Thermal Inactivation Kinetics for *Salmonella* Enteritidis PT30 on Almonds Subjected to Moist-Air Convection Heating

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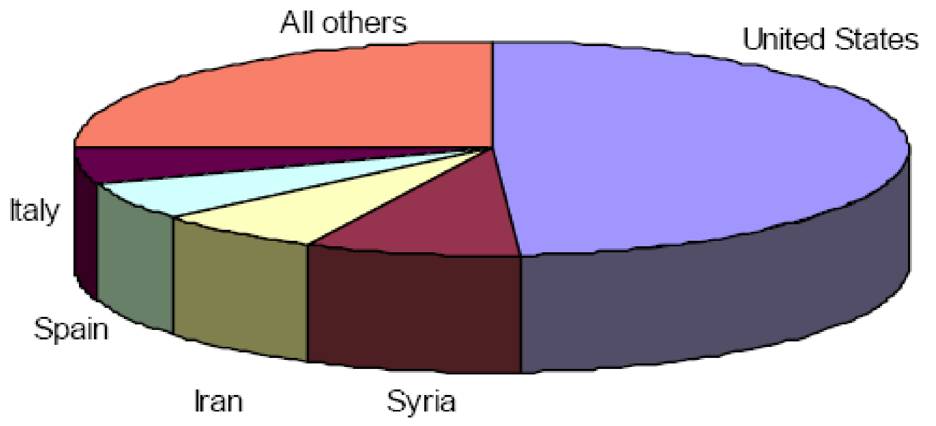
Almond Industry (USA)

- World’s biggest producer & exporter
  - ¾ of the world market in 2003 (in-shell & shelled)

Figure 6

World almond production, by country, 2004



Source: Food and Agriculture Organization, United Nations.

Health Risk & Impact

- **Outbreaks**
  - California almonds were implicated in two widely publicized outbreaks of salmonellosis in the past five years, prompting a recall of nearly 13 million lbs of raw almonds
- **Regulation**
  - Mandatory pasteurization of California almonds, and the final rule was recently published (7 CFR Part 981.442).
- **Impact**
  - A significant, industry-wide demand for technologies and process validation tools to achieve safety and quality goal.

Thermal Inactivation

- **Moist-air Impingement Cooking System**
  - Jet of steam-air mixture through an array of nozzles or slots onto the food product
  - High heat transfer rate by reducing boundary layer thickness at the surface of the product
  - Fast cooking and better water retention of processed products
- **Dynamic process**
  - Condensation & Evaporation

Challenges

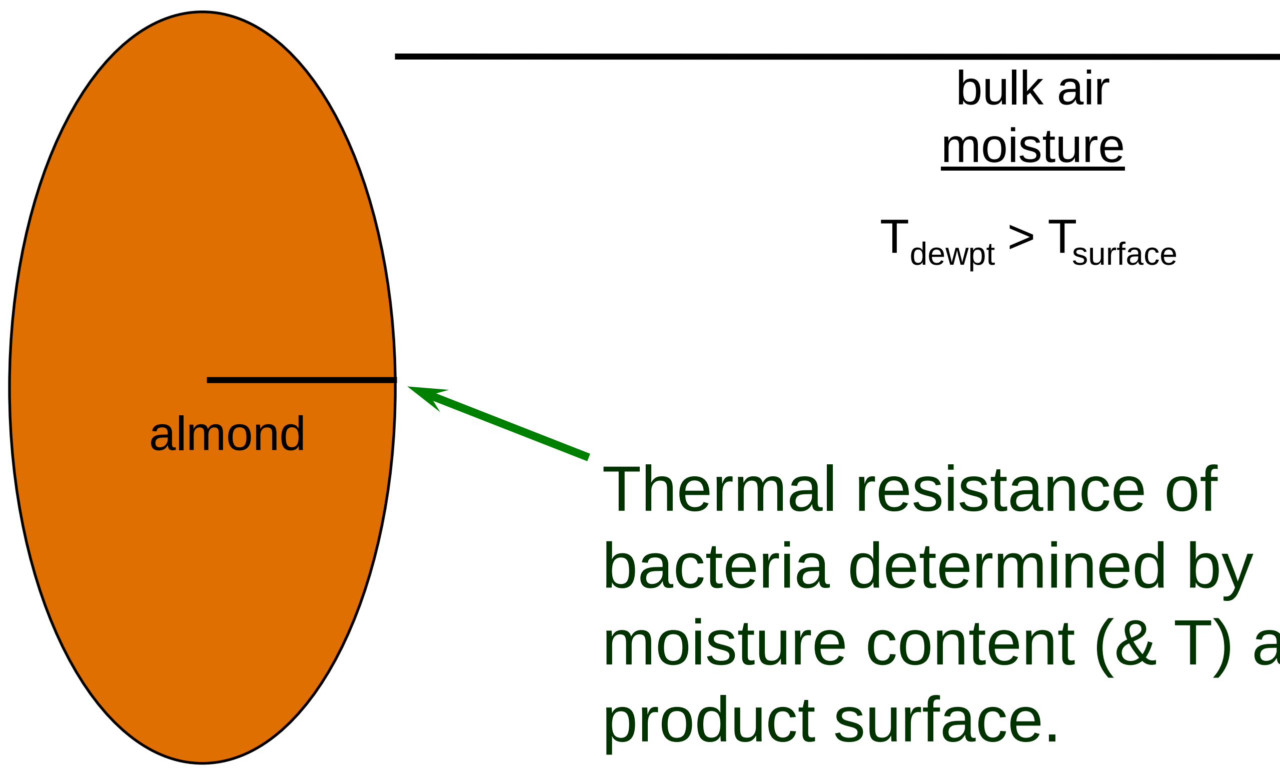
- Measuring accurate surface temperature.
- Difficulties in defining surface moisture state and real-time measurement.
- Complexities with the behavior of microorganisms in dynamic water activity.

