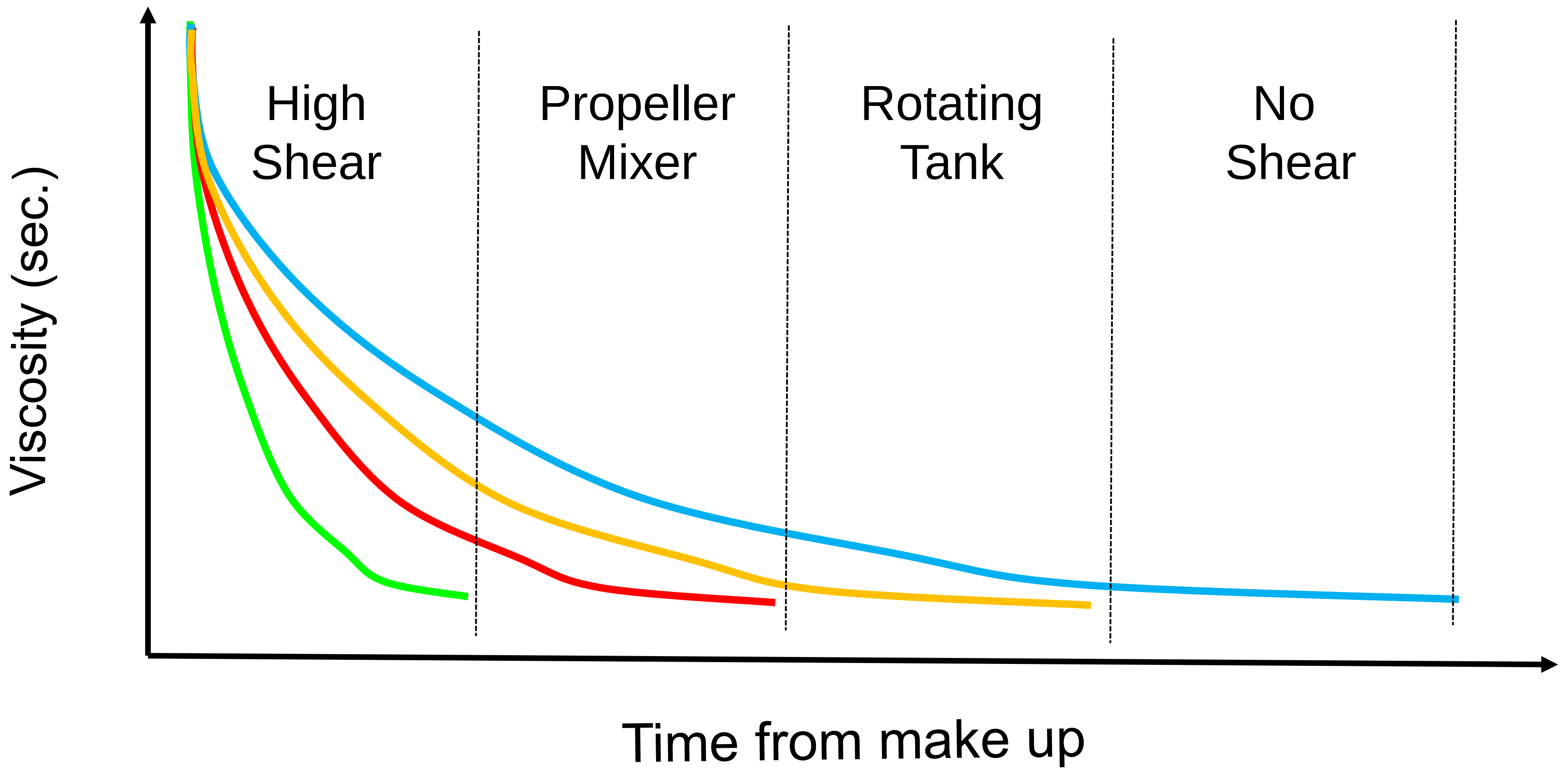
Slurry Preparation
Mixing Equipment

- No shear – barrel rollers
  - Only for makeup
  - Long wet in times (days)
- Low shear – rotating tanks
  - Not good for makeup
  - Good for working tank
  - OK for makeup with propeller
- Moderate shear – propeller mixer
  - Good for makeup and working
  - Best practice tip: add a timer
- High shear – Cowles or Hockmeyer type
  - Short stabilization times
  - Makeup only
  - Watch for heat buildup and degradation



