Temperature Control in Honeybee Hives

Matthew Burnham

Dr. Bequetter
October 11, 2005
Background

- Honeybees regulate air temperature in hive by cooling via flapping wings or heating via huddling heat generation

Bees cooling the hive entrance.
Modeling Equations

\[
(mc_p)_H \frac{dT_H}{dt} = (UA)_{amb} (T_{amb} - T_H) - (UA)_{inner} (T_H - T)
\]

\[
(mc_p)_{nest,air} \frac{dT}{dt} = (mc_{p,air})(T_{amb} - T) + Q_{gen} + (UA)_{inner} (T_H - T)
\]

\[
(mc_{p,air}) = \alpha (mc_{p,air})_{max}
\]

\[
Q_{gen} = \beta Q_{gen,max}
\]

\[
\alpha + \beta \leq 1
\]

Developed by B. Wayne Bequette in July 2005
More Modeling Stuff

\((mc_p)_H\) = hive "thermal mass" (solid material)

\(T_{amb}\) = ambient air temperature

\(T_H\) = hive (solid material) temperature

\((UA)_{amb}\) = HT coeff * area, ambient heat transfer

\((UA)_{inner}\) = HT coeff * area, inside nest heat transfer

\(T\) = inside hive air temperature

\((mc_p)_{nest,air}\) = inside hive "thermal mass" (air)

\((mc_p,air)\) = air flow through hive * heat capacity

\(Q_{gen}\) = bee heat generation rate

\(\alpha\) = fraction of bees fanning their wings

\(\beta\) = fraction of bees huddling and generating heat
Open Loop Simulations

• Taking the second modeling equation…

Etc…
Nonlinear Modeling

• Taking both modeling equations...
Nonlinear modeling (cont)
Results for 2K increase in Tamb
Results for 2K decrease in Tamb
Ramp (Morning) Simulation
Full day (Sine-wave) Simulation
Observations

• One thing noted after the sine-wave simulation was that the heating and cooling terms were not at the same rate (which was expected)

• So analyze this by extracting the $Q_{gen}$ and $M_{dot C_{pair}} \cdot \Delta T$ terms
Qgen and Mdot graphs
Analysis

• The way the problem was solved was with \( \alpha + \beta = 1 \)
• We can see that the heating term is much greater than the cooling term.
• In real life \( \alpha + \beta \neq 1 \).
• Since cooling is less efficient then heating we remove some heating bees.
Heating bees halved, 2K increase in Tamb
Heating bees halved, 2K decrease in Tamb
Further Analysis

- This is more efficient for cooling the hive and less efficient for heating the hive (inherently)
- It is necessary to have the number of bees heating depend upon some other constraint.
- Introduce percent of nectar brought to the hive (100% means lots of nectar and lots of bees can be heating)
2K increase 75 percent nectar
2K increase 25 percent nectar
2K decrease 25 percent nectar
Further Analysis

• The same problems hold with this model when both nectar is low and ambient temperature drops

• Problems are minimized though by good nectar collections the previous day
Further work

• Deducing why mdot term goes positive in some cases (change of air flow from out of to into the hive)
• Integrating percent nectar collected into modeling equations
• Developing other, more realistic, models for alpha + beta !=1
• Possible RDB stuff.
Extra

• Ambient T so that Hive Air Temp is at 308 K with alpha = .5 is 300.6 K.