Institute for Sustainable Process Technology

Energy Efficient Milky Sprays

Project leader: Marc Wittner (dsm – firmenich)

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Format final report
(public summary)

Project Number RVO and/or ISPT(-TKI)	DR-20-13
Project Title + Acronym	Energy Efficient Milky Sprays – EEMS Study the effect of solids content and main constituent components of model liquids on atomization efficiency of the nozzle.
Secretary (penvoerder)	Institute for Sustainable Process Technology – ISPT
Name Program Director	Peter de Jong
Name project leader	Marc Wittner (per 1 September 2023; formerly Joost Beekman, both dsm-firmenich; ad interim Jasper Vollenbroek, FrieslandCampina, for period of 1 year).
Researchers (name & title thesis)	Cristina Garcia Llamas (Chemical Engineering and Chemistry, Multi-scale Modelling of Multi-phase Flows): Numerical investigation of the primary atomization process of a laminar liquid jet in a gas media. Vivekanand Swami (Chemical Engineering and Chemistry, Multi-scale Modelling of Multi-phase Flows): Comparative Analysis of Drop-size Measurement in Dense Sprays using Shadowgraphy, PDA and SLIPI.
Funding	TKI Toeslag 2018
Project start	1-3-2019
Project original end date	1-3-2023
Project final end date	12-11-2023

See KPI's: also allowd as text, without table.

KPI	Omschrijving
1. Organisation/ Coordinator	Institute for Sustainable Process Technology (ISPT)
2. Projectnumber- or file number	DR-20-13
3. Projecttitel evt. acronym	Energy Efficient Milky Sprays (EEMS)
4. TRL at closure, main category	NEA (non-economical activities) + IO (industrial research)
5. TRL at closure, detail category	TRL3
6. Project successes	The project was not executed satisfactorily as too little trials could be performed, and the content of the deliverables/milestones was adjusted. as the work on emulsions had to be somewhat restricted. In the project, a Direct Numerical Simulation method was created that is able to predict the secondary break-up of Newtonian and non-Newtonian liquids (droplet-droplet interactions). In addition, the primary break-up of cylindrical and rectangular jets can be predicted accurately using the method. It could be shown that the inlet velocity profile is determining for the break-up length of the jets/sheets. The method was extended to include the three-phase contact angle for model situations, which is ground-breaking for this type of methods.These simulations have been validated with dedicated experiments. Furthermore, a Structured Laser Illumination Planar Imaging (SLIPI) technique was developed and tested on a high-pressure swirl nozzle..
7. Follow up(s)	To ensure that project successes can be obtained, the project is extended and all results of this extension will be presented in the *DRoplet AGglomeration in Spray Dryers* (DRAGONS Egg) project. Also part of the research activities have been transferred to the DRAGONS Egg project. Assisting reasearch in spray drying dynamics and agglomeration behaviour in spray dryers is performed in the S*teering Agglomeration Processes in spray dryers* (**StAggloP**) project that started were forces were joined by biannual project progress meetings. The follow up project *DRoplet AGglomeration in Spray Dryers* (**DRAGONS Egg**) started March 2023 to use the results from both EEMS, StAggloP and DRAGONS as stepping stones towards the project **DRAGONS Hatchling** (to be submitted) were a lumped parameter model that will be developed for creating a toolbox for large scale industrial spray dryers to obtain energy efficiency and to make implementation of all research results possible.

KPI	Omschrijving
8. Number of realized peer-reviewed publications	9; see publications overview
9. Number of expected peer-reviewed publications	10-15; see publications overview
10. Number of realized non-peer-reviewed publications	12; see publications overview
11. Number of patent applications	None
12. Number of granted licences	None
13. Number of prototypes	None
14. Number of demonstrators	How many demonstrators developed + short introduction per demonstrator: none
15. Number of spin-offs/ spin-outs	0
16. Number of improved/new processes/ services introduced	1
17. Impact	The project has resulted in the development of novel computational (LFRM) and experimental (SLIPI) techniques to study the atomisation of liquids. The methods have been used to study several simplified geometrics and resulted in fundamental understanding of the effect of the liquid phase properties and the velocity profiles on the break-up of liquid sheets. These effects will be further studied in the remainder of the project to connect this to the industrially relevant swirl nozzle atomisation.

