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HALF-COOLING TIME OF BEER IN CONTAINERS INSULATED WITH AIR BUBBLE FILM

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Abstract

The half-cooling time of beer in the most exposed pallet in a double-air-bubble film insulated 40 ft-container is 45 hours. Compared with the half-cooling time of a non-insulated container (20 hours), an improvement of 125% was obtained. Theoretically a half-cooling time of 65 hours was expected, if also the floor of the container had been insulated.

type of insulation	shortest half-cooling time (hours)
non insulated	20
single air bubble film	29
double air bubble film	45

1. Introduction

Beer is transported in containers and therefore subjected to ambient temperature conditions. The rate of cooling of beer in containers under cold weather conditions depends on the "half-cooling time". The half-cooling time is the elapsed time in which the temperature of the beer decreases of a temperature exactly between the initial beer temperature and the ambient air temperature. The half-cooling time has the important property that it is independent of the real initial beer and ambient air temperature, and only depends on the characteristics of the produce, the package, packaging, stowage and container wall. Therefore the "half-cooling time" is a very convenient measure for expressing cooling rates and comparing them under a wide range of conditions (see figure 1.1).
In this particular case, bottles of beer in the corners of a pallet, the first half-cooling time is shorter than the next half-cooling times. This is the reason why the basis of the calculation of the half-cooling time is taken 10 hours after the start of cooling.
The half-cooling time of a bottle of beer in the centre of the pallet is theoretically equal to the half-cooling time of a bottle in the corner. The difference is that the lag time factor for the centre is positive and for the corner negative. This means that for a centre point the apparent initial beer temperature is higher than the virtual beer temperature.
On the other hand the apparent initial beer temperature in the corner is lower than the virtual beer temperature. The intercept of the straigt cooling curve with the vertical axis determinates the apparent initial beer temperature (see figure 1.2).

2. K-value of additional insulation

The measured shortest half-cooling time of beer, EB-8 in six packs on pallets wrapped in shrinkfilm, in a non-insulated container is 20 hours (lit.: Sprenger Institute, report nr. 192). From the results of Australian research on warming of chilled products in insulated containers, the half-cooling time is known as a function of the K-value of the insulation. Figure 2.1 shows the relation between half-cooling time and K-value.
If a container is exposed to -10^{o}C ambient air temperature, starting with a beer temperature of 10^{o}C, the temperature of the beer will be -1^{o}C (very sale limit) after 1, 2 numbers of half-cooling times. If the transport time is 4 days (= 96 hours) the half-cooling time needed to prevent the beer from freezing is 80 hours.

Figure 2.2 shows that a half-cooling time of 80 hours can be achieved with a K-value of 0.9 $W/(m^2 \cdot K)$.
A practical solution of additional insulation is the use of air-bubble film. One layer of air-bubble film has a K-value of 3.3 $W/(m^2 \cdot K)$, resulting in a K-value of the container wall of about 2 $W/(m^2 \cdot K)$. Two layers of air-bubble film result in a K-value of 1.1 $W/(m^2 \cdot K)$, expecting a half-cooling time of 65 hours (see figure 2.1).
Considering the advantages (price, handling) of air-bubble film and considering the theoretical K-value (1.1) nearly equals the needed K-value (0.9), an experiment with two containers has been executed.
The biggest problem is that in practice the floor of the container cannot be insulated, resulting in a high normal K-value of 3.2 $W/(m^2 \cdot k)$.
A 40 ft container was insulated with two layers of air-bubble film.
The floor was not insulated and behind the doors 3 layers of air-bubble film were present. A 20 ft container was insulated with 1 layer of air-bubble film.

3. Experimental procedure

The containers, loaded with pallets of warm beer, were placed in a cold room of the auction Westland-Noord (Nieuweweg 56c, Monster, tel. 01749-45959). The main temperature in the cold room was 1.8°C and the air velocity around the container was approximately 0.3 to 1 m/s.
The start of the experiment was at 11.15 A.M. on Saturday September 11, and it lasted to Monday-morning 6.30 A.M. The temperature sensors were placed in the corner-bottles of the indicated pallets in figure 3.1.
A few air temperature sensors were placed in and around the containers.

4. Results of the cooling experiment

4.1. 40 ft container, half-cooling time from temperature

The cooling down curves are given in figure 4.1. As already explained the determination of the half-cooling time is based on the time 10 hours after the start of the cooling.
Figure 4.1 indicates that the shortest half-cooling time is 45 hours.
Points 4, 8 and 9 cool down very fast because the bottles of beer are surrounded by 3 wide air gaps. Points 5, 6 and 7 cool more slowly.

Sensor 0 drops very fast to 5°C. This sensor measured the temperature between the door and the layers of air bubble film. It shows that the door does not give much protection, because the air temperature above the pallets is 15°C to 12°C.

