DRAIN HOLES IN REEFER CONTAINERS AND THE CONFLICTING INTERESTS OF CONTROLLED ATMOSPHERE AND DEHUMIDIFICATION.

LEO J.S. LUKASSE, MAXENCE J.M. PAILLART

Wageningen University & Research, P.O Box 17,
Wageningen, 6700AA, The Netherlands
fax. +31 317 483 011, www.climatecontrol.wur.nl / www.wageningenur.nl/fbr
leo.lukasse@wur.nl

ABSTRACT

Most reefer containers have four drain holes in the corners of the floor to expel water. Drain holes may especially be beneficial to cargos that benefit from low relative humidity. Some reefer containers are CA (Controlled Atmosphere) reefers. For CA reefers air tightness is important in order to be able to maintain a sufficiently low oxygen concentration. Drain holes may cause air leakage. The objective of this study is to clarify how the omission of unit-end drain holes affects oxygen concentration during CA operation and relative humidity during dehumidification operation. A series of climate chamber tests was done to assess air tightness and lowest feasible relative humidity for different numbers of open drain holes. The main conclusion is: dehumidification benefits from open unit-end drain holes, while for CA it is best to omit unit-end drain holes, because open unit-end drain holes increase air leakage by a factor six.

1 INTRODUCTION

Air tightness of refrigerated transport equipment is important to avoid the undesired ingress of ambient heat and moisture (Xie *et al.*, 2011; Lukasse & Staal, 2010; van Gerwen *et al.*, 1999). That is why DIN8959 and DIN1815 set air tightness standards for refrigerated road transport equipment, IATA80/1 for refrigerated air freight containers, and ISO1496-2 for 20 ft and 40 ft reefer containers. In Controlled Atmosphere (CA) transport equipment the importance of air tightness is far higher in order to be able to maintain a low oxygen concentration. For CA storage facilities ISO6949 sets extra stringent air tightness requirements, justly stating that in general the respiratory oxygen consumption should at least be equal to the rate of oxygen ingress due to air leakage. Also a Dutch air tightness standard for CA stores was already set in 1961 (Noordzij, 1961), which in The Netherland is still used. To our knowledge no specific air tightness standard exists for CA transport equipment.

Integral reefer containers usually have four drain holes: one in each corner of the floor. Drain holes are openings and therefore deteriorate air tightness. Drain holes are usually provided with plugs to close them. In practice people preparing containers for shipment tend to neglect the plugging/unplugging of the drain holes, or even don’t know what would be beneficial to their shipment. An added complication is that unit-end drain holes are positioned underneath the baffle plate and therefore hard to access. At the unit-end the air flow velocity over the openings is highest, so there the air leakage rate is probably higher than at the door-end. In view of the extra importance of air tightness in CA reefers the natural question is: could drain holes, and esp. unit-end drain holes, safely be omitted from CA reefers?

CA reefers are multi-purpose. They may be used for CA shipment of fruit like avocado, mango, and bananas. They may also be used for regular atmosphere shipments of goods where low temperature and low relative humidity are important, like garlic, onions or tulip bulbs.

In any reefer container drain holes serve as a backup system to drain the evaporator’s condense water and/or defrost water to outside the container. Ideally water condensed or frozen at the evaporator coil is expelled from the container through its drain gutters and drain line mounted underneath the evaporator. In practice however this drain-off system is not perfect, and clogged drain lines are a returning issue in the industry. Then the absence of unit-end drain holes deteriorates the backup system for condense water and/or defrost water drain off. This may especially be a problem for cargos that benefit from low relative humidity, while the moisture load may be significant. A notorious example of this is tulip bulb shipments with large fresh air exchange.

Aim of this research is to quantify to what extent omitting the two unit-end drain holes:

1. improves air tightness, which is beneficial in CA shipments, and
2. increases relative humidity (RH), which is a disadvantage in shipments with low RH settings.

