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Theoretical Approach for Predicting Plasticized Firmness of Cellulose Acetate Filter Rods

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Objectives

- Review background of filter rod firmness
- Discuss key variables and response trends
- Review theoretical basis for trends
- Present novel equation form for modeling firmness

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Background

Firmness and Plasticizer

- Consumers expect “firm” filters
- Achieving minimum firmness levels in acetate filters usually requires use of a plasticizer
- Triacetin most common plasticizer for cellulose acetate
- Application levels vary, generally 6 - 8%
- Applied with spinning brush or spray nozzles onto a bloomed tow band

Plasticized cellulose acetate fiber

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Background
Firmness Testing

- Numerous test methods for firmness
- Exact methods vary but basic procedure is constant
  - Apply set force to filter
  - Measure deflection in filter from starting point
  - Divide deflection by initial diameter
- Destructive test

Background

Historic Approach

- Previous work developed linear regressions to predict firmness
- Key Variables Identified
  - Denier per filament (dpf)
  - Total denier
  - Plasticizer application level (%PZ)
  - Effective crimp index (ECI) i.e. point-in-range
  - Filter circumference
  - Time
- Model deteriorated at circumferences < 22.0 mm
- New approach sought to model firmness across wider range with increased accuracy

Focus of this work

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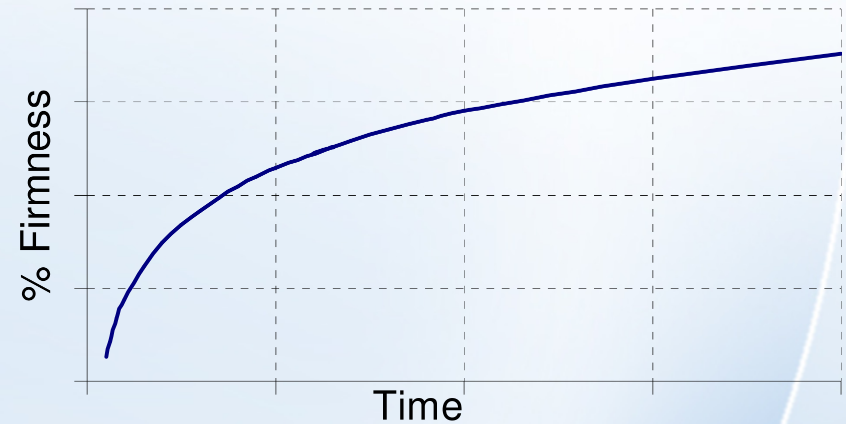
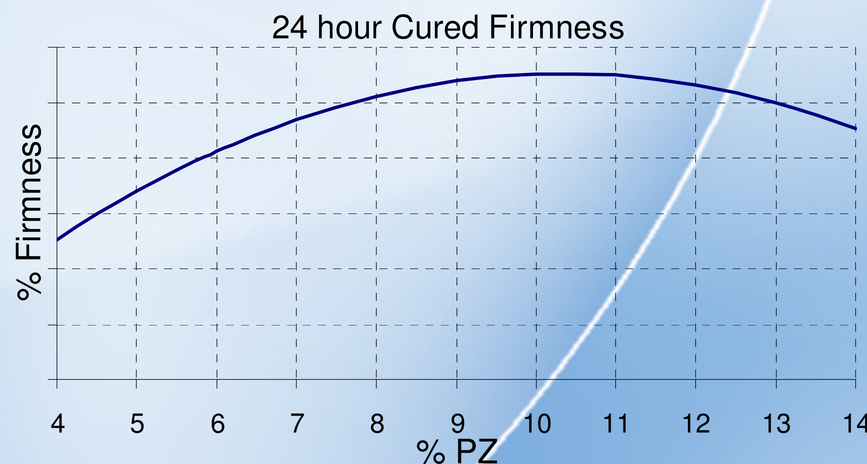
Background

Plasticizer Application and Curing

- Plasticizer application creates logarithmic firmness increase
  - Firmness = A + B·ln(time)
  - A and B primarily depend on initial firmness
  - After 24 hours firmness assumed cured
- Excessive plasticizer application adversely affects cured firmness
  - Varies by item
  - Too much plasticizer reduces firmness
    - Melting rather than bonding fibers





