Prediction of RVA Starch Gelatinization Curves as a Function of Amylose Content Using Parameter Estimation Techniques

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Abstract

The effect of starch composition on gelatinization curves has not been included in predictive modeling. The objective of this paper was to estimate gelatinization parameters for a viscosity model as a function of amylose content and time- temperature history and strain history. Data of starch viscosity at different percentages of amylose collected by Juhasz and Salgo (2008) were used as example data. The dependent variable was viscosity (RVA unit), while the independent variables were temperature (the standard AACCI RVA starch temperature profile), impeller speed (160rpm), concentration of amylose at 0%, 27%, 34.2%, 41.3%, 45.6%, 50%, 55.7%, 60% and 70%, time-temperature history [K.s], and strain history. The parameters to be estimated were maximum relative increase in viscosity (A), relative amount of viscosity reduction due to irreversible mechanical degradation (B), first-order rate constant for shear history (d), exponent describing molecular weight effect on viscosity (alpha), gelatinization rate constant at reference temperature (k), and gelatinization activation energy (E_g). The parameters were estimated using nlinfit in Matlab. Confidence interval, prediction interval, and sensitivity coefficient were plotted to show the expected error. In conclusion, the starch viscosity model can help reduce number of experiments, and save time and cost for food manufacturers who use starch as the main ingredient in product development research.

Introduction

In the food industry, the knowledge of rheological behavior of starch gelatinization is very important in pipe line design when pumping starch base material and in food formulation. Many researchers have studied rheological properties of starch gelatinization for temperatures below 95^{o}C using fundamental rheological instruments and few have developed a viscosity model from it (Lagarrique and Alvarez, 2001).

In the cereal world, many researchers commonly determine the viscosity of starch gelatinization using empirical rheological instrument called Rapid Visco Analyzer (RVA). But there are no studies found on modeling starch gelatinization behavior from data collected from RVA.

Parameter estimation provides a powerful tool that one can use to obtain the optimal estimate of parameters (constants) in model studied by efficient use of the measured values of input and output data (Beck and Arnold, 1976). If a model equation for any phenomena is already developed, parameter estimation principles can be used (Dolan, 2003).

Objective

- To estimate gelatinization parameters for a viscosity model as a function of amylose content and time-temperature history and strain history using parameter estimation (P.E.) techniques.

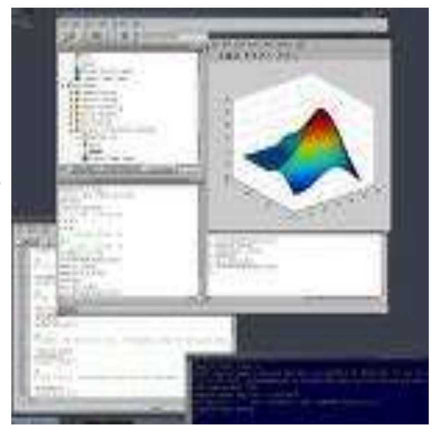
Materials and Methods

1. **Collect the measured data.** In this work data collected from published data (Juhasz & Salgo, 2008),using software DataThief III , a program to extract (reverse engineer) ***data*** points from a graph.

2. **Create the starch gelatinization model**. Dolan & Steffe (1990) starch gelatinization model was used in this study by emphasis on time-temperature history and strain history effects.

3. **Use P.E. techniques** to estimate the parameters in the model:

   - *Scaled* ***Sensitivity Coefficient Plot***: Take the derivates of the dependent variable with respect to the each constants in the model and multiply with the constant itself.