2 MATERIALS AND METHODS

A series of tests was performed on container MMAU101713-1 (Figure 1) in a well-vented climate chamber for refrigerated transport equipment. This climate chamber is part of our designated ATP testing station.
The container possesses the following characteristics:

- dimensions: 40ft HC, internal volume 67.4m³ (L=11.59m; W=2.29m and H=2.54m)
- integrated design Starcool CA and refrigeration unit (SCI-40-W-CA)
- inside the container at 10 cm from the doors a rails is present to affix a CA curtain to improve air tightness (like in all CA containers)
- four drain holes (one in each corner of the floor). The drain holes can be hermetically closed inside the container with a rubber plug (Figure 2a and b). A rubber sock, in the industry known as kazoo, is affixed at the outside of the drain holes underneath the container (Figure 2d). In the drain holes only a sieve separates the container's interior from the exterior (Figure 2b), there is no water lock incorporated in the drain hole
- a system of drain gutters, drain pan and drain line to expel the evaporator's condense water and/or defrost water from the container
- equipped to cool, heat, dehumidify, maintain oxygen at or above set point, and maintain CO_2 at or below set point. dehumidification control

During all tests the outlet of the unit's drain line was closed with a rubber cap and adhesive tape in order to avoid air leakage and water drain off through the drain line.

Figure 1, test container in climate chamber.

First a series of tracer gas concentration decay measurements was done to assess airtightness in different combination of drain hole closures with and without CA curtain at the door-end.
Secondly the equilibrium relative humidity was assessed for typical tulip bulb transport conditions under tropical ambient conditions, first with closed and then with open unit-end drain holes.

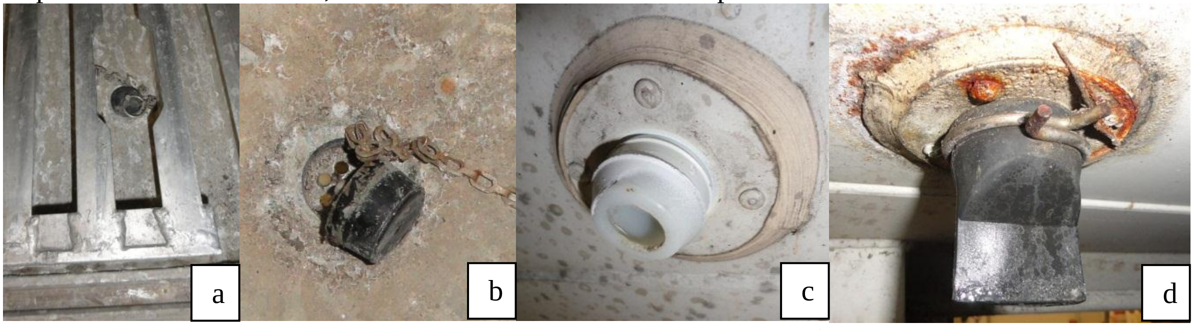

Figure 2, drain hole plugged [a], drain hole unplugged [b], output of drain holes – underneath the container without rubber sock [c], rubber sock underneath the drain hole [d].

2.1 Effect of drain holes and CA curtain on O_2 and CO_2 concentrations in CA shipments.

A series of air tightness tests was performed through tracer gas measurements during normal operation of the refrigeration unit. During all tracer gas decay tests the fresh air exchange vent was closed (0 m^3/h). CO_2 (carbon dioxide) was used as a tracer gas, because at our premises both the gas and the required CO_2 sensor are readily available. The air tightness was assessed for eight different combinations of drain holes closure and CA curtain.

The CA curtain was installed (Figure 3a) using the curtain rails meant for that.

