Required Conditions for Fast Firing Vitreous Whiteware Products

Case Study of a Sanitaryware Casting Body and Plastic Processed Body

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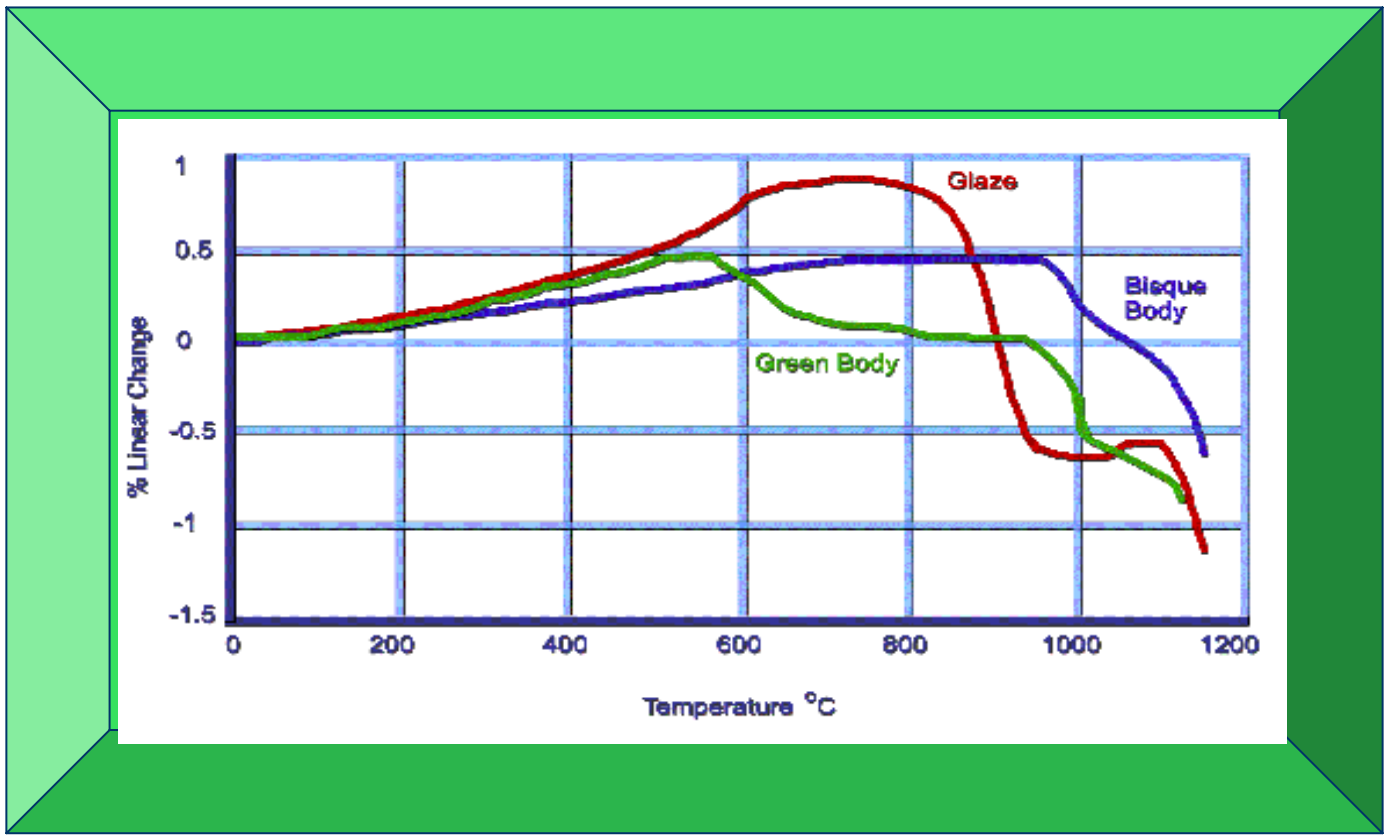
Reactions During Heating & Cooling

