Energy Saving on Distribution of Liquid Animal Feeds at Pigsty Farms

Ivan Ivanovich Girutski, Andrei Grigorievich Senkov and Natalja Mikhailovna Matsveichuk

Department of Automated Production Management Systems, Belarusian State Agrarian Technical University, Minsk 220023, Belarus

Abstract: This paper focused on the task of reducing power consumption and improving energy efficiency in the technological process of distribution liquid feeds in a pigsty. The liquid feeds in a pigsty are distributed to the stables via pipelines. A centrifugal pump driven by an electric motor is used to supply the liquid feed and to move it through the pipeline. The electric motor is the major electric energy consumer in the process. As shown by experimental data and as following the theory, there is a non-linear relation between the electric motor power, the pump throughput and feed humidity. The purpose of the paper is to calculate such an optimal value of the electric motor power that provides the minimal energy consumption on the process of feed distribution. The problem is solved by the Lagrange multiplier method of nonlinear mathematical programming, taking into account geometrical parameters of the pipeline, humidity and portions volumes of distributed feed. The energy saving effect is estimated and reducing power consumption is shown.

Key words: Automation, energy saving, pigs feeding, liquid feed distribution.

1. Introduction

Improvement, development and implementation of efficient energy technologies and equipments in agriculture are a way to reduce the cost of agricultural products [1, 2]. Reducing the consumption of heat and electricity can be achieved by automatic control of technological processes [1-3]. That will allow quick adjusting and optimizing the structure and parameters of the control algorithm according to real time information data about the state of the controlled biotechnical object.

Today, in the livestock industry, it is widely used technology of liquid feed distribution through pipelines [4-6]. An example of the functional scheme of such a process line is shown in Fig. 1 [7]. Liquid feed is prepared by mixing the required mass portions of dry feed and water. Then, a centrifugal pump supplies the liquid feed to the stables through the pipeline. The selector carriage successively opens and closes the faucets of the corresponding stables. The

main consumer of electricity in such a technological line for distribution of liquid feed is a centrifugal pump driven by an electric motor used to supply the liquid feed and to move it through the pipeline. The hydrostatic head H provided by the centrifugal pump is spent on overcoming the friction at moving the wet feed through the pipeline. The value of H depends on the power of the pump motor P (kW) and feed humidity W (%), and determines the throughput of the pump Q (L/s), i.e., the speed of feed distribution, as Eq. (1):

$$P = P(Q, W) \quad (1)$$

So, the reduction in energy consumption is proposed to be achieved by optimal regulation of the electric motor power and the throughput of the pump. The purpose of the paper is to calculate such an optimal value of the electric motor power that provides the minimal energy consumption on the process of feed distribution.

2. Description

To theoretically determine the exact mathematical

Corresponding author: Andrei Grigorievich Senkov, Ph.D., research field: automation of technological processes.

Fig. 1 Functional scheme of the process line for feeding pigs.

1—a control block with a microprocessor controller; 2—flowmeter for water; 3—flowmeter for liquid feed; 4—feed weigher; 5—a centrifugal pump supplying the liquid feed into the pipeline; 6—a selector carriage; 7—a pipeline.

form of the relation in Eq. (1), which is a very complicated task, there should be taken into account many factors, such as geometrical parameters of the pipeline, the speed of the wet feed flow through it and the feed humidity. Therefore, in this study, the mathematical relation between power P and practically important parameters of Q and W had been found empirically using the experimental data [7, 8] received by the authors and shown in Table 1.

Since the humidity value W of the feed distributed is determined by zootechnical requirements, so the real practical importance has the approximation of the relation in Eq. (1) between the pump motor power P and the throughput Q at any constant value of W . Based on Refs. [7, 8], there has been chosen the following approximating Eq. (2) for the data in Table 1:

$$P_{W=const} = l \cdot K_0 (W) \cdot Q^\gamma \quad (2)$$

where, l is the distance from the pump to the stable, K_0

and γ are approximating coefficients.

Therefore, to reduce the electric energy consumption in the technological process of distribution the wet feed through the pipeline, it is necessary to control automatically the power P of the electric motor used to operate the centrifugal pump. Take into account that the whole time duration of the process must be less than $t_{\max} = 30$ min, which is determined by technological requirements [7, 8].

Assume there are N stables and $i = 1 \dots N$. The authors introduce the following notation: V_i is the amount of feed that must be supplied to stable i (L); Q_i is a value of the pump's throughput at the moment of supplying the feed to stable i (L/s); P_i is electrical motor power of the pump at the moment of supplying the feed to stable i (kW); l_i is the distance from the pump to the stable i (m).

