

“Numerical analysis of conjugate heat and mass transfer phenomena in food freezing using hydrofluidisation impingement method”

PhD thesis by Michal Stebel

Reviewer report

Pieter Verboven, KU Leuven, 6/7/2022

General comments

The PhD thesis presents the development, verification and application of different numerical simulation tools to assess different parts of the complex transport phenomena occurring during food freezing in a turbulent flow freezing liquid induced by a hydrofluidisation impingement system. While the method has been developed by earlier research, the current work adds significantly to the knowledge of the mechanisms and parameters involved in the process, while making progress in coupled fluid and particle flow modelling.

Different aspects of fluid and particle flow and heat and mass transfer are covered in different chapters sequentially considering different complexities of the process, from (1) turbulent fluid flow modeling, (2) HTC and phase-change heat transfer during HF freezing, (3) (semi-) discrete particle flow and (4) coupled heat and mass transfer.

The PhD has resulted in 4 original research articles in well classified peer review journals.

In some instances it is not always clear how the approaches presented here are a progress to methods presented by earlier works. This is most evident with regards to the macroscopic particle model in comparison to discrete element modelling. Some reflection concerning positioning this work in the broader context would be welcomed.

The results of the different chapters are discussed in terms of their individual merits. Some integral analysis of the research results would have been welcome in the last chapter. How would the different models be integrated and for which purpose (within and beyond the application field) can they be used and which methodologies would be additionally required? What are their limitations and what are the future developments concerning the modelling approaches?

Detailed comments and questions for discussion

The figures in the chapter summaries are difficult to comprehend without reading the full papers. The figure captions could be made more explanatory such that the figures can be read independently.

Chapter 1. Introduction

When discussing the different model approaches for phase change modelling it would be welcome to also touch upon methods such as phase field modeling and ice crystal growth modelling approaches. Although maybe not directly useful for the current work, they would offer a more complete view of the modeling field and explain where they might have contributions in improving understanding or predictive power.

The drawbacks of the used modelling approaches could have been better explained.

Concerning the properties of hydrofluidisation systems, can also the need for pumps and aspects of cleaning be taken into consideration.

In Fig. 1.2 a general layout of a HF freezing system is presented. How critical are the aspects of the design that are not modeled in this thesis? Such as the plenum, overflow, pumps and piping.

Formulation of the fluid appears to be a critical aspect in HF systems. One property that appears to have less attention in this work is fluid viscosity. Does it play a role and do the developed models account for it?

With respect to the objectives, it is not entirely clear what is meant by the 'consideration of the most accurate formulas' of properties. Would this not mean you need to develop them?

Chapter 2. Turbulent flow modeling in HF

With reference to figure 2.3: It is assumed that the mean flow is presented. What are the turbulent or transient characteristics of the flow and can they be retrieved from the PIV and compared with those of the models?

What were the important aspects of the flow turbulence and how well could they be represented by the presented modelling approaches?

Chapter 3. Food freezing model

(Also in other chapters) I am a bit confused with the formulation of the diffusion terms in the transport equation (eq. 1 in the paper, eq; 3.9): it uses a single gradient operator, while a second order derivation is expected. It could be a definition issue, but then still the position of the parameters within the derivative could be discussed.

The flow and heat transfer modelling is executed separately using HTC values derived from one and applied in the other. Which simplifications does this imply and can you quantify the consequences?

Predictive equations are used to calculate the thermal properties. Could you consider other approaches and what would be there advantages/disadvantages?

How sensitive are the results for uncertainty/variability of parameters?

Chapter 4. Particle-flow model

Can you explain in what sense the approach is similar and different to DEM?

There appears a circular problem with solving the system of equations 4.1 to 4.3, with F_D dependent on u and C_D , and C_D also dependent on u through Re .

If F_D is derived directly from the simulation, why are surface heat fluxes not?

If well understood, the model uses an artificial surface to prevent the particles from floating. How does that stroke with reality and what is the impact on heat transfer?

How do initial positions of the spheres affect the results?

Chapter 5. Coupled heat and mass transfer

In the last term of eq. 5.1: is there a density factor missing (based on units analysis)?

How would you measure/predict tortuosity?

Do you account for difference in solubility of the components in freezing liquid and the food product?

Conclusion

The PhD adds significantly to the knowledge of the mechanisms and parameters involved in the process, while making progress in coupled fluid and particle flow modelling. There are multiple peer reviewed articles from this research and therefore it is concluded that this work is very valuable and should be accepted for granting the PhD title to Michal Stebel.

Leuven, 31/7/2022

A handwritten signature in blue ink, appearing to read 'P. Verboven', with a large, stylized initial 'P' and a long, sweeping underline.

Pieter Verboven