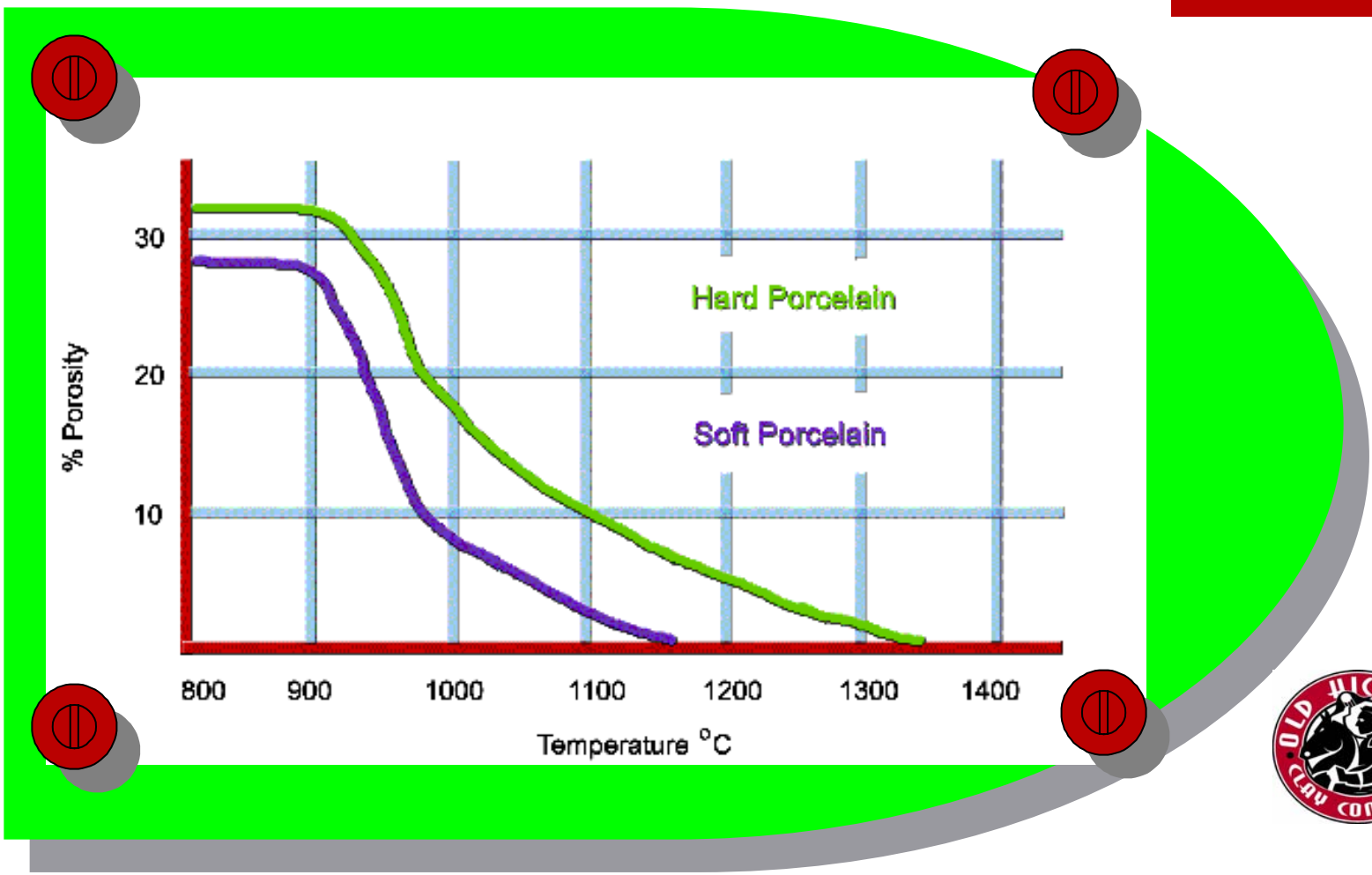
Temp. °C

- 50 – 250 . . . . . Hygroscopic water is removed
- 250 – 370 . . . . . Low Temperature organics are removed
- 370 – 650 . . . . . Carbon / iron oxidation
- 480 – 600 . . . . . **Dehydroxylation** (chemical water is removed)
- 563 . . . . . Quartz Inversion
- 550 – 650 . . . . . Magnesite decomposition
- 750 – 850 . . . . . Calcite decomposition
- 850 + ... Sintering / densification
- 900 + ... Glass / new compounds form
- 1260 – 816 . . . . . Sulfur evolution
- 1260 and below . . . . Contraction
- 573 . . . . . Quartz inversion
- 925 – 560 . . . . . Glass solidifies
- 280 – 210 . . . . . Cristobalite inversion

