論文 Utilisation of Poultry Waste Feathers* -1. Industrial Phase**

by Yasuhiro TODA¹ and Michio NONAKA²

The demand of poultry meats, especially broiler, should be increased toward 21st century as one of the most promising protein resources. The production of broiler is accompanied with large amounts of waste feathers. We have focused attention on the extraction of proteins from waste feathers and a simple extraction process has been developed. The extracted protein liquid indicates a strong foamability, which should be useful as a raw light material to be mixed with a solid raw material to produce a low density material. The foaming characteristics have been experimentally evaluated and ferric sulphate has been confirmed to reinforce and stabilise generated protein foams. The optimal additions of ferric sulphate and the protein liquid have also been decided by observing the drainage rate of liquid from generated foam films. To demonstrate the capability of protein foams to produce low density materials bubble cement and bubble mortar have been evaluated in terms of the mouldability, bubble dispersibility and compressive strength. The mouldability and the homogeneous dispersion of bubbles in a moulded material have been guaranteed even when the bubble volume fraction exceeds 0.5. We regard this demonstration as a convincing evidence of the capability of protein foams as a light raw material to be mixed with a solid raw material in producing a low density material with high performances in heat, sound and water protection.

KEY WORDS : Poultry, Waste Feathers, Protein Extraction, Protein Foam, Foam Stability, Light Material

1. Introduction

The demand of poultry meats should be much increased toward 21st century as one of the most important protein resources to overcome the future food crisis. Especially, broiler is regularly produced under the well controlled conditions with the growth cycle of about 60 days. The production cycle in a poultry slaughterhouse is expected to be shortened by improving the current breeding environments. However, broiler meat is produced along with large amounts of feathers to be wasted. Some parts of waste feathers have been recycled to poultry slaughterhouses as feather meals¹⁾, which could be recognised as a protein source in the feed to the poultry. However, the feather meal is not sufficiently digestible and hence, it can not contribute to improve one of the breeding conditions in poultry slaughterhouses. Another parts of waste feathers have been incinerated as an industrial waste. However, the odour emission is inevitable during incineration, which causes a new environmental problem for inhabitants in the vicinity of the incineration plant. A bio-conversion process for poultry feathers has recently been proposed²⁾. However, it is not realistic for the industrial application taking into account the slow conversion rate in any bio-process, i. e.

the throughput of the treatment process must be too low to deal with large amounts of waste feathers.

In 1996 about 1.6 million tons of broiler were produced in Japan, which corresponds to about 600 million birds³⁾. About 30 g of dry feathers are wasted to produce broiler meat from one bird. Hence, about 50 tons of waste feathers are daily discharged from poultry slaughterhouses in Japan. Taking into account the huge volume of waste feathers we have to develop an integrated management system as soon as possible supported by an efficient treatment process for waste feathers. About 0.5 million tons of broiler were also imported into Japan in 1996 from China, Thailand, USA, Brazil, etc⁴⁾. Moreover, south-eastern Asian countries are still keen on the broiler production without any sophisticated thought on the waste treatment. We have to focus attention on the waste treatment of poultry feathers from a global point of view. The treatment of waste feathers should be recognised as one of the most substantial global environmental issues hidden behind the promising phase of the food production.

Waste feathers are regarded as one of protein resources similar to horns and hooves of deer, cow, etc. It is known that an aqueous solution of protein has strong foamability. A sort of fire extinguishers utilises foams generated from an aqueous solution of proteins extracted from horns and hooves. However, uncomfortable smell is used to be spread out from an extraction plant of horns and hooves. Moreover, it is generally difficult to keep enough availability of these raw materials. On the other hand waste feathers discharged from poultry slaughterhouses are one of the by-products in food processing and hence, waste feathers are also hygienically supervised

* Received November 13, 1997; accepted for publication April 16, 1998

** A part of this work has been presented at The Spring Meeting of MMIJ in 1997

1. Managing Director, R & D Centre, Shizuoka Plant Service Co., Ltd.

2. Membership of MMIJ, Lecturer, Dr. Eng., Field of Geosystem Engineering, Division of Engineering, Graduate School, The University of Tokyo, Bunkyo-ku, Tokyo 113-8656

[For correspondence] FAX 03-3818-7492 (Tokyo Univ.)

same as broiler meat, which means any hazardous matter or contaminant must not be detected in the protein extraction process, i. e. no environmental problem is expected to come up in the vicinity of the treatment plant.

