Session 5: Physical and chemical processes in the application of CA/fumigation

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Rapporteur's Report

In the past, most of the research dealing with the use of controlled atmospheres (CA) and fumigation for control of pests in stored-grain has been empirical. Many researchers have conducted experimental studies to characterise the mortality of one or more life stages of various stored-product pests. These studies have been valuable in the application of CA/fumigation technology for preserving stored grain. Little attention, however, has been paid to the understanding of the physical processes in CA storage systems. In my opinion, it is because engineers and physical scientists have not been involved since the beginning. I would like to encourage the researchers in this area to work together as multidisciplinary teams of biologists, engineers, and physical scientists. This interdisciplinary approach is necessary because the deterioration of living grain occurs due to interaction among many biotic (e.g., insects, mites, fungi, bacteria) and abiotic (e.g., temperature, moisture content, intergranular gaseous composition) factors. I realize that at times such cooperation is not possible due to organizational or personality conflicts. In a world of fast, inexpensive, and reliable communications technology, the cooperating scientists do not have to belong to the same research laboratory or even be from the same country. I believe, if there is a will, the creation of interdisciplinary teams is widely possible.

This session focused on certain aspects of physical processes in the application of CA/fumigation technology. The session was well planned. The first paper by Dr. Banks discussed the sorption and desorption of fumigants on grain. The results of this type of study provide a better understanding and rational improvement of fumigation practices. As an example, Dr. Banks mentioned that sorption of fumigants increased with an increase in grain moisture content, a decrease in temperature, and an increase in the amount of husk on grain. The practical implications of these results are that the concentrations produced in the intergranular space will be dependent on these factors, and they will affect the amount of fumigant required to create lethal levels. For example, wet-paddy at low temperatures will require more fumigant to create the same concentration as in dry-wheat at high temperatures. It is probable that due to sorption the concentration of fumigant may not be high enough in the paddy for controlling pests and the fumigation may be considered a failure. Proper understanding of sorption phenomena eliminates the risk of control failures. The results on sorption of fumigants help us understand the dispersion of fumigants in the grain. The rate and magnitude of the formation of fixed residues is also affected by the sorption of fumigants. The quantification of desorption of fumigants is useful in determining the time required to ventilate treated grain before allowing workers to enter storage structures.

The second paper by Mr. Cofie-Agblor and associates presented the results on sorption of carbon dioxide (CO_2) by wheat. In CA storage, CO_2 or N_2 are introduced in the grain mass to create lethal atmospheres for pests; CO_2, however, is more effective in controlling pests than N_2. The practical implications of the results on the sorption of CO_2 by grain are similar to the sorption of fumigants. The moisture and temperature affected the sorption of CO_2 in a manner similar to the sorption of fumigants. Mr. Cofie-Agblor reported that the sorption of CO_2 by wheat increased with an increase in moisture content and a decrease in temperature. These results may partially explain the observations that CO_2 is more effective in controlling pests when dry grain is treated at high temperatures. Mr. Cofie-Agblor reported that depending of the experimental conditions, 60-78% of total amount of CO_2 sorbed in 24 h was sorbed in the first 4 h and saturation seemed to occur in 24 h. Both these papers provide basic data required in mathematical models of movement of CO_2 or fumigants within the bulk grain. The mathematical models can be used for planning, design, and operation of CA/fumigation treatment structures.

Dr. Wang and associates presented a mathematical model of a "Triple-Low" (low temperature, low concentration of oxygen, and low concentration of phosphine) storage technique used in China and other Southeastern Asian countries. Mathematical models of heat and mass transfer for predictions of temperature and gas concentrations with storage period in stored grain were presented. The predictions of the model were not compared with experimental data. The need for considering three factors in an interactive rather than an individual manner was emphasized. The effect of a small amount of phosphine on temperature distribution in stored grain was presented to illustrate the interaction among phenomena. As the title of the paper indicates, the presented results were preliminary rather than extensive in nature.

Mr. Alagusundaram and associates presented a three-dimensional mathematical model of CO_2 diffusion in stored-grain bulks. The mathematical model of CO_2 diffusion was solved using the finite element method, which allows the applicability of the model to any shape or size of storage structure filled to a levelled or a non-levelled top surface. The model does not include CO_2 sorption and generation by grain. Experimental data of studies such as of Mr. Cofie-Agblor would be useful for incorporating these phenomena into the model. The need for inclusion of dependence of movement of CO_2 on kernel orientation was identified. The predictions of the mathematical model were compared with the experimental data on distribution of CO_2 in a 1.45-m-diameter galvanized steel bin filled to depth of 1.37 m. The predicted CO_2 concentrations were considerably lower than the measured concentrations in the stored bulk.

The paper by Ducom and Bourges showed the production of phosphine from five commercial preparations at four temperatures (15, 20, 25, and 32°C) and 75% relative humidity. The time required for release of phosphine decreased with an increase in temperature. The rate of release of phosphine from magnesium phosphide tablets was twice the rate from aluminum phosphide tablets. Results of this type of study would be useful in defining the initial conditions for fumigation models such as presented by Annis and Banks in the next presentation. The model of Annis and Banks predicted the phosphine production and decay in many sizes of storage structures. The predictions of the model compared well with the measured data. The validated model can be used by the applicators in deciding the effectiveness of phosphine fumigation in controlling insects in a given storage structure.

I would like to suggest to the developers of the mathematical models that they validate the models before publishing them. Comparison of the predicted data with the measured data forces the developers of the mathematical models to examine the validity of the assumptions and to refine the models. Without such validation, mathematical models are useless and publication of invalidated mathematical models is only dependent on the graphic capability of the research laboratory. Fancy graphs and three-dimensional plots should not be used as a substitute for validation. The validation, in my opinion, is not the perfect agreement among measured and predicted results but a detailed discussion of the reasons for the disagreement in the results. Such a discussion would be used by future developers of mathematical models of similar problems in improving the usefulness of the mathematical models.

In summary, I would like to emphasize the need for expansion of research efforts towards the development of a comprehensive stored-grain ecosystem model which will be able to predict both physical and biological parameters at various locations in the stored bulk. Such a model will be used as a tool in managing the stored-grain ecosystems. I realize that the development of such a model will require considerable research efforts towards the understanding of the fundamentals of many physical and biological processes and techniques of solution of complicated mathematical problems. Therefore, cooperation among various research laboratories is required to avoid significant duplication of research efforts and to expedite the development of the comprehensive mathematical model of stored-grain ecosystems.