Expansion / Contraction Curves



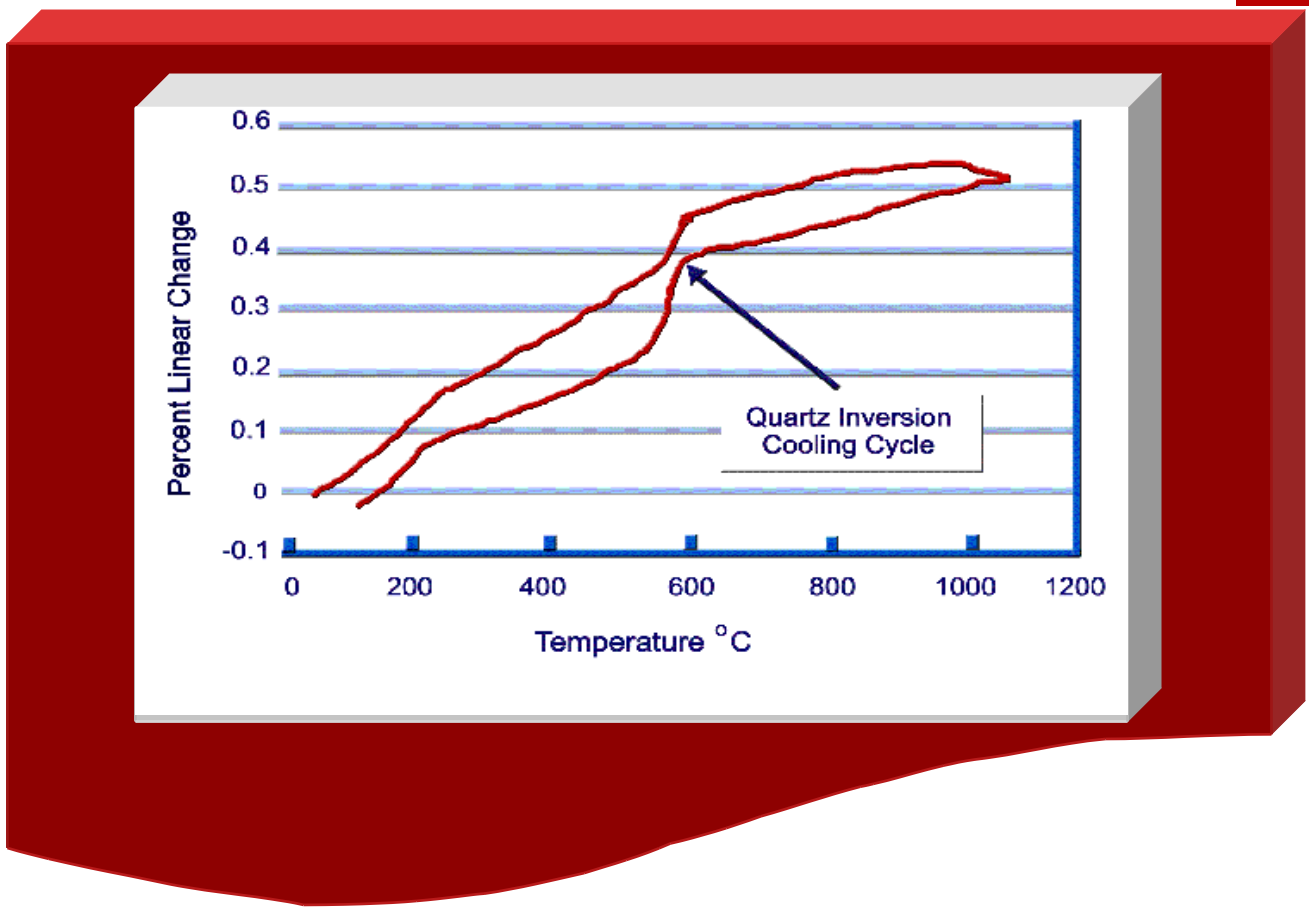
Porosity
Hard & Soft Porcelain Bodies



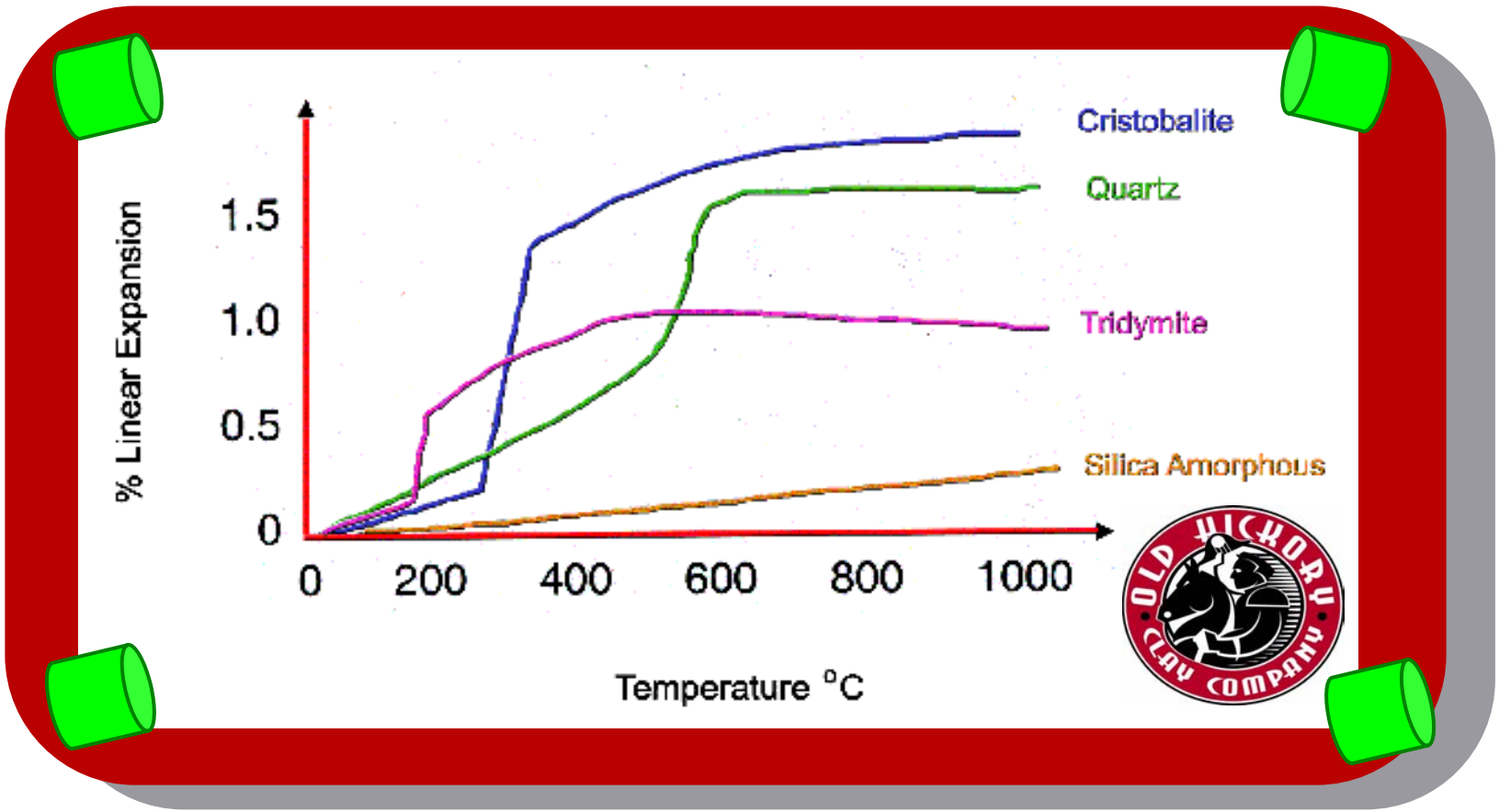
BALL CLAYS
Suitable for Fast Single Fire Whiteware Bodies

	A	B	C	D
CHEMICAL DATA				
SiO_2	56.7	58.7	55.3	58.7
Al_2O_3	29.9	27.7	30.2	27.3
Fe_2O_3	1.0	1.0	1.1	1.3
K_2O	1.1	0.6	0.4	1.5
LOI	9.6	9.9	10.2	8.9
MINERALOGICAL				
Quartz	18.4	21.4	18.4	22.4
Kaolinite	71.1	72.9	74.9	64.5
Feldspar (K_2O, Na_2O)	7.3	2.6	3.2	9.7
Organic	0.6	0.0	0.0	0.7
PARTICLE SIZE DISTRIBUTION - % Less				
5 µ	83	84	87	68
1 µ	61	63	65	43
0.5 µ	50	53	53	33

Alpha / Beta Quartz Thermal Behavior



Common Silica Phases



SANITARYWARE FORMULAS

