CHAPTER 4
Gas Behaviour in Grain Storage During Fumigation

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4.1 INTRODUCTION

This chapter will present the application of mathematics in agriculture. Specifically, fumigation of grain in storage or silo, typical of Australian agricultural setting.

Grain such as rice, oat, corn, and wheat are often used as main sources of food. Commonly, grain needs to be kept in storage after being harvested (Ziegler, 2021). One of the practices in Australia is to put the grain into a storage known as silo as shown in Figure 4.1. However, the existence of the insect and the growth of mould in the storage have caused the deterioration in quality of cereal grains (Ziegler, 2021; Brabec 2022). Method that is commonly used to deal with this problem is fumigation where the insect population are being controlled by fumigating the grain bed with gas such as phosphine (Brabec, 2022; Chidemo, 2023). The process is done by injecting the phosphine gas through a small inlet attached at the bottom of the silo with a slight pressure. Phosphine is the most widely used fumigant as it is known for its cheapness, effectiveness and residue free. However, despite these advantages, the method has its drawback where it was identified that there are parts in the storage where the gas did not well distributed (Collins, 2010). Because of the urge to sustain the fumigation method by phosphine, research to investigate the behaviour of the phosphine gas during fumigation has been conducted. Here is where the mathematical approach has been used.

(a) (b)

Figure 4.1 Typical construction of silo: (a) silo with conical based, (b) silo with flat bottom based (North West Ag Services, 2021; Made in China, 2021)

Before we proceed with the details of the mathematical approach, let's review some of the previous works that have been conducted related to fumigation mathematically. In the study by Hunter (1986), the radial flow in two and three dimensional space is considered and the solution for cross flow in a circular cylindrical store have been obtained. Smith (1996) modelled the gas flow as a flow in two-dimensional bin with sharp corners. This model is known as triangular cross section with a triangular inlet. Then this research was continued by De Ville and Smith (1996) where the flow (air in this study) in porous media is modelled as a rectangular slab. The quantity was assumed only in two spatial variables. Air is blown through the grain bed by fan positioning below $z = 0$, in order to allow the air to pass into the grain bed. However, the air cannot escape through the bin walls ($x = \pm 1$) but the air is able to escape through the top of the bin ($z = 1$). While in the study by Smith and Jayas

(2004), they considered two-dimensional flow from a straight duct (upward and downward flow), and the approximate solution to the case of upward flow in circular cylindrical store with a conical bottom and a central supply duct also presented. Besides, the simulation of the phosphine distribution in grain storage for two-dimensional flow has been modelled by using computational fluid dynamics (Boac, 2014). In their study, the fumigant was quickly transported from the inject point along the top of grain storage. Air inlet and phosphine inlet are at both sides on the simulation while the outlet was placed at the bottom centre of the simulation model. In Isa et al. (2016), they provided a closed form solution for pressure and velocity, as well as the traverse time for a fumigant gas in a cylindrical storage. They then continued to predict the phosphine distribution based on a three-dimensional mathematical model with the help of computational fluid dynamics (CFD) software, FLUENT (Isa et al., 2016a). Overall, the research related to fumigation has been started many years ago and still progressing indicating that it is very important to understand the behaviour of the gas movement in the storage. So that, to make sure all areas receive enough phosphine and the problem on the existence of insect and growth of mould in the grain storage is overcome.

This chapter will discuss on how the gas behaviour can be investigated mathematically by referring to work done by Isa et al. (2016). Firstly, the flow of the phosphine gas is modelled using Darcy's law since the gas in grain storage is a gas flow in porous media. This then leads to the contribution of Laplace equation in solving the problem. The Laplace equation can be solved using the method of separation of variables. The analytical solutions that are obtained consist of the gas pressure and velocity. From the pressure and velocity, graphs of which showing how the gas is moving or behaving in the storage can be plotted.