Temperature Dependence and Nutrient Use Efficiency of Chemostat Reaction

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Outline

- Background information on Tai et al. (2007) paper
- Chemostat conditions established in Tai et al. (2007)
- Our modeling objectives
- Methods for accomplishing our objectives
- Description of parameters used in differential equations within model
- Solving for activation energy and frequency factor constant
- Evaluating and modeling efficiency as a function of residual glucose
- Discuss implications of findings
- Reflect on experimental process and results

Tai et al. (2007) Background Information

- Evaluated gene transcriptional response to low temperature in *Saccharomyces cerevisiae* using chemostate method
- Stated that chemostat was more effective for this study
    - Transcriptional responses to low temperature and low specific growth rate can be separated by using chemostat cultures instead of batch cultures

Tai et al. (2007) Main Findings and Conclusions

- The only indistinguishable group of genes that was similarly regulated in low-temperature chemostats and batch culture studies on low-temperature adaptation were related to lipid metabolism
- Trehalose is not involved in steady-state low-temperature adaptation
- Transcript levels of environmental stress response genes were reduced at 12 C
- It is important to differentiate phases of physiological adaptation in response to environmental change
- Response to low temperatures by S. cerevisiae is not entirely dependent on changes in transcription

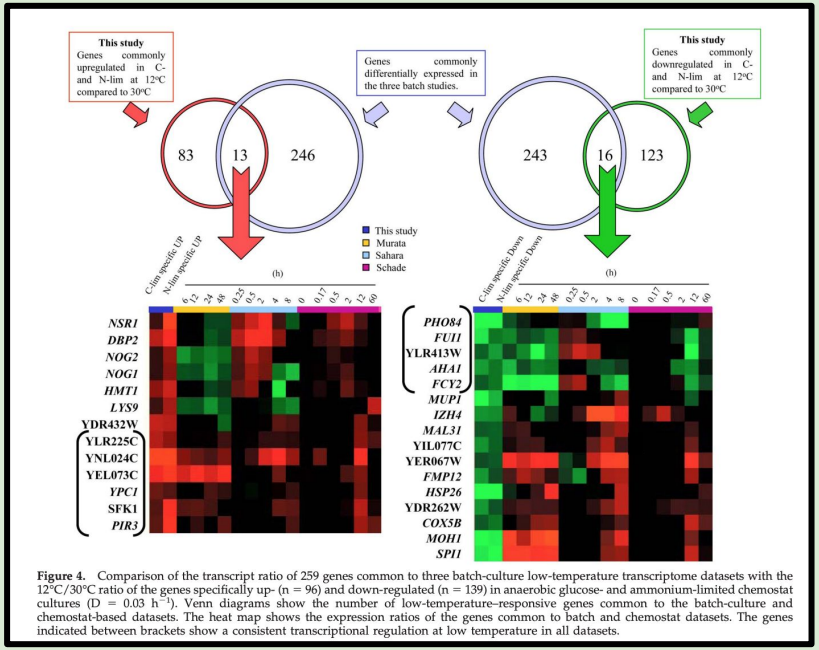

Figure 4. Comparison of the transcript ratio of 259 genes common to three batch-culture low-temperature transcriptome datasets with the 12°C/30°C ratio of the genes specifically up- (n = 96) and down-regulated (n = 139) in anaerobic glucose- and ammonium-limited chemostat cultures (D = 0.03 h^{-1}). Venn diagrams show the number of low-temperature–responsive genes common to the batch-culture and chemostat-based datasets. The heat map shows the expression ratios of the genes common to batch and chemostat datasets. The genes indicated between brackets show a consistent transcriptional regulation at low temperature in all datasets.

