Pressure tests for gaseous applications in sealed storages: theory and practice

Shlomo Navarro[1]

Abstract

Pressure tests and monitoring devices described in this paper apply to structures destined for gaseous treatments to control principally insects in durable agricultural commodities including cereals. The gaseous treatments included here are: modified atmosphere (MA), controlled atmosphere (CA) and fumigation. These pressure tests are designed to estimate the permissible limits for effectively maintaining the gas composition in small, medium and large size warehouses and silos during the treatment. They are not capable however of measuring gas losses that occur by permeation through structural membranes such as concrete and plastic. Theoretical work to describe the process of gas loss from structures is well documented This paper reviews essential considerations in measuring gastightness. However field work to correlate gas loss to pressure tests are very scarce. The described pressure tests in this paper are applicable for rigid and flexible types of structures. Variable and the constant pressure tests are fully described. In the variable pressure test, time is taken for the pressure to fall between two pressure limits while in the constant pressure test, the flow rate at a given constant pressure is measured. A table is presented for provisional ranges of the variable pressure tests to be applied in structures destined for MA, CA and fumigant treatments

Introduction

Afundamental requirement for the successful application of gaseous treatments to control stored-product insects is a well-sealed structure These gaseous treatments include the application of modified atmosphere (MA), controlled atmosphere (CA) and fumigation. In the sealed structure, the desired gas concentration should be maintained at a sufficient level to control insects, whereas otherwise the gas concentration would decrease rapidly without effect The requirement for gastight storages for application of CA's and MA's appears to be more critical than the requirement for application of fumigants (Bond, 1984). In spite of the trend towards improved sealing of existing silos in some countries (Newman, 1990; Delmenico, 1993), the objective has been either to obtain increased fumigation efficiency, or to convert structures for storage under CA's. To control stored-product insects Jay (1971) recommended a concentration of 60% carbon dioxide (CO_2) in air for 4 days at a temperature of 27℃ or above In the context of MA's, sealed storage of grain termed 'air-tight storage' or 'hermetic storage' is also considered (Hyde, et al, 1973; De Lima, 1990). In the hermetic storage method, the structure should be sufficiently air-tight to enable insects and other aerobic organisms in the grain-mass to reduce oxygen (O_2) concentrations below those permitting insect development

Fumigants have been used for many years with limited requirements for structural tightness, and covering the grain bulk or the storage under plastic sheets was usually considered satisfactory. Gastightness has for years been a problem for the application of fumigants in storage. The consequences of poorly sealed storages under fumigation should be considered in view of the development of insect resistance to fumigants in poorly sealed structures (Banks and Desmarchelier, 1979; Banks, 1981; Zettler, 1993).

Methods to determine gastightness have been investigated for different purposes. For the analysis of the energy requirements of buildings, air infiltration is a primary source of energy loss and this infiltration can be measured experimentally. CO_2 has also been used experimentally as a tracer gas (Navarro, 1997) Hunt (1980) reviewed some tracer gas techniques to measure air infiltration into buildings and compared fan-pressurization-evacuation procedures to estimate comparative tightness of those structures. The dynamic characteristics of air infiltration into buildings have been studied in order to predict the heating and cooling load of seasonal energy requirements (Hill and Kusuda, 1975). The ASHRAE Handbook of Fundamentals describes the air change method and the crack method in predicting air infiltration rates (Anon., 1972) The crack method or the constant pressure test is usually regarded as more accurate as long as the leak characteristics can be evaluated properly (Hill and Kusuda, 1975). With this method airflow is expressed as:

[1] Department of Stored Products, Agricultural Research Organization, The Volcani Center, P O Box 6, Bet Dagan 50250, Israel e-mail: vtshlo@netvision net il

$Q = b \cdot \_P^n$

where Q = the volumetric flow rate of air; b = the proportionate constant; n = the exponent and $\_P$ = the pressure difference exerted on an enclosure.

