Modeling Inactivation Kinetics for *Enterococcus faecium* on the Surface of Peanuts during Convective Dry Roasting

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Salmonella thermal resistance

- Foodborne illness risk can be decreased through thermal processing steps (e.g., roasting, baking, toasting, extruding)
- *Salmonella* is notoriously hard to kill in low-moisture environments[1,2,3]
- Decreased water activity (or moisture) is generally correlated with a higher D-value and z-value[4]
- FSMA requires a validated hazard reduction[5]

From Smith et al. (2016):

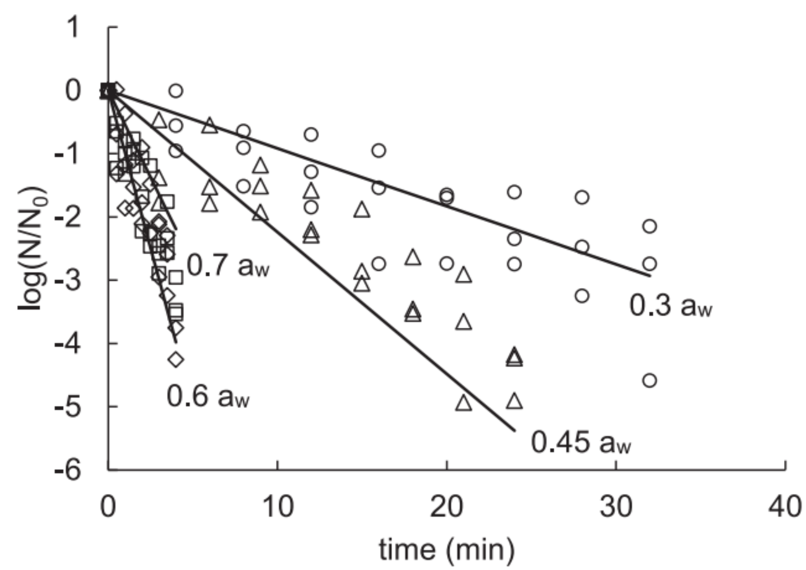


FIGURE 2. *Survivor curves for* Salmonella *inoculated into wheat flour at four nominal* a_w *levels and treated at 80°C. Lines are log-linear/modified-Bigelow model (equations 1 and 6) predictions.*

Model-based validations: a historical perspective

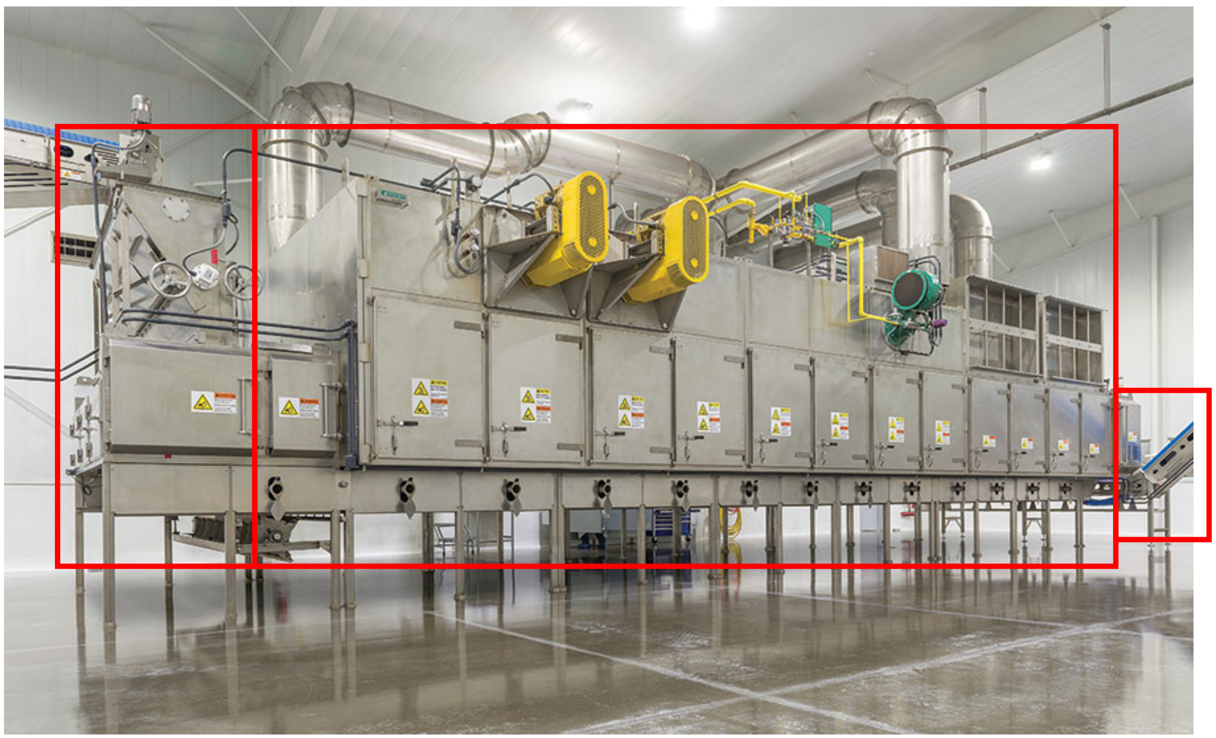
- Conduct a temperature distribution study to get an idea of thermal distribution in a retort (i.e., where is the coldest spot?)[6]
- Conduct a thermal penetration study to determine the rate at which the slowest heating can will heat up (i.e., what is the minimum time required to achieve specified 12D lethality?)[6]
- Heating food in a can or pouch inside a retort is predictable
- Death kinetics are consistent and characterized based on temperature
- With well-characterized product heating, we can use models to predict lethality and validate a retort