Slurry Preparation

Slurry Makeup - Effect of Mixing Equipment



Slurry Preparation
Amount of Addition

- Liquids only
  - Will mix in easily, depending on mixing equipment
  - Typically less than an hour
- Top-ups
  - Formula additions
  - Actual time depends on mixing equipment and amount of addition
- Refractory only
  - Will take longest to mix in, depending on amount and mixing equipment
- $\Rightarrow$ Addition is well mixed when viscosity is stable

Slurry Preparation
Slurry Formula

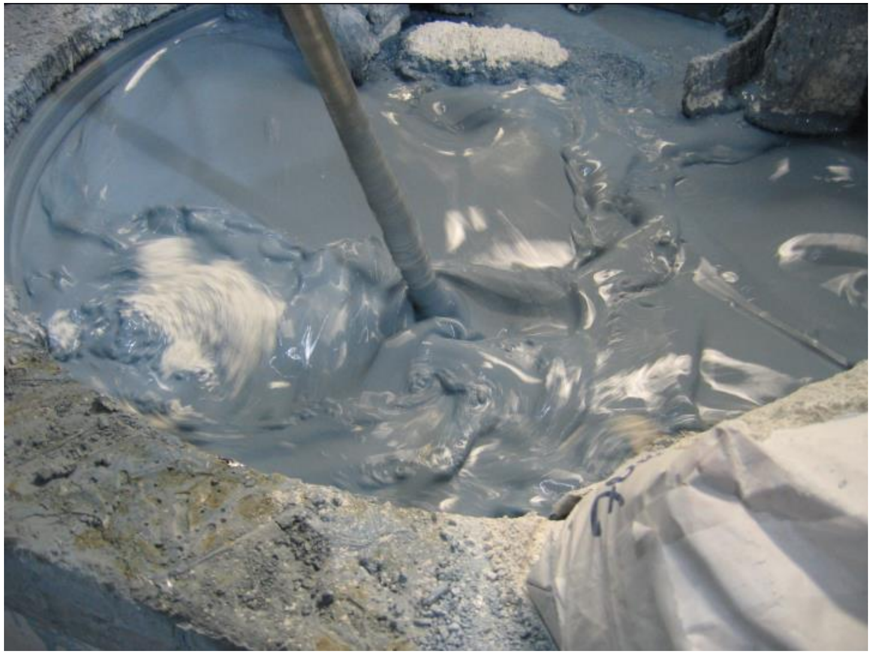
- Primary slurries and other high refractory level slurries take longer to stabilize
- Backup slurries stabilize quicker than primary slurries
- Lower density refractories may take longer to stabilize
- When adding the same refractory with two different particle sizes, add the finer one first
- With mixed slurry refractories, add lowest density refractory first

Slurry Preparation
Makeup Procedures

- "Poor" technique
  - Measure binder to line in buckets
  - Count bags and ½ bags of flour
  - Dump ingredients in and break up lumps

- Suggested technique
  - Weigh all materials
  - Slowly add or sift in flour
  - Best practice tip: turn mixer on and off to release trapped air

Slurry Preparation
Mixing Slurry



Air released when mixer shut off

Slurry Preparation

Slurry Makeup - Documentation

- Identify equipment
- Specify ingredient (batch sheets, pictures)
- Specify amounts (weight and volume)
- Specify order of addition
- Specify rates of addition
- Identify controllable variables and how/when to use
  - Adding extra water
  - “Burping” the slurry
  - Etc.
- Specify target viscosity for stabilization

