280371 Process Engineering Operations

Lecture 5: Product Weight Loss

Product mass (weight) loss

- A significant quantity of water can be lost from unwrapped products during:
  - Chilling and freezing
  - Storage, distribution & retail display
  - Home storage
- Can be 2-20% depending on product:
  - Loss of saleable weight
  - Loss of visual quality
  - Loss of texture (fruit & vegetables)

Mass loss examples

Chilling and Freezing

- Chilling
  - Important to cool product quickly

- Freezing
  - Weight loss before packaging
  - Individual Quick Frozen (IQF)
  - Quickly freeze and quickly pack

Factors affecting weight loss

- Surface area/volume ratio
- Surface coatings
- Mechanical damage to tissues
- Vapour pressure around product important – difference provides driving force for water loss

Control of water loss

- Lower product temperature
- Increase humidity
- Reduce air movement
- Packaging
  - Different packaging materials reduce water loss
    - Paper and fibre board
    - Wood
    - Polyethylene films
  - Reduces the rate of cooling

Packaging

- Any packaging film around the product will provide an extra resistance to mass transfer and thus reduce (or eliminate) weight loss.
  - But will also slow rates of cooling

- The presence of large amounts of corrugated cardboard packaging with unwrapped product will act as an additional moisture sink (with associated loss of cardboard strength)

Mass loss during Cooling (chilling and freezing)

- Mass loss obtained by integrating the mass transfer equation over the time it takes to complete the process.

$$m_v = \int_{start}^{finish} k_y A_{prod} \left(H_{prod\,surface} - H_{air} \right) dt$$

k_y can be estimated from heat transfer coefficients (from correlations)
$H_{\text{prod surface}}$ is a function of $\theta_{\text{prod surface}}$ which changes with time

Weight Loss During Chilling and Freezing

k_y - estimated from heat transfer coefficients (kg m^{-2} s^{-1})

$$k_y \approx \frac{h}{c_p}$$

c_p = specific heat of humid air

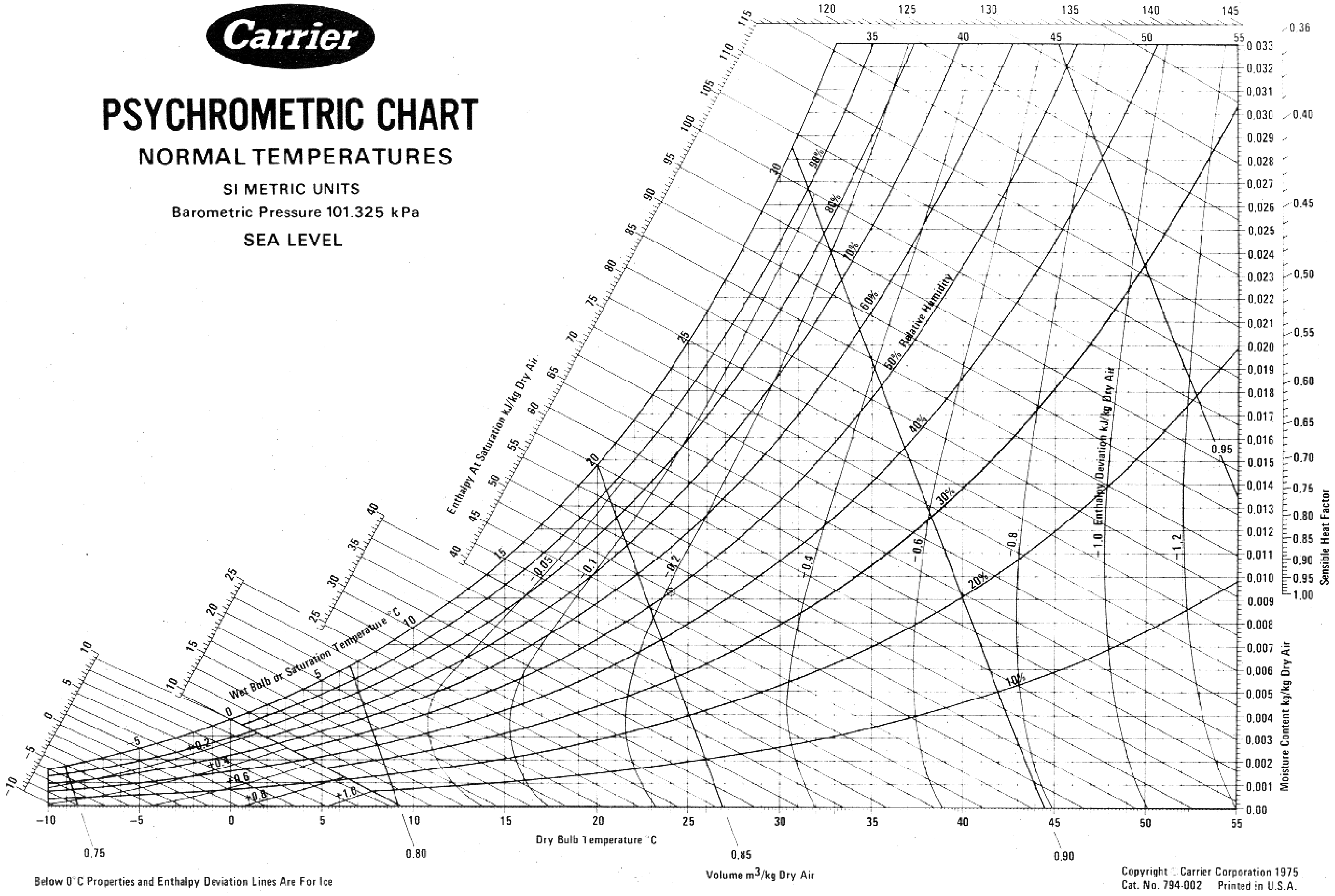
= $c_{p\ air} + H_{air}\, c_{p\ steam}$ (J kg^{-1} K^{-1})