According to Eq. (2), the relation between the power P_i and throughput Q_i is as Eq. (3):

Table 1 Experimental data of electrical motor power P depending on the pump throughput Q and feed humidity W .

W (%)		Corresponding Q and P					
85.9	Q (L/s)	1.28	1.52	2.25	2.98	3.63	3.79
	P (kW)	0.80	1.20	1.60	2.30	3.40	4.20
84.0	Q (L/s)	1.32	1.69	2.33	2.96	3.41	3.82
	P (kW)	0.60	1.00	1.60	2.30	3.30	4.30
82.5	Q (L/s)	1.11	1.74	2.28	2.63	3.28	3.56
	P (kW)	0.60	1.10	1.60	2.40	3.40	4.30
80.0	Q (L/s)	0.93	1.32	1.51	1.94	2.82	3.37
	P (kW)	0.68	1.10	1.60	2.40	3.30	4.30
78.6	Q (L/s)	0.44	0.71	0.92	1.11	1.47	2.03
	P (kW)	0.70	1.10	1.70	2.40	3.30	4.30
77.0	Q (L/s)	0.28	0.53	0.85	1.10	1.20	1.33
	P (kW)	0.70	1.20	1.80	2.60	3.50	4.40

Table 2 The results of fitting the experimental data according to Eq. (2).

W (%)	77.0	78.6	80.0	82.5	84.0	85.9
γ	1.12	1.26	1.42	1.68	1.78	1.36
K_0	0.0210	0.0152	0.0064	0.0037	0.0030	0.0047

$$P_i = K_0 \cdot l_i \cdot Q_i^\gamma \quad (3)$$

where, K_0 and γ are constant coefficients, and the numeric values of K_0 and γ corresponding to the value of feed humidity W should be taken from Table 2.

The expression of Eq. (3) can be transformed to the following Eq. (4):

$$Q_i = (K_0 \cdot l_i)^{-\frac{1}{\gamma}} \cdot P_i^{\frac{1}{\gamma}} \quad (4)$$

In this way, the time spent on supplying the required amount of feed to the stable i is determined as Eq. (5):

$$t_i = V_i / Q_i \quad (5)$$

The energy consumption for supplying the stable i with feed is determined as Eq. (6):

$$E_i = P_i \cdot t_i \quad (6)$$

If transform Eqs. (5) and (6) referring to Eqs. (3) and (4), then we will have the next Eq. (7):

$$t_i = V_i \cdot (K_0 \cdot l_i)^{-\frac{1}{\gamma}} \cdot P_i^{-\frac{1}{\gamma}}; \quad (7)$$

$$E_i = P_i \cdot t_i = V_i \cdot (K_0 \cdot l_i)^{-\frac{1}{\gamma}} \cdot P_i^{1-\frac{1}{\gamma}}$$

The value of the product $V_i \cdot (K_0 \cdot l_i)^{-\frac{1}{\gamma}}$ from Eq. (7) is determined by the feed humidity W and the

distance from the pump to the stable i . So, we can designate it as Eq. (8):

$$c_i = V_i \cdot (K_0 \cdot l_i)^{-\frac{1}{\gamma}} \quad (8)$$

Therefore, the objective function (minimization of energy consumption) takes the form of Eq. (9):

$$E_\Sigma = \sum_{i=1}^N c_i \cdot P_i^{1-\frac{1}{\gamma}} \rightarrow \min \quad (9)$$

The constraint on the maximum allowed duration time of the process is as Eq. (10):

$$t_\Sigma = \sum_{i=1}^N c_i \cdot P_i^{-\frac{1}{\gamma}} \leq t_{\max} \quad (10)$$

The constraint on the maximum allowed electric motor power is as Eq. (11):

$$P_i \leq P_{\max} \quad (11)$$

Let introduce a new variable expressed in Eq. (12):

$$x_i = P_i^{-\frac{1}{\gamma}} \quad (12)$$

Then, an optimization problem can be formulated as Eq. (13):

$$E_\Sigma = \sum_{i=1}^N c_i \cdot x_i^{1-\gamma} \rightarrow \min,$$

$$\sum_{i=1}^N c_i \cdot x_i - t_{\max} \leq 0,$$

$$x_{\min} < x_i < x_{\max} \quad (13)$$

So, it has a non-linear objective function and linear inequality constraints.