Viscosity Measurement

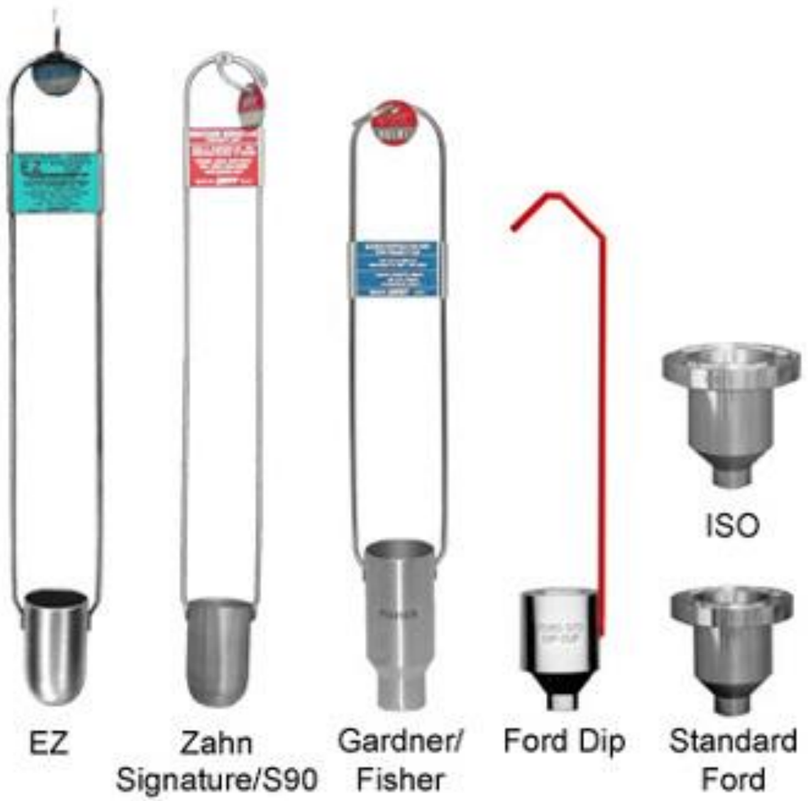
- Objective
  - Determine if the slurry is in range and “fit for use,” based on flow measurement
- Viscosity test is the only test on a slurry that can be done “at the tank” to determine if a slurry is fit for use

Viscosity Measurement
General Procedure

1. Fill a clean dry flow cup with slurry
2. Measure efflux time of slurry from flow cup
3. Start stopwatch at initial flow stop at endpoint
   - Break at bottom
   - Through the hole
   - One inch below