Weight Loss During Chilling and Freezing

Plot

$$k_y A_{prod}\left(H_{prod\,surface} - H_{air}\right) \quad vs \qquad time$$

- Initial weight loss is fast – surface temperature ($\theta_{prod\ surface}$) hotter than air temperature
- Weight loss slows as time progresses
- Surface temperature of product continually changing hence $H_{surface}$
- Need values for $k_y A_{prod}\left(H_{prod\,surface} - H_{air}\right)$ with time



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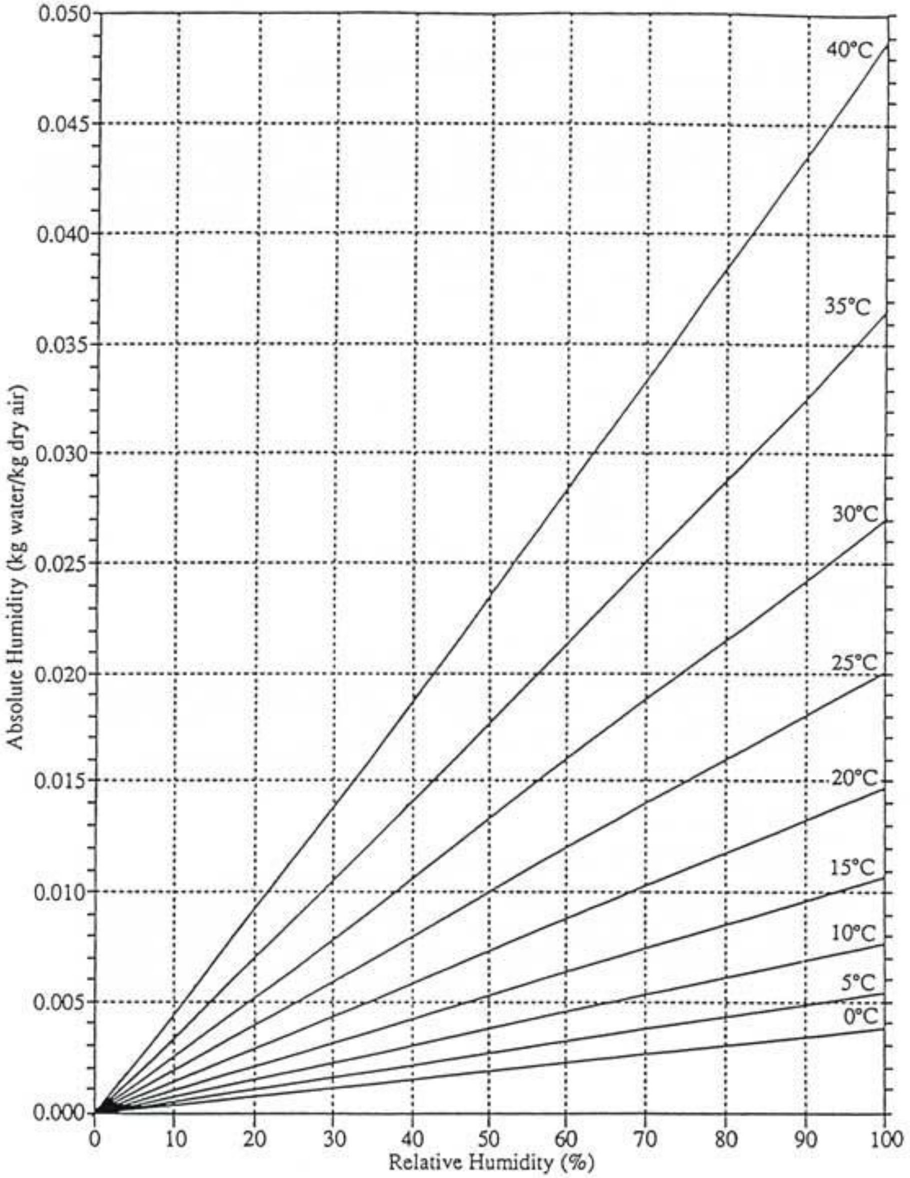