Meiering (1982) investigated a constant pressure test and a variable pressure test for measuring specific silo permeability in silage systems, where the sealed shell is designed to limit entry of O_2 to minimize losses in quality The effect of variations in environmental temperature and atmospheric pressure on O_2 intake of silos was simulated, and permeability limits required for proper O_2 control in silos containing silage were defined. Gas interchange within freight containers and factors leading to gas interchange between containers and external atmosphere were detailed by Banks et al. (1975). They found that the relationship between applied pressure and gas leak rate gave a useful measure of gastightness Banks and Annis (1977) developed a practical guide for storage of dry grain under MA and specified requirements for silo gastightness. Their specifications correspond to pressure decay times needed to maintain the atmospheric composition in the silos. Sharp (1982), using the constant pressure test, measured the gastight level of sealed structures These tests are designed to estimate the permissible limits for effectively maintaining the gas composition in the stores during the treatment.

A decision of the degree of gastightness which is satisfactory or what gas concentrations can be maintained under given environmental and structural conditions should be made prior to the gaseous treatment. This decision should be weighed against the investment involved in sealing a leaky structure to prevent excessive loss of the treatment gas This paper describes the use of the variable and the constant pressure tests and summarizes provisional recommendations for pressure tests for the successful application of gaseous treatments to control storage insects.

Materials and Methods

Structures for Gaseous Treatments

Pressure tests are applicable for two types of structures: rigid and flexible.

A- Rigid Structures

Rigid structures can withstand the positive pressures exerted on them during the test without changes in volume Rigid structures may be constructed of concrete, metal or a combination of the two For CA treatments the structures may be equipped with a pressure relief valve in order to avoid structural failure under extreme and sudden pressure variations

・Sizes of the rigid structures

①Small size structures

These structures are conveniently used for treatment of stacked commodities. They are often referred to as fumigation chambers. Their volumes can range from a few cubic meters (m^3) to 500m^3

②Medium size warehouses and silos

Structures in this category may be vertical or horizontal (longer than tall) and the volumes may range between 500 and 2,000 m^3. The commodities in store may be stacked or in bulk

③Large warehouses and silos

The warehouse and silo sizes in this category are commonly used as central stores and may range from 2,000 to 10,000 m^3 in volume. Single bins of larger sizes are generally less common.

・A general precaution for rigid structures

In conducting the pressure tests, care should be taken to carefully monitor the pressure applied, especially within the rigid structures, so as not to exceed the pressure limits this structure can withstand. A small blower used to pressurize the structure can eventually produce enough pressure to cause structural damage. This is particularly important in large stores. It is always advisable to seek the advice of a civil engineer regarding the structural soundness of a storage before conducting pressure tests

B-Flexible structures

Flexible structures include plastic sheeted structures, bagged stacks sealed in plastic enclosures and bunker type storages. Positive pressures exerted on them cause uncontrolled expansion in volume. Therefore pressure tests in such structures should be performed by creating a negative pressure by evacuation until the sheeting adheres to the commodity or the packed material

・Size of the flexible structures

①Small size structures

These are mostly destined for indoor gaseous treatments of stacked commodities. The dimensions of the structure are dictated by the manageability of the stack Sizes of such structures for indoor gaseous treatments can range up to 500 m^3 volume

A recent development is to store stacked commodities in fumigatable small flexible structures outdoors using heavy duty liners They are used for MA storage of stacks of 10 − 50 tonnes capacity termed storage cubes, and designed for storage at the farmer-cooperative and small trader level (Donahaye et al., 1991)

②Medium sized flexible structures

In this category structures are made from heavy duty material. The flexible silo linings are contained within a circular wall consisting of metal weld mesh. Such structures are fumigatable and suitable for the hermetic storage or MA storage of grain in bulk or in bags and have capacities of up to 1500m^3(Calderon et al., 1989;Navarro and Donahaye, 1993; Navarro et al , 1994; Navarro et al , 1990)

