STORAGE AND EQUIPMENT ENGINEERING

Dr. EL Houssine BARTALI

Hassan II Institute of Agricultural and Veterinary Medecine

Departement of Agricultural and Hydraulic Engineering
B.P. 6202, Rabat-Institutes, Rabat - Morocco

ABSTRACT

Conception of storage systems is governed by various parameters. Those related to structures and equipment and their interaction are covered. Various technics to control the interior environment and protect stored products are examined. Theoretical modeling is a design tool used in design of storage structures and equipment. Intensive data acquisition and experiments on real scale storage structures are needed to apprehend grain storage systems.

1. INTRODUCTION

For a given storage system, there is a direct interaction between design of a storage structure and its related equipment on one hand and the environment offered for the stored product on the other. This interaction conditions the performance of the storage system as a whole. Various parameters govern this interaction among which physical, biological and environmental ones. Continuous investigation is being devoted to a thorough knowledge of the variation of the various parameters and to their mutual influence. A design of a storage system based on the specific user's needs has to adress issues regarding the structure of the system and its related equipment and the stored product characteristics in such a way that adequate protection is offered to the stored commodity. This paper tries to cover these aspects and to illustrate how the requirements of the stored product are being met.

2. STORAGE SYSTEM CONCEPTION

A wide range of storage systems is used for the conservation of agricultural products. Each design is influenced by the socio-economical context and the geographic area where it is implemented.

In order to achieve a better protection of the stored product in various places of the world, adequate design of storage systems usually requires a package of solution technics where appropriate technologies should not be overlooked. As a matter of fact, in developping countries, there is a specific need for appropriate solutions to storage problems that should meet the specific needs of the users categories depending on factors such as income level, tradition, socioeconomical context.

Shukula and Patil (1990) have stated that storage of foods has evolved as a science and as an art. They reported that in India, as much as 170 millions mt of food grain are annually produced and that has stressed the need for sufficient and adequate storage capacity. They contended that the economics of storing grain is an important consideration which has an influence on aspects such as structural, environmental and economical ones.

Cribs and reed bins

Simple structures such as cribs for storage of corn used in many places in tropical Africa offer natural drying of the product and protect it from rodents. This type of structure is light, made of local materials and is easy to build. Farmers reed silos, about 1.5 mt capacity are also used in north african countries for storage of grains and legumes. These storage units allow aeration of the product. Protection from insects and rodents is accomplished by means of selected lining material and plants.

Clay straw silos

Construction materials other than conventional reinforced concrete and steel are being investigated for use in storage systems for the purpose of economy; simplicity and good storage conditions. Clay straw silos represent an excellent system that makes advantage of good thermal properties of clay straw material and uses natural ventilation of the stored product. An extensive use of this type of construction was done in China and similar usage is being developed in Morocco.

Bartali et Lamzouri (1990) studied the performance of a clay straw storage silo adapted from a chinese technique. This system that has successfully functioned under moroccan conditions for barley and wheat storage offers several advantages. It is a low cost system that does not involve any sophisticated technology, and that can be easily reproduced by individual farmers or cooperatives of farmers.

Bag storage

Bag storage in warehouses also is practiced and is occasionnaly combined with bulk storage. This system- requires limited initial investment compared to real structures. However this system- needs much more labor for its management and presents some difficulties for its control. Chemineу systems are made within the grain bulk using bag in order to allow for air circulation and aeration of product. This type of storage makes it difficult ot acheive grain treatment against insects. Bags need to be repaired or replaced for each harvesting campaign. Outdoor sheet covered bag storage is often practised in order to compensate for shortages in storage capacities and is usually considered as temporary. The user then tends to pay insufficient attention for the control of the stored product leading to some product loss-

Covered bulk storage

Alternative methods for temporary outdoor covered bulk storage have been developed in countries such as the US, Australia or Europe. The system components include retaining walls made of corrugated metal sheets or precast reinforced concrete panels and a cover sheet.

Such systems present several advantages compared to bag storage with respect to their cost and efficiency and are being also developed in other countries. Large storage capacities can be accomodated using this system.