4.2. Half-cooling time from the ln (dimensionless temperature)

As already explained in section 1 a cooling down process can be determined more exactly using an apparent initial beer temperature, and a semi ln plot. Figure 4.2 shows the dimensionless temperature (ln-presentation) versus time.
From this figure the half-cooling times and the dimensionless apparent initial beer temperature (j) of all bottles are taken.
Table 4.1. shows the results.
The apparent initial beer temperature is: $T_{ao} = T_{amb} + j(T_o - T_{amb})$
where:

T_{ao}	°C	apparent initial beer temperature
T_{amb}	°C	ambient air temperature
T_o	°C	virtual initial beer temperature
j	-	dimensionless apparent initial beer temperature

For example the initial beer temperature of sensor 3 is 23°C, the ambient air temperature is 1.8°C, thus taking j = 0.75 from table 4.1. yield an apparent initial beer temperature of:

$$T_{ao} = 1.8 + 0.75\ (23 - 1.8) = 17.7\,^{o}C.$$

Table 4.1. Half-cooling time and apparent initial beer temperature (dimensionless). 40 ft-container

sensor nr.	half-cooling time hours	j
2	52	0.89
3	55	0.75
4	46	0.75
5	62	0.79
6	64	0.85
7	61	0.89
8	46	0.75
9	49	0.71
	54	mean 0.80

4.3. 20 ft container, half-cooling time from temperature

Figure 4.3 shows the measured temperatures.
The shortest half-cooling time has sensor 13 with 29 hours. Sensor 18 has a half-cooling time of 34 hours.

4.4. 20 ft container, half-cooling time from ln (dimensionless temperature)

Figure 4.4 shows the semi-ln representation of the experiment.
The half-cooling times and dimensionless apparent initial beer temperatures are taken from figure 4.4 and given in table 4.2. It is not clear why sensor 17 cools so slowly. It is a top bottle in the middle of the container and it should follow sensor 12 or 15.

Table 4.2. Half-cooling time and dimensionless apparent initial beer temperature (j) of the 20 ft container

sensor nr.	half-cooling time hours	j
13	33	0.75
14	37	0.75
15	37	0.75
16	42	0.82
17	61	0.82
18	36	0.69
19	50	0.75
		mean 0.76

5. Interpretation of results

5.1. Half-cooling time

A fast interpretation of the results is possible using the half-cooling times only. Introduction of the apparant initial beer temperature is only necessary in very exact calculations. According to the theory the needed half-cooling time is 80 hours. The 20 ft-container, insulated with one layer of air bubble film, does not reach this criterium ($t_{\frac{1}{2}}$ = 29 hours). The 40 ft container, with two layers of air bubble film, has a shortest half-cooling time of 45 hours. This is less than the expected value of 65 hours.

Table 5.1. Transport time in days of insulated and non-insulated containers

	temperature (°C)			
	initial beer	mean ambient -5	-7.5	-10
insulated	15 (10.5)	5.6 (5.2)	4.0 (3.5)	3.3 (2.8)
	10 (6.5)	4.7 (4.3)	3.4 (2.9)	2.6 (2.2)
non-insulated	15	2.5	1.8	1.5
	10	2.1	1.5	1.2

The data in brackets are the calculated transport times using the apparent initial beer temperature (also in brackets).

The non-insulated floor seems to be the reason for this difference. The mean half-cooling time of the 8 corners (54 hours) however approaches the expected half-cooling time. There is a marked difference between the shortest half-cooling time of a non-insulated container ($t_{\frac{1}{2}}$ = 20 hours) and an insulated container ($t_{\frac{1}{2}}$ = 45 hours), resulting in 125% improvement.

5.2. Transport time

The transport time depends on the initial beer temperature and the mean ambient air temperature and can be calculated with the help of figure 2.2 Using the real freezing point of beer (-25°C) table 5.1 shows the effect of different temperatures on the transport time. Reefers are indispensable on very cold routes, while double-air-bubble-film-insulated containers can be used on moderate cold (-5 - -7°C) routes.

5.3. Apparent initial beer temperature

Using the shortest half-cooling time (46 in table 4.1) and the mean apparent initial beer temperature, the transport times are also calculated. This more exact approach reduces the transport time with 0.5 days in all cases.

