TEKA Kom. Mot. Energ. Roln. – OL PAN, 2009, 9, 395–402

EFECTIVENESS OF ENERGY AND WATER CONSUMPTION IN A POULTRY PROCESSING PLANT

Janusz Wojdalski, Bogdan Dróżdż, Agnieszka Powęzka

Department of Production Management and Engineering, Warsaw University of Life Sciences, Nowoursynowska 166, 02-787 Warsaw, janusz_wojdalski@sggw.pl

Summary. The results of research have been presented on variability of electrical energy and water consumption in a poultry processing plant with an average poultry throughput of 10000 kg. The variability of factory coefficients of electrical energy and water consumption per manufactured unit was defined while taking into account the impact of twenty-four hour processed poultry volume on the consumption of electrical energy and water. The obtained coefficients may be used to define environmental standards, eco-effectiveness and electrical energy carrier consumption forecasts as well as manufacturing costs resulting thereof.

Keywords: poultry processing, energy and water consumption, eco-effectiveness.

SPECIFICATION OF LETTER SYMBOLS APPLIED IN THIS PAPER

B_{ce1} - twenty-four hour coal equivalent consumption with value E_{t1}, kg c.e./24 h,
B_{ce2} - twenty-four hour coal equivalent consumption with value E_{t2}, kg c.e./24 h,
B_{rz} - consumption of real fuel, kg/24 h,
E_c - twenty-four hour thermal energy consumption ($E_c = B_{rz}$), MJ/24 h,
E_e - twenty-four hour active electrical energy consumption, kW· h/24 h,
E_{t1} - total energy consumption (with 1kW· h = 12MJ), MJ/24 h,
E_{t2} - total energy consumption (with 1kW· h = 3.6MJ), MJ/24 h,
E_w - total water consumption, m^3/24 h,
K_m - installed power of electrical appliances per 1000 kg of processed poultry in twenty-four hours ($K_m = P \cdot Z^1$) kW/Mg of poultry,
P - installed power of electrical appliances in kW,
r - correlation coefficient,
Q_{ce} - calorific value of coal equivalent (29.3076 MJ/kg per unit),
- calorific value of real fuel, MJ·kg^{-1},
W_c - factory coefficient of thermal energy consumption per manufactured unit in twenty-four hours ($W_c = E_c \cdot Z^1$), MJ/Mg of poultry,
W_e - factory coefficient of electrical energy consumption per manufactured unit in twenty-four hours ($W_e = E_e \cdot Z^1$), kW· h/Mg of poultry,

W_{ce1} - factory coefficient of coal equivalent consumption per manufactured unit, with 1 kW· h = 12 MJ, kg c.e./Mg of poultry,

W_{ce2} - factory coefficient of coal equivalent consumption per manufactured unit with 1 kW· h = 3.6MJ, kg c.e./Mg of poultry,

W_{rz1} - factory coefficient of total consumption of electrical energy in real fuel per manufactured unit (with 1 kW· h = 12MJ), MJ/Mg of poultry,

W_{rz2} - factory coefficient of consumption of total electrical energy in real fuel per manufactured unit (with 1 kW· h = 3.6MJ), MJ/Mg of poultry,

W_{t1} - factory coefficient of consumption of total electrical energy per manufactured unit (with 1 kW· h = 12MJ), MJ/Mg of poultry,

W_{t2} - factory coefficient of consumption of total electrical energy per manufactured unit (with 1 kW· h = 3.6MJ), MJ/Mg of poultry,

W_w - factory coefficient of water consumption per manufactured unit in twenty-four hours ($W_w = E_w \cdot Z^1$), m^3/Mg of poultry,

Z - twenty-four hour throughput of poultry, Mg/24 h,

Z_h - twenty-four hour throughput of poultry, poultry units /24h.

INTRODUCTION

In the light of the presented research, effectiveness can be defined as a result of economic (industrial) activity representing the obtained effect / outlay quotient. It can be expressed by the application of per unit consumption of electrical energy or water, while taking into account parameters of the processing plant. Energy effectiveness can be defined as a decrease in the consumption of energy, which takes place at the stage of transformation, transmission and its final use. This can result from technology changes ensuring the same or a higher level of manufacturing or services. The above-mentioned process is also defined as eco-effectiveness consisting in obtaining an improvement of environmental effects which consists in energy saving, economical use of natural resources, reduction in emission of environment polluting substances as well as lower waste production at every stage of poultry manufacturing and processing [Pagan et al., 2002, Pelletier, 2008, Truchliński et al., 2001].