Experimental Setup

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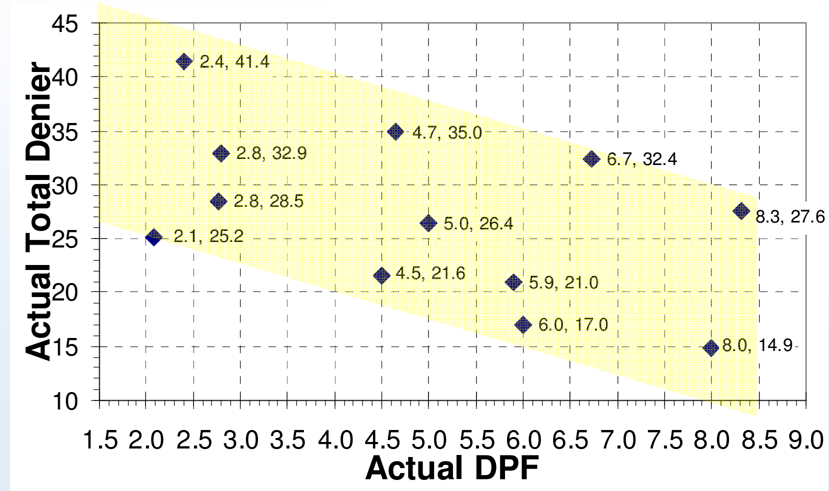

