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Freight Containers——Are They Sufficiently Gastight for Quarantine & Pre-shipment Fumigation with Methyl Bromide in the 21st Century?

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Abstract: Freight containers are used to transport virtually all non-bulk cargoes traded internationally, with a considerable proportion of this freight still subject to quarantine or pre-shipment fumigation with methyl bromide. Most of these fumigations are carried out under sheets. Some quarantine and other authorities allow fumigations to be carried out directly in the container, without sheeting or tarping, often with additional restrictions to ensure success of the treatments. Restrictions include specifying minimum levels of sealing or gastightness, such as measured by pressure test, or use of particular kinds of containers only, e. g. reefers. Where a container can be demonstrated to be gastight by pressure testing, it may be used directly as a 'chamber' or gastight enclosure.

This paper presents a summary of the mathematical background to pressure testing, information relating to gas loss from freight containers, and some practical observations on fumigant retention at different pressure test values. Both the theory and limited practical studies available support a minimum pressure test specification of 10 seconds pressure half life for containers to be used directly as enclosures, without sheeting. This applies to the container in the filling condition to be treated. Below this level of sealing, risk of fumigation failure increases.

Key words: fumigation, pressure testing, methyl bromide, emissions.

Introduction

It is well known that many fumigations carried out in tarpless (unsheeted) containers fail because the sealing level of the container is poor, and there is excessive leakage. This means the fumigant gas is not retained for long enough at a high enough concentration to kill all life stages of the target pests because the requisite Ct-product is not achieved.

Some quarantine authorities discourage or do not approve the use of tarpless in-container fumigation of goods in general purpose containers because of the uncertainty over the sealing level and the risk of treatment failure. It is often an official requirement that the container be fumigated with doors open and under gastight sheets or tarpaulins ('tarped')[1]. Tarping of containers is a labour-intensive, time consuming operation. It is increasingly being regarded as an unsafe work practice by occupational health and safety authorities, particularly where there is wind or the containers are stacked. Furthermore, treatment under tarps has, itself, a substantial risk of failure under windy conditions or where poor quality (i. e. leaky) or damaged sheets are used[2].

An alternative to fumigation under sheets is to use the container itself as the fumigation enclosure. Many modern general purpose containers, such as those used for transport of durable stored products (e. g. grains, pulses, animal feeds, wooden materials), are quite well sealed. This procedure has been widely adopted in many parts of the world wherever the contents of containers have to be fumigated.

One of the main reasons for its popularity, particularly in developing countries, has been the availability of cans containing 680 or 750g methyl bromide, which made fumigation with this fumigant "as easy and simple as fumigation with phosphine" generated from aluminium phosphide tablets or pellets. This convenience together with a range of novel but unorthodox application equipment allowed one person provided with a moped to carry out fumigation treatments "very easily and very cheaply". This casual approach to fumigation provides, at best, no quality assurance beyond the dosage of methyl bromide applied into the container[2].

However, in-container fumigation is used on the assumption that the fumigant can be retained adequately to achieve target disinifestation levels. For quarantine treatments, the target Ct-levels can be quite high, and Barak et al. [3] provide an example of some in potential treat-

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ments of Asian Longhorn Beetle to quarantine standards-in untarped containers.

An important aspect of quarantine and preshipment fumigations is that they are carried out to a standard where the risk of failure is acceptable. However, this in turn requires monitoring of fumigant concentrations within the container (fumigation enclosure) to assess whether an adequate Ct-product has been achieved. While there are measures that can be taken to compensate for poor gasholding to some extent (e. g. topping up'[1,4], slow release systems[5]), it is better in a fumigation to retain gas at adequate levels with minimal or no intervention, and better still to have an objective measure of the sealing level of the enclosure before adding gas, to give confidence that the fumigation will be successful.

Pressure testing is a simple and quick quality control process that can be applied on most fumigation enclosures or containers, some flimsy or flexible structures excepted.

