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Development and applications of the hermetic storage technology

P. Villers[1], T. de Bruin[2], S. Navarro[3]

Abstract

Use of hermetic storage has resulted in safe, pesticide-free, and sustainable storage suitable for many commodities and seeds, particularly in hot, humid climates. It is currently being used in Africa, Asia, South and Central America. Hermetic storage takes three distinct forms: a) "Organic-Hermetic storage", often referred to as "Hermetic Storage". It relies on the metabolic activity of organisms (insects and/or molds) present in the commodities to generate a low oxygen modified atmosphere; b) "Vacuum-Hermetic Fumigation" (V-HF) – creating a very low pressure atmosphere to allow accelerated disinfestation of non-crushable commodities; and c) Gas-Hermetic Fumigation (G-HF) using an external gas (usually CO_2) for generating a controlled atmosphere to allow accelerated disinfestation in the case of crushable commodities such as dried fruits. The oxygen-depleted atmosphere thus generated prevents development of cancer causing mycotoxins and maintains the moisture level of the commodity regardless of ambient humidity. Organic-Hermetic storage, the most frequent form of hermetic storage, is used widely for grain reserves using large Cocoons™ up to 300MT. These have been applied on a substantial scale in the Philippines, Ghana, Sri Lanka, and Rwanda. The method is also suitable for storing rice bran, Basmati rice, and high-value commodities, particularly coffee, cocoa, peanuts and spices as used in Costa Rica, Indonesia and India. Organic-Hermetic storage for rice seeds by the International Rice Research Institute (IRRI) is in large scale use. An increasingly popular transportable form of hermetic storage, SuperGrainbags™, provides capacities ranging from 10 to 1,000 kg, with 50 – 60 kg capacity being the most common. G-HF has been used for fumigating figs in Turkey (Ferizli and Emekci, 2000), and V-HF for soybeans and wheat flour in Israel (Fikelmann et al., 2004; Mbata et al., 2004). Field and laboratory data on long-term hermetic storage of coffee, peanuts, cocoa, rice, corn, and rice seeds, shows very significant quality and quantity preservation in the stored commodities.

Key words: hermetic storage, superGrainbag™, modified atmosphere, long-term storage, cocoon™

What is Organic Hermetic Storage?

Organic-Hermetic storage or "hermetic storage", consists of a sealed storage system containing a modified atmosphere. This means that as a result of respiration effects there generally develops a very low Oxygen (O_2), high Carbon Dioxide (CO_2). The low permeability envelope maintains a constant moisture environment. Pioneering modern hermetic storage, (Calderon and Navarro, 1980; Navarro et al., 1989; Navarro and Calderon, 1980) has

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resulted in the broad use of safe, pesticide-free hermetic storage suitable for many commodities and seeds, particularly in hot, humid climate. These hermetic storage systems as used primarily in Africa, Asia, South and Central America for a growing variety of both high and medium value commodities. Hermetic storage takes three distinct forms: a) "Organic-Hermetic storage", relies on the metabolic activity and respiration of insects, microflora and the commodity itself to generate a modified, non-life sustaining low oxygen atmosphere; b) "Vacuum-Hermetic Fumigation" (V-HF) – uses a vacuum pump to rapidly create a very low pressure atmosphere for accelerated disinfestation of non-crushable commodities through asphyxiation; and c) Gas-Hermetic Fumigation (G-HF) uses an external gas source (usually CO_2) for crushable commodities, such as dried fruit, prior to shipment. These methods (Figure 1), create a low oxygen modified atmosphere which normally results in 100 % insect mortality of al life stages in a few days to two weeks as well as preventing mold development, protecting quality and preventing losses in the commodity. It also prevents development of cancer causing mycotoxins such as aflatoxins and ochratoxin A (OTA). The low permeability of the hermetic structure also maintains safe constant moisture levels in previously dried commodities regardless of ambient exterior humidity.

In some applications, such as for rice bran, brown rice, peanuts, and cocoa beans the quality loss due to increase of Free Fatty Acids (FFAs) are prevented through a low oxygen environment (De Bruin and Murali, 2006; Finkelmann et al., 2003; Montemayor, 2004). This is often a key consideration. Another benefit is foregoing the need for pesticides in post-harvest storage.