③Large size structures

Those are mostly bunker type stores with capacities of 1500m^3 or larger. These bunkers are usually used for bulk storage of commodities. Ramps of concrete, metal or earth, border the bunkers on three sides in order to raise the walls and increase capacity. Before loading the bunkers, the floor and the ramps are lined with plastic sheeting and then an overliner is used as a cover After loading, the two liners are overlapped and folded to form a hermetic seal. and the over liner is welded closed in order to form a continuous enclosure. Bunker storage for hermetic storage of grain in large bulks of 10,000 to 15,000 tonnes capacity are in current use in Cyprus and Israel (Navarro et al , 1984; Navarro, et al , 1993; Navarro and Donahaye, 1993).

Gas permeation through the rigid structure membrane

Gas loss through the structural membrane during gaseous treatments is an important phenomenon. Membranes of concrete, plaster and plastic liners permit gas permeation and gas exchange. Pressure tests, as described below are not capable of measuring the degree of such losses.

Comparative results with variable pressure test

In variable pressure test, the structure is pressurized to a value above atmospheric, using a fan. The air supply is then shut off and the pressure is allowed to fall by natural leakage to a new value The time taken to fall from the high (positive or negative) pressure serves as a measure of the degree of sealing. Time elapse to half the pressure is usually considered for comparisons of gastightness level. A constant static pressure test is more accurate than a variable pressure decay test and has the advantage of being independent of bin volume. However the variable pressure decay test is quicker and therefore the most practical means of measuring gastightness in grain storage (Anon., 1989; Navarro, 1997; Zahradnik, 1968)

To minimize the thermal influence tests should be carried out preferably before sunrise and in still weather. A pressure of 250 Pa may be taken as an upper limit, but for some structures even this pressure may cause poor seals to open. Welded steel cells and concrete silos may be able to stand 500 Pa, but higher pressures are usually unnecessary.

Comparative tests with variable pressure tests are scarce. Table 1 was prepared as provisional guidelines based on best estimates available in the literature. The suggested times given in Table 1 were doubled for empty storages as an approximation to the intergranular airspace, since for barley, corn, rough rice and wheat, this free space is in the range of 35 to 65% of the total volume (Trisviaskii, 1966).

Banks and Ripp (1984) tested sealed flat storages from 4,500 to 27,000 tonnes capacity and compared the fumigant effectiveness using phosphine with pressure decay time from 150 to 75 Pa. Their tests resulted in successful control of insects when half life pressure decay was 3 min. for the storage capacity of 15,600 and 16,500 tonnes, whereas full insect control could not be achieved when half life pressure decay was less than 1 min for capacities of 4,800 tonnes. In Table 1 a minimum of 3 min for large size structures and a minimum of 1.5 min. for the small range served as basis for half life decay time for full storages.

As a special case for hay fumigation applying methyl bromide (MB), in containers of 12 2 m (40 ft) long pressures from 200 to 100 Pa for a decay time of >10 sec was reported by Ball and van Graver (1997). Although, the minimum 200 g h m^{-3} Ct product was attained using this standard decay time of >10 sec, gas loss was significant. For exposure times of 12 – 15 h, MB concentration dropped from 58 g m^{-3} to the range of 12 – 18 g m^{-3} and after 22 – 27 h exposure to the range of 10 – 18.5 g m^{-3}, pressure halving times ranged from 11 to 85 sec

With sorptive fumigants like MB, a pressure decay test for the assessment of gas retention is not a precise concept since there are several forces that contribute to the gas loss through the leaks in the structure Sorption by the treated material is a major cause for drop in gas concentration during the exposure time Wheat flour treated using MB in experimental jars, resulted in sorption of 70% of the initial gas concentration after 24 h exposure at 25℃ (Navarro, 1977) Since the rate of gas loss is independent of leakage from the enclosure, in well sealed structures the overall gas loss rate will approach that expected from sorption only.