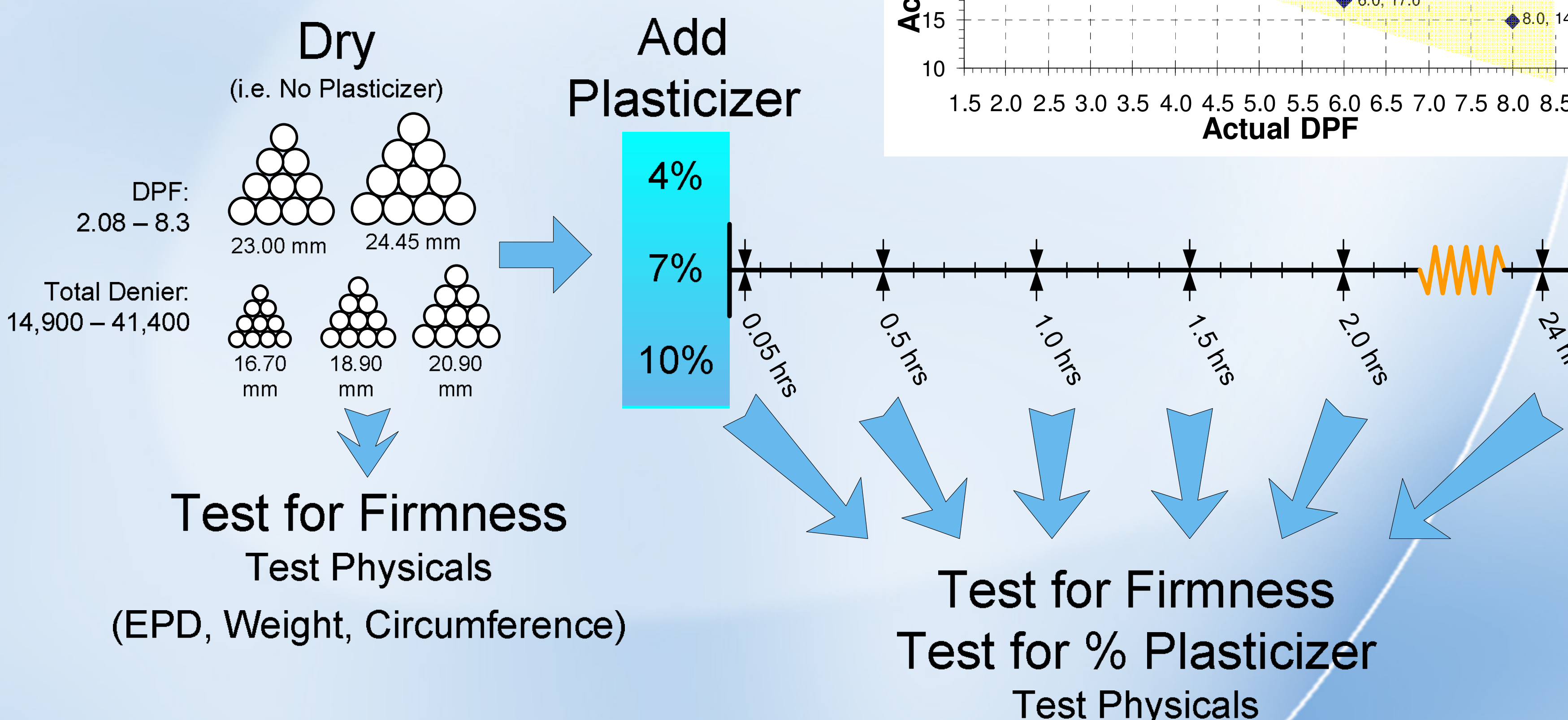

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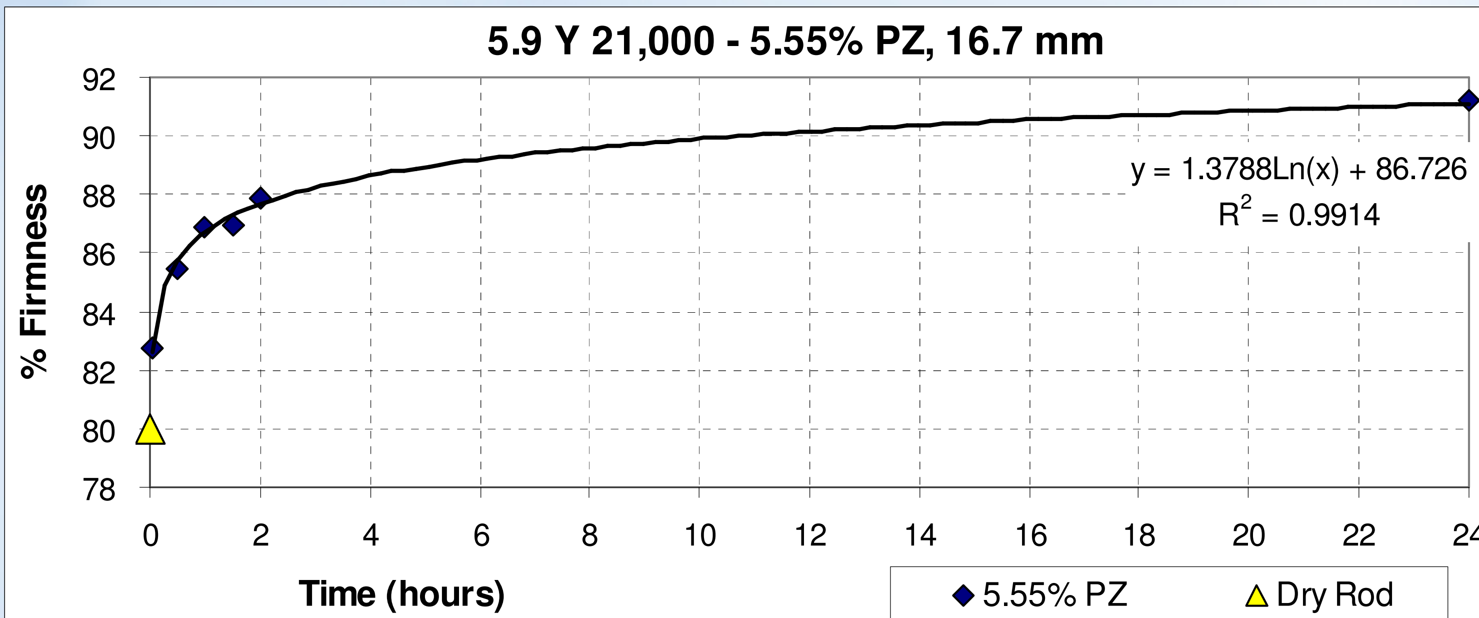
Model Development

Firmness vs. Time

- Firmness curing closely follows logarithmic form until 24 hours when filter rod considered “cured”
- $F_t = F_0 + A_1 + B_1 \cdot \ln(\text{time})$