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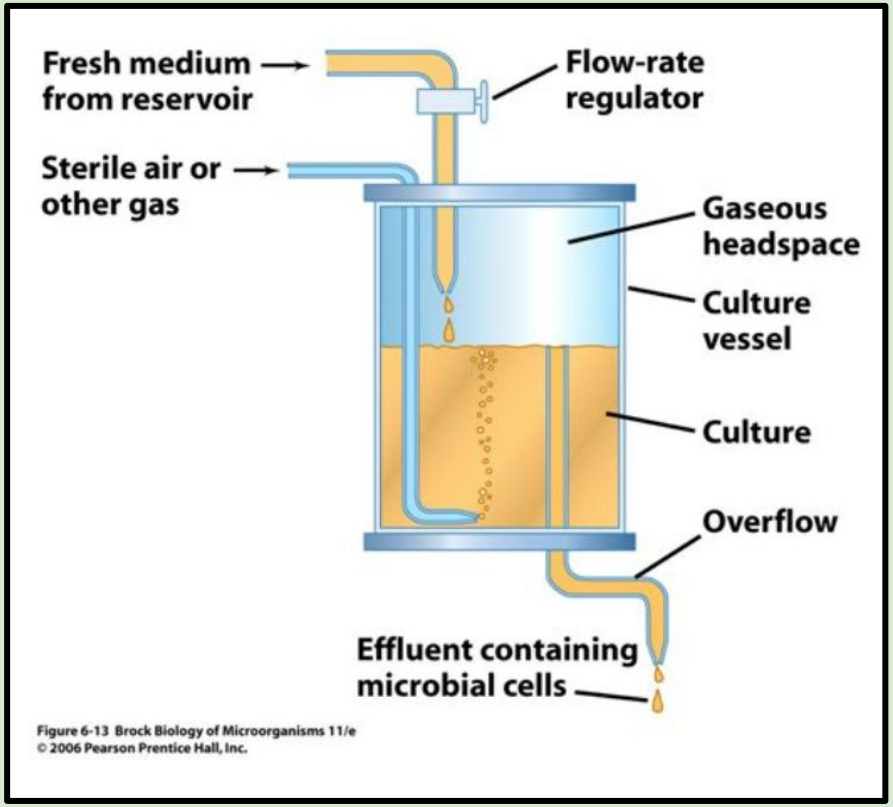
Tai et al. (2007) Chemostat Conditions



- Anaerobic conditions
- 1 L culture solution
- Allowed system to reach steady state before collecting date

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Modeling Objectives

1. Identify the activation energy ‘b’ and frequency factor constant ‘a’ using the arrhenius equation:

$$r = ae^{-\frac{b}{RT}}$$

2. Determine if efficiency of nutrient to biomass conversion is dependent on residual glucose. If so, construct a function of efficiency in terms of residual glucose

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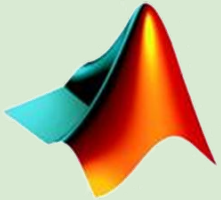
Methods

Obtained parameters from Tai et al. (2007)

Established model for two nutrient chemostat and input parameters from Tai et al. (2007)



MATLAB

```
ry    = r*(y/(K+y))*(z/(L+z))
dxdt  = (ry)*x - q*x
dydt  = q*(u - y) - ep*ry*x
dzdt  = q*(v - z) - fp*ry*x
```

Solved for activation energy and frequency factor constant to find specific growth rate using arrhenius equation at 15, 20, and 25 C

Developed function for efficiency of glucose conversion to biomass as a function of residual glucose, to determine if there was any change from the original model

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Parameter Descriptions

r → specific growth rate

E → efficiency of conversion from glucose to biomass

F → efficiency of conversion from ammonia to biomass

q → dilution rate

u → glucose feed concentration

v → ammonium feed concentration

K,L → substrate concentration when the reaction velocity is equal to 1/2 of the max velocity for the reaction

