Chemical Engineering and Processing 87 (2015) 104–109

Contents lists available at ScienceDirect

Chemical Engineering and Processing: Process Intensification

journal homepage: www.elsevier.com/locate/cep

Microwave-enhanced hydrolysis of poultry feather to produce amino acid

Jinyang Chen [a,b,*], Siyuan Ding [a], Yimei Ji [a], Junying Ding [b], Xuanyu Yang [a], Mihua Zou [a], Zhilian Li [a]

[a] School of Environmental and Chemical Engineering, Shanghai University, Shanghai 200444, China
[b] State Key Laboratory for Mineral Deposit Research, School of Earth Sciences and Engineering, Nanjing University, Nanjing 210093, China

ARTICLE INFO

Article history:
Received 20 June 2014
Received in revised form 1 November 2014
Accepted 28 November 2014
Available online 29 November 2014

Keywords:
Microwave heating
Hydrolysis
Amino acid
Poultry feather
High temperature and pressure

ABSTRACT

Poultry feather was hydrolyzed at relatively mild high temperature ranging from 433 to 473 K and autogenous pressure by intensification of microwave heating. The hydrolysate mainly contains arginine, alanine, threonine, glycine, praline, serine, glutamic acid, aspartic acid, cystine and tyrosine, which corresponds with hydrochloric acid catalytic hydrolysis. Based on the orthogonal experimental result, the total yield of amino acid attains about 54.72% with feather containing about 71.83% keratin at optimum reaction condition of temperature 473 K, time 20 min and weight ratio of water/feather 37.5. The high yield of amino acid and high efficiency of hydrolysis indicate that the microwave has better intensification on hydrolysis comparing with traditional strong acid catalytic or sub-critical hydrolysis. The apparent activation energies (E_a) are 85.12 and 63.00 kJ/mol as to the hydrolysis of feather and the degradation of produced amino acid with consecutive pseudo-first-order reaction kinetic model, and the great decrease of the values comparing with non-microwave heating should be the reason of the enhanced effect of microwave.

1. Introduction

The poultry industry produces a great amount of feather each year globally and if not handling properly, it will result in environment pollution [1–3]. Feather is mainly composed of keratin [4,5] and it can be hydrolyzed to produce amino acid, thus it can not only reduce environment pollution but also obtain high-value products [6].

As for hydrolysis of feather to produce amino acid, the traditional methods are hydrolysis with strong acid, alkali, or enzyme catalysis [7–10]. Strong alkali or acid catalytic hydrolysis will result in environment pollution and difficulty for the separation of amino acid. Up to now, the enzymatic hydrolysis is still very slow to prevent its industrial application because the keratin in feather is a structural protein characterized by a high cystine content and a significant amount of hydroxyl amino acids, especially serine and it contains a range of non-covalent interactions (electrostatic forces, hydrogen bonds, hydrophobic forces) and covalent interactions (disulfide bonds). Hydrolysis with super- and sub-critical water is a new green method to convert biomass to amino acid without any catalysts [11–14] and this is a high efficient and eco-friendly technology, but the need of high temperature and pressure will not only cause the degradation of amino acid [15] but also bring difficulty to design equipment for industrial utilization because the critical point of water is about 374 °C and 22 MPa. Therefore, it is important to study some intensification effects on hydrolysis at a relatively mild reaction condition to avoid the disadvantages.

Microwave (MW) is a kind of electromagnetic wave with the frequency of 300 MHz–3000 GHz. Since 1986, MW technology has been introduced to chemical reaction and its enhanced chemistry has become a popular research topic [16–19]. MW irradiation works through 'in-core' volumetric heating (direct coupling of MW energy with reaction mixture) which results in rapid temperature attainment and in the framework of process intensification, microwave fields are seen as one of the promising new forms of energy that may help to drive chemical reactions faster and more efficiently in intensified equipment. Whereas, the conventional reflux heating is relatively slow and inefficient to transfer the energy into a reaction mixture because there is (non-) homogeneous heat flow from the wall to the medium, leading to specific and time dependent temperature profiles such as convection currents and the thermal conductivity of medium (reaction vessel, reactants and solvent phase etc.) [20], which makes – especially in

* Corresponding author at: School of environmental and chemical engineering, Shanghai University, Shanghai 200444, China. Tel.: +86 21 66137729; fax: +86 21 66137725.
E-mail address: chenjy@shu.edu.cn (J. Chen).

http://dx.doi.org/10.1016/j.cep.2014.11.017
0255-2701/

batch experiments – a correct prediction of the reaction and sub-reaction rate more tedious. Therefore, now microwave technology has been known is a proficient and swift route to carry out chemical transformations and has become a widely accepted non-conventional protocol for chemical engineering and process as an intensification way [21–23].

Recently MW irradiation has been shown an enhanced effect for hydrolysis of cellulosic waste to form glucose [24] and a more efficient technology of hydrolysis of hog hair to produce amino acid than the traditional heating method of a hot plate [25]. In addition, MW had been applied to prepare some unnatural amino acids and it not only had the high purity and yield but also simplified reaction steps [26,27]. Therefore, we adopt self-design MW heating batch-type autoclave reactor to enhance the hydrolysis of poultry feather to produce amino acid at high temperature and pressure without any catalysts. With MW heating, the reaction condition is relatively mild temperature comparing with the traditional sub-critical hydrolysis in order to decrease degradation of amino acid and increase safety by lowing the temperature and pressure.

