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Interactions between size reduction and thermal processes during treatment of animal by-products

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Abstract. Animal by-products from slaughterhouses often go through a process known as rendering to economically recover protein sources. Common raw material treatment technologies are: pre-handling; reduction of the size of raw material particles; thermal treatment with pressure or sub-pressure impact; natural or artificial chemical treatment; fractionation (percolating, straining, centrifuging with or without thermal treatment, etc.) and handling of material fractions (dehydrating; defatting; demineralisation, etc.).
Thermal treatment is a long-term process that lasts up to 90 minutes – and is the primary disadvantage of known solutions because hot processing influences the natural properties of proteins contained in the raw materials rendering them less valuable.
Size-reduction is the most power-intensive phase rendering technologies when reproducible grinding conditions, short grinding times, precise results, and loss-free operation are required. The size reduction ratio of the material influences the effectiveness of the following treatment stages (thermal impact and others) and quantitatively affects the extraction intensity of components from the pre-treated material.
To maximise the efficiency of heat treatment and fractionation operations on by-products for food, feeding, or technical purposes it is necessary to optimally design the technological equipment to fit within the specific requirements of the particular cooking and rendering application.
The knowledge gained from this project will be used by designers and equipment producers of cooking, frying, and other heat treatment systems for food, feed and technical purposes.
This information will enable more accurate determination of heating times corresponding to the processed material properties and batch loads.

Key words: animal by-products, meat-bone raw material, rendering, crushing ratio and fineness, heat treatment, heat transfer coefficients.

INTRODUCTION

Processing technologies used in meat, fish and other food industries (Ockerman & Hansen, 2000; Toldra, 2010) consist of four main stages: preparation of raw materials (crushing, milling); hot processing of raw materials; fractionation (protein, fat and solid particles); and processing of components (protein extraction, fat purification, meal drying and grinding of solid fractions). Of these stages, preliminary processing is relatively short; for hot processing, both dry and wet processing methods are used, wherein processing takes place under atmospheric pressure or overpressure conditions at temperatures between 90–150 °C.

Size reduction process. In different schemes of material reprocessing, the main technological steps, beside the pre-treatment, drying, fractionation, and thermal treatment, are crushing, milling, or a combination of both.

Size reduction is usually applied because it is often a prerequisite to carry out basic physical, thermo-physical, and chemical processes in downstream technological stages, Sannik & Pappel, 2004.

Common applications of size reduction are: preparation of the raw material for the next handling steps; dividing and/or separation of fractions; intensifying chemical, thermal and other treatment processes, Couper et al 2012.

Depending on materials needed to handle, several types of equipment can be used, for instance: equipment using reciprocating crushing tools (jaw crushers); equipment using rotary crushing tools (cone crushers), equipment using rollers (e.g. shaft-crushers); equipment using discs-rotors (disc-mills, disintegrators, dismembrators), equipment using rotary beaters (hammer-mills), equipment disintegrating by tumbling (ball mills) etc.

Size reduction operations are performed in stages. The equipment involved, often crushers or grinding mills, provides different relationships between feed and discharge sizes. This makes it possible to introduce different types of size reduction methods: primary and coarse crushing, medium crushing, small and fine grinding, Sannik & Erg, 1990.

Thermal treatment process. Extended thermal treatment times (30…120 minutes) may cause a decline in the protein score when reprocessing materials of animal origin, (Boles, 2010). In addition, excessive energy-consumption often necessitates optimising these processes.

Process optimisation should continue to enhance the quality of the protein and reduce the overall energy utilisation in both traditional and novel systems, Awuah et al 2007. The need for efficient unit operation processes will continue to drive the development of system automation, control, and monitoring systems that implement complex mathematical models in real time.

Different methods of material size reduction – using coarse, medium, small, and fine types of crushing as well as heat treatment processes for each type of crushed material are provided in the present study. For all types of crushing the crushing ratio reached 2…4 and the fineness of product (% passing the sieve) after milling 10…0.01 mm.

We also present the interactions between size reduction and thermal processes during treatment of animal by-products containing 50% meat and 50% bone.