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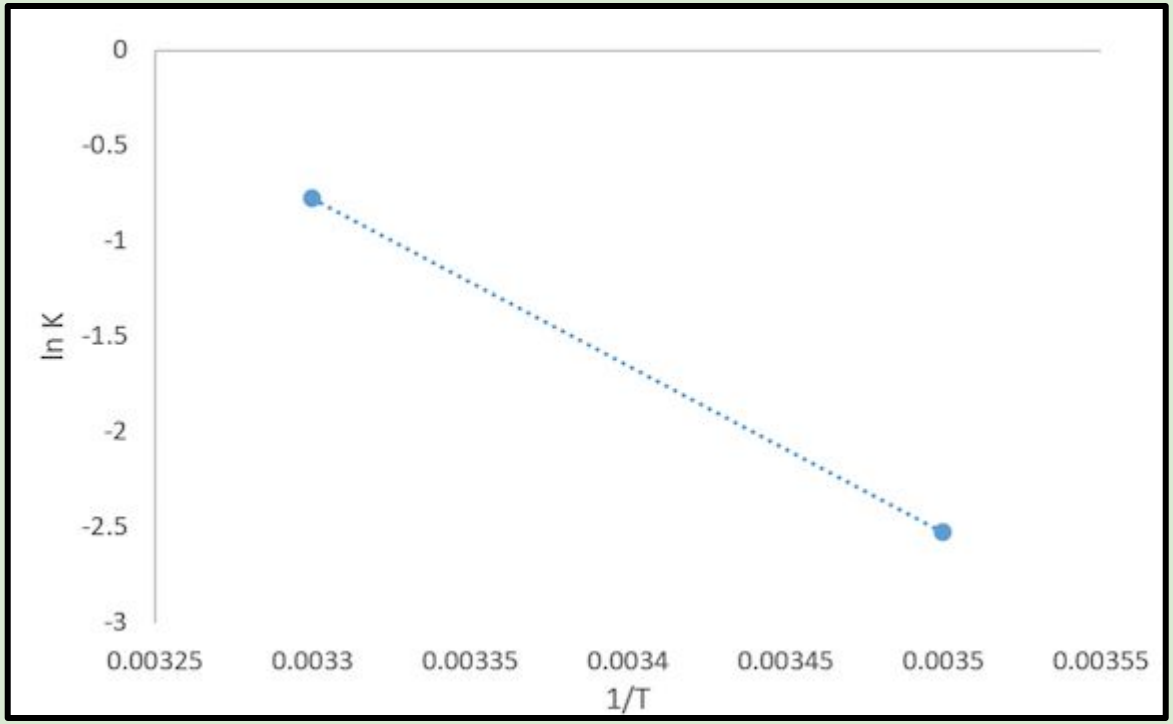
Solving for Ea (‘B’) and Frequency Factor Constant (‘A’)