For controlled atmosphere storage in Australia, with structures of 300 to 10,000 tonnes capacity, a decay time of 5 min for an excess pressure drop of 2,500 – 1,500 Pa or 1,500 – 750 Pa or 500 – 250 Pa was regarded satisfactory (Banks et al , 1980) According to Banks and Annis (1980) this range of pressures was chosen so that it is the highest usable without unduly stressing the storage fabric of the store. They commented also that above 10,000 tonnes capacity, pressure testing is difficult to carry out satisfactorily since it requires very stable atmospheric conditions From analysis of the data presented by Banks et al. (1980) it would appear that for storages with capacities in the range of 1,600 – 1,900 tonnes in CA with an initial CO_2 concentration of about 60 – 85% for an average decay time of 11 min , the daily decay rate was about 4% CO_2 With similar range of initial CO_2 concentration in a structure of 150 m^3 capacity daily gas loss was correlated to different levels of pressure decay times (Navarro et al , 1998) Their comparison resulted in a pressure decay time of 3 min. for a daily decay rate of about 4% CO_2

The influence of hermetic storage on controlling insects was examined using small scale 15, 30 and 52 m^3 capacity sealed plastic structures for out door storage of wheat,

paddy and corn (Navarro et al., 1995). Pressure decay rates were compared with daily CO_2 decay rates. With these structures successful insect controls were obtained with > 1% CO_2 daily decay rate which was found to be equivalent to 5 min. half life pressure decay time Similarly comparative data was obtained using hermetic bunker storages of about 19,000 m^3 capacity, where successful results were obtained when the half life pressure decay was about 9 min. (Navarro et al., 1984).

According to Banks and Annis (1984) daily ventilation rates tolerable in various insect control processes are estimated as 2.6% for hermetic storage, 5% for N_2 based CA, 7% for CO_2 based CA, and 10% for phosphine fumigation. Based on the proportions of ventilation rates, this would account for ventilation rates for fumigation using phosphine being two fold of N_2 based CA, and the latter being as much as twice as hermetic storage. These values were also considered in extrapolating the different ranges given in Table 1

Constant pressure tests

For the constant pressure test a fan, a valve, hosing, a pressure sensor and a gas flow meter (e.g a Rotameter) is required. The capacity of the flow meter needed varies with the size of the enclosure under test. It is often convenient to make up a series (battery) of flow meters, which gives a range of flow measurements from 0.005 to 3 m^3/min., in order to accommodate widely varying requirements and give a wide range of test flows. Alternatively, an electronic thermo-anemometer type flow-meter to cover a wide range of flow may be used. An adjustable rheostat (e.g. Variac) is useful for regulating the speed of the fan if it has a brush motor.

Table 1. Provisional recommended ranges for variable pressure test carried out in structures destined for gaseous treatments to control storage insects.

Type of gaseous treatment	Structure volume in cubic meters	Variable pressure test decay time (min.) 250 − 125 Pa	
		Empty Structure	95% Full
Fumigants	Up to 500	3	1 5
	500 to 2,000	4	2
	2,000 to 15,000	6	3
CA	Up to 500	6	3
	500 to 2,000	7	4
	2,000 to 15,000	11	6
MA, including	Up to 500	10	5
airtight storage	500 to 2,000	12	6
	2,000 to 15,000	18	9

Test Conditions

Pressure tests can be performed while the structure contains the stored commodity or when the structure is empty. In both cases the rate of heating or cooling of the structure under test resulting in expansion and contraction of the structure due to ambient climatic conditions, will influence the accuracy of the test. To avoid such situations the tests should be carried out under as stable temperature conditions as possible. With large metal structures it is advisable to perform the tests before sunrise