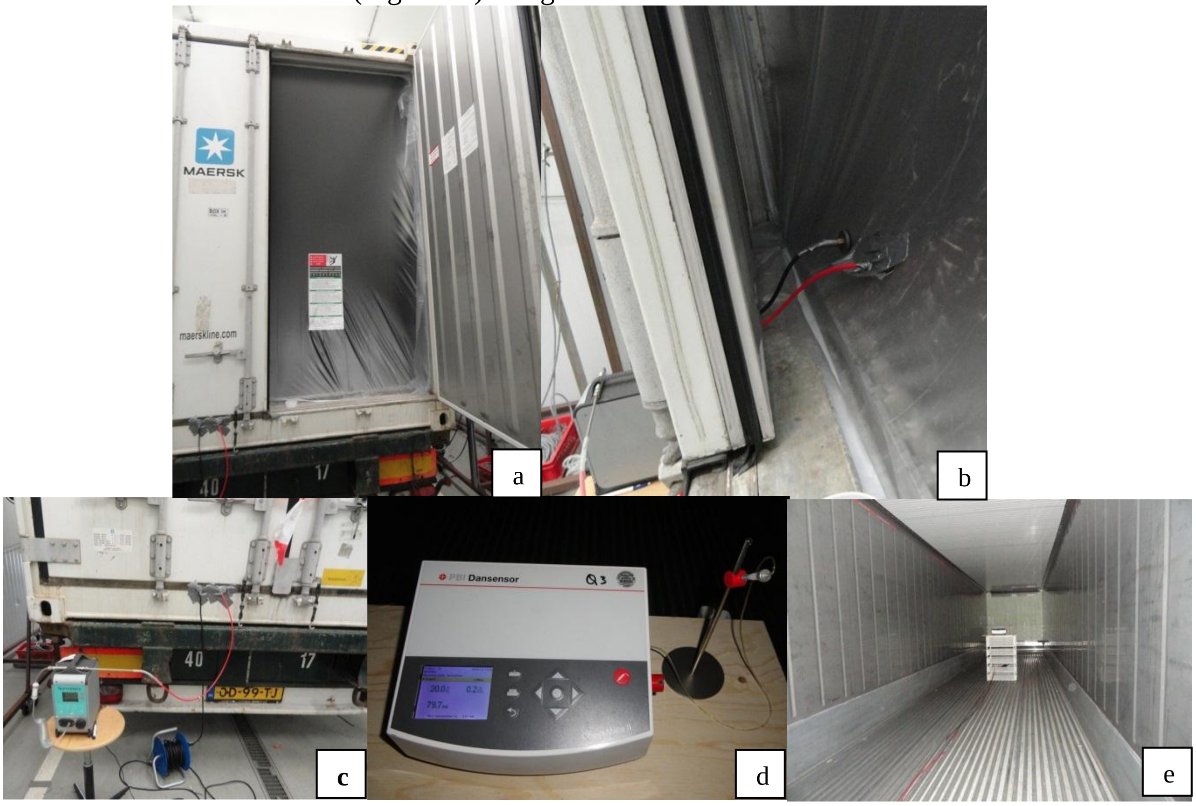

Figure 3, air tightness test of the CA container. Door opening closed with CA curtain [a], CO_2 injection tube going through the CA curtain [b], CO_2 concentration measurement from outside the container [c] , CO_2 concentration sensor and recorder – PBI Dansensor CheckMate II [d], position of CO_2 injection tube outlet and CO_2 sensor inside the container [e].

CO_2 was injected in the container via a tube with 6mm internal diameter. This tube enters the container underneath the door gaskets (Figure 3c) and through the CA curtain (Figure 3b). Potential leakage between the tube and the CA curtain was avoided by taping them together. The output of the injection tube was situated in the middle of the container at 20 cm height from the floor. During the tests the CO_2 concentration inside the container was recorded at an interval of 5 minutes by a PBI Dansensor CheckMate II (Zirconia sensor: relative accuracy +/- 2%) (Figure 3d). The CO_2 sensor was also placed in the middle of the container at 1.10m from the floor (Figure 3e).

CO_2 was injected in the container till reaching a CO_2 concentration of approximately 12%. In order to avoid overpressure inside the container, the fresh air vent was slightly opened during the injection of the CO_2 gas. Once the desired CO_2 concentration was reached inside the container, the fresh air vent and the injection tube were closed.

During the gas concentration decay measurements the refrigeration unit ran its usual temperature control program at a setpoint of 14.0 °C, while the climate chamber is maintained at 25 °C. The tests lasted till recorded CO_2 concentration had dropped at least 1%.

Table 1 lists the combination of drain hole closures and CA curtain installation for which air tightness was assessed. Each drain hole can be closed with a plug, and has rubber socks (in Table 1 just named ‘rubbers’) underneath. The plug closes the drain hole hermetically. So if the drain hole is plugged the presence of a rubber sock makes no difference. Hence each drain hole has three possible degrees of air tightness: completely open (without plug, and without rubber sock), half-open (without plug, but with rubber sock), and completely closed (with plug, rubber sock irrelevant). As Table 1 shows, it was chosen to measure air tightness for seven combinations of drain holes closure with CA curtain, and for completely closed drain holes without CA curtain.

