Vacuum prevention in reefer containers

The formation of a vacuum during the process of refrigeration and transportation can have a damaging effect on reefer containers*

With the advancement of technology, the typical internal temperature and the air leakage rates of reefer containers have both dropped significantly. These two factors have led to incidents of damage resulting from the formation of a vacuum inside the container that have rarely, if ever, happened before.

China International Marine Containers (CIMC) has studied this phenomenon and concludes that since the extent of the vacuum has a direct relation with the air leakage rate of the reefer container concerned, a series of preventative measures can be taken to avoid the possibility of such damage occuring.

During maritime, road and rail transportation, containers are subject to many forces, for example those imposed during the process of lifting the container or forces resulting from the effect of strong wind and wave motion in maritime transport.

These forces will have a direct effect on the strength of a reefer, which is why every newly-built unit must satisfy the requirements of ISO Standard 1496/1-1996 with regard to strength.

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Collapse of roof panel as a result of a vacuum forming inside the container

Internal forces...

As far as the structure of a reefer container is concerned, the forces involved come mainly from the gravity of the load on the base and the stress on the door panels, side panels and front end wall by the payload of the cargo being carried. However, these forces all act from inside the container to the outside. Little thought has been given as to whether any forces act from the outside to the inside. If there are any, it is only those posed by gravity during operations - perhaps 300 kg and hardly worth mentioning.

In accordance with ISO 1496/1-1996, the force that a container side panel must withstand should be equal to 0.6Pg. Pg refers to the gravity of an object with a weight of P and can be represented as follows:

$$P = R - T$$

Where:

P = the maximum payload allowed in a reefer, represented in kg.
R = tare weight plus maximum payload allowed in kg.
T = tare weight of a reefer in kg.

Suppose R = 30,480 kg and T = 4,000 kg, then Pg = 264.800 kN. The force imposed on the side panel at 0.6Pg (0.6 x 264.800) is 158.880 kN ≈ 16t. Suppose the side panel is 11.5m in length and 2.5m in height, the force is equivalent to a pressure of 533 mmH_2O.

...external forces

The same case applies in reefer transportation, which is why the test requirement for a reefer container is the same as that for a standard dry freight container.

However, during the refrigeration process, the reefer is also subject to an external force caused by thermodynamic change. This force imposes a stress on the reefer box, especially to the walls, that is even greater than the stress on the side panel during transportation.

This force can lead to the sudden collapse of the side panel and the roof panel and cause damage to the reefer. This problem has never been taken into account by ISO but should be accorded greater importance.

The internal temperature of a reefer is normally maintained at -20°C. However, in such regions as South East Asia, South America and Africa, the ambient temperature frequently exceeds the 38°C regulated by the ISO. In addition, these regions invariably have a higher humidity. In the refrigeration process, the hot air in the container will cause a vacuum to form because of contraction.

Theoretical calculation suggests in this case that the pressure can reach 1900 mmH_2O. But this does not take into account that:

- The starting point of a reefer is often below 38°C.
- The internal volume continues to reduce during the formation of vacuum because of the pressure on side and roof panels.
- Ambient air will enter the reefer container during the formation of vacuum due to exterior and interior pressure differences and air leakage.

But what is certain is that the vacuum in the refrigeration process is great.

It is, in fact, because of these reasons, especially the fact that air can enter the box continuously during the refrigeration process because of the difference in pressure, thereby reducing the theoretical stress diversity, that the incidence of damage to reefer containers is relatively low.

These are also the reasons why so little attention has been paid to incidents of this kind, but with the reduction in air leakage rate and lower internal temperatures, the problem has become more serious and should attract more attention.

Three scenarios

In practical terms, there are three ways in which a vacuum can be formed and cause damage to a reefer container:

- Vacuum created in the process of refrigeration, ie the vacuum created during the reduction of temperature from ambient level to setpoint.

Since air leakage will alway exist, and it takes a relatively long running time to pull a reefer down to setpoint (usually three hours in hot weather), ambient air will leak into the container at the same time as the vacuum is forming. As a result, the vacuum in the reefer box will reach its peak in 15-30 minutes and then begin to fall.