As seen in Figures 5 and 8, hermetic storage for grain reserves frequently uses large flexible plastic enclosures called Cocoons™ (also formerly called "Cubes" and "Volcani Cubes") with a capacity up to 300 tonnes for either indoor and outdoor storage in such places as Philippines, Ghana, Sri Lanka, and Rwanda (Villers, 2003; 2006). The method is also suitable for long-term storage of rice bran, Basmati rice, and such high-value commodities as coffee, cocoa, peanuts and spices in addition to permitting long-term seed preservation without refrigeration (Van Chin, 2005; Villers, 2006; US-ISTF, 2001).

A more recent but increasingly popular transportable form of hermetic storage, called SuperGrainbags™, as shown in Figure 2 from the International Rice Research Institute (IRRI) in the Philippines utilizes a thin, transparent, extremely low permeability co-extruded multi layer plastic as a liner to a conventional jute or polypropylene bag. SuperGrainbag capacities can range from 10 to 1,000 kg, with 43 – 60 kg capacity being the most common. At the individual small farm level they can be protected from rodents by storage in empty 55-gallon drums.

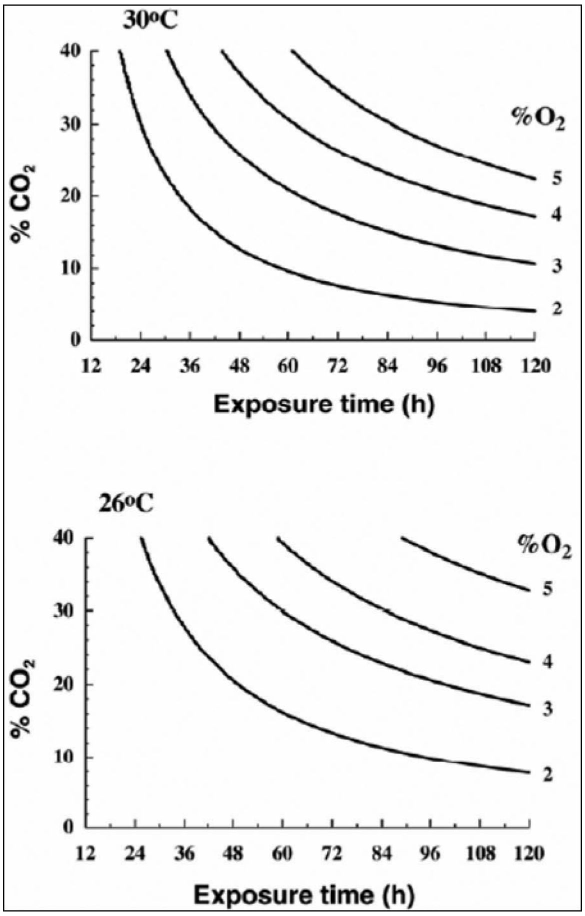

Figure 1. Exposure time vs. CO_2 levels with 95 % mortality for *Tribolium castaneum* at 57 % r.h.

Figure 2. SuperGrainbag as a liner in a polybag container for rice seed at IRRI.

Microflora and critical moisture content

Molds, yeasts, and bacteria make up what we call the "microflora" population. At an elevated humidity they contribute significantly to the respiration processes within the stored commodities. Most mold populations are "aerobic", they need oxygen for their development. Humidity requirements for rapid mold growth of aerobic microflora are within the range of 65 % to 85 % r.h. (Figure 3).

Another term of importance is the "critical moisture content", which is the level that a commodity's moisture content will reach at a given temperature in equilibrium with 65 % r.h. (Figure 3). At higher levels of moisture content significant mold growth will take place except, importantly, when stored in a controlled atmosphere with low 0_2 and high CO_2 levels.