To solve the optimization problem in Eq. (13), the method of Lagrange multipliers [9] was used. As a result, it was found that to minimize electric energy consumption, the pump motor should run at a constant value of the power P determined by Eq. (14):

$$P^* = t_{\max}^{-\gamma} \cdot K_0 \cdot \left(\sum_{i=1}^N V_i \cdot l_i^{\frac{1}{\gamma}} \right)^{\gamma} \quad (14)$$

In that case, the electric energy consumption for distribution the whole required volume of the wet feed can be estimated by Eq. (15):

$$E_{\Sigma}^* = P^* \cdot t_{\max} \quad (15)$$

3. Results and Discussion

The practical importance has an estimation of the reduction of energy consumption, depending on the humidity W and total volume $V_{\Sigma} = \sum_{i=1}^N V_i$ of the feed distributed at once, as these parameters are defined by zootechnical requirements and their values may vary depending on the age, weight, daily weight gain and other features of farmed animals. For example, the total volume V_{Σ} would obviously increase with the increase of the age and live mass of the livestock. Consequently, it would increase the time duration t_{Σ} of the feed distribution process. Similarly, the feed humidity W may vary within some limits for various feeds. And the less the humidity W value is, the more would be the value of t_{Σ} . So, if we assume the electric motor power P as a constant value at any values of V_{Σ} and W (i.e., the reference case without the proposed calculation of optimal value P^* by Eq. (14)), then the time duration t_{Σ} would be the maximal at the maximum value of V_{Σ} and the minimum one of W .

The initial data for the estimation are taken as the following:

$N = 24$ is the total number of the stables supplied by wet feed;

$l_0 = 30$ is the distance from the pump to the 1st

stable (m);

$l = 4$ is the distance between the two adjacent stables (m);

$V_{\min} = 500$ is the minimum total volume of the feed distributed (L);

$V_{\max} = 5,000$ is the maximum total volume of the feed distributed (L);

$t_{\max} = 30$ is the maximum allowed duration time of the feed distribution process (min);

$W_{\min} = 77\%$ is a minimum value of the humidity W of the feed;

$W_{\max} = 85.9\%$ is a maximum value of W .

As follows from Eq. (2) to decrease the energy consumption of the technological process, one should decrease the pump throughput Q . This in turn will lead to increasing the time duration t_{Σ} of the process. But according to the technological requirements, the time t_{Σ} in any case should be no more than $t_{\max} = 30$ min. So, let consider as a reference point, such a constant value of the electric motor power P of the centrifugal pump, at which a maximum total volume $V_{\max} = 5,000$ L of the feed and $W_{\min} = 77\%$ humidity, equal portions distribution into $N = 24$ stables for the maximum allowed duration time of $t_{\max} = 30$ min. Substituting the values of $V_{\max}$, $t_{\max}$, l_0 , l and N to Eq. (14) and determining the approximating coefficients K_0 and γ from Table 2, one can calculate P_{ref} by Eq. (16):

$$P_{\text{ref}} = t_{\max}^{-\gamma(W=77\%)} \times K_{0(W=77\%)} \times \left(\sum_{i=1}^N \frac{V_{\max}}{N} \cdot (l_0 + i \cdot l)^{\frac{1}{\gamma(W=77\%)}} \right)^{\gamma(W=77\%)} \quad (16)$$

So, we obtain a reference value: $P_{\text{ref}} \approx 5$ kW.

Considering a reference case, it is supposed that the value P_{ref} is constant regardless of the values of feed total volume V_{Σ} and humidity W . The choice of the reference point means that even at the worst conditions (the maximum total volume V_{Σ} and minimum humidity W), the time duration of the process would satisfy the above mentioned constraint. Substituting the numerical value P_{ref} into Eq. (7) and taking into account the data in Table 2, the estimation

Fig. 2 Reducing the energy consumption at various values of the feed humidity W .

Fig. 3 Saving the energy at various values of feed total volume V_{Σ} .

values of the energy consumption were obtained at any values of V_{Σ} and W .

Reducing the energy consumption at various values of the feed humidity W is shown in Fig. 2. And saving the energy at various values of feed total volume V_{Σ} is shown in Fig. 3. On both these figures, E_0 means the energy consumption of the process at the reference point and E_{opt} means the energy consumption of the process optimized by the proposed method.

Thus, as one can see from the Figs. 2 and 3, the proposed method of optimal power control of the pump motor takes into account geometric parameters of the pipeline, the spatial arrangement of the stables, the feed humidity and total volume, and provides reduction in energy consumption for the technological

process of distribution of wet feed. Depending on the conditions of the liquid feed, the energy saving effect may vary from 0% up to 40% for a single act of feed distribution.

4. Conclusions

This paper solved the problem of reducing the energy consumption for the process of liquid feed distribution through pipelines at pigsty farms. The proposed optimization formula calculates an optimal power value of the electric motor of centrifugal pump taking into account geometrical parameters of the pipeline, humidity and portions volumes of distributed feed, and provides the minimum total energy consumption on the process. The energy saving effect is estimated and reducing power consumption up to 40% is shown.

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