https://funfactz.com/food-and-drink-facts/canned-food-safe-to-eat/

Model-based validations: a historical perspective

- Once we know where the lowest lethality is achieved, the log reductions can be calculated using general method[7]
- Numerical integration of D- and z-value models as a function of process time and product temperature[7]
  - Graph lethal rate, $10^{\frac{T-T_{ref}}{z}}$ [=] log reduction/time
  - Calculate area under curve to get lethality [=] log reductions
- Kinetics for *C. botulinum* (target pathogen) are well-known

Digression for a quick roaster tutorial

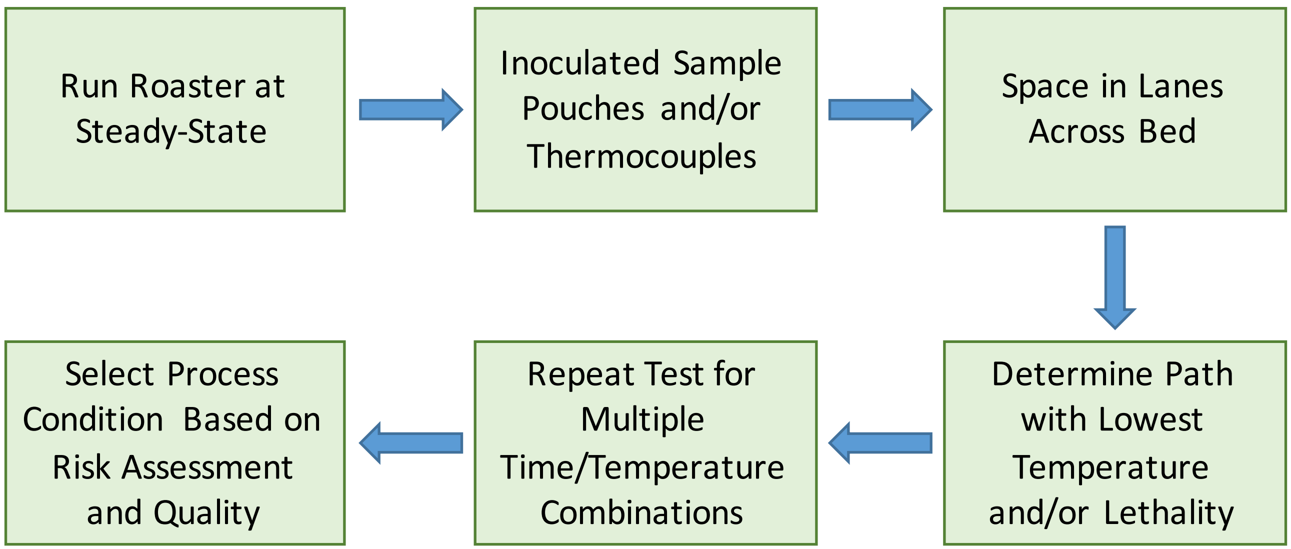


https://www.plantengineering.com/single-article/advances-in-dryer-design/d2a11a53b2316f5ae3f602c631acdafd.html