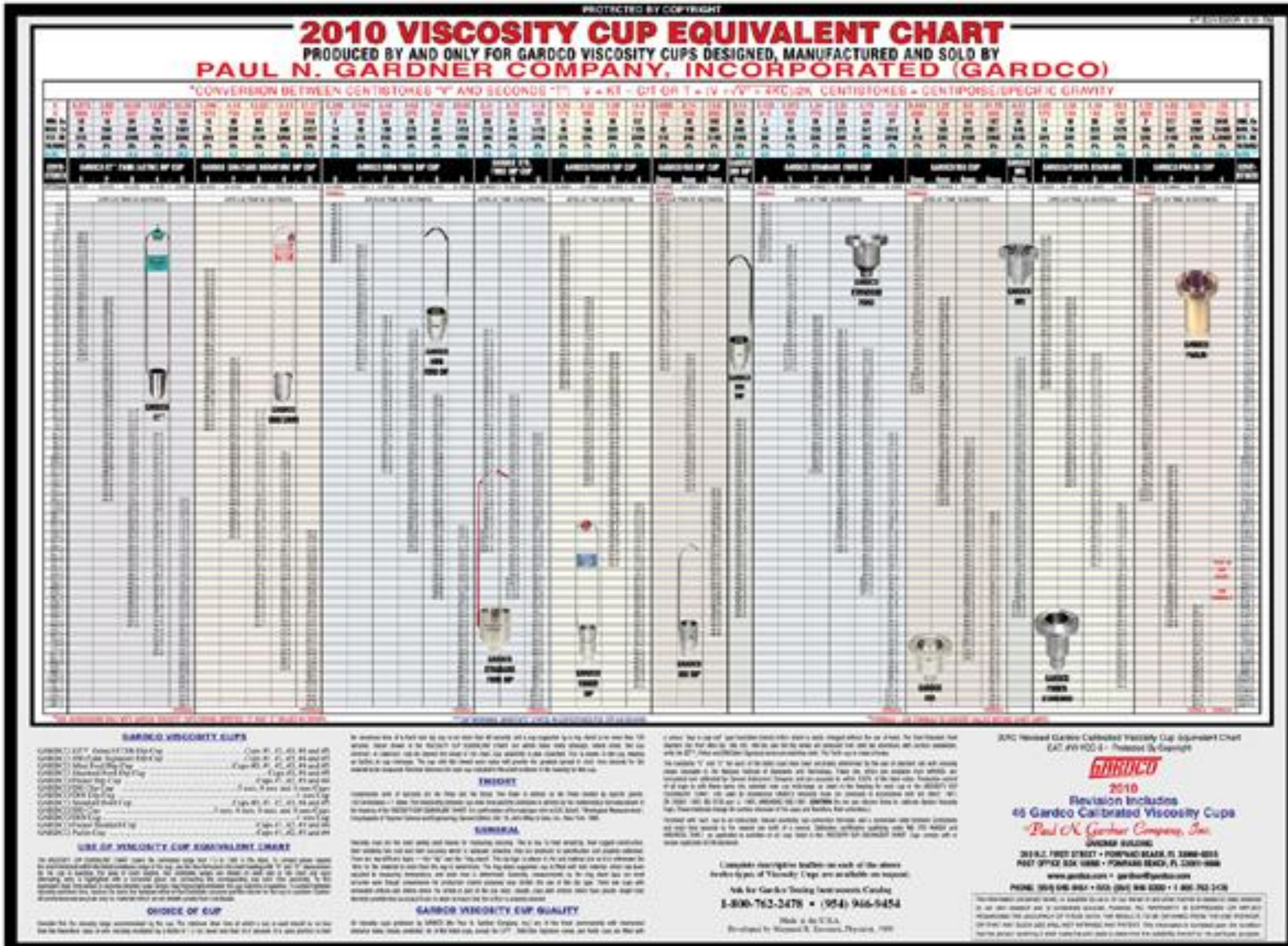
☞ Key is to be consistent

Viscosity Measurement
Define Cup



- Not all cups are created equal
- Specify type first
- Then specify number
- #5 EZ ≠ #5 Signature

Viscosity Conversion Chart



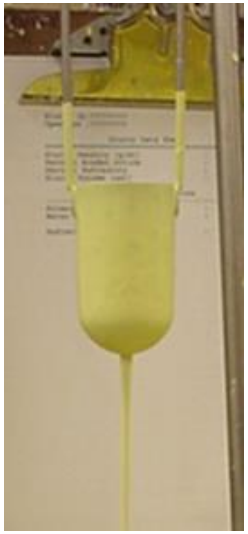
Viscosity Conversion – Proper cup selection

354 Centistokes (Primary Slurry) Liquid - Efflux Time (sec)			
	#3	#4	#5
EZ Cup	36.7	28.5	16.9
Signature Cup	36.2	24.8	14.4