It is not advisable to perform pressure tests under windy conditions. Pressure differentials, in addition to those created during the test, may be generated by air entering the structure through leaks. Also, fluctuations in the reference pressure may be excessive under windy conditions Plot of the natural logarithm of flow rate, lnQ against the natural logarithm of the corresponding pressure, ln-P would give a linear relationship. Then the slope (n) and intercept ($\ln b$) of this graph can be calculated and also the flow rate corresponding to a standard equilibrium pressure, e g. 100 Pa or 250 Pa need to be quoted

In a detailed study Banks and Annis (1984) presented a model which may be used to calculate the total rate from maximum expected individual contributions of the various phenomena giving rise to gas loss This model assumes that gas loss from an imperfectly sealed enclosure is largely dependent on the pressure across the leaks in the enclosure fabric and the size and flow characteristics of these leaks. They compared values of the sum of the leak-dependent and of the leak-independent components of ventilation on four types of storage for which the decay time was 5 min. for a pressure difference of 500 to 250 Pa. Ventilation rate was used as a measure of gas interchange rate, alternatively termed as air change rate, or gas loss rate constant. Ventilation produced by wind and temperature variation were considered as leak-dependent major forces. Whereas, diffusion and variation of barometric pressure were considered as negligible forces to cause gas loss Using the model they attempted to explain why a single pressure test standard to cover all storage structures is inappropriate. Pressure decay testing in its simple form does not determine the value of (n) Accordingly, the value of (n) lies between 0.5 and 1.0 and generally, for well sealed storages structures it was considered in the order of $0.8 < n < 1.0$.

On the other hand in experimental laboratory work carried out by Navarro (1997), a 665.7-L silo, was used to demonstrate the dependence of (n) values on orifice length. In a grain bin or silo, this orifice length may constitute the thickness of the wall. Accordingly, the longer the orifice was the higher the value of the empirical parameter (n) was. Based on experimental observations it was also

demonstrated that synoptic variations in barometric pressure played a significant role in air infiltration into the experimental silo. During the experiments synoptic variations in barometric pressure ranging between 11 and 17 Pa/h were observed in the test room. The measured CO_2 concentrations were compared with the calculated values based on equations that took into consideration initial CO_2 adsorption by the wheat, diffusion of CO_2 trough the leak, and variations in temperature and barometric pressure Under experimental conditions, close agreement between the measured and calculated values was obtained.

In view of the work involved in determining the (n) value, a rather simplified expression of using the airflow to maintain a constant pressure may be proposed as an alternative. With a similar approach, Banks et al. (1975) used the flow rate at a constant pressure of 125 Pa to correlate with daily gas interchange rate in freight containers. Such comparative results with constant pressure tests for larger structures and for different gaseous treatments are needed in the literature Until such information is obtained, provisional decay times for variable pressure test given in Table 1 may serve as guidelines to determine the suitability of specific storage structures for the successful gaseous control of storage insects

References

Calderon, M. , Donahaye, E , Navarro, S and Davis, R 1989 Wheat storage in a semi-desert region. Tropical Science, 29, 91 – 110.

De Lima, C P F 1990. Airtight storage: Principle and Practice In: Calderon, M and Barkai-Golan, Rivka Ed , Food preservation by modified atmospheres, Chapter 2, CRC Press Inc. , Boca Raton, Florida 9 – 19

Delmenico, R. J 1993 Controlled atmosphere and fumigation in Western Australia – a decade of progress. In: Navarro, S. and Donahaye, E. ed. , Proceedings International Conference on Controlled Atmosphere and Fumigation in Grain Storages, Winnipeg, Canada, June 1992, Caspit Press Ltd , Jerusalem, 3 – 12

Donahaye, E , Navarro, S. , Ziv, A. , Blauschild Yehudit, and Weerasinghe, D. 1991 Storage of paddy in hermetically sealed plastic liners in Sri Lanka Tropical Science, 31, 109 – 121.