- Infeed (hopper)
- Preheat
- 4 heating zones, individually temperature controlled
- Cooling
- Discharge

State-of-the-art for roaster validation

- How do we validate flat-bed dry roasters?[8]

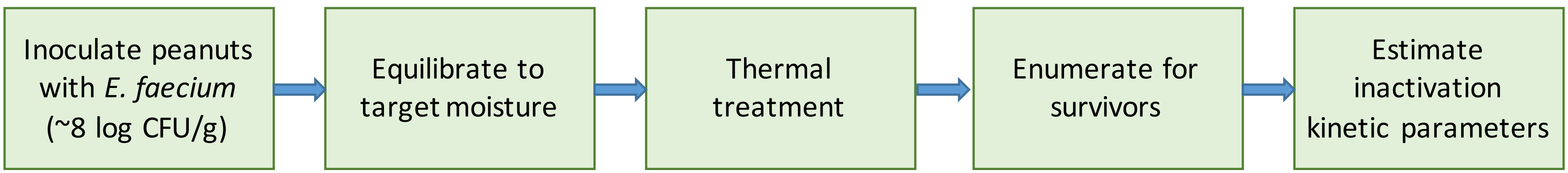


Wouldn’t it be great if we could use a model and not have to worry about inoculated samples?

Why use a model?

- Run “what-if” scenarios to change a process or if there is a process deviation[9]
- Temperature (and/or moisture, humidity, velocity, etc.) mapping is easier than a microbial validation
- Reducing sources of variability

Experimental Overview



Thermal Treatment

- Roasting conditions:

	1.0 m/s	1.3 m/s
121°C	x3	x3
149°C	x3	x3
177°C	x3	x3

Estimate Inactivation kinetics

Perform thermal treatment of samples and enumerate survivors, record temperature and moisture

Temperature curve

Moisture curve

$$D_{T,MC}(t) = D_{ref} \times 10^{\frac{T_{ref} - T(t)}{z_T} + \frac{MC_{ref} - MC(t)}{z_{MC}}}$$

