CONVECTIVE DRYING OF POULTRY MANURE BY DIFFERENT AIR SPEEDS

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Abstract. The high content of water in poultry manure creates problems for its collection, transport and storage in the large scale farms with laying hen breeding. Other problems with high moisture of manure are in the case of application of manure in the crop production or in the processing for another purpose of the use. The aim of this paper is to inform about the experimental and theoretical investigations of moisture content reduction from poultry manure by drying. Based on the experimental data we found the theoretical drying coefficient, useful for description and modelling of the drying process, calculated the theoretical results of moisture removal and compared with the experimental results obtained from the measurement. Using the experimental data with different convective air speed in the laboratory conditions there was calculated the drying coefficient depending on the drying time and air speed at constant temperature. The influence of the air speed was recognised as an important parameter, which can serve especially in the design and construction of the new equipment with the belts for housing of poultry or improvement of the use of the drying tunnel or in similar applications.

Key words: convective drying, manure, drying rate.

Introduction

The great problem of intensive animal production, especially in the countries with high density of population and also with high density of animal farms, is the animal waste management. Pollution of environment by animal waste can be a problem which should be solved in the whole production and logistic chain. Modern farms with egg production are typical with large capacity and concentration of hens in one location, which enables the use of industrial principles of technology but with respect to the animal welfare Council Directive 1999/74/EC [1].

Poultry manure can be a valuable resource of a significant amount of nitrogen, phosphorus, and many other components. The rapid growth of the animal breeding including the poultry industry in recent years and the application of waste to agricultural land has resulted in excessive concentration of the farms in many locations. Therefore, direct fertilizing using fresh excrements is strictly limited by its consistence which does not allow uniform spreading. Another limitation is the seasonality of application – it can be used only in a specific time-frame and is limited by the quantity [2].

An application without treatment or non-appropriate disposal can become risky for environment and humans as such application might lead to the spread of diseases and may pollute the soil and groundwater. Therefore, great attention is paid to the technical solutions in the areas with intensive animal production [3].

One of the reasonable solutions can be drying and reduction of the water content in manure that can help to the solution of environmental problems and also reduce the costs of the logistics, storage and application for the farmers. Different technical principles of drying systems for poultry manure were used during the previous years. The producers of the technological equipment for poultry usually apply the practical and empirical experience for the construction of the drying equipment. The main principles are described in the literature, e.g., Chiumenti [4]. The previous research work at the Faculty of Engineering CULS Prague on this field resulted in some publications, e.g. [5] in recent years.

In order to understand the drying process and find the optimal drying regime it is necessary to understand the transport mechanisms which take place within and on the surface of the product. The drying process is characterized by the existence of the transport mechanisms, such as surface diffusion, pure diffusion, capillary flow, evaporation, thermo-diffusion, etc. There are various researches in which drying processes of different materials were studied [6-8].

The aim of this work is to bring some new experimental and theoretical investigations of drying of poultry manure which could be generalized and create new theoretical background for these problems.

Materials and Methods

The laboratory measurements were carried out at the Faculty of Engineering CULS Prague during summer conditions. The technical equipment used for the experiments was a simple forced convection system, simulating the real technical system used in some cages with the belt conveyer for poultry manure removal and pre-drying inside the poultry house.

It consists of the perforated plastic tube, to which a small 9 W fan forced the air. All 264 holes (4 x 66) with the diameter of 3 mm were drilled through the tube at the distance of 10 mm in the axis of the tube along its length and with spacing of 16 mm around the perimeter in four rows on the bottom of the tube. The air speed was measured by the anemometer CFM 8901 Master with resolution 0.0 $m \cdot s^{-1}$ and accuracy ± 2 % of the final value. Air temperature and humidity were measured by the sensor FHA646-E1C connected to the data logger ALMEMO 2690-8.

The moisture content in the manure was identified by gravimetric measurement in regular time intervals. The samples were weighed on the digital laboratory balance KERN-440-35N with maximum load weight 400 g and with resolution 0.01 g. The total drying time was adapted to the need for determination of the final moisture content.

There was used manure from the poultry house with laying hens in the cages. The manure was transported in the closed barrel to the laboratory and used for the measurement. The measuring plates (Fig. 1, Fig. 2) with approximately 200 g of manure were placed under the perforated tube in two distances from the tube, in order to achieve the air speed 0.27 $m \cdot s^{-1}$ and 0.45 $m \cdot s^{-1}$. The device has been adapted to simulate the actual pre-drying equipment used in buildings for laying hens.

The samples were weighed during drying on a laboratory balance and the values were recorded. Each measuring plate was weighed during the first 3 hours every 15 minutes, later during the next 2.5 hours every 30 minutes and after that every 60 min.