RAW MATERIAL	Fast Single Fire 1300 °C @ 7.25 – 7.50 hours (cold – cold)	Typical Firing Cycle - 8 – 12 Hours Cone 8-9
Ball Clay	37.5%	35.0%
Kaolin	12.0	15.0
Feldspar (Na_2O)	44.0	28.0
Silica	6.5	22.0
Total	100%	100%

CALCULATED CHEMICAL ANALYSIS

SiO_2	62.9%	67.2%
Al_2O_3	22.6	20.2
Na_2O/K_2O	6.3	4.2
Miscellaneous	6.1	2.6
LOI	5.7	5.8
Carbon	0.5	0.5-1.0

Original Plastic Body – Conversion from Original 2 Fire to Single Fire Glazed Product

ORIGINAL FORMULA

RAW MATERIAL	
Ball Clay	30%
Kaolin	20
Feldspar (Na_2O)	30
Silica	14
Talc	6
Total	100%

CALCULATED CHEMICAL ANALYSIS	
SiO_2	64.2%
Al_2O_3	21.9
Na_2O/K_2O	2.6
CaO/MgO	2.3
LOI	6.2
Misc. Trace	1.9

Original Firing Data & Characteristics

- Final Fire Cone 2-3, 2100 °F - 10 hours
- Porosity (% water absorption) 1% or less