Underground storage

Underground storage of agricultural products has been practised for centuries in various places of the world. This system is very appropriate for on farm storages, Bartali (1987). Investigation is focused on this alternative storage system- particularly in the US, Brazil and Morocco. Objectives are to evaluate the advantages of this system for reduced cost, long term storage, large capacities and controlled atmosphere. Bartali et al. (1990) investigated the potential of plastic bags as liners for underground storage structures. This type of lining tested for barley and wheat storage has proven very efficient in reducing grain losses as compared to traditional straw lining. Such improvement will help- rehabilitate an appropriate low cost and a naturally controlled atmosphere storage system used for on farm storage.

3. STRUCTURAL DESIGN OF STORAGE STRUCTURES

Several storage structures over the world are made of the two structural materials, steel and reinforced or prestressed concrete that can be used alone or combined with each other. Various capacities can be stored in these storage units but large capacities are often targeted in order to keep the cost per ton of stored material lower.

The design of such tall structures has to be achieved in order to meet safety and economy requirements. In the cost repartition, the structural part of a storage facility can exceed 50 % of the total cost of the facility.

The system made of stored granular material on one hand and its holding structure on the other is complex and has its own specificities. Their mutual interaction has some similarities to a soilstructure interaction.

Stored material

The agricultural stored product, is a living granular material which exhibits a complexe constitutive law and an impredictible behavior. Loads on the silo wall rise from the action of the granular material itself, Hatfield F.J. and Bartali H. (1988),as well as from the action of various parameters on the stored product. Moisture content and temperature are two main parameters in this respect. A change in either of them affects the physical and mechanical properties of the stored product which adds to the stress or strains on the silo wall. Benedetti (1990) studied the effect of moisture content on coefficient of friction and angle of repose for different types of grains. They found that coefficients of friction have a general tendency to increase with moisture content. The same tendency was equally found with the angle of repose with significant levels of correlation.

Silo wall design

Critical load combinations

The performance of the silo wall has to be tested against some load combinations that are met in daily use of silos. Handling of the stored material by filling or emptying or both generates dynamic effects. Temperature, wind or vibration effects need also to be considered.

Steel silos

Steel structures present the advantge of being light structures, easy to erect and to move. However their vulnerability under some load combinations is to be noticed particularly when being empty, they are subjected to non axsisymetriacl loading. Another disadvantage resides in the excessive heat conduction of the steel material that exsposes the stored product to temperature increase and may require ventilation.

A thorough investigation of steel silo wall behavior under various load combinations has been initiated by the CTICM and the "mission silo" in the full scale experiment facility of Chartres in France. The purpose being to evaluate present design specifications from-different codes and to validate new ones. Various silo shapes and silo surfaces are studied with means of appropriate transducers that simultaneously measure friction and normal forces, Khelil and Roth (1990).

Concrete silos

Concrete structures offer competitive alternatives to steel silos under some given circumstances.

Concrete units are preferred for harbor silos in order to prevent corrosion. Concrete structures are also suitable as relatively tall structures are needed in order to achieve large storage capacities in a limited harbor space. Reinforced concrete silos offer relatively better thermal insulation to the stored product. However, temperature gardients can develop through the structure wall. Bartali and Hatfield (1990) studied how temperature gradients and unifrom temperature decrease through the silo wall affect the resistance of the wall depending on the wall edge constraints.

Ribadiere (1990) examined an alternative storage structure particularly suitable for long term storage of commodities such as grains. Advantages- related to structure include limited civil engineering work for foundations due to the light weight type of the structure, prompt erection. This type of structure also offers thermal insulating and air proof walls. This helps reduce condensation and allows for storage under inert atmosphere.

4. EQUIPMENT AND ENVIRONMENT

Management of storage units may require the application of various quantities of insectisides, or fumigants using various equipments in order to keep the storage environment in the safe zone. The treatment against insects is connected to issues such efficiency of the technic used for insecticide application, levels and frequencies of treatment, side effects and remanence of treatment. Some insect treatment practices among farmers have lead to the opposite of the objective pursuied or even to accidents.

Research has been conducted in order to improve insecticide application technics or to eliminate the need for it. Nicholis (1990) has developed and accurate system of applying concentrated insecticide to grain, which system reduces the operator contact with insecticides. This system has been successffuly tested on small and large storage bulks.

Appropriate gas compositions of the storage atmosphere have been studied as a means to reduce insect development and better protect the stored product.

