HFE 305 Feed Manufacturing Technology

Expander treatment

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INTRODUCTION

Tait and Beames (1988) reviewed methods for processing and preservation of cereals and protein concentrates. In their review, extruding received three lines of attention, whereas expanding, as a method for feed processing, was not mentioned. However, the introduction of the annular gap expander in the late 1980's (Pipa and Frank, 1989) changed this. Today are expansion, expanding, expander-processing, expander treatment or high-pressure conditioning terms commonly used to describe treatments where the feed material is subjected to high temperatures for a short time. An important success factor is that the method allows a relatively large amount of feed to be processed at a high temperature at a relatively low cost.

The expander treatment affects the nutritive value of feedstuffs. In Norway, the influence of the expander treatment on the nutritive value of protein and amino acids for ruminants has been explored, but this approach is rather narrow compared to the multiple applications of the expander technique that exist throughout the world (Pipa and Frank, 1989; Peisker, 1992a, 1992b, 1993). One approach is gelatinisation as starch. However, gelatinisation of starch is not always beneficial but depending on feedstuff to process and type of animals to be fed. Moreover, excessive heat treatment may reduce the availability of certain nutrients. For example, lysine is susceptible to heat treatment through the reaction with reducing sugars and the formation of Maillard products (Broderick *et al.*, 1991). Thus, care must be taken when assessing the expander treatment in production of feeds for various animal species.

Hygiene is another application of the expander treatment. Heat and pressure produced during expansion will effectively kill harmful pathogens, and in several countries is killing of salmonella an important issue. Moreover, expander treatment efficiently takes out most weed seeds. In Norway, the expander has been used to produce compounds guaranteed free of wild oats. In addition to nutritive influences, the expander treatment affects technical quality and properties of the feed production. Pre-conditioning with an expander usually improves pellet quality and pellet press capacity. The method allows for increased addition of liquid ingredients as fat and molasses. Expandate is an unpelletised expanded feed, which is of particular interest in production of feeds for pigs and poultry. In this paper, some technical applications and nutritional effects of the expander treatment are focused.

THE EXPANDER TREATMENT

In principle, expander treatment is related to extruder treatment. The feed material enters a feed barrel through an inlet gate (Figure 1). An anger or screw conveyor driven by an electrical motor forces the feed material towards a resistor in the outlet gate of the expander. This creates high shear and pressure, and aided by addition of steam, heat is produced. After the material passes the resistor in the outlet gate, the pressure immediately drops to atmospheric. The release of pressure and spontaneous evaporation of water makes the feed material expand in volume and the temperature to drop rapidly. The temperature can rise to high levels, but the entire process is usually completed within seconds. The process is often referred to as an HTST-process (HTST = High Temperature Short Time). Several types of expanders exist. The annular gap (ring-spalt) expander, or Kahl expander, is most used in Norway. Other expanders are Boa Compactor, Almex Contivar, Matador Food Processor, and others. The configuration and processing conditions vary to some extent between the expanders. In this paper, the Kahl expander is focused. In the Kahl expander the resistor in the outlet is a cone that is hydraulically regulated. By increasing the hydraulic pressure, the outlet gate closes allowing for input of more energy and thereby increased temperature. Stop bolts in

the expander body ensures kneading of the feed material and sufficient friction to prevent the feed material to rotate with the anger.