Microbial inactivation curve

$$\log \frac{N(t)}{N_0} = -\int_0^t \frac{1}{D_T} dt$$

Actually a single step regression

Models Used

$$\log \frac{N(t)}{N_0} = -\frac{t}{D}$$

$$\log \frac{N(t)}{N_0} = -\left(\frac{t}{D}\right)^n$$

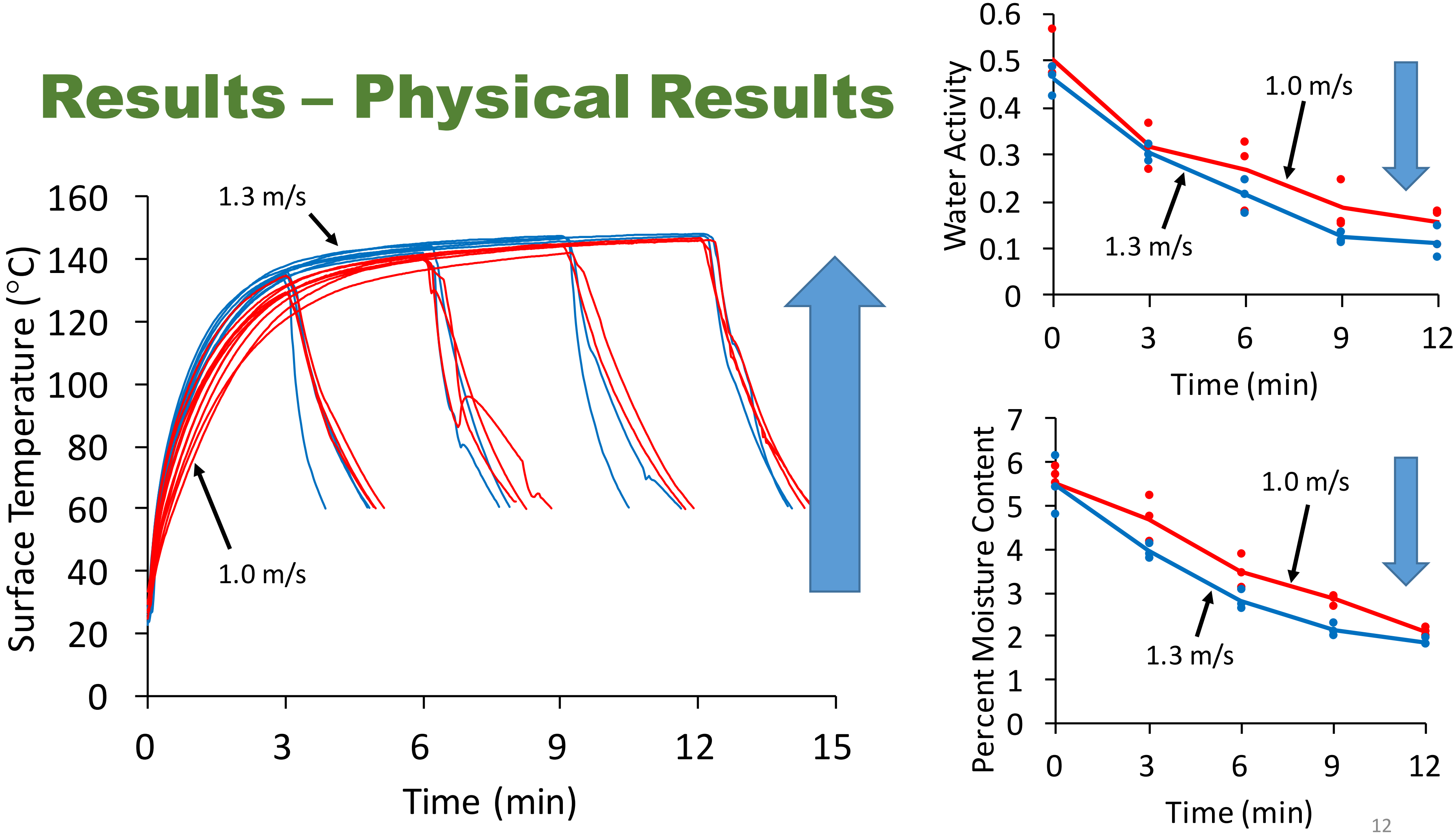
(yes, that's actually δ!)

$$\Rightarrow D(T) = 10^{f(T)} = 10^{\frac{T_{ref}-T}{z_T}}$$

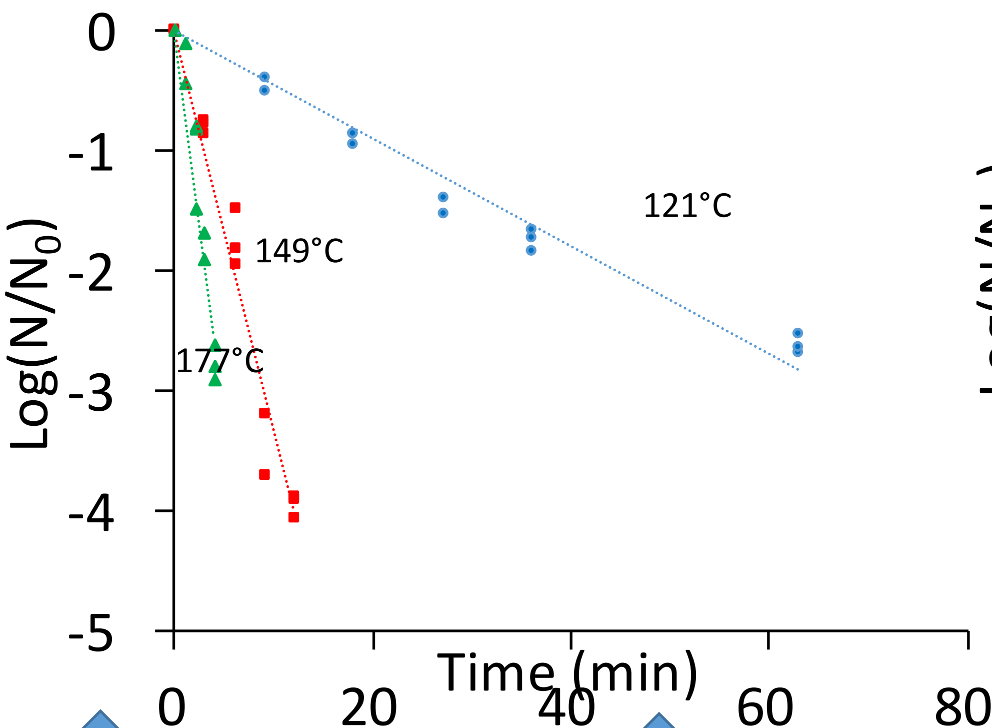
$$\Rightarrow D(T, a_w) = 10^{f(T)+f(a_w)} = 10^{\frac{T_{ref}-T}{z_T}+\frac{a_{w,ref}-a_w}{z_{a_w}}}$$