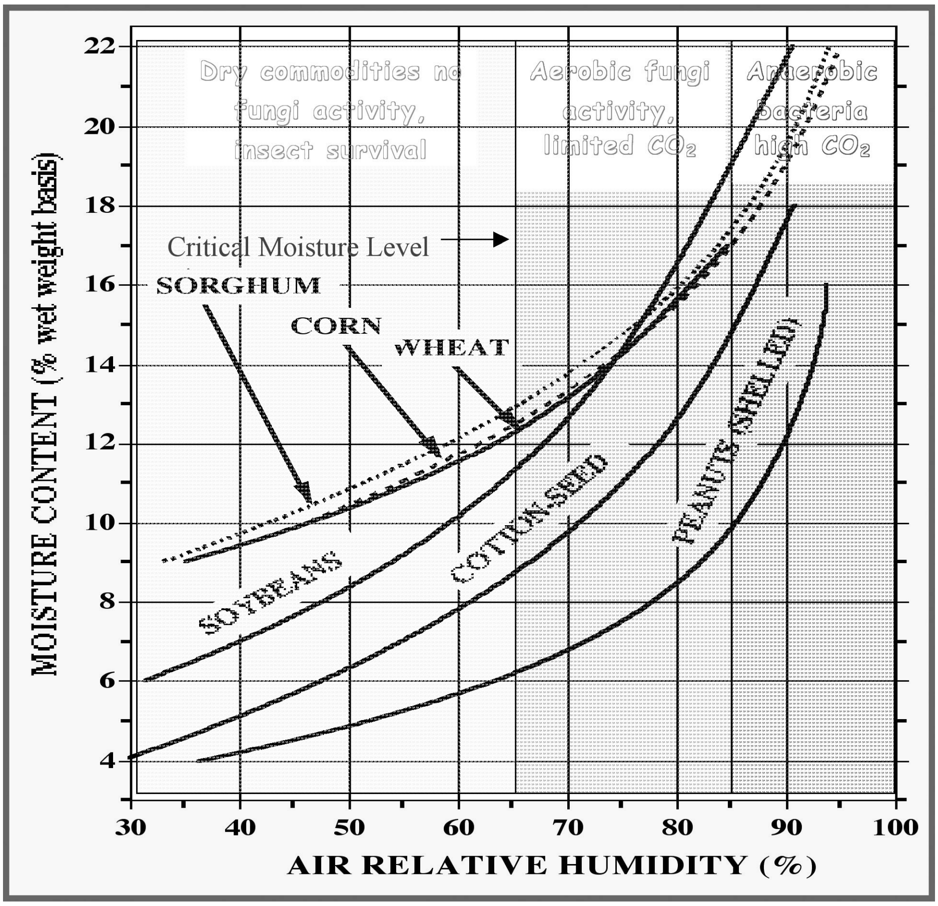

Figure 3. Critical moisture content vs. r.h. – various commodities (De Bruin, 2006).

As also seen in Figure 3, yeasts and bacteria require a higher humidity level to flourish.

Why different types of hermetic storage?

The existence of three different types and several different forms of hermetic storage has to do with meeting different post-harvest storage and transportation needs. The most widely used form of hermetic storage is Organic-Hermetic storage. These systems are used for medium to long-term storage of conventional grain bags and are commercially available in 5 tonne to 300 tonnes capacity. They are used for farm, village, district level, or commercial storage of bagged grains or seeds of many different types for periods ranging from a month to, in some cases, several years. The commodities range widely in value from such high volume grains as sorghum, wheat, pulses, corn and rice to expensive commodities such as spices, cocoa, coffee and various hybrid seeds.

A further distinction in hermetic storage types has to do with transportability. Most hermetic storage systems made from flexible food grade PVC such as those in Figures 5 and 8 are light-weight and portable when empty, but not portable when full. With the introduction in 2001 of SuperGrainbags as seen in Figure 4, hermetic storage became possible during transport and subsequent distribution. Major applications at present are for a variety of seeds, coffee and cocoa beans.

Figure 4. SuperGrainbags™, paddy seed, Philippines.

Why hermetic storage for seeds?

The principal reasons for using hermetic storage for seeds is to prevent further insect development, by creating a low oxygen, high CO_2 atmosphere lethal to insects already present inside the container. It is also used to prevent rodent penetration during storage, and prevent the growth of molds as well as deterioration of the commodity by protecting it from the high outside relative humidity levels that prevail in hot humid climates. In the case of seeds, maintaining seed germination percentage and vigor is the dominant consideration (De Bruin, 2005).