Table 1, tracer gas concentration decay tests performed.

no.	name	rubber socks	plugged	CA curtain
1.	unit-end open, door-end open	unit-end: no door-end: no	unit-end: no door-end: no	yes
2.	unit-end closed, door-end open	unit-end: yes door-end: no	unit-end: yes door-end: no	yes
3.	unit-end half-open, door-end half-open	unit-end: yes door-end: yes	unit-end: no door-end: no	yes
4.	unit-end closed, door-end half-open	unit-end: yes door-end: yes	unit-end: yes door-end: no	yes
5.	unit-end open, door-end closed	unit-end: no door-end: yes	unit-end: no door-end: yes	yes
6.	unit-end half-open, door-end closed	unit-end: yes door-end: yes	unit-end: no door-end: yes	yes
7.	unit-end closed, door-end closed.	unit-end: yes door-end: yes	unit-end: yes door-end: yes	yes
8.	unit-end closed, door-end closed, no curtain.	unit-end: yes door-end: yes	unit-end: yes door-end: yes	no

After collection of the CO_2 decay curves, the air leakage rate q [m³/h] was estimated for each test. This was done using the physical knowledge that the CO_2 balance is given by:

$$V\dot{x}(t) = q(x_{amb}(t) - x(t)) \quad [10^{-2}\ m^3/h] \qquad (1)$$

Where V is the internal volume of the container [m³], q is the leakage rate [m³/h], x is the CO_2 concentration inside the container [%] and x_{amb} is the CO_2 concentration outside the container [%].
The above equation is a first order differential equation with static gain one and time constant

$$\tau = V/q \quad [h] \qquad (2)$$

It is safe to assume that q and x_{amb} are constant during one experiment. When q and x_{amb} are constant this kind of equation has the following analytical solution:

$$x(t) = e^{-\frac{t}{\tau}} \times (x_{ini} - x_{amb}) + x_{amb} \quad [\%] \qquad (3)$$

The air leakage flow rate q was estimated from the data by fitting above equation to collected CO_2 measurement time series.
To assess the significance of the measured air leakage rates, the consequential O_2 (oxygen) leakage rate at 3% O_2 was calculated using:

$$\dot{O}_2 = q(O_{2,amb} - O_2)/100 \quad [m^3\ O_2/hour] \qquad (4)$$

The choice for 3% O_2 is motivated by the fact that that is currently the lowest O_2 concentration at which this type of CA unit is used. It is chosen to focus on O_2 leakage rate instead of CO_2 leakage rate, because O_2 leakage rate is larger during CA conditions due to its larger concentration difference between inside and outside the container.

2.2 Lowest feasible relative humidity.

Two tests were done to assess how the absence of unit-end drain holes affects the lowest feasible return air RH in a worst case scenario. As a worst case scenario was defined: a high moisture load and the container inclined at an angle of 0.10° with the unit-end down. An inclination of 0.10° was assumed to be a maximum practical value. For a 300m long container ship it causes 0.5m height difference between front and end. In test 1 the unit-end drain holes were closed. In test 2 they were open. At the start of test 1 the container floor was flooded. The excess water inside the container was drained off through the two open door-end drains. This results in 20 mm water on the floor at the unit-end.

The container was placed in a climate chamber of 30°C and RH around 75% to simulate a trip through tropical regions. The high relative humidity was created using a humidifier of Contronics (Hu-45; max. capacity 3 kg/h) (Figure 4). The humidifier was controlled by a self-made Labview® program. Relative humidity in the container was recorded with an Escort junior temperature and humidity datalogger with RH accuracy ± 3%. It was positioned in the centre of the container, *i.e.* at 1.20 meter above the floor centre adjacent to the CO_2 sensor (Figure 3e).


Figure 4, climate chamber humidification.

The reefer unit settings during both tests were: set temperature 30 °C, set RH 60% and fresh air exchange 220 m^3/h (max. opening).

