COMPARISON OF TWO METHODS OF POULTRY MANURE DRYING

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Abstract. The high content of water in poultry manure creates problems for its collection, transport and storage on the large scale farms with breeding laying hens. The aim of this paper is to inform about the experimental and theoretical investigations and comparisons of moisture content reduction from poultry manure by two different methods of forced convection. The experimental data created the background for calculation and modelling, which resulted in definition of the theoretical drying coefficient, useful for description and modelling of the drying process. The theoretical model has been verified and compared with the experimental results obtained from the measurement. Manure drying is compared with the air flow on the top of manure, with the air flow passing from the bottom through supporting trays with different diameter holes and therefore through manure up. Using the experimental data with different convective air speed and hole size in the laboratory conditions there was the drying coefficient calculated depending on the drying time and air speed at constant temperature. The experimental data show that the air flow will significantly increase the amount of moisture carried away from the material. The hole size does not significantly affect the water runoff by convection without additional air flow.

Keywords: convective drying, manure, drying coefficient.

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 enable the use of industrial principles of technology but with respect to 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].

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 soil and groundwater. Therefore, strong 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, which 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 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. [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 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 forced convective drying of poultry manure by two air velocities going from tube to surface of trays with manure is given at [9].

The aim of this work is to bring some new experimental and theoretical investigations of drying of poultry manure, compare two drying technologies (air flow on the top of manure and air flow through the manure layer from the bottom to the top) which could be generalized and create the 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 (manure drying by air flow on the top) used for the experiments was a simple forced convection system Fig. 1., simulating the real technical system used in some cages with a belt conveyer for poultry manure removal and pre-drying inside the poultry house.

It consists of the perforated plastic tube, to which small 9 W fan forced the air. All 264 holes (4 x 66) with diameter of 3 mm were drilled through the tube at 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 0.01 $m \cdot s^{-1}$ and accuracy ±2 % of final value. The air temperature and humidity were measured by the sensor FHA646-E1C connected to the data logger ALMEMO 2690-8.

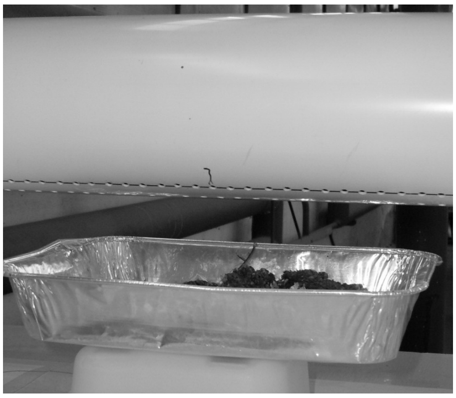

Fig. 1. **Forced convective drying of poultry manure by air streams going from tube to surface of plate with manure**

Fig. 2. **Manure before drying**

The second experimental equipment used for the experiments was the forced convection system (Fig. 4), simulating partly the real technical system used in some drying tunnels with a belt conveyer for drying in the poultry farms, Fig. 3.

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. Each measuring tray was weighed during the first 3 hours every 15 min, later during the next 2.5 hours every 30 min and after that every 60 min. We researched drying kinetics of manure placed on trays with three different hole sizes (3, 4, 5 mm) and a sieve with mesh 3x4 mm.

Manure from the poultry house with laying hens in the cages was used. The manure was transported in the closed barrel to the laboratory and used for measurements. The measuring plates (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 $m \cdot s^{-1}$, Fig. 1.

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 the porous material layer drying process [6; 11] we can describe the manure drying process mathematical expression:

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

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

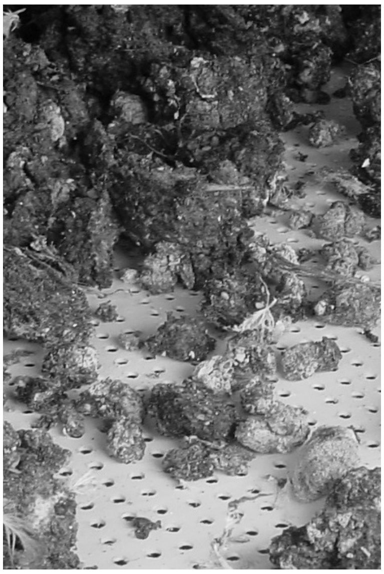

Fig. 3. **Perforated belt conveyer at work for drying manure in poultry farms.**

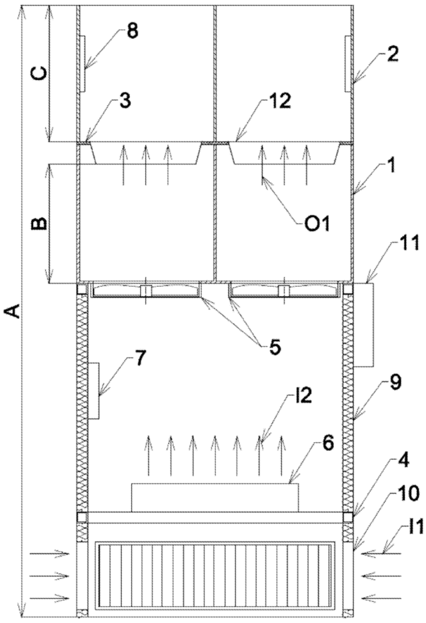

Fig. 4. **Scheme of equipment used for manure drying [10]:** 1 – lower drying chamber; 2 – upper drying chamber; 3 – underlay; 4 – structure; 5 – fans; 6 – air heating; 7 – sensors; 8 – sensors; 9 – thermal insulation; 10 – inlet air; 11 – control panel; 12 – perforated tray with measured manure; I1 – inlet of fresh air; O1 – air passing through perforated tray with measured manure; A – overall height; B – height of the lower chamber; C – height of the upper chamber

Lack of knowledge of the drying coefficient $K(t)$ makes the drying process modelling difficult. Note that the $K(t)$ expression depends not only on the drying product but also on 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 took the common transport coefficient $K(t)$, which was found by the methodology using at [11].

Experimental and theoretical results

We compared the convective drying process of manure from the top Fig. 1 with the air speeds 0.27 $m \cdot s^{-1}$ and 0.45 $m \cdot s^{-1}$ and drying caused by forced convection of manure placed on trays Fig. 4 with three different hole sizes (3, 4, 5 mm) and a sieve with mesh 3x4 mm with the air speeds 1.13 $m \cdot s^{-1}$ and 2.05 $m \cdot s^{-1}$ and compared it with not forced drying.

For long drying time the experimental results showed that the water removal process from manure can be divided into two stages: linear and asymptotic stage [9]. The existence of these stages can be explained by the water removal transport mechanism, it is that 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.

We were more interested in the first stage of drying, when the drying coefficient is linear and there is the greatest water runoff. The drying time in this stage may be from 8 to 16 hours, depending on the type of drying (top, bottom), air flow velocity, drying temperature, etc. At this stage, there are two thirds of water removed from the manure. 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 $m \cdot s^{-1}$ to 0.45 $m \cdot s^{-1}$ linear part of drying is reduced from 20 to 13-15 hours, at which the removed moisture content is higher. It can be explained by the fact that moisture gradient at the top is higher and moisture is faster removed from the material.

Using the methodology described in [11] and the experimental data the drying coefficient (2) for manure drying is obtained by convection with 22 °C ambient air flow on the top of the layer by velocity v = 0.45 m·s^{-1} is:

$$K(t) = 2.6 \cdot 10^{-3} \cdot t + 56.1 \cdot 10^{-3}, \text{ with coefficient of determination } \eta^2 = 0.92. \quad (2)$$

where t – drying time (h).

The drying coefficient (3) of the drying process with the air velocity v = 0.27 m·s^{-1} was:

$$K(t) = 3.4 \cdot 10^{-3} \cdot t + 16.7 \cdot 10^{-3}, \text{ with coefficient of determination } \eta^2 = 0.76. \quad (3)$$

If we compare (2) and (3) it can be seen that the free constant at (2) is approximately 3 times bigger than the constant at (3). It can be explaining by that flowing air reduces moisture on the surface and thus increases the moisture gradient.