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Absolute Humidity (kg water/kg dry air)
0
10
20
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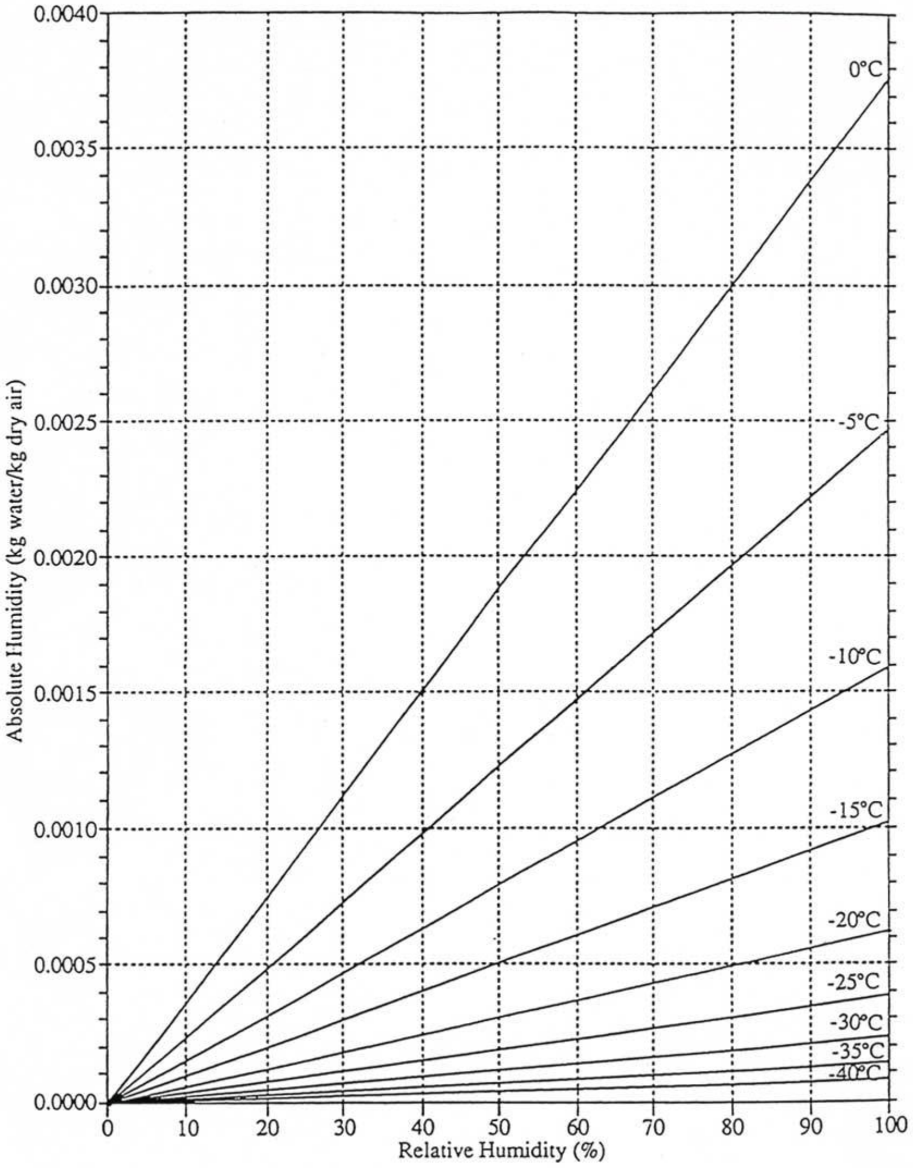
Relative Humidity (%)
40°C
35°C
30°C
25°C
20°C
15°C
10°C
5°C
0°C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Absolute Humidity (kg water/kg dry air)
0
10
20
30
40
50
60
70
80
90
100
Relative Humidity (%)
0°C
-5°C
-10°C
-15°C
-20°C
-25°C
-30°C
-35°C
-40°C

