MATHEMATICAL MODELLING OF BULK STORED ONIONS IN TRANSPORT CONTAINERS

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ABSTRACT

Export onion bulbs are predominantly transported from New Zealand loose in sacks which are bulk loaded into intermodal transport containers. Product respiratory heat, water vapour, and volatiles are dispensed of by a fan unit installed in the end of the container, ventilating the stow by forcing ambient air from a false floor up through the crop and exhausting the air from a head space.

The objective of this study was to mathematically model this system with respect to onion bulb temperature and weight loss, and internal container air temperature and relative humidity. These product and flowfield variables were predicted at different locations within the transport vessel. Bulb temperature and weight loss were simulated as dynamic variables using ordinary differential equations, and air temperature and relative humidity were simulated as quasi steady state variables using algebraic equations.

A validation experiment was conducted to evaluate the simulation model by placing temperature and humidity sensors throughout the product and flowfield space measuring the respective properties. Onion and air temperatures were predicted with satisfactory accuracy in almost all measured locations of the container. Prediction of relative humidity varied considerably throughout the container, although excessive sensor errors were identified casting suspicion on some validation measurements. Simulated relative humidity could not therefore be fully verified. Bulb weight loss was predicted with variable levels of accuracy. Significant variability in the validation data was evident in the upper and lower regions of the container preventing complete model validation. Central regions of the container were simulated with satisfactory accuracy.

A model sensitivity analysis revealed that container ventilation rate strongly influenced model performance with respect to temperature and relative humidity. The mass transfer coefficient, as expected, was most influential over product weight loss.

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LIST OF SYMBOLS

Symbol in Text	Symbol in Model	Description	Units
A	As	surface area of onion bulb	m^2
A_z	-	total surface area of onions in zone	m^2
AHL	-	absolute humidity lowering effect	-
Bi	-	Biot number	-
C_p	Cpa	specific heat capacity of air	$J.g^{-1}.°C^{-1}$
$C_{p(on)}$	Cp	specific heat capacity of onion	$J.g^{-1}.°C^{-1}$
CO_2^f	-	carbon dioxide final concentration	%
CO_2^i	-	carbon dioxide initial concentration	%
d	-	diameter of average onion	m
dm_C/dt	DelMd	mass transfer of carbon	$g.s^{-1}$
dm_{H_2O}/dt	DelMw	mass transfer of water vapour	$g.s^{-1}$
dT_{on}/dt	DelT	temperature change of onion	$°C.s^{-1}$
D_{AB}	-	binary mass diffusion coefficient	$m^2.s^{-1}$
g	-	gravitational acceleration	$m.s^{-2}$
Gr	-	Grashof number	-
h_c	htc[]	convective heat transfer coefficient	$W.m^{-2}.°C^{-1}$
j_h	-	Colburn *j* factor for heat transfer	-
j_m	-	Colburn *j* factor for mass transfer	-
k	-	thermal conductivity of onion	$W.m^{-1}.°C^{-1}$
k_a	-	convective air mass transfer coefficient	$g.m^{-2}.s^{-1}.Pa^{-1}$
$k_{a(r)}$	-	convective air mass transfer coefficient	$m.s^{-1}$
k_s	-	skin mass transfer coefficient	$g.m^{-2}.s^{-1}.Pa^{-1}$
k_t	-	mass transfer coefficient	$g.m^{-2}.s^{-1}.Pa^{-1}$
$k_{t(r)}$	mtc[]	mass transfer coefficient	$m.s^{-1}$
L	-	characteristic dimension	m
m	-	mass of onion bulb	kg
$\dot{m}_{a(z)}$	-	mass flow of air in zone	g
$\dot{m}_{H2O}$	fevap	mass flow rate of water vapour	$g.s^{-1}$
m_s	-	mass of onion sample	kg
m_z	-	mass of onions in zone	kg

M_C	-	molecular mass of carbon	$g.mol^{-1}$
P_a	pa[]	vapour pressure of air	Pa
P'_a	pasat	saturated vapour pressure of air	Pa
P_{ATM}	-	atmospheric pressure	Pa
P_{PDS}	-	air pressure in pressure drop system	Pa
P_s	-	vapour pressure of onion surface	Pa
Pr	-	Prandtl number	-
ΔP_{z1i}	-	air pressure difference across zone column	Pa
r_h	-	heat of respiration	$W.kg^{-1}$
rr_C	-	relative respiratory carbon mass depletion	$g.kg^{-1}.s^{-1}$
rr_{CO_2}	-	relative respiratory carbon dioxide production	$mol.kg^{-1}.s^{-1}$
Re	-	Reynolds number	-
RH	RH[]	relative humidity of air	%
Sc	-	Schmidt number	-
St	-	Stanton number	-
St_m	-	Stanton number for mass transfer	-
t	-	time	s
T_a	Ta[]	temperature of air	°C
ΔT_a	-	temperature change of zone air	°C
$T_{a(i)}$	Tai	temperature of air entering zone	°C
$T_{a(o)}$	Tao	temperature of air exiting zone	°C
ΔT_m	lmtd	onion/flowfield log mean temperature difference	°C
T_{on}	Ton[]	temperature of onion	°C
T_s	-	temperature of onion surface	°C
u	-	air velocity	$m.s^{-1}$
u_∞	-	upstream air velocity	$m.s^{-1}$
v	v[]	volumetric air flow rate through zone	$m^3.s^{-1}$
V	-	volume of onion bulb	m^3
V_j	-	volume of jar	m^3
V_s	-	volume of onion sample	m^3
W	wtfrac	onion water content fraction	-
α	-	thermal diffusivity of air	$m^2.s^{-1}$
β	-	volumetric thermal expansion coefficient	K^{-1}
ε	-	packed bed volumetric void fraction	-

λ	Lambda	latent heat of vaporization of water	$J.g^{-1}$
ρ	rho[]	density of air	$g.m^{-3}$
ρ_{on}	-	density of onion	$kg.m^{-3}$
ν	-	kinematic viscosity of air	$m^2.s^{-1}$
ϕ_{conv}	Qc	convective heat transfer from onion to zone air	W
ϕ_{evap}	Qevap	latent heat transfer from onion to zone air	W
ϕ_{resp}	Qresp	heat generation from respiration	W
χ	Xa[]	absolute humidity of air	$g.m^{-3}$
$\Delta\chi$	-	absolute humidity change of zone air	$g.m^{-3}$
χ_i	Xai	absolute humidity of air entering zone	$g.m^{-3}$
$\Delta\chi_m$	lmXd	onion/flowfield log mean absolute humidity diff.	$g.m^{-3}$
χ_o	Xao	absolute humidity of air exiting zone	$g.m^{-3}$
χ_{on}	Xonsat	absolute humidity of onion surface	$g.m^{-3}$

Additional symbols used in model not used in text

Asav	surface area of average onion bulb	m^2
fresp	mass transfer rate of carbon	$g.s^{-1}$
massav	mass of average onion bulb	kg
masst	total mass of onions in container	kg
Mdon[]	mass of onion dry fraction	g
Mon[]	mass of onions in zone	g
Mwon[]	mass of onion wet fraction	g
number	number of onion in container	-
pin	vapour pressure of air entering container	Pa
psatin	saturated vapour pressure of air entering container	Pa
rhoin	density of air entering container	$g.m^{-3}$
RHin	relative humidity of air entering container	%
simtime	simulation step length	s
step	simulation step length	s
Tin	temperature of air entering container	°C
vent	total container ventilation rate	$m^3.s^{-1}$
Xin	absolute humidity of air entering container	$g.m^{-3}$

where:

[] = array of zone positions