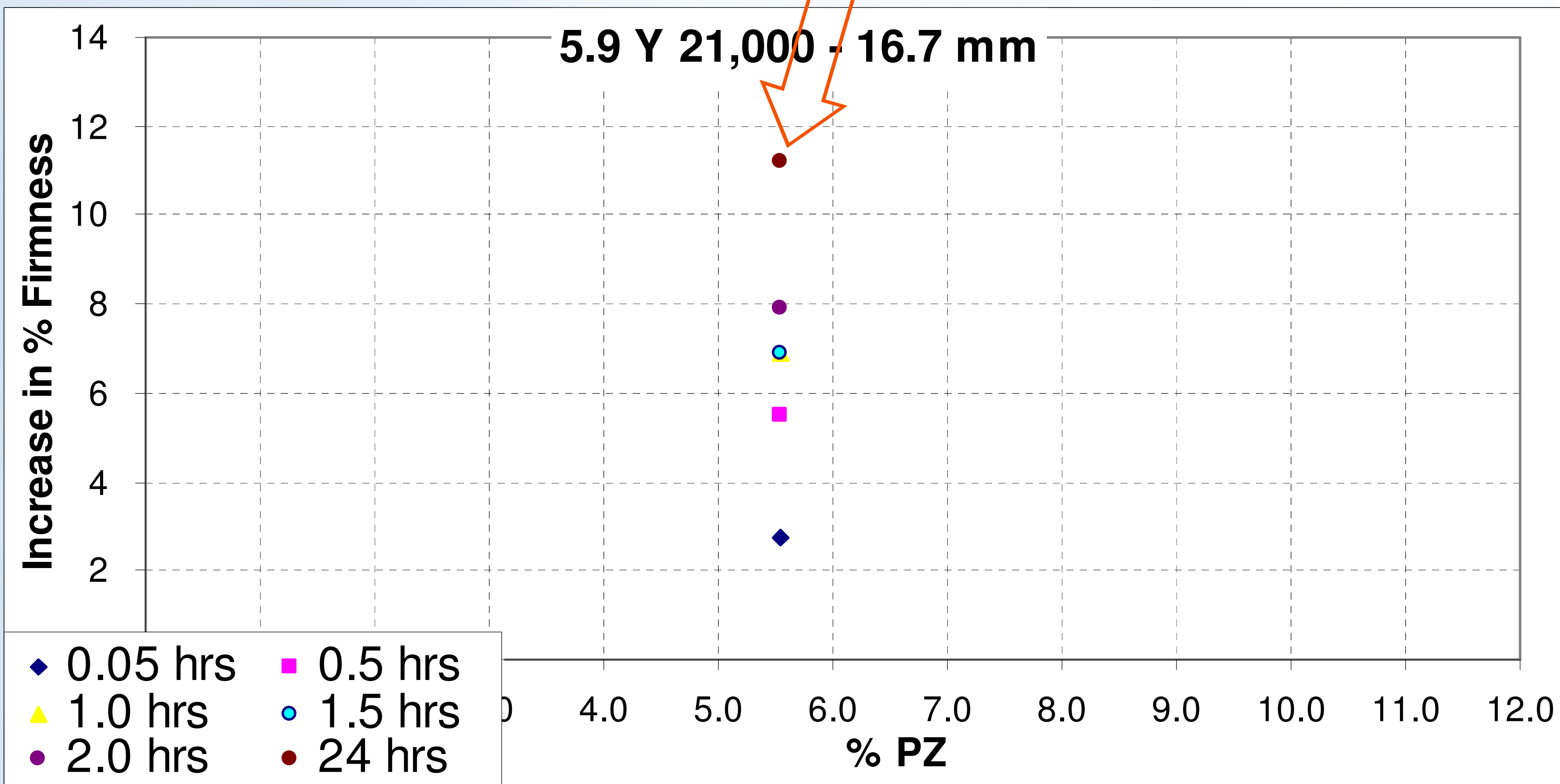


Challenge—How to predict A and B for all conditions?