Hermetic storage for seeds – in practice

Starting in the 1990s work on the application of hermetic storage of seeds, focusing especially on rice seeds, was carried out by the International Rice Research Institute (IRRI) in the

Philippines (Rickmann and Aquino, 2003; 2004). This led to the increasingly widespread use for seed storage, not only of the large flexible hermetic storage known as “Cocoons™”, shown storing maize seeds in Thailand, Figure 5 but more recently to storing seed in man portable hermetic storage called SuperGrainbags™ used as liners to conventional bags in the 50-60 kg range such as seen in Figures 2 & 4. In turn, this latter form has the benefit of allowing hermetic storage during the transportation and distribution phase where otherwise previously safely stored seed might degrade. The hermetic technique for maintaining seeds, as also shown in Table 1 from IRRI, has equivalent results to more expensive refrigeration processes in maintaining a high level of germination and vigor. As seen in Table

2, results for hermetic storage of seeds show large differences over conventional unrefrigerated bagged storage in retention of germination and vigor when stored in hot humid climates (De Bruin, 2005).

Gas-Hermetic Fumigation (G-HF): Hermetic storage for disinfestation of dried fruit

G-HF hermetic storage is used for dried fruit such as for figs in Turkey, for rapid pesticide-free "fumigation" before shipment, using bottled CO_2, as shown in Figure 6. This modified atmosphere at room temperature causes complete kill of all life stages of such pests as the tropical warehouse moth (*Ephestia cautella*), a major pest of dried figs, within 5 days or less. A different version called a PITS Tunnel™, is suspended from a light frame and is especially designed for more rapid loading/unloading.

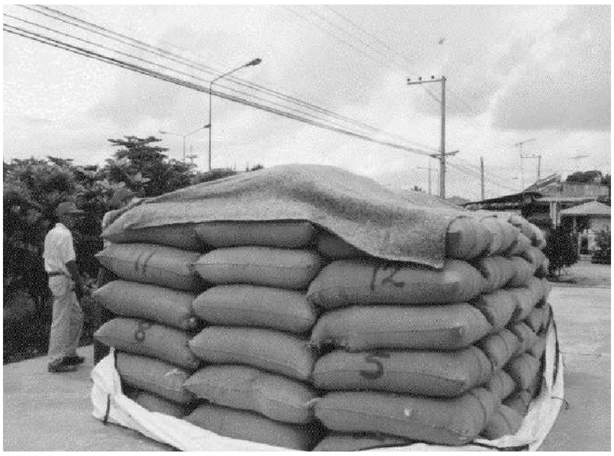

Figure 5. Cocoon™, 10 MT of seed, Uniseed, Thailand

Storage of rice and rice products

Asia has become the largest user of hermetic storage principally because of its use for safe storage of rice seeds and rice products. Rice stored in hot humid climates not only has a high degree of insect infestation and problems with rodents, but also has issues with quality: normally taste and appearance deteriorates significantly in storage – typically after about 6 months. Milled rice, which is more difficult to store, takes 20 % less storage space than paddy (un-milled rice). Experiments in the Philippines at IRRI have shown that when milled rice is stored hermetically, it can be safely kept for more than one year (Rickman and Aquino, 2003; 2004).

In the case of rice bran and brown rice low oxygen levels occur very rapidly due to the commodity's respiration, typically to below 1% oxygen (Montemayor, 2004), allowing safe storage for periods of time otherwise not possible.

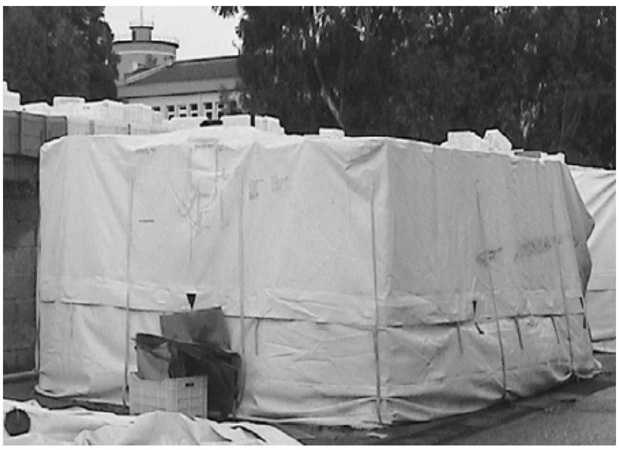

Figure. 6. Dried figs (left), G-HF Cocoons in Turkey (right) (Ferizli and Emekci, 2000).