Wageningen, 4 oktober 1982

GvB/MJ

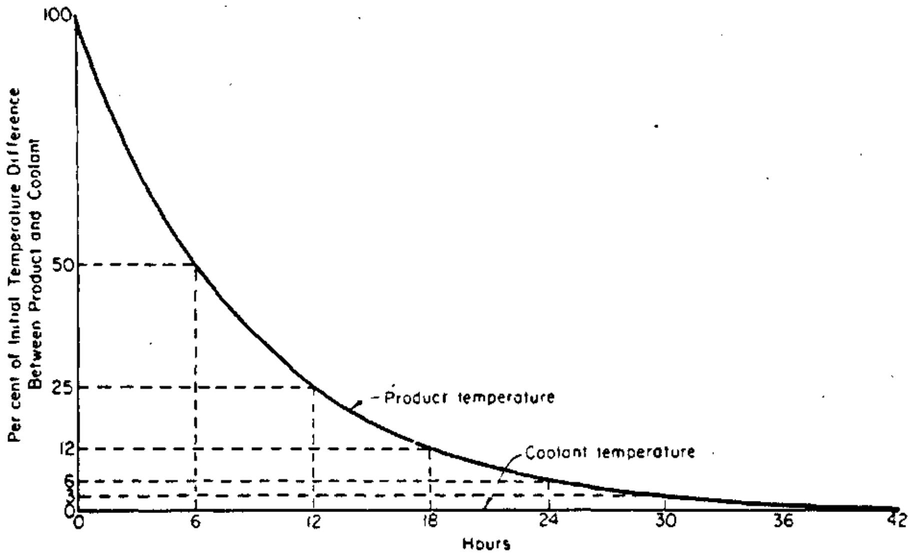


Figure 1.1