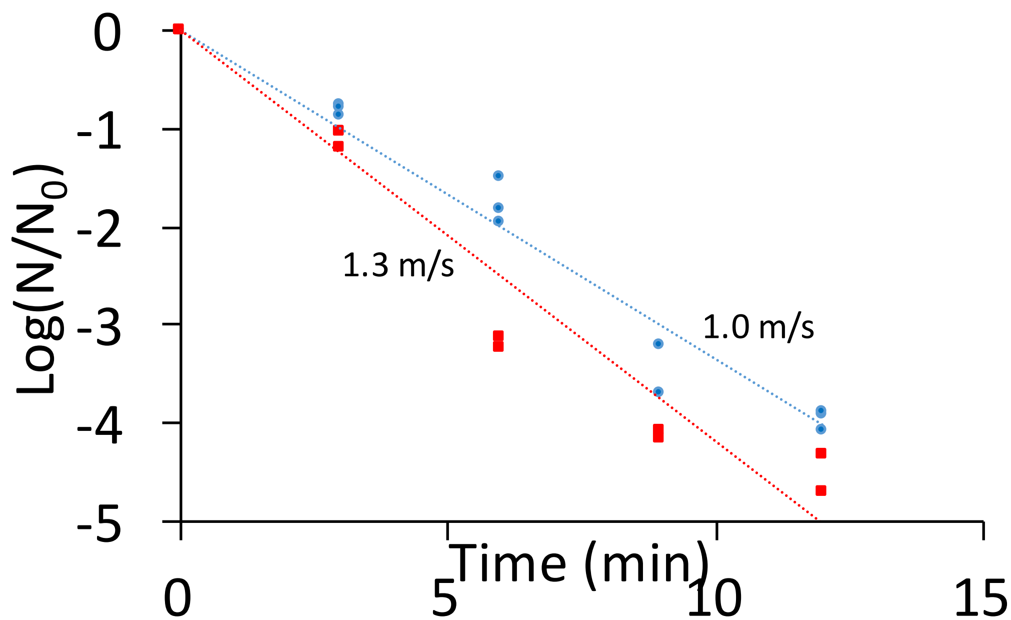
$$\Rightarrow D(T, \%MC) = 10^{f(T)+f(\%MC)} = 10^{\frac{T_{ref}-T}{z_T}+\frac{MC_{ref}-MC}{z_{MC}}}$$

Results – Physical Results



Results – Microbiological Results





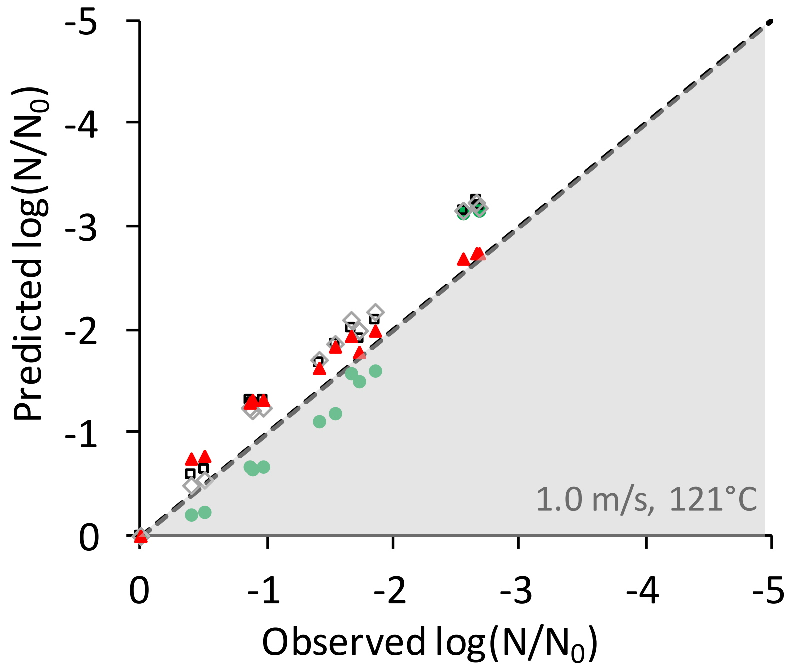
Temperature ↑ **Air Velocity** ↑ **Microbial Inactivation** ↑