Example 13: Freezing weight loss.

Peas are being frozen in a fluidized bed freezer. The peas are present for 110 seconds in an air temperature of -38°C and with a surface heat transfer coefficient of 150 W/m^{2}K. The air relative humidity is approximately 90%. Each pea is 8mm in diameter and the density of the peas is approximately 1000 kg/m^3. Estimate the % weight loss in freezing if the measured surface temperature/ time data is as follows. $C_p$air □ 1000 J/kgK @-38°C

time (s)	Surface temp	$H_{surface}$	$K_y * A(H_s - H_{air})$
0	20		
10	8		
20	0		
30	-2		
40	-4		
50	-6		
60	-8		
70	-11		
80	-14		
90	-18		
100	-21		
110	-26		

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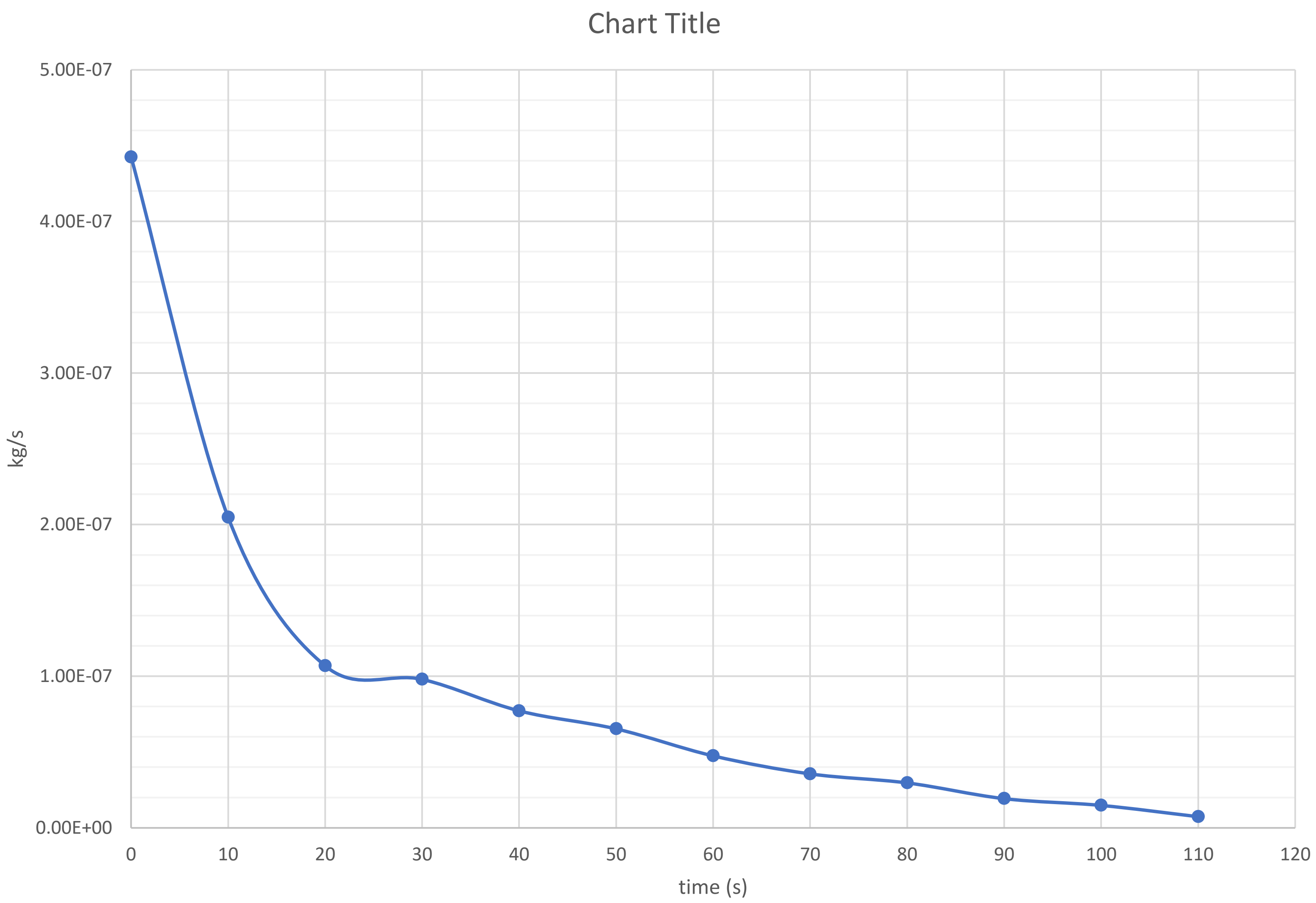
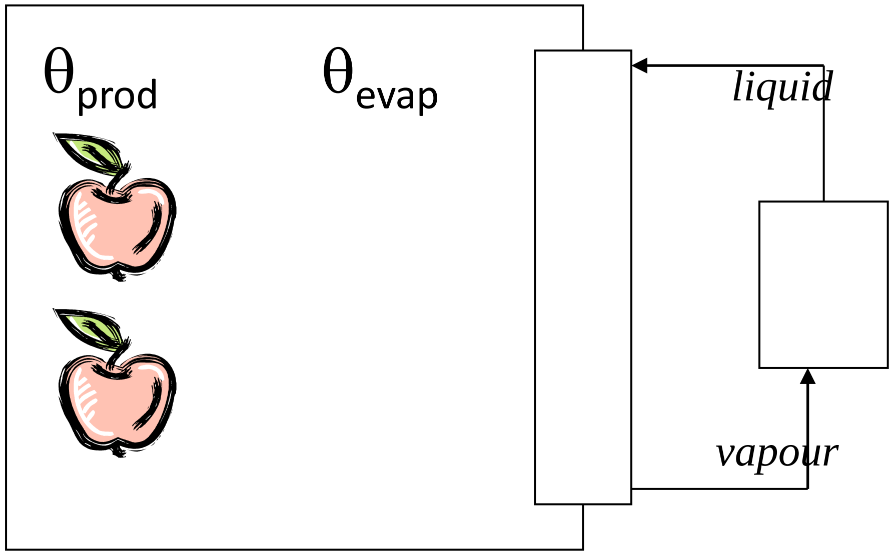
time (s)	Surface temp	$H_{surface}$	$K_y * A(H_s - H_{air})$
0	**20**	0.01500	4.42E-07
10	**8**	0.00700	2.05E-07
20	**0**	0.00370	1.07E-07
30	**-2**	0.00340	9.80E-08
40	**-4**	0.00270	7.72E-08
50	**-6**	0.00230	6.53E-08