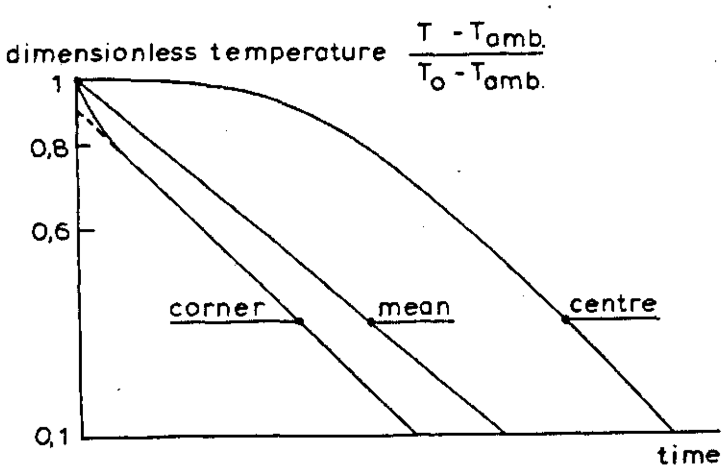
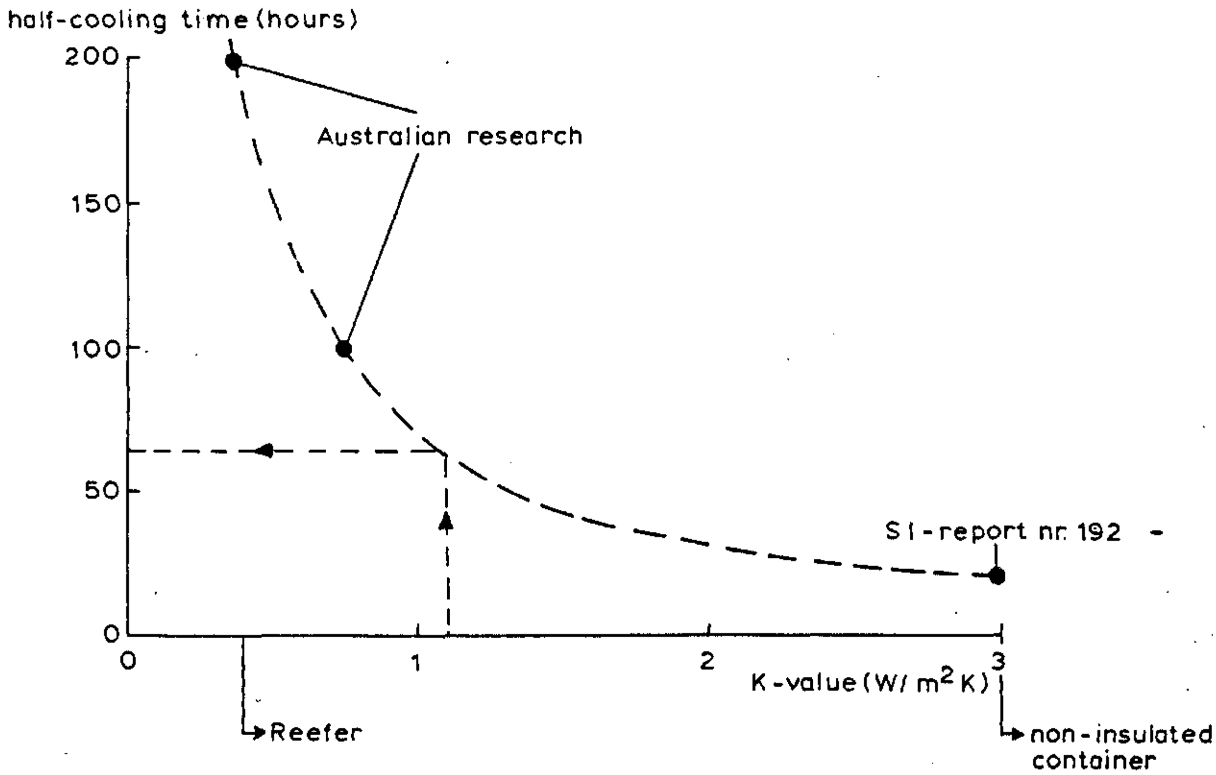
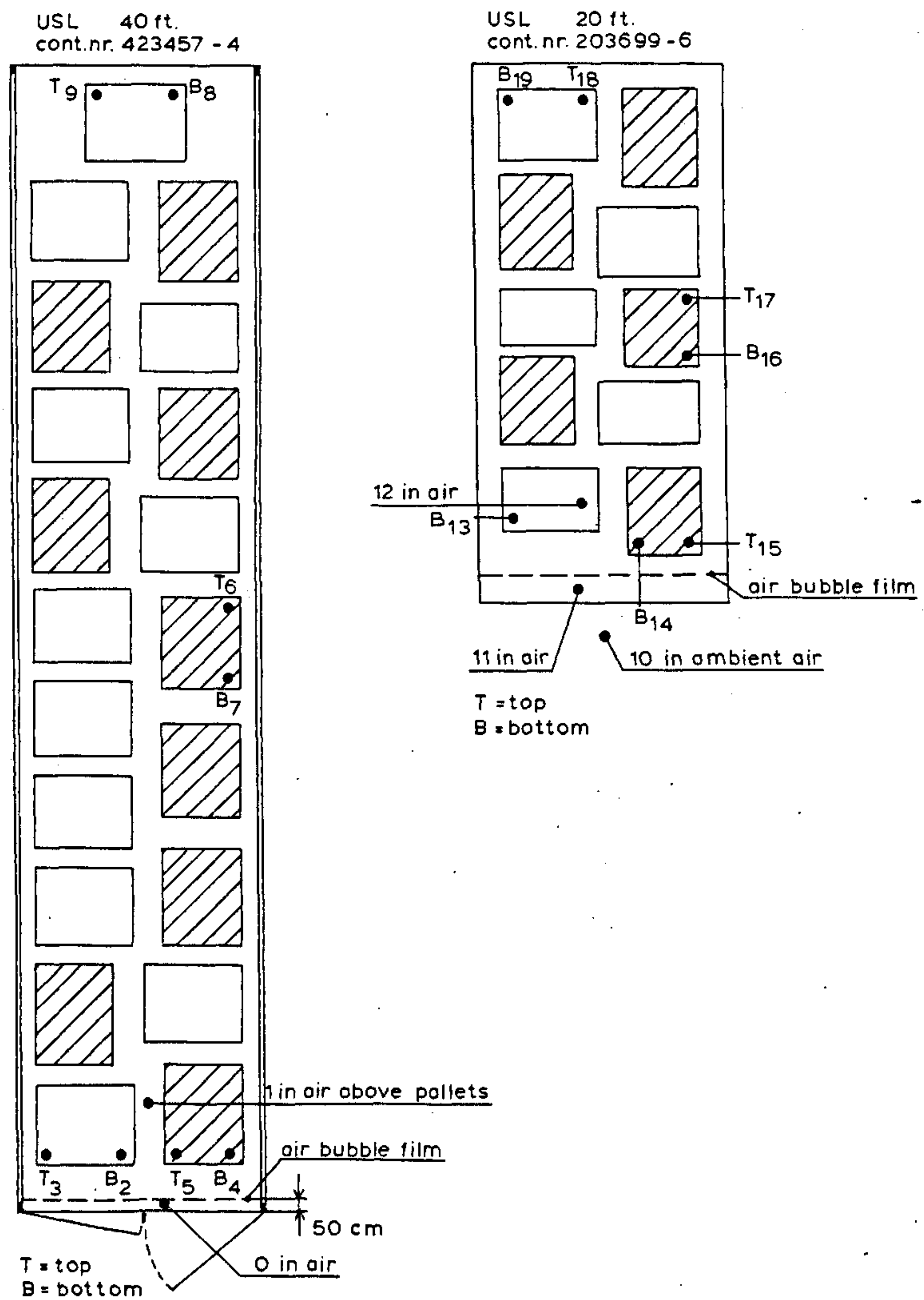