Hill, J E and T Kusuda 1975. Dynamic characteristics of air infiltration Trans. Amer. Soc. Heat. Refrig Air Cond. Engn. 81: 68 – 185

Hunt, C M 1980. Air Infiltration: A Review of Some Existing Measurement Techniques and Data pp 3 – 23 In: C. M. Hunt, I C. King and H. R. Trechsel (eds.). Building Air Change Rate and Infiltration Measurements. Amer Soc for Testing and Materials. ASTM STP 719

Hyde, Mary B , Baker, A A , Ross, A. C. , and Lopez, C. O. 1973. Airtight grain storage, FAO Agricultural Services Bulletin 17, 71p.

Jay, E. G. 1971. Suggested conditions and procedures for using carbon dioxide to control insects in grain storage facilities. U S. Dept. Agric. , ARS 51 – 46, 6 pp.

Meiering, A. G. 1982 Oxygen control in sealed silos. Trans Amer. Soc. Agric. Eng . 1349 – 1354.

Navarro, S 1977. A laboratory method for fumigating grain with methyl bromide Rep. Vis Scient. Vic. Plant Res. Inst. 1977: 54 – 62 Burnley, Victoria.

Navarro, S 1997. Sealing efficiency assessment in modified atmosphere storages. Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products (Edited by Donahaye, E. , Navarro, S. and Varnava, A 21 – 26 April. Printco Ltd. Nicosia, Cyprus, 371 – 384.

Navarro, S and Donahaye, E. 1993 Preservation of grain by airtight storage 5th Int. Cong on Mechanization and Energy in Agriculture, 11 – 14 Oct. 1993, Kusadasi, Tokiye, 425 – 434

Navarro, S , Donahaye, E and Fishman Svetlana 1994. The future of hermetic storage of dry grains in tropical and subtropical climates Proceedings of the 6th International Working Conference on Stored-Product Protection, (Edited by Highley, E , Wright, E. J , Banks, H J and Champ, B. R), Canberra, Australia, 17 – 23 April 1994, CAB International, Wallingford, Oxon, UK, pp 130 – 138.

Navarro, S , Donahaye, E. , Caliboso, F M. , and Sabio, G C. 1995. Application of modified atmospheres under plastic covers for prevention of losses in stored grain Final Report submitted to U S Agency for International Development, CDR Project No C7 – 053, August 1990-November 1995 32 pp

Navarro, S. , Donahaye, E , Kashanchi, Y , Pisarev, V. , and Bulbul, O. 1984 Airtight storage of wheat in a P V. C. covered bunker In: Ripp, B. E. et al. , ed. , Controlled Atmosphere and Fumigation in Grain Storages, Amsterdam, Elsevier, 601 – 614.

Navarro, S. , Donahaye, E , Rindner Miriam, and Azrieli, A. 1990 Airtight storage of grain in plastic structures. Hassadeh Quarterly, 1(2), 85 – 88.

Navarro, S. , Donahaye, E. , Rindner Miriam, and Azrieli, A. 1998. Storage of dried fruits under controlled atmospheres for quality preservation and control of nitidulid beetles International Fig Symposium, Ege University, Bornova, Izmir Turkey, 1997. International Society for Horticultural Science. Leuven, Belgium (in press).

Navarro, S. , Varnava, A. , and Donahaye, E. 1993. Preservation of grain in hermetically sealed plastic liners with particular reference to storage of barley in Cyprus. In: Navarro, S. and Donahaye, E. ed. , Proceedings International Conference on Controlled Atmosphere and

Fumigation in Grain Storages, Winnipeg, Canada, June 1992 , Jerusalem, Caspit Press Ltd. , 223 – 234

Newman, C. J. E. 1990. Specification and design of enclosures for gas treatment. In: Champ, B. R , Highley, E. , and Banks, H. J. ed. , Fumigation and controlled atmosphere storage of grain: proceedings of an international conference, Singapore, ACIAR Proceedings No. 25 14 – 18 February 1989, 108 – 130

Sharp, A. K. 1982 Measurement of gastightness with an automatic decay timer. Sci. Tech. Froid. 1982 – 1, 361 – 367.

