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RESEARCH ARTICLE

APPROACHES TO UNDERSTAND HEAT AND MASS TRANSFER PHENOMENON IN FOOD GRAIN STORAGE SYSTEMS

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ABSTRACT

Grain storage is a major factor in ensuring food security in the country. It enables the markets to allow uninterrupted supply of grains even during off seasons. In a grain storage ecosystem, the interactions of different biotic and abiotic factors cause damage to the grain. Controlling these interactions by monitoring the heat and mass transfer in grain bulk during storage period is of great importance. Predicting the heat and mass transfer in storage structures is also necessary to make proper management protocols and guidelines to built safe bulk storage systems. This paper discusses various approaches to understand the heat and mass transfer phenomenon in food grain storage system.

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INTRODUCTION

The global grain production is increasing steadily due to the advances in technology over last decades and around two billion tonnes of grains are produced annually. The grains after harvest undergoes a series of operation like harvesting, threshing, winnowing, bagging, transportation, storage, and processing before it reaches the hands of consumer. Among these, storage of food grains is very important in order to ensure constant supply of grains throughout the year since they are seasonal and location specific. Considerable amount of grain is being spoiled after harvest due to the lack of storage and post-processing facilities (Singh and Sathyapathy, 2003). Accurate estimates of post harvest losses of grains are not available but it can vary from 1-2% in the developed countries, where the grain is stored in well managed facilities, to 20-50% in less developed countries with poorly managed storage systems (Jayas, 2012). In India, the post-harvest losses amount to 12 to 16 million metric tons of food grains each year, an amount that the World Bank stipulates could feed one-third of India's poor. The monetary value of these losses amounts to more than Rs. 50,000 crores per year (Singh, 2010). Losses during grain storage account for 6 % due to the lack of proper storage facilities (Sharon *et al.,* 2014).
The grains produced must be saved from losses in order to ensure self sufficiency in food grain production.

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For that the grain storage sector has to be strengthened with proper scientific protocols and guidelines. Understanding the heat and mass transfer phenomenon in grain bulk will help to develop safe management protocols in grains storage and there by ensures food security and sustainability.

Grain storage ecosystem

Stored-grain bulk is a man-made ecological system in which deterioration of the grain may be caused by interactions among the physical, chemical, and biological factors that influence the system (Jayas, 1995). The lack of proper management of these factors results the deterioration of the grain. The important factors which influence the stored grain bulk are abiotic factors like grain moisture, temperature and relative humidity and biotic factors, such as insects, rodents, and microorganisms. The interactions of these factors should be carefully monitored and managed for long term preservation of grains.

Heat and mass transfer during food grain storage

Temperature fluctuations and moisture migration are the key factors which governs the heat and mass transfer in stored grain bulk. Temperature in the stored grain bulk is affected by both internal and external factors. External factors are those associated with ambient daily and/or seasonal air temperature fluctuations. Internal factors are biological and biochemical reactions caused by either insect activity or mould growth resulting from improper storage of the product (Lapko, 2005). Inside a storage structure, temperature variations can influence two distinct regions: the head space and the grain bulk. Temperatures within the head space can fluctuate substantially on a daily basis, but the daily fluctuation is much as in the grain bulk due to the low thermal diffusivity of grain (Muir *et al.,* 1989). Temperature, moisture, and air movement inside the headspace might influence temperature gradients at the top of the stored grain mass which might cause moisture migration (Jayas, 1995; Navarro and Noyes, 2001). Moisture migration occurs within the stored grain bulk due to heat-induced natural convection currents, (Thorpe, 1981; Smith and Sokhansanj, 1990; Thorpe *et al.,* 1991). Moisture migration takes place in storage structures even though the grains are at moisture level generally considered as safe for storage. The movement of moisture is a slow process and equilibrium conditions are never established for any practical length of time in a mass of grain due to hysteresis and the fluctuation of water vapour pressure (Thorpe, 1980). This moisture movement in stored grain increases chances of distribution of insects, mites and fungi and thus results deterioration of grain quality (Brooker, *et al.,* 1992; Converse *et al.,* 1973). Seasonal variations in ambient temperature can prompt safe moisture contents of grain bulks to fluctuate, and results the redistribution of moisture content (Figure 1). When the grains are stored in the fall, grains become warm. The cool air inside the surface of the bin moves down along the edge of the bin, across the bottom and then near the centre of the bin where the air and grain are warm. As a result the moisture condenses on the top of the grain and consequently spoilage takes place at the top of the bin. In spring, the atmospheric temperature rises, as a result air current moves down through the centre of the bin to the bottom. At this point, the moisture condenses on the cold spot. The air then moves to the walls and due to higher temperature goes upwards. Due to the moisture accumulation at the bottom of the bin spoilage of grains takes place at bottom (Sahay and Singh, 2001).