Single Fire Characteristics

- Firing Temperature Cone 1-2, 2005 °F – 12 hours
- Porosity (% water absorption) 4.5% or more
- Final Product Quality
  - Unacceptably High Porosity
  - Major Glaze Appearance Deficiency, Blisters and Pinholes

CLAYWORLD

Modified Plastic Body for Improved Single Fired Performance

Modified Body

RAW MATERIAL	
Ball Clay	40.0%
Pyrophyllite	27.5
Nepheline Syenite	26.0
Spodumene	3.0
Talc (chlorite)	3.5
Total	100%

CALCULATED CHEMICAL ANALYSIS	
SiO_2	65.0%
Al_2O_3	21.9
Na_2O/K_2O	5.0
CaO/MgO	1.3
LiO_2	0.2
LOI	5.3
Misc. Trace	1.3

Fired Characteristics

- Firing Temperature, 2005 oF - 12 hours
- Porosity (% water absorption) 1% or less
- Final Product Quality
  - Proper Degree of Vitrification
  - Smooth Glaze Surface (no pinholes or blisters)
  - Improved Firing Range of Body (no warpage)

SINGLE FIRE / RAPID FIRE

Requirements for Optimum Glaze Appearance

CONDITION

Glaze must permit gases to escape from the body, then melt and anneal to contain small and minimal quantity bubble structure.

Bubble Size – Microns	Defect
400-800 µ	Blister
100-400 µ	Pinhole
< 80 µ	Low Visible Bubble

IDEAL GLAZE CONDITIONS

High melt fluidity (low viscosity) to permit rapid gas expulsion and heal over of bubble exit point.

Low surface tension of melt phase but sufficiently high to discourage gas reabsorption.

Sanitaryware Glaze Comparison

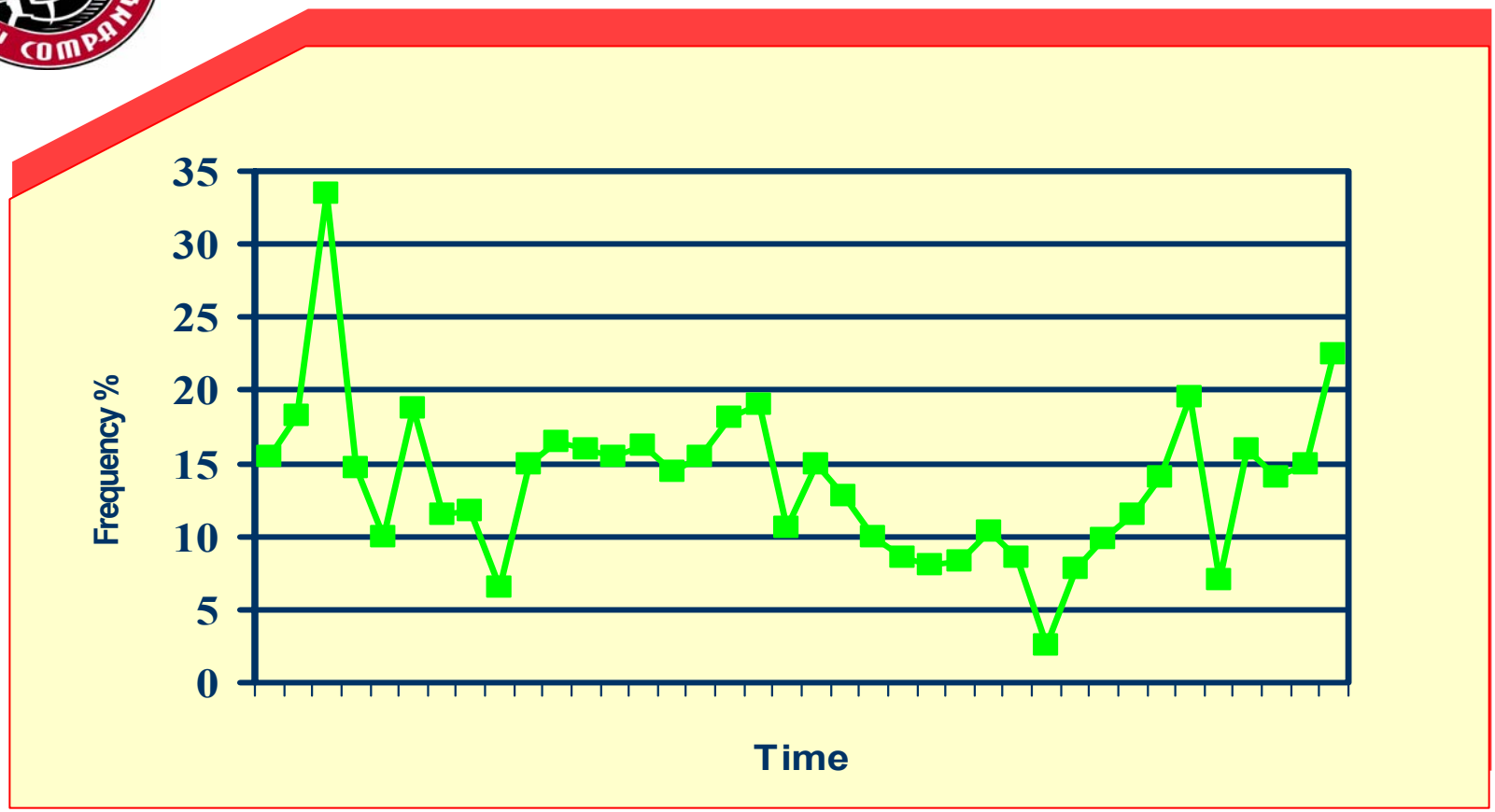
Typical Cone 8 vs. Rapid Low Fire Cone 5 - 6