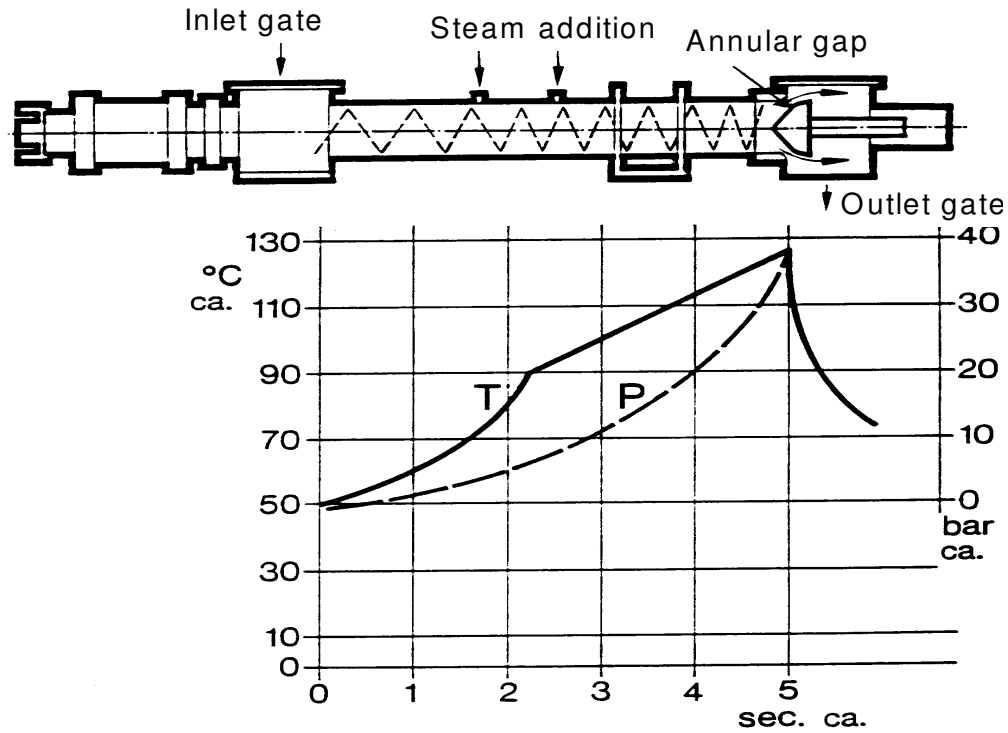


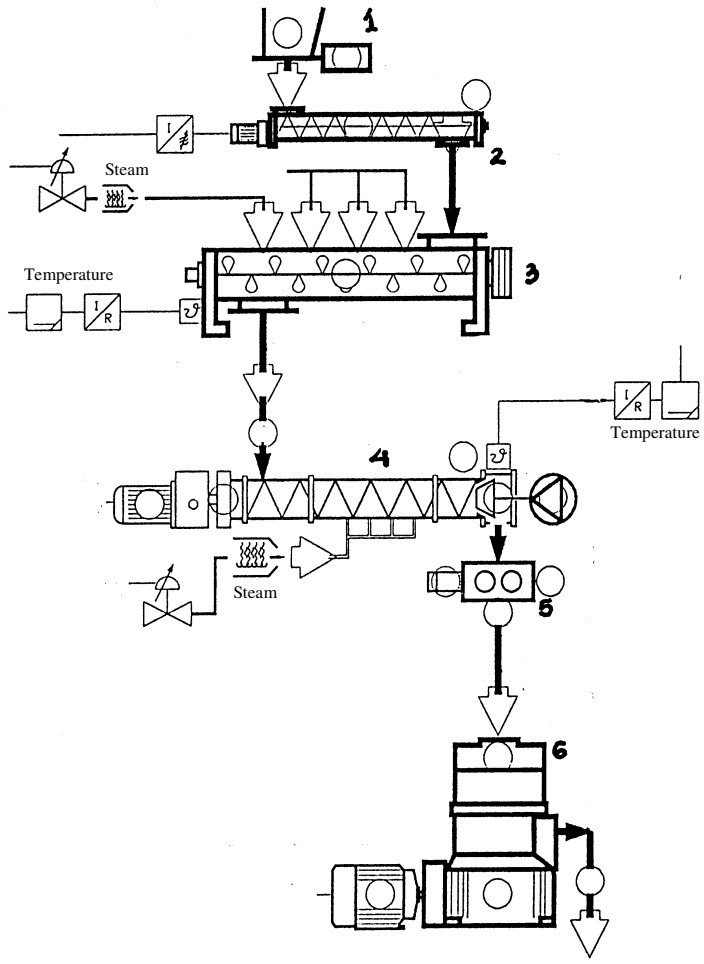
Figure 1. The annular gap expander. Pressure (P) and temperature (T) graphs demonstrate processing conditioning in the expander (Pipa and Frank, 1989).

When the feed passes through the expander, the temperature may rise to more than 150°. However, a typical range is between 90 and 130°C. Commercially, temperatures above 120 to 130°C is not easily achieved and is highly energy demanding, whereas on the other side, the temperature easily will rise above 100°C although 80 to 90°C would have been sufficient. The preferred content of water in the feed material during processing is 16 to 18%. The retention time of the fed material in the expander barrel is short, only a few seconds (2 to 10 seconds). The production capacity may vary between 2 and 70 tonnes per hour depending on the size of the machine. In Norway, most expanders are producing 10 to 20 tonnes per hour. However, both temperature and capacity (throughput) of the expander is highly dependent on the running of the machine, the feed formula and addition of lubricants as fat or water. Another aspect to consider is the influence of high shear on the machine itself. Friction gives mechanical wear and frequent maintenance is necessary to ensure optimal treatment condition. The front paddles in the anger and the cone is the most susceptible components. Wear in these components may result in backflow of feed material and problems with reaching capacity and temperature. Fat and water acts as lubricants and thereby reduces the wear of the machine.

The expander processing line

Compared to an extruder, the simplicity of the expander allows an effective treatment of relatively large quantity of feed at a low cost. In the Norwegian compound feed industry, the expander treatment is performed "in line" as an integrated part of the production process (Figure 2). Alternatively, the expander can be used "off line" to treat individual ingredients

such as barley. If so, the expander-treated barley will be considered as an individual ingredient and processed in an ordinary pellet line afterwards.



