AVOIDING CAKING IN BULK LACTOSE – THE EFFECT OF AMORPHOUS LACTOSE

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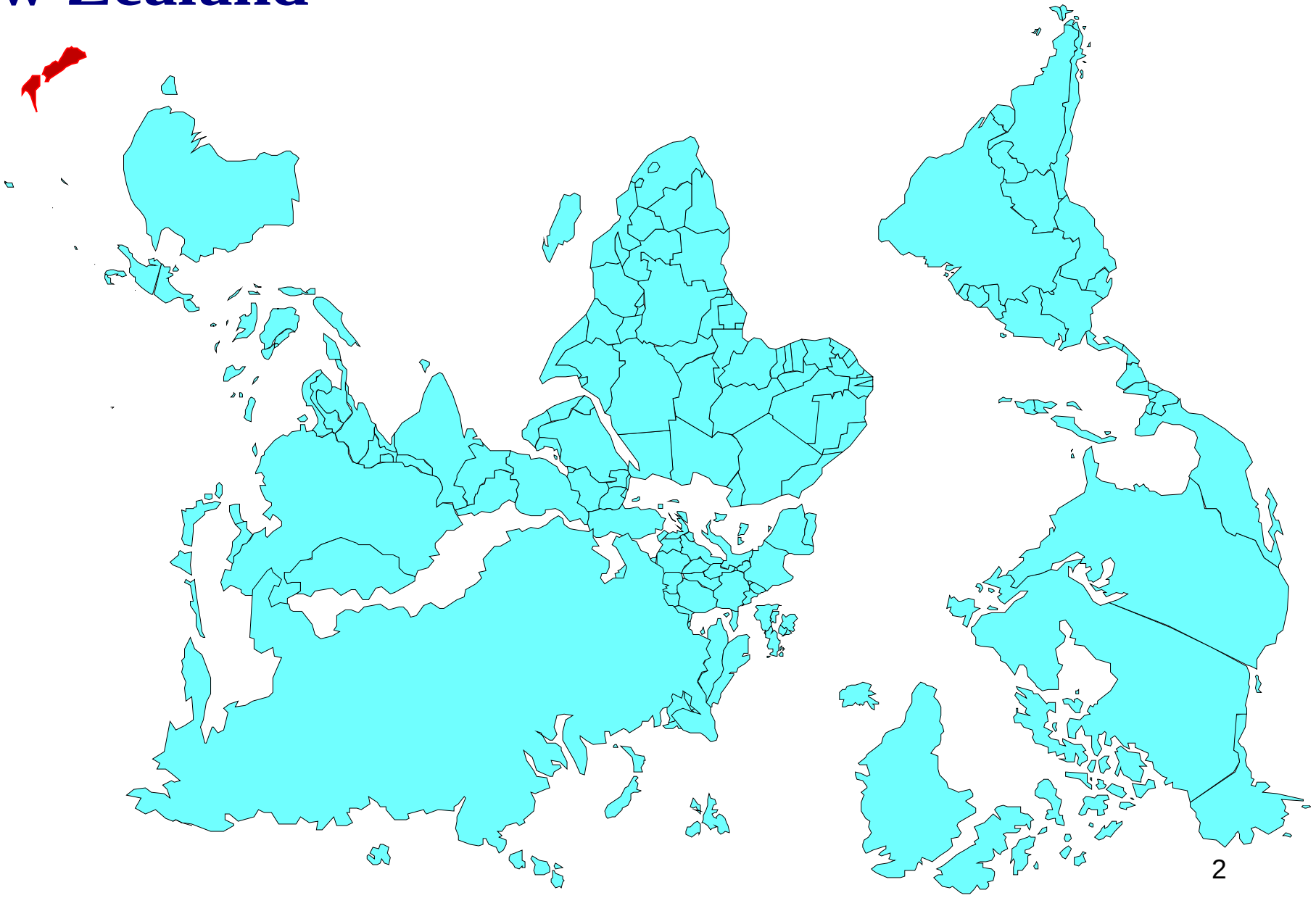
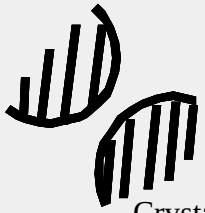


Caking in Lactose



Crystal

In High R.H. Environments.

Adsorption, surface dissolution and liquid bridging.