60	**-8**	0.00170	4.75E-08
70	**-11**	0.00130	3.56E-08
80	**-14**	0.00110	2.97E-08
90	**-18**	0.00075	1.93E-08
100	**-21**	0.00060	1.48E-08
110	**-26**	0.00035	7.42E-09

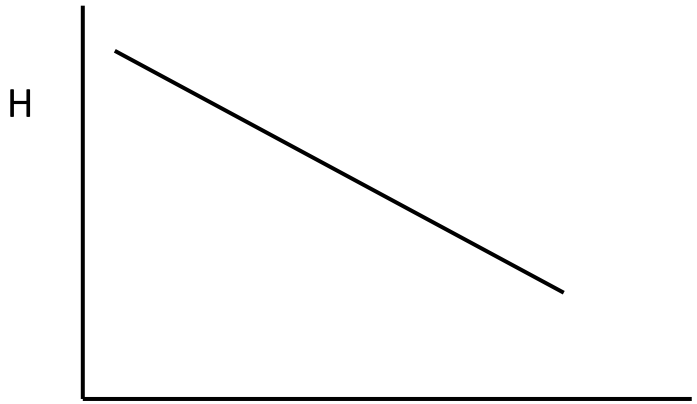
Graphical integration



Weight Loss During Storage

- Evaporator of refrigeration system is colder than storage room temperature
- Evaporator surface creates a sink for condensing moisture





Evaporator

Mass loss during storage

- driving force for heat transfer: ($\theta_{room} - \theta_{evap}$)
- The low θ_{evap} creates a sink for condensing moisture in the air, and a concentration driving force between:
  - the product (hot, high water conc.)
  - the evaporator (cold, low water conc.).
- There are two mass transfer resistances for moisture to travel from the source to the sink
  - transport from the product to the bulk air
  - transport from the bulk air to the evaporator.
  - these resistances can be summed in series to obtain the rate of weight loss.