Objectives

- To develop a mathematical model predicting decimal reduction time (D-value) for thermal inactivation of *Salmonella* Enteriditis PT30
  - on the surface of almonds
  - subjected to moist-air heating
  - as a function of almond surface temperature and process humidity

Dynamic Process effects

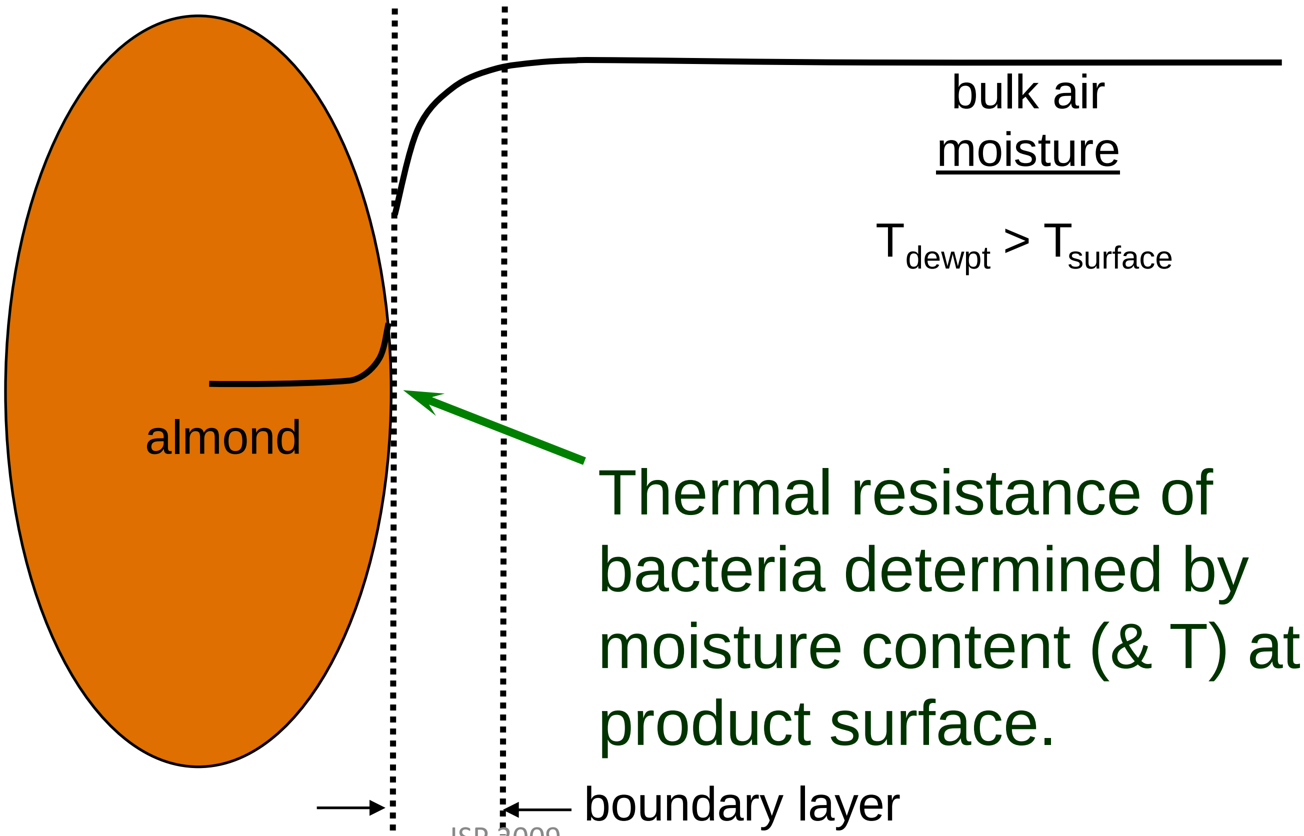
- Initial condition



Thermal resistance of bacteria determined by moisture content (& T) at product surface.