It would appear that the existence of pressure testing as a tool for quality control has been overlooked by the fumigation community. Pressure testing plays an ongoing role in our everyday lives, for example, by ensuring the safety of the canned food we eat, the cylinders that supply LPG to our kitchens, as well as enclosures used for fumigation.

Navarro[6] described some features of pressure testing for grain storages. Two forms are used with containers the pressure decay test (Pt-test) and pressure/equilibrium flow test (PQ-test). The pressure decay test involves adding or withdrawing air from the enclosure to give a set pressure differential across the enclosure walls, shutting off the air addition or removal and timing the decay of pressure between two set values, typically giving a pressure half life. The pressure/equilibrium flow test involves adding or withdrawing a measured, set flow of air and observing the equilibrium pressure difference achieved.

PQ-tests are slower to carry out and require more complex measuring equipment than Pt-tests. The latter require only a simple pressure measuring device and a timer, while the former requires accurate measurement of both pressure and air flow. Thermal (refrigerated or reefer) containers are built to a pressure test standard specified by a PQ-test[7] and some of the research with gasholding of containers carried out in the 1970s (e. g. Banks et al.[8]) also used PQ-tests to specify level of sealing. The PQ-test and Pt – tests are correlated for a particular type of container construction, but the correlation is different for different types[9].

A question is "what is the minimum test value that gives a satisfactory level of confidence in a fumigation while being achievable in routine practice" The choice is between increased risk of failure and industrial feasibility. Fortunately, the level of sealing that can routinely be achieved in practice also affords a satisfactory management of risk, in otherwise well conducted fumigations.

Because Pt-tests can be carried out quickly and easily, they tend to be specified for determining level of seal in fumigations. The discussion below is largely related to Pt-tests, with data originally related to PQ-tests translated to Pt-test equivalents.

Mathematical Background to Pressure Testing

Formulae relevant to pressure tests in containers were summarised by Banks[5].

In a decay test, the decay of pressure from the initial level Δp_1 to final level Δp_2 over time t for a container of volume V filled with material of mass m_{bulk} and true density ρ_{bulk} is given by:

$$\Delta p_1^{\,1-n} - \Delta p_2^{\,1-n} = (1-n)\ b\ K\ t \qquad (1)$$

for $n \neq 1$, and

$$\ln \Delta p_1 - \ln \Delta p_2 = b\ K\ t \qquad (2)$$

for $n = 1$, where

$$K = \rho RT / (28\ (V - m_{bulk}/\rho_{bulk})) \qquad (3)$$

and b, n are constants in the equation

$$Q = b\Delta p^n, \qquad (4)$$

relating input air flow, Q, to equilibrium differential pressure Δp.

The mathematics implies that the equilibrium flow for a set pressure (e. g. 250 Pa) should be inversely proportional to the pressure decay time (e. g. time from 200 to 100 Pa). However, because of nonlinearities in the pressure part of the equations, the pressure halving time varies with the pressure values used.

Typically loss of concentration of fumigant, c, in a container follows pseudo first order decay kinetics after an initial rapid sorption with apparent concentration at zero time of c_0 and where k is the decay constant or ventilation rate constant. Thus:

$$c = c_0 e^{-kt}. \qquad (5)$$

The decay constant may be made up of several individual components related to factors causing gas loss.

Factors Causing Gas Loss from Containers

There is a range of different forces that cause gas loss from structures, including freight containers[8,10] Their individual contribution to observed loss of fumigant can be modelled and ranked according to size and susceptibility to sealing.

For containers, the main forces causing gas loss are:

- Thermal expansion of gases within the container
- Synoptic and tidal barometric atmospheric pressure reductions
- Wind effects and transport velocity
- Ascent and descent.

It is apparent that those forces that are cyclic and operating on long time scales, of the order of hours or days, are insensitive to levels of sealing where there is a pressure decay time of the order of seconds. Those forces that are not cyclic, i. e. wind and transport velocity are directly affected by level of sealing.

