Popular summary

In 2013, 80 million tons of extruded fish feed was produced for finfish, crustaceans and molluscs, world-wide. 7 million tons were produced for marine cage aquaculture, including 3 million tons supplied solely for salmonid species. As much as 7 percent of the produced feed are estimated to be lost to the environment in marine cage aquaculture. A significant part of this loss arises from poor technical quality of the feed, resulting in feed breakage and formation of fines during handling and transport. This imply that for every percent lost to the environment, 70.000 tons of extruded feed was discharged from world marine aquaculture in 2013. For salmonid marine aquaculture alone, each percentage of lost production costs approximately US$ 30 million, using an average feed price at US$ 1.0 / kg. Feed costs in marine cage aquaculture at the same time accounts for more than 50 % of the total production cost. As for costs of feed production, the drying process often account for more than 60 % of the total thermal energy usage. Improvement of energy efficiency in the drying process of extruded fish feed can in many occasions be realized, but often there exist some reluctance in the industry to investigate how changing the drying parameters can improve the energy efficiency, from the risk of compromising the technical quality of the finished product. This industrial PhD thesis concern the challenge of improving energy efficiency in the drying process of extruded fish feed, while safeguarding, or even improving the technical quality, and in particular the mechanical durability.

A mathematical model has been developed to allow the prediction and optimization of energy efficiency, provided constrains of dryer dimensions, product moisture and capacity, using drying parameters as free variables. An experimental lab dryer have been designed and manufactured to calibrate and experimentally validate the developed drying model. It was found that the model was able to reproduce drying conditions at an accuracy (root mean square error) of 6 – 13 %. Spatial details of moisture and temperature in the pellets are also predicted in the dryer model. These are applied to allow prediction of mechanical durability of fish feed – at was found that durable feed pellets have viscoelastic structural properties.

It was demonstrated experimentally, using the custom-built Lab Dryer, that the observed structural properties of extruded fish feed can be predicted in the framework of glass transition theory, generally stating that a viscoelastic material have a low glass transition temperature at high moisture contents, and vice versa. This implies that water acts as plasticizer, increasing the pellets' viscous character, and that drying in the rubbery phase, at temperatures above the glass transition point, ensures phase mobility and reduces surface tension.

From experiments it was found that at (or immediately before) glass transition onset, drying temperature should generally be lowered to avoid the surface to transcend to its glassy state at a high rate, to avoid build-up of stresses in the pellets. Additionally it is proposed that when glass transition occur at high temperatures, surface non-enzymatic browning reactions are promoted, which in turn decreases the pellets' viscoelastic character, resulting in hard and brittle pellets. By using the spatial details of pellets' moisture and temperature, as obtained in the developed drying model, it was demonstrated that a low surface temperature following evaporative cooling significantly reduces the mechanical durability. This is believed to be a direct consequence of achieving an early glass transition in the pellets. A final 'quality estimate' was developed and found to be a significant effect, for the prediction of mechanical durability.

Following the present PhD thesis, it is proposed that high temperature, high humidity and high air velocity promote viscoelastic character of extruded fish feed pellets, improving their mechanical durability. It should be desirable to constantly be at a position on the pellets' glass transition curve, not too far away from the glass transition point, to reduce high product temperatures as well as spatial temperature and moisture gradients at actual onset into the glassy state. In this way, differences in glass transition from surface to center should be minimized. The numerical model developed therefore form basis for a multi-objective optimization tool for the hot air drying of extruded fish feed; objective is to increase energy efficiency whilst utilizing drying conditions that does not compromise technical quality of the fish feed.