1. Prebin

2. Dosing unit

3. Mixer-conditioner (addition of steam)

4. Expander (addition of steam and input of electrical energy)

5. Crusher (structuring unit)

6. Pellet press

To cooler and dryer

Figure 2. The expander processing line.

Excluding grinding and other pre-treatments, the expander processing line starts with dosing an appropriate volume of material into the mixer-conditioner. In the mixer-conditioner, steam is added, increasing the temperature and moisture content of the feed material. Depending on the type of mixer-conditioner, the total retention time when the feed material is exposed to elevated temperatures may be altered here. The processing conditions in the expander are created by addition of thermal (steam) and (or) electrical energy, which is monitored as heat (°C). In the annular gap expander, the resistor in the outlet gate is a conical-shaped piston head, which is hydraulically regulated. The hydraulic pump pressure (bar) required keeping the piston head in position during processing is monitored as a treatment condition. After the feed material passes the outlet gate, it is transported by gravity to a crusher where the feed material is chopped into a uniform structure. Thereafter, the feed material is transported (by gravity or force-fed by a feed screw) to the pellet mill and formed into a pellet. Finally, the pellets are transported to a cooler where they are cooled and dried before storage.

Expander details

Figure 3 gives some details about the Kahl expander configuration. The top picture shows a cross section of the empty expander with the screw shaft, the nozzles for liquid addition, the stop bolts and the hydraulic cone. The mid picture illustrates the flow of feed material around the cone, whereas the bottom picture shows a cross section of a working expander.

