SRDC END OF PROJECT FINAL REPORT

JU010 Mathematical modelling of circulation and crystallisation in vacuum pans

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Objectives:

1. Survey Australian sugar mills to determine details of vacuum pans in current use. Information to be sourced includes the type of vacuum pans, whether batch or continuous pans are used and whether or not mechanical stirrers are employed.
2. Analyse the flow and heat transfer in calandria tubes using a two-phase (vapour/massecuite) Eulerian/Eulerian CFD model. Compare results with published experimental data.
3. Construct a numerical model of the overall flow field and temperature field in a typical high grade vacuum pan with natural circulation.
4. Investigate the effect of adding a mechanical stirrer on the circulation patterns, heat transfer and crystallisation process.
5. Propose modifications to the geometry and/or operation of stirred and unstirred vacuum pans that will improve the circulation patterns and the crystal growth.

Findings of project:

This project undertook an investigation into mathematical modelling of natural circulation in high grade batch vacuum pans.

Batch vacuum pans are an important part of a sugar factory, with the circulation in such vessels being a key factor in successful sucrose extraction. The flow within a batch vacuum pan is laminar with three phases (molasses, crystal and vapour) present, and is driven by buoyancy, which results from vapour formation due to boiling. Numerical modelling of natural circulation in batch vacuum pans has been limited in the past by computational power and available computer software, and has suffered from the necessity for very restrictive assumptions to make modelling possible.

This project has used computational fluid dynamics (CFD) as a tool to develop an improved batch vacuum pan model to investigate the detailed distribution of velocity and temperature within a batch vacuum pan at various stages throughout the strike. A segmented modelling approach has been developed where the vacuum pan is divided into two segments: the space inside the calandria tubes (the calandria tube segment), and the remaining part consisting of a downtake and the space above and below the calandria (the external flow segment). The external flow segment is modelled using multiphase CFD approach, whereas the calandria tube segment is represented by a one-dimensional finite volume model. The two segments are coupled together to obtain the overall model of the entire vacuum pan.

The calandria tube segment is the key to the vacuum pan model as the majority of the driving force for natural circulation is developed from the vapour formed due to boiling

within the calandria tubes. The one-dimensional constant wall temperature tube model developed within this project demonstrates, for most parameters, reasonable agreement with previous experimental data. The tube model results have been presented in the form of characteristic curves showing pressure difference, heat transfer and evaporation rate as functions of mass flow rate. These curves provide a new insight into the boiling process within calandria tubes. Improvement of the one-dimensional model predictions would require more experimental data pertaining to the volume fraction distribution in the axial and radial directions, as well as an improved correlation for the boiling heat transfer coefficient.

Quasi-static, two-dimensional, axi-symmetric CFD simulations of the vacuum pan were performed for three discrete levels of filling, representing the start, middle and end of the batch process. It was found that the magnitude of the flow speed through the tubes decreases drastically with increasing level within the vacuum pan. This reduction has two causes: first, the effect of increased viscosity with increasing head; and second the effect of the increased boiling point with increasing head. Both of these effects combine to give a much lower heat transfer rate within the tubes, thus producing less vapour to drive the flow. As the head above the calandria increases, the size, strength and existence of recirculation zones also increases. These recirculation zones do not provide any assistance in circulating the flow through the tubes.

The simulations provide an improved understanding of the mechanisms producing natural circulation and allow suggestions of possible improvements to vacuum pan designs. Recommendations for changes in pan design and operation to increase heat transfer have been made. With the large change in fluid viscosity from start to finish of the boiling process, combined with the change in saturation profile due to the increasing head, it is difficult to conceive a batch vacuum pan design that will operate at the maximum heat transfer and evaporation point for all times during the strike. Continuous pans, which have a fixed level, do not suffer from this limitation.

The model developed is a useful tool for analysis of vacuum pan operation, and may be applied to both batch and continuous pans. The segmented modelling approach, which is a novel contribution of this work, also provides a framework for future model improvements as new experimental data becomes available.

The PhD thesis by Stephens (2001) contains a full description of the findings of this project.

References

STEPHENS, D.W., (2001), "Modelling Natural Circulation in Batch Vacuum Pans". Ph.D. thesis, James Cook University (submitted for examination).