Trisviaskii, L. A. 1966 Storage of grain. Translated from Russian by D M Keane. Vol 1 – 3, 1969, Natl. Lending Library Sci Technol. , Boston Spa, England, 845 pp.

Zahradnik, J. W. 1968 Methods for evaluating controlled atmosphere (C – A) storage gas seals American Society of Agricultural Engineers, Paper No 68 – 887, 5 p.

Zettler, L. H. 1993. Phosphine resistance in stored-product insects In: Navarro, S. and Donahaye, E ed. , Proceedings International Conference on Controlled Atmosphere and Fumigation in Grain Storages, Winnipeg, Canada, June 1992, Jerusalem, Caspit Press Ltd. , 449 – 460. Anon 1972 . ASHRAE Handbook of Fundamentals Amer Soc Heat Soc. Heat. Refrig Air. Cond Eng. Inc. New York.

Anon. 1989. Suggested recommendations for the fumigation of grain in the ASEAN region 1. Principles and General Practice. ASEAN Food Handling Bureau, Kuala Lumpur and Australian Centre for International Agricultural Research, Canberra.

Ball, S. and van S. Graver, J. E. 1997. Pressure tests to determine need for sheeting loaded freight containers before fumigation. Proc. Int. Conf. Controlled Atmosphere and Fumigation in Stored Products (Edited by Donahaye, E. , Navarro, S. and Varnava, A. 21 – 26 April Printco Ltd. Nicosia, Cyprus, 353 – 358

Banks, H J , Sharp, A. K. and Irving, A. R. 1975. Gas interchange in freight containers Proc. 1st Intrnt. Wking Conf. Stored-Prod. Entomol. Savannah, GA 1974. p 519 – 531.

Banks, H. J. 1981 Sealed grain storage systems in Australia: merits and problems. Proc. 1st. Aust. Stored Grain Pest Control Conf. , Melbourne, May 1981. Sect. 5, pp 1 – 3.

Banks, H. J. and Annis, P C. 1977 Suggested procedures for controlled atmosphere storage of dry grain. CSIRO Aust. Div. Entomol. Tech. Pap. No. 13, 23 p

Banks, H. J. and Annis, P C. 1980. Conversion of existing grain storage structures for modified atmosphere use p. 461 – 473. In: J. Shejbal (ed.) Controlled Atmosphere Storage of Grains, Elsevier, Amsterdam.

Banks, H. J and Desmarchelier, J. M. 1979. Chemical requirements for a fumigant to be used in partially sealed enclosures. pp 92 – 98 In: D E. Evans (ed) Australian Contributions to the Symposium on the Protection of Grain Against Insect Damage During Storage. Moscow, 1978 CSIRO, Division of Entomology, Canberra

Banks, H. J. and Ripp, B E. 1984. Sealing of grain storages for use with fumigants and controlled atmospheres. Proc. Third Int Wking Conf. Stored Prod. Entomol. Manhattan, Kansas, 375 – 390

Banks, H. J. , Annis, P. C. , Henning, R C , and Wilson, A. D. 1980. Experimental and commercial modified atmosphere treatments of stored grain in Australia. p. 207 – 224. In: J. Shejbal (ed.) Controlled Atmosphere Storage of Grains, Elsevier, Amsterdam

Banks, H J. and Annis, P. C. 1984 Importance of processes of natural ventilation to fumigation and controlled atmosphere storage. In: Ripp, B. E et al. , ed. , Controlled Atmosphere and Fumigation in Grain Storages, Amsterdam, Elsevier. 299 – 322.

Bond, E. J. 1984 Manual of fumigation for insect control FAO Plant Production and Protection Paper No. 54, 432 p.