The Effects of α-Amylase on the Flow Behaviour of Liquid Feed

Meno Türk[1] and **Wolfgang Heinzl**[2]
[1] Institut für Agrartechnik Bornim e.V. (ATB), Potsdam
[2] BASF-Aktiengesellschaft, Ludwigshafen

Feed enzymes have been used for a long time in pig feeding. A new objective is the reduction of the viscosity of liquid feed through the addition of α-amylase. Using the same measuring method, the most important feedstuffs and feed mixtures for pigs were analyzed. Mixing- and flow curves were measured, compared and assessed. An α-amylase marketed by BASF (Natustarch®) reduces the viscosity of liquid feed rich in starch.

Keywords
Feed enzymes, α-amylase, liquid feed, flow behaviour

Description of the Problem

Liquid feed generally consists of crushed grain and water. In pig husbandry, it is mixed, pumped, and administered fully automatically. Sometimes, further feed components, such as potatoes, CCM, or alternative feedstuffs rich in starch are added. The liquid feed mixtures often have the consistency of thick mash. Rheologically, they are classified as non-Newtonian fluids with pseudo-plastic or non-linear plastic flow behaviour. They are coarsely structured, sometimes tend to sediment, and may even have thixotropic properties.
In order to secure their ability to be pumped, the water content may not fall below a certain level. For crushed grain, the mass relation of dry feed : water is generally 1 : 2 to 1 : 3. The higher water content improves the flow- and conveying behaviour. However, it also increases the tendency towards sedimentation, reduces the nutrient concentration of the feed, and leads to larger quantities of liquid manure.
In the food- and feedstuff industry, enzymes have been used for a long time as so-called *bio-catalyzers*. Their optimal efficiency, however, is limited to very specific chemical processes at a certain concentration and in a precisely defined milieu (pH, temperature, reaction time). BASF markets *Natustarch*®, an α-amylase, as a feed enzyme which allows the viscosity of liquid feed to be reduced while the water content remains the same. This goal is achieved by splitting the long-chain starch molecules into shorter, easily soluble polymers. This is supposed to enable the pig keeper to guarantee the pumpability of liquid feed even if the water content is reduced. In detail, the following advantages are expected [1]:

- better flowability, i.e. reduction of the viscosity of liquid feed;
- lower water requirements;
- higher nutrient concentration of the feed;
- lower energy requirements during pumping;
- reduced clogging tendency of pumps and pipes;
- lower quantities of slurry and, hence, reduced expenses for storage and spreading;
- higher flexibility when using cheap liquid feed components.

The effects of different doses of α- amylase on the flow- and conveying behaviour of different feedstuffs and feed compositions, as well as their most important influence factors were examined, assessed, and described under rheological aspects [2].

Material and Method

Mixing- and flow curves, as well as pipe- and pump parameters were measured in laboratory- and technicum experiments respectively. In these trials, liquid feed with added enzymes was always compared with the same feed mixture without enzyme additives (zero sample).
The standard experiments were carried out with a MC 1/RM 300 rotational viscometer from the PHYSICA company (**figure 1**).

Figure 1: Rotational viscometer MC 1/ RM 300 from the PHYSICA company with exchangeable agitating bodies

This measuring instrument has been specially designed for highly viscous, coarsely structured organic suspensions in agriculture. It has an enhanced drive and can be controlled using both torque and rpm. The rotational viscometer features an anchor agitator on one side and a measuring cylinder on the other (**figure 2**).

Figure 2: Measuring cylinder, measuring cup, and anchor agitator of the rotational viscometer

Both agitating bodies have the same diameter of 60 mm. The measuring cup features an interior diameter of 76 mm,

and the sample volume amounts to 300 ml. The anchor agitator was used in order to provide a high degree of security against de-mixing while recording the mixing curves M (t). After the mixing curve had been recorded, the anchor agitator was replaced with a measuring cylinder, and a flow curve τ ($\dot{\gamma}$) was measured with the same sample filling. This allowed manipulations of the examined samples to be avoided in the case of them being poured into a different container, temperature changes, sample division, etc.
In liquid feeding, the entire mixing- and distributing process generally takes up to 30 min. During this time, the structure of the liquid feed is altered due to swelling effects (water intake) and mechanical strain. This also changes the rheological properties. Therefore, time influence was observed at maximum agitator rpm (300 min^{-1}) over the entire mixing period of 30 min, and the mixing curves were recorded at a constant temperature. If the liquid feed was highly viscous, the agitator rpm was reduced to 150 min^{-1} in order not to put too much strain on the drive motor of the rotational viscometer. Thus, mixing curves for different feedstuffs and feed mixtures were recorded and compared qualitatively (**figure 3**, upper part).
The alteration of the torque with the time dM/dt is directly proportional to the change in viscosity dη/dt given a laminar flow as well as constant rpm and temperature.
The relative course of the torque enables the estimated size of the effect of feed enzymes to be shown more clearly (figure 3, middle). Since all mixing curves were measured with the same time pattern, the single values of the torque M (t) in feed mixtures **with** an enzyme additive can be correlated with the zero sample A **without** an enzyme additive. As a parameter of mixing behaviour, δ_R is defined as follows:

$$\delta_R = \frac{M_i\,(t)}{M_0\,(t)} \qquad (1)$$

This shows whether and to what extent the torque (i.e. also the flow behaviour) is altered by the enzyme additives during the mixing process. All parameters < 1 indicate an improvement of flow behaviour, i.e. a reduction in viscosity.
A comparison of the flow curves (figure 3, lower part) allows for a quantitative assessment of the effect of enzyme additives in a quasi-stationary state. The flow curves are described in the form of a model using the aid of the power laws of OSTWALD and DE WAELE (for plastic behaviour)

$$\tau = K\,\dot{\gamma}^n \qquad (2)$$

and of HERSCHEL and BULKLEY (for non-linear plastic behaviour)

$$\tau = \tau_0 + K\,\dot{\gamma}^n \qquad (3)$$

For this purpose, proven evaluation techniques [3] are being used. The determined flow parameters are a prerequisite for the calculation of the pipe parameters when planning liquid feed distributors.
According to this method, the most important kinds of grain in a crushed form (wheat, rye, barley, oat, maize, triticale), steamed potatoes, potato peel waste, autoclaved food residues, and feed mixtures with different composition and different form (crushed and expanded) used in practice were examined.
On the conveyor test stand in the ATB, pipe- and pump parameters for selected grain feed mixtures were measured.

Results

The absolute mixing curves of liquid feed with crushed wheat show a behaviour which is typical of grain feed mixtures (figure 3). Swelling processes result in increased mixing resistance. The flow behaviour of liquid feed with wheat, rye, barley, or maize is only insignificantly influenced by α-amylase. The greatest effects were observed when a dose of 40 ppm was added to crushed rye and wheat. This causes viscosity to diminish by a maximum of 15%.
In principle, it is assumed that torque reductions of < 10% cannot be attributed to secured enzyme effects. This applies to all examined kinds of grain below the conglutination temperature. However, a sudden change occurs as soon as this temperature (60 to 70°C) is reached (**figure 4**). As of this point, a considerable effect of α-amylase (up to δ_R = 0.2) can be observed. At lower temperatures, the enzymes do not produce any noticeable effect. This means that a clear improvement of flow behaviour due to α-amylase is limited to thermally digested starch. In addition to potatoes and tapioca, wheat and maize exhibit such a marked effect. In the process of starch production, heat-resistant enzymes, such as α-amylase and glucoamylase, are required during the so-called liquefaction phase in order to increase the temperature of the starch batch beyond the swelling- and conglutination temperature and to reduce the high viscosity which is unavoidable at this stage.

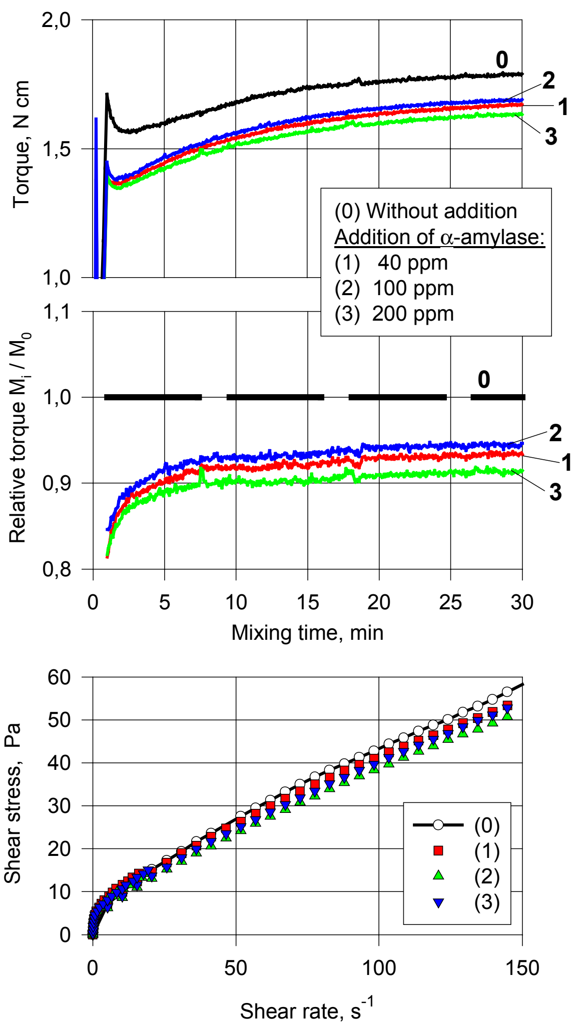

Figure 3: Mixing- and flow behaviour of liquid feed consisting of wheat and water (1:2), DS = 32.2 %