Fig. 1. **Manure before drying**

Fig. 2. **Manure after drying**

Assuming that the product is placed in a thin, porous layer it can be considered that the manure moisture W depends only on the drying time (at constant drying temperature). Taking into account the mathematical model of porous material layer drying process [6; 7] we can write the manure drying process mathematical expression:

$$\frac{dW}{dt} = K(t) \cdot \left(W_p - W\right), \text{ with condition } W(0) = Ws \tag{1}$$

where W_s – manure moisture at the beginning of the experiment,%;
W_p – equilibrium moisture content, dry basis, %;
$K(t)$ – drying coefficient, h^{-1}.

Lack of knowledge of the drying coefficient $K(t)$ makes difficult the drying process modelling. Note that the $K(t)$ expression depends not only on the drying product but also the drying temperature and conditions. In addition, the drying rate is variable during drying due to the different moisture transport mechanisms such as surface diffusion, pure diffusion, capillary flow, evaporation, thermo-diffusion, etc. We take the common transport coefficient $K(t)$, which was found by the methodology used at [7].

Experimental and Theoretical Results

We measured the manure convective drying process with the air speeds 0.27 m·s^{-1} and 0.45 m·s^{-1}. The experimental results showed that the water removal process from manure can be divided into two stages: linear and asymptotic stage. The existence of these stages can be explained with the water removal transport mechanism as at the first stage of the drying process the greatest influence comes from surface diffusion, capillary flow, evaporation, at the second stage this impact is less and an important role is played by pure inside diffusion (Fig. 3). Connecting the two stages it is profitable to use squared type of the drying rate expression $K(t) = a_2t^2 + a_1t + a_0$, which could well describe the drying rate changes during the drying process (sample surface and internal moisture migration).

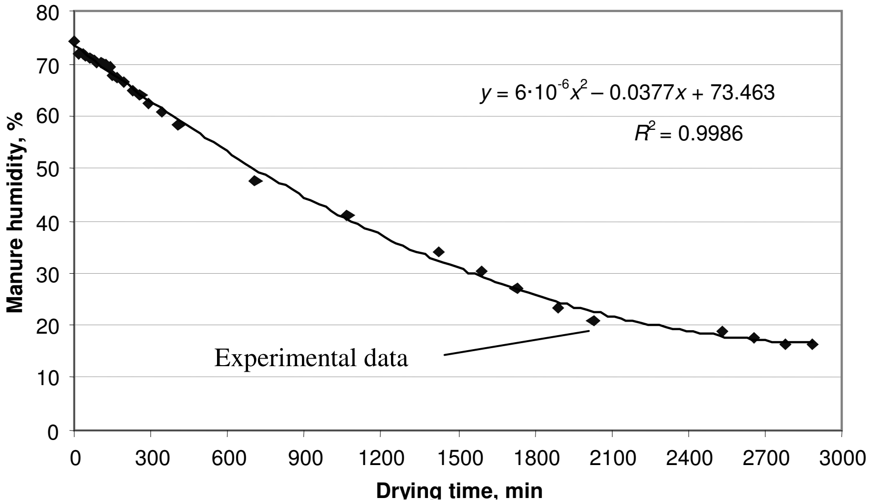

Fig. 3. **Manure humidity changes by convection with air speed at top 0.27 m·s^{-1}**

Using the methodology described in [7] and the experimental data obtained the drying coefficient for manure drying by convection with 22 ºC ambient air is:

$$K(t) = -1.5 \cdot 10^{-5} \cdot t^2 + 1.7 \cdot 10^{-3} \cdot t + 21.4 \cdot 10^{-3}, \quad (2)$$

with the coefficient of determination $\eta^2 = 0.87$. There t is drying time (h).

The theoretical manure weight changes using (1) and (2) we can calculate as

$$W = (W_s - W_p) \cdot \exp\left[-(-\frac{1.5 \cdot 10^{-5}}{3} t^3 + \frac{1.7 \cdot 10^{-3}}{2} t^2 + 21.4 \cdot 10^{-3} \cdot t) \right] + W_p. \quad (3)$$

The theoretical mass change results and the results with experimental data are shown (Fig. 4). The max absolute value of the difference between the corresponding theoretical and experimental data was 10 g with standard deviation 2.3 g. For linear $K(t)$ the standard deviation from the differences received 3 g it is approximately 30 % higher. The equilibrium moisture content of manure in the experiment was 16 %.

Approximately 15-20 hours are the first stage of drying and modelling this stage we can use the linear type of the drying coefficient. At this stage, two thirds of water from manure is removed. Increasing the air speed at the top the drying velocity increases. The experiments described in Fig. 5 show that the first stage (linear moisture removing) is shorter if the air velocity at the top is faster.

Increasing the air velocity from 0.27 m·s^{-1} to 0.45 m·s^{-1} the linear part of drying is reduced from 20 to 13-15 hours, at which the removed moisture content is higher. It can be explained that the moisture gradient at the top is higher and moisture is faster removed from the material.

