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Numerical Simulation of Drying Process within a Novel Rotary Drying Machine for Palm Oil Sludge

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ABSTRACT

This study investigated how to model a centre-offset annular rotary drum using OpenFOAM and the meshing software GMSH. The diameter of the outer cylinder D_o is 600 mm, diameter of the inner cylinder D_i 200 mm, the centre-offset $\alpha = 150$ mm, and rotation rate $n = 60$ rpm. When the centre-offset is zero, the quality of mesh is preserved as the drum rotates. Introduction of the offset causes the mesh to be deformed to the point of being unusable as the drum is rotated. The reason was found to be the fixed nodes adjacent to the walls of the outer and inner cylinder. These nodes only respect the motion of the wall they are adjacent to. To circumvent this, we separated the inner volume of the rotary drum to allow the implementation of an OpenFOAM dynamic mesh handling scheme called arbitrary mesh interface (AMI). Implementing AMI allows the quality of the mesh to be kept even when the inner cylinder is rotating under nonzero-offset conditions. This is because AMI permits the sliding of non-conforming meshes next to each other. This preserves the quality of the mesh and secures a reliable and reproducible dynamic mesh motion for the implementation of the drying process in the future.

1. Introduction

Palm oil has been one of the main drivers of the Malaysian economy, in addition to being one of its more effective instruments of expression in the geopolitical arena for over 50 years [1]. However, in recent years, environmental issues have been cited as grounds to impose restrictions on the nation's palm oil exports especially from the European Union and North America [2]. One of the main thrusts of the lobbying effort by the Malaysian government to ease the restrictions is by addressing the environmental concerns stemming from palm oil production. The treatment and repurposing of

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palm oil mill sludge can significantly cut down the amount of waste products released to the environment and harm the ecosystem, especially when it can be repurposed into fertiliser.

The sludge is most commonly dried through ponding - or lagooning - as part of the palm oil mill effluent (POME) treatment process. However, ponding is totally reliant on evaporative drying and is therefore time-consuming [3]. Furthermore, this method of treatment results in soil and water quality degradation, with immediate adverse effects to communities located within the vicinity of the palm oil industry [4].

The drying process that is key to the manufacturing of fertiliser is known to be energy intensive. Previous efforts to improve the efficiency of the process includes the introduction of rotation to wring the moisture away from the sludge through centrifugation [5]. This process is known as dewatering as the water content is mechanically removed from the moist substrate whilst in liquid form. Drying, on the other hand, involves removal of moisture whilst in the gas phase; its transport dictated by the relative humidity of air, speed of air flow, and the pressure and temperature of the surrounding air. Increasing the moisture removal rate and ensuring product consistency have been the issues overshadowing further improvement of the rotary dryer, requiring extensive trial-and-error to guide the development process. In this study, we propose that the dewatering a drying process take place simultaneously in an annular rotary drum. In addition, by placing the inner cylinder at an offset from the axis of the outer cylinder, we imposed a pseudo-pressing motion on the sludge to augment the removal of liquid water from centrifugation (Figure 1). The literature review in the next section gives an account of the previous works that inspired this idea.

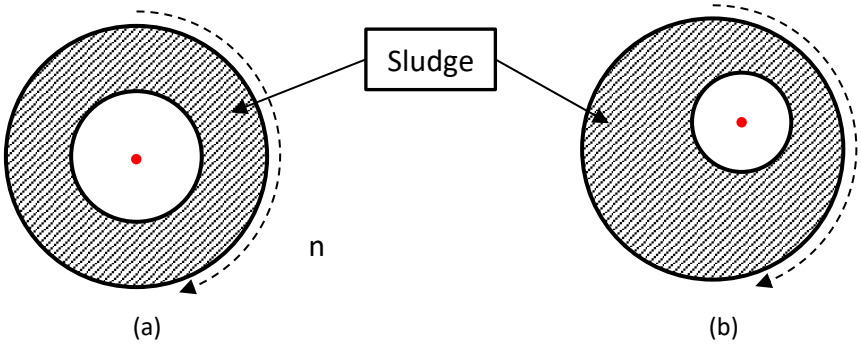

Fig. 1. The proposed annular rotary drum investigated in this study, (a) The coaxial annular rotary drum, (b) The offset annular rotary drum

Computational fluid dynamics (CFD) can help expedite the trial-and-error loop and automate the testing of novel rotary drum designs and evaluate them against design targets. However, several challenges stand in the way of utilising CFD for numerical study of new rotary drum designs for sludge drying. For example, mathematical modelling of the sludge inside the rotary drum, implementation of the drying process, and imposing the rotation of the offset inner cylinder along a path parallel to the circumference of the outer cylinder. This work focuses on the latter, especially towards maintaining the quality of the mesh as the offset inner cylinder moves through the contents of the outer cylinder (rotary drum).

2. Literature Review

2.1 State-of-the-art of Drying Process

Drying, as opposed to dewatering, relies on the phase transition of water inside the moist substrate from liquid to gas. The change of phase from liquid to gas is mainly dependent on the