Model Development

Firmness vs. PZ

Transform Data to Firmness
Increase relative to dry firmness

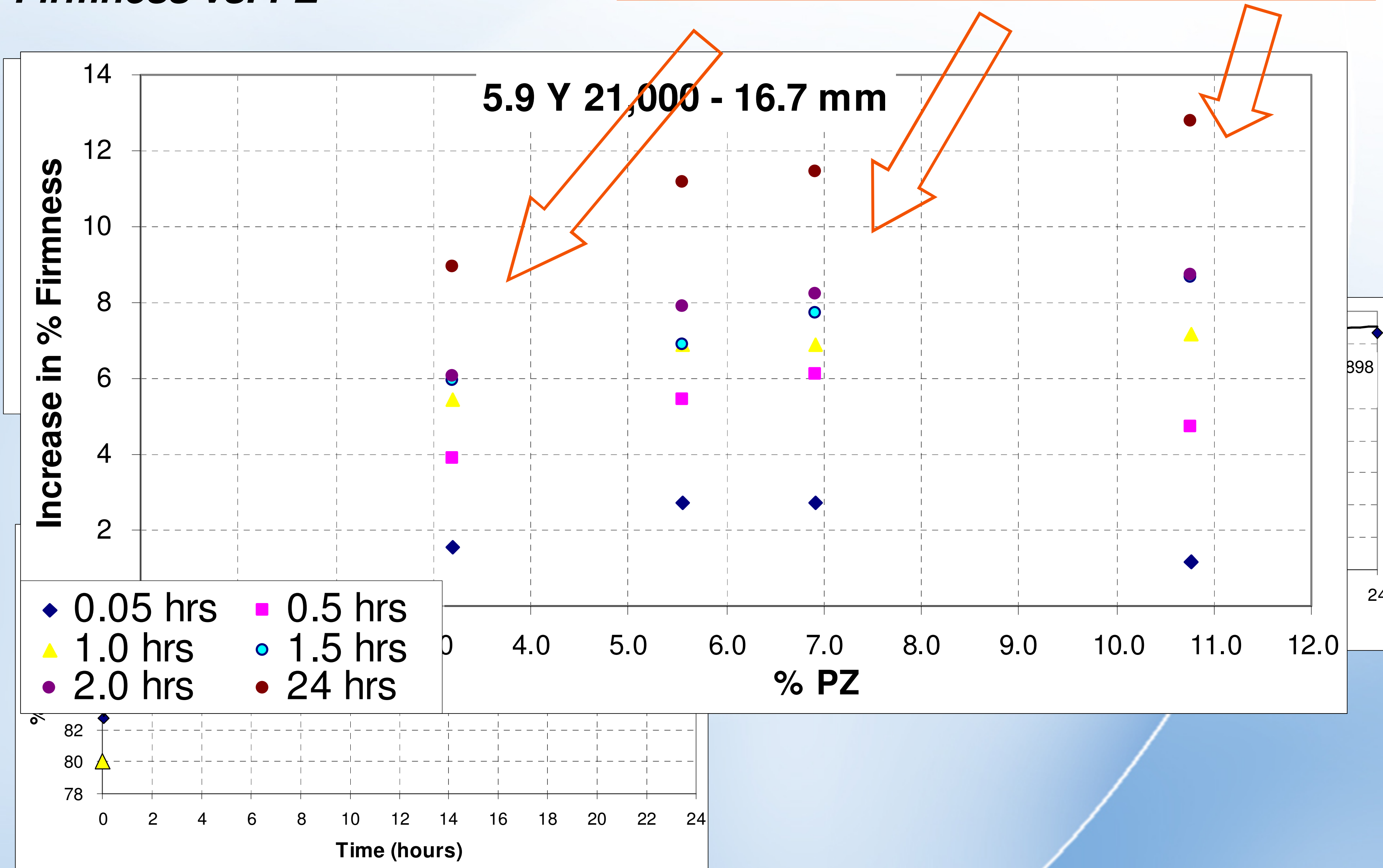