Using the methodology described in [7] and the experimental data obtained the drying coefficient for manure drying by convection with 22 ºC ambient air flow on the top of the layer by velocity $v = 0.45$ m·s^{-1} is:

$$K(t) = 2.6 \cdot 10^{-3} \cdot t + 56.1 \cdot 10^{-3}, \quad (4)$$

with the coefficient of determination $\eta^2 = 0.92$. There t is drying time (h).

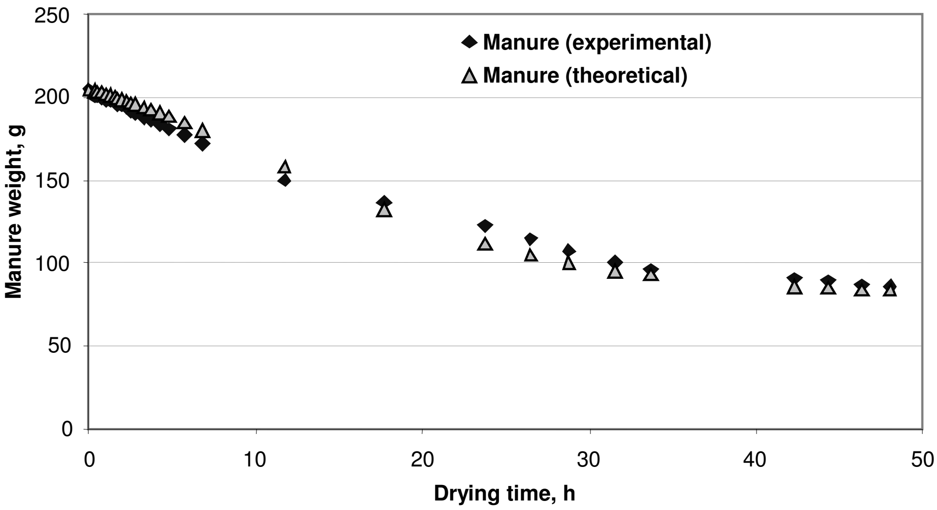

Fig. 4. **Manure weight changes during the drying process by convection with air speed at top 0.27 m·s^{-1}**

The max absolute value of the difference between the corresponding theoretical and experimental data was 2.6 g with standard deviation 0.6 g.

The drying coefficient of the drying process with air velocity v = 0.27 m·s^{-1} was

$$K(t) = 3.4 \cdot 10^{-3} \cdot t + 16.7 \cdot 10^{-3}, \quad (5)$$

with the coefficient of determination $\eta^2 = 0.76$.

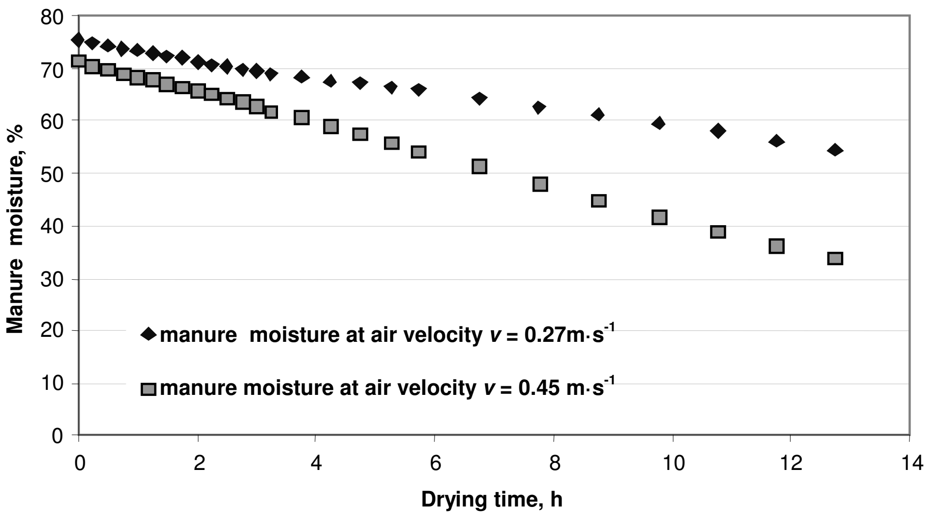

Fig. 5. **Manure moisture changes during the drying process by convection with air speeds at top 0.27 m·s^{-1} and 0.45 m·s^{-1}**

The max absolute value of the difference between the corresponding theoretical and experimental data was 6 g with standard deviation 2.3 g.

If we compare (4) and (5) it can be seen that the free constant at (4) is approximately 3 times bigger than the constant at (5). It can be explained that the flowing air reduces the moisture on the surface and thus increases the moisture gradient.

Conclusions

1. The proposed methodology [7] is applicable for finding the manure drying coefficient in a thin layer of material.
2. It has been found that the air velocity has a strong influence on the drying time.
3. In order to achieve the suitable moisture of manure for following applications with economic benefits, the optimization of the drying time should be provided and respected.

4. Future research should be focused on the study of other factors influencing the drying process partly described and expressed by the drying coefficient.

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