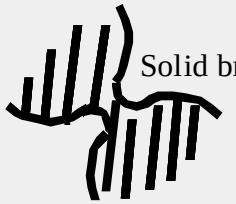
Lumping

Liquid Bridge

In Low R.H. Environments

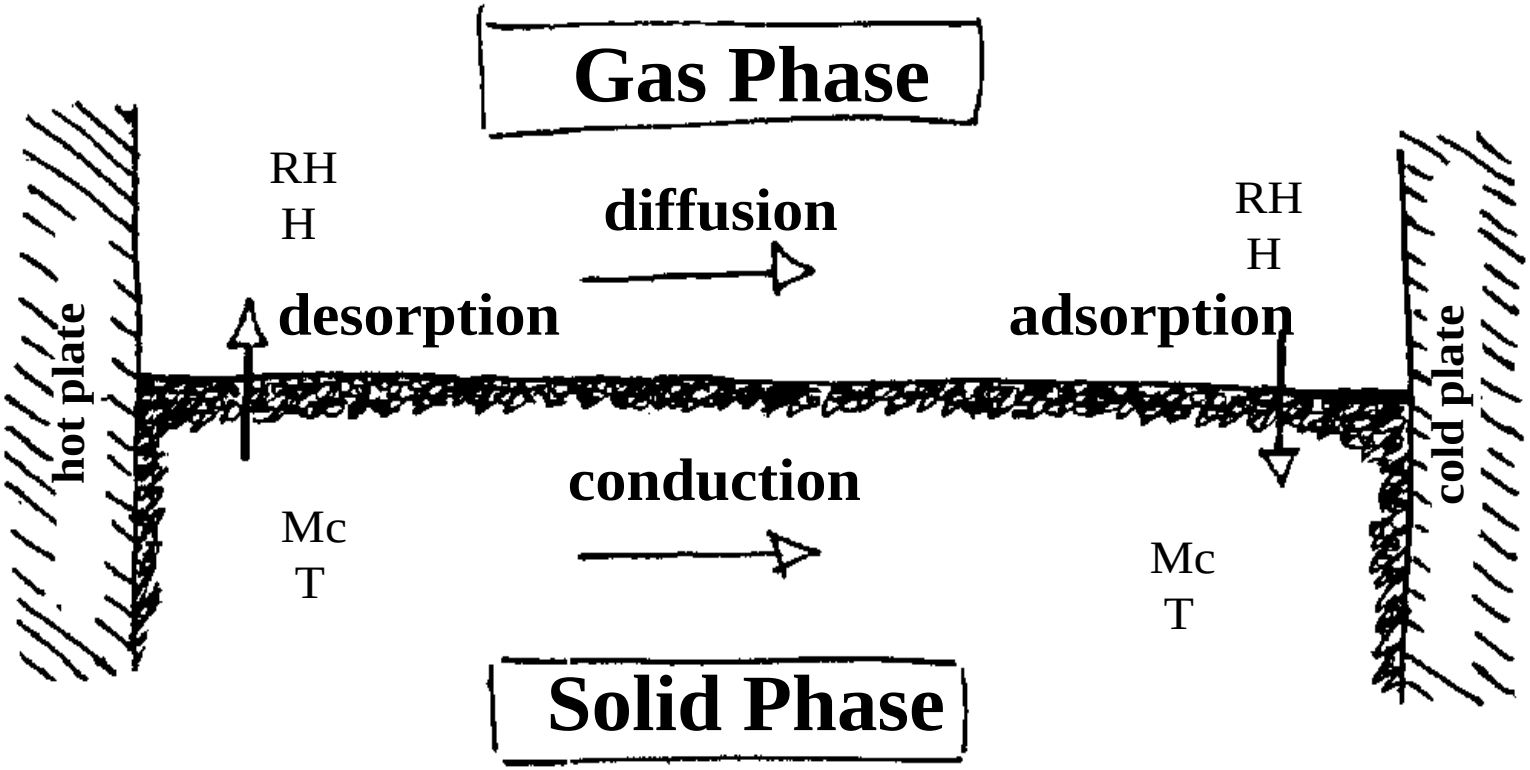
Desorption and crystallisation

Caking