The loss rate constant caused by wind or transport velocity, k_w, has been found experimentally[11] to be directly proportional to the equilibrium flow, Q_5, for a 5 Pa pressure.

Thus: $k_w = -\alpha\, v\, Q_5/V$, (6)

where α is 0.012 s · m^{-1} and v is the wind or transport velocity (or a combination thereof).

Banks[5] gave estimates for the contributions of these forces for under some typical condition, both static and in transit. Table 1 provides a recalculation of these figures for various decay times for a well filled container.

Table 1. Calculated rate constants (seconds^{-1}) for gas loss from a standard filled container, caused by various factors

	Pressure decay value (200 – 100 Pa) in seconds				
Factor	1	2	5	10	20
10℃ cycle per day in headspace	0.024	0.024	0.024	0.024	0.024
1000 Pa barometric pressure variation	0.010	0.010	0.010	0.010	0.010
Wind at 2 m s^{-1}	0.242	0.121	0.048	0.024	0.012
Totals	0.276	0.155	0.082	0.058	0.046

Calculated for a 28m^3 container filled with 22t wheat at 25C with value of $n = 0.6$ and an estimated air volume content of 10.2 m^3.

It can be seen from Table 1 that it is predicted that the wind effect from a moderate, but continuous, wind becomes similar in magnitude to the combined predicted effects of temperature and barometric pressure variation at around 10s pressure halving time (200 – 100 Pa).

This model is based on a filled container in the state that would typically be fumigated. The load provides some damping of the thermal cycling in the container. These results relate to decay time only and are independent of fill of the system. Decay times at a given level of seal are a function of the contained air volume. Thus the container must be tested at the fill level at which it will be fumigated. If it is tested empty, but treated full, the pressure test result needed has to be corrected according to the change in contained gas volume. In the example above (Table 1), a 10 sec decay half life in a filled container corresponds to about 27 sec empty.

Sustained average wind speeds of 2 m · s^{-1} (7 kph) are common in areas used for container fumigation. The adverse effects of wind on gasholding of fumigation enclosures, including containers, are well-known, though poorly documented. Mulhearn et al[12]. collected some information on this. A modern analysis using the CFD approach for fumigant retention in flour mills is given by Cryer[13].

Practical Observations of Fumigant Holding for Various Pressure Test Values

There are very few published, experimental studies on the influence of pressure testing on retention of fumigant under commercial conditions. The few that are available support a pressure test standard of around 10 s pressure half life. This level of sealing is easily attainable in modern ply floored general purpose containers, and reefers, in good condition (intact and undamaged door seals, well-fitting doors, no holes in the sides and roof).

Using tracer gas tests Banks et al. [5,8] showed that pressure tests were a good measure of the gasholding in freight containers that was caused by factors other than cyclic changes in internal temperature and external barometric pressure.

Ball and van Graver[14] summarised work with fumigation of hay in containers. Fig. 1 shows results from commercial fumigation of 41 containers with methyl bromide under various conditions and pressure test values. Some further information on retention of phosphine and methyl bromide as a function of pressure test is given by De Lima et al. [15].

Banks[5] showed that a 10 s half life provided adequate retention of CO_2 in a study of 36 containers loaded with grain and supplied with a slow release box to maintain CO_2 levels over the target 10 day exposure.