In this first report we focus attention on the industrial utilisation of protein extracted from waste feathers. The extraction process of protein from waste feathers is explained in the second section. The foaming characteristics are experimentally evaluated and the optimal foaming conditions are discussed in the third section. The production of light materials is carried out using generated protein foams and the physical characteristics are evaluated in the fourth section. Finally, the concluding remarks are summarised. In the second report another phase of the utilisation of the protein liquid extracted from waste feathers, as an organic compost and a soil modifying agent, will be discussed from a view-point of the global environmental protection.

2. Protein Extraction Process

Waste feathers discharged from poultry slaughterhouses are recognised as a bio-resource with a high protein content, i. e. above 750 g (crude-protein)/kg (dry-feathers). A combined enzyme-alkaline technology was recently proposed for processing waste feathers⁵⁾, by which the feather protein concentrate of a greyish powder with a mass of 19.3 kg was produced from 40 kg of raw waste feathers. Taking into account the water content of raw feathers is about 500 g/kg the recovery of the feather protein concentrate is approximately 50 % in the enzyme-alkaline process. However, it is generally not so easy to control the enzyme activity in a process accompanied with an enzyme reaction, which means the enzyme-alkaline process is difficult to be operated in an industrial scale. We have developed a much simpler processing technology supported by the dissolution of keratin in an alkaline solution under a high pressure.

The outline of the protein extraction process is shown in Fig. 1. Waste feathers from a slaughterhouse are disintegrated to less than 10 mm by the cutting machine in which feathers are also dried. The disintegrated feathers of 10 kg are supplied into the cylindrical pressure vessel with the volume of 0.3 m³ in which a surface active agent of dodecylbenzene sodium sulphonate is added first with hot water of around 100 °C. The addition of the surface active agent is adjusted to 8 % of total dry feathers on the weight basis. Then calcium hydroxide and sodium sulphide are added with hot water. The

overall solids concentration is 10 % on the weight basis in the pressure vessel. The extraction liquid are kept in the vessel for 1–2 hours under a pressure of $2.0\text{--}2.5 \times 10^5$ Pa heating to 130 °C. These conditions decide the molecular weight distribution of extracted proteins. The reaction liquid is neutralised by adding phosphoric acid to indicate pH 7.5. Then the liquid and residue are separated by filtration. The liquid phase is concentrated by water evaporation to take the protein concentration of 50 %, whilst the solid phase is dried and served as a solid compost. The extraction process can produce 0.01 m³ of the protein liquid and 6 kg of the solid compost from 10 kg of dry feathers. As can be seen from Fig. 1, no waste is discharged from the extraction process except for evaporated water. The extraction process is batchwisely operated. To increase the throughput of the extraction process a few normal scale batch systems is recommended to be operated parallel because much cost should be needed for the scale-up of the pressure vessel.

The smell of the protein liquid is almost undetectable. It has been found that about 93 % of the crude protein contained in waste feathers can be recovered in the extraction process. Namely, according to the protein content, the protein liquid can be added to the group of the protein source of animal origin such as fish meal (710 g/kg protein content), blood meal (820 g/kg protein content), etc⁷⁾. Furthermore, the amino acid composition of the protein liquid has also been confirmed to be approximately same as that of waste feathers, which indicates no decomposition of any amino acid occurs in the extraction process.

3. Foaming Characteristics of the Protein Liquid

One of the most promising utilisation ways of waste feathers in an industrial sense is to apply the protein liquid to make foams, which are useful in producing light weight materials such as bubble cements, bubble ceramics, etc. Most of proteins generally have foaming characteristics in aqueous phase. However, the distribution of the molecular weights should be optimised to produce stable foams endurable for mixing with solid materials. The extraction time is empirically adjusted in the developed process to take approximately the same weight ratio in the molecular weights of 5,000–10,000, 3,000–5,000 and less than 3,000. The foamability is depressed when the extraction time is shortened and the molecular weight distribution shifts to a larger side, whilst the shift to a smaller side leads to generate too stiff foams to mix with solid materials.

A simple foaming device has been developed to evaluate the foaming characteristics of the protein liquid. The schematic configuration is illustrated in Fig. 2. The aqueous protein solution of 1,000 ml prepared to take a desired protein concentration is fed to the vessel(5) with the volume of 2,000 ml through the feed pipe(1) and the liquid valve(3). Then after closing the liquid valve the compressed air is supplied through the air inlet pipe(2) and the air valve(4). The protein solution is subjected to a fixed pressure of 8.3×10^5 Pa for a while. The aqueous protein solution and compressed air flow

Fig. 1 Outline of the protein extraction process.