MATERIALS AND METHODS

The materials in each experiment reduced in size and thermally treated were selected from high-on-the-hog cut skeleton parts (*thoracic* and *lumbar vertebrae*) – 50% back bone parts and 50% meat tissues.

Particle size reduction. This study utilised several types of cutting, crushing, and milling equipment for meat-bone raw material handling including band saw, breaker with rotating shaft, and impactors with vertical and horizontal-mounted rotors.

The primary size reduction process – coarse crushing – was handled using band saw type KT-360 produced by Koneteollisuus OY. The material particles after coarse cutting mostly ranged between 7…150 mm.

Medium crushing of primary processed raw material (containing 50/50 meat and bones) was handled on Cutting mill SM100 produced by Retsch GmbH. This equipment has a spinning shaft with knives (breakers) attached to the shaft. The rotating shaft impacts the material, sending it against knife-plates mounted on the inside of the exterior walls. The material continues to impact until it passes a screening plate, thus ensuring the required particle size is achieved.

The equipment was used without a screening plate in the crushing stage, to obtain a particle size distribution that corresponds to medium crushing, i.e. the particles with sizes 3…35 mm.

For materials with sizes between 0.6…10 mm after small crushing a briquette from meat recovery system type MRS-20 (produced by Stork-Protecon) was used.

In parallel, small crushing tests were made on Cutting mill SM100 using a screen-plate with 10 mm holes.

The fine grinding of pre-ground material was provided by an Ultra Centrifugal Mill ZM 200. The material in this disc-mill type equipment is violently hurled about between the grinding bodies and broken up into a more or less desired state of fineness. The material continues to impact until the desired particle size is achieved where upon it will fall between the space between the rotating shafts and the knife-rotors. The average size of the finished product was adjusted to be 1.5 mm.

Granulometry-analysis by sieving meat-bone material after milling was applied with a Retch A5200 (the nine-level sieve set) to quantify the percentage of particles that passed the sieves.

Optimising the thermal treatment processes. Typical thermal treatment is relatively long (between 30…120 minutes) and reduces the protein score when reprocessing materials of animal origin, at the same time heat treatment must ensure that the heat fully penetrates the meat-bone material.

Therefore, predicting the time for heating processes is an important part of the optimisation process.

The time required to warm up materials in various media can be described using three dimensionless numbers: the Fourier number, the Biot number, and dimensionless temperature, Dincer, 1993; Becker & Fricke, 2004; Rizvi et al 2006; Marcotte et al 2008.

Fourier number, (F_o) describes the ratio of the heat conduction rate to the rate of thermal energy storage, and together with the Biot number can describe transient conductive heating:

$$F_o = at/r^2$$

a is a thermal diffusivity ($m^2\,s^{-1}$); t is a heating time (s); r is a characteristic dimension of food item (m) (for instance – radius of the sphere (meat or bone particle)).

The Biot number (B_i) is the ratio of external heat transfer resistance to internal heat transfer resistance:

$$Bi = \lambda r/\alpha$$

λ is a heat transfer coefficient (W $m^{-2}K^{-1}$); α is a thermal conductivity (W $K^{-1}m^{-1}$).

Material properties considered in present heat transfer simulation are as follows (Sman van der, 2003; Calderon, 2004; Marcotteet al 2008; El-Brawany et al 2009; Trujillo et al 2010):

	a (m^2s^{-1})	α (W $K^{-1}m^{-1)}$
meat	1.64 10^{-7}	0.49
bone	1.47 10^{-7}	0.25

The heat transfer coefficient has only a minor role under particle size < 50 mm, Eszes et al 2009.

The dimensionless temperature (fractional unaccomplished temperature difference Δ), is defined as follows:

$$\Delta = (T - T_i) / (T_m - T_i)$$

T_m is a temperature of the medium (°C); T is a temperature of the warmed-up material (°C); T_i is a material initial temperature (°C).

