APPLICABILITY OF CHEMICAL ENGINEERING MODELS IN THE ESTIMATION OF MEAT GRINDING ENERGY

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SUMMARY

A torque/speed sensor mounted on a domestic grinder equiped with a speed variator was used to evaluate the amount of energy necessary to grind a mass m of meat. The results were fitted into the equations of Kick, Von Rittinger and Bond, to check their applicability in meat grinding. It was found that none of these models could satisfactory predict the amount of energy necessary to grind the meat, although Kick's equation seemed to provide the best results. A new equation was developed, taking into account an index K_w derived from a Warner-Bratzler (W-B) shear experiment. K_w was defined as the ratio between the shear energy and the total energy evaluated during a W-B test.This equation seemed to work better than the others in the range of study.

Introduction

Grinding is a widely used operation in meat industry. It consists schematically in forcing with an archimedian screw in a barrel, pieces of meat through a perforated plate (die plate). It is a size reduction operation. There are at least two reasons to undergo this operation, firstly to enhance the textural quality of the thougher pieces of the carcass by mechanical action on muscle fibres and connective tissue sheath, and secondly to obtain raw material for the formulation of new products (ground steaks, delicatessen_).

Grinding in meat field is similar in certain points to crushing or grinding in ore and cereal industries where energy consumption models have been developed since the end of last century. Among these models, the most popular are those of Von Rittinger, Kick and Bond which are described in most chemical engineering textbooks (Mc Cabe and Smith, 1976; Loncin and Merson, 1979; Geankoplis, 1983).

Galanty (1963), Austin and Klimpel (1964) made a critical analysis of the models mentioned above, pointing out that the equations did not account for the utilization of the energy, knowing that less than 2% of the grinding energy effectively create new surfaces. Energy losses can occure by joule effect and friction in the motor, friction between particles, friction between particles and elements of the grinder, plastic and elastic deformations of the particles without rupture and transport of the particles inside the grinder (potential and cinetic energy).

When meat grinding is concerned, almost nothing is found in the literature about the topic. No equation has been described to predict meat grinding energy. The aim of this work is to check the applicability of Rittinger, Kick and Bond's empirical models in the prediction of meat grinding energy, and to propose new equations.

Materials and methods

Meat samples

Semitendinosus muscles from old Pie Noire Breed cows were used. The vacuum packed meat were kept at -18°C . Part of the samples was cut into cubes of 10 or 20 mm side (for grinding)or cored into cylinders of 25 mm in diameter and 20 mm in length (for Warner-Bratzler shear), and thawed at 10°C before testing, while the other part was sliced, thawed at 10°C, heat treated with a variable power microwave oven (SFAMO, France) to reach heart temperatures of 42, 62 or 73°C, before cutting into cubes and cylinders for testing.

Grinding test

The equipment used to perform this test was previously described by Kenmegne Kamdem and Hardy (1994a,b).

It consists in a screw grinder (Moulinex, France) connected to a 440W -AC- motor through a torque/speed sensor (Vibrometer, Switzerland). A speed variator mounted on the motor was used to adjust the screw speed to the desired value.

The hopper was filled with 100g of meat cut into cubes of side D_1. The grinder plate was chosen to produce ground meat cores of diameter D_2. When the motor was set on, the torque and speed profiles were recorded during grinding .

Specific grinding energy E (J/g) is given by the relation
where M is the mass of the meat in g, t_0 and t_f the initial and final grinding times in s, T the instantaneous torque in Nm, V the screw speed in r.p.m and C=0.1047 a factor depending on the units.

Assuming that V is constant and equal to mean speed Vm, equation (1) becomes

The term is estimated graphically from the torque profile.

Warner-Bratzler shear test

Cylindrical samples of 25 mm in diameter and 20 mm in length stamped out from meat portions with a corer, were used in a Warner-Bratzler shear device mounted on a universal testing machine (INSTRON model 1122). An example of the force profile recorded during the test is shown on figure 1 where the texture index K_w is defined.

Description of the models

Walker et al. (1937) had found an empirical equation relating the specific energy E to the characteristic size D of the particles
where K and a are constants.

Von Rittinger's law (1867)

Taking a=2 and integrating equation (3) between the initial size D_1 and the final size D_2, leads to Rittinger's law
(4)
where K_r is a constant. It is assumed for this relation that the entire energy is converted into new surfaces.

