Efficient Production of New Alternative Aquafeeds

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New challenges in extrusion processing alternative aquafeeds

With rapid development in aquaculture, the industry has realized that the use of capture fish and fish processing by-products (so called fish meal) in aquafeed threatens aquaculture's sustainability. Sooner or later, not enough fish meal can be used for aquafeed manufacture. Meanwhile, the aquaculture product increasingly plays a more important role in global food supply with the increase in world population, because agriculture productivity is limited by the amount of cultured land. As the aquaculture will play an important role in global food supply, the development of alternative materials to replace fish meal becomes one crucial aspect to allow the industry to expand in a sustainable manner.

Many efforts have been made to use plant-based ingredients in alternative aquafeed production. The potential plant-based alternatives already in use include soybeans, barley, rice, peas and other crops, along with canola, lupine, wheat gluten, corn gluten, various plant proteins and algae. With these potential ingredients, a many new aquafeed recipes can be formed for processing in the product development stage. To process all these new recipes in the extrusion process is a very expensive task in terms of time and raw material cost and can become a bottleneck sometimes. Although extrusion processing has been widely applied in aquafeed production, the understanding of the process is still very limited. In most cases, the search of suitable extrusion processing parameters depends on trial-and-error experiments and experience. To face these challenges, new methods should be adapted to improve the efficiency in extrusion processing new aquafeed recipes.

Improvement of extrusion processing method for aquafeed production

Extrusion cooking technology is a very efficient processing method in feed production. Nowadays, nearly all auqafeed is produced using extrusion. Within extrusion processing, several processes may occur, including fluid flow, heat transfer, mixing, shearing, particle size reduction and melting, where feed materials are exposed to high temperatures for a very short time. This gives a distinct advantage over conventional pressure cooking, in which the exposure could last several minutes at high temperatures. In the extrusion of food and feed, pellet expansion (or bulk density) is one important property in product quality control and measurement during pellet manufacture, which is different from paste and spaghetti production.

Different strategies have been proposed to improve extrusion process technology. In industrial practice, two strategies are typically employed to control and determine suitable extrusion parameters to obtain the correct expansion pellet. One method is to set up extrusion parameters from experience and experimentation and to analyze processing results through response surface methodology or other methods. The other way is to modify the mechanical segments in the extrusion line, such as screw configuration and die structure, and to change raw material particle size and precondition parameters. In industrial practice, however, the optimal combination of these methods is a very difficult job when initial trials cannot give the correct pellet expansion for one or several new recipes. In such a case, industrial practice experiences play a crucial role. At the same time, engineers and researchers have also made efforts to search for new methods to improve the extrusion efficiency in terms of time and raw material cost for new product development.

Recently, engineers have worked on using a new mathematical modelling method to analyse extrusion processing aquafeed to improve extrusion parameters.

Application of modelling method to improve the procedure that determines extrusion parameters

Various modelling techniques have been established to describe and analyse extrusion process operations, such as response surface methodology, principle component analysis, neural network method, genetic algorithm and numerical simulation. In the application of response surface methodology, principle component analysis and other multivariate data analysis methods, the extrusion process is treated as a black box. All possible factors are analysed through a statistic algorithm for identification of impact on pellet properties, e.g. pellet bulk density. The neural network method and genetic algorithm can be treated as a grey-box model for the extrusion process, in which the model can automatically update its equation behaviours in a few cases, learning from real extrusion process operation data. The numerical simulation method is built from a basic physical principle to describe an extrusion process. However, the construction of the numerical simulation method involves several equations to describe the extrusion process so that it has to be simplified for a real process and to yield a numerical solution.

Engineers have started to explore a grey-box model to correlate the relationship between pellet bulk density and extrusion parameters based on the work of Cheng and Friis (Cheng, H. and Friis, A. Food and Bioproducts Processing, 2010, 88:188-194). In the model, the pellet bulk density is correlated with important extrusion process parameters, e.g. die temperature, moisture content, screw speed and specific mechanic energy. The formulation of the model is simple and can be solved using common mathematical tools, such as Microsoft Excel. The application of the model shows it does correlate pellet bulk density with extrusion parameters. An application is shown in the following section.