Raw Materials	Cone 8-9	Cone 5-6
Feldspar (Na_2O)	0.0	29.0
Feldspar (K_2O)	26.3	0.0
Silica	28.4	23.5
Barium Carbonate	5.9	2.2
Calcium Carbonate	3.2	15.5
Dolomite	11.4	0.0
Talc	4.4	0.0
Kaolin	10.3	10.0
Frit	0.0	3.5
Zinc Oxide	4.7	4.5
Zirconium Oxide	9.8	11.8

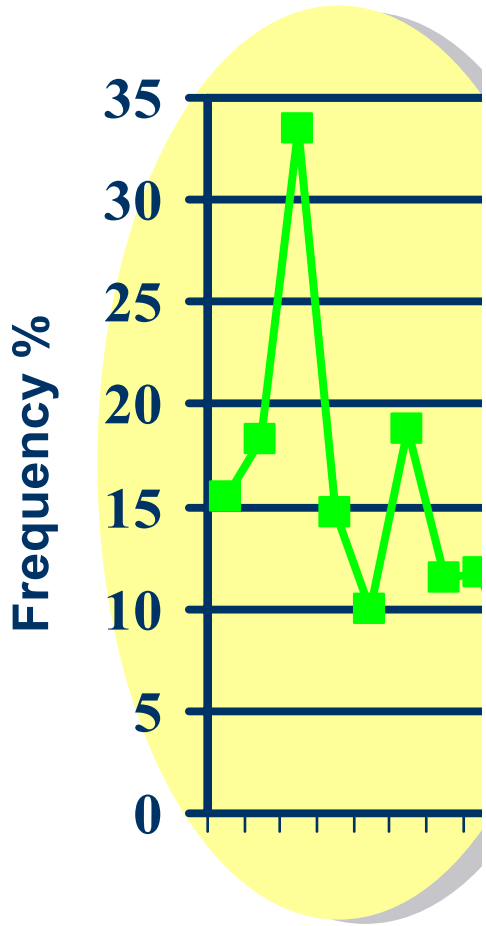
Cone 5 – 6 Glaze Comparison

- Employs Sodium Feldspar
- Utilizes a Frit Addition

Glaze Pinhole Occurrence vs. Select Kiln Firing Data And Glaze Comparison



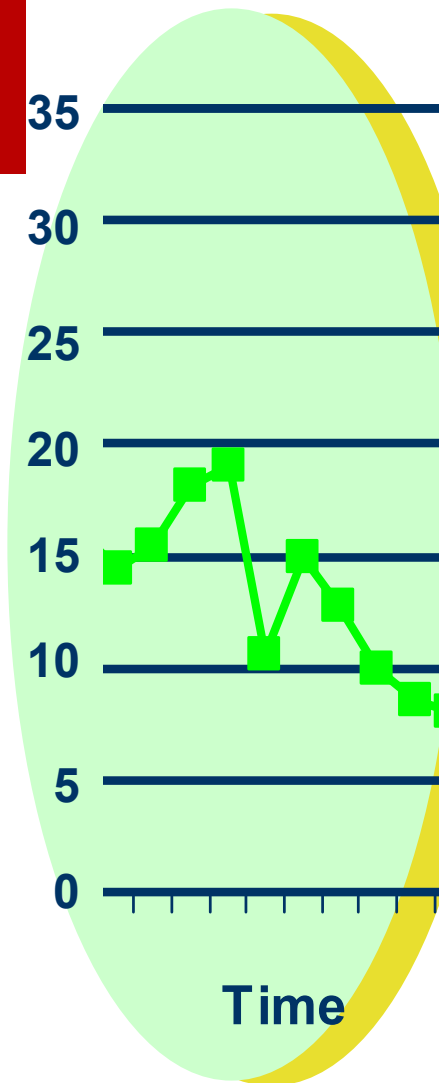
Glaze Pinhole Occurrence vs. Select Kiln Firing Data and Glaze Composition



- Area represents traditional 2-fire process.
- Glost fire is lower than recommended by 15° F and kiln car schedule pushed ahead by 8 minutes.
- Glaze formula is 63% total Frit @ 1:1 ratio using a S_RO (1750°F) frit with a CaO (1550 °F) frit.
- The glaze formula is low fluidity by flux block test.

