Sabbatical Leave Report for Fall Semester 2007

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Summary

I spent the sabbatical leave from August 2007 to December 2007 at the Laboratory of Food Process Engineering (LMVT) of the Swiss Federal Institute of Technology Zurich (ETH Zurich). The main purpose of this sabbatical leave was to establish a research collaboration in the area of multi-phase flows with applications to sprays in food processing. The short-term objectives stated in the Sabbatical Leave Research Program [1] were largely achieved, and the foundation for a long-term research collaboration was established.

Accomplishments

The main objective of this sabbatical leave was the adaption of the current engine spray simulation environment to food processing applications such as cold sprays.

- **Objective 1:** *Adapting existing spray simulation methodologies to the production of powdered substances in food processing.*

  The pre- and post-processing tools have been modified to account for the specific conditions of this project. The main issue was the much larger physical dimensions of this problem which requires the generation of a computational mesh that yields sufficient spatial resolution.

  The performed sensitivity studies on various spray parameters showed that the pressure atomizer model used in engine simulations is not suitable for food sprays because the relatively low injection pressures are insufficient to yield the desired small drop size distribution. Consequently, the development of an air-assist atomization model was a necessity for the simulation of food sprays. The approach taken was to extend the existing Cascade Atomization and Drop Breakup (CAB) model (c.f. [2, 3, 4]), originally developed for high-pressure sprays in engine applications, to account for the air-assist atomization process. The main idea behind this model extension was to account for the increased relative velocity between the liquid jet and the air stream at the nozzle exit, which leads to an increased Weber number and hence to smaller mean drop sizes.

  The model performance has been successfully validated with experimental data of a cocoa butter melt. Additional simulations have been performed for nutriose liquid sprays and for foam sprays. In both cases the results have given useful insight into the spraying mechanisms of these materials and have yielded essential information for the experimental setup of such sprays.

- **Objective 2:** *Adapting an existing computational environment used in automotive spray optimization problems to find optimal powder size distributions in food processing applications.*

  The optimization method has been further developed for automotive sprays which resulted in the two publications given in refs. [5, 6]. The optimization for the food sprays, however,

has been postponed to a later stage. There are indications that the freezing process will play a dominant role in the determination of the drop size distribution. The reason for this is that for non-freezing sprays, the drop coalescence and the secondary drop breakup downstream from the nozzle have a strong influence on the drop size distribution (cf. [7, 2]. The competing processes of coalescence and subsequent breakup will be mainly suppressed in a freezing spray and, therefore, the freezing process will have to be taken into account via a special freezing module.

- **Objective 3:** *Strengthening my ties with the Institute of Food Science and Nutrition at ETH Zurich and to laying the foundation for an active long-term research collaboration.*

  The research conducted during the sabbatical leave forms the basis for a long-term collaboration with the LMVT. The problems that are currently under investigation address further model developments and testing of the air-assist atomizer. In a further step, a freezing module will be developed that accounts for the liquid-solid phase change of the spray particles. Additional research is planned to develop a model to account for non-Newtonian effects. Also, the optimization procedure which has been further developed during the sabbatical leave, will be instrumental for the improvement of the experimental spray apparatus, the atomizer and the injection system in particular.

Talks and Presentations

The following talks, seminars and poster presentations have been given during the sabbatical leave.

- Tanner, F. X., "Introduction to Turbulence," Wildhaus Seminar Series, Laboratory of Food Process Engineering, Swiss Federal Institute of Technology Zurich (ETHZ), September 12, 2007.
- Tanner, F. X., "Modeling and Simulation of Sprays, Part I: Basic Concepts and Mathematical Formulation," Lecture Series on Computational and Experimental Investigations of Non-Newtonian Fluids, Swiss Federal Institute of Technology Zurich (ETHZ), October 24, 2007.
- Tanner, F. X., "Modeling and Simulation of Sprays, Part II: Applications and Illustrations," Lecture Series on Computational and Experimental Investigations of Non-Newtonian Fluids, Swiss Federal Institute of Technology Zurich (ETHZ), October 26, 2007.
- Tanner, F. X. and Windhab, E. J., "Modeling and Simulation of Sprays," Poster presented at the Annual Meeting of the Swiss Group of Rheology (SGR), Nestlé Research Center, Vers-chez-les-Blanc, November 1, 2007.
- Tanner, F. X., "Spray Simulations in Food Processing," Institute of Food Science and Nutrition (ILW) Colloquium, Swiss Federal Institute of Technology Zurich (ETHZ), November 6, 2007.

Publications

The following papers have been submitted or prepared during the sabbatical leave.

- Macek, J., Vitek, O., Srinivasan, S., and Tanner, F. X., "1-D Modeling of Transient Engine Operations Using Data Generated by a CFD Code," SAE Paper 2008-01-0357, 2008.
- Tanner, F. and Srinivasan, S., "Optimization of an Asynchronous Fuel Injection System in Diesel Engines by Means of a Micro-Genetic Algorithm and an Adaptive Gradient Method," SAE Paper 2008-01-0925, 2008.

- Tanner, F. and Srinivasan, S., "CFD-Based Optimization of Fuel Injection Strategies in a Diesel Engine Using an Adaptive Gradient Method," *J. Applied Mathematical Modeling*, accepted for publication.
- Tanner, F. X., Althaus, T. O., and Windhab, E. J., "Modeling and Simulation of an Air-Assist Atomizer for Food Sprays," *Proc. 21st ILASS-Americas Annual Conference*, Orlando, FL, May 2008, in preparation.

Additional Activities

- Visiting the research facilities of Wärtsilä Ltd. in Oberwinterthur, Switzerland, October 29, 2007.
- Interactions and discussions with ETH and visiting professors/scientists.
- Attending colloquia and seminars at ETH Zurich.
- **Conference Organization:** Diesel Fuel Injection and Sprays session at the SAE World Congress in Detroit, April 2008.
- **Refereeing/Reviewing** papers for SAE Conferences, ICEF 2007, Atomization and Sprays, and Int. J. Thermal Sciences.
- Continuing collaborations with the Engine Research Center at the University of Wisconsin–Madison and the Czech Technical University in Prague.

References

[1] Tanner, F. X., "Sabbatical Leave Research Program," Michigan Technological University, February 27, 2007.

[2] Tanner, F. X., "Liquid Jet Atomization and Droplet Breakup Modeling of Non-Evaporating Diesel Fuel Sprays," *SAE Transactions: Journal of Engines*, vol. 106, no. 3, pp. 127–140, 1998.

[3] Tanner, F. X. and Weisser, G., "Simulation of Liquid Jet Atomization for Fuel Sprays by Means of a Cascade Drop Breakup Model," SAE Paper 980808, 1998.

[4] Tanner, F. X., "Development and Validation of a Cascade Atomization and Drop Breakup Model for High-Velocity Dense Sprays," *Atomization and Sprays*, vol. 14, no. 3, pp. 211–242, 2004.

[5] Macek, J., Vitek, O., Srinivasan, S., and Tanner, F. X., "1-D Modeling of Transient Engine Operations Using Data Generated by a CFD Code," SAE Paper 2008-01-0357, 2008.

[6] Tanner, F. and Srinivasan, S., "Optimization of an Asynchronous Fuel Injection System in Diesel Engines by Means of a Micro-Genetic Algorithm and an Adaptive Gradient Method," SAE Paper 2008-01-0925, 2008.

[7] Tanner, F. X. and Boulouchos, K., "A Computational Investigation of the Spray-Induced Flow and Its Influence on the Fuel Distribution for Continuous and Intermittent DI-Diesel Sprays," SAE Paper 960631, 1996.