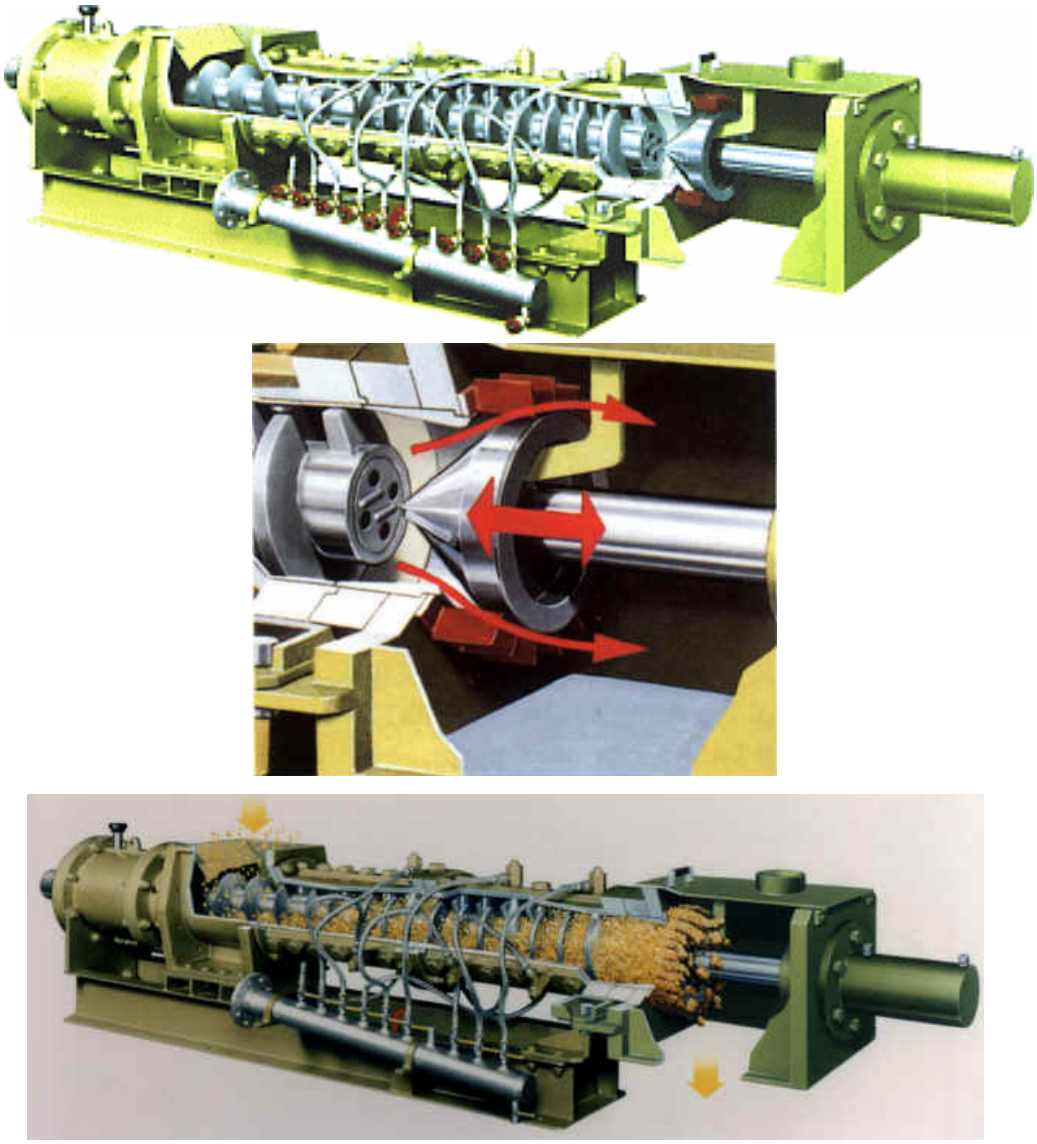


Figure 3. Pictures of the empty expander (top), details of the cone (mid) and the working expander (bot). Taken from A. Kahl GmbH's internet pages.

Expanders vs. Extruders

Although expanders are similar to extruders, they differ considerably in treatment effects and applications. Extruders consist of barrels with one or two screws, which transport the feed mash. The screw configuration can be varied by addition of reverse screw elements, pressure rings or air locks, in order to alter the amount of shearing action during transport. Water can

be used to adjust the moisture content to the required level before processing and may exceed 25-30%. The high water content during extrusion implies that the extruder processing lines requires a dryer, whereas a cooler usually is sufficient when expanding. Although friction may be sufficient to increase temperature during extrusion, the barrel wall can be additionally heated by steam or electrically. The combination of high temperature, pressure, moisture and shear, allows for a considerable expansion when the material leaves the barrel, changing the properties of the material and its digestive behaviour. Processing time in extruders varies from 10 to 150 s, while temperatures range from 80 to 200°C. Extrusion can be considered as a high shear treatment. The shear action during expander treatment is much less. The production capacity is usually lower, whereas the production cost usually is higher for an extruder than for an expander. Extrusion has received the dominating role in production of fish feed.

PROCESS CONTROL

Process control is achieved through fully integrated computer control and logging of critical parameters. A typical screen set up for the Kahl expander is shown in Figure 4.

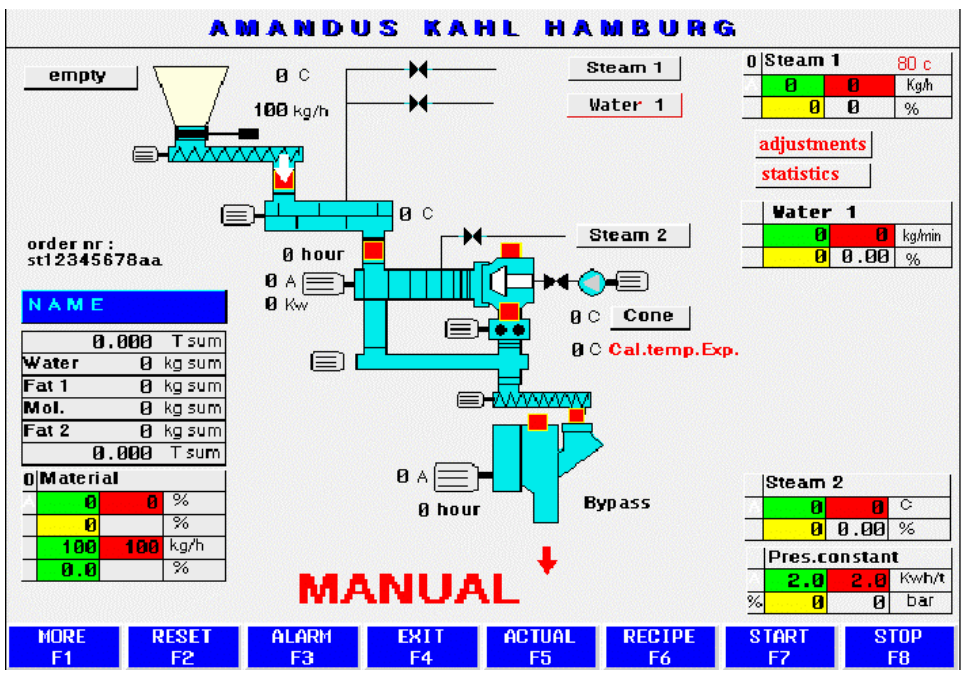


Figure 4. Screen set up for process control of the Kahl expander.

An integrated process control allows for an optimal function of the processing line. The functionality of important parameters is logged, and critical errors leads to automatic stop in the process, for example when the feed material runs out, or the crusher or the pellet press blocks. However, the main function of the process control is to be the operator's tool for achieving certain processing conditions. The main parameter in the expander processing line is usually temperature at the expander head outlet. The temperature is achieved through input of thermal energy as steam in the mixer-conditioner or the expander, or by friction caused by the input of mechanical energy. The temperature may be calculated using the equation $\mathbf{t = t_o + \Delta t_t + \Delta t_m}$, where the temperature t is determined as the sum of the starting temperature (t_o), the thermal temperature (t_t), and mechanical temperature (t_m). In the screen control this measure is marked as Cal. temp. Exp. The calculated temperature allows for a precise and fast

regulation of the process. This is of importance especially in the start-up of the process. The temperature sensor needs some time for adaptation to the processing conditions, resulting in feed losses and waste of energy. The relations between measured and calculated temperature compared to target temperature at start-up of a cold expander is shown in Figure 5.