Bell et al. (1990) have found that atmospheres produced by the combustion of hydrocarbon fuels and containing 10 to 14 % CO_2 and 1 % O_2 have a significant effect on the control of insect pests of stored products. Exposures to such atmospheres were particularly efficient against adult beetles. The self cooled controlled atmosphere generator has been tested under various operating conditions and appears to be a suitable equipment to help- control insect pests.

Rignault et al. (1990) tested storage using inert gas in sealed silos in France. The experiment was conducted for storage of corn using controlled atmosphere enriched with CO_2 or hydrogene phosphorus for wheat. These storage systems were found efficient with regard to insect pest control and cost.

An alternative source of nitrogen based controlled atmosphere storage of grain has been developed by Banks and Rigby (1990). This technology that has been found economic and well suited to small scale storage uses membrane separation systems for the production of a nitrogen-enriched gas stream from air. Less than 1% O_2 content can be generated by this technology.

Protection of stored products can be acheieved by means of aeration particularly under hot climate conditions. Aeration aims at reducing the temperature increase in the product and keeping it in a safe zone where depredators and germination wont affect it. Aeration can be performed naturally by allowing air movement through the product. This system is used in clay straw silos and aeration chimneys in bulk storage. Mechanical ventilation is based on forced circulation of air through the product. More research work has been accomplished in integrated control of temperature and relative humidity. This helps increase the management efficiency of silos.

5. MODELING AND ACCURATE DATA ACQUISITION

During the last years, thorough investigation has been devoted to model storage conditions in order to predict variations of parameters governing the storage environment and to help the designer. Hypothesis used as grounds for the simulations are selected in order to integrate as many parameters as possible such as heat transfert with internal and external sources, mass transfer, two or three dimension models.

Intensive effort was also made for accurate data acquisition in order to achieve a better knowledge of the storage system- parameters. Variations of physical parameters such as temperature, relative humidity of intersticial air, CO_2 and O_2 contents are covered. The study of real scale experiments has developed. This helps adress questions that cannot be answered or extrapolated from lab model experiments. It is to be mentionned that extensive work has taken place in this field. The Chartres research facility in France for the investigation of stored products loads on steel silos, other research facilities in Morocco and Kansas are worth mentionning.

Numerical Modeling applied to aeration and fumigation of stored grain has been examined by Wilson (1990) in the perspective of providing the user with a tool for sizing and evaluating the performance of grain-store ducts. The PC program developed predicts velocity, pressure, flow uniformity and fan pressure load and can be used for horizontal or vertical grain stores with various ducts layout.

Dzisi et al. (1990) have developed a two dimensional computer model to simulate the heat transfer in a sheeted bagstack of maize. The model that has been validated showed many similarities with observed temperature distribution data obtained from a storage experiment run in Ghana. The model predictions fairly compared with actual data from a warehouse in Ghana.

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EVALUATION DES POTENTIALITES DU STOCKAGE SOUTERRAIN DES CEREALES

Dr. Houssine BARTALI

Institut Agronomique et Vétérinaire Hassan II
B. P. 6202, Rabat-Instituts

Résumé

Le stockage souterrain des céréales et autres denrées agricoles est un technique connue de longue date dans plusieurs régions du monde. Une évaluation de ce système de stockage a été entreprise dans le cadre des travaux de recherche - développement de l'Institut Agronomique et Vétérinaire Hassan II de Rabat avec un support financier du Science Advisor Council de l'AID Washington.

L'expérience menée a couvert le stockage de l'orge et du blé dur dans des entrepôts souterrains de 15 quintaux de capacité chacun. Une analyse approfondie des paramètres physiques de stockage température, humidité relative de l'air interstitiel et de la teneur en CO_2 dans les entrepôts souterrains à revêtement interne en paille ou en plastique a été opérée. Une analyse parallèle des échantillons de produits stockés prélevés aux niveaux des capteurs de température a été réalisée par une équipe pluridisciplinaire de chercheurs travaillant sur les denrées stockées. Cette recherche qui s'est déroulée sur une période de 16 mois pour le stockage du blé dur et de 6 mois pour celui de l'orge, a mis en évidence le rôle du revêtement plastique étanche des parois d'entrepôts souterrains. En effet, les taux des pertes ont été réduits grâce au revêtement plastique de près de 20 % par rapport aux niveaux qu'ils atteignaient avec un revêtement paille classiquement utilisé par les agriculteurs.