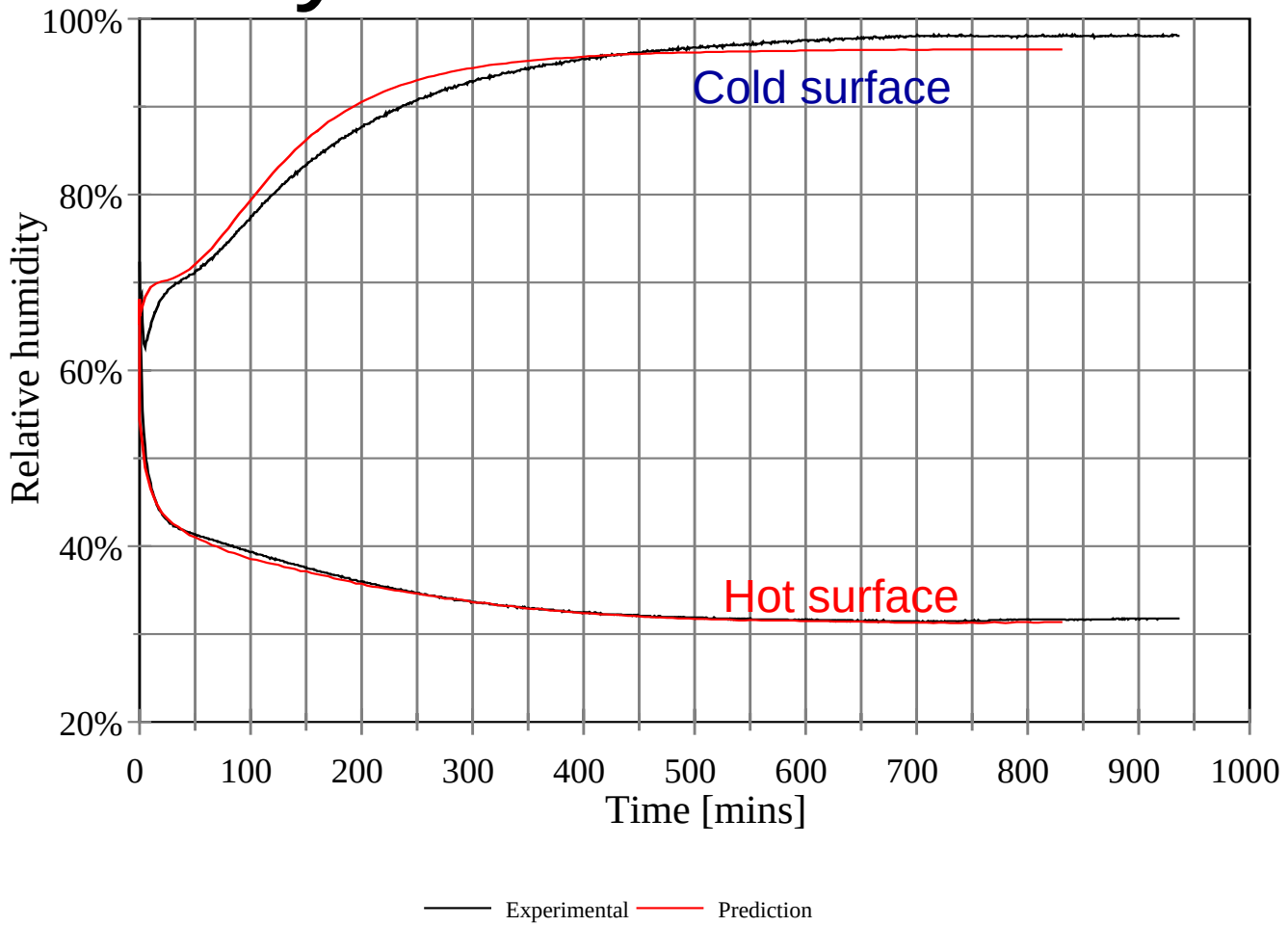


Solid bridge

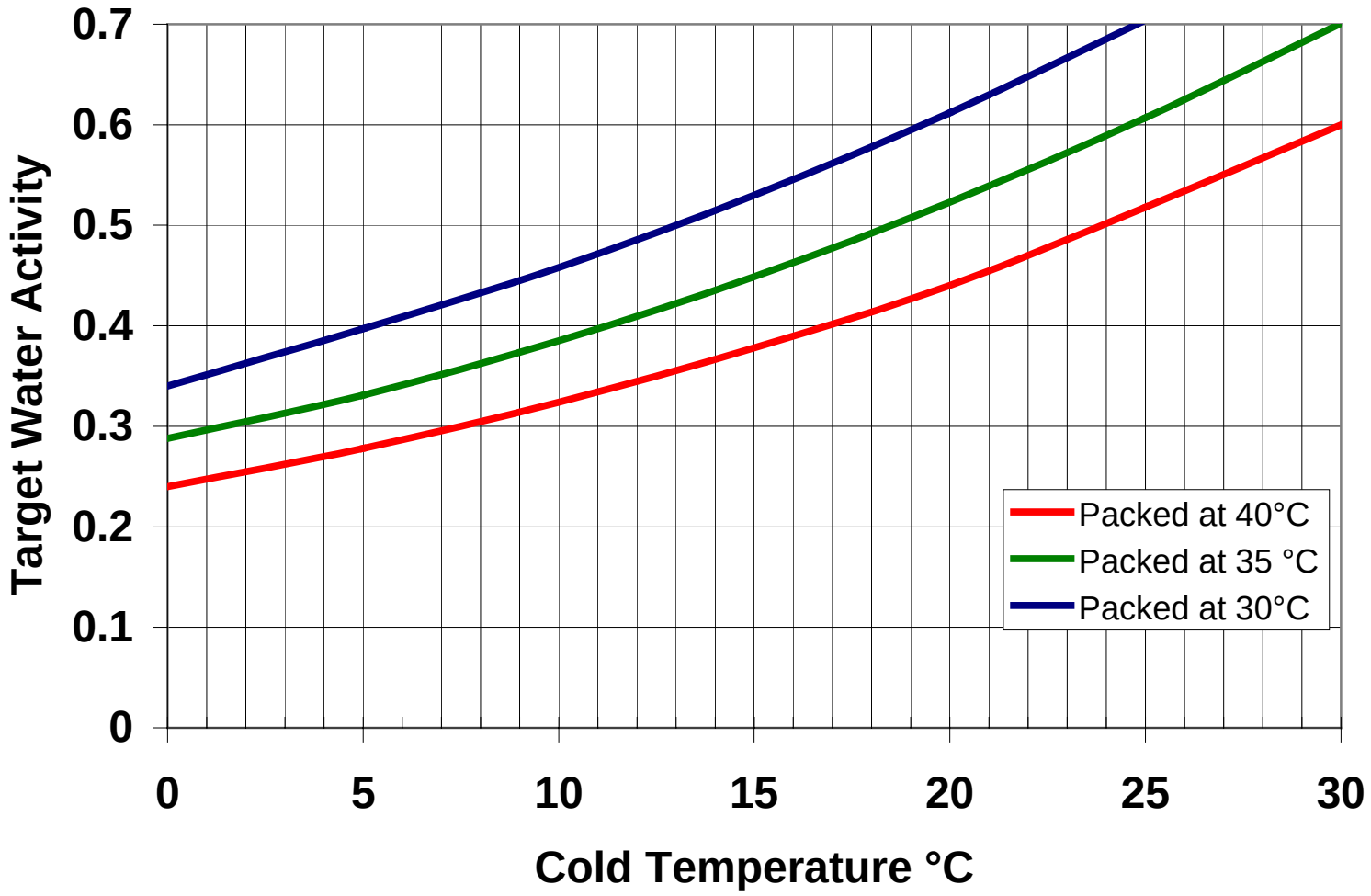
Moisture migration



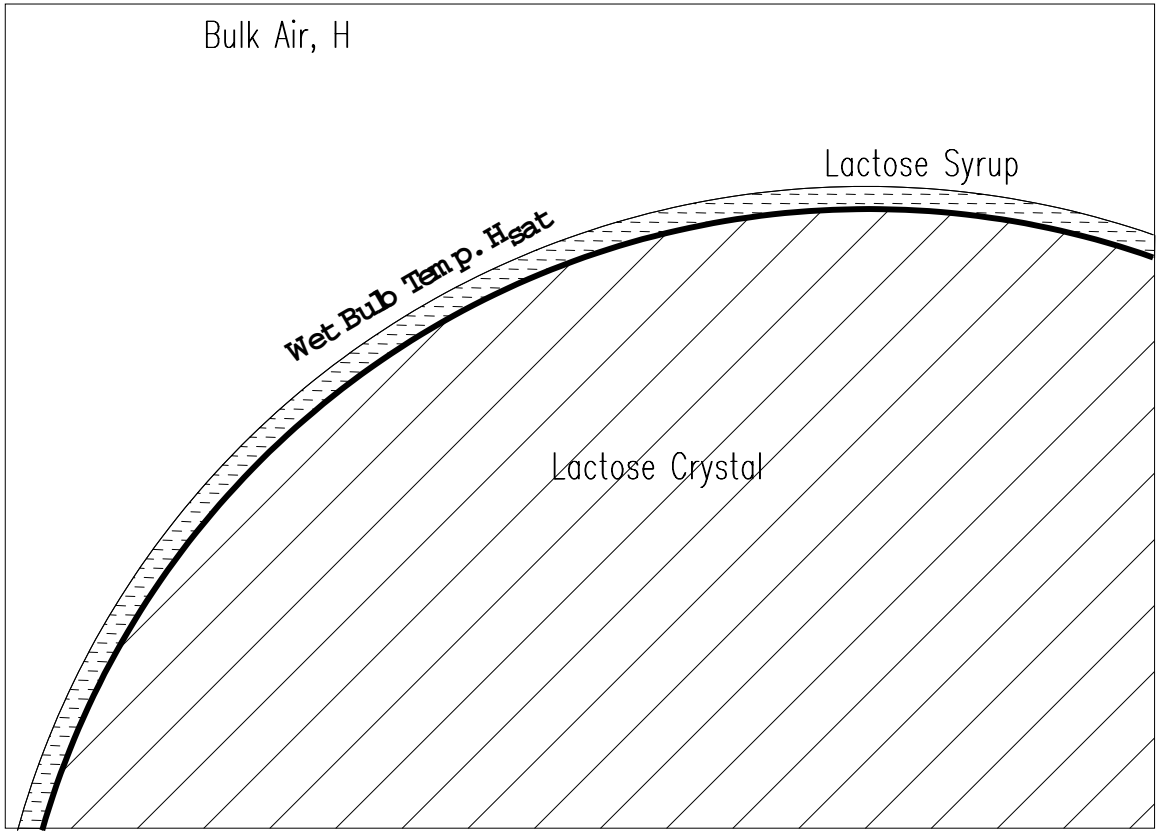
Moisture migration in crystalline lactose