The demand for energy carriers in poultry processing plants depends on numerous factors; the following are the most frequently mentioned: throughput volume and structure, thermo-physical properties of the raw material, the applied production technology, production processes mechanization degree, human labour share and manufacturing capacity utilization rate [Corry et al., 2007, Fritzson & Berntsson, 2006, James et al., 2006, Marcotte et al., 2008, Somsen et al., 2004]. The quantities of the used energy carriers are allowed for in the integrated license representing a collection of requirements and principles aimed at effective environment protection taking into account the best manufacturing techniques available [WS Atkins Int., 1998].

The problems touched on hereinabove are dealt with in such publications as IFC – World Bank Group [2007], Ramirez et al. [2006]. However, the reasons for variability of energy carriers and water in poultry processing plants of different sizes have not been fully accounted for.

The target of this paper was to determine the effectiveness of energy and water management in a small-size poultry processing plant. Besides, this paper is aimed at supplying materials useful in the construction of models of poultry-processing plants as energy and water users as well as at seeking interdependences between the poultry slaughter volume and the demand for energy carriers, constituting a component of manufacturing eco-effectiveness.

MATERIAL AND METHODOLOGY

The material for study was collected in a poultry plant which employs a total of 50 workers and which processes an average of about 4260 poultry units in twenty-four hours, while the throughput volumes range from 2130 to 6580 poultry units. The slaughtered broiler chicken volume ranged from 4290 to 19620 kg/ 24 h and amounted to an average of 10760 kg/ 24 h. The plant's useful surface was 1325 m^2 and the cubic capacity 7347 m^3.

The total installed power of plant P electrical appliances amounted to 150.53 kW. A mean value of the K_m coefficient for the twenty-four hour period amounted to 16 kW/Mg of the processed poultry volume. For the implementation of the objective of this paper, the authors used a model of a food processing plant as an energy carrier user and factory coefficients of electrical energy and water consumption per one manufactured unit as defined by the method presented in a study published by Wojdalski and Dróżdż [2006].

In only few studies published up to date (e.g. Dróżdż et al., 2006, Dróżdż and Wojdalski, 2004) thermal energy consumption, electrical energy consumption or water consumption have been presented, mostly on a separate basis. For instance, Jekayinfa (2007) also included the human labour input in three plants with different production process mechanization degrees. It should be pointed out that from the point of view of costs and selection of a specified technology, it is important to use a coefficient that would comprise the total energy consumption both in the processing plant and that expressed in energy derived from alternative sources. For this end, the following factory coefficients of electrical energy consumption per manufactured unit were adopted:

$$W_{t1} = E_{t1} \cdot Z^{-1} = \left(12 \cdot E_e + B_{rz} \cdot Q_w^r\right) \cdot Z^{-1} \text{ MJ/kg of poultry,}$$

$$W_{t2} = E_{t2} \cdot Z^{-1} = \left(3.6 \cdot E_e + B_{rz} \cdot Q_w^r\right) \cdot Z^{-1} \text{ MJ/kg of poultry.}$$

The above-mentioned coefficients were expressed in t.o.e. (ton of coal equivalent):

$$W_{ce1} = W_{t1}/Q_{ce},$$

$$W_{ce2} = W_{t2}/Q_{ce}.$$

The coefficients were also expressed in energy that may be obtained from different renewable sources, by applying the following formulas:

$$W_{rz1} = W_{t1}/Q_w^r,$$

$$W_{rz2} = W_{t2}/Q_w^r.$$

An assumption was made that a twenty-four hour poultry throughput volume (Z) affects the demand for energy carriers in a processing plant. The up-to-date studies have shown that this is the most useful factor for an assessment of an impact of poultry processing plants on the environment and for the determination of the best manufacturing techniques available [Wojdalski and Dróżdż 2004, WS Atkins Int. 1998].

In order to determine the dependence between the poultry throughput volume (Z) and energy carrier and water consumption (E) – both being real values observed in practice, the following equation was adopted:

$$E = b + aZ,$$

wherein: E – consumption of energy carriers and water (the variable explained – E_e, E_c, E_w), Z – the poultry throughput volume (the explaining variable).

With those conditions fulfilled:

$$aZ \geq b \text{ and } Z \geq 0,$$

the application of the obtained regression equations allowing for correlation (r) and determination coefficients (R^2) enables partial explanation of the problem under discussion in the analyzed poultry processing production plant.

A similar procedure was adopted to define how the poultry throughput volume (Z) affects coefficients of electrical energy and water consumption per manufactured unit (W_e, W_c, W_w).