1. Transport from product to bulk air

$$\frac{1}{k_{y\,prod}\,A_{prod}}$$

2. Transport from the bulk air to the evaporator

$$\frac{1}{k_{y\,evap}\,A_{evap}}$$

3. Sum the resistances in series
4. Overall mass transfer coefficient K_y

$$\frac{1}{K_y\,A_{prod}} = \frac{1}{k_{y\,prod}\,A_{prod}} + \frac{1}{k_{y\,evap}\,A_{evap}}$$

- *Weight loss during storage of a product*

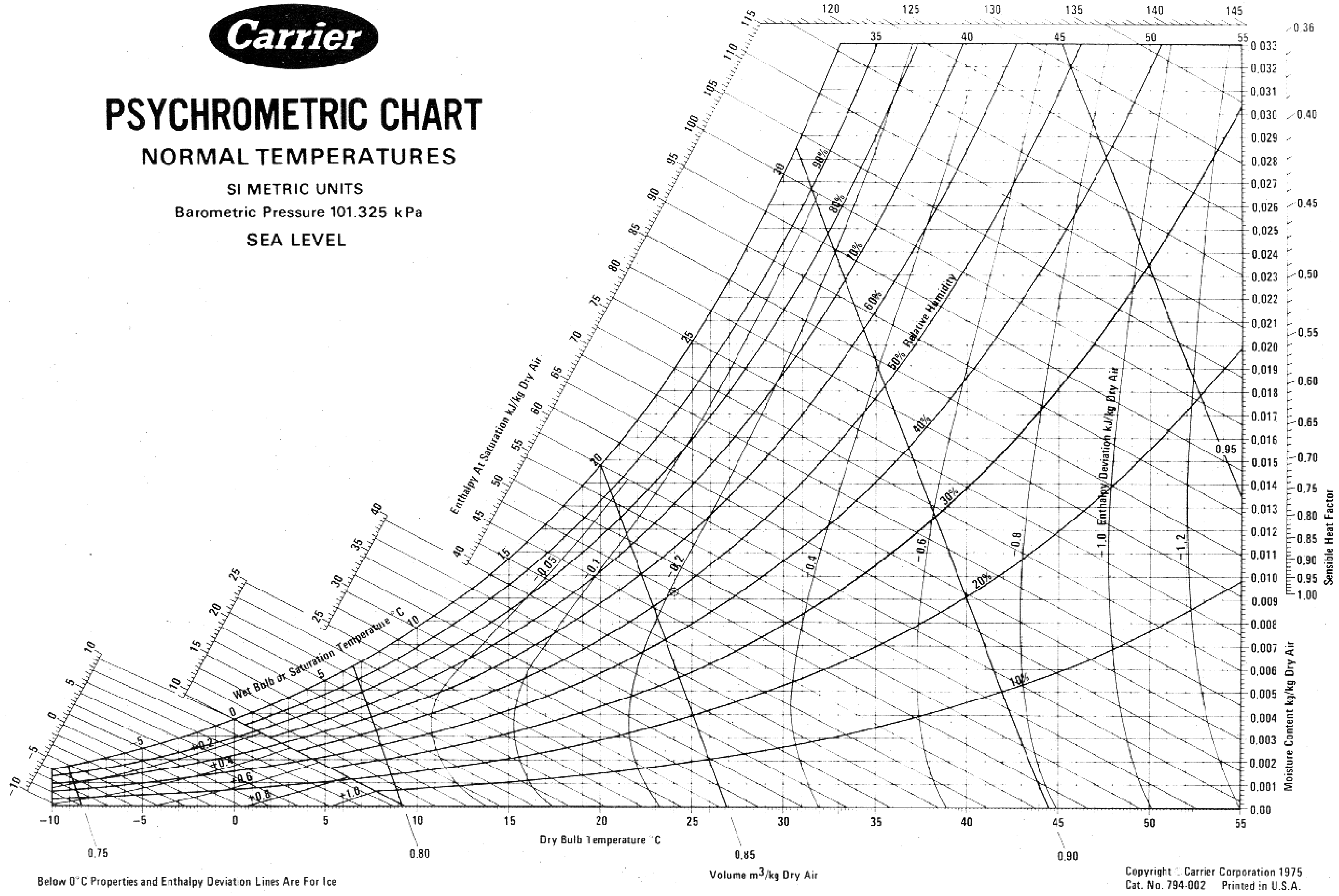
$$w = K_y A_{prod} \left(H_{prod\,surface} - H_{evap} \right) \Delta t$$