Crystalline Lactose Curves of Maximum Aw=0.8

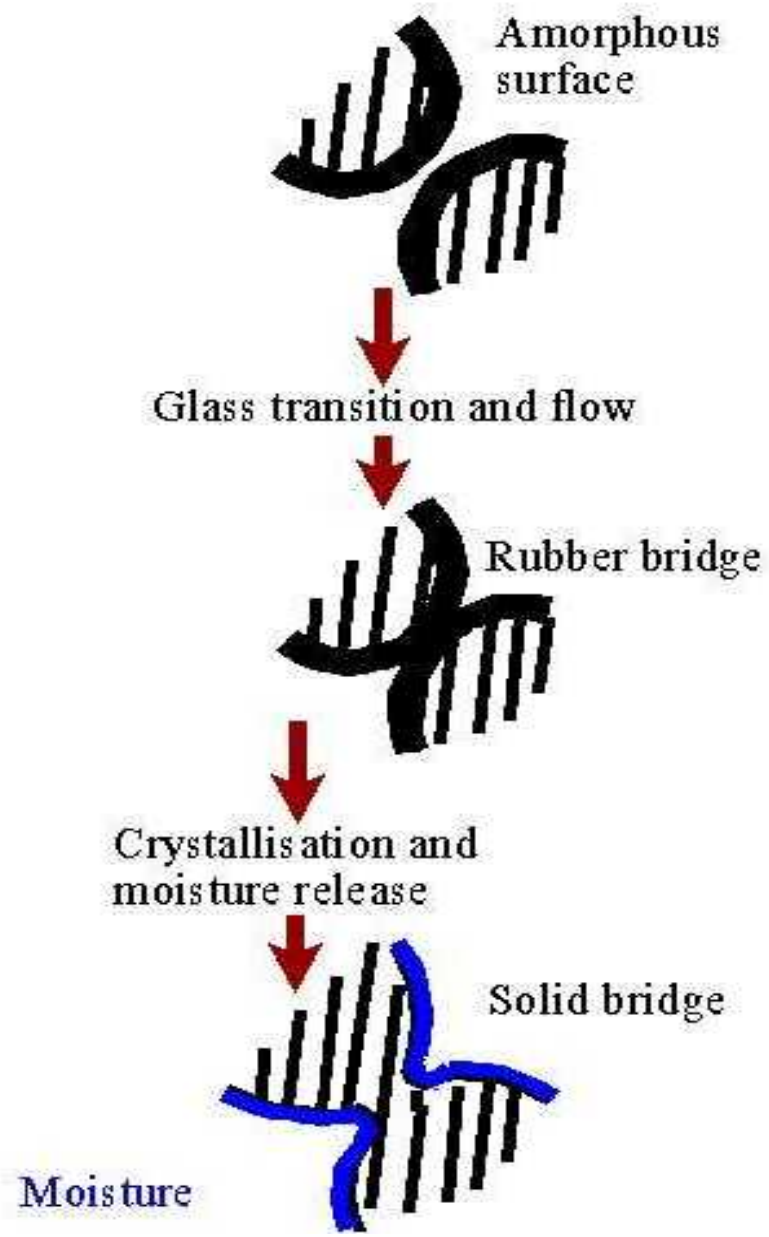


Effect of amorphous lactose



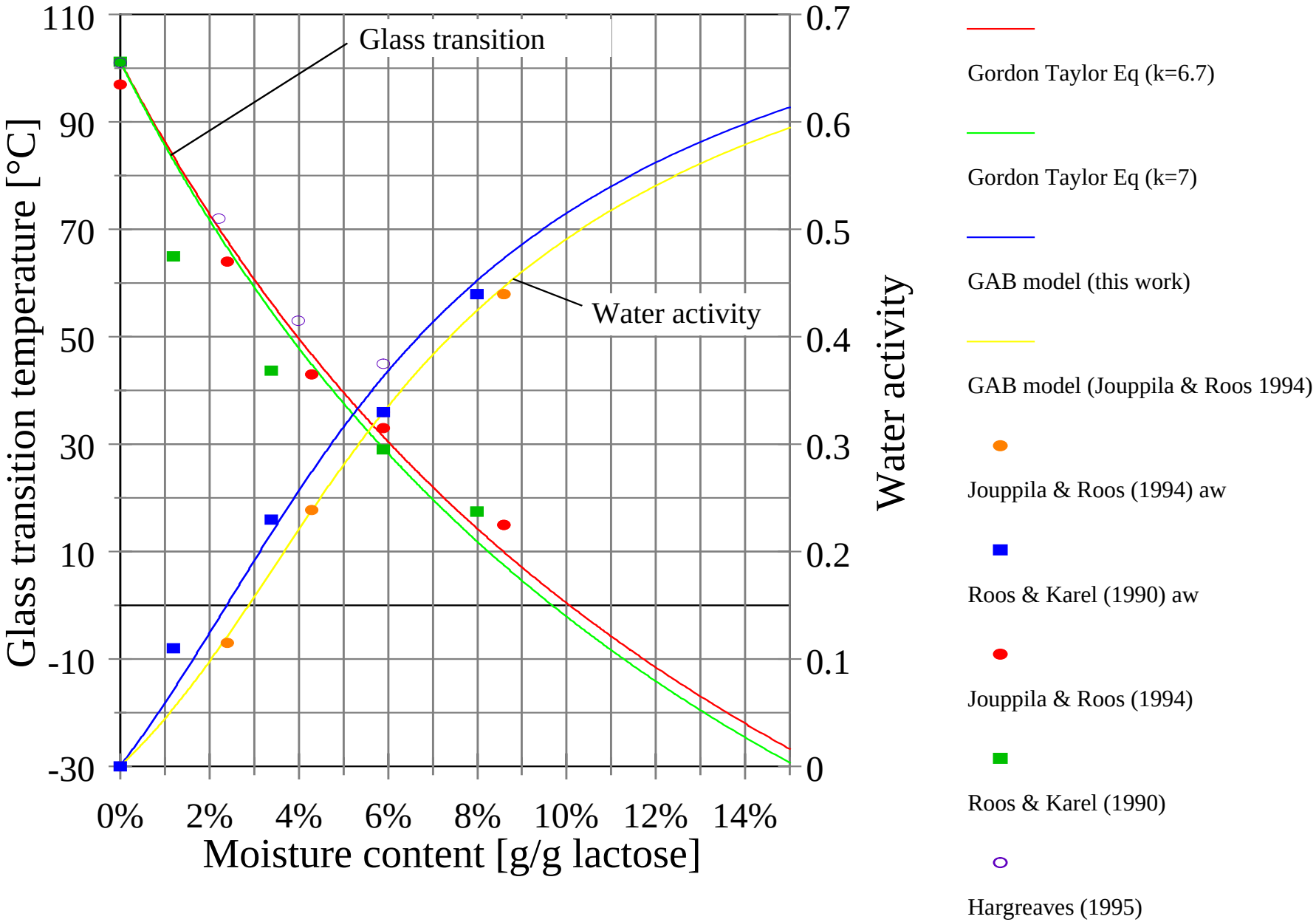
Amorphous Lactose Flow

- Above T_g
  - flow
  - bridges formed

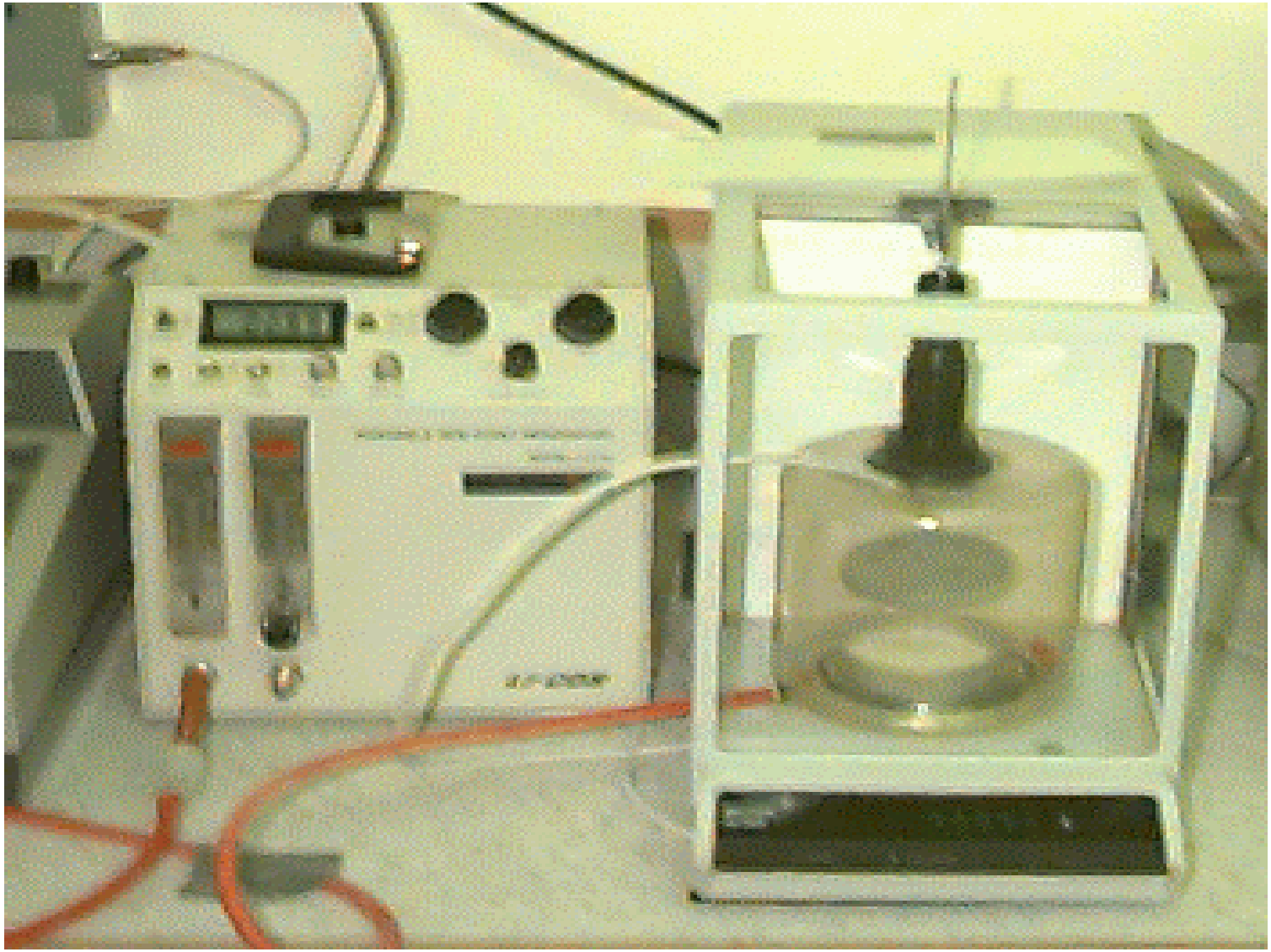


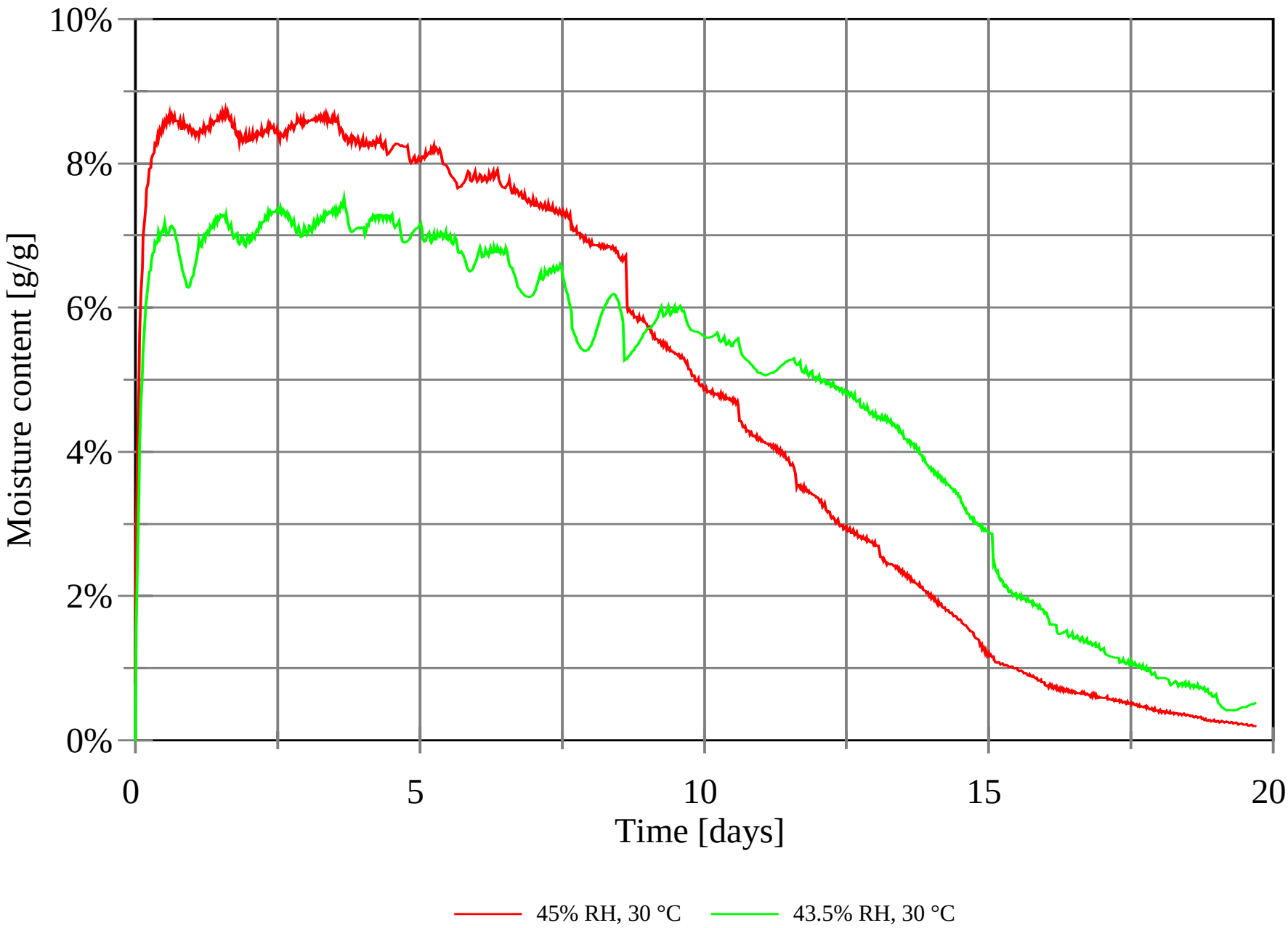
To include amorphous lactose:

- Need to know:
  - Glass transition temperature relationship to MC
  - Water activity relationship to MC: sorption isotherm
  - Amorphous lactose crystallisation kinetics as a function of MC/water activity/Tg


Glass transition
Water activity
Glass transition temperature [°C]
Water activity
Moisture content [g/g lactose]
110
90
70
50
30
10
-10
-30
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0%
2%
4%
6%
8%
10%
12%
14%
Gordon Taylor Eq (k=6.7)
Gordon Taylor Eq (k=7)
GAB model (this work)
GAB model (Jouppila & Roos 1994)
Jouppila & Roos (1994) aw
Roos & Karel (1990) aw
Jouppila & Roos (1994)
Roos & Karel (1990)
Hargreaves (1995)

Amorphous lactose crystallisation kinetics




10%
8%
6%
4%
2%
0%
Moisture content [g/g]
0
5
10
15
20
Time [days]
45% RH, 30 °C
43.5% RH, 30 °C

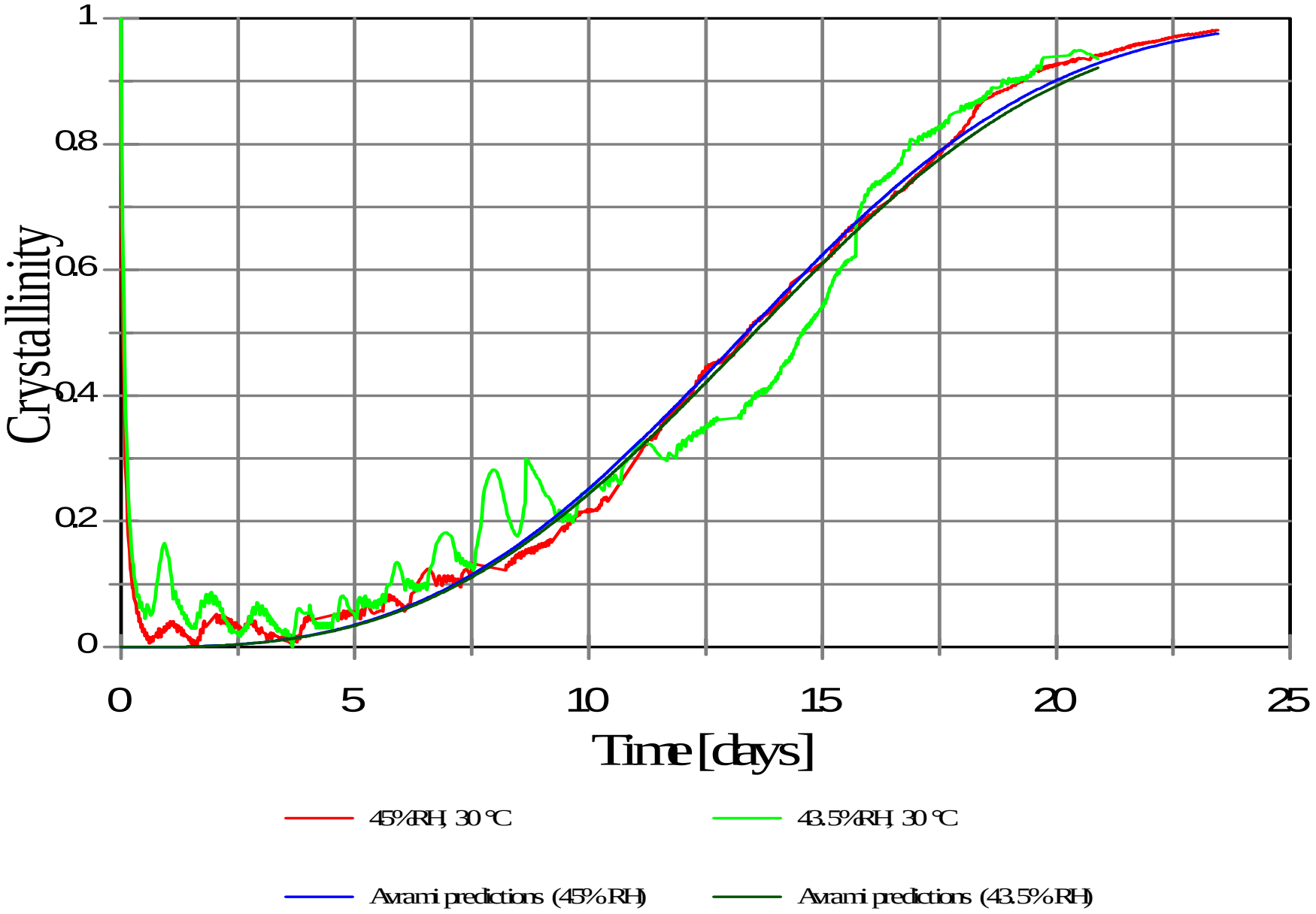
Equations!!

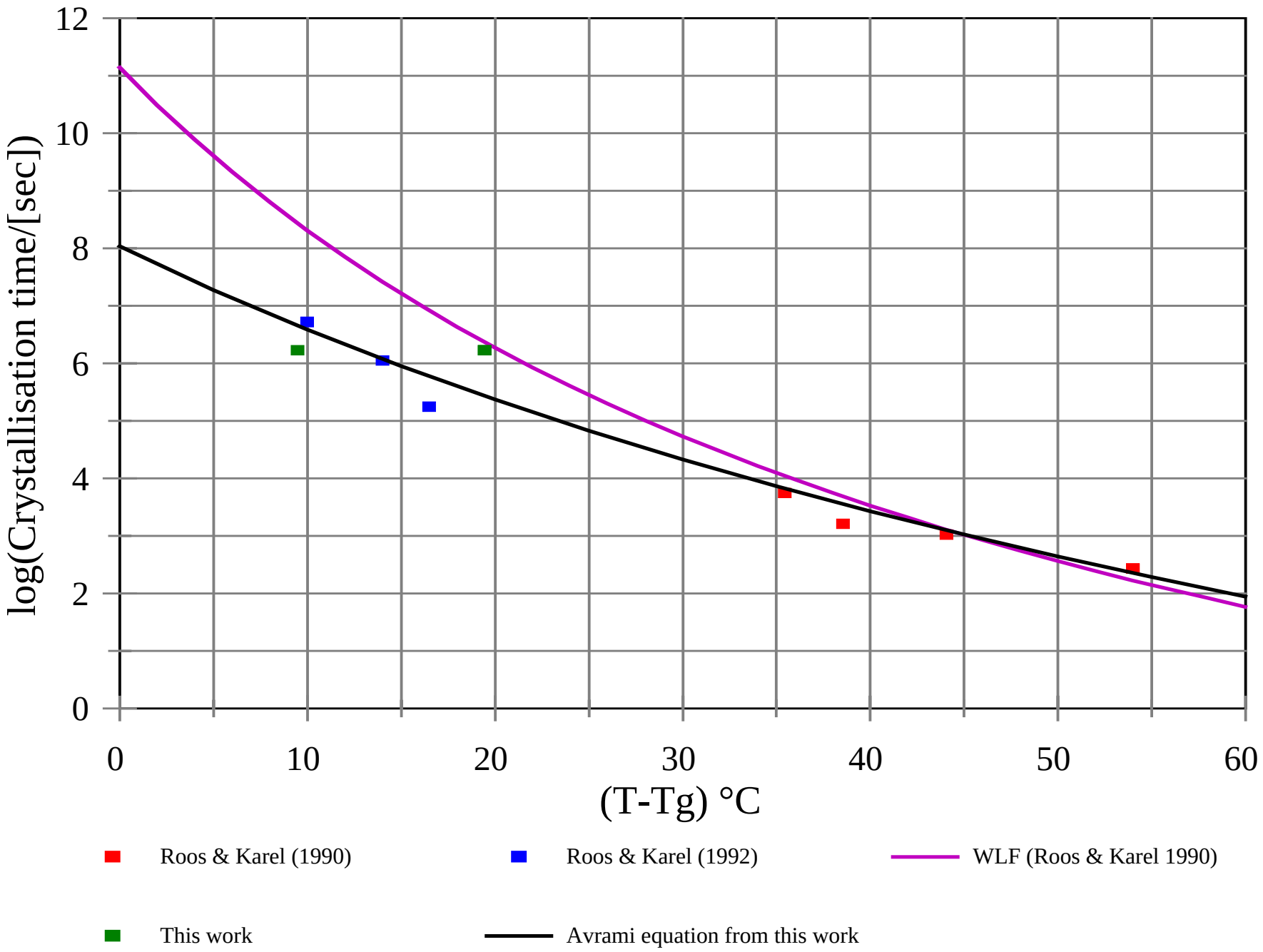
- Differential Avrami equation:

$$\frac{d\left(1-Y\right)}{dt} = nKY\left[\frac{-\ln\left(Y\right)}{K}\right]^{\frac{n-1}{n}}$$