An application of the model

In the development of new alternative aquafeed, the extrusion engineer often has to process a batch of different new recipe feeds in a pilot plant extrusion process. Even if the production is not in a large amount, the production cost may be high in terms of time and materials. In practice, a typical method is to conduct initial trials in an existing extrusion line from experience to obtain the correct feed pellet. An experienced engineer may reach the correct feed pellet in a few runs. If the test run fails for one or several new recipes, the engineer must investigate all possible reasons, such as more extrusion parameter combinations, particle size, screw configuration, etc. The feed pellet extrusion processing may become a bottleneck in the alternative recipe development.

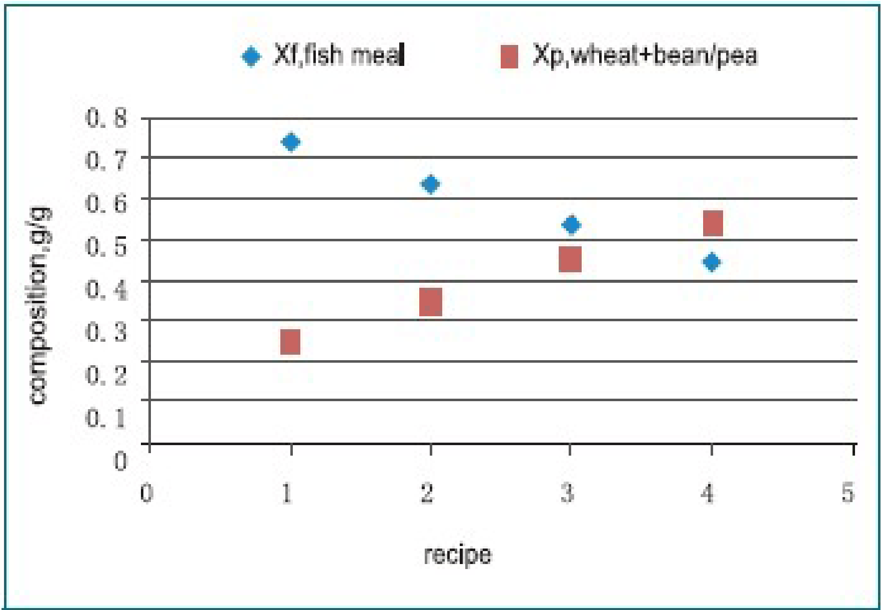
To improve the current procedure for processing a group of new recipes, we introduce the modelling method of Cheng and Friis to analyse the trial results. For a group of new recipes, we first use a composite design method to arrange the initial trial sequence. Using the trial results, the pellet bulk density can be correlated to extrusion process parameters using the modelling method. By the correlation results, we analyse the effects of adjusting extrusion parameters on pellet bulk density. From the analysis, we can obtain an optimal direction with which to adjust the extrusion process for a specific recipe.

For example, there are four new recipes for processing, which is shown in **Figure 1**. In these recipes, the fish meal content (Xf) decreases with increasing wheat+bean/pea content (Xp). A small composite design method is used to arrange the extrusion process parameter adjustment table, which includes temperature, moisture content and screw speed. Between eight and 11 runs are arranged for each recipe. From these runs, a set of experimental data can be obtained. Based on the experimental data, we use the mentioned modelling method to take into account the effects of extrusion parameters on pellet bulk density. The modelling results are represented in **Figures 2-4**. In **Figures 2-4**, the z axis represents the pellet bulk density (g/l), the x and y axes represent, respectively, die temperature Td (°C) divided by 25°C and parameter group Pd/SME, where Pd is the die pressure (bar) and SME is the specific mechanic energy, $SME=\tau \cdot Ns/F_T$ (τ: torque, Nm, Ns: screw speed, rpm, F_T: total flowrate in extruder, kg/hr).