Simplified equation for Δ (Fricke & Becker, 2002) is:

$$\Delta = \exp(-\mu^2 F_0) 2B_i \sin\mu / (\mu - \sin\mu\cos\mu)$$

μ is a coefficient from equation $\mu \tan \mu = B_i$

In practice, the material is considered heated when T_m and T differ by 5%; i.e. Δ = 0.95; hence, the Fourier number, μ, the Biot number, as well as optimal heating times ($t(r) = r^2F_o(r)/a$) for various crushing types of meat-bone material can be determined.

RESULTS AND DISCUSSION

Size reduction using multi-stages disintegration.

The crushing stages are guided by feed size limitations and the end product quality.

The variation in particle size, expressed as % passing, is equally as important as the actual granulometry, but is dependent on the requirements of the downstream unit operations.

Size reduction operations were performed in 4 stages in the present study. The equipment involved – cutting, crushing and milling – has a different relation between feed and discharge sizes, and this is termed the reduction ratio (Table 1).

The size reduction ratio of material affects the effectiveness of the following treatment stages (thermal impact and others) and it quantitatively affects the extraction intensity of components from the material pre-treated.

Table 1. Average reduction ratios using different disintegrating methods

Disintegrating method	Average particle size before disintegrating, mm	Average particle size after disintegrating, mm	Limits of particle sizes, mm	Reduction ratios
Coarse crushing	150	49	75…1	3.06
Medium crushing	49	16	40…0.5	3.06
Small crushing	16	3.49	15…0.16	4.55
Fine crushing	3.49	1.43	6…0.05	2.44

The average size of meat-bone particles after coarse crushing was 49 mm and about 50% of the particles were below this size. According to the data obtained using sieve analyses, 10% of the particles were below 7 mm and 10% were above 150 mm after the first particle reduction stage.

The average size of meat-bone material-particles after medium crushing was 16 mm, and 10% of the particles were below 3 mm, and 10% were above 35 mm; the average size of particles after small crushing was 3.5 mm and 10% of the particles were below 0.6 mm and 10% were above 10 mm. The average size of meat-bone particles after fine crushing was 1.5 mm and about 50% of the particles were below this size. According to the sieve analyses 10% of the particles were below 0.25 mm and 10% were above 4 mm. The size distribution is presented in Fig. 1.

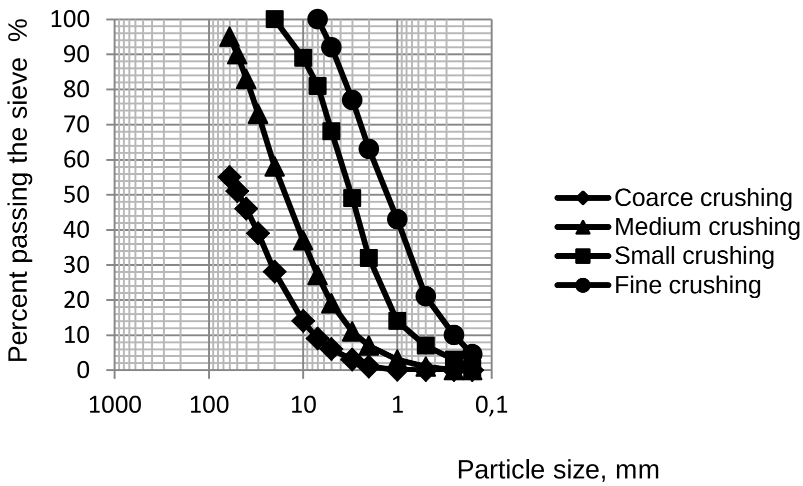

Figure 1. Diagram of sieve-analyses.

Determination the thermal treatment time for material particles

Characteristic sizes (d) of material particles 40; 16; 10; 6; 3; 2; 1; 0.5; 0.2; and 0.1 mm are taken into consideration in present calculations.

The Fourier and Biot numbers, as well as heating times ($t(d)$ = d2$F_o(d)/a$) are determined for various crushing types of meat-bone material based on the sizes provided in Table 2.