RESULTS AND DISCUSSION

Table 1 presents 24-hour variability ranges of energy carriers and water consumption within the period of 17 labour days.

By way of supplementing the data contained in the table, it can be added that average values of coefficients of per unit consumption of electrical energy (W_e), thermal energy (W_c) and water (W_w) reached respectively 123.6 Wh/1000 poultry units, 485 MJ/1000 poultry units and 7.12 cubic meters/1000 poultry units.

The biggest 24-hour fluctuations were observed in thermal energy consumption (6 times) and the lowest in 24-hour water consumption (by approximately 70%).

Table 1. Consumption of energy carriers and water in the examined period, taking into account the poultry throughput volume

The dependent variable, energy carrier and water consumption coefficient	Symbols and units	Range	Average
Electrical energy	E_e [kWh/24 h]	392.2 – 705.6	539.3
	W_e [kWh/Mg of poultry]	35.96 – 330.2	95.13
Thermal energy	E_c [MJ/24h]	450 - 2706	2120
	W_c [MJ/Mg of poultry]	61 - 342	207
Total energy	E_{t1} [MJ/24 h]	5157 - 11051	8591
	W_{t1} [MJ/Mg of poultry]	628 - 1507	798
	E_{t2} [MJ/24 h]	1862 - 5124	4061
	W_{t2} [MJ/Mg of poultry]	211 – 680	377
Coal equivalent	B_{ce1} [kg.c.e./24 h]	176.0 – 377.0	293.1
	W_{ce1} [kg c.e./Mg of poultry]	21.43 – 51.42	27.93
	B_{ce2} [kg.c.e./24 h]	63.53 – 174.83	138.56
	W_{ce2} [kg c.e./Mg of poultry]	7.20 – 23.20	12.86
Water	E_w [m^3/24 h]	20.69 – 36.21	29.66
	W_w [m^3/Mg of poultry]	1.85 – 5.79	3.06

Having subjected the collected data to the statistical analysis method, linear regression equations expressing variability of electrical energy and water consumption were obtained, which were presented in Table 2.

Table 2. The effect of 24-hour poultry throughput (Z_h) on the consumption of energy carriers

Item	Regression equation	r (R^2)	Symbols
1.	$E_e = 0.039 \cdot Z_h + 366.4$	0.437 (0.191)	E_e [kW·h/24 h] Z_h [poultry units/24h]
2.	$W_e = -0.028 \cdot Z_h + 253.25$	0.727 (0.529)	W_e – [kW·h/poultry units] Z_h – [poultry units/24h]
3.	$E_w = 0.002 \cdot Z_h + 18.08$	0.735 (0.540)	E_w [cubic meters/24 h] Z_h [poultry units/24h]
4.	$W_w = -10^{-6} Z_h + 0.013$	0.837 (0.701)	W_w [cubic meters/poultry unit] Z_h [poultry units/24h]
5.	$E_c = 0.0003 \cdot Z_h + 0.692$	0.495 (0.245)	E_c [MJ/24 h] Z_h [poultry units/24h]
6.	$W_c = -0.033 \cdot Z_h + 0.639$	0.192 (0.037)	W_c [MJ/ poultry unit] Z_h [poultry units/24h]

The poultry throughput volume affected the most substantially the factory water consumption per manufactured unit (by more than 70%). 24-hour water consumption was also accounted for in 54% by the slaughtered poultry volume. The factory electrical energy consumption per manufactured unit was accounted for in a smaller degree (in about 53% of the slaughtered poultry volume). In practice, no important interdependence between the slaughtered poultry volume and the thermal energy consumption (steam and hot water) was found.

The obtained results were compared with the data comprised in the studies by IFC World Bank Group, 2007. It results from the herein above quoted paper that the total electrical energy consumption per manufactured unit in EU poultry plants amounted to 0.152 – 0.86 kW·h/kg of the slaughtered poultry volume, which, after conversion into comparable units as contained in this study, amounts to 547.2 – 3096.0 MJ/Mg of poultry.

The comparison proves that in the plant under study the electrical energy consumption was below the average electrical energy consumption level in similar plants in the EU. The quoted source also provides the results of Scandinavian studies on electrical energy consumption per manufactured unit (W_e = 0.16 – 0.86 kW·h/kg of the slaughtered poultry volume). In the plant under study, the average value of this coefficient amounted to approximately 0.1 kW·h/kg of the slaughtered poultry volume, which is evidence of low electrical energy consumption of the manufacturing process.