In **Figures 2-4**, the modelling results are given in three moisture content conditions for four recipe composition variations. As shown in **Figures 2-4**, four surfaces represent pellet bulk density behaviours along the extrusion parameters for four recipes. On each surface, the pellet bulk density can be read through given die temperature, Td and SME (calculated from screw speed). An operation window or range can be outlined from the surface. The analysis can help the engineer determine an optimal parameter adjustment direction to improve pellet bulk density. For example, **Figures 2-4** shows that Td/25=4.0-4.5 and Pd/SME=0.1-0.2 will give lower pellet bulk density or good expansion for processing all four recipes.

To take advantage of extrusion process modelling work

As shown in the application, the modelling work provides a quantitative tool with which to aid the engineer in analyzing the effects of extrusion parameters on pellet bulk density. The modelling results can give a guide to avoid the blind trial-and-error procedure when a recipe processing cannot give the correct pellet bulk density. From the modelling work, we do not need to examine every possible extrusion parameter combination and, therefore, can reduce the amount of experimental tests. The modelling result can quantitatively determine the relationship between pellet bulk density and extrusion operational parameters and, thus, can predict the pellet bulk density that has not been reached in experimental trials. Therefore, the time and raw material cost can be reduced in processing a group of new recipes in the new product development stage. From our experience in application of the model for different extruders, the model is suitable for both twin-screw and single-screw extruders and can also be applied for laboratory, pilot and industrial-scale equipment.



▫ *Figure 1 composition changes of four recipes*

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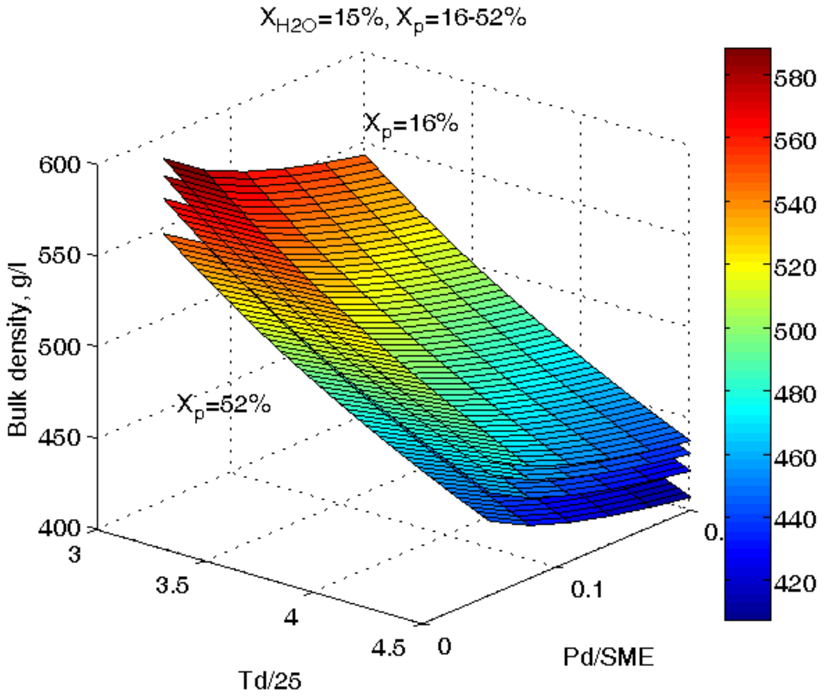

Figure 2 water content (X_{H2O})=15%, fish meal (X_f)=48-84%, wheat+bean (X_p)=16-52%.