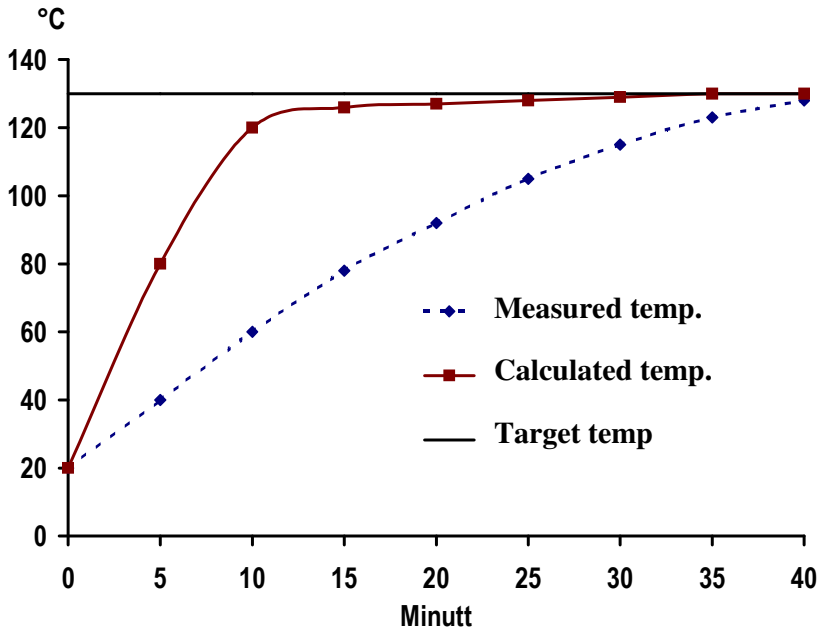


Figure 5. The relation between measured and calculated temperature at start-up of a cold expander. The process target temperature is 130ºC.

An aspect of steam addition and temperature increase in the mixer-conditioner, is increased moisture content of the feed. In general, 10 degrees increase in temperature corresponds to ca. 0.7% water added as steam. Thus, if the temperature in the mixer-conditioner increases with 50ºC form 20 to 70ºC, the water content increases with 3.5% (0.7 x 5). The temperature increase from mechanical friction energy is calculated from energy input (kWh), production rate (kg h^{-1}) and the specific heat capacity of the feed material. In most feedstuffs the specific heat capacity is 0.5. How that is done will not be commented on in this course.

EFFECTS OF EXPANDING ON NUTRIENTS

As mentioned in the introduction, ruminants and monogastrics may respond differently to influences of the expander treatment on various nutrients. Thus, correct expander treatment depends on the type of animal to be fed. The expander treatment affects the nutritive value of feedstuffs. The most extensively studied nutrients are protein and starch, and the main influence is coagulation of protein and gelatinisation of starch. Although protein and starch are the only nutrient mentioned in this presentation, fibre, fat and especially vitamins, may also be affected by the treatment.

Protein

The expander treatment does not affect the content of protein in the feed. Moreover, no major effects on amino acid content by the expander treatment have been observed (Prestløkken, 1999). In an initial stage, unfolding and denaturation of proteins at moderate heat treatment is known to increase the digestibility of protein, especially by inactivating anti-nutritional factors. At higher energy inputs, cross-links that are resistant to enzymatic hydrolysis might be

formed (Schwab, 1995; Voragen *et al.*, 1995). Formation of cross-links is favoured by increased temperature and retention time. In addition, moisture content, water-activity, pH and shear forces created during the physical treatment of the feed material are important (Voragen *et al.*, 1995). Thus, heat treatment may to a great extent alter properties of proteins. To outline in what extent these reactions take place in the expander process is complicated, but they are expected to affect digestibility of protein and amino acids. Excessive processing can reduce the protein value by making protein or amino acids indigestible in the small intestine. So far, the expander treatment does not appear to reduce digestibility of protein or amino acids. However, lysine, in particular, is susceptible to heat-treatments through its reaction with sugars and the formation of Maillard products. Thus, processing conditions that favour this reaction should be avoided. High temperature in combination with a high moisture content and prolonged retention time is probably most damaging. Such conditions rarely would be achieved in practice by expander treatment.