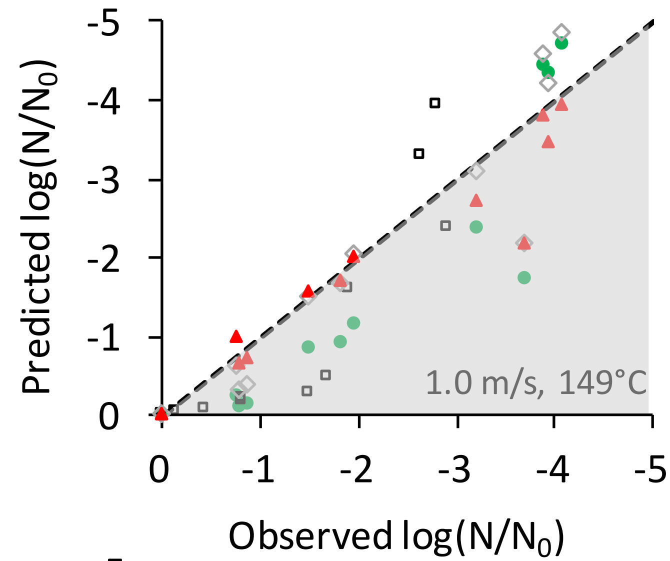
Results – Parameter Estimates

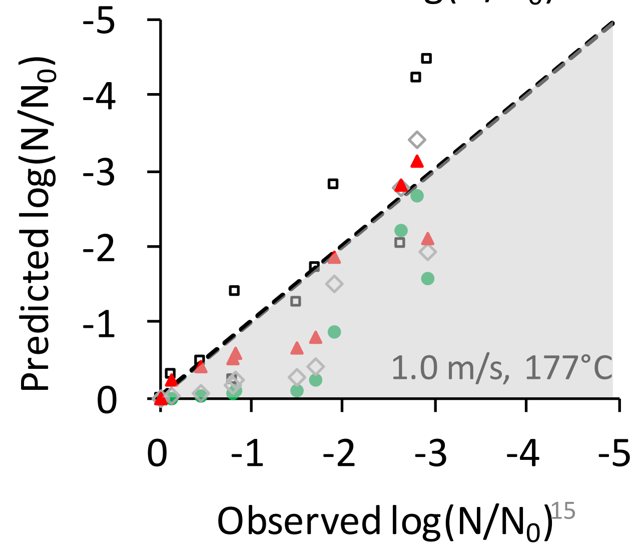
Models Used		Optimized Reference Conditions	Parameter Information			Model Statistics			
Primary	Secondary		Name	Value	Relative Error (%)	Mean Residuals	RMSE	Maximum Correlation	AIC_c
Log-Linear	Bigelow	T_{ref}=139°C	D_{ref} (min)	3.04	3.71	-0.307	0.674	-0.0367	-64.8
			z_T (°C)	22.7	3.03				
Log-Linear	Modified Bigelow (a_w)	T_{ref}=138°C $a_{w,ref}$=0.236	D_{ref} (min)	2.94	2.87	-0.159	0.534	-0.425	-103
			z_T (°C)	25.8	2.9				
			z_{aw}	0.532	13.8				
Log-Linear	Modified Bigelow (%MC)	T_{ref}=138°C MC_{ref}=3.33% MC, db	D_{ref} (min)	2.97	2.86	-0.156	0.532	-0.3233	-104
			z_T (°C)	24.9	2.71				
			z_{MC} (%MC, db)	5.01	14.0				
Weibull	Bigelow	T_{ref}=132°C	δ_{ref} (min)	1.66E-06	9.11	-0.0188	0.379	0.1245	-163
			z_T (°C)	8.75	2.87				
			n	0.22	0.38				

Results – Model Biases

- Statistically “worst” model – log-linear and Bigelow
- Statistically “best” model – Weibull and Bigelow







<u>**Statistical differences**</u> were clear,
but <u>**practical differences**</u> were minor

References

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Questions/Comments

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