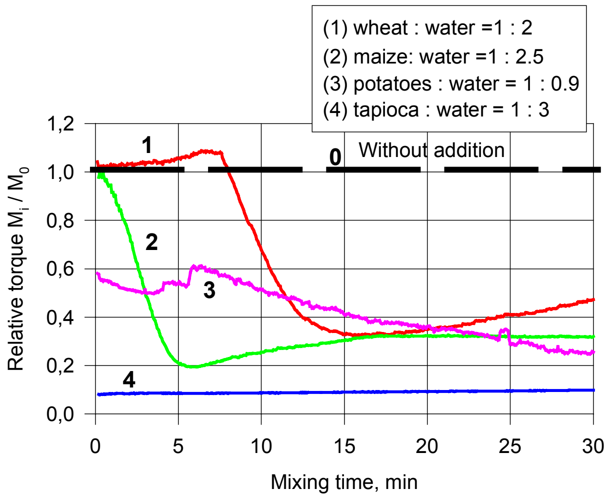

Figure 4: Modification of the flow behaviour of liquid feed after thermal starch digestion through addition of α-amylase

They are also necessary so that the starch molecules can be broken down as evenly as possible into medium-sized fragments [4].
If the conglutination temperature is reached through hydrothermal processes during expanding, for example [5], improved flow behaviour is possible and explainable. Experiments with expanded structural feed, however, did not show any positive effects with regard to reduced viscosity caused by added feed enzymes. Obviously, temperature and reaction time were insufficient for starch digestion. In the annular gap expander, the mixed feed is pressed through an adjustable annular gap at high pressure (20 to 40 bar) and high temperatures (80°C to 110°C) like in an extruder. During this process, vapour, water, molasses, and other liquids can be added. The expanded material has a structure similar to granulate and, as liquid feed, it binds considerably more water. This leads to a significantly smaller tendency towards sedimentation and better mixability. However, it also causes higher viscosity.
α-amylase exerted the strongest influence on the flow behaviour of feed mixtures containing thermally digested potato starch. It was possible to reduce the viscosity of mixtures of steamed potatoes and water by up to 60%. Similar results were observed for tapioca starch. Of course, these positive effects are reduced in practical feed mixtures containing grain. Here, the reduction in viscosity amounts to a maximum of 30 to 40%. **Figure 5** shows the mixing curves of a liquid feed mixture with steamed potatoes and wheat in a mass relation of 1 : 2. A zero sample (without additives) is compared with samples which contain 40, 100, and 200 ppm of α-amylase as an additive. There is an influence of time which causes the enzymes to reach their maximum effect after 5 to 10 min of mixing time. This corresponds to the practical conditions during liquid feeding. An influence of the quantity cannot be deduced from this example.
The measured flow curves show non-linear-plastic flow behaviour, i.e. there is a yield stress τ_0 according to equation (3). The flow parameters are the basis of pressure-loss calculations for pipe flow and pump design. For a series of agricultural non-Newtonian liquids and thick materials, a calculation program was developed at the ATB, which is frequently used for plant design for liquid feed, slurry, and bio-sludge [6].
When potato peel waste is used as liquid feed, the reduction in liquid feed viscosity cannot be expected to exceed 10 to 20% (**figure 6**).

Summary

Feed enzymes have been used in pig feeding for a long time. What is new, however, is the goal of reducing the viscosity of liquid feed by adding α-amylase. With the aid of the same measuring methods, the most important feedstuffs and feed mixtures for pigs were examined. Mixing- and flow curves were measured, compared, and evaluated. Especially in liquid feed with thermally digested starch, an α-amylase marketed by BASF (*Natustarch®*) causes a considerable reduction in viscosity.