Starch

Starch is made up of the glucose polymers amylose and amylopectin. In cereals, the starch is stored in granules organised in a protein matrix. The expander treatment does not affect the content of starch *per se*, but the heat-treatment gelatinises the starch making it more accessible to enzymatic digestion (van Soest, 1994). However, although the expander treatment usually gelatinises starch to a high extent (Peisker, 1992a), restricted amounts of water in the process may limit gelatinisation. Moreover, heating and subsequent drying and cooling, may result in reassociation of starch and formation of starch that are resistant to enzymatic digestion (van Soest, 1994). In addition, the protein-starch matrix may also influence treatment effects. Thus, the effects of the expander treatment on starch vary depending on processing conditions.

The nutritive properties of starch vary considerably among the different cereals. Especially in oats, but also in barley and wheat, even native starch is easily digested. In contrast, maize and sorghum contains starch that is rather resistant to enzymatic digestion. Thus, the meaning and importance of starch gelatinisation differs depending on type of cereal to process. In countries where maize is an important feedstuff, expander treatment may be an efficient way to improve the nutritive value of starch both for ruminants and monogastrics, although gelatinisation of starch usually is considered negative for ruminants.

Other effects on nutrients

Heat treatments also affect other nutrients. In particular, some vitamins and most enzymes and feed anti-oxidants are heat sensitive. Today, most synthetic vitamins are relatively heat stable (also vitamin C, E and K) allowing for feed addition prior to the heat treatment. With respect to enzymes, they usually must be applied post-treatment, e.g by spraying on the pellets with liquid soluble enzyme. The expander treatment is also an efficient heat treatment from a hygienic point of view. Salmonella is efficiently killed by expanding at a minimum of 81ºC.

PROTEIN PROTECTION OF BARLEY AND OATS, THE NORWEGIAN STORY

Barley and oats are important as feed ingredients in Norway and constitute normally more than 70% of concentrate mixtures fed to ruminants. In high producing dairy cows the daily intake of barley and oats may exceed 8-10 kg. Therefore, the nutritive quality of barley and oats cannot be neglected. These cereals serve mainly as an energy component of the diet, with starch as an excellent nutrient for synthesis of microbial protein. In addition, although the protein content of cereals is low, due to the high inclusion in the diet, a significant amount of

the dietary feed protein is of barley and oats origin. Consequently, the protein value of barley and oats is of great interest.

In ruminants, the protein value of a feedstuff is determined by the amount of amino acids absorbed in the small intestine. Endogenous protein, microbial protein and dietary protein escaping rumen degradation (UDP) constitute these amino acids, with microbial protein as the main contributor (Clark *et al.*, 1992). The amount of microbial protein is inadequate to meet the requirements of high-yielding animals. Thus, it is common to supplement these diets with UDP (Satter, 1986). However, in Norway, UDP is expensive, resulting in increased feed costs. It is well documented that heat processing can increase the amount of UDP in proteinaceous feedstuffs (Kaufman and Lüpping, 1982; Satter, 1986; Broderick *et al.*, 1991; Schwab, 1995). In short, the Norwegian expander story is the use of the expander technology to increase the amount of UDP and thereby the protein value of cereals for ruminants.

On average, expander treatment at high treatment intensity (125-130°C) increases the protein value of barley and oats with 20 and 35%, respectively, which is considerable (Prestløkken 1999). An example showing how this increase in protein value of barley and oats has been used in composing feed compounds for ruminants is shown in Table 1.

Table 1. Examples in use of expander treated barley and oats for composing compounds.

	Traditional	Expanded A	Expanded B
Ingredients, %;			
Soybean meal	6,73	2,01	0,00
Corn gluten meal	2,61	0,77	0,00
Rapeseeds	1,81	3,54	1,18
Barley	45,00	45,00	60,00
Oats	25,84	30,00	25,00
Wheat bran	10,00	10,00	4,45
Molasses	4,00	4,00	5,20
Fat	1,00	1,00	1,00
Vitamins and minerals	3,01	3,68	3,17
Protein value, g/kg dry matter;			
Crude protein	164	133	118
Absorbed amino acids (AAT)	105	105	105
Protein balance in rumen (PBV)	0	- 32	- 48
Relative feed cost (1995)	100	94	89

The table clearly shows that it by use of expanded barley and oats is possible to compose compounds with the same protein value (seen in Table 1 as a constant AAT-value) to a considerable reduction in feed cost. However, simultaneously as the protein value is improved by increasing rumen undegraded protein, the rumen degradable protein decreases (seen in Table 1 by as a decrease in PBV). This may be of great importance for the rumen microbes. To avoid lack of nitrogen in the rumen, using compounds with expander treated barley and oats implies supplementation with degradable protein, preferably from silage. Using grass silage as the example, the protein content should be increased with 2-3% units (DM basis) when using expander-treated instead of ordinary barley and oats. The requirement for rumen degraded protein may also be met by the addition of urea, but urea does not contain branch-chained carbon skeletons or sulphur, which both are important for microbial protein synthesis.