Table 1. Live insects per 500 gm of grain for 12 month storage, Philippines, 2002.

Month	Cocoons	Open	Air	Cold	251 plastic	Aluminium
0	4.4	1.6	4.2	4.2	3.7	5
3	0.0	117.6	0.8	0.0	0.7	1.0
6	0.2	57.2	1.5	0.0	0.8	1.8
9	0.2	27.2	1.7	0.0	0.6	0.6
12	1.1	13.6	4.5	0.0	0.6	0.1

Table 2. Maize (corn) and Paddy trials. Seed storage of various commodities, hermetic vc non-hermetic storage.

Seed storage	Storage condition	Length of trial (days)	Initial germination %	Germination potential at end of trial (%)	Moisture content (%) at start of trial	Moisture content (%) at end of trial	Insect infestation life insects/kg at start of trial	Insect infestation life insects/kg at end of trial
Mexico[1]								
(maize)	hermetic	3	97	95	14.5	14.3		
	non-hermetic	3	97	97	14.5	14.2		
	hermetic	6	97	78	14.5	14.2		
	non-hermetic	6	97	74	14.5	14.0		
	hermetic	3	96	76	16.6	17.6		
	non-hermetic	3	96	19	16.6	16.5		
	hermetic	4	96	44	16.6	17.6		
	non-hermetic	4	96	14	16.6	16.5		
Thailand[2]	hermetic	90	97.21	98.2	12.4	12.2	2	0
Outdoor	non-hermetic	90	97.21	95	12.4	11.5	0	27
Thailand	hermetic	280	97.21	81.21	12.2	13.6	0	27
Outdoor	non-hermetic	280	97.21	0	12.2		0	100
(paddy)								
Bangladesh[3]	hermetic	120		87	10	11	-	-
(paddy)	non-hermetic	120		9				
Bangladesh[4]	hermetic	100	98	95	13.1	12.7	85	1
(paddy)	non-hermetic		98.3	74	13.2	12.8	74	77
	hermetic	210	98	90	13.1	13	85	12
	non-hermetic		98.3	1	13.2	13.5	74	47
Combodia[5]	hermetic	223	97	91	13	13.6	13.7	0
(paddy)	non-hermetic		95	66	13.1	14.8	32.3	25.8

[1] See Moreno et al. (1988).
[2] See Minagri (2006).
[3] Data supplied by Allied Agro Industries, Dhaka.
[4] Testing of the GrainPro Cocoon for storage pf Paddy in BRRI, prepared by M. Aul Quasen, SSO, FMPHT Div. and A. Abdur Rahman, SSO, FMPHT Div. Gazipur - 2001.
[5] Data collected by Som Bunna, Agricultural Engineer at CARDI, Phnom Penh, dated 15 Mar 2001.

Bulk applications of organic hermetic storage

Today hermetic storage of maize and wheat is used on a large scale in several countries. For instance in Rwanda a total of several hundred 50 tonnes to 225 tonnes capacity Cocoons, such as those seen in Figures 7 and 8, are now used. Cocoons are used there for long-term storage of corn, sorghum, and beans. In a Rwandan Ministry of Agriculture ("Minagri") report (Minagri, 2006) they conclude (as translated) "... after more than 30 months of storage in some units, we observed the following:

- The insects present in the grains during initial storage were all dead and no reinfestation was recorded.
- In most cases the grains remained identical in appearance and preserved their germination potential.

They estimate losses under conventional storage as 12.5-25 % over 12 months. A USAID sponsored study (Usaid, 1996) showed that wheat could be preserved with excellent results in flexible hermetic storage systems for periods of up to five years. Figure 8 shows a 150 tonnes Cocoon together with its GrainShade™ used outdoors in the Philippines for storing rice paddy by the National Food Authority (NFA).