$H_{prod\ suface}$ - is a constant as a dynamic equilibrium has been achieved

Example 14: Weight loss from stored product

(a) Calculate the weight loss from stored unwrapped lettuce (diameter = 20cm) over 2 days in a domestic fridge when the lettuce temperature is 4°C and the evaporator plate temperature is -5°C. The heat transfer coefficients to the lettuce and to the evaporator plate are estimated to be 15 W/m^2K and 20 W/m^2K, respectively. The evaporator plate is 20 cm high and 20 cm wide.

(b) What temperature do you expect the air around the lettuce to be at? Will the air in the fridge be saturated with moisture?



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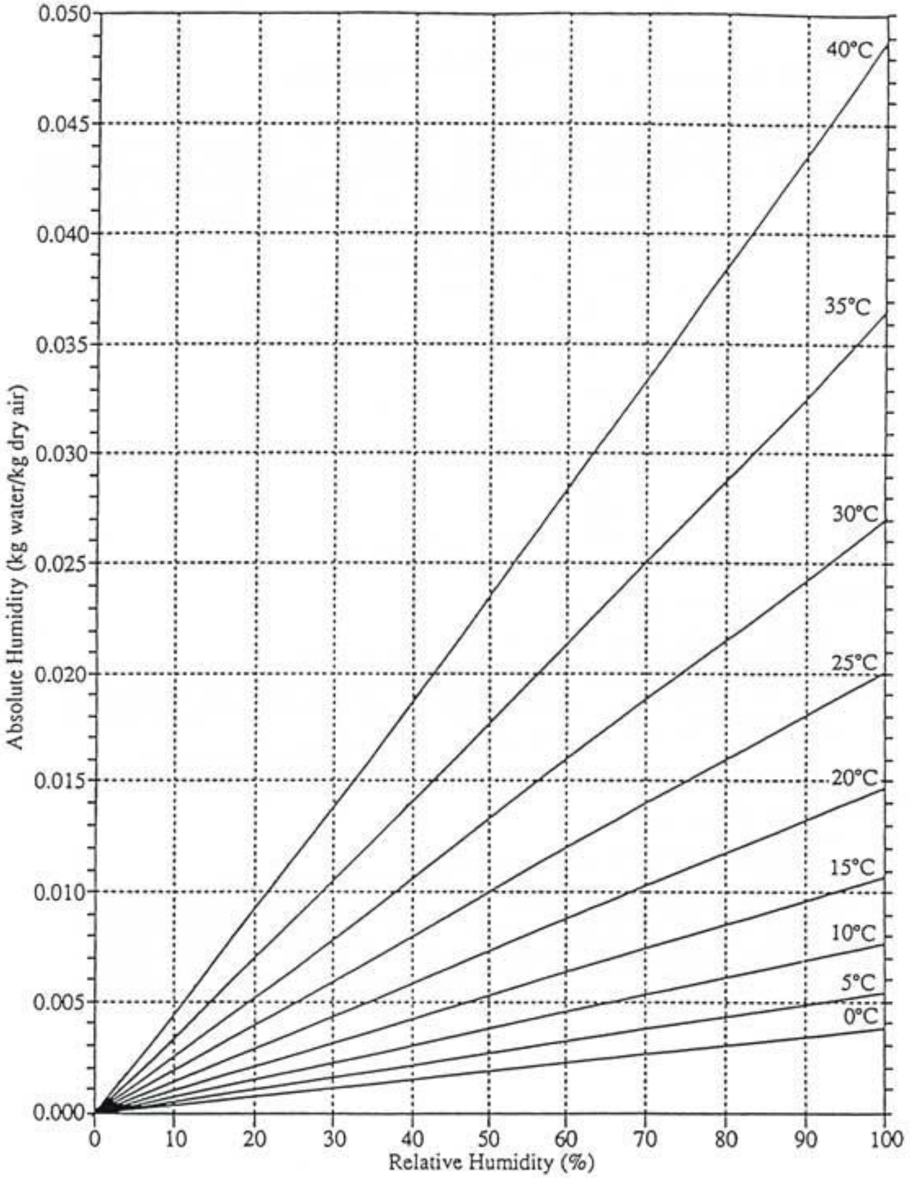
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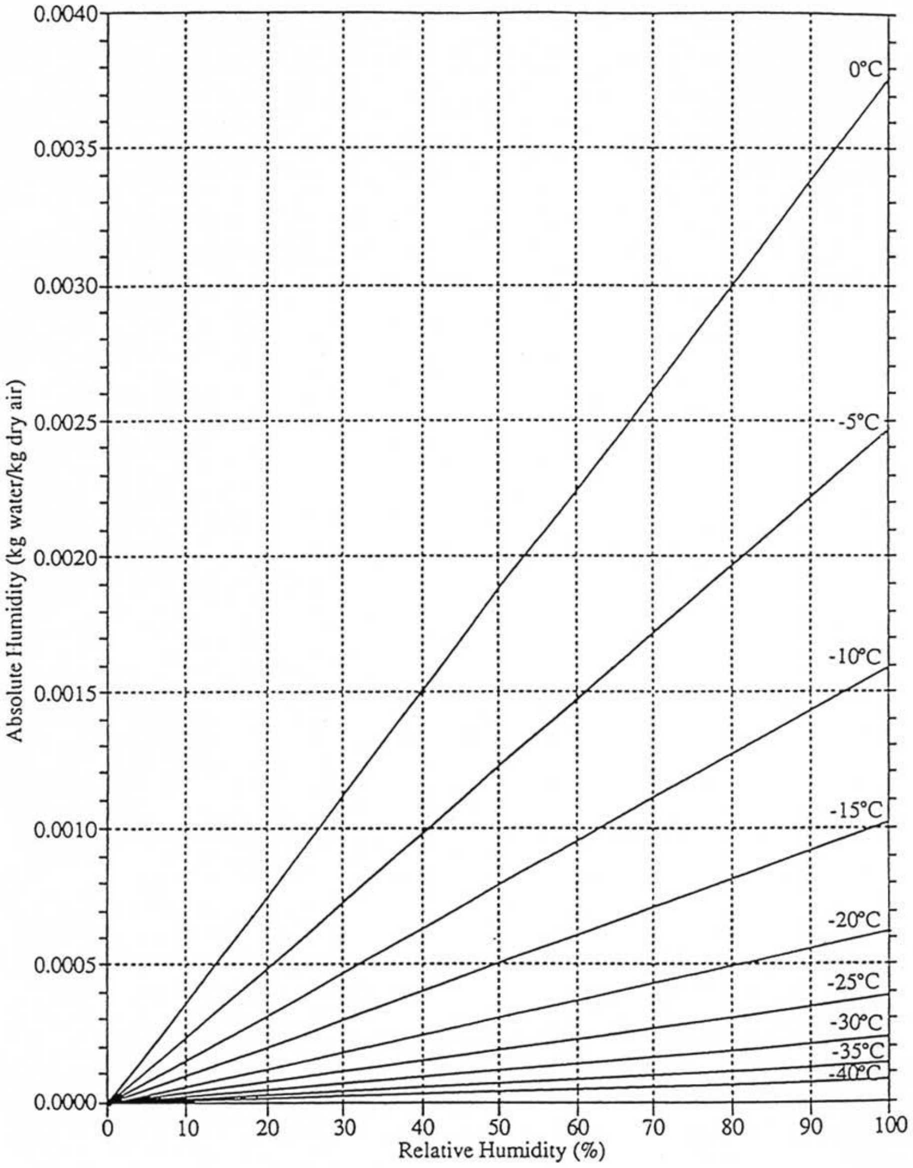
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-40°C

Example 15: Weight loss from stored product

A half peeled 8cm diameter apple was found beside the body in the shed. Mr. Holmes the detective carefully cut the apple in half to find that the unpeeled half weighed 0.2% more than the peeled half. Consulting the weather bureau he determined that the 50 m^2 of shed cladding surrounding the body would have been at approximately 10°C while the air inside the shed (and the apple) was at 12°C. He estimates that the heat transfer coefficient from the air to the cladding (and the apple) is approximately 5 W/m2K and the density of the apple is 1000 kg/m^3. Taking out his trusty weight loss calculations he determines the time of the murder. How long ago was it ?