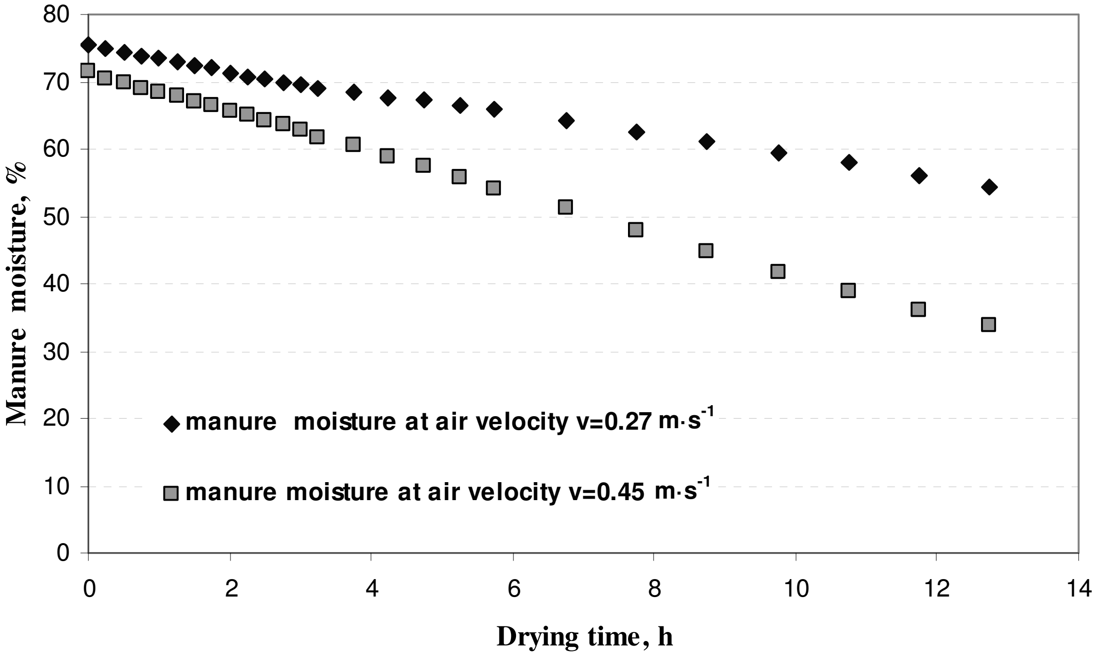

Fig. 5. **Manure moisture changes during the drying process by convection with air speeds at top 0.27 m·s^{-1} and 0.45 m·s^{-1}**

The experimental results of manure drying with forced convection from the bottom showed that the water removal process from manure does not significantly affect the hole size. Most significant acceleration of the drying process was observed through a sieve especially at higher air speeds (Fig. 6, Fig. 7). Average air temperature during the drying process was 21.9 °C.

This can be explained by the greater surface area of the manure through which the air flow is passing. Comparing the effects of the air velocity, it can be seen that higher air speed significantly increases the speed of the drying process at the beginning of the drying process. This can be explained by the migration of moisture from the surface of the product. Later, when water runoff provides diffusion, the air velocity effect on the product drying rate decreases.

The air flow velocity significantly affects the amount of water carried away, especially during the first 2-3 hours of drying (Fig. 6, Fig. 7). During the first 3 hours of drying at 2.04 m·s^{-1} air speed by 5 % more moisture is removed than with the air speed of 1.13 m·s^{-1} at all perforation holes. After 3 hours of drying with the air velocity 2.04 m·s^{-1} manure moisture is reduced to 22.7 % with a sieve tray.

The experimental results show the strong influence of the air velocity on water removal when manure is drying from the top (Fig. 8). Increasing the air flow rate from 0.27 m·s^{-1} to 0.45 m·s^{-1} the total water removal from 100 g manure with moisture 73 %, during 13 hours drying, increases approximately 2 times, it is from 21.3 g to 37.6 grams (Fig. 8).

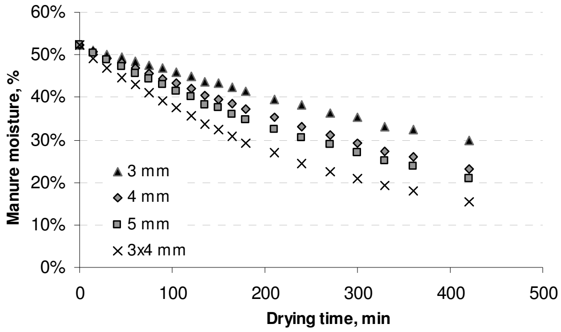

Fig. 6. **Moisture changes of manure placed on trays with different sizes of holes, by forced convection with air speed at bottom 1.13 m·s^-1^**

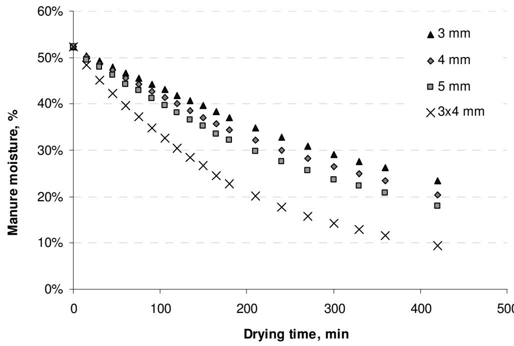

Fig. 7. **Moisture changes of manure placed on trays with different sizes of holes, by forced convection with air speed at bottom 2.05 m·s^-1^**