Figure 7. Coffee, Monte D'Oro Cooperative, Costa Rica.

Figure 8. 150 MT Cocoon with GrainShade™, Philippines.

Storage of premium coffee and of shelled Peanuts

Only in the last few years have the benefits of hermetic storage been fully appreciated in maintaining the quality – aroma and taste, as determined by cupping tests, as well as appearance of coffee stored in hot humid climate. In Costa Rica for instance, the coffee crop is harvested from October through February. This coffee is then consumed or exported from March onward. Therefore, the need for long-term storage, which preserves the quality of premium coffee beans, is critical. The first large commercial user of hermetic storage for coffee was Café Britt in Costa Rica.

According to their professional cupper, after storage of five months: "The (cup average) quality remained at 4.0 (5 point scale) for those in the Cocoon and dropped to 3.0 for unprotected coffee beans. The superiority of coffee stored in hermetic Cocoons became very noticeable" (Figure 9).

Recently the use of hermetic storage has been extended to the storage of peanuts where the increase of FFA (Free Fatty Acids), and mold development may result in production of cancer-causing aflatoxins, and can cause entire shipments to be rejected. Studies done in Vietnam found, as seen in Figure 10, that hermetic storage of unshelled peanut seeds for 8 months in SuperGrainbags maintains constant moisture and germination rates virtually identical with the costly refrigerated storage while in unprotected storage. The germination rate dropped to 3% (Van Chin, 2005). As seen in Table 2, similar results have been observed for rice seed.

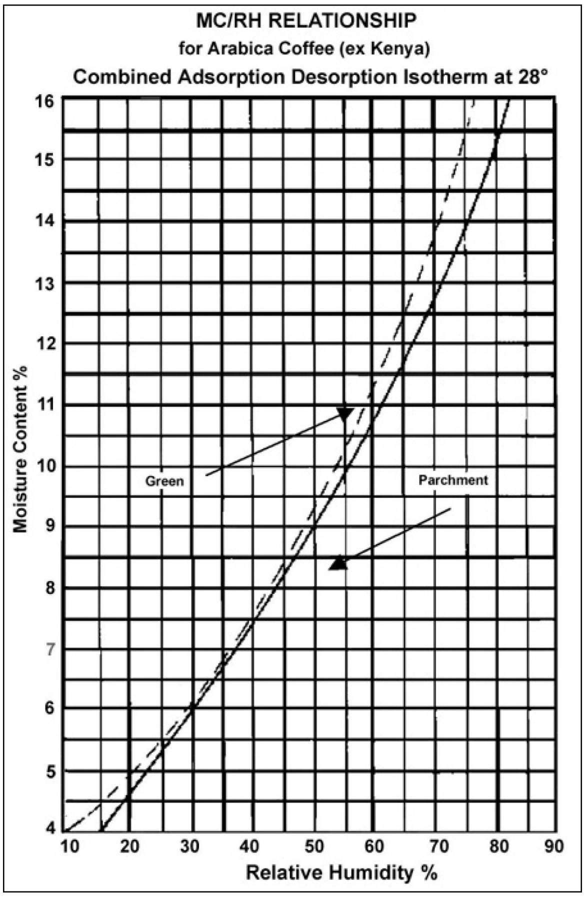

Figure 9. Equilibrium moisture content (EMC) of coffee beans vs. r.h. under equilibrium conditions at 28 °C.

Storage of cocoa – special considerations

Particularly problematic in cocoa bean storage is the deleterious effects of molds, microflora, and oxidation. Oxidation leads to the increase of free fatty acids (FFAs), which have a negative impact on the quality of cocoa. With hermetic

