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Air tightness and heat leakage in insulated bodies

Leo Lukasse, Aart-Jan van der Voort, Johan Ploegaert

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Colophon

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Author(s)	Leo Lukasse, Aart-Jan van der Voort, Johan Ploegaert
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Agrotechnology & Food Innovations B.V.
P.O. Box 17
NL-6700 AA Wageningen
Tel: +31 (0)317 475 024
E-mail: info.agrotechnologyandfood@wur.nl, info@reefertransport.nl
Internet: www.afsg.wur.nl, www.reefertransport.nl

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Content

1 Introduction

1.1 Objective

The objective of this project is to gain quantitative insight in the relation between measured air tightness and the K-value of insulated bodies measured in a designated ATP testing station.

1.2 Context

At the start of this research project the authors had no quantitative knowledge on the relation between air tightness and measured K-value. This project aims to gain insight in that relation in cooperation with a body manufacturer. The body manufacturer involved has a long tradition in the manufacturing of high quality insulated bodies for refrigerated transport. By virtue of his desire to manufacture high quality insulated bodies he wishes to increase his insight in the relation between air tightness and heat leakage. This research project is meant to increase that insight by measuring the K-value of an insulated body for a range of several air tightness values.

2 Air tightness standards

The authors are aware of the air tightness standards for refrigerated transport equipment listed in Table 1.

Table 1, air tightness norms (all at 250Pa pressure difference).

norm	norm value	norm unit	internal pressure	temperatures
DIN8959 (par. 5.1.4), regardless FRC/FNA:	0.25	m3/h.m2	positive	Ti=Te
ISO 1496-2 for 20' and 40' reefer containers:	10 + 5 per side door	m3/h	positive	Ti = Te ± 3 °C, 15<Ti<25 °C, 15<Te<25 °C
DIN1815 (par. 5.1.3) for FNA vans:	0.75	m3/h.m2	negative	Ti = Te = 25 ± 1 °C
DIN1815 (par. 5.1.3) for FRC vans:	0.25	m3/h.m2	negative	Ti = Te = 25 ± 1 °C

3 Materials and methods

An insulated FRC class vehicle (Table 2) has been placed in our ATP climate chamber. In the climate chamber both the K-value and the air tightness of the vehicle have been measured 4 times for 4 different degrees of air tightness. The degree of air tightness has been altered by drilling holes in the vehicle's vent opening (p. 9: Fig. 2, Fig. 3). The K-value has been measured according to ATP procedures with our standard ATP measurement equipment (Fig. 4, p. 9). Air tightness has been measured with our own brandnew air leakage measurement device at temperatures $T_i = T_e = 16$ °C using an internal underpressure. These test conditions comply with a mixture of the norm guidelines listed in Table 1.

Table 2, principal characteristics of test body.

description	value
Length (m)	8.200
Width (m)	2.598
Height (m)	2.532
mean wall surface (m^2)	92.946
No. of rear doors	2
No. of side doors	2
No. of vent openings	1

3.1 Air tightness measurement

For this project an air leakage rate measurement device has been built (Fig. 5, p. 10). In the design of the device the objective has been to develop a device which can easily be employed stand-alone in the field to measure the air tightness of any insulated vehicle in compliance with any standard in Table 1. In the design process the existing air leakage measurement device of Germanischer Lloyd served as an example. The basic components of the air leakage measurement device are a controllable air compressor, a vane anemometer to measure airflow, a pressure difference sensor and a logging unit to monitor pressure drop and air flow.

4 Measurement results

Table 3 presents the four air leakage measurement results. Table 4 presents the four K-value measurement results. Table 5 lists the details for K-value measurement no. 1. The details of the three other K-value measurements are omitted from the report. The quality of the other K-value measurements is equal to measurement no. 1 and all four K-value measurements meet the ATP standards. Fig. 1 depicts the relation between measured heat transfer coefficient K and air tightness by plotting the airflow measurements (Table 3) on the horizontal axis and the K-value measurements (Table 4) on the vertical axis.

