VENTILATION EFFECTS AND REQUIREMENTS IN CONTAINERISED REFRIGERATED TRANSPORT

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ABSTRACT

Fresh fruits and vegetables are alive and require fresh air to allow respiration. Without ventilation during transport, respiratory gases can build up and damage the produce. Historically, high ventilation rates have been used, which impact unfavourably on temperature control, humidity, and energy use. Calculation programs are now available which allow easy calculation of ventilation requirements in containerised transport for given upper levels of carbon dioxide or ethylene.

These programs are described and are used to compare necessary ventilation rates with those generally used in transport. It is shown that, for produce with low rates of respiration, ventilation rates are generally appreciably higher than necessary.

INTRODUCTION

The majority of refrigerated containers are designed for the carriage of both chilled and frozen cargoes. Many chilled cargoes comprise perishable produce, fruits or vegetables that require ventilation with fresh air to maintain a satisfactory storage atmosphere. Most refrigerated containers therefore incorporate ventilation arrangements.

For chilled cargoes, temperature controlled air is circulated around the cargo by fans at a rate of around 4,000 m^3/h. Fresh air requirements vary in the range from 25 to 250 m^3/h and are typically in the range 25 to 75 m^3/h. If the ventilation rate is too low, produce may suffer from build-up of carbon dioxide or ethylene. Increased ventilation has effects on the refrigeration system operation: more cooling power is needed, more moisture is introduced resulting in a greater need for defrosting, close temperature control becomes more difficult, more energy is used.

In most refrigerated containers, the rate of fresh air ventilation is set at loading and does not vary. For satisfactory carriage without excessive energy use, it is important to set the correct ventilation rate, neither too high nor too low.

1 RESPIRATION AND VENTILATION

All vegetables and fruits are alive and continue to respire and metabolise. The metabolic process evolves carbon dioxide and metabolic heat. There is a clear relationship between heat of metabolism and evolution of carbon dioxide, and for every 2.96 watts of metabolic heat 1g of $C0_2$ is generated. This is discussed fully in ASHRAE (1998). Respiration may also release water vapour and ethylene.

The level of respiration is dependent on produce type and on temperature. It also varies with produce maturity. For example, at 0°C, Thompson seedless grapes produce 5.8 watts per tonne, whereas sprouting broccoli produces 55.3-63.5 watts per tonne. The variation with temperature is illustrated in table 1, with data from ASHRAE (1998).

From this it is seen that substantial amounts of carbon dioxide may be produced, but the amount will vary over a wide range. To prevent excessive build-up of carbon dioxide, ventilation is necessary. Too much carbon dioxide can produce tissue damage or “fizzy” fruit; in apples this condition is known as brown heart. Without ventilation there can also be a lack of oxygen, which can result in anaerobic respiration; in this case the metabolic pathway is incomplete and the final product becomes alcohol resulting in alcoholic tasting fruit. Too much water vapour can encourage the development of moulds, rots and fungi. However, too little is just as bad as it results in desiccation of fruit and vegetables. Ethylene gas is a ripening hormone, very small quantities building up can promote premature ripening in fruit or de-greening in green vegetables and loss of leaves. It also can cause abortion of embryonic flowers in bulbs.

Table 1. Metabolic heat production of sprouting broccoli

Temperature, °C	Metabolic heat, W/tonne
0	55.3-63.5
5	102-475
15	515-1008
20	843-1011
25	1155-1661

2 REFRIGERATION IMPLICATIONS

Any ventilation will increase the need for cooling, as the air introduced must be cooled to the cargo carriage temperature. Humidity introduced in the fresh air will need to be removed, requiring still more cooling power and also leading to more frequent or longer defrosting periods. Thus ventilation can add substantially to cooling power requirements. A ventilation rate of 100 m^3/h of air at 20°C above the cargo temperature requires about 650 watts of sensible cooling, which can be more than doubled by latent cooling to remove excess humidity.

The addition of fresh air at one point in the container can lead to loss of uniformity of temperature control across the width of the container, leading to a wider temperature range within the cargo.

Whilst ventilation is essential for many cargoes, excessive amounts of ventilation will increase energy use and reduce the quality of temperature control provided. It is therefore important to ensure that the correct amount of ventilation is supplied, no more and no less.