Protein value of expander treated barley and oats

As mentioned, the protein value of feedstuffs for ruminants is determined by the amount of amino acids from rumen undegraded protein (RUP) and rumen microbial protein that is absorbed in the small intestine. The amount of RUP may be increased by reducing the soluble protein fraction (A), increasing the degradable protein fraction (B) or by reducing the rate of degradation (C) of the degradable protein fraction. The expander treatment mainly affects the RUP by reducing the soluble fraction and by reducing the rate of degradation of the degradable fraction. This can be read from Figure 6 showing typical degradation curves for untreated and expander treated barley. Expanding reduced the soluble fraction from 30 to 20%, whereas the rate of degradation was reduced from 8 to 4 % per hour. The total degradation was unaffected giving a reduction in protein degradability from 65 to 50%. This corresponds to an increase in protein value from ca. 100 to 120 g amino acids absorbed (AAT) per kg dry matter (and a reduction in protein balance (PBV) from –20 to – 45 g per kg dry matter). Although only barley is shown in the example, expander treatment affects rumen degradation in oats, soybean meal and rapeseed meal and some other feedstuffs as well.

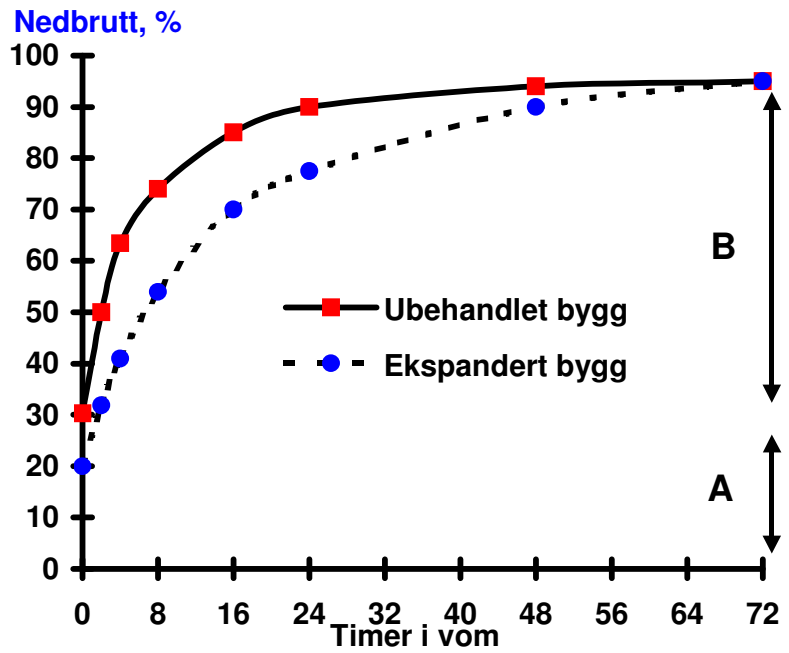


Figure 6. Rumen degradation curves of untreated and expander treated barley. Degraded (Nedbrutt) at 0 to 72 hours in the rumen (Timer i vom).

The mechanisms for protection of protein vary, and is for expander treatment not well known. Heat treatments coagulate proteins, which probably reduces rumen solubility. In addition, protein and starch are organised in a matrix that may physically protects each other. Another possibility is reactions within and between proteins, or between proteins and sugars, e.g. as in the Maillard reaction. With respect to Maillard reactions, lysine is particularly susceptible. Extended heat treatments may reduce digestibility of susceptible amino acids or proteins.

The intention of feed processing for decreasing ruminal degradation of protein is to increase the amount of protein that can be digested in the small intestine. So far, no indications for that the expander treatment reduces digestibility of protein or amino acid has been found. Usually, moderate treatment in fact may have a positive effect on protein digestibility. But at some

stage, excessive heat treatment decreases digestibility of protein. Thus, treatments should be performed in a way that does not impair digestibility. Figure 7, modified after Satter (1986), expresses the balance between ruminal degradation and intestinal digestibility that gives the optimal window of rumen escape of intestinal digestible protein. As indicated in Figure 7, the amount of protein digested in the small intestine paradoxical may increase although total digestibility of feed protein is reduced, whereas reduced digestibility of protein always is negative fore monogastric animals.