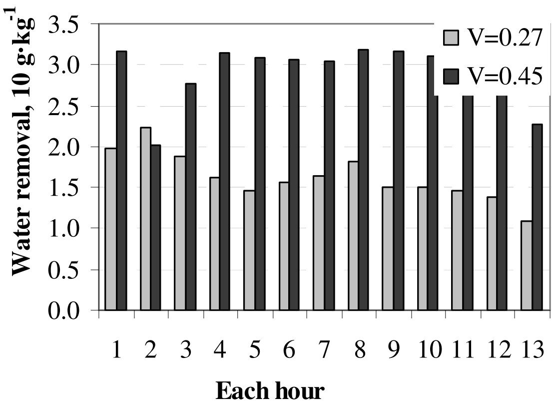

Fig. 8. **Moisture removal from manure (10 g·kg^{-1}) with initial manure moisture 73 %, at each hour of drying with air speeds at top 0.27 m·s^{-1} and 0.47 m·s^{-1}**

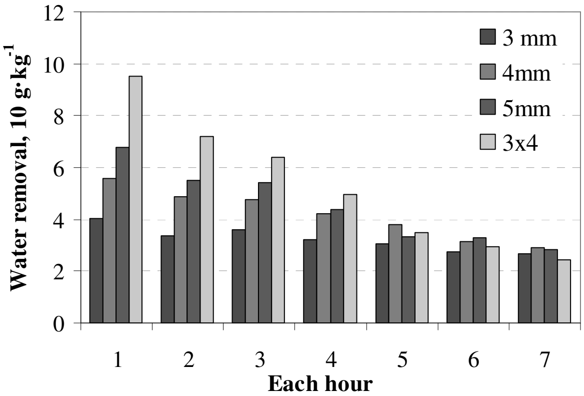

Fig. 9. **Moisture removal from manure (10 g·kg^{-1}) with initial manure moisture 52.4 %, at each hour of drying with air speed at bottom 1.13 m·s^{-1}**

Comparing water removal in the drying process when manure is drying from the top and bottom it can be seen that the forced convection from the bottom is much more effective, especially at the beginning of the drying process, Fig. 9.

Using the methodology described in [11] and the experimental data for manure drying by forced convection at a sieve with mesh 3x4 mm with the air velocity 1.13 m·s^{-1} variable drying coefficient is obtained (4):

$$K(t) = 0.71 \cdot 10^{-5} \cdot t + 39.3 \cdot 10^{-4}, \text{ with coefficient of determination } \eta^2 = 0.89, \tag{4}$$

where t – drying time (min).

The theoretical manure weight changes using (1) can be calculated as (5):

$$W = (W_s - W_p) \cdot \exp[-(\frac{0.71 \cdot 10^{-5}}{2} t^2 + 39.3 \cdot 10^{-4} \cdot t)] + W_p. \tag{5}$$

The theoretical and experimental results of changes of manure mass are shown (Fig. 10).

We obtained the constant drying coefficient as average of drying coefficient values at each point of time. The average value of the difference between the corresponding theoretical and experimental data was 1 g with standard deviation 0.7 g (for linear $K(t)$) and 2.6 g with standard deviation 1.6 g (for constant drying coefficient). The equilibrium moisture content of manure in the experiment was 16 %.

The manure drying coefficient (6) in case of forced air by velocity 1.13 m·s^{-1} placed in a tray with holes 5 mm was:

$$K(t) = 0.23 \cdot 10^{-5} \cdot t + 27.77 \cdot 10^{-4}, \text{ with coefficient of determination } \eta^2 = 0.88. \tag{6}$$

With holes 4 mm (7):

$$K(t) = 0.22 \cdot 10^{-5} \cdot t + 23.23 \cdot 10^{-4}\text{, with coefficient of determination } \eta^2 = 0.95. \quad (7)$$

And with holes 3 mm (8):

$$K(t) = 0.2 \cdot 10^{-5} \cdot t + 19.1 \cdot 10^{-4}\text{, with coefficient of determination } \eta^2 = 0.93. \quad (8)$$

Comparing the equations (6-8) we see that the hole diameter does not significantly affect the drying rate dependence on the time. Diameters have a significant impact at the beginning of the drying process, which is characterized by free expression members at equations (6-8). Comparing these expressions with (2) we see that the tray with the sieve significantly increases the drying rate dependence on the time. This effect is more than 3 times larger than with the trays with holes.

