Development of Quality Control Framework for accurate Computational Fluid Dynamics modelling of crop storage environments

The environment of storage facilities is governed by non-linear heat transfer and fluid-flow processes. The process of using computers to simulate such flows in a realistic way is called computational fluid dynamics (CFD). In order to design energy efficient storage facilities agricultural advisors and researchers must exploit CFD in an effective and efficient way. For accurate simulation-oriented analysis and design analysts must operate within a framework that (a) reduces the uncertainty of simulations with minimal expense, and (b) enables a process of robust design development using multi-objective optimisation.

Ventilation is an essential process during the storage of all crops (e.g. onions, potatoes grain, oilseeds). It accounts for between 30% and 90% of the energy used during storage (Potato Council, R439) and is key driver of all heat and mass transfer processes in the store. With energy prices continuing to trend upwards (e.g. since 2007 electricity prices increased by 48%) there is an increasing need to design new range of energy efficient storage systems. Such efforts align with UK governmental indicatives to reduce 2020 carbon emissions by 26% (relative to 1990).

The drying/cooling of crops involve multiple coupled physics such as heat, mass and momentum transport both within the crop bulk, and between the crop and the open-store environment (at the air-crop interfaces). The complexities and various length scales involved in the key drying/cooling mechanisms at crop level are presented in the below figure. Air distribution in the store is an important design factor to ensure efficiency and uniformity in drying/cooling. However, air distribution is an elusive parameter that cannot be directly measured in large structures, and typically air mixing is used as a proxy through distributed measures of air temperature and humidity. These measurements may be useful (albeit time-consuming to collect) as a store diagnostic tool but, due to the non-linearity of airflow, have limited potential in store optimisation and the design of new storage facilities. The effective employment of accurate high-fidelity thermal-fluid simulations around the crop is therefore essential.

Over the last three decades the computing power available in personal workstations has increased massively and CFD software has become widely available. CFD has also been used/recognised in AHDB sector projects; (i) the evaluation of greenhouse environments (HDC - PC47; HDC –PC162); (ii) the evalutaton of grain aeration and pesticide distribution systems (HGCA -246, HGCA-269); (iii) Groves (2007) noted that CFD should be exploited for potato storage design in a industry review for the Potato Council.

To exploit CFD to its full capacity the analysis must:

1. continuously verify and validate solutions to ensure what is simulated is truly realistic;
2. be carried out using well known engineering-design principles which are:
    a. robust design - development of superior design solutions by minimizing the effects of variation on system performance
    b. multi-objective design optimisation - multiple objectives must be considered in a rigorous fashion that accurately reflects preferences of the design and constraints of the system environment

The aim of this PhD studentship is to develop a Quality Control Framework (disseminated via an industry guide) to enable accurate application of CFD to crop storage environments using

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a step-by-step benchmarking process. It will incorporate engineering-design principles of robust design and multi-objective design optimisation. This methodology will be applied to 3 key crop storage cases, potato crop, onion crop and grain crop. This guide will allow agricultural advisors and researchers to build accurate solutions for energy efficient crop storage.

OBJECTIVES

The objectives of this project are to:

1. Develop a procedure to integrate step-by-step benchmarking linking heat and mass transfer mechanisms within a crop store,
2. Implement and verify this procedure through CFD applications – taking potato storage as an exemplar,
3. Develop and integrate an approach for robust design and multi-objective design optimisation.

PROJECT TEAM

Dr Norton will be managing the project at HAU. The project will be carried out in collaboration with scientists at the Sutton Bridge Crop Storage Research Centre (SBCSR) scientist and will employ the research grade crop storage facilities available there.

WORK PLAN

1. Quantitative Benchmarking for CFD Analysis/Design of Crop Stores
2. Case studies: CFD Analysis in Crop Storage Scenarios
3. Integrating Robust-Design and Multi-Objective Design Optimisation

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