1. Public Summary

Spray drying is a very energy intensive process and a relatively inefficient way of drying in terms of energy consumption, but very effective for converting an aqueous solution, like milk or dairy related products, into a functional dry powder while maintaining the desired properties. Considerable energy savings can be achieved if (more) water is removed prior to the spray drying operation and a more concentrated solution is atomized and dried.

The EEMS (Energy Efficient Milky Sprays) project focussed on the understanding of the effects of highly viscous liquids and non-Newtonian flow behaviour on the atomisation of the liquid and by that the quality of the obtained powder after spray drying. When a liquid with typically 50% solids content (absolute level highly depending on composition) is atomized in a high-pressure atomizer and dried under the influence of hot air, the internal liquid flow in a high-pressure swirl nozzle largely influences the liquid sheet formation, sub-sequent breakup and hence determines droplet size distribution. This in turn determines the spray drying efficiency and product quality. These high solid content liquids are typically highly viscous and can exhibit non-Newtonian flow behaviour depending on the exact composition.

The research used a combined experimental and numerical approach to gain this understanding. First of all, binary droplet collisions were investigated using a Local Front Reconstruction Model (LFRM) and dedicated experiments for both Newtonian and non-Newtonian liquids. A parameter study showed that the collision outcomes are highly dependent on the power-law index, i.e. the boundaries of collision maps are not only dependent on the viscosity of the liquid but also on the power-law index.

Secondly, the primary break-up of laminar circular jet and rectangular jets was investigated both numerically and experimentally. LFRM was able to capture the break-up length, the droplet sizes, the axis-switching behaviour (for rectangular jets) and the complex interface deformations during the bursting of the jet in the second wind-induced regime. Based on the computational results of the circular jet in the second wind-induced regime and the rectangular jet, it is concluded that the outlet velocity profile of the nozzle largely influences the break-up length of the jet.

In addition, the novel Structured Laser Illumination Planar Imaging (SLIPI) technique was developed and used to determine the atomization of liquids experimentally for a Delevan SDX-III nozzle. Besides the size of the droplets, the velocity profiles outside the nozzle were studied for both water and more viscous fluids (using maltodextrin solutions). These measurements will be extended in the extension of the project and reported in the DRAGONS Egg project.

Besides the studies outside the nozzle, the fluid flow inside the nozzle was also studied. To allow visualization of the flow and the air core inside the nozzle, the nozzle was scaled hydrodynamically to 5 and 10 times the initial size, respectively. Initial findings on these scaled nozzles indicate that the formation of the air core in the nozzle and its stability point are correlated with the inlet Reynolds number. These findings will also be explored further in the extension of the project and reported in the DRAGONS Egg project.

To study the flow inside the nozzle numerically, the contact angle near the gas-liquid-solid surface needs to be represented correctly. In this project, we developed a new approach for the implementation of the gas-liquid-solid contact points. The implemented contact angle model will be used in the extension of the project and in the DRAGONS Egg project to simulate the flow inside the nozzle.

There are still investigations to be executed in the running DRAGONS Egg project and the planned DRAGONS Hatchling project, to improve understanding of the effects of highly viscous liquids and non-Newtonian flow behaviour on the atomisation of the liquid. If the outcomes of these investigations are translated towards application by the industry, the impact could increase the capacity on each spray dryer with 10%. This will lead to decreased production costs and reduced CO2 emissions.

These results of the EEMS project form together with the results the StAggloP project a stepping stone towards the just started DRAGONS Egg project to study the effect of drying on the droplet formation and interaction. The results of the EEMS project will have an impact on the to-be-submitted DRAGONS Hatchling project in which a lumped parameter model will be created that allows the industry to translate the obtained results of the EEMS, StAggloP and DRAGONS projects to increase the energy efficiency of their spray drying processes.