-***Non linear regression analysis*** by

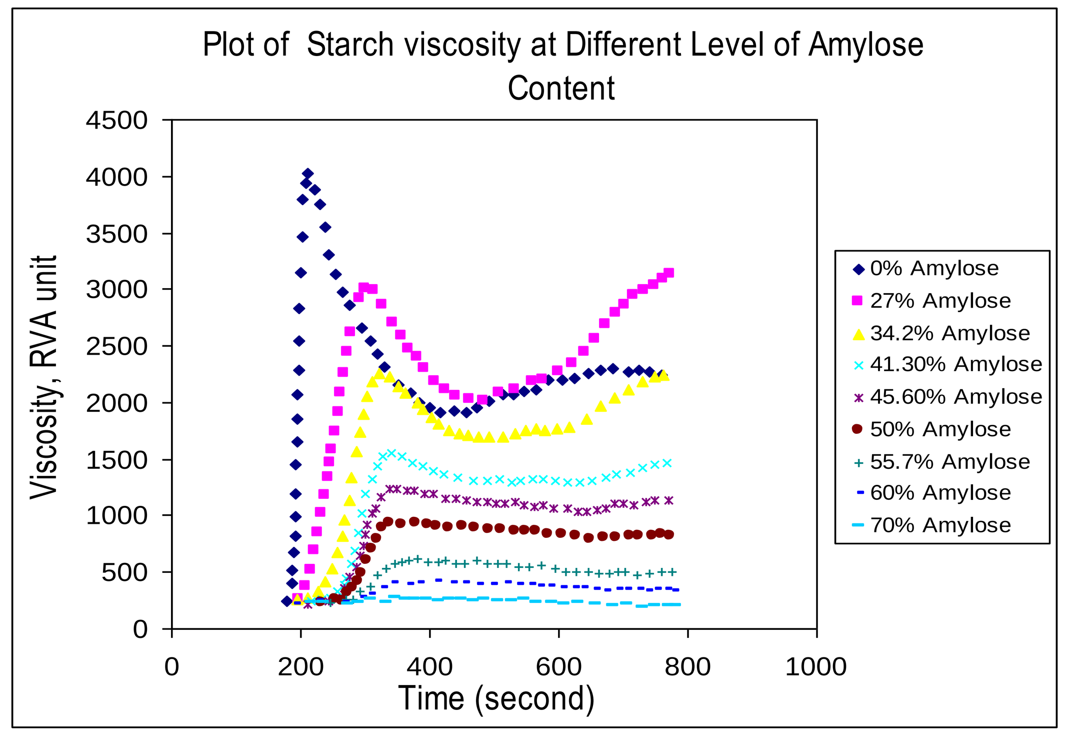
A matlab program using 'Nlin fit' was used