Since the peak value is not very high, this will not cause any damage to the container unless the air leakage rate is too low or the strength of the sidewall is not sufficient due to defects in the manufacturing process.

- Vacuum created by opening the door of the reefer when it is fully loaded and closing it soon after.

This happens occasionally. When the reefer is fully loaded, a high vacuum will be caused when the door is closed soon after it is opened. But the force will be offset by the supportive force of the loaded cargo acting on the sidewall and should not cause damage to the cargo or the reefer container.

- Vacuum caused by opening the door and closing it soon after, when the reefer container is partly loaded/empty.

This situation is commonplace in practice. After miles of road transportation, the reefer typically arrives at a warehouse and the door is opened to have some of its cargo unloaded. The door is then closed and the reefer is transported to another site.

In tropical regions, with a high level of humidity, this is highly dangerous and can cause the box to collapse as the accompanying pictures show.

In the latter case, consider the following equation:

$$\frac{P1 \times V1}{T1} = \frac{P2 \times V2}{T2}$$

This shows that as the ambient pressure (P1), internal volume before the door is closed (V1) and (on the assumption that) internal volume after the door is closed (V2) remain unchanged, then:

$$P2 = \frac{P1 \times T2}{T1}$$

Thus the higher the temperature T1 is, the lower T2 is and the smaller P2 is, the higher the vacuum is.

Since the ambient temperature remains the same (+38°C) and the internal achievable temperature is, in most cases, specified by the customer (-18°C to -29°C), -20°C is taken here as the reference standard.

Humidity also has a great effect on vacuum formation. In the hot and humid weather in South East Asia, humidity in the air can reach more than 90%. Moisture in the air frosts during the refrigeration process, reducing the pressure of the vapour in the air, with the result that the vacuum will increase substantially in accordance with the Dorton Rule. According to theoretical calculation and practical tests, the effect humidity has on vacuum can sometimes reach 50-100 mmH_2O, equal to 0.005-0.01P1. But this is inevitable because of the working condition of reefer containers.

Air leakage

The factor bearing the greatest influence on vacuum formation, and idds manually adjustable, is the air leakage rate. In the process of cooling, the vacuum in the reefer allows air to enter the container and so decrease the vacuum. The more air leaked into the reefer, therefore, the smaller the vacuum.

Suppose Q represents the quantity of air leaked, g represents air leakage rate and t represents the time, then:

$$Q\ (m^3) = g\ (m^3/h) \times t\ (h)$$

For certain reefers, g remains unchanged, so the more time it takes, the more air is leaked and the smaller the vacuum is. This applies to the creation of a vacuum during pull down.

However in the more extreme condition where the door is open and closed when the reefer is partly loaded/empty, the vacuum forms rapidly (peak reached after only 5 minutes) because of the sudden drop in internal temperature. Since the time period is relatively short and the airflow is relatively small, the vacuum is high and very dangerous.

At the same time, the quantity of air leaked is in proportion with the air leakage rate. Thus the higher the air leakage rate, the more air is leaked and the smaller the vacuum is.

Moreover, when the air leakage rate remains unchanged, and the greater the difference is between pressures inside and outside the container, the more air is leaked.

Empirical proof

A number of tests have been carried out to prove this point. In the case of a

A vacuum inside the container has caused the sidewall to go concave

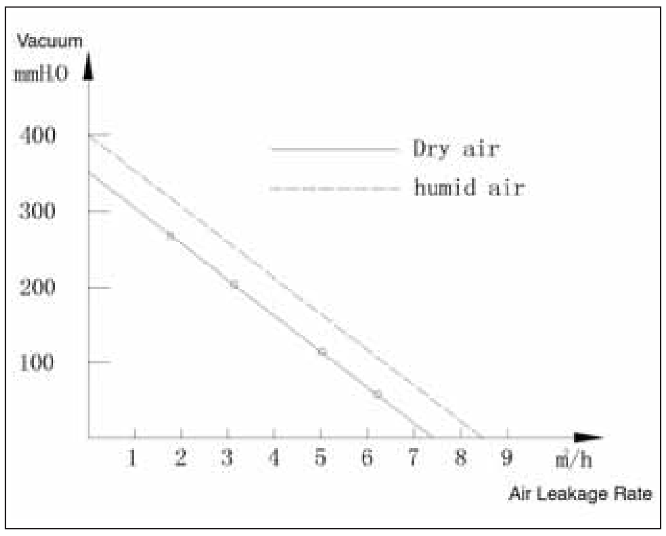

Figure 1: Air leakage rate at the beginning of refrigeration and vacuum formation (ambient temperature +38°C, setpoint -20°C)

vacuum forming in the refrigeration process, a reefer container was tested under air leakage rates of 6 m^3/h, 5 m^3/h, 3 m^3/h and 1.8 m^3/h respectively, with the ambient temperature at +38°C and the internal temperature at -20°C.