Plot each time as separate series

Model Development

Firmness vs. PZ

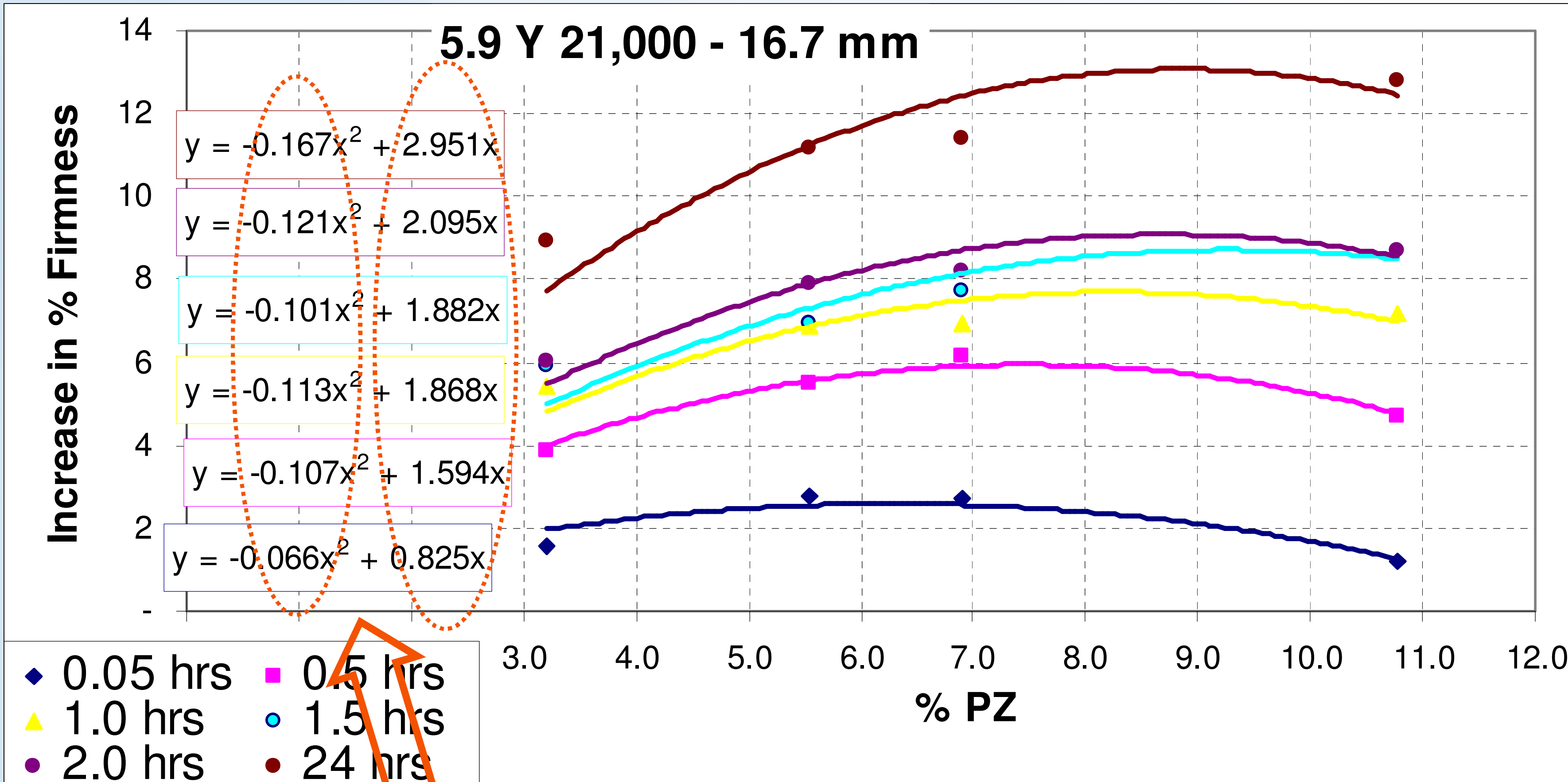
Repeat transformation at other plasticizer levels