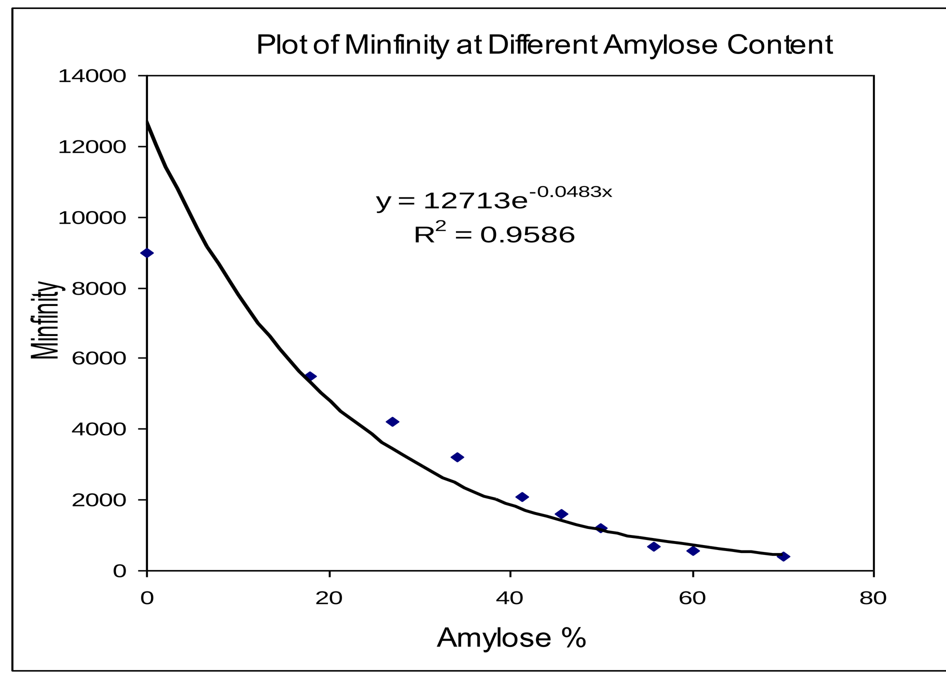
-***Confidence Interval***

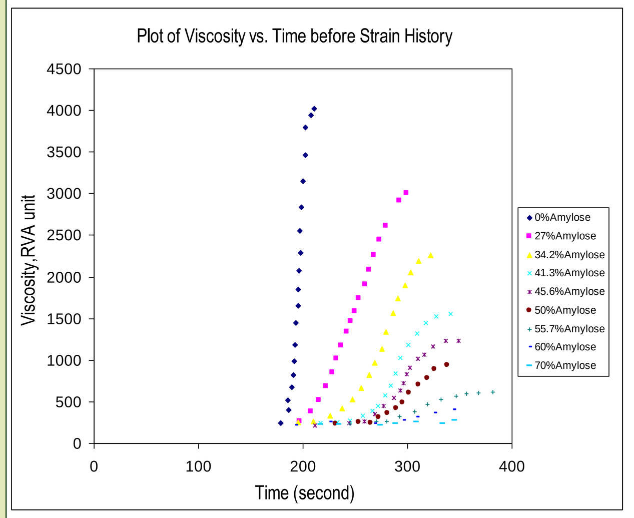
-***Prediction Interval***

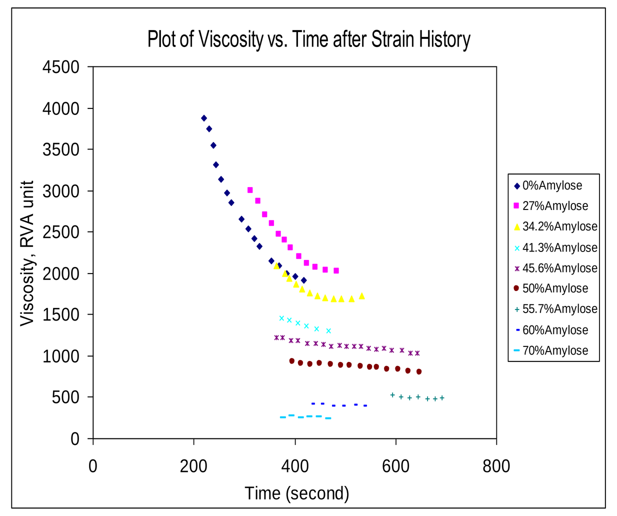
Results and Discussion

1. Plots of RVA data:









2. Model Equation and Parameter Estimation Techniques

A) Define Parameters in the model :

$$M = M_o * \left[1 + A^{\alpha}\left(1 - e^{-k\psi}\right)^{\alpha}\right] * \left[1 - B\left(1 - e^{-d\Phi}\right)\right]$$

Where:

$$\psi = \int_0^{t_f} T(t)\, e^{\frac{-E_g}{R}\left(\frac{1}{T(t)} - \frac{1}{T'_r}\right)} dt$$