3 RESULTS

3.1 Effect of drain holes and CA curtain on O_2 and CO_2 concentrations in CA shipments.

Table 2 shows the measurement results (mean ± standard deviation) for the eight test conditions described in Table 1. Column 3 contains the air leakage rate estimated by fitting eqn. 3 to time series like shown in Figure 5, and subsequently calculating the air leakage rate *q* from eqn. 2. The model fitting was done by a non-linear regression analysis using Genstat. Column 4 contains the O_2 leakage rate $\dot{O}_2$ in case of 3% O_2 inside the container (eqn. 4).

Table 2, measured air leakage rates and consequential O_2leakage rate $\dot{O}_2$ at 3% O_2.

no.	**name**	**q [m³/h]**	**$\dot{O}_2$ [m³ O_2/hour]**
1.	unit-end open, door-end open	1.82 ± 4.6e-3	0.33 ± 8.2e-4
2.	unit-end closed, door-end open	0.72 ± 3.9e-3	0.13 ± 7.0e-4
3.	unit-end half-open, door-end half-open	0.61 ± 3.5e-3	0.11 ± 6.3e-4
4.	unit-end closed, door-end half-open	0.19 ± 2.6e-3	0.03 ± 4.6e-4
5.	unit-end open, door-end closed	1.10 ± 1.4e-3	0.20 ± 2.5e-4
6.	unit-end half-open, door-end closed	0.52 ± 4.4e-3	0.09 ± 7.9e-4
7.	unit-end closed, door-end closed.	0.18 ± 2.3e-3	0.03 ± 4.2e-4
8.	unit-end closed, door-end closed, no curtain	1.11 ± 1.0e-3	0.20 ± 1.8e-4

Figure 5 presents the CO_2 concentrations recorded inside the container during two tests arbitrarily selected from the tests listed in Table 1. The black lines in the figures are model outputs of eqn. 3 after fitting the air flow rate to the collected CO_2 data.

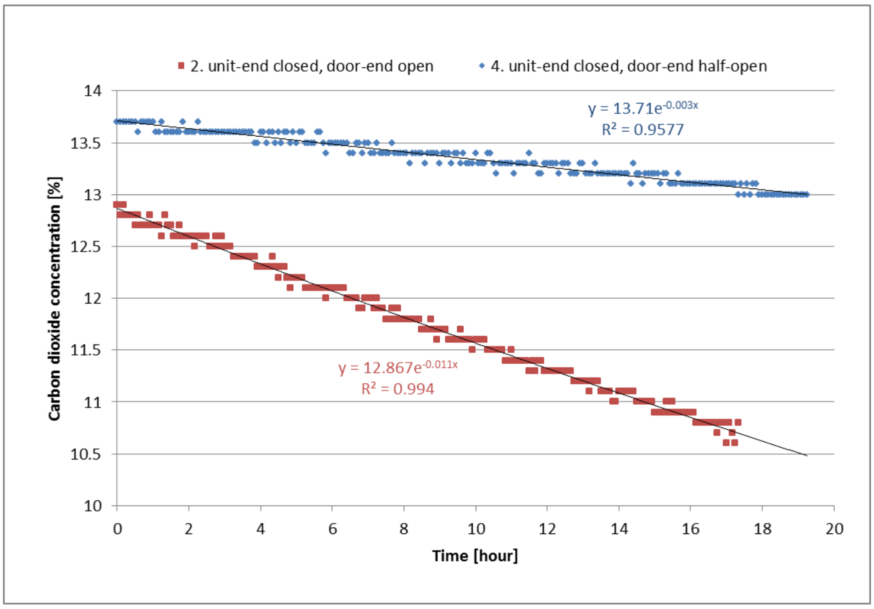

Figure 5, CO_2 concentration inside the CA container during tests 2 and 4.

3.2 Lowest feasible relative humidity.

Figure 6 and Figure 7 present the RH and temperature recorded in the centre of the container during steady state operation over a period of more than 12 hours. The 4 ~ 5 sudden jumps in RH and temperature mark defrosts. Table 3 summarizes the time-averaged conditions achieved during the complete steady state periods shown in Figure 6 and Figure 7.