END RESULT:

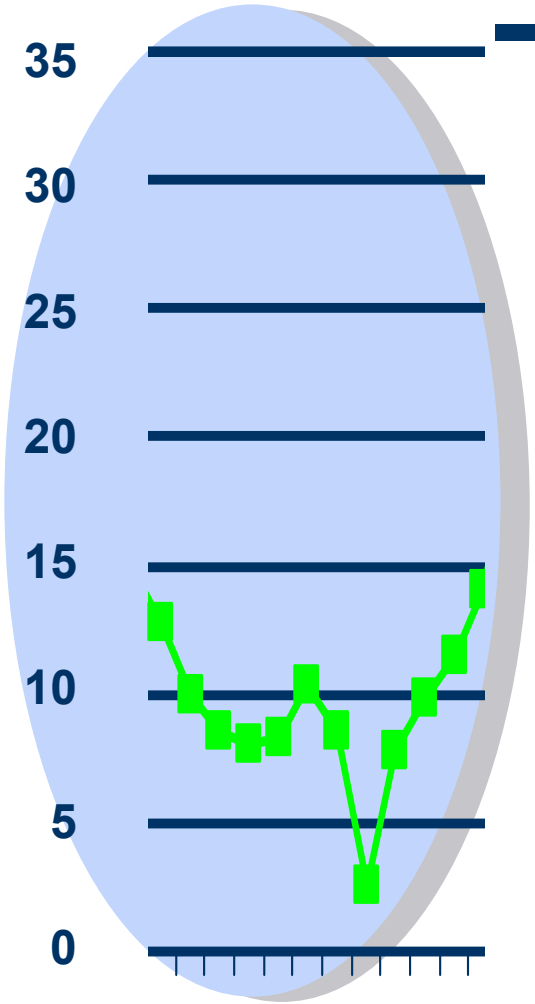
Extremely high incidence of pinholes



Glaze Pinhole Occurrence vs. Select Kiln Firing Data and Glaze Composition

- Same body and glaze as Area No. 1
- Glost Fire increased 15 ^{o}C and car push schedule reduced by 3 minutes.
- Lower pinholes illustrates influence of adhering to firing rates and temperatures of a particular formula.

Glaze Pinhole Occurrence vs. Select Kiln Firing Data and Glaze Composition

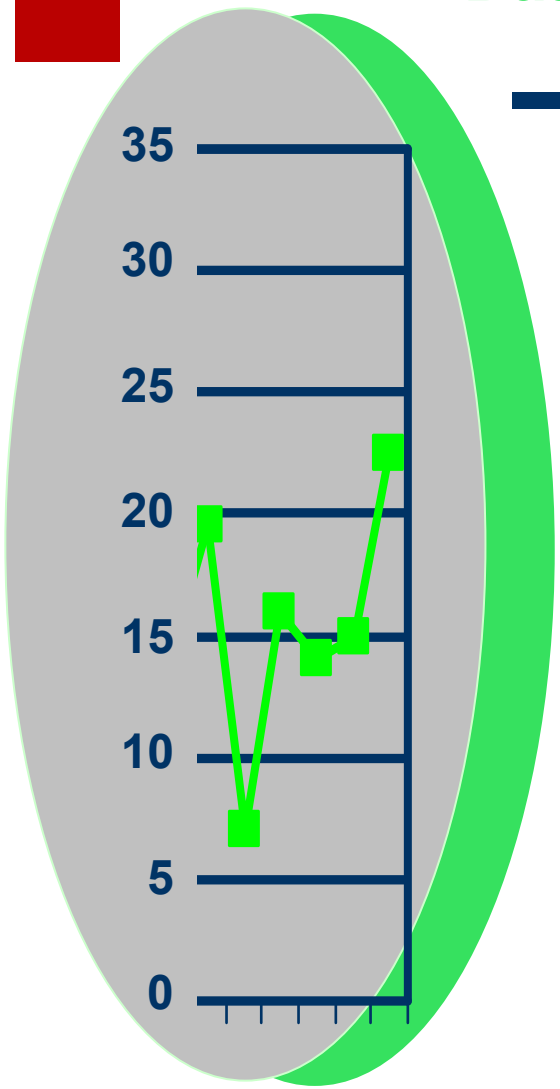


- Same body but single fired at same temperature as Area No. 2 and 5 minutes reduced car push (higher heat work in effect).
- Glaze changed to more fluid type consisting of 80% frit content.
- Frit ratio changed to reflect 50% of total addition consisting of CaO frit (1550 °F)

END RESULT:

Very Low Levels of Pinholes

Glaze Pinhole Occurrence vs. Select Kiln Firing Data and Glaze Composition



- Single Fired Body using same glaze type as previous slide.