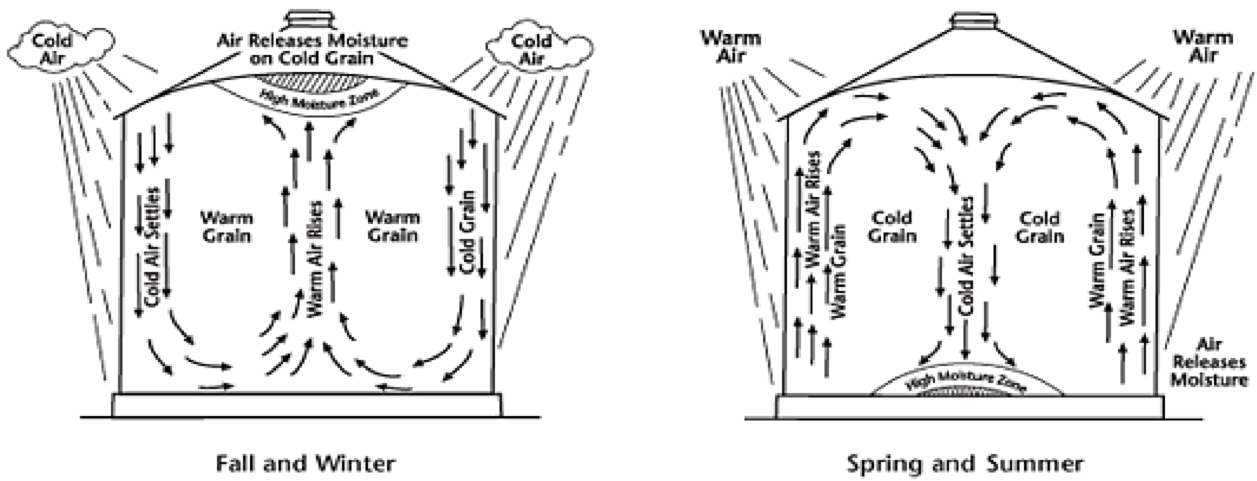
involve experimental methods, mathematical modelling and simulation.

Experimental determination

Monitoring temperature and moisture data at various points within the grain bulk over a long period is one way of finding temperature and moisture distributions. Many researchers studied temperature variation in the grain bulk using experimental methods (e.g. Alabadan *et al.,* 2006; Siebenmorgen *et al.,* 1989; Sawant *et al.,* 2012; Jian *et al.,* 2009). This approach of monitoring the grain temperature at various points in a stored grain bulk is inefficient, requires a lot time, cost and labour (Alabadan, 2005).