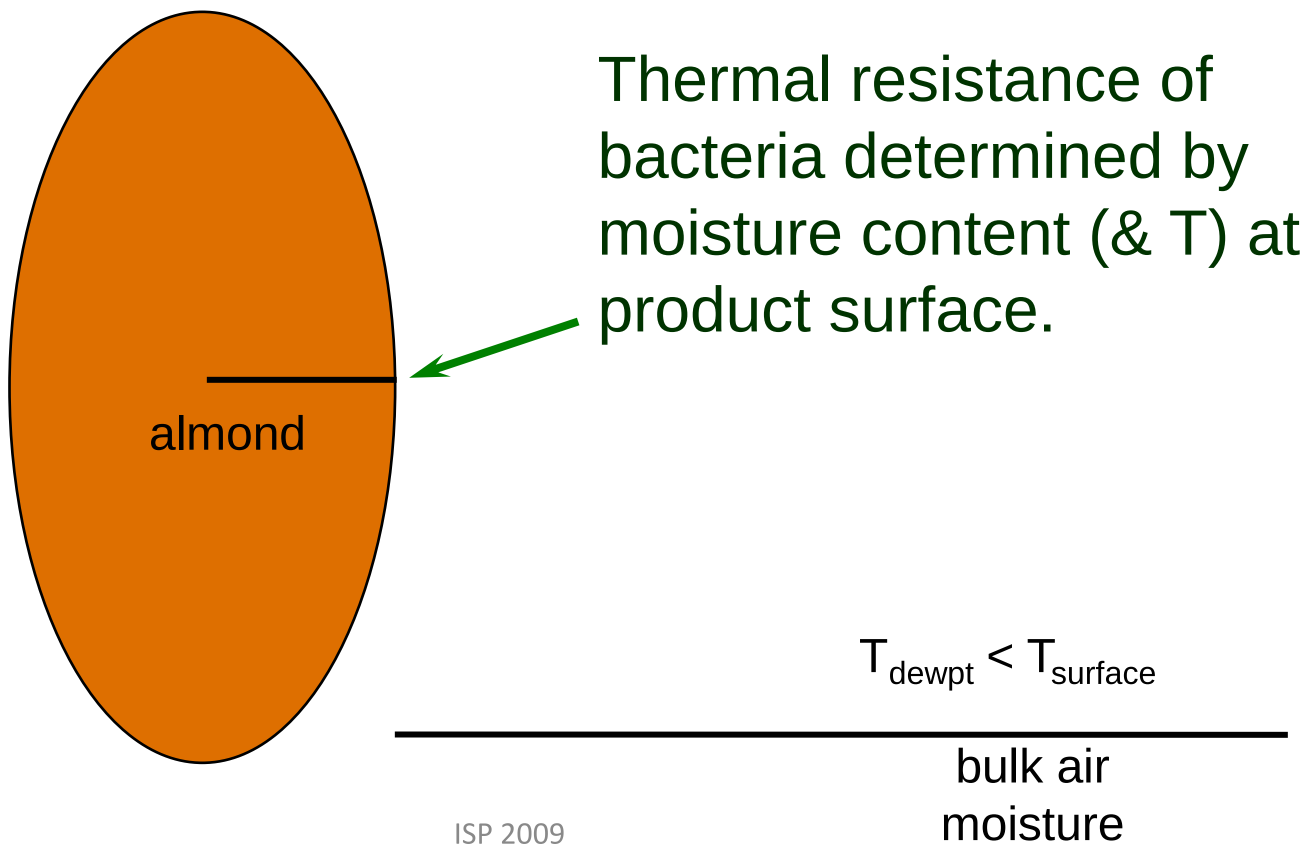
Dynamic Process effects

- Condensation



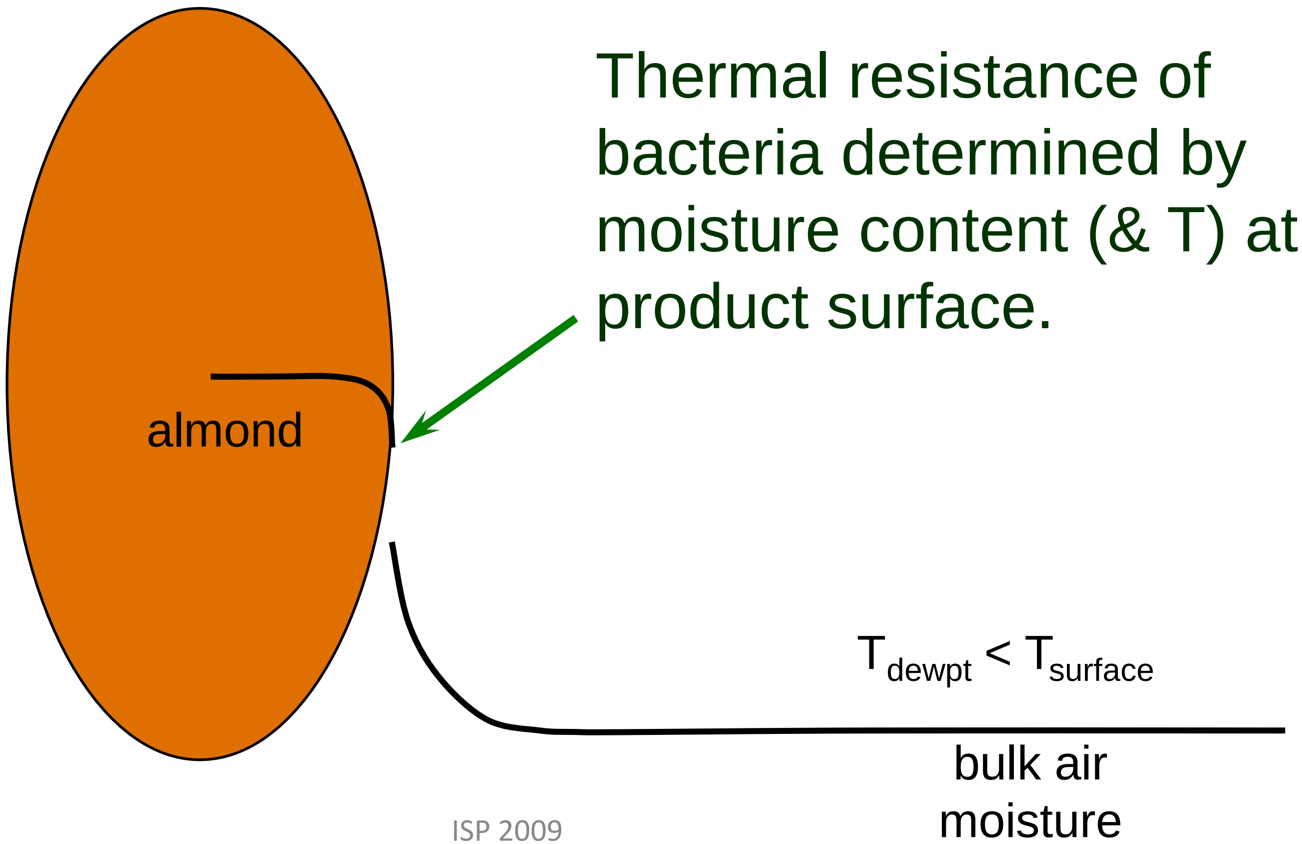
Dynamic Process effects

- Evaporation starts.



Dynamic Process effects

- Evaporation



Model Development

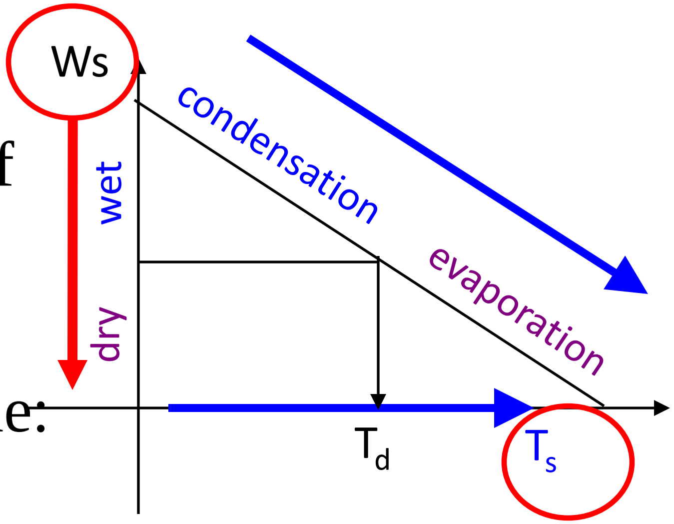
- *D-value*: time required to achieve 90% reduction of microbial population
- *Z-value*: temperature dependency of D-value
- Traditional model: $D=f(T; D_r, z)$

$$D = D_r \cdot 10^{\left((T_r - T)/z\right)}$$

  – dependent only on process temperature (T)
- Needs:
  – Effect of varying <u>water status at the surface</u> ('surface wetness') of almonds during moist-air heating need to be defined.

Model Development

- Transient surface wetness (W) due to condensation and evaporation of moist-air:
  - $W_s = a(T_d - T_s) + b$
- Modified kinetic model for D-value:
  - $D = f(T_s, T_d; D_{ref}, z_T, z_M)$



$$D_{Ts,Td} = D_{ref} \cdot 10^{\left[\left(\frac{T_{ref} - T_s}{z_T}\right) + \left(\frac{(T_{d,ref} - T_d) - (T_{ref} - T_s)}{z_M}\right)\right]}$$

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Model Parameter Estimation

- Cumulative log reduction:
  - Numerical integration for non-isothermal process

$$\log\left(\frac{N}{N_0}\right) = -\int_0^t \left(D_{T_s,T_d}^{-1}\right)\cdot dt$$

- Parameters in the modified model:
  - T_r= 82°C, $T_{d,r}$=midpoint in a range
  - D_r , z_T, z_M were optimized to minimize ∑ SSE of log reduction using Excel SOLVER