Figure 1.2

Figure 2.1



half-cooling time (hours)
200
150
100
50
0
Australian research
SI-report nr. 192
0
1
2
3
K-value (W/ m^2 K)
Reefer
non-insulated container


USL 40 ft.
cont.nr. 423457 - 4
T9
B8
T6
B7
1 in air above pallets
air bubble film
T3
B2
T5
B4
50 cm
0 in air
T = top
B = bottom
USL 20 ft.
cont.nr. 203699 - 6
B19
T18
T17
B16
12 in air
B13
T15
air bubble film
B14
11 in air
10 in ambient air
T = top
B = bottom

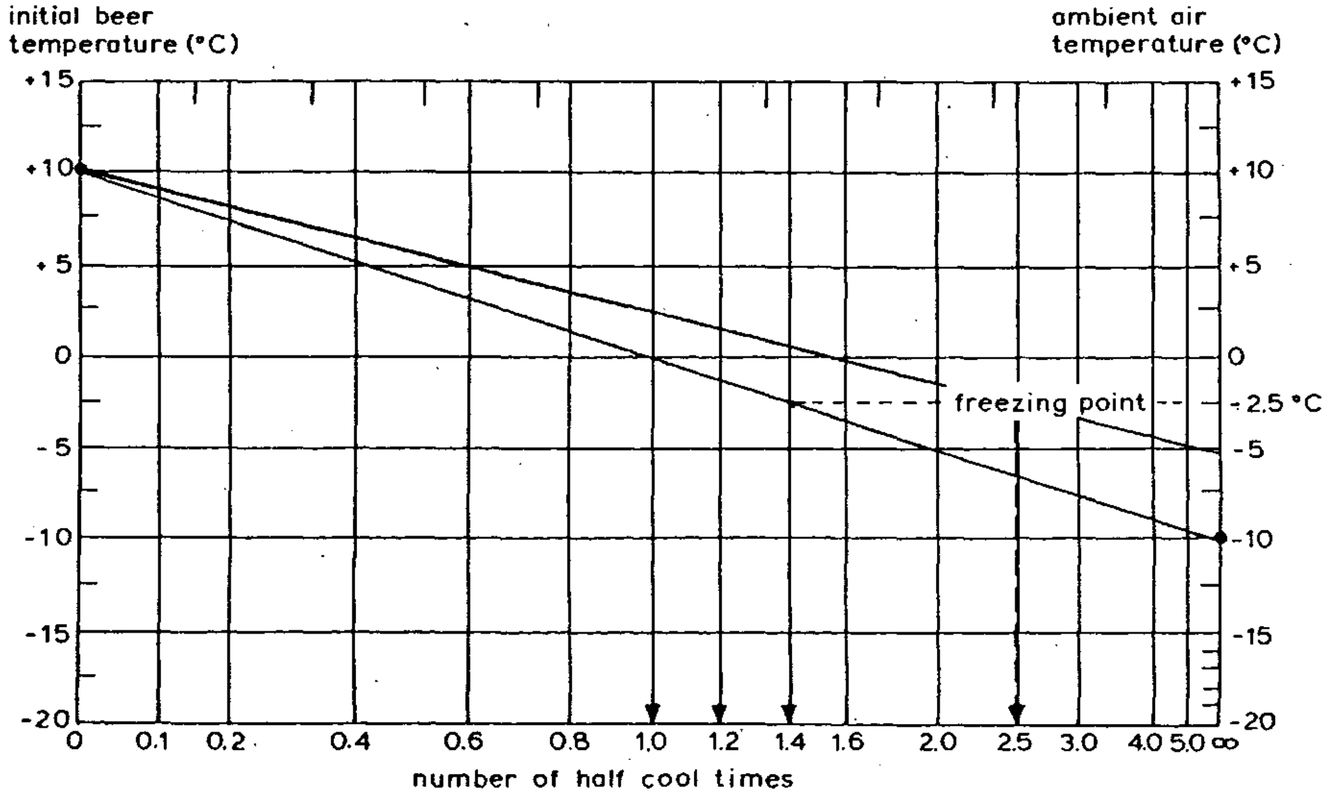
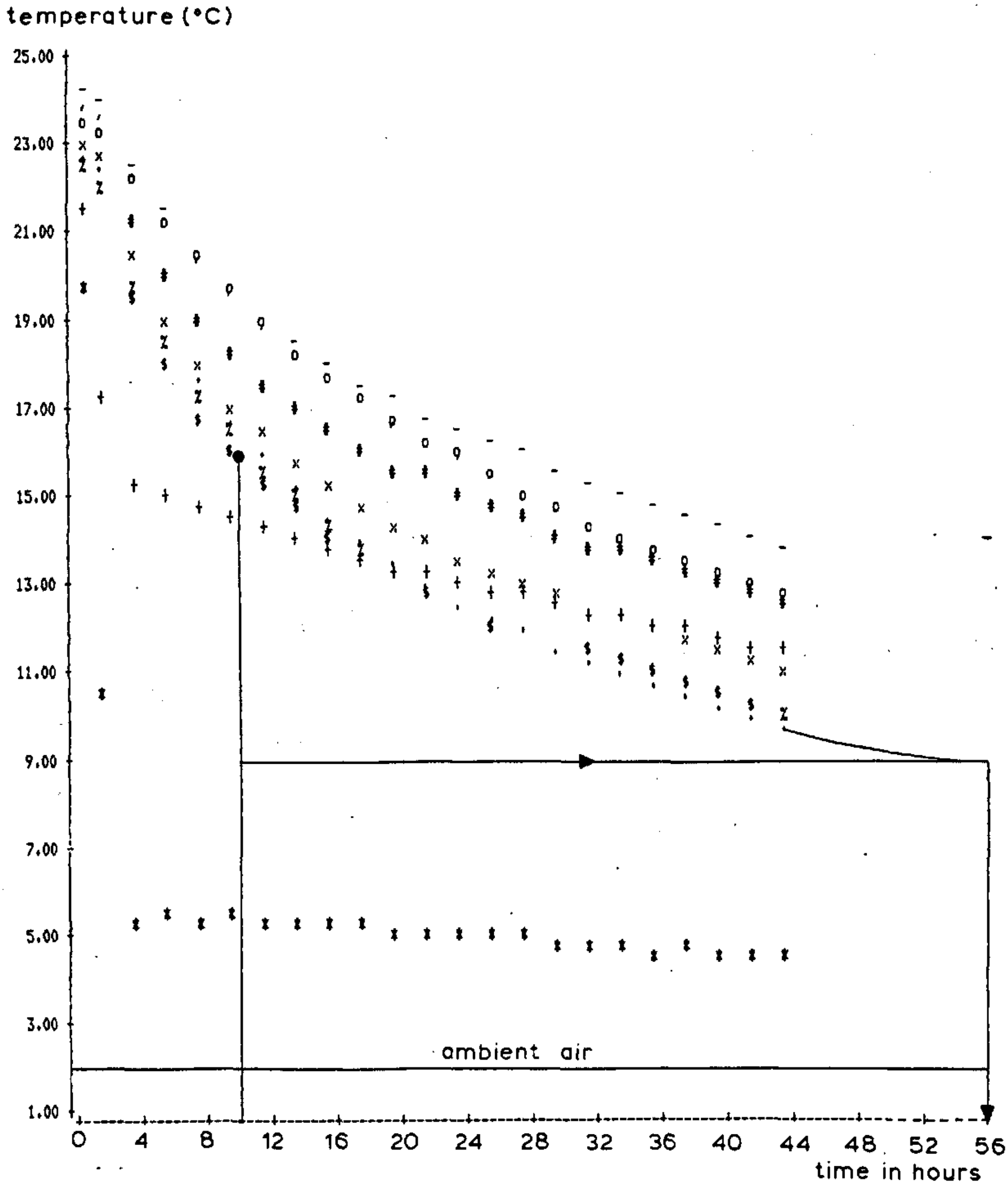
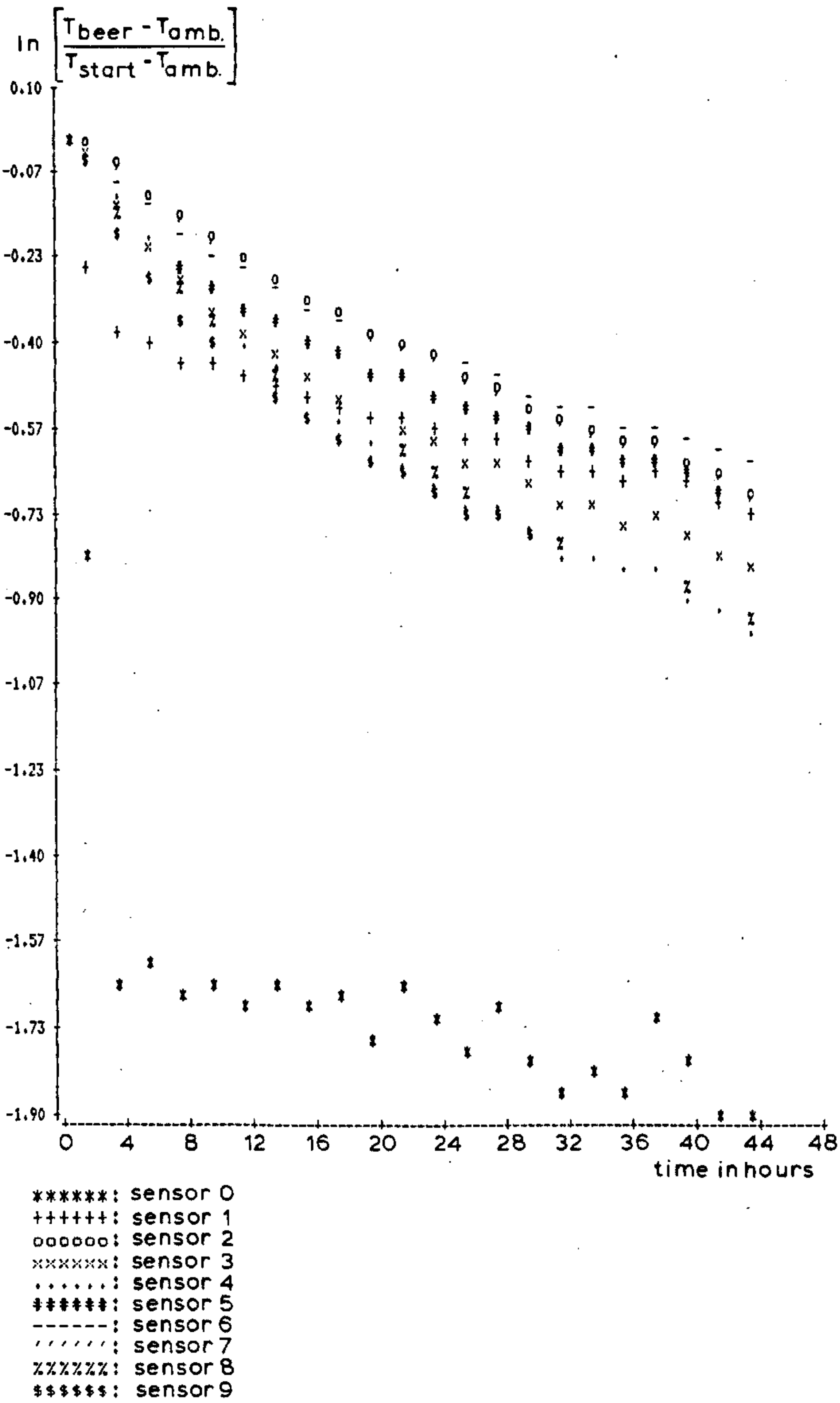