Model Development

Firmness vs. PZ

Determine best fit parabolic equation…
Constraint: 0% PZ = 0% Δ Firmness

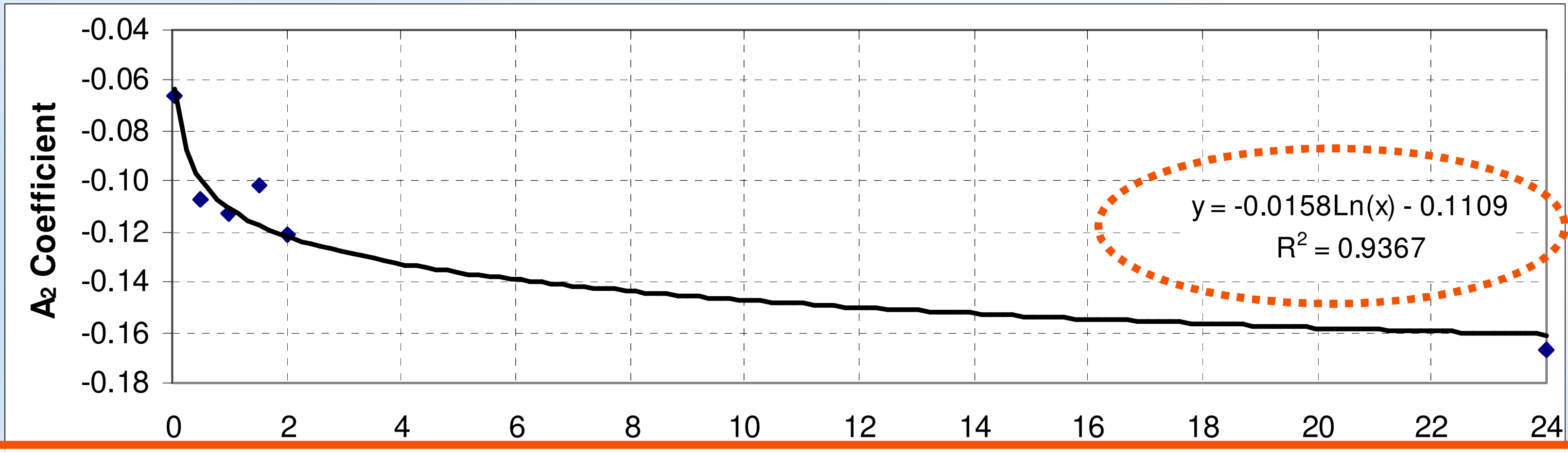


…Can then plot the equation coefficients

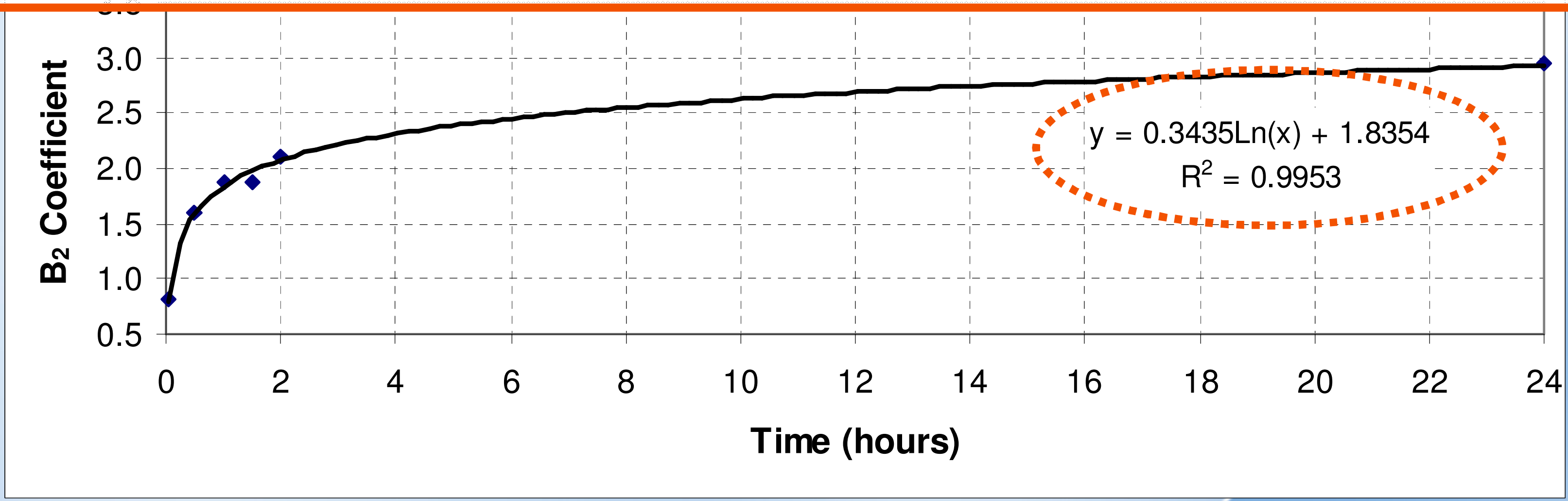
Model Development

Firmness vs. PZ

$$\Delta \text{ Firmness} = A_2 \cdot (\%PZ)^2 + B_2 \cdot (\%PZ)$$



Same logarithmic behavior observed as in Firmness vs. Time relationship
Proves connection between time and plasticizer relationships