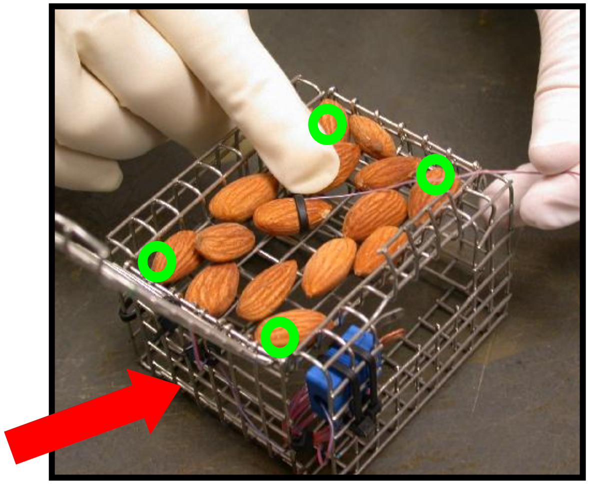
Thermal Treatment

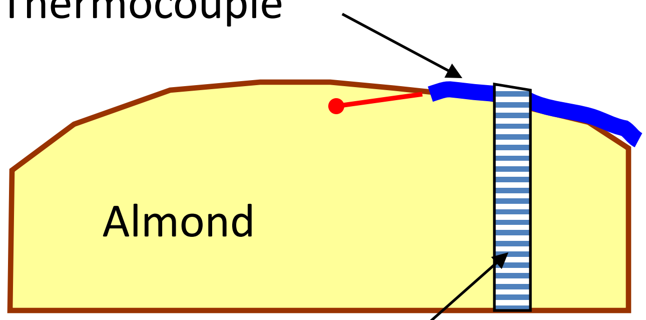
- Experiment design:
  - Full factorial design: 125 conditions
  - 5 dry bulb temperatures
    - 121, 149, 177, 204, 232 ˚C
  - 5 air humidities
    - ~0, 30, 50, 70, 90 %MV
  - 5 heating durations designed to achieve:
    - 0.5, 2, 3.5, 5, 6 log red.
  - 2 replications for each condition

- Equipment:
  - Computer controlled, lab-scale, moist-air convection oven
- Treatment:
  - Heating samples for each specific duration
  - Immediate cooling in 40˚F circulating air after heating

Surface Temperature Measurement

- Loading:
  - Approximately 15 g of inoculated almonds per rack
- Thermocouple wires:
  - T-type/36-gauge/pre-fused junction
- Measures:
  - Temperature just below the almond surface (< 1mm)
  - Negligible spatial variability in temperature measurement