Where:

$$K = C_3\left[e^{-\frac{C_1}{R\left(C_2+T-Tg\right)}}\right]^3$$

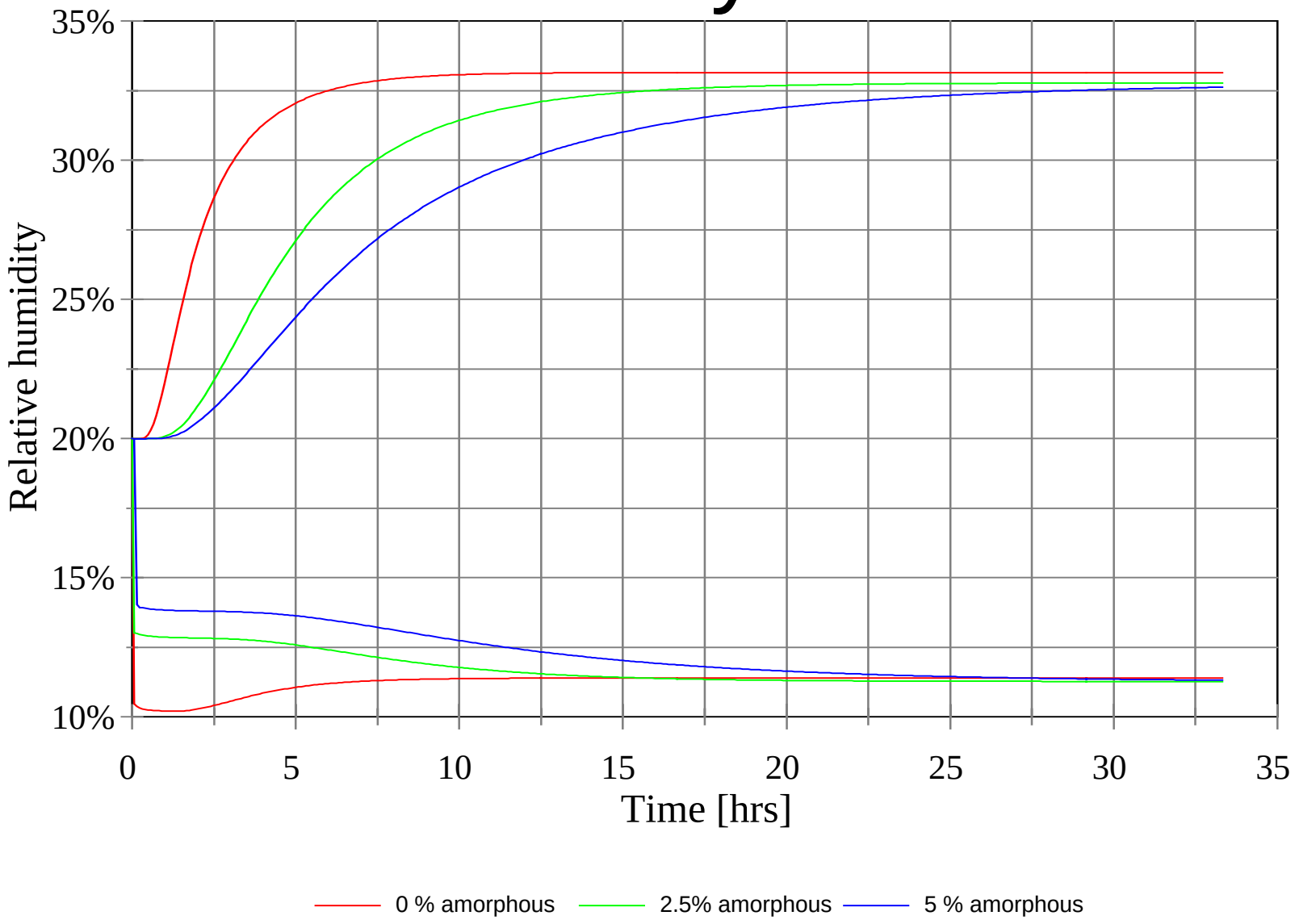

Crystallinity
1
0.8
0.6
0.4
0.2
0
0
5
10
15
20
25
Time [days]
45%RH, 30 °C
43.5%RH, 30 °C
Avrami predictions (45%RH)
Avrami predictions (43.5%RH)


log(Crystallisation time/[sec])
12
10
8
6
4
2
0
0
10
20
30
40
50
60
(T-Tg) °C
Roos & Karel (1990)
Roos & Karel (1992)
WLF (Roos & Karel 1990)
This work
Avrami equation from this work

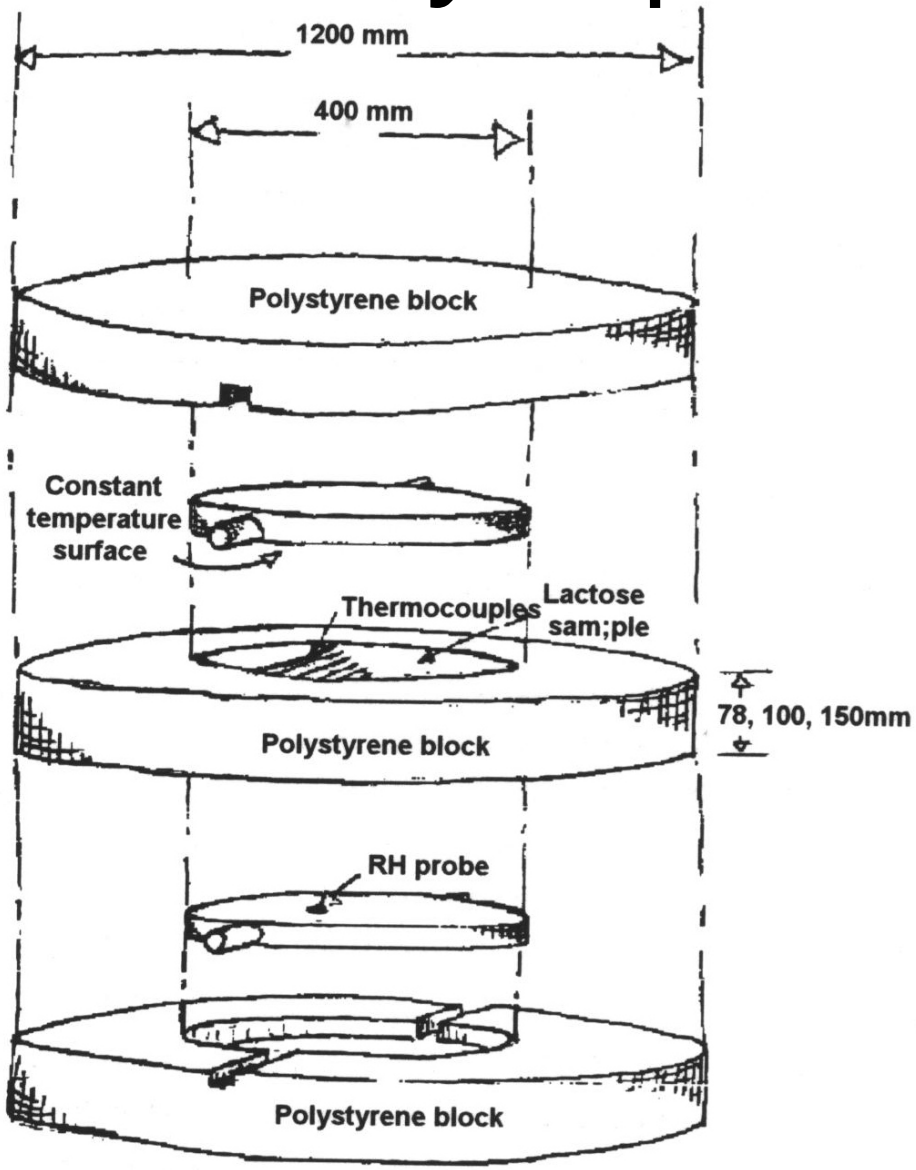
Amorphous lactose modifications made to model