Normally the vacuum reaches its maximum after 15-30 minutes. From Figure 1, it can be concluded that the four air leakage points are linear and that the air leakage rate is in reverse linear relation with the vacuum.

It can also be concluded from Figure 1 that when the ambient air is dry, and the quantity of air leaked is 0, the maximum vacuum is 350 mmH_2O. When the air leakage rate exceeds 7.5 m^3/h, there will be no vacuum formed during the refrigerating process.

When it comes to humid air, the moisture in the air condenses into water and the pressure in the air is reduced. The vacuum will, in turn, increase by 50 mmH_2O as shown by the dotted line in Figure 1. It can be assumed that for a reefer with a small air leakage rate, when the air is humid, the maximum vacuum can hit 400 mmH_2O, but will not exceed this amount.

When the air leakage rate exceeds 8.5 m^3/hr, there will be no vacuum formed in the refrigerating process so an empty reefer is unlikely to be damaged by the formation of a vacuum in refrigeration process.

Higher vacuum

In a test condition with the ambient temperature at +38°C, humidity at 20% and the internal temperature maintained at -20°C for an hour, then the door is opened for two minutes before closing, the vacuum in the reefer will rise rapidly.

The maximum vacuum varies for different reefer containers: The lower the air leakage rate, the higher the vacuum. The maximum vacuum for the four different air leakage rates is shown in Figures 2 and 3.

The following conclusions can be drawn:

- The air leakage rate is in reverse linear relation with the vacuum. The smaller the air leakage rate, the higher the vacuum and the more dangerous it is.
- When the air leakage rate is low, the vacuum will rise rapidly when the refrigeration machinery is left running.

The test load in the ISO side panel test is 18t (0.6p). Suppose the length of the sidewall is 11.5m the height is 2.5m and the pressure is equal to 553 mmH_2O.

In the condition where the ambient temperature is +38°C, the humidity is 100%, the internal temperature is -20°C and the air leakage rate is 5 m^3/h, the vacuum will be 553 mmH_2O when keeping the refrigeration machinery running during the opening and closing of the door, the same as that assumed in the ISO test.

Note: the air leakage rates referred to in this article are the rates at a pressure of 25mmH_2O

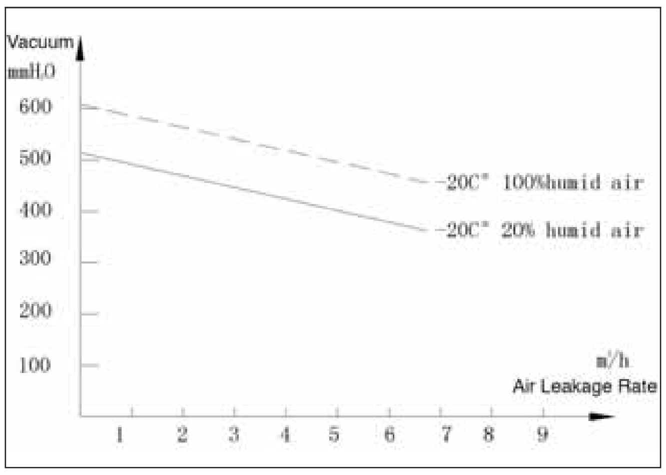

Figure 2: The relation between vacuum and air leakage rate when the reefer unit is stopped