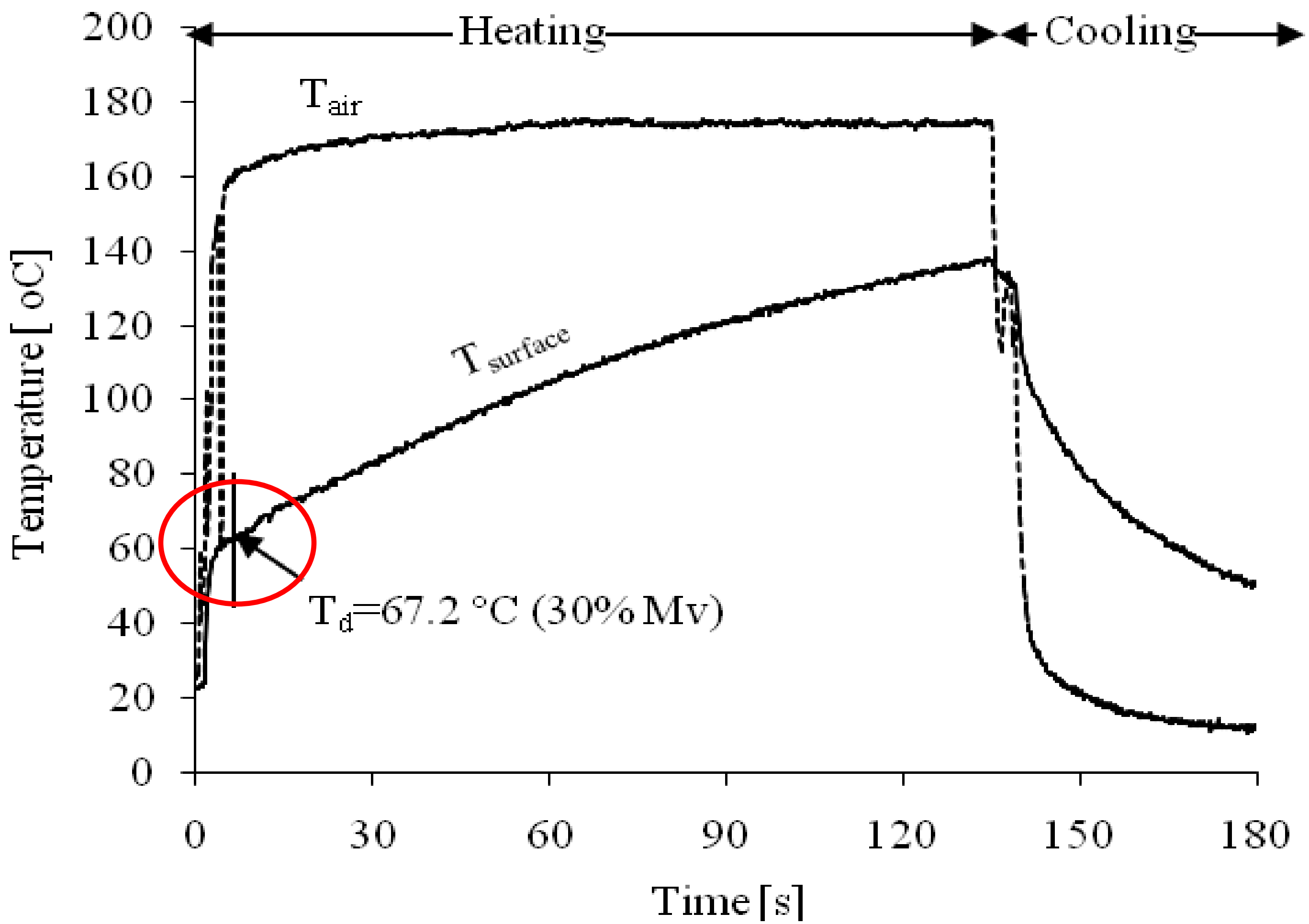




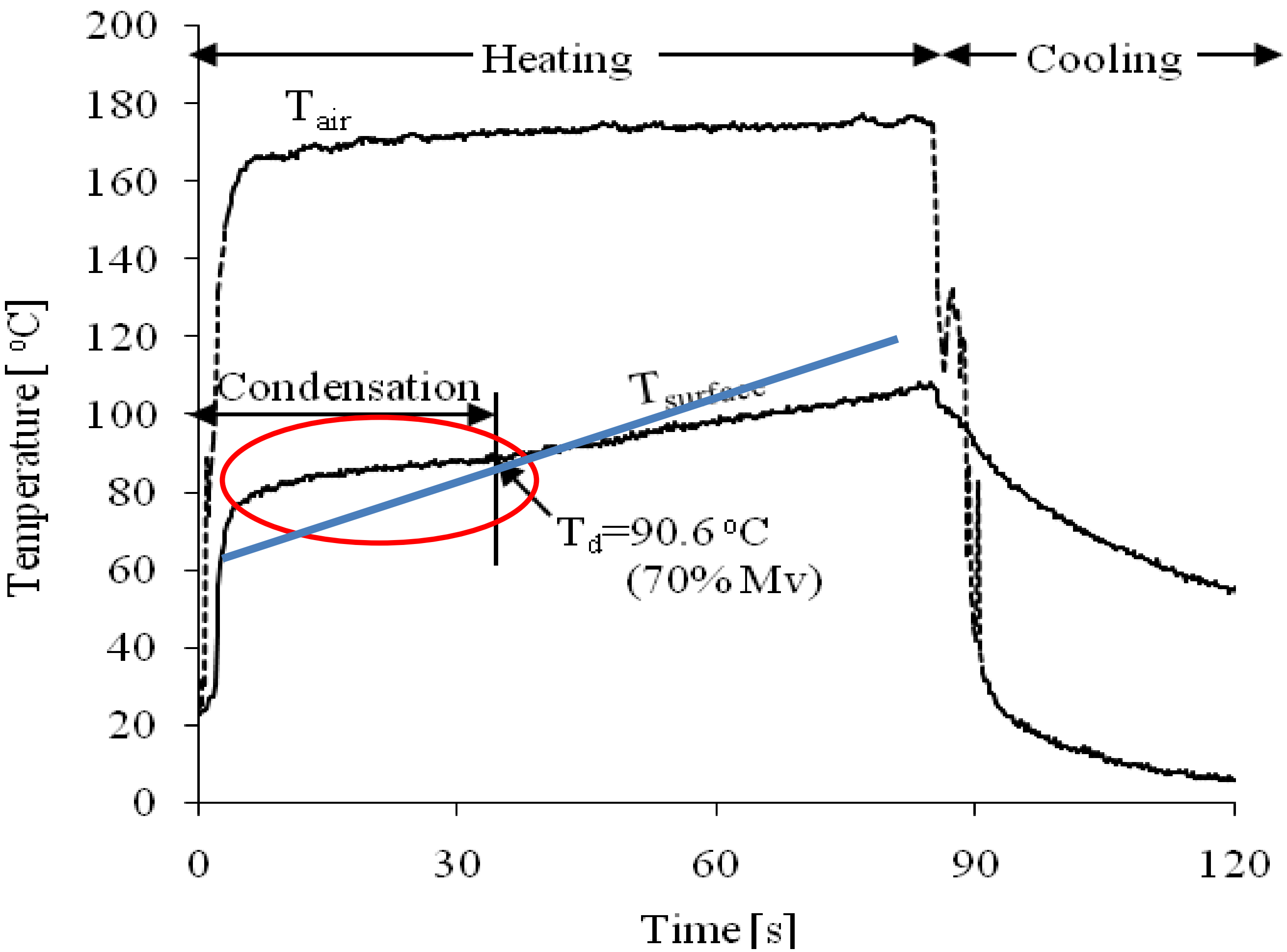
Model Validation

- 1/3 of the data were used for validation statistics
- Best-fit parameters were determined for the five sub-sets of process humidity levels.