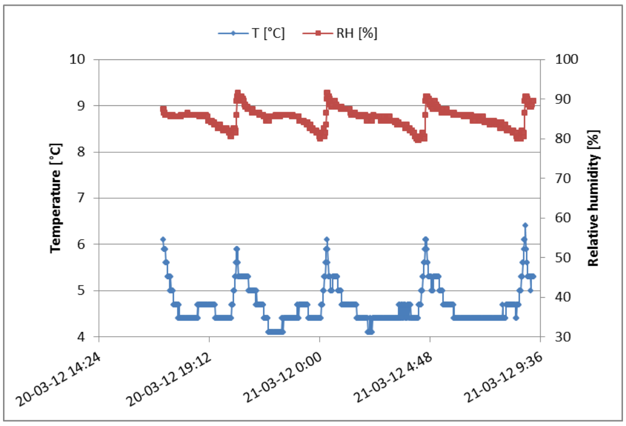

Figure 6, relative humidity and temperature in the centre of the container while the unit-end drain holes are closed.

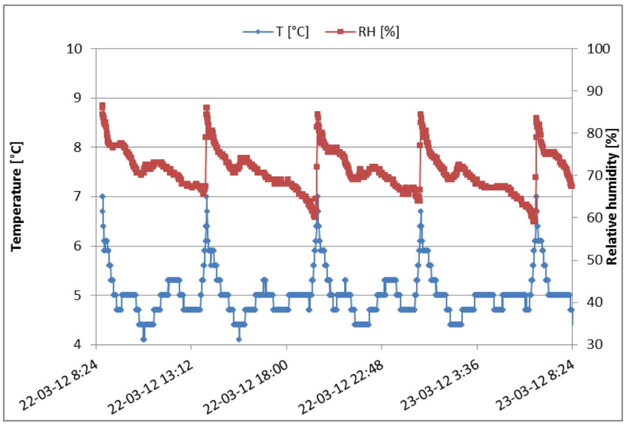

Figure 7, relative humidity and temperature in the centre of the container while the unit-end drain holes are open.

Table 3, summary of RH test results.

variable	**test 1 (unit-end drains closed)**	**test 2 (unit-end drains open)**
chamber temperature	30 °C	30 °C
realized avg. chamber RH	71%	77%
RH in container centre	85%	71%
temperature in container centre	4.6 °C	5.0 °C
abs hum in container centre	4.4 g/kg	3.8 g/kg

4 DISCUSSION

4.1 Effect of drain holes and CA curtain on O_2 and CO_2 concentrations in CA shipments.

The 95% confidence interval (two times the standard deviation) of all estimates in Table 2 is less than 3% of the estimated mean value for all eight estimates. This means that in the mutual comparison of two tests there is no need to question the statistical significance of an observed difference if the difference is more than 6%.

The lowest measured air leakage rate is approx. 200 litre/hour (Table 2, tests 4 and 7). This was achieved by closing the unit-end drain holes and either closing the door-end drain holes (test 7) or affixing the rubbers underneath the door-end drain holes (test 4). One should be aware that this leakage rate was measured for one arbitrarily selected container. It is unknown to what extent this measurement is representative of the average container. Also the bandwidth of air leakage rates occurring in practice is unknown.

The lowest air leakage rate of 200 litre/hour was measured while the drain line was artificially closed with a rubber cap. In practice it should be closed by the water lock present in the drain line. It is believed to be a safe assumption that this water lock is adequate.

It was visually observed that the drain holes are water tight when properly closed with the plugs provided. It is safe to assume that then also air leakage through the drain holes is negligible.

Some noticeable differences when mutually comparing the results presented in Table 2:

1. Not closing the unit-end drain holes deteriorates the air tightness by a factor 6 (compare test no. 5 and 7 in Table 2).
2. Unit-end drain holes cause more air leakage than door-end drain holes (in Table 2 compare test no. 4 to 6, and no. 2 to 5).
3. Omitting the CA curtain elevates air leakage as much as opening the unit-end drain holes (compare test no. 5 and 8 in Table 2).

4.2 Lowest feasible relative humidity.

If the two unit-end drain holes are closed and the container is inclined by 0.10° with the unit-end down and for whatever reason some of the evaporator's condense water reaches the floor, then that condense water accumulates on the floor at the unit-end. Although the supply air is dehumidified, it is then directly blown over that water pool on the floor. In the test condition this results in an average RH of 85% in the centre of the container (Figure 6).