200 Centistokes (Backup Slurry) Liquid - Efflux Time (sec)			
	#3	#4	#5
EZ Cup	23	18	11.5
Signature Cup	22.7	15.9	-

Viscosity Measurement
Define Endpoint


Through the hole

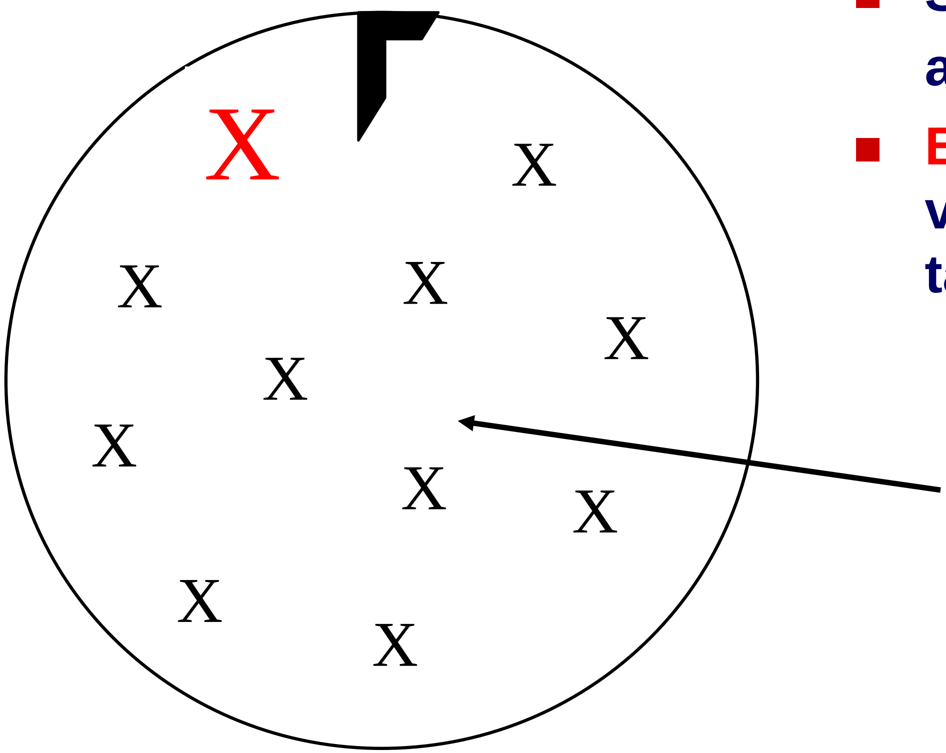

One inch below


Break at the bottom

- **Different endpoints give different readings**
  - **TTH ≠ Bottom ≠ 1 inch**
- **Key is to be consistent**
  - **Operator to operator**
  - **Shift to shift**
- **Best practice tip: conduct a gage R&R analysis on viscosity readings**

Viscosity Measurement
Define Location

- Slurry Tank Surface



X – Viscosity Reading Location

- Specify where to read viscosity in tank
- Suggested right behind plow at "X"
- Best practice tip: survey the viscosity profile across the tank
  - Variation should be minimal
  - Lower viscosity and pooling in center of tank can create thinner shells
  - Adjust mixing speed, paddle design, etc., to improve mixing

Viscosity Measurement
Best Practice Tip

- Have two sets of cups
  - Floor cups
  - Supervisor cups
- On a regular basis, have a designated operator check slurries with both cups and record
- As floor cups are used (dropped, dinged, etc.), readings can change
- When variation between floor and supervisor cups occur,
  - Swap out floor cups with supervisor cups
  - Purchase new supervisor cups
  - Establish a correlation between cups

Viscosity Measurement
Documentation

- Specify viscosity cup type
- Specify the cup number
- Specify location in tank where to take the reading
- Specify the endpoint
- Other things to consider
  - Number of readings per test
  - Set allowable variation reading to reading
  - Cup cleaning and storage between test
    - Clean in water
    - Store in water or dry

Shell Dipping and Draining

- Objective: to coat the wax pattern or previously applied shell coat with adequate slurry and then create a complete and even layer of slurry on the wax or pattern
- How do we measure: typically this is done visually
- Fixed variables
  - Trees or clusters
  - Slurry properties
  - Hand dip or robot
- Controllable variables
  - Orientation of cluster
  - Manipulation in slurry or during drain
  - Time

Shell Dipping and Draining

What part of shell construction?

- Technically three different dipping and draining processes
  - Primary coats
  - Backup coats
  - Seal coats
- Dipping and draining techniques are not necessarily the same for each

Shell Dipping
Primary Coats

- Objective: create the initial layer of the shell that must capture all the detail of the wax pattern and create the shell surface the metal will be poured against

- Items to consider for dipping
  - Orientation
    - For dipping, need to orient the part to maximize detail wetting and minimize trapping air
    - Dip clean wax into slurry and allow it to flow up the pattern, filling detail as it rises
  - Manipulation
    - Is rotation in the slurry required to help fill detail and release air
  - Time
    - Not normally a factor or concern

Shell Draining
Primary Coats

- Items to consider for draining
  - Orientation
    - Need to create and even slurry coat, so changing orientation (vertical, 45° angle up/down etc.) is required
  - Manipulation
    - Parts should remain in motion and allow the slurry to slowly drain off the pattern
    - Need to determine if external manipulation is needed
      - Air
      - Brushing
  - Time
    - Drain times are typically longer for primes
    - No time constraints, just watch for over drain

Shell Dipping
Backup Coats

- Objective: create the bulk of the shell; which determines shell properties and dimensional characteristics
- Items to consider for dipping
  - Orientation
    - For dipping, need to orient the part to maximize detail wetting and minimize trapping air
  - Manipulation
    - Is rotation in the slurry required to help fill detail and release air
  - Time
    - Dwell time in slurry becomes a bigger factor for backup coats

Shell Dipping
Backup Coats

- Dwell time in slurry
  - A dried shell is like a sponge (it will absorb moisture)
  - If the shell is in the slurry a long time, it will absorb moisture from the slurry and the resulting slurry layer will flow more evenly and drain thinner
  - If the shell is in the slurry for a short time, the shell will absorb moisture from the slurry layer which will change rheology as moisture is absorbed
  - Parts with detail and geometry should have longer dwell times
  - A longer dwell time may eliminate the need for a prewet in some cases
- Best practice tip: determine minimum/maximum time in slurry