Table 3, air tightness measurement results.

no.	F(m^3/h)	ΔP (Pa)	T_i/T_e (°C)	date, time
F(1)	19.4	250	16/16	9-12-05, 15.30
F(2)	21.9	250	16/16	12-12-05, 17.00
F(3)	35.7	250	16/16	14-12-05, 16.00
F(4)	42.9	250	16/16	14-12-05, 18.00

Table 4, summary of K-value measurement results.

no.	**K (W/m².°C)**	**start (date and time)**	**end (date and time)**
K(1)	0381	2005-12-10-20:00:00	2005-12-11-08:00:00
K(2)	0.381	2005-12-13-03:00:00	2005-12-13-15:00:00
K(3)	0.383	2005-12-14-00:00:00	2005-12-14-12:00:00
K(4)	0.384	2005-12-15-20:00:00	2005-12-16-08:00:00

Table 5, detail of measurements for K(1).

meas. characteristic	**meas. value**	**meas. unit**
testing method	inner heating	-
Start of inner heating test	09.12.2005, 18:14:00	dd.mm.yy, hh:mm:ss
steady state condition start	10.12.2005, 20:01:00	dd.mm.yy, hh:mm:ss
steady state condition end	11.12.2005, 08:05:00	dd.mm.yy, hh:mm:ss
Duration of steady state condition	12:04:00	hh:mm:ss
Duration of inner heating test	37:51:00	hh:mm:ss
mean temperature outside body	7.41	°C
max. difference between two average outside temperatures	0.09	°C
max. difference between two outside measuring points	0.36	°C
mean temperature inside body	32.62	°C
max. difference between two average inside temperatures	0.04	°C
max. difference between two inside measuring points	0.59	°C
Temperature difference inside/outside	25.21	°C
mean wall temperature	20.01	°C
Heating power including fan power	893.79	W
Total heat leakage rate U	35.45	W/°C
Overall coefficient of heat transfer K	**0.381**	**W/m².°C**

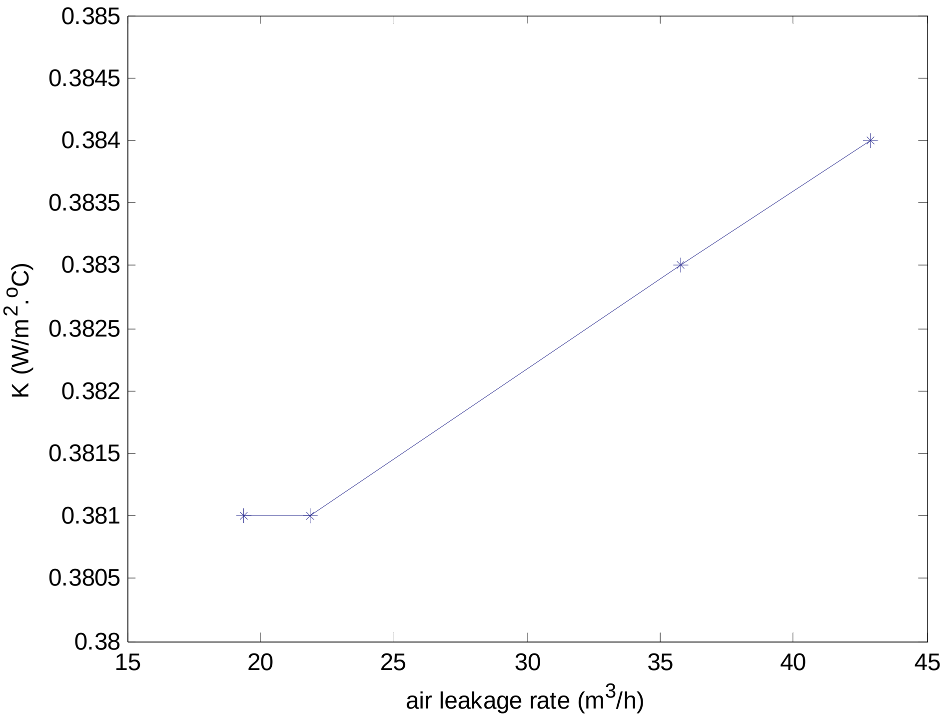

Fig. 1, measured heat transfer coefficient K as a function of air tightness.