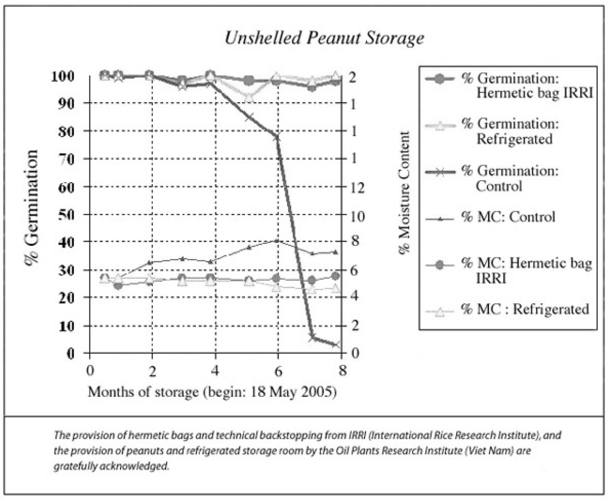

Figure 10. Peanut seed storage germination vs. time.

storage of cocoa, as seen in Figure 11, oxygen levels typically go down to 2 % or less in a week, protecting the commodity against insects, oxidations effects, and the growth of molds (De Bruin and Murali, 2006).

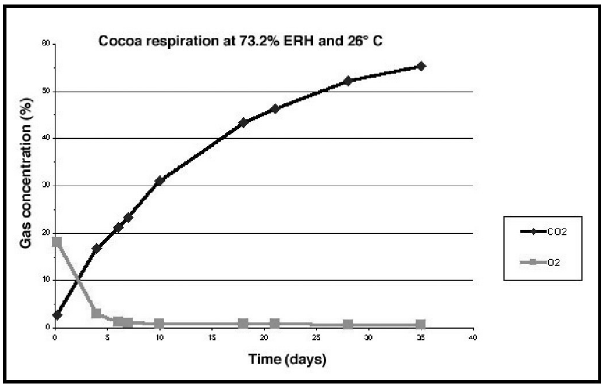

Figure 11. Changes in modified atmosphere, cocoa beans, 73.2 % ERH (De Bruin, 2006).

Alternatives to hermetic storage

Alternatives to hermetic storage and modified atmosphere include use of fumigants, refrigeration, freezing, and conventional unprotected storage. With fumigants full penetration of the commodity is often a problem, repeated applications are frequently necessary and fumigants do not prevent losses from rodents or the growth of molds. In addition insects have developed tolerance to widely used fumigants and the most popular fumigant, Methyl Bromide is being phased out. Refrigeration, in the case of seeds, remains widely used, but consumes significant energy, and requires special facilities. Freezing, another expensive process, has also been used. Most of the world still uses conventional storage, such as storage of bagged grains under large tin roofs in open warehouses. This provides no protection from rodents, limited protection by spraying against insects, and no meaningful steps to prevent mold growth. In hot humid climates losses are frequently of 12.5 to 25 %. (Minagri, 2006).

Hermetic storage as compared to older storage processes is still relatively new, and not as well known, but its use in some 20 countries and its increasing acceptance in particular niche markets where the need for better storage techniques is urgent, is causing rapid growth. Particularly noteworthy in this respect are applications for seeds, cocoa, coffee, rice (including basmati rice, brown rice and rice bran) as well as large stores of staple grains.

Future Applications

Among promising new large-scale applications are those with high moisture corn (30 %) used for ethanol production and for the starch industry – both use large amounts of dry corn and then re-moisturize before processing. Ethanol produced from corn is a fast growing industry due to the increased energy prices worldwide.

In the U.S. high moisture corn is already being used for feeding cattle. In China high moisture corn is being used for ethanol production during the cold winter months.

Conclusion

Almost 25 years after modern hermetic storage systems were first developed, the use of hermetic storage is now becoming widespread using modern low permeability plastic materials which are light-weight, can be used indoors or outdoors, have long lives (10-15 years in the case of Cocoons) and are now, in the case of SuperGrainbags, transportable when full. Pesticide-free Hermetic storage technology has already been found suitable for a number of markets. This is especially true where conventional storage, such as in hot humid climates, fails to adequately protect the stored commodity for the desired time and this results in large losses in quantity and quality (Villers, 2006).

Hermetic storage is sustainable; it is user-friendly and an environmentally benign technology that does not necessitate the use of chemical pesticides. The technology can be adapted to the protection of commodities in sizes ranging from that of conventional grain bag size to many thousands of tonnes.

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