Tabel 2. Heat transfer coefficients and heat penetration times in meat-bone particles

d, mm	40	16	10	6	3	2	1	0.5	0.2	0.1
F_o, meat	1.42	1.58	1.77	2.1	2.73	3.21	4.2	718	31.13	61.08
B_i, meat	44.76	17.9	11.19	6.71	3.38	2.24	1.12	0.56	0.22	0.11
t, meat(s)	3349	571	238	95	29	15	6.4	2.7	1.7	0.5
F_o, bone	1.37	1.46	1.56	1.73	2.1	2.43	4.2	7.18	28.24	31.13
B_i, bone	24.68	9.87	6.17	3.7	1.85	1.23	0.62	0.31	0.12	0.06
t, bone(s)	3,865	688	300	129	42	22	7.14	3.05	2.12	1.04

A plot of the heat penetration time in meat-bone material particles is provided in Fig. 2.

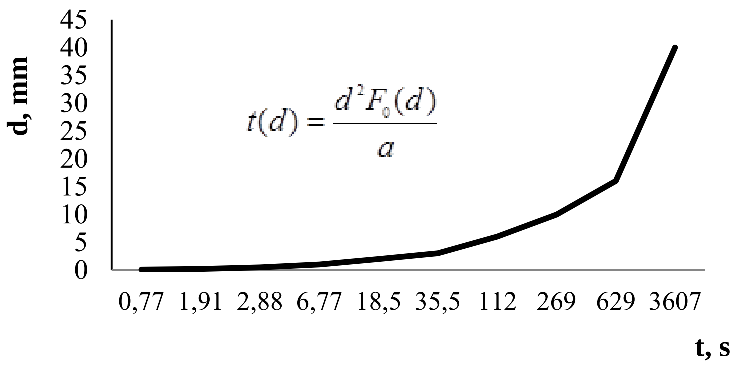

Figure 2. Heat penetration time as a function of meat-bone particles size.

The possibility to determine the heat penetration time depending on the size of meat-bone particle sizes allows one to optimise the heat treatment time of by-products of animal origin.

Heat treatment must ensure that the heat fully penetrates the meat-bone material, and the required time depends on the crushing type: for fine grinded material 15…20 seconds, small grinded material 0.5…2 minutes, medium grinded 5…10 minutes and coarse grinded material up to one hour.

The proper size-reduction equipment and technology should be chosen. It is required to use the multi-stages disintegrating technology for various types of animal by-products. In principal the new type of size reduction equipment can be designed using rotating two-shaft breakers that consists of numerous longitudinal bars fixed to a rotating shaft. This crusher is similar to the hammer-mill crusher, but the breaker bars are not allowed to pivot at the shaft.

Effectively short pre-treatment time of animal by-products ensure the optimum amount of drive power is combined with a high throughput performance.

It is important when selecting type of equipment, it should be verified by testing, as to capacity, the power and crusher speed as these can be varied, thus creating different characteristics from initial feed and end material sizes.

CONCLUSION

Pre-treatment processes such as particle size reduction can critically influence the effectiveness of downstream unit operations. Size-reduction is the most power-intensive phase of various technologies, whenever reproducible grinding conditions, short grinding times, precise results and loss-free operation are required.

The variation in particle size expressed as % passing is equally as important as actual granulometry, but again dependent upon requirements of the following treatment.

Size reduction ratio of material affects to the effectiveness of following treatment stages (thermal impact and others) and it quantitatively affects to the extraction intensity of components from the material pre-treated.

Factors such as throughput and available processing technology, whilst minimising operating costs, can have an impact on processing. Perhaps the most important criteria in selecting equipment to process raw materials of animal origin are matching the best technology with the feedstock to produce the desired end product. The machines should be economical, reliable, easy for cleaning and have a long service life.

However, advances in technology provide opportunities to maximise the potential of valuable resources. The protein score of valuable resources of animal origin can be increased by reducing thermal treatment time.

Crushing and milling are the most power-intensive phase of various technologies, when reproducible grinding conditions, short grinding times, precise results, and loss-free operation are required. Optimal equipment and technology is that which achieves the required crushing type with other cost factors minimised.

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