Kick's equation (1885)

By integrating equation (3) between D_1 and D_2 for a=1, Kick's equation is obtained
(5)
where K_k is a constant. The relation assumes that energy consumption during size reduction is principally due to deformation.

Bond's equation (1952)

For a=1,5, the integration of Walker's relation leads to Bond's equation
(6)
where D_1 and D_2 are initial and final particles sizes in μm, and Wi a constant called "work index".

New equations

For a given muscle i.e for a given texture index K_w, the relation below was used
(7)
This equation was obtained by changing Kick's relation in a way that the logarithmic term tends to zero when D_2 becomes very large (D_2>>D_1). A second constant B_1 was added to take into account the effect of the screw speed. But B_1 will be considered constant on a small speed range.

When the mechanical properties of the meat vary, for example by submitting the samples to a heat treatment, the texture index K_w has been introduced in equation (7) as a new variable, leading to
(8)
C also varies with the screw speed, but can be considered constant on a small range.

Results and discussion

Table 1 gives the values of Rittinger, Kick and Bond's equations constants in the conditions of the study, and also the values of the texture index K_w. Looking at the 6th, 7th and 9th columns of table 1, it is found that K_r, K_k and W_i vary with the initial size D_1 and final size D_2 of the meat, although K_k seems to be more constant than the others. Nevertheless, by pure hypothesis, it is assumed that K_r, K_k and W_i are constant for a type of grinder and for a given meat sample. Therefore, the characteristic constants can be calculated for the different equations. The mean constants for Rittinger, Kick and Bond's equations are respectively K_r=0.0692 with a coefficient of variation C.V.=47.7%, K_k=17.8 with C.V.=19.6% and W_i=146.9 with C.V.=31.4%. Using these values in the right equations, grinding energy can be predicted. Figure 1 shows the correlation between predicted E and experimental E for a) Rittinger's law, b) Kick's equation and c) Bond's relation. The correlation coefficients are r=0.88 ($p<0.0005$) for a), r=0.90 ($p<0.0005$) for b) and r=0.90 ($p<0.0005$) for c). Although the correlation coefficients are similar, Kick's model seems to match much better to the experimental data than the two others. In fact the slope of the regression line is closer to 1 with this model than with the two others (figure 1).

When equations (7) and (8) are used, the relations between predicted E and experimental E are respectively shown on figure 2 a) and b). The constants for equation (7) are A_1=17.7 and B_1=-2.3. For equation A_2=25.8, B_2=119 and C=-63.4. The coefficients of correlations are r=0.90 ($p<0.0005$) when equation (7) is used and r=0.93 ($p<0.0005$) when equation (8) is used as indicated on figure 2. It is important to recall that in contrast with the other models, equation (8) can predict the grinding energies of all the samples (heated and raw). One can notice that by eliminating the arrowed point on figure 2b, equation (8) will predict the energies with more accuracy, the equation of the regression line becoming y=-0.015+1.05x with r=0.95.

Conclusion

From the present study, it comes out that Kick's model is more apt to predict meat grinding energy than the equations of Rittinger and Bond. This model can be used for a defined sample or for samples which are mechanically very similar. Equation (8) applies even when the textural properties of the meat samples are different. But it is important to keep in mind that all these equations are only applicable in the conditions of the study and this situation constitutes a real problem for empirical models while considering the extrapolation to larger equipment. Then, it will be worthy to look to another approach of the problem.

References

Austin, L.G. and Klimpel, R.R., (1964). The theory of grinding operations. Ind. Eng. Chem., 56:18-29.

Galanty, H.E., (1963). The size reduction paradox. Ind. Eng. Chem., 55:46-52.

Geankoplis, C.J., (1983). Transport processes and unit operations. Allyn and Bacon, Inc., Newton.

Kenmegne Kamdem, A.T. and Hardy, J., (1994a). Grinding as a method of meat texture evaluation . Meat Sci. (in press).

Kenmegne Kamdem, A.T. and Hardy, J., (1994b). Influence of various conditions on meat grinding characteristics. J. Food Eng. (in press).

Loncin, L. and Merson, R.L., (1979). Food engineering. Academic Press, Inc. London.

Mc Cabe, W.L. and Smith, J.C., (1976). Unit operations of chemical engineering. 3rd ed. Mc Graw -Hill, New York.

Walker, W.H., Lewis, W.K., Mc Adams, W.H. and Gilliland, E.R., (1937). Principles of chemical engineering. 3rd ed. Mc Graw -Hill, New York.