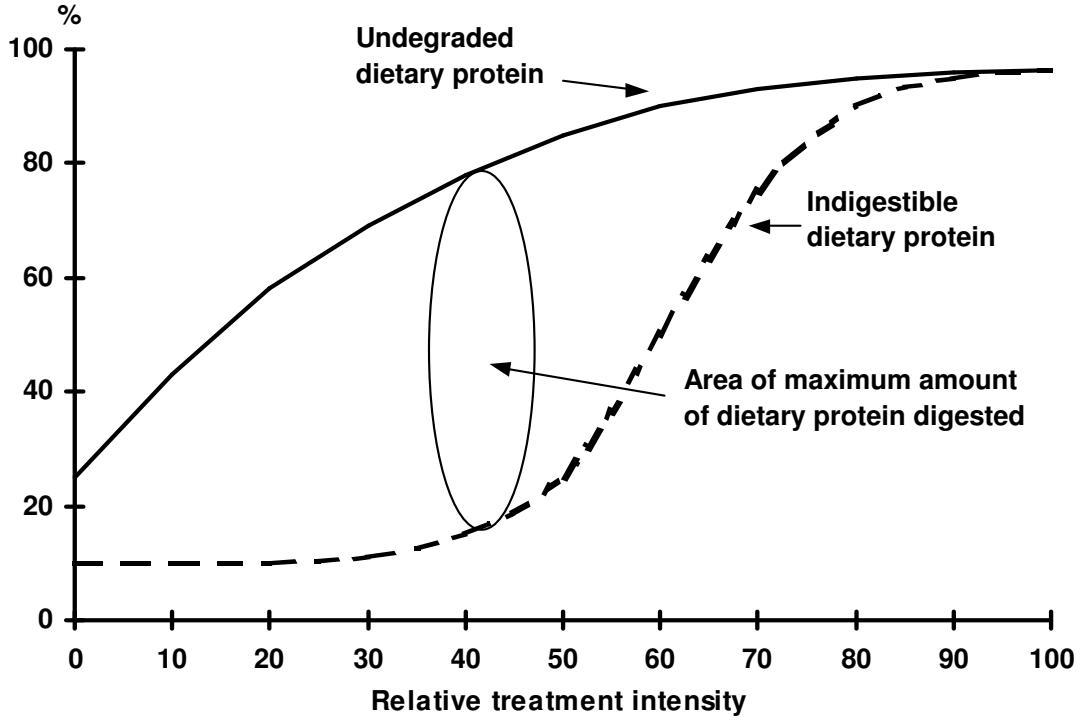


Figure 7. Effect of increasing treatment intensity and maximum amount of dietary protein digested in ruminants (modified from Satter, (1986))

Heat treatments in order to increase RUP in cereals usually results in gelatinisation of starch, which also is the case in expander treatment although degree of gelatinisation vary with processing conditions (usually increased gelatinisation with increased treatment intensity). Gelatinisation makes the starch more accessible to microbial digestion in the rumen, which may impair rumen environment and consequently utilisation of the feed ration. The effort is therefore how to protect protein without gelatinising the starch. These contradicting effects are not easily achieved. For monogastrics, gelatinisation of starch is usually beneficial for fish, fur animals and to some extent swine, whereas poultry usually digest unprocessed starch well.

Variation in expander effects

On average, expander treatment increased the protein value of barley and oats with ca. 20 and 35%, respectively (Prestløkken 1999). Expander treatment, as most other biological processes, does not, however, give a constant response. Prestløkken (1999) found a standard deviation of protein degradability of 5 and 8 units in barley and oats respectively. Moreover, the treatment effect starts at temperatures considerably lower than 130ºC. The general picture of treatment effects and variation in these effects is shown in Figure 8. Notice that the response to increased treatment intensity and the variation in treatment effect is bigger for oats than for barley, indicating that optimal treatment of barley and oats differ.

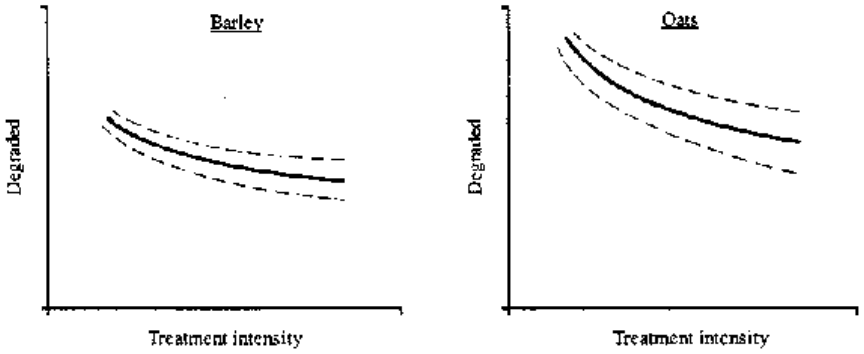


Figure 8. Relation between treatment response and variation in treatment response in expander treated barley and oats (from Prestløkken, 1999).

CONCLUSIONS

The expander treatment allows a relatively large amount of feed to be processed at a high temperature to a relatively low cost. Several applications exist, and the expander has received a widely acceptance in a few years. The expander process affects nutritive as well as technical properties of the feed. Some of these aspects have been discussed. In Norway, the expander treatment is extensively used to improve the protein value of barley and oats for ruminants.

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