According to WS Atkins Int. [1998], energy effectiveness (expressed by the W_e coefficient), amounts on average to 840 kW·h/Mg for the slaughtered poultry volume in Polish poultry plants (to homogenize the units, the authors of the present paper adopted the mass of one poultry unit to be 2.5 kg).

The factory water consumption per one manufactured unit in the plant under study is similar to the bottom consumption level in the EU (according to IFC Word Bank Group, 2007 the bottom value of water consumption per one manufactured unit amounted to 5.07 cubic decimetre/kg of the poultry slaughtered).

Coefficients presented in Table 1 may be applied for the analysis of a manufacturing plant environmental impact.

With coefficients W_{t1} and W_{t2} converted, and allowing for calorific values of different fuels contained in the literature on the subject [Niedziółka and Zuchniarz, 2006, Rosiński et al., 2006], Table 3 presents the consumption of the referred-to energy carriers (real fuel). Calorific values expressed in MJ/kg of real fuel were used for these calculations.

Table 3. Coefficients of per manufactured unit consumption of energy deriving from different fuels

Energy carriers	Calorific value , [MJ/kg]	Coefficients of consumption of fuels per manufactured unit	
		W_{rz1} [kg/Mg of poultry]	W_{rz2} [kg/Mg of poultry]
Vegetable oil	37.5	21.3	10.0
Liquid flammable waste	37.2	21.4	10.1
Wheat straw	17.3	46.1	21.8
Barley straw	16.1	49.6	23.4
Maize straw	16.8	47.5	22.4
Colza straw	15.0	53.2	25.1
Sawdust	17.0	46.9	22.2
Wood powder	19.3	41.9	19.5
Willow chips	16.5	48.4	22.8
Pellets	18.0	44.3	20.9
Straw briquettes	17.1	46.6	22.0
Wood briquettes	18.0	44.3	20.9

The selected numerical data comprised in Table 3 may be of importance when analyzing possibilities of substituting traditional fuels by energy derived from alternative sources.

The results comprised in this paper may serve for comparison with those of other poultry processing plants both in terms of their specific characteristics arising from manufacturing technology and of the applied research methods [Amorima 2007, Jekayinfa 2007, Matsumura and Mierzwa 2008, Nery et al. 2007 and Yetilmezsoy and Sakar 2008].

CONCLUSIONS

The poultry processing plant under analysis was characterized by decreased values of coefficients of energy consumption per manufactured unit as compared with those found in the quoted literature. This resulted from a complete utilization of its manufacturing capacity. At the same time, water consumption per manufactured unit was substantially lower than the results achieved in similar EU plants, which proves that a high manufacturing eco-effectiveness was reached when that carrier was used. The conducted research proved that active monitoring is expedient as one of the best techniques of energy management in conjunction with the current production volume. The results presented in this paper may help to verify environmental standards as well as to implement principles of cleaner manufacturing processes. Besides, the obtained coefficients may be of importance in an assessment of manufacturing costs and emission of pollutants into the atmosphere and waters.

REFERENCES

Amorima A.K.B., I.R. de Nardi, V. Del Nery, 2007: Water conservation and effluent minimization: Case study of a poultry slaughterhouse. Resources, Conservation & Recycling, 51, 93-100;

Corry J.E.L., S. J. James, G. Purnell, C.S. Barbedo-Pinto, Y. Chochois, M. Howell, C. James, 2007: Surface pasteurisation of chicken carcasses using hot water. Journal of Food Engineering, 79, 913–919;

Dróżdż B., J. Wojdalski, 2004: Selected aspects of energy consumption in poultry processing plants. Annals of Warsaw Agricultural University. Agriculture (Agricultural Engineering). Warsaw, 45, 69-74;

Dróżdż B., J. Wojdalski, J. Sawicki, G. Gujski, 2006: Czynniki technologiczne wpływające na zużycie wody w zakładzie przetwórstwa drobiarskiego. Postępy Techniki Przetwórstwa Spożywczego. Wyższa Szkoła Menedżerska. Warszawa, 1, 51-54;

Fritzson A, Th. Berntsson, 2006: Energy efficiency in the slaughter and meat processing industry - opportunities for improvements in future energy markets. Journal of Food Engineering, 77, 792–802;

IFC – World Bank Group, 2007: Environmental, Health, and Safety Guidelines for Poultry Processing, April 30, 1-18;

James C., C. Vincent, T.I. de Andrade Lima, S.J. James, 2006: The primary chilling of poultry carcasses - a review. International Journal of Refrigeration, 29, 847-862;