5 Discussion

For the test body with mean wall surface 92.946 m^2 (Table 2) DIN8959 (Table 1) allows a max. air leakage rate of 92.946 x 0.25 = 23.2 m^3/h. The lowest air leakage rate measured is 19.4 m^3/h (Table 3). This is the air leakage rate of the insulated body without any on purpose holes drilled into the vent opening. The air leakage rate of 19.4 m^3/h is just below the norm of 23.2 m^3/h set by DIN8959. For a medium sized body with two side doors (Table 2) this is just fine!

The *measured* K-value is hardly affected by the air leakage as can be seen in Fig. 1. This is a truth for these measurements performed in our test facility. Our test facility is not a wind tunnel with air flowing from the front to the rear end of the climate chamber. Air circulates around the vehicle instead. In a wind tunnel there will be a (minor) pressure drop over the vehicle in longitudinal direction. Hence there the dependence of K on air leakage may be stronger.

The dependence of K on air tightness also depends on the position of the air leaks. For example two minor leaks at the lower and upper end of a door may cause a chimney effect during the K-value test: warm inside air (32.5°C) leaving the vehicle through the upper leak, and cold outside air (7.5°C) entering through the lower leak.

How to extrapolate measured air tightness to 'on the road situations'? Three additional effects are to be expected on the road: 1) increased pressure drop due to vehicle velocity, 2) increased pressure drop due to wind, 3) pumping of refrigeration units in start-stop operation, as they continuously oscillate the internal air density and hence pressure. Some numbers about the worsening of the K-value 'on the road' as compared to ATP test conditions: 18% (Bodenheimer, '77), 26% (Potynski, '67) and 55% (Bachmaier and Bornschlegl, '65). It is unclear to what extend air leakage is responsible for this worsening, but it is likely that it is a significant factor.

6 Conclusions

- The air leakage rate of the insulated test body without any on purpose holes drilled into the vent opening meets the requirements set by DIN8959, despite the presence of two side doors.
- In the measurements collected in our ATP test laboratory during this study the measured K-value is hardly affected by the measured air leakage rate.

Acknowledgements

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Appendix 1, photos

Fig. 2, holes drilled into vent opening (outside view).

Fig. 3, holes drilled into vent opening (inside view).

Fig. 4, K-value measurement equipment inside test body.


Fig. 5, air leakage measurement device.

Test log

Date [dd-mm-yyyy]	**Description of activities**
09-12-2005, 16.00h	First air leakage measurement F(1) @ $T_i = T_e = 16$ °C
09-12-2005, 18.00h	Start of first K-value measurement K(1)
12-12-2005, 9.30h	Climate chamber set at 16 °C, body doors opened, internal heating terminated. Both T_i and T_e 16 °C
12-12-2005, 16.00h	Hole drilled. Air leakage measurement F(2) @ $T_i = T_e = 16$ °C
12-12-2005, 17.00h	Start of 2nd K-value measurement K(2)
13-12-2005, 16.00h	Hole enlarged. Start of 3rd K-value measurement K(3)
14-12-2005, 12.00h	Climate chamber set at 16 °C, body doors opened, internal heating terminated. Both T_i and T_e 16 °C
14-12-2005, 16.20h	Air leakage measurement F(3) @ $T_i = T_e = 16$ °C. Hole enlarged. Air leakage measurement F(4).
14-12-2005, 17.00h	Start of 4th K-value measurement K(4)
16-12-2005, 12.30h	Measurement terminated.