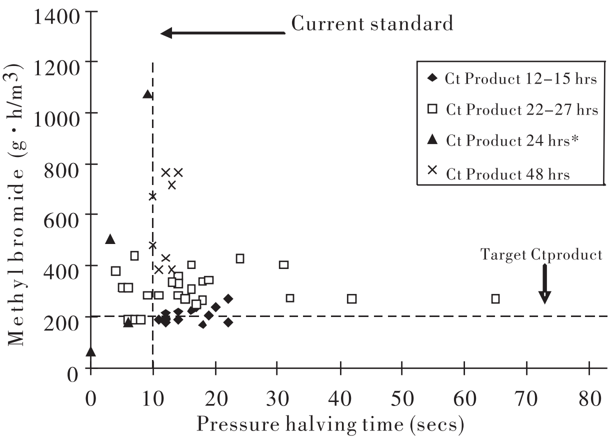

Fig. 1 Methyl bromide Ct products as a function of pressure decay testing of freight containers loaded with hay (redrawn from Ball and Graver[14])

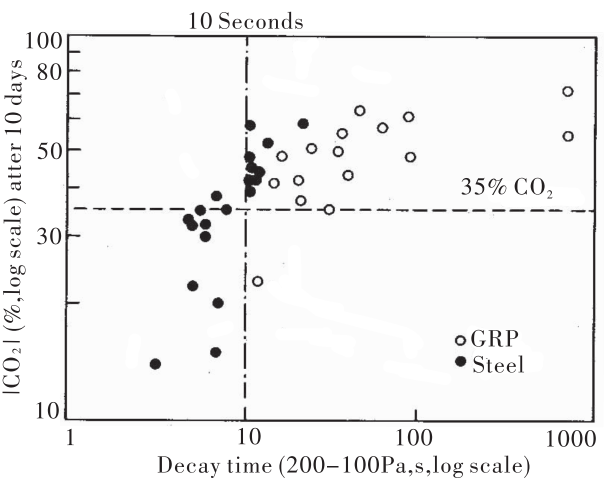

Fig. 2 CO_2 level present after 10 days as a function of pressure decay test in either static steel or glass reinforced plastic containers, load 18 t wheat, CO_2 added, 30 kg loose with 30 kg in a '10 day' box (redrawn from Sharp and Banks[10])

All these studies show good retention of fumigant at the 10 s half life or greater, with low risk of failure. Furthermore there were many successful fumigations at a half life between 5 – 10 s, but some indication of reduced reliability in this range. The data in Fig 2 indicate reduced gasholding in this range and substantial decrease below 5 s, while the data in Fig 1 shows 4 of the 8 fumigations to have been marginal with the target Ct-product of 200 ghm^{-3} not quite achieved at 24 h exposure. All containers that achieved > 10 s pressure test and were observed for > 22 h achieved > 200 ghm^{-3}.

While these data support the, 10 s decay standard of AQIS methyl bromide standard[1], their application to a 5 s half life decay time may, particularly under adverse weather conditions, be marginal.

Conclusions

The analysis above shows that under even moderate wind, e. g. 20kph (5.5 m/s), sustained for a few hours, there is a substantial risk even with > 10 s decay time that the gasholding of methyl bromide may be insufficient for effective fumigation.

It is interesting that up to 24 February 2008, USDA APHIS had prudently forbidden in-container fumigation of containers (excepting reefers) with methyl bromide when severe winds, defined as sustained winds or gusts of 30 m. p. h. (about 13 m/s) or higher for any time period are forecast.

However, on 25 February 2008 the USDA APHIS[15] suspended tarpless container fumigations using methyl bromide due to concerns regarding their efficacy and instructed fumigators that all container fumigations must be conducted under tarpaulin. The notice continues by indicating that a study will be conducted to determine if the tarpless fumigation process would be efficacious if performed solely on containers that were pre-certified as leak-proof, based on pressure testing. The study will also determine the optimum dosage rate that is needed to maintain adequate gas concentrations of methyl bromide for an efficacious treatment.

The outcome of the proposed study will be of interest to fumigators who have deemed the AQIS pressure test requirement to be too limiting in its range, with calls to allow containers to be fumigated without enclosing them under fumigation sheets using a less stringent pressure test regime.

Will such compromises with the potential for both increased emissions of methyl bromide and higher risk of failure be accepted as best fumigation practice for quarantine purposes?

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