Slope of ln k vs 1/T = -8400.36

Slope = -Ea/R = B/R

B = 69,840.59

rate = $ae^{-\frac{b}{RT}}$

A = 4.979 x 10^11

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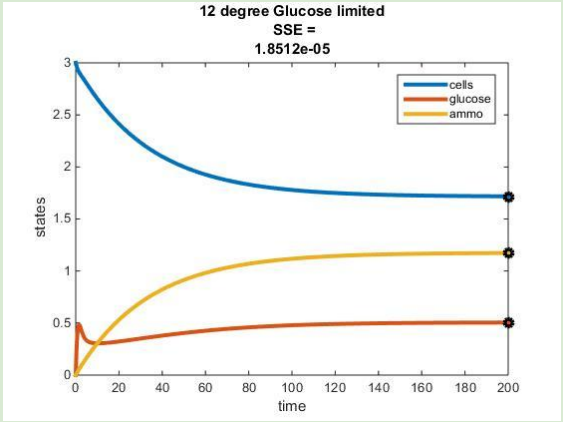
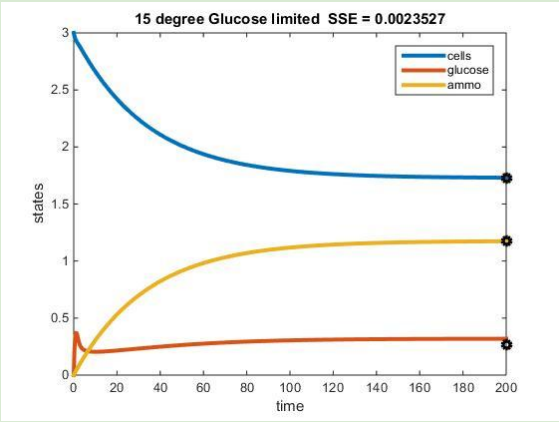
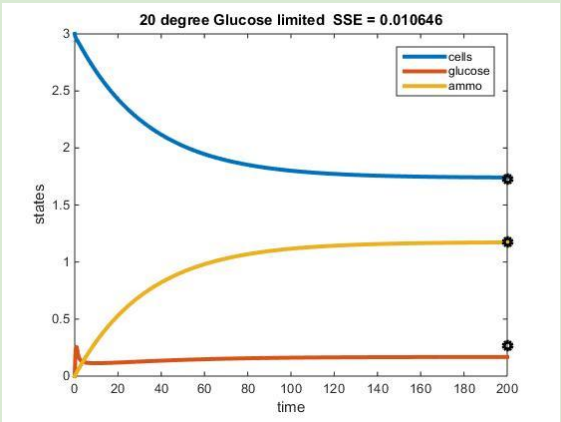
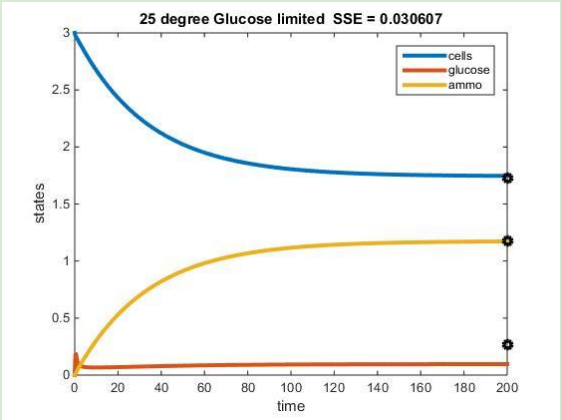
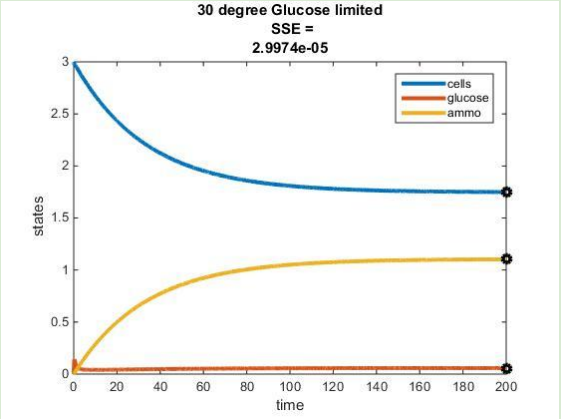
Applying Growth Rates for Glucose Limited at Varying Temperature



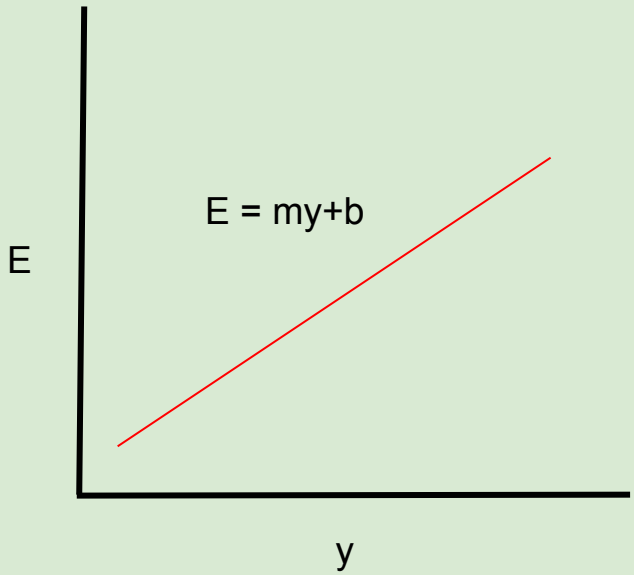








Efficiency as a Function of ‘y’ (Residual Glucose)