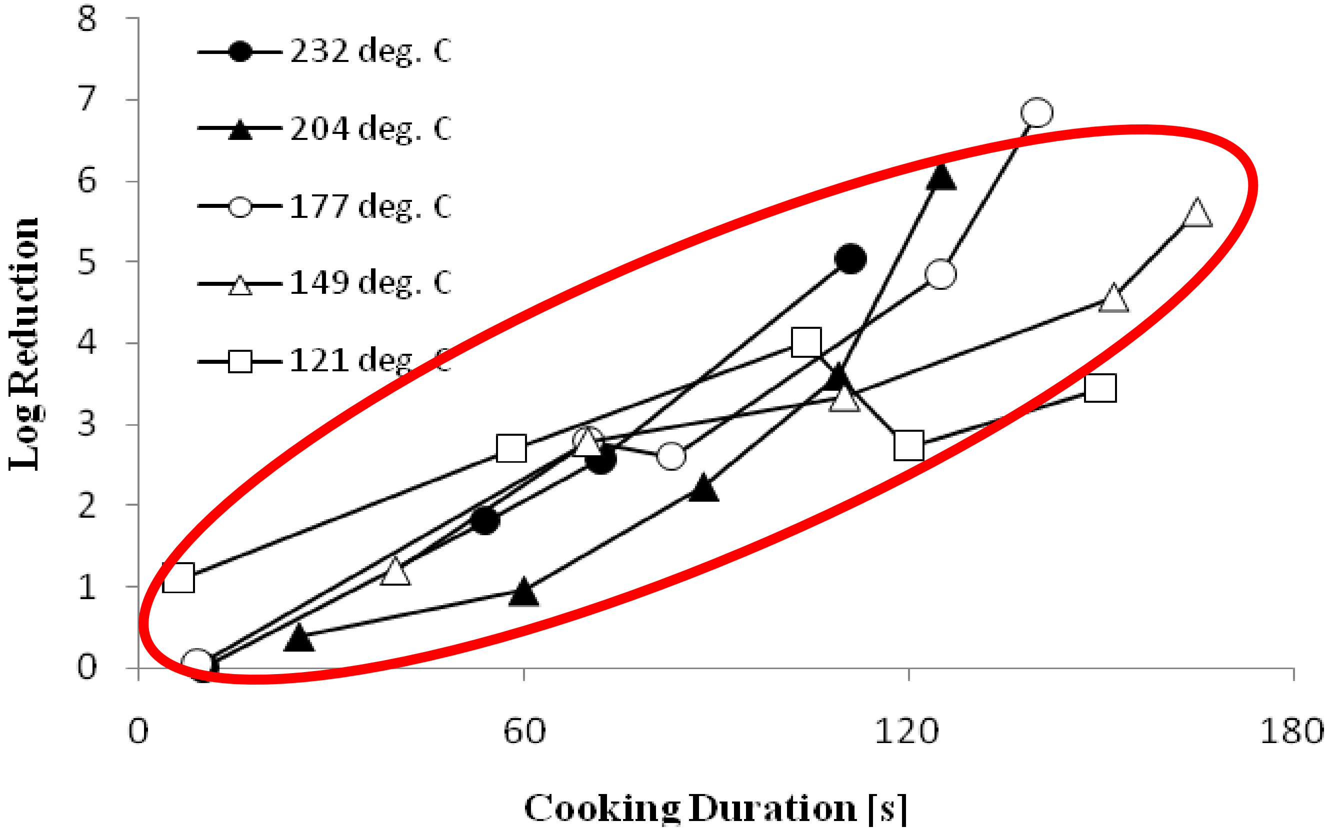
Results: Low process humidity



Results: High process humidity

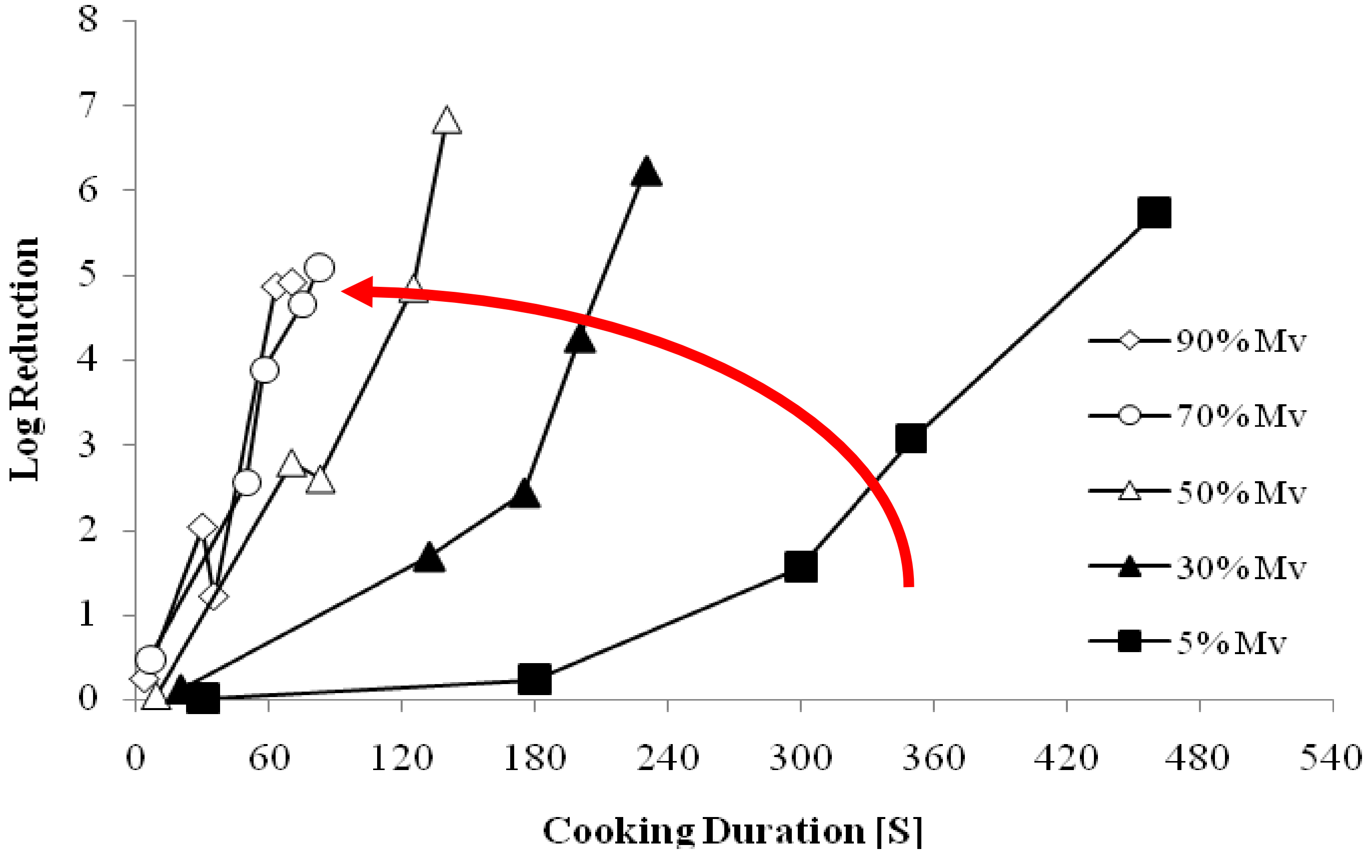


Results: Process Effects



Effect of process humidity and temperature on log reduction of *Salmonella* Enteritidis PT30 on the surface of almond at 50% Mv.

Results: Process Effects



Effect of process humidity and temperature on log reduction of *Salmonella* Enteritidis PT30 on the surface of almond at 177°C.

Results: Traditional Model

		Traditional Model				
	Humidity (%Mv)	**Dry (5)**	**Low (30~50)**	**Medium (50~70)**	**High (70~90)**	**Full (5~90)**
Model	***RMSE***	1.00	1.37	1.06	0.94	2.52
	No. of data	14 (0[c])	34 (1)	35 (1)	30 (0)	78 (1)
Validation	***RMSE***	1.07	2.25	1.65	1.18	2.56
	No. of data	11 (0)	14 (0)	14 (0)	15 (0)	40 (1)
Parameters	D_{ref} [s]	2925.90	52.43	30.83	19.08	86.27
	z_T [°C]	45.19	1.47×10^6	2.31×10^6	3.01×10^3	3.04×10^7
	T_{ref} [°C]	82.22	82.22	82.22	82.22	82.22