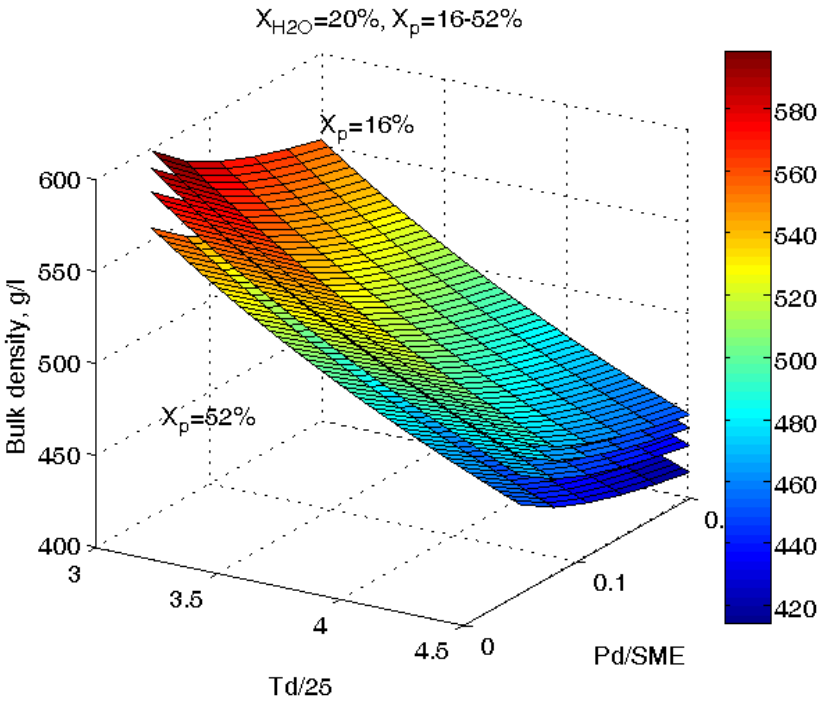

Figure 3 water content(X_{H2O})=20%, fish meal(X_f)=48-84%, wheat+bean(X_p)=16-52%

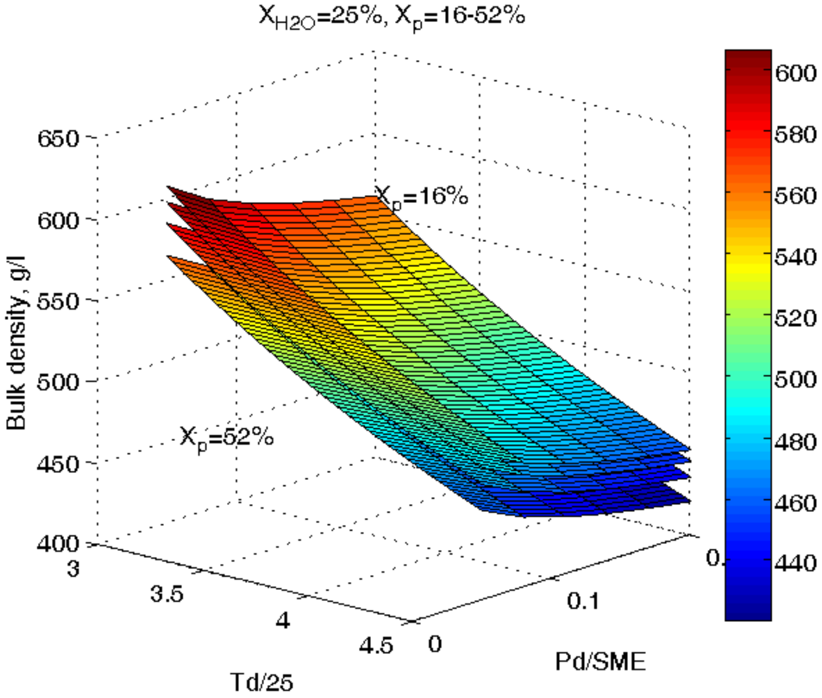

Figure 4 water content(X_{H2O})=25%, fish meal (X_f)=48-84%, wheat+bean(X_p)=16-52%