- Assumed relationship between efficiency and residual glucose was linear
- Used point slope formula to solve for slope
- Inputted back into y - intercept formula to solve for b

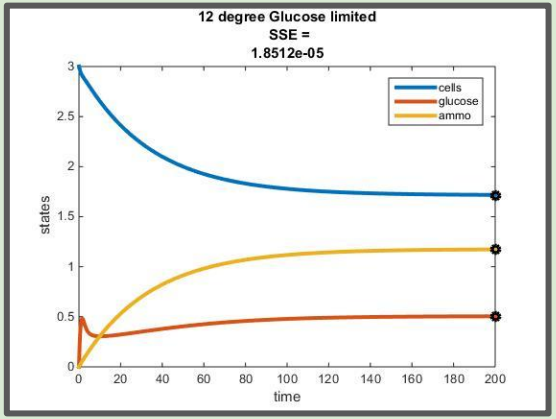
12 C

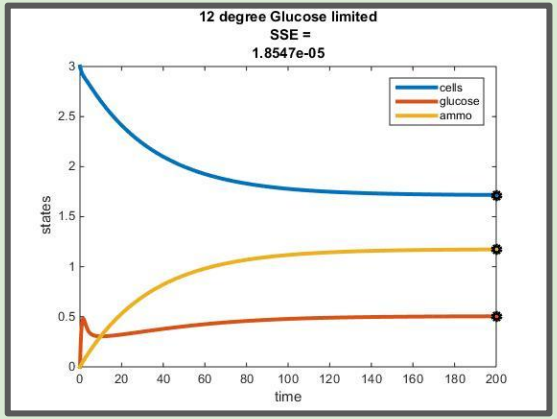
- E = 0.363y + 14.107

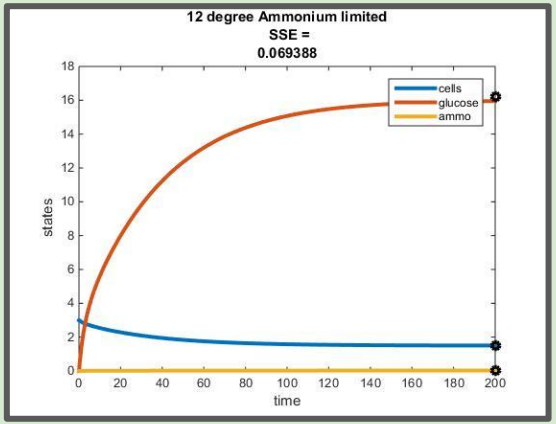
30 C

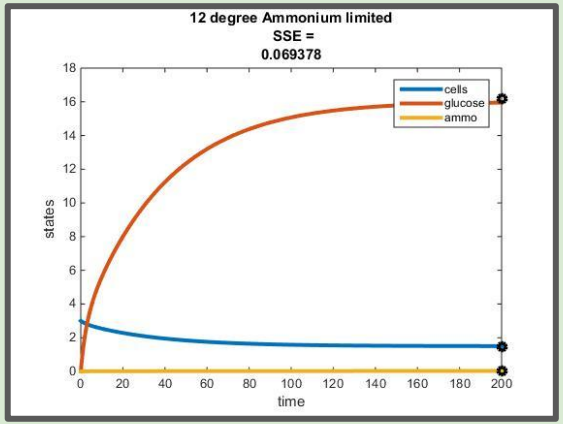
- E = 0.7004y + 14.252

Comparing Adjusted Efficiency to Original Model at 12 C







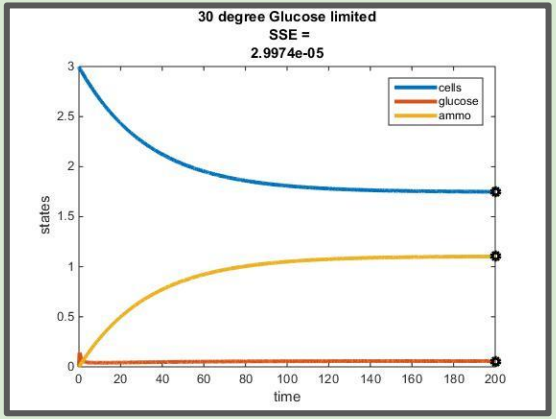


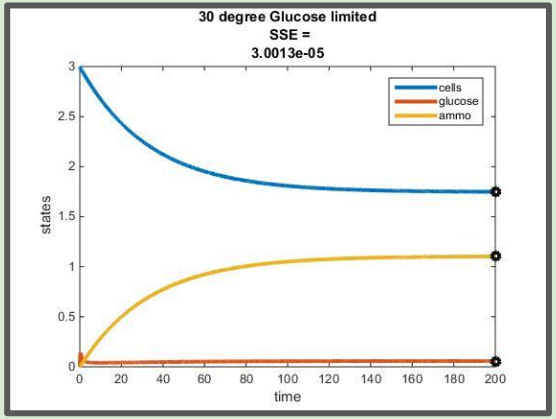
Original

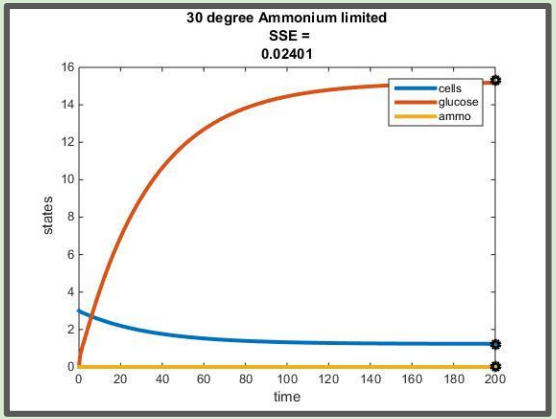
Adjusted

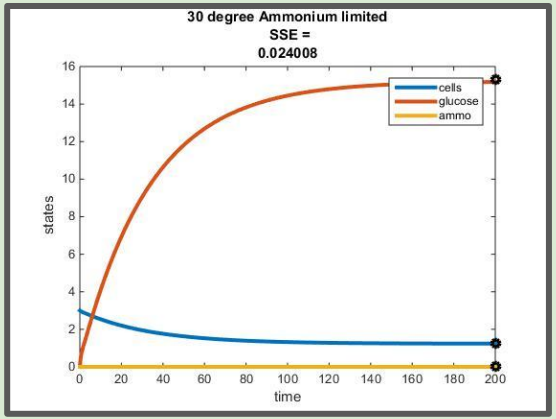
- No significant difference between original model with E denoted as 1/Y compared to E as a function residual glucose at 12 C

Comparing Adjusted Efficiency to Original Model at 30 C









Original

Adjusted

- No significant difference between original model with E denoted as 1/Y compared to E as a function residual glucose at 30 C

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Discussion

- Both original and adjusted model show steady state being reached after 100 hours, contradicting our initial calculation
- Defining efficiency of the conversion of glucose to biomass as a function of residual glucose did not improve the accuracy of the model
- The sharp increase in glucose concentration upon starting the chemostat followed by an abrupt decrease in the glucose limited culture may reflect fast rate of glucose consumption followed by slower consumption as glucose levels decrease
- When glucose is in excess, glucose consumption rate does not reduce the concentration of glucose, as in glucose limited conditions
    - Suggests glucose is a more valuable nutrient for yeast utilization

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Reflection

- Tai et al. (2007) did not provide sufficient information to model the chemostat conditions used to obtain their results
    - Did not specify maximum growth rate (r) which was required for our model
- Include equations for carbon dioxide and ethanol to determine if they have an effect on efficiency of conversion of nutrients to biomass\
- Investigate sharp increase in glucose concentration upon starting the chemostat followed by an abrupt decrease in the glucose limited culture at 30C

Acknowledgments

- Dr. Fitzpatrick
- Dr. Dahlquist
- Fellow Classmates
- LMU Biology and Math Departments

References

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