	z_M [°C]	NA[e]	NA	NA	NA	NA
	$T_{d,ref}$ [°C]	NA	NA	NA	NA	NA

Results: Modified Model

		Modified Model				
	Humidity (%Mv)	**Dry (5)**	**Low (30~50)**	**Medium (50~70)**	**High (70~90)**	**Full (5~90)**
Model	***RMSE*^{d}**	1.10	0.86	0.65	0.64	1.40
	No. of data	14 (0)	34 (1)	35 (1)	30 (1)	78 (1)
Validation	***RMSE***	1.23	1.55	0.96	1.06	1.33
	No. of data	11 (0)	14 (0)	14 (0)	15 (0)	40 (1)
Parameters	**D_{ref} [s]**	957.28	55.74	23.57	16.40	43.94
	z_T [°C]	14.68	27.89	33.19	44.53	31.95
	T_{ref} [°C]	82.22	82.22	82.22	82.22	82.22
	z_M [°C]	21.74	34.19	36.61	54.82	40.73
	$T_{d,ref}$ [°C]	43.89 (9%Mv)	76.11 (40%Mv)	86.11 (60%Mv)	93.89 (80%Mv)	78.89 (45%Mv)

Conclusions

- Modified dynamic D-value model was successful for predicting the log reduction of *Salmonella* PT30 on almonds subjected to a moist-air convection process.
- Modified dynamic D-value model was more robust and generally more accurate than the conventional D-value model.

Questions