$$\Phi = \int N\, dt$$

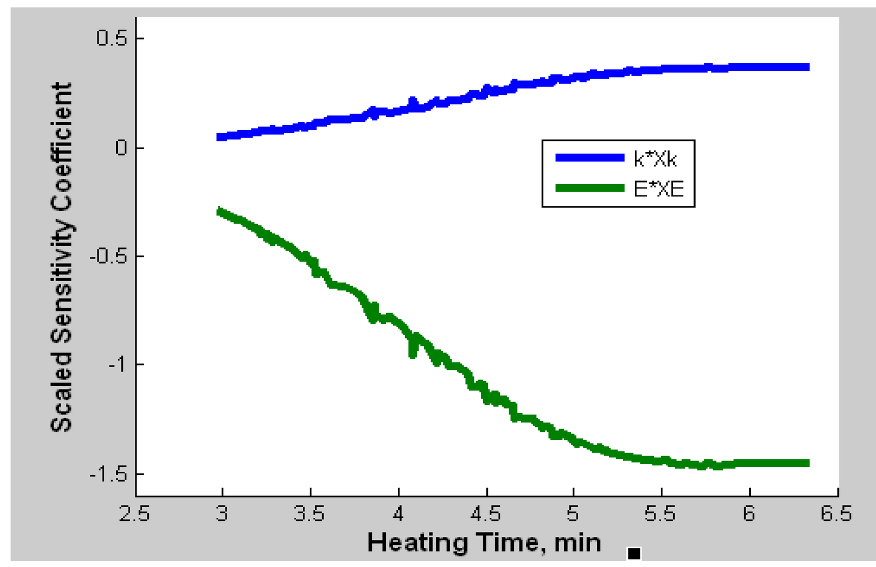
$$A = \frac{M_\infty - M_o}{M_o}$$

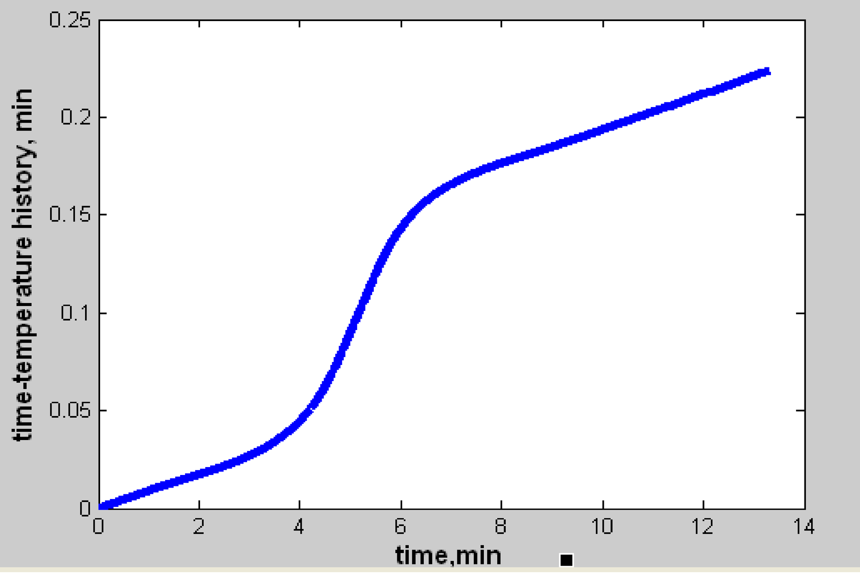
Nomenclature:
A=maximum relative increase in viscosity as function of amylose, dimensionless
B=relative amount of viscosity reduction due to mechanical dimensionless as function of Amylose, dimensionless
d=first-order rate constant for shear history,dimensionless
E_g =activation energy, J/gmol
k=rate constant at Tr, [concentration] $^{1-n}$[time]$^{-1}$
M=torque, Nm
Mo=initial torque, Nm
$M_{infinity}$=constant torque value after gelatinization, Nm
n=flow behavior index, dimensionless
N=impeller speed
R=universal gas constant, 8.314 J/mol K
T=Temperature, K
Tr=reference temperature, K
t=time, s
Ψ=time-temperature history, s
ϕ=strain history, dimensionless

B) Scaled Sensitivity Coefficient Plot for Time-Temperature History Effect and Time-Temperature History vs. Time

$$kX_k = k\frac{\partial M}{\partial k}$$

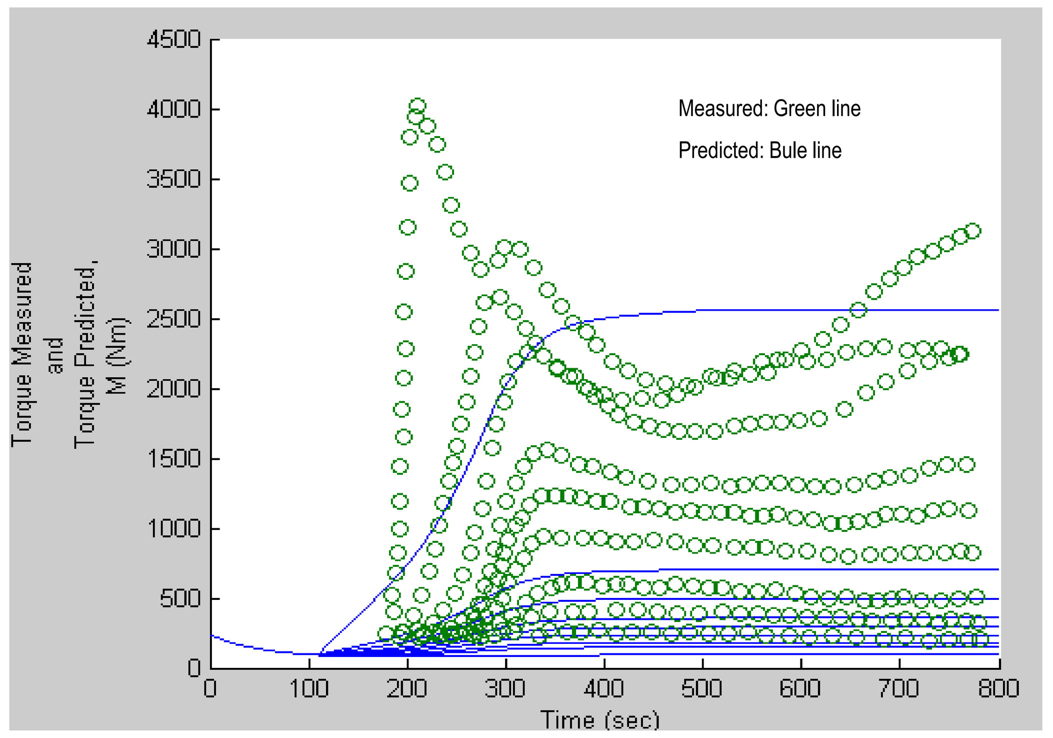
$$E_g X_{E_g} = E_g \frac{\partial M}{\partial E_g}$$