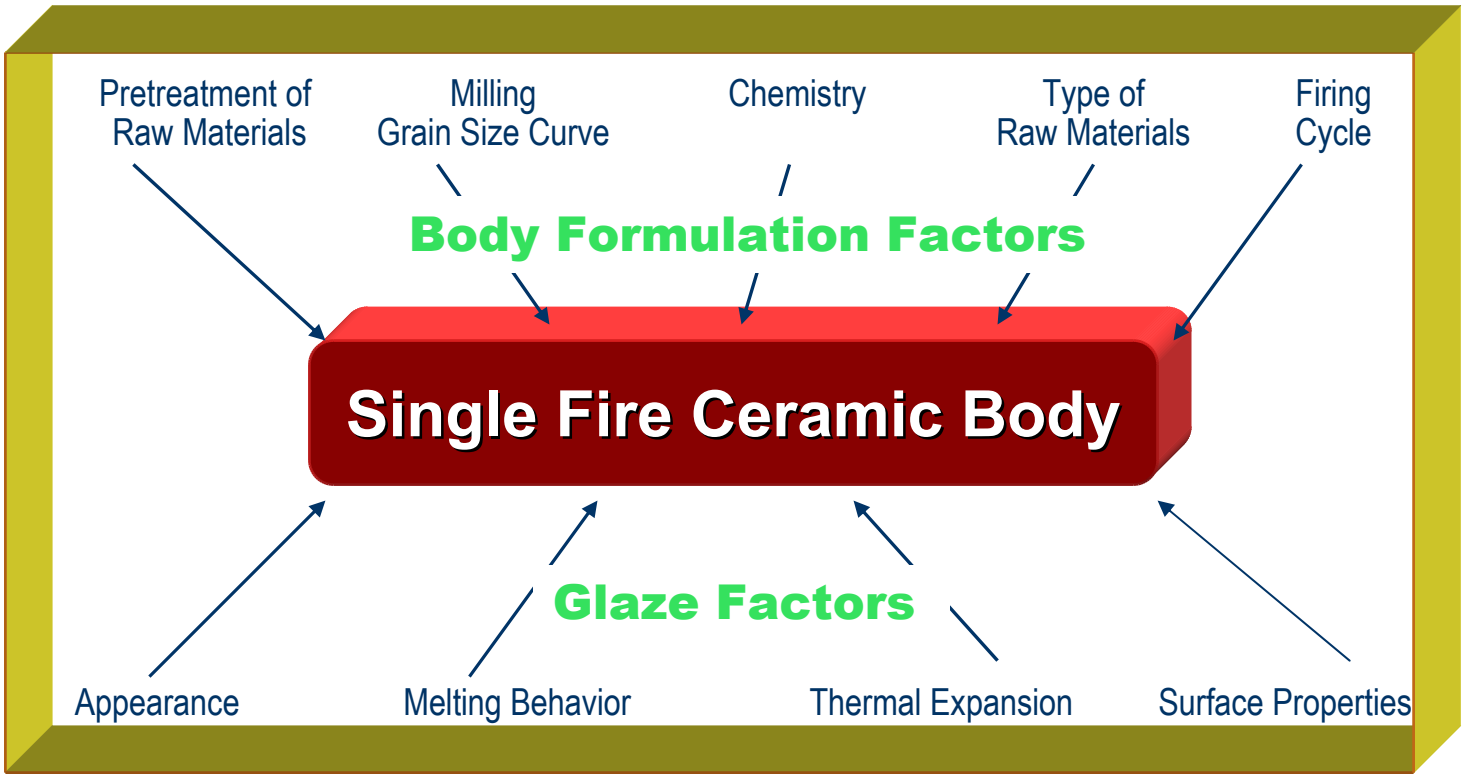
- Firing Temperature reduced 5 °F and kiln car push increased by 5 minutes.

(Cold Fire)

END RESULT:

High Level of Pinholes

Interaction Factors of Single Fire



Conditions for Fast Single Firing Vitreous Ceramic Whiteware Products

MINERALS SERVICE VALUE