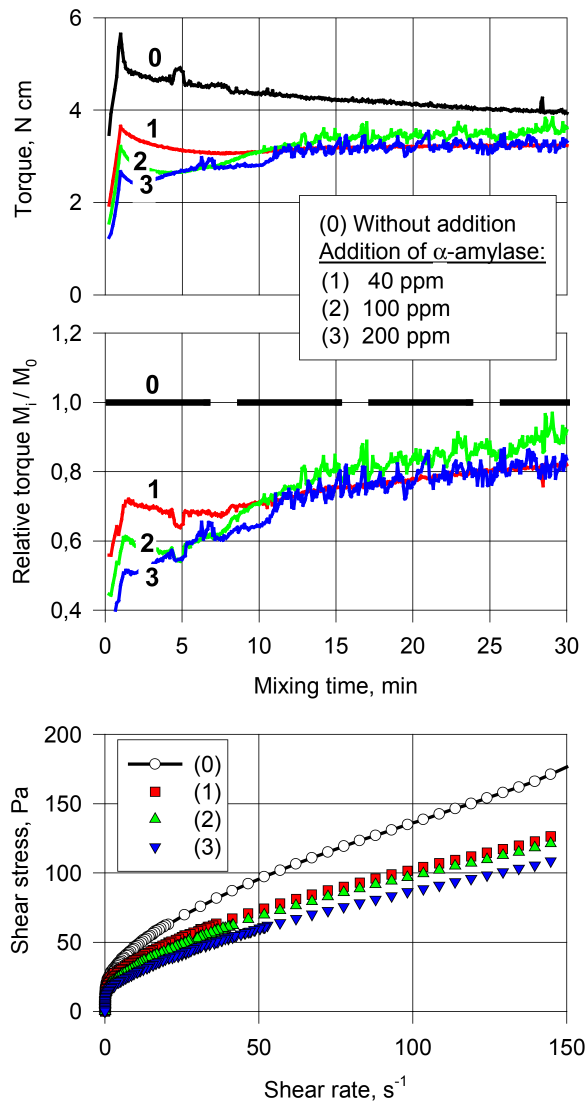

Figure 5: Mixing and flow behaviour of liquid feed consisting of steamed potatoes, wheat (1:2) and water (1:1), DS = 34.4 %

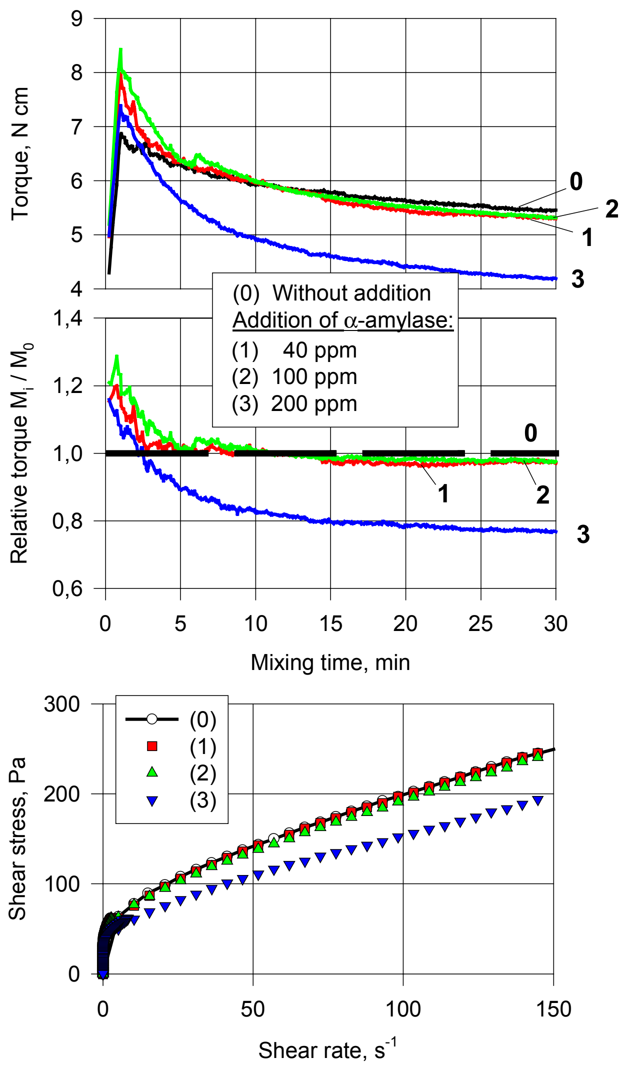

Figure 6: Mixing- and flow behaviour of potato peel waste, DS = 16.8 % and T = 60 °C

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These studies were carried out at the ATB on behalf and with financial support of BASF AG in Ludwigshafen.

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Authors

Dr.-Ing. habil. Meno Türk
Institut für Agrartechnik Bornim e. V. (ATB)
Abt. Technik in der Tierhaltung
Max-Eyth-Allee 100
14469 Potsdam
Tel.: +49/(0)331/5699-513
Fax: +49/(0)331/5699-849
e-mail: mtuerk@atb-potsdam.de

Dr. Wolfgang Heinzl
BASF-Aktiengesellschaft
Leiter Globales Marketing Carotinoide und Enzyme
67056 Ludwigshafen
Tel.: +49/(0)621/6099551
Fax: +49/(0)621/6021589
e-mail: wolfgang.heinzl@basf-ag.de