3 VENTILATION RATES

The ventilation rates of up to 250 m^3/h available in modern refrigerated containers are well in excess of those needed for most produce, so it is necessary to choose a reduced ventilation setting appropriate to the commodity being carried. Shipping lines and equipment manufacturers provide guidelines, and a brief survey of some of these shows wide variations as follows:

Apples (Gala)	30 – 125 m^3/h
Asparagus	12 – 70 m^3/h
Avocado (Haas)	30 – 125 m^3/h
Broccoli	30 – 125 m^3/h

Faced with this range, how does the shipper decide what to select? What is needed is a simple-to-use calculation program to show the effects of different ventilation rates.

4 CALCULATION PROGRAMS

The gas calculation program is a tool designed to enable the user to predict the level of gas concentration in a volume of space after a length of time. Gas calculation programs are available from a number of sources; one developed for easy use is described here. The tool uses a general expression widely recognised in Building Services which encompasses a number of variables. It gives the user easy access to find the stabilisation period and final gas concentration resulting from set ventilation and gas production rates.

After completing all the input parameters the program calculates the resultant gas concentration for a set duration and indicates the concentration stability by plotting the rate of change up to this point on a graph.

4.1 Growth and Decay Equation

The equation is related to fluid dynamics and uses standard derivatives found in many books for calculating contamination growth and decay, e.g. Douglas *et al.* (1995).

Fresh air with no contaminant.

$$C = C_o e^{-n} \quad \text{------------------------------------} \quad (1)$$

Fresh air with contaminant.

$$C = C_a\left(1 - e^{-n}\right) \quad \text{------------------------------------} \quad (2)$$

Gaseous contamination as a result of metabolism or other active process.

$$C = \left(\frac{10^6\,\dot{V}_c}{\dot{V}}\right)\left(1 - e^{-n}\right) \quad \text{------------------------------------} \quad (3)$$

Overall combined equation for all scenarios mentioned above.

$$C = \left(\left(\frac{10^6\,\dot{V}_c}{\dot{V}}\right) + C_a\right)\left(1 - e^{-n}\right) + C_o e^{-n} \quad \text{-----------------------------------} \quad (4)$$

4.2 Respiration Parameters

The production of contaminant gas will in many scenarios be quantified using volumetric flow; this neatly fits into equation (3). However, when the gas contamination is from respiration, conventional units measure rate of energy consumption.

Respiration of all living structures results in the metabolisation of glucose with oxygen and the by-products are carbon dioxide, water and heat (Kays, 1991).

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + \text{Heat (2860kJ)} \quad \text{------- ---------} \quad (5)$$

Using the molar mass synopsis above it is possible to evaluate the volumetric rate for carbon dioxide production, or oxygen consumption when measuring respiration.

4.3 Fixed Assumptions

This program assumes:

1. Conditions are always at 101,325 Pa or SAP.
2. Metabolising produce remains constant as gas concentrations change.
3. The temperature is approximately 10°C,
   therefore: i) $\rho_{\text{carbon dioxide}} = 1.9\text{kg/m}^3$
   ii) $\rho_{\text{oxygen}} = 1.33\text{kg/m}^3$
4. One mole carbon dioxide = 477kJ / 44g = 10.85×10^6 J/kg
5. One mole oxygen = 477kJ / 32g = 14.91×10^6 J/kg
6. Temperature and gas concentrations are evenly distributed throughout the store.
7. Relationship between volume of gas produced and metabolic mass of gas production:

$$\text{Volume of gas produced} = \frac{\text{Total Gas Production (mW)}}{\text{Gas Density (kg/m}^3\text{) x 1000 x Energy Consumed (J/mole.kg)}}$$

$$= \text{m}^3\text{/sec}$$

This program has been assembled in an Excel spreadsheet, and can be used by inputting airspace volume, type of gas to be removed, initial gas concentration, produce mass, rate of respiration, and ventilation rate. The program then calculates the change of gas concentration for the desired duration and the concentration at the end of this period. An example is shown as Figure 1.