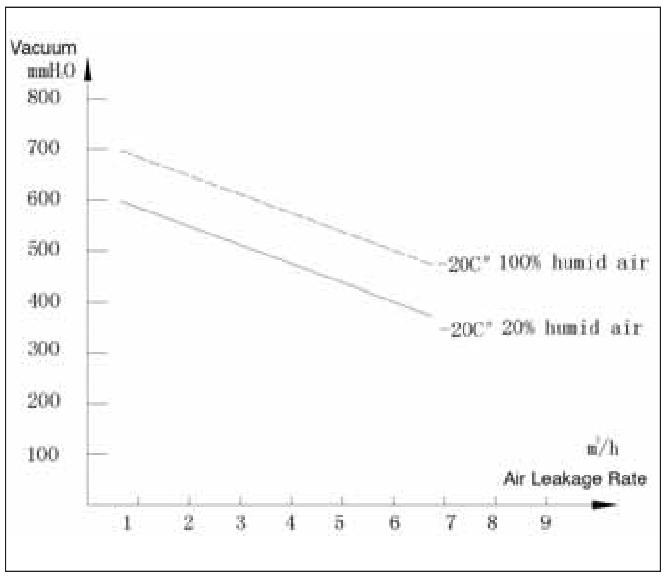

Figure 3: The relation between vacuum and air leakage rate when the reefer unit is running

Clearly, therefore, it is not advisable to reduce the air leakage rate endlessly and, equally, it would be advisable to stop the refrigeration unit when opening and closing the door.

Air vent

Considering the close relation between the vacuum and the air leakage rate, it follows that if the air leakage rate is increased manually - by opening the container's air vent - the vacuum should be reduced.

In this respect, the following series of tests was conducted:

- *Vacuum test on opening the vent*: With the ambient temperature at +38°C, humidity at 20% and the internal temperature maintained at -20°C for an hour, the vent was opened a quarter of the way and the door opened for two minutes and then closed without stopping the refrigeration unit. The maximum vacuum reached 40 mmH_2O.

With the ambient temperature at +38°C, humidity at 20% and the internal temperature maintained at -20°C for an hour, the vent was opened an eighth of the way and the door opened for two minutes and then closed without stopping the refrigeration unit. The maximum vacuum was 200 mmH_2O, far smaller than the load of a reefer.

It can be concluded, therefore, that as long as the vent is open, even one eighth of the way, the reefer will not be damaged in any condition, even if the refrigeration unit is running.

- *Starting the refrigeration unit after stopping for a period:* It can be seen from Figure 3 and 4 that when the air leakage rate is low, the vacuum is much higher if the refrigerated unit is running when the door is open and closed.

If the refrigeration unit is stopped when opening and closing the door and started some time later, it follows that the vacuum should be reduced.

In this respect, a test was carried out with the air leakage rate of the reefer at 2m^3/h, the ambient temperature at +38°C and humidity at 20%. The door was opened and the refrigeration machinery stopped. The door was then closed after two minutes and the machinery restarted 13 minutes later.

This test showed that the vacuum increases rapidly after closing the door and reaches its maximum (485 mmH_2O) five minutes later. At this point the air leakage takes effect and the vacuum drops to 397 mmH_2O around 13 minutes after closing the door.

Thereafter the vacuum rises slowly after the unit is restarted and reaches 490 mmH_2O after a further five minutes, before slowly dropping again. This suggests that if the unit is closed for 15 minutes, the reefer will not be damaged even if the unit is started shortly thereafter.

It can be concluded from this latter test that the vacuum in a reefer container reaches its maximum level 5-6 minutes after restarting the unit, a similar timescale to that found in the other tests. Stopping the unit for around 15 minutes after closing the door, therefore, will effectively prevent damage to the reefer.

Ever present

In summary, the risk of a vacuum forming after opening and closing the door of a reefer container is ever present and as required carriage temperatures inside a reefer fall, the phenomenon will become increasingly serious. Measures must be taken to prevent damage to the reefer container.

The following recommendations are made to minimise the problem:

- The air leakage rate of a reefer should not be too low; 5 m^3/h is a good choice.
- An instruction should be put on the container door advising that the air vent should be opened and the refrigeration machinery stopped after the door is closed - stop the unit when the door is open and restart it 15minutes after the door is closed.
- A vacuum relief valve should be installed. Open the valve when the vacuum is reaching the critical point to let the air into the reefer and thereby prevent damage as a result of vacuum formation. ❑