2. Materials and methods

2.1. Materials

Duck feather is a typical poultry feather and the sample of duck feather was provided by Xinyi Hanling Biological Engineering Co., Ltd. (Xuzhou, China). It was washed with water, dried and cut into small pieces to use.

Reagents including standard amino acids are purchased from Sigma–Aldrich Co., LLC, Sinopharm Chemical Reagent Co., Ltd. and Aladdin Reagent Co., Ltd.

2.2. MW heating hydrolysis

The MW heating hydrolysis was carried out with a self-design batch-type autoclave reactor of the maximum power of 1200 W (the photo and schematic diagram shown in Fig. 1). The reaction vessel was about 500 ml teflon spraying cylinder vessel with a height of about 6 and a diameter of 10 cm. All samples put into the vessel were about 350 ml to maintain appropriate autogenous pressure and keep relatively smooth reaction.

After the desired reaction time, the cylinder vessel was taken out from the equipment after it cooled to ambient temperature. The residual solid and liquid were separated by filtration. The liquid was analyzed to determine the amino acids of hydrolysis from the feather.

2.3. Analysis of the feather and hydrolysis products

Elemental analysis of C, N and H about the feather was carried out with EA3000 of Euro Vector. The content of protein and main composition of amino acid in the feather were determined by hydrolysis with 6 mol/L HCl solution to produce amino acids at the reflux temperature about 105 °C during 24 h.

The amino acids were analyzed by amino acid analyzer (AAA-Direct, DIONEX) and the measuring condition was the same described in the former paper [11].

3. Results and discussion

3.1. The composition of the feather

C, N and H elemental analysis of the feather were as follows: C (70.05%), N (12.19%) and H (11.82%). The protein content was calculated as N × 6.25 [28], and thus it could be estimated about 76%.

In order to know the composition of keratin, the feather was hydrolyzed with 6 mol/L HCl to analyze amino acids of the hydrolysate. Fig. 2 gives the chromatograms of standard amino acids and hydrolysate. According to the standard amino acids, the main amino acids of feather are arginine, alanine, threonine, glycine, praline, serine, glutamic acid, aspartic acid, cystine and tyrosine, and the corresponding contents are 5.93, 4.17, 7.71, 6.77, 10.35, 8.27, 6.82, 5.94, 9.51 and 6.36%. Thus, the total content of keratin in the feather is determined to 71.83% based on the above ten main amino acids, which almost accord with the above elemental analysis.

3.2. Orthogonal experimental

The aim of the orthogonal experiments was to find the important factors on the process of the feather hydrolysis and determine the optimum reaction condition to produce amino acid. The yield percentage of amino acid is a criterion and expressed as follows: $Y_{\text{aminoacid}} = M_t/M_0 \times 100\%$, where M_t and M_0 are the weight of initial feather and produced amino acid.

The weight ratio of water/feather represents the initial concentration and has effect on the contact of feather with water [14] to influence the hydrolysis rate and the cost of the process because the higher ratio of feather is more efficient. Reaction temperature and time are no doubt important to the hydrolysis of feather. Thus, the three factors of reaction temperature, time and initial weight ratio of water/feather were chosen as the orthogonal

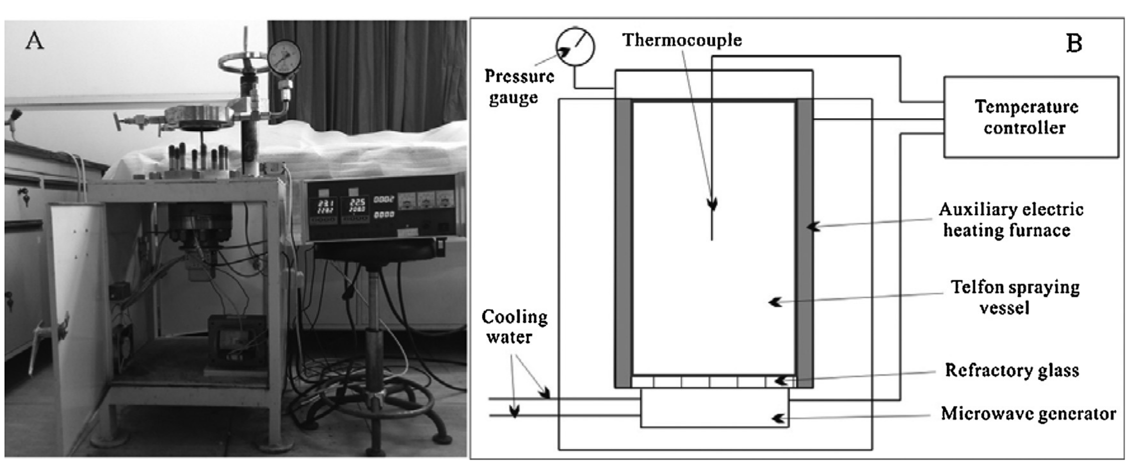

Fig. 1. The self-design batch-type microwave autoclave reactor system; A. its photo; B. its schematic diagram.