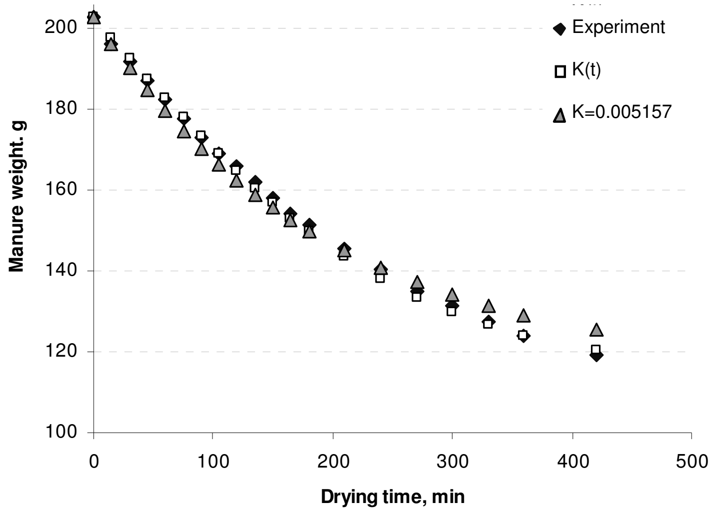

Fig. 10. **Theoretical (with constant and changing drying coefficient) and experimental changes of manure moisture at sieve with mesh 3x4 mm with forced air speed 1.13 m·s^{-1}**

The results show that the forced air flow significantly increases the drying speed. Free convection is ineffective in manure drying especially during the first hours of drying (Fig. 10).

The experimental data show that the mesh has the greatest impact on reducing the drying time. Increasing the forced convection air speed up to 2 times (from 1.13 m·s^{-1} to 2.05 m·s^{-1}) manure on the sieve dries approximately 10 % faster with the air velocity v = 1.13 m·s^{-1} than manure on the tray with 3 mm holes with the air velocity v = 2.05 m·s^{-1} (Fig. 11).

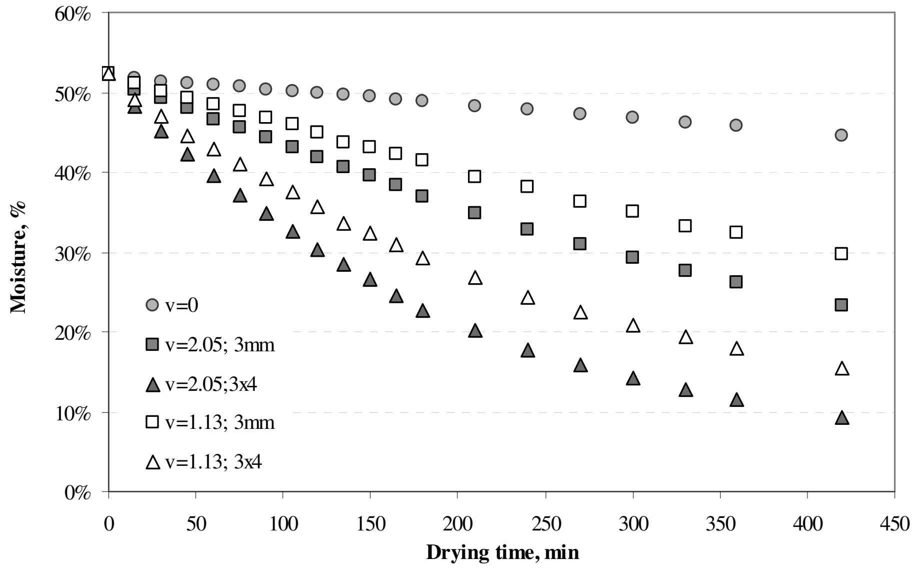

Fig. 11. **Changes of manure moisture at tray (holes size 3 mm and sieve with 3x4 mm mesh) with different forced air speeds v (m·s^{-1})**

Conclusions

1. The proposed methodology [11] is applicable to finding of the manure drying coefficient in a thin layer of material with different drying conditions.
2. It has been found that the air velocity has a strong influence on the drying time and water removal particularly drying from the top. Increasing the speed of the air flow from 0.27 $m \cdot s^{-1}$ to 0.45 $m \cdot s^{-1}$, the total water removal increases approximately 2 times (from 21.3 g to 37.6 g per 100 g manure with moisture 73 % during 13 hours of drying).
3. The theoretical and experimental research shows that the shape and dimensions of holes are not so important influencing the drying time when the drying process goes through the layer from the bottom to the top. Manure moisture is reduced approximately from 52.4 % to 22.7 % with a sieve tray with the air velocity 2.04 $m \cdot s^{-1}$ after 3 hours, while drying by the air speed 1.13 $m \cdot s^{-1}$ reduced only to 28 % due to smaller air flow.
4. The free convection is not efficient for the poultry manure drying, e.g., only approximately 5 % of moisture was removed during 3 hours.

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