ENERGY EVALUATION OF WATER ADSORBENT REGENERATION NODE OF BIOETHANOL DEHYDRATION FACILITY

Adolfs Rucins, Kristine Zihmane-Ritina, Gunars Bremers, Gints Birzietis, Arturs Baltins, Arnolds Skele, Juris Bergs
Latvia University of Agriculture
gints.birzietis@llu.lv

Abstract. In order to reduce energy consumption in production of bioethanol, new bioethanol dehydration method was developed at Latvia University of Agriculture which has received E-patent No. EP 2316549 B1 "*Method and device for removing water from ethanol by combined adsorption and distillation*". Whereas for testing the bioethanol dehydration method variants, an experimental device has been created at the Agency "The Research Institute of Agricultural Machinery" of Latvia University of Agriculture in cooperation with the Institute of Physical Energetics within ERDF project *"Development of measuring devices for establishing of innovative bioethanol dehydration technology and its parameters" No. 2010/0281/2DP/2.1.1.1.0/10/APIA/VIAA/003* in order to perform the evaluation of constructive nodes of the developed method for obtaining optimal solutions. Considering the fact that regarding developed experimental device patent No. LV110068 *"Adsorbent granules regeneration block of bioethanol semi-dry congruent dehydration facility"* has been registered at the Latvian Patent Office, which serves as a priority document to the European patent application No. EP2524722 A1, *"Compact set of bioethanol semi-dry congruent dehydration facility"*, that is why the facility necessary for the implementation of method technology and its nodes are only shown in the form of block schemes. Energy consumption results of the performed water adsorbent regeneration node of bioethanol dehydration technological facilities, as well as consequent conclusions are shown in research results.

Keywords: bioethanol dehydration, adsorbent dehydration node, energy consumption.

Introduction

It is assumed that energy efficiency of bioethanol dehydration is defined as heating vapour consumption per one kilogram of the produced bioethanol. Leading manufacturers of technological facilities, introducing various ways to economize energy, try to reduce this consumption by comparing it with the initial, the so-called "traditional technology" vapour consumption.

In practice the amount of heating vapour is calculated for