- Adsorption into amorphous lactose layer
- Crystallisation kinetics added

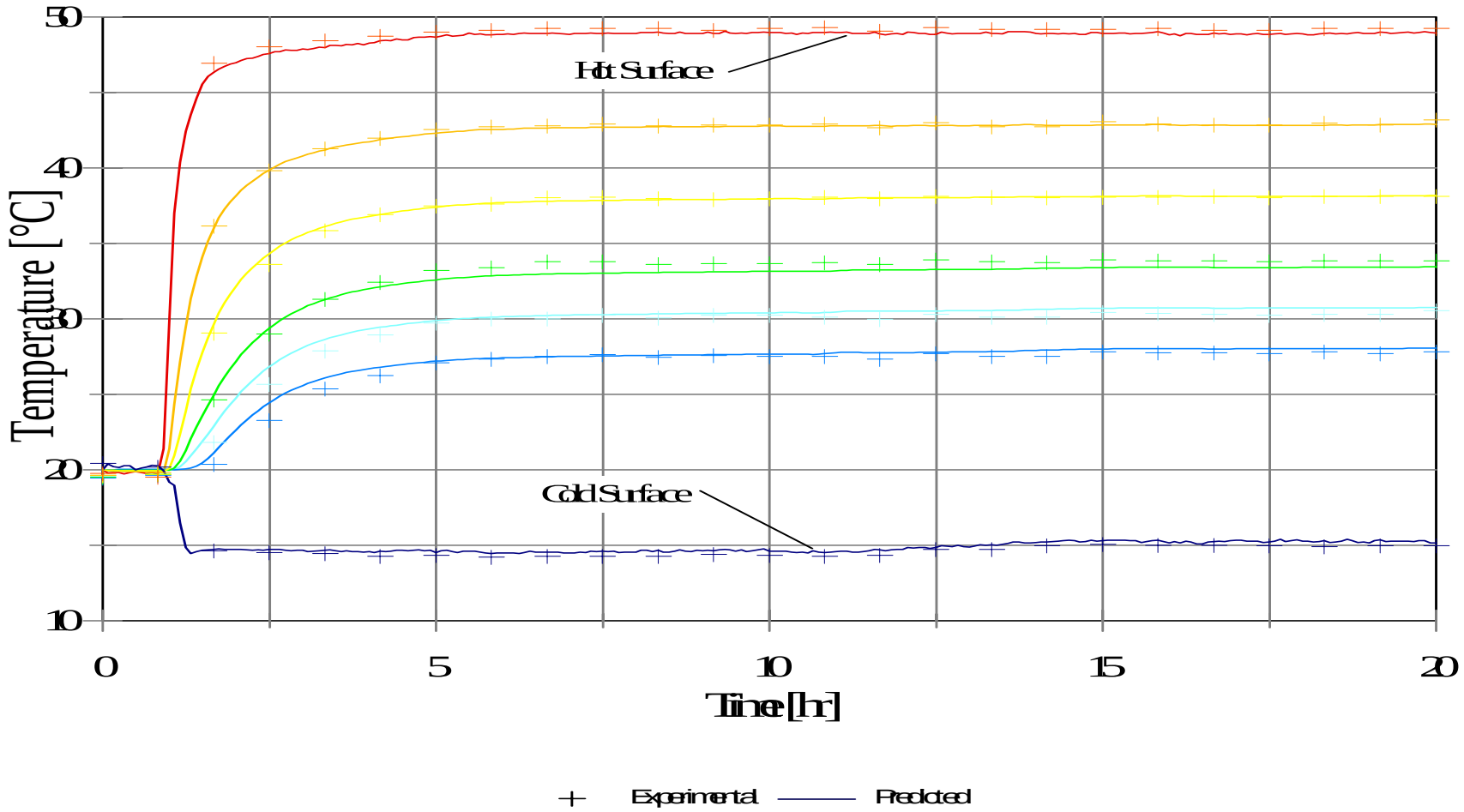
Effect without crystallisation



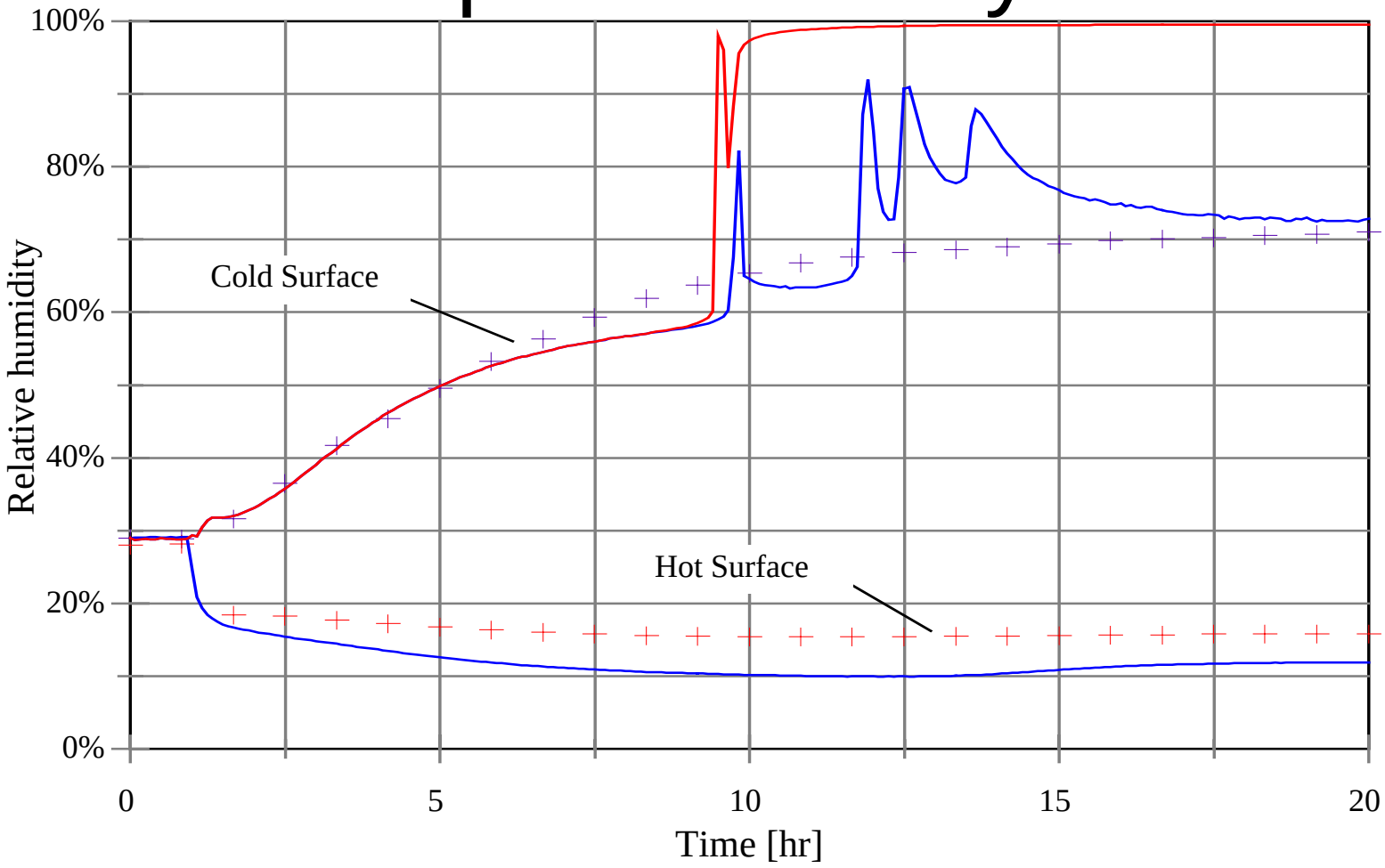
Validation by experiment



Temperature profile

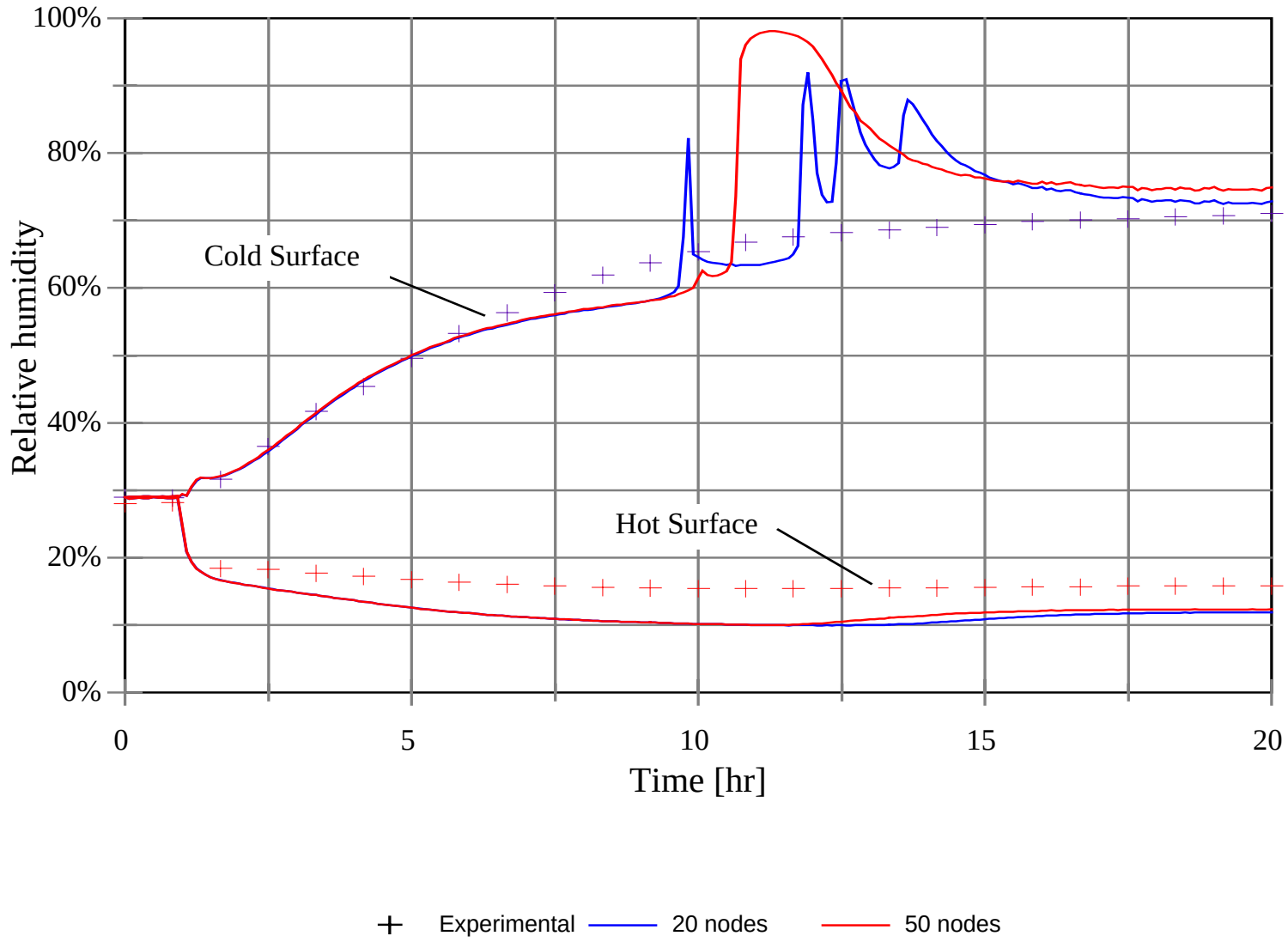


Effect of product of crystallisation



Experimental alpha lactose product beta lactose product

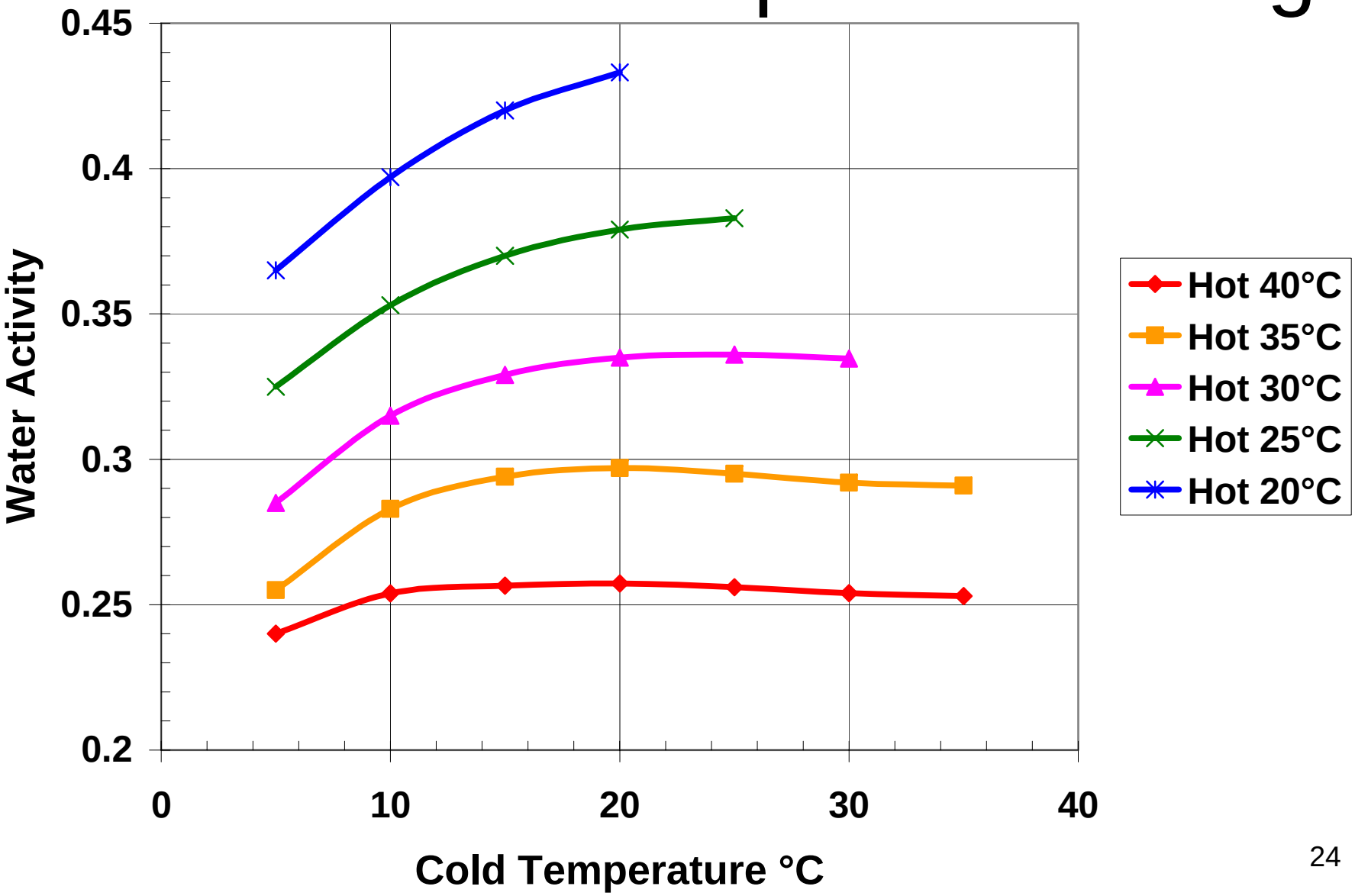
Effect of number of nodes in model



Results

- Predictions show a bigger effect than what is observed in practice.
- Using more nodes improves predictions, but once crystallisation starts model reacts too fast
- probably a resistance to the water escaping that is not modelled
- New approach: identify where Tg exceeded.

Cold surface temperature at Tg



Conclusions

- Amorphous lactose presence means lactose powders must be dried to lower water activities
- If amorphous lactose is present, it must be kept below its Tg at all times (especially at pack out)
- Large temperature gradients are needed for the moisture movement to become a factor at higher pack out temperatures