When the unit-end drain holes are open, water reaching the floor underneath the unit is drained out of the container at the unit-end. Then no water pool forms in the T-bars. In the test condition the refrigeration unit is then able to reach an average relative humidity of 71% in the centre of the container (Figure 7). This is a significantly lower RH than in case of closed unit end drain holes, and hence it is better.

4.3 Balancing the interests of CA and dehumidification.

The accessibility and visibility of unit-end drain holes is poor. So it is realistic not to rely on the human factor for appropriately closing/opening unit-end drain holes when preparing a reefer for a specific shipment.

Controlled atmosphere shipments benefit from omitting or closing unit-end drain holes. This is especially true for those CA reefers where produce respiration is the only mechanism to reduce oxygen concentration.

Some commodities benefit from low RH, like flower bulbs, garlic and onions. These are shipped at low RH settings. Then the air inside the container is actively dehumidified. These shipments benefit from open unit-end drain holes (Table 3).

In view of the above listed contradictory interests of CA and dehumidification it has to be concluded that a compromise is needed: either optimize a CA reefer for CA by omitting the unit-end drain holes, and accept its reduce suitability for dehumidification shipments, or optimize for dehumidification by using four drain holes and accept reduced suitability for CA.

Of course there are alternatives to circumvent the dilemma studied in this paper, but these alternatives also have their drawbacks. For example:

- Use more advanced drain holes, where a water lock is incorporated in the drain hole. Drawback is again the human factor: this design demands more maintenance in terms of cleaning, moreover every now and then a shipper hammers a big screw driver through the drain holes to ensure that it lets water through.
- Pay more attention to the prevention of condense water spills on the floor. Very true. Unfortunately, for the time being the backup system of drain holes still has a function.
- Move the unit-end drain holes 20cm in the direction of the door-end in order to improve the accessibility and visibility of the plugs for closing the drain holes. This would reduce the risk of human mistakes.

- Use CA units that can actively remove or replace O_2, so they become more tolerant to air leakage. These units exist in the market, but are more costly.
- Don’t use CA reefers for dehumidification shipments. This is an option. Drawback is that it limits the usability of CA reefers. That increases the logistic hassle and costs of container operators, as it is yet another parameter that needs to be taken into account when accepting bookings or repositioning empty equipment.

5 CONCLUSIONS

A reefer meant to be able to do both CA shipments and dehumidification shipments requires a compromise: for CA it is best to omit unit-end drain holes, while for dehumidification it is best if they are there and open. Some facts about the dilemma involved:

1. When properly closed with fitting plugs air leakage through drain holes is negligible.
2. Not closing the unit-end drain holes does deteriorate the air tightness by a factor 6 (compare test no. 5 and 7 in Table 2).
3. Air leakage is larger through unit-end drain holes than through door-end drain holes (in Table 2 compare test no. 4 to 6, and no. 2 to 5).
4. Omitting the CA curtain elevates air leakage as much as opening the unit-end drain holes (compare test no. 5 and 8 in Table 2).
5. Open unit-end drain holes help to reduce relative humidity in the container if condense water from the evaporator reaches the container floor (Table 3).

Alternatives to circumvent the dilemma exist. Unfortunately these come with other drawbacks.

6 ACKNOWLEDGEMENTS

The authors thank Maersk Line, represented by Captain Peter Wedell-Neergaard of Centre of Reefer Management, for supporting this study.

7 REFERENCES

1. Xie R., Sun Y., Foster A., Liu G., Liu H. (2011). Dynamic performance of infiltration from a refrigerated container. *Proc. of Int.’l Conf. of Refrigeration, Prague, Czech Republic*. paper ID 554.
2. Gerwen, R.J.M. van; S.M. van der Sluis; H. Schiphouwer; R. Bennahmias; R.David; T. Slama; G. Panozzo 1999. *Energy labelling of refrigerated transport equipment.* Final report of contract no, XVII/4.1031/Z/96-019 intended for the commission of the European Communities Directorate-general for energy.
3. Lukasse L., Staal M. (2010). Air leakage and heat leakage in insulated road transport equipment. *Proc. 1st IIR Int.’l Cold Chain Conf., Cambridge, UK.*
4. Noordzij, P. (1961). (In Dutch) Bouw en inrichting van gascellen. *IBVT Mededeling No. 19.*