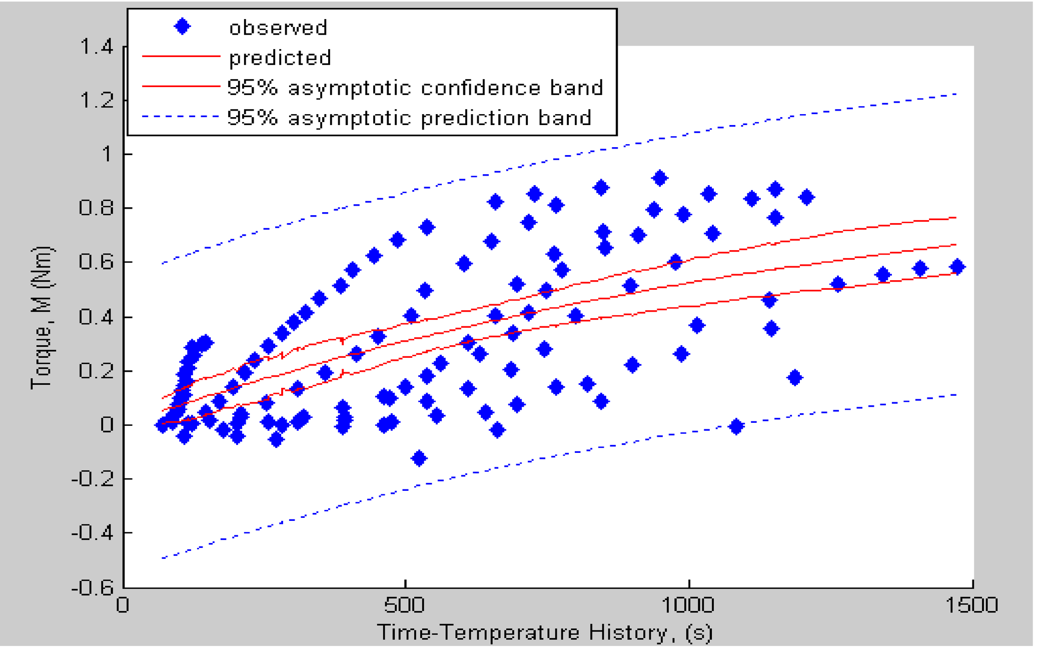


Results and Discussion

C) Measured and Predicted Torque,M at different amylose content



D) Confidence and Prediction Interval



Conclusions

•Using the Excel and Matlab program of Nlinfit, the following values were estimated: **A=53.7exp(-0.048 * %Amylose) -1, B = -0.0072 (% amylose) + 0.51, d = 0.007 rev^{-1}, alpha = 1.57, k = 0.188(Ks)$^{-1}$, E_g increase linearly from 138 KJ/gmol at 60ºC to 206 KJ/gmol at 95ºC, and RMSE = 0.218 RVA units.**

•The sensitivity coefficient plots shows that to obtain a better estimate of the parameter (k and E_g) in the model,the best time to take the measurement should be between 3 to 6 min. The scaled sensitivity coefficient are large and uncorrelated during this time, which improves the estimation.

•The measured and predicted torque plot shows that the values are underpredicted especially at lower amylose content. This indicate that the model used in this study need further modification.

•The confidence and prediction band shows that work need to be done in order to have a better estimate of the parameters in the starch gelatinization model as a function of amylose content.

Literature Cited

1. Beck J. and Arnold, K. 1977. *Parameter Estimation in Engineering and Sciences*. John Wiley & Sons, Inc.
2. Dolan K.D. 2003. *Estimation of Kinetic Parameters for Nonisothermal Food. Concise Reviews and Hypotheses in Food Science*. J. Food Sci. Vol. 68,Nr 3, 728-741
3. Dolan K.D. and Steffe J.F. 1990. *Modeling Rheological Behavior of Gelatinizing Starch Solutions using Mixer Viscometry Data*. J. Text. Stud., Vol 21, 265-294.
4. Juhasz Reka and Salgo Andras. 2008. *Pasting Behavior of Amylose, Amylopectin and Their Mixtures as Determined by RVA Curves and First Derivatives*. J. Starke, vol 60,pg 70-78.
5. Lagarrigue S. and Alvarez G. 2001. *The Rheology of Starch Dispersions at High Temperatures and High Shear Rates: A Review*. J. Food Engineering 50, 189-202.