Mathematical modelling and simulation

Mathematical models of heat and moisture transfer can play a major role in designing and evaluating methods of reducing temperature and moisture gradients in stored grain, in predicting locations within the bin where spoilage can occur, and in determining rates of deterioration. Many investigators have developed mathematical models of heat transfer for prediction of temperatures in grain bulk (Yaciuk *et al.,* 1975; Longstaff and Banks 1986; White 1988; Alagusundaram *et al.,* 1990a, 1990b; Chang *et al.,* 1993; Jayas *et al.,* 1994; Basunia *et al.,* 1996 and Lucas and Alabadan 2002). Mathematical models can potentially predict with accuracy temperature distributions with effects of several internal and external variables on the stored grain bulk (Alabadan, 2005). Khankari *et al.,* (1995) developed two numerical models to simulate the moisture migration process by using the sorption isotherm concept in the transport equations. Abbouda *et al.,* (1992b) developed a two-dimensional, finite difference model to simulate milo moisture distribution in a cylindrical steel bins under unventilated storage conditions. Their model showed good agreement with experimental results.



Source: Sahay and Singh 2001

Figure 1. Moisture migration in grain bulk during different seasons of storage

Approaches to understand heat and mass transfer phenomenon

Numerous attempts have been made to predict heat and mass transfer phenomenon in stored grain bulk. The major approaches to understand heat and mass transfer in grain bulk involve experimental methods, mathematical modelling and simulation.

Thorpe (1981) used a one-dimensional mathematical model to describe the diffusion of moisture due to temperature gradients in a grain bulk, using Fick's law of diffusion and the sorption isotherm relationship for wheat. Nguyen (1986) developed a two dimensional model to describe moisture transfer in stored grains due to natural convection and he found that, natural convection currents are strong during day time and weak during night times when conduction is a dominant mode of heat transfer. Mathematical simulation can be used to predict temperature distribution in grain storage bins with different sizes, wall materials, grain varieties and locations. Heat transfer models have been solved using analytical (e.g., Converse *et al.,* 1973), finite difference and finite element (e.g., Alagusundaram *et al.,* 1990b) methods. Most of the researchers have used finite difference method for predicting the temperature distribution in stored grain bins (Lo and Chen, 1975; Yaciuk *et al.,* 1975; Muir *et al.,* 1980; Metzger and Muir, 1983; Obaldo *et al.,* 1990; Chang *et al.,* 1993). However the finite difference method is inconvenient and difficult-to-solve irregular geometry with mixed boundary problems including solar radiation and air convection (Ruska and Timar, 2009).

The finite element method provides the flexibility and versatility necessary for the analysis of such complicated boundary problems. Therefore the finite element method has been widely applied in simulating temperature changes of grain during storage (Shufen and Jofreit, 1987; Alagusundaram *et al.,* 1990; Mao, 1991; Jia and Cao, 1998). The main advantages of mathematical modelling and simulation include its lower cost and it takes less time consumption than is needed in the experimental investigations. It allows analyzing systems that are impossible to accomplish by experimental investigations and it allows the complementation of experimental investigations with more detailed information (Andrade *et al.,* 2002; Jian *et al.,* 2005; Franca and Haghighi, 1995).

Directions for future work

For safe and scientific storage, proper care should be given starting from the selection of storage site, including its maintenance, pest management and aeration strategies. There is an urgent need to understand the various critical parameters in the stored grain ecosystem and to find out ways and means to maintain the quality of the grain during long term storage. Developed countries have well established grain storage and handling systems. The safety of the food grains during long term storage is not assured in developing countries due to the lack of proper scientific knowledge. Scientific efforts have not been made in India to investigate the effect of local weather conditions on the stored grain bulk and also the aeration benefits. Evaluating the efficacy of ambient aeration is important to estimate the maximum safe storage period of grain and to predict the necessary aeration time. Accurate predictions of grain temperature can be used to develop and evaluate aeration control strategies. With these evaluations, it is possible to analyze the aeration viability for a specific region and to optimize control strategies.

Conclusion

Grain storage is an important link between the procurement and distribution system. Hence it is very important to ensure the quality and safety of grains during storage .There are no scientific methods available for managing stored grain bulk in tropical countries like India. Research efforts has not been carried out to find the effect of local weather changes and aeration on the temperature and moisture changes in stored grain bulk in tropical countries like India. An understanding of these will help in building good bulk storage chain and thereby assuring safety of grains.

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