Model Development

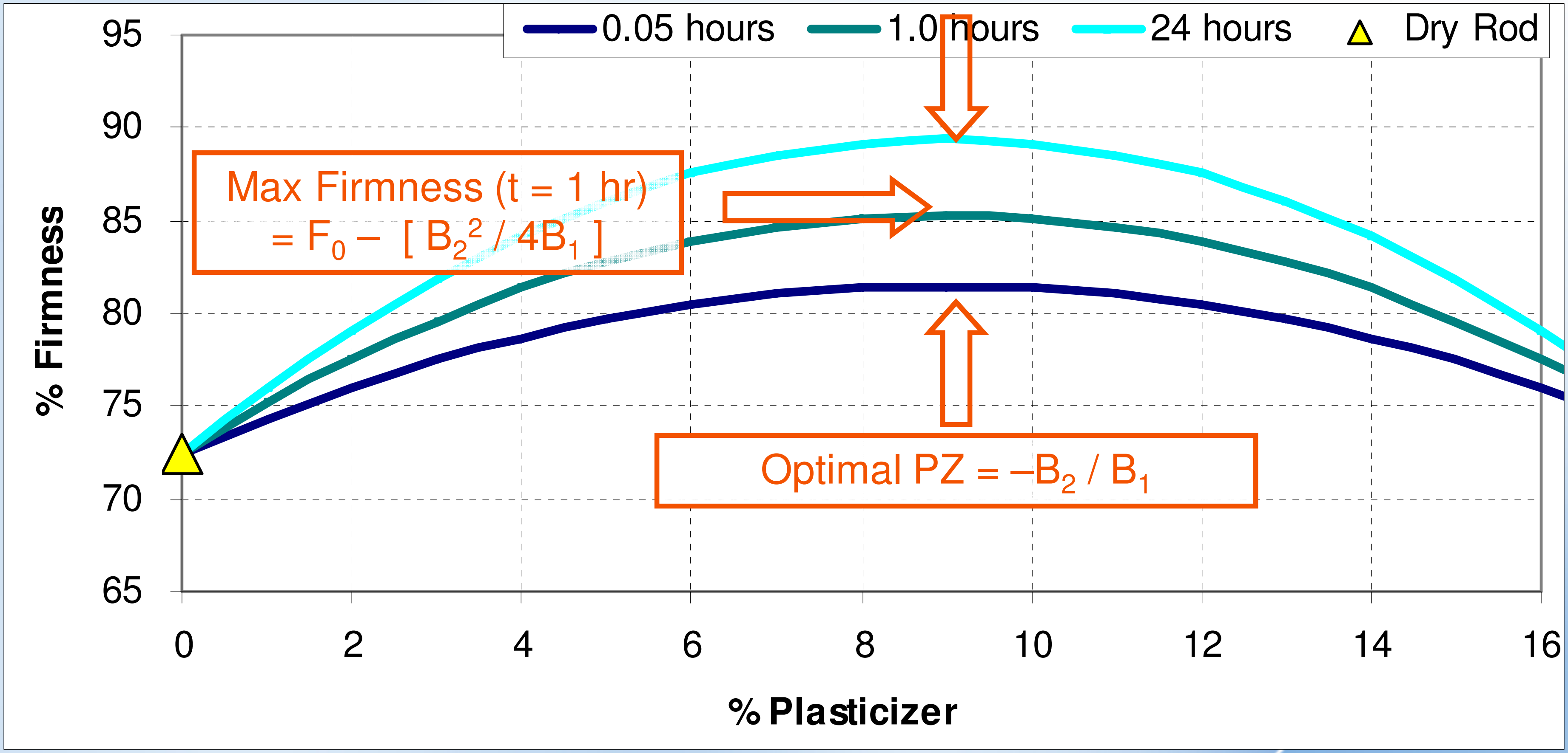
- Combining forms gives new equation for modeling firmness

$$F_t = F_0 + [A_1 \ln(\text{time}) + B_1] \cdot \%PZ^2 + [A_2 \ln(\text{time}) + B_2] \cdot \%PZ$$

- Advantages
  - At constant PZ will always follow logarithmic curing pattern
  - Reflects reduction in firmness seen at very high plasticizer levels
  - Separates dry firmness into separate equation that can developed or improved independently

Theoretical Model

$$F_t = F_0 + [A_1\ln(\text{time}) + B_1] \cdot \%PZ^2 + [A_2\ln(\text{time}) + B_2] \cdot \%PZ$$



Theoretical Modeling

- Can calculate firmness at any time from 0 to 24 hours
- Can calculate firmness with any plasticizer level from 0% to past optimal (10-12%)
- Inputs Needed to calculate Firmness
  - Plasticizer
  - Time
  - Dry Firmness (F_0)
  - Denier per filament
  - Total Denier
  - Circumference
- Factors such as weight or point-in range contribute indirectly by heavily impacting dry firmness

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Summary

- New approach to modeling firmness offers:
  - Greater consistency with known theory
    - Declining effectiveness of plasticizer at higher application levels
    - Logarithmic firmness curing
  - Improved accuracy over historic models
  - Mathematical derivations for optimal %PZ and firmness
- New model present in TowPlus® 3.1
  - Simulate effect of more or less plasticizer on product specifications
  - Estimate optimal plasticizer level
  - Predict firmness of dry filter rods
  - Model super-slim filter firmness

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