Shell Draining
Backup Coats

- Items to consider for draining
  - Orientation
    - Need to create and even slurry coat, so changing orientation (vertical, 45° angle up/down etc.) is required
  - Manipulation
    - Best Practice tip:
      - When shell first exits the slurry, stop all movement
      - Allow excess slurry to “gush” off the part
      - Then manipulate part to smooth remaining slurry
      - Last direction of drain should be to a critical area (ie bottom of shell)
  - Time
    - No time constraints, just watch for over drain as evident by poor stucco coverage on edges

Shell Dipping
Seal Coats

- Objective: encapsulate shell in slurry to avoid loose stucco in subsequent processes
- Items to consider for dipping
  - Orientation
    - Dip at an angle to minimize air entrapment
  - Manipulation
    - As required
    - Not as critical as backup coats
  - Time
    - Minimize time in slurry
    - Avoid soaking in moisture from slurry

Shell Draining

Seal Coats

- Items to consider for draining
  - Orientation
    - Not as critical as backup coats
    - Likely some need for changing orientation (vertical, 45° angle up/down etc.)
  - Manipulation
    - Best Practice tip:
      - When shell first exits the slurry, stop all movement
      - Allow excess slurry to “gush” off the part to the point that dripping nearly stops
      - Then manipulate part to smooth remaining slurry
  - Time
    - No time constraints, but short dwell times and long “gush” times can speed the seal coat process

Shell Dipping and Draining
Documentation

- Document instructions for dipping and draining by coat
  - Prime
  - Backup
  - Seal coat
- Dictate orientation, manipulation and time for each
- Document intervention (air wand, brushing)
- Set minimum and maximum for dwell and drain times
- Implement “gush” to speed up draining cycle

Shell Drying Environment

- Objective: utilize drying conditions to remove moisture as fast as possible without causing damage to the pattern/shell during drying

- Five factors dictate the drying time for every shell
  - Temperature – will impact drying but not normally a factor that is changed due to adverse affect on wax pattern
  - Airflow – from fans or blowers
  - Humidity – lower RH promotes faster migration of moisture to surface of part
  - Part geometry – slots and holes slow down drying versus flat surfaces
  - Slurry system and shell construction sequence

Shell Drying Environment
Environmental Factor Review

- Temperature
  - Maintain drying room at ±5°F
  - Allow waxes to stabilize at temperature prior to dipping
  - Use a window or room air conditioner
  - Best Practice Tip: Clean filter frequently
- Humidity
  - The lower the humidity, the faster the drying
  - Very expensive to lower humidity
  - Air conditions will lower the humidity
  - Room dehumidifiers can be used to help lower the humidity
  - Best practice tip: if possible, cover tanks or dehumidify a separate drying room so water is removed from shells and not slurry

Shell Drying Environment
Environmental Factor Review

- Airflow
  - Biggest bang for your buck!
  - Greatest influence on reducing drying times of shells
  - Provide from all directions
  - Turn parts
  - Blow air across blind holes – not into
  - Use oscillating fans
  - “Pipe in” air using a blower
  - Best practice tip: you have too much airflow if it causes breakage of your parts, otherwise the more the better!

Shell Drying Environment

Environmental Factors - Effect on Drying

HUMIDITY (%)	AIRFLOW (M/S)	BU COAT 1 Dry time (mins)	BU COAT 4 Dry time (mins)
40	0	210	590

Increasing airflow has a greater impact
on dry time than lowering humidity

Measurement Equipment –Drying Environment
Best Practice Tip

- Portable weather meter
- Can be used to measure/monitor
  - Airspeed
  - Temperature
  - Relative Humidity
- $150-200

Measurement Equipment - Shell Drying

Best Practice Tip

- There are multiple methods to determine shell dryness.
- One simple way is the use of an optical pyrometer.
- $100-200

Measurement Equipment - Specific Gravity
Best Practice Tip

- Methods for testing binder SG
  - Volumetric
    - 10 ml flask
    - $10-20
  - Density Meter
    - Anton Paar – DMA35
    - $3500
  - Alternative
    - Anton Paar - EasyDens
    - Works with cell phone via App
    - Less expensive
    - $400

Thank You

Discussion and Questions