Jekayinfa S. O., 2007: Energetic Analysis of Poultry Processing Operations. Leonardo Journal of Sciences, Issue 10, 77-92;

Marcotte M. A.R. Taherian, Y. Karimi, 2008: Thermophysical properties of processed meat and poultry products. Journal of Food Engineering, 88, 315–322;

Matsumura E.M., J.C. Mierzwa, 2008: Water conservation and reuse in poultry processing plant—A case study. Resources, Conservation and Recycling, 52, 835–842;

Nery V., I.R. de Nardi, M.H.R.Z. Damianovic, E. Pozzi, A.K.B. Amorimd, M. Zaiat, 2007: Long-term operating performance of a poultry slaughterhouse wastewater treatment plant. Resources, Conservation & Recycling, 50, 102–114;

Niedziółka I., Zuchniarz A., 2006: Analiza energetyczna wybranych rodzajów biomasy pochodzenia roślinnego. MOTROL, Motoryzacja i Energetyka Rolnictwa. Tom 8A. Lublin, 232-237 (Energetic analysis of seleted types of plant-derived biomass. MOTROL, Motorization and power engineering in agriculture);

Pagan R., M. Renouf, P. Prasad, 2002: Eco-efficiency manual for meat processing. Meat and Livestock Australia Ltd.;

Pelletier N., 2008: Environmental performance in the US broiler poultry sector: Life cycle energy use and greenhouse gas, ozone depleting, acidifying and eutrophying emissions. Agricultural Systems, 98, 67–73;

Ramirez C.A., M. Patel, K. Blok, 2006: How much energy to process one pound of meat? A comparison of energy use and specific energy consumption in the meat industry of four European countries. Energy, 31, 2047–2063;

Rosiński M., Furtak L., Łuksa A., Stępień A., 2006: Wykorzystanie olejów roślinnych i urządzeń do spalania w procesach suszarniczych. MOTROL, Motoryzacja i Energetyka Rolnictwa. Tom 8A. Lublin, 243-250 (Utilization of vegetable oils and incinerating devices in drying processes. MOTROL, Motorization and power engineering in agriculture);

Somsen D., A. Capelle, J. Tramper, 2004: Production yield analysis in the poultry processing industry. Journal of Food Engineering, 65, 479–487;

Truchliński J., W. Podgórski, R. Koper, W. Lebiedowicz, 2001. Bioenergetyczne aspekty produkcji brojlerów kurzych. MOTROL, Motoryzacja i Energetyka Rolnictwa. Tom IV. Lublin, 333-340; (Bioenergetic aspects of production of chicken broilers. MOTROL, Motorization and power engineering in agriculture, volume IV);

Wojdalski J., Dróżdż B., 2006: Podstawy analizy energochłonności produkcji zakładów przemysłu rolno-spożywczego. MOTROL, Motoryzacja i Energetyka Rolnictwa. Tom 8A. Lublin, 294-304; (Fundamentals of analysis of energy consumption in agricultural and food processing plants. MOTROL, Motorization and power engineering in agriculture, volume 8A)

WS Atkins Int., 1998: Ochrona środowiska w przemyśle rolno-spożywczym. Standardy środowiskowe. FAPA, Warszawa, 37-41, 78, 82, 85, 87, 105; (Environmental protection in agricultural and food industry. Environmental standards. FAPA, Warsaw, 37-41, 78, 82, 85, 87, 105);

Yetilmezsoy K., S. Sakar, 2008: Development of empirical models for performance evaluation of UASB reactors treating poultry manure wastewater under different operational conditions. Journal of Hazardous Materials, 153, 532–543.

EFEKTYWNOŚĆ ZUŻYCIA ENERGII I WODY W ZAKŁADZIE PRZETWÓRSTWA DROBIARSKIEGO

Streszczenie. Przedstawiono wyniki badań nad zmiennością zużycia energii i wody w zakładzie przetwórstwa drobiarskiego o średnim przerobie ok. 10000kg drobiu. Określono zmienność zakładowych wskaźników jednostkowego zużycia energii elektrycznej i cieplnej oraz wody. Wyjaśniono wpływ dobowego przerobu drobiu na zużycie energii i wody. Otrzymane wyniki mogą być wykorzystywane do określania standardów środowiskowych, ekoefektywności oraz prognozowania zużycia nośników energii i wynikających stąd kosztów produkcji.

Słowa kluczowe: przetwórstwo drobiarskie, zużycie energii i wody, ekoefektywność.