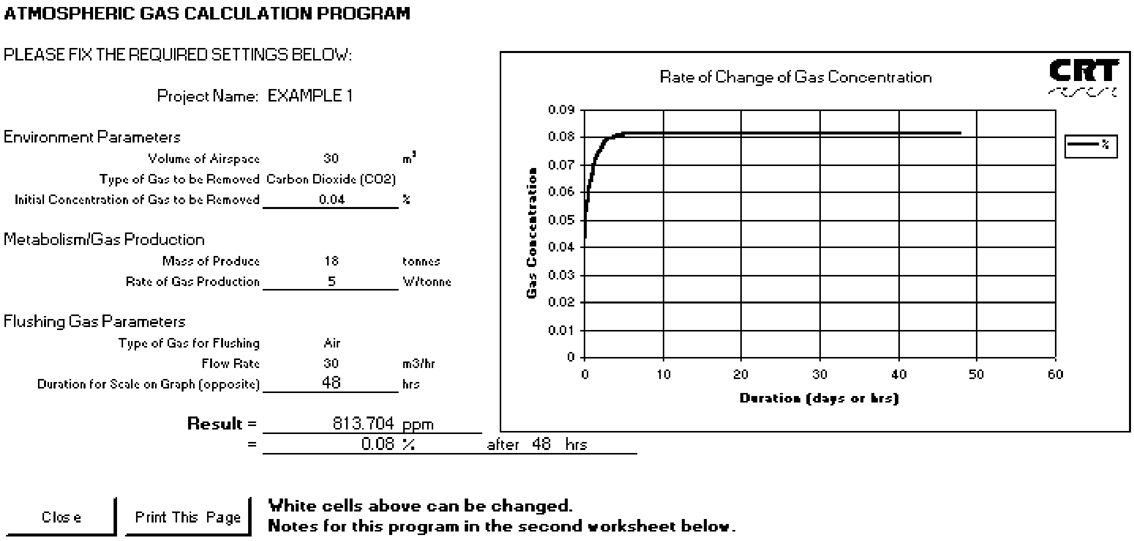

Figure 1. Sample calculation program output.

5 RESULTS

This program has been used to examine the needs of the produce listed in section 3 above, using the following ranges of metabolic heat:

Apples (Gala)	9.7 – 18.4 mW/kg
Asparagus	81 – 238 mW/kg
Avocado (Haas)	183 – 466 mW/kg
Broccoli	50 – 55 mW/kg

The ventilation rate required for a CO_2 level of 0.5% after 120 hours was determined, and was found to be as follows.

Apples (Gala)	3.6 – 6.7 m^3/h
Asparagus	30 – 87 m^3/h
Avocado (Haas)	67 – 170 m^3/h
Broccoli	19 – 20 m^3/h

Comparing these rates with those in section 3 above, it is seen that for the apples, recommended rates are up to 10 times those necessary for this level of CO_2 , for asparagus they are about right, for the avocado they could be a bit low, and for broccoli the higher recommendations are too high.

6 CONCLUSIONS

Current recommendations for ventilation rates are inconsistent between data sources. There is a need to re-assess ventilation rate recommendations, as excessive rates impact on energy use and on temperature control, whereas low rates affect produce quality. Tools are now available which make the calculations easy. Before they can be used, it is necessary to establish, for each commodity, the criteria controlling ventilation, which could be carbon dioxide level, ethylene level or humidity. If this is done, more accurate statements of ventilation requirements can be made, which will lead to improved produce quality and reduced energy use.

NOMENCLATURE

Symbol	Description	Units
ρ	Density	(kg/m^3)
V	Volume of space	m^3
$\dot{V}$	Rate of ventilation	(m^3/sec)
$\dot{V}_c$	Rate of gas production	(m^3/sec)
C_a	Concentration of gas in ventilation	(ppm)
C_o	Initial concentration of gas in space	(ppm)
C	Instantaneous gas concentration	(ppm)
n	Number of air changes per second, $\frac{\dot{V}_c t}{V}$	-
t	Duration for calculation	Sec
SAP	Standard Atmosheric Pressure	Pa

REFERENCES

ASHRAE, 1998, *Refrigeration Handbook,* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta GA.
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Kays, S.,1991, *Postharvest Physiology of Perishable Plant Products*, Van Nostrand Reinhold, New York, Ch.3:p.100-101.

RESUME: Les fruits et légumes sont vivants et ont besoin d'air afin de respirer. Sans ventilation lors du transport, les gaz de respiration peuvent s'accumuler et être dommageables pour les produits. Dans le passé, on a employé des vitesses de ventilation élevées, ce qui a exercé des effets défavorables sur le contrôle de température, l'humidité et la consommation d'énergie. On dispose désormais de programmes de calcul permettant de calculer les besoins en termes de ventilation pour le transport en conteneurs, avec les teneurs en dioxyde ou en éthylène maximaux prédefinis.

Ces programmes sont décrits, puis utilisés afin de comparer les vitesses de ventilation requises avec celles habituellement utilisées lors du transport. On montre que, pour les fruits et légumes à faible taux de respiration, les vitesses de ventilation sont en général nettement supérieures aux vitesses requises.