initial beer temperature (°C)
ambient air temperature (°C)
+15
+10
+5
0
-5
-10
-15
-20
-2.5 °C
freezing point
0
0.1
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
2.0
2.5
3.0
4.0
5.0
∞
number of half cool times

Figure 4.1



******: sensor 0
++++++: sensor 1
oooooo: sensor 2
xxxxxx: sensor 3
,,,,,,: sensor 4
######: sensor 5
------: sensor 6
//////: sensor 7
%%%%%%: sensor 8
$$$$$$: sensor 9


ln [(Tbeer - Tamb.) / (Tstart - Tamb.)]
0.10
-0.07
-0.23
-0.40
-0.57
-0.73
-0.90
-1.07
-1.23
-1.40
-1.57
-1.73
-1.90
0
4
8
12
16
20
24
28
32
36
40
44
48
time in hours
******: sensor 0
++++++: sensor 1
oooooo: sensor 2
xxxxxx: sensor 3
......: sensor 4
######: sensor 5
------: sensor 6
'''''': sensor 7
%%%%%%: sensor 8
$$$$$$: sensor 9

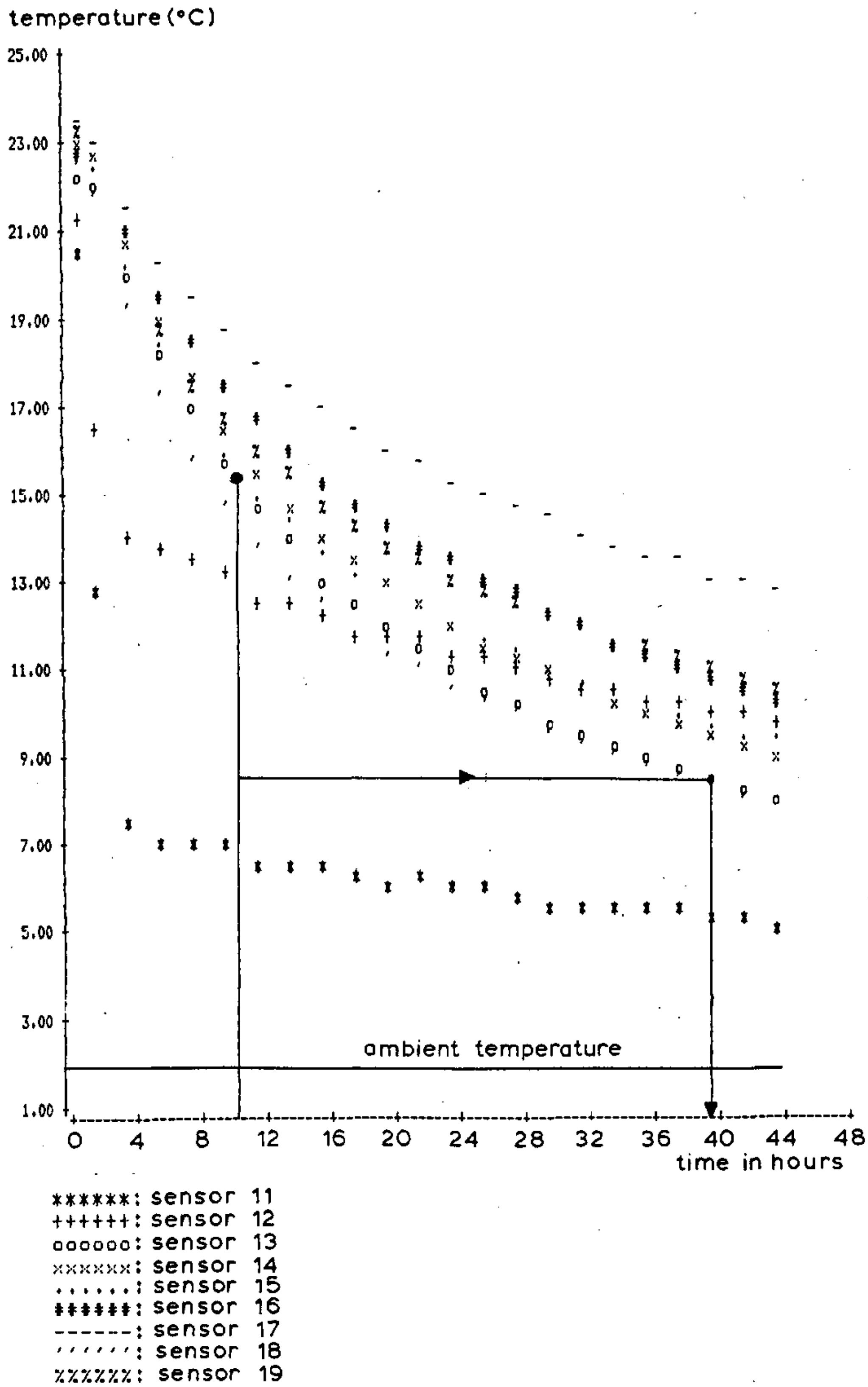
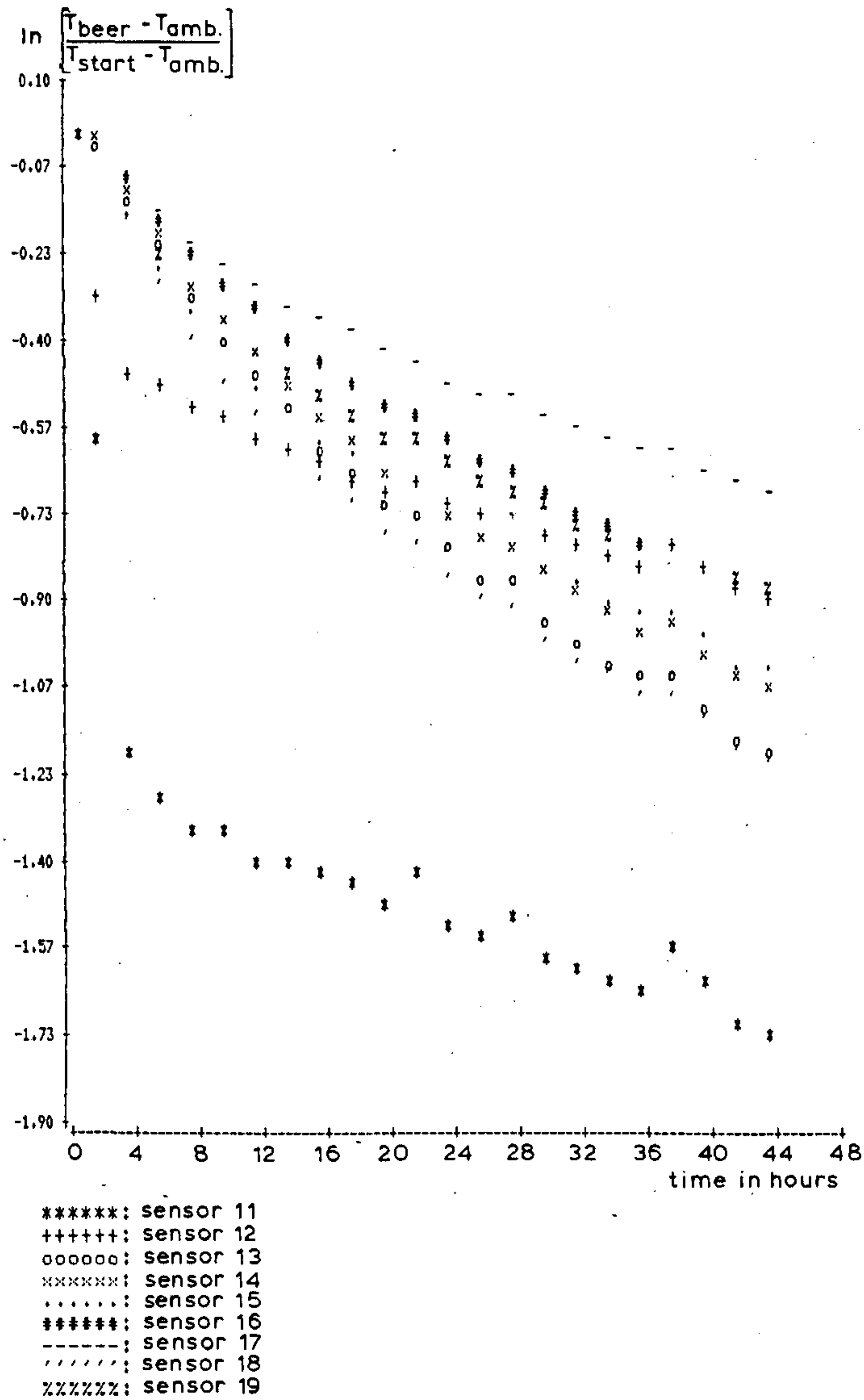

temperature (°C)
25.00
23.00
21.00
19.00
17.00
15.00
13.00
11.00
9.00
7.00
5.00
3.00
1.00
ambient temperature
0 4 8 12 16 20 24 28 32 36 40 44 48
time in hours
******: sensor 11
++++++: sensor 12
oooooo: sensor 13
xxxxxx: sensor 14
......: sensor 15
######: sensor 16
------: sensor 17
'''''': sensor 18
%%%%%%: sensor 19

Figure 4.4


ln [(T_beer - T_amb.)/(T_start - T_amb.)]
0.10
-0.07
-0.23
-0.40
-0.57
-0.73
-0.90
-1.07
-1.23
-1.40
-1.57
-1.73
-1.90
0 4 8 12 16 20 24 28 32 36 40 44 48
time in hours
******: sensor 11
++++++: sensor 12
oooooo: sensor 13
xxxxxx: sensor 14
......: sensor 15
######: sensor 16
------: sensor 17
'''''': sensor 18
%%%%%%: sensor 19