Fig. 2 Schematic configuration of the foaming device.

down through the connecting tube(6) when the outlet valve(7) is released. The liquid and air are mixed in the foaming section(8), in which glass beads with the diameter of about 2 mm are packed and generated foams are discharged from the outlet of the foaming section. Respective piece of the glass beads packed in the foaming section has a penetrated hole of about 0.6 mm at the centre of the piece. The overall void fraction is considered as about 0.51 in the foaming section, which is given by the observation carried out using same size beads without holes and by the calculation of the total hole volume.

The stability of foams is gradually deteriorated by the liquid drainage from bubble films. The drainage process has been modelled⁶⁾ and the electric conductivity has been shown to be useful to evaluate the foam stability⁷⁾. Here, we have introduced a much simpler method for the evaluation of the foam stability. Namely, the volume of the liquid phase drained by the collapse of foam films has been observed leaving a foam column filled in the cylindrical part of a glass vessel for 24 hours without any water evaporation. The cylindrical part has the inside diameter of 40 mm and the height of 150 mm. The cylindrical part is followed by a glass funnel connected by a stainless screen of 100 mesh. The drained liquid is accumulated in the lower cylinder of the glass funnel and the accumulation height is observed. The drainage rate is defined as the ratio of the liquid volume derived from the collapse of foam films to the liquid volume initially contained in the foams. The stabilised stiff foams have been difficult to be generated when only a protein solution is supplied into the foaming device. It is known some of multi-valent metal ions are active to stabilise protein-based foams. For example, tri-valent aluminium ions strongly affect on the stability of a food protein foam⁷⁾. Various kinds of metal ions, i. e. Al^{3+} , Fe^{3+} and Cu^{2+} , have been added respectively to the aqueous solution of the protein liquid and the foam stability has been evaluated. As a result, ferric ions have been confirmed to indicate a remarkable effect not only on the foam stability but also on the foaming property.

A series of foaming and stability tests have been carried out using ferric sulphate as the stabilising agent. The optimal concentration of ferric ions has been decided first using the aqueous solution of proteins containing 60 ml or 40 ml of the extracted protein liquid in 1,000 ml of tap water. The result of the stabilising test is shown in Fig. 3, where the drainage rate

Fig. 3 Effect of the ferric sulphate addition on the drainage rate.

is regarded as the stability index. As can be seen, despite the concentration of the protein liquid (abbreviated as PL) is varied the drainage rate is drastically decreased, i. e. the stability is drastically increased, along with the addition of ferric sulphate and the stability is gradually decreased with the more addition of ferric sulphate beyond an appropriate amount. The appropriate amount of addition can be regarded as 0.25 mol/l-PL in both cases of the protein concentration.

Then the optimal addition of the protein liquid has also been decided by evaluating the drainage rate of foams. Various amounts of the protein liquid have been dissolved in 1,000 ml of tap water. Two levels of the ferric sulphate addition (abbreviated as FS), i. e. 0.25 mol/l-PL of the optimal addition and 0.17 mol/l-PL of the smaller addition, have been evaluated as shown in Fig. 4. As can be seen, the optimal addition of the protein liquid is regarded as 60 ml/l-water because more addition has little effect on the stability of foams.

The bubble sizes in foams generated under the optimal conditions have been confirmed to be distributed between about 50 μm and about 200 μm by using an optical microscope. The average bubble size can be manipulated by varying the void fraction of packed media and the flow velocity in the foaming section of the device shown in Fig. 2. The flow velocity is controlled by the air pressure. Other methods have also been tried to generate stabilised foams. However, stiff stabilised foams have not been generated by, for example, cavitation by reducing pressure, aeration by enhanced agitation, etc. Although these methods could be available in direct

Fig. 4 Effect of the protein liquid addition on the drainage rate.

Fig. 5 Dependence of the compressive strength on the bubble volume fraction.

foaming of solid raw materials mixed with the protein liquid the aeration rates are not expected to be enhanced and homogeneous dispersion of bubbles in a solidified material must be impossible because of bubble rising in the raw material due to the low viscosity.

4. Production of Light Materials

We can regard foams generated from the extracted protein liquid as a raw material with a low density to be mixed with a solid raw material with a high density to produce a light material. Solid materials containing bubbles inside have also excellent physical properties in heat, sound and water protection. In order to evaluate the capability of foams as a light raw material bubble cement and bubble mortar have been produced. The dispersion state of bubbles and the compressive strength have been evaluated for the moulded light materials in relation to the bubble volume fractions.

A series of experimental works have been carried out using Portland cement or mortar which is made of Portland cement and river sand mixed with same weight. Respective solid raw material was mixed first with tap water to take a fixed water-solid ratio. Then generated foams were added and homogeneously mixed in the rotating cylindrical drum with the inside diameter of 300 mm and the length of 300 mm, in which six lifter bars are installed, to take a predetermined bubble volume fraction. The rotational speed was 25 rpm and the mixing time was 10 min. The mixed raw material was moulded in the steel box with the dimensions of 40 mm width, 160 mm length and 40 mm depth. Three moulded samples were produced after leaving 28 days respectively, which were subjected to the compression tests to evaluate the compressive strength as given by averaging three observations. The compression tests were carried out according to JIS A1108.

The effect of the bubble volume fraction on the compressive strength of bubble cement is shown in Fig. 5, where the bubble volume fraction is varied keeping the water-cement ratio 0.60. As can be seen, the compressive strength is almost linearly decreased along with the increase of the bubble volume fraction. The densities of the moulded dry materials were observed as 1,612 kg/m³ and 808 kg/m³ for the bubble volume fraction of 0.40 and 0.67, respectively. Moreover, the bubble cement has been confirmed to be mouldable even when the bubble volume fraction approaches to 0.7. Bubbles in the raw material have not disappeared during moulding for 28 days,

which is proved by evaluating the initial bubble volume fraction, the densities of the raw material and moulded dry materials. Furthermore, the gradual decrease of the compressive strength along with the bubble volume fraction indicates the homogeneous dispersion of bubbles is still maintained even when the bubble fraction is increased beyond 0.5.

As for bubble mortar, Portland cement, river sand, tap water and generated foams were mixed keeping the cement-mortar ratio 1 and the water-solid ratio 0.35. The experimental procedures were similar to those of the former experiments. The observed compressive strength is also shown in Fig. 5. As can be seen, the strength is decreased almost linearly as the bubble volume is increased. The densities of the moulded dry materials were observed as 1,538 kg/m³ and 969 kg/m³ for the bubble volume fraction of 0.42 and 0.62, respectively. The mouldability and the homogeneous dispersion of bubbles are indicated here again even in the case where the bubble volume fraction exceeds 0.5. The compressive strength should be varied depending not only on the bubble volume fraction but also on the cement-sand ratio and the water-solid ratio.

Although the lightweight materials produced in these tests seems to be weak for the compressive force materials indicating a similar compressive strength can be used as outer wall materials of houses. For example, the autoclaved lightweight concrete⁹⁾, generally called ALC, panel indicates the compressive strength of about 3.4 MPa, which is widely used as a outer wall material. However, to increase the strength of a moulded light material the initial water content has to be reduced taking into account that the extreme reduction below the limit of the normal water content leads to the collapse of bubble films. The limit is inherent in respective solid material and hence, the operating conditions under which the maximum strength is achieved has to be decided by trial-and-error. Another way to enhance the strength is to use a water reducing agent⁸⁾ which is a sort of surface active agents to improve the fluidity of a raw material. The water reducing agent adsorbed on solid particles can depress the collapse of bubble films and can decrease the consistency of a solid-water mixture.

Furthermore, aforementioned autoclaved lightweight concrete has recently been developed by controlling the cement reaction under a saturated steam pressure of about 1 MPa and the temperature of about 200 °C. The basic components of ALC are silica stone, cement and lime. Bubbling is generally caused by the addition of aluminium powder. The protein foams can possibly replace the aluminium powder to generate dispersed bubbles in ALC. It has been actually confirmed that a test piece of protein-based-ALC indicates the compressive strength of about 7 MPa even with the density of about 500 kg/m³.

We regard above demonstration as a convincing evidence of the capability of protein foams as a light raw material to be mixed with a solid raw material in producing a low density material. Consequently, we have found a flash of hope in the industrial utilisation of waste feathers discharged from slaughterhouses.

5. Conclusions

Large amounts of waste feathers are daily discharged from poultry slaughterhouses, which causes a new environmental problem. As an industrial phase of the waste utilisation waste feathers have been treated in an alkaline environment under a high pressure and the protein liquid has been extracted with the protein recovery of about 93 %. The residue from the extraction process is utilised as an organic compost. The distribution of protein molecular weights is controlled so as the protein liquid indicates excellent foaming characteristics. To enhance the foamability of the protein liquid a simple foaming device with a packed column has been developed. The stability of foams has been confirmed to be reinforced by the addition of ferric sulphate. The optimal addition of ferric sulphate has been recognised as 0.25 mol/l (protein liquid) by observing the drainage rate of generated foams. The optimal concentration of the protein liquid has also been derived from observing the stability of foams as is given by 60 ml/l (water). To evaluate the capability of protein foams as a raw light material to be mixed with a solid raw material for producing a low density material bubble cement and bubble mortar have been moulded to be subjected to the compression test. The compressive strength has been found to be decreased along with the bubble volume fraction in a moulded material. However, the mouldability has been guaranteed even in the case where the bubble volume fraction exceeds 0.5. Moreover, the homogeneous dispersion of bubbles

has been expected from the approximately linear decrease of the compressive strength along with the bubble volume fraction. We regard this demonstration as a convincing evidence of the capability of protein foams as a light raw material to be mixed with a solid raw material in producing a low density material with high performances in heat, sound and water protection.

Acknowledgements The authors wish to acknowledge Mr. Karutani, Mr. Ujihara and Miss Kuribayashi, who are master course students in The University of Tokyo, for their efforts on the experimental works. We are also grateful to Kurimoto Corporation for the financial support and the arrangement of experimental tools.

References

- 1) El Boushy, A. R., van der Poel, A. F. B. and Walraven, O. E. D. : Biological Wastes, Vol. 32, p. 39-74, (1990)
- 2) Hood, C. M. and Healy, M. G. : Resources, Conservation and Recycling, Vol. 11, p. 179-188, (1994)
- 3) <http://www.maff.go.jp/toukei/970702-08.html>
- 4) <http://www.lin.go.jp/lipc/statis/dome/1997/4040a.htm>
- 5) Dalev, P. G. : Bioresource Technology, Vol. 48, p. 265-267, (1994)
- 6) Germick, R. J., Rehill, A. S. and Narsimhan, G. : Journal of Food Engineering, Vol. 23, p. 555-578, (1994)
- 7) Sarker, D. K., Wilde, P. J. and Clark, D. C. : Colloids and Surfaces A, Vol. 114, p. 227-236, (1996)
- 8) Kinoshita, M., et. al. : Japanese J. of Polymer Science and Technology, Vol. 52, p. 363-372, (1995)
- 9) Isu, N., et., al. : J. of Ceramic Society of Japan, Vol. 102, p. 785-789, (1994)

養鶏廃棄羽毛の有効利用—1. 工業的フェイズ

戸田 泰寛¹ 野中 道郎²

養鳥肉、特にブロイラーの需要は、もっとも見込みのあるタンパク質源の一つとして 21 世紀に向かって増大していくはずである。しかしブロイラーの生産には多量の廃棄羽毛を伴う。そこで廃棄羽毛からタンパク質を抽出することに着目し、簡単な抽出プロセスを開発した。抽出したタンパク液は強い発泡性を示すがそれは、固体原料と混合することで低密度物質を生成するための軽量素材として有用であろう。発泡特性について実験的に評価を行い、硫酸第 2 鉄が生成したタンパク質フォームの安定性強化に役立つことを確認した。フォーム液膜からの液のドレーン率を測定し、硫酸第 2 鉄とタンパク質液の最適添加量を決定した。タンバ

ク質フォームによる低密度物質生成の可能性を調べるため、気泡セメントおよび気泡モルタルについて、成形性、気泡分散性および圧縮強度によって評価を行った。その結果、0.5 以上の気泡体積率の場合でも成形性および成形体中での気泡の均一分散性が保たれることが確認できた。これらの試験から、タンパク質フォームが、耐熱性、防音性および遮水性に優れた低密度物質生成のための軽量素材として利用可能であることを実証できた。

1. 静岡プラントサービス(株)R & D センター所長
 2. 正会員 工博 東京大学講師 大学院工学系研究科地球システム工学専攻
- キーワード：養鳥、廃棄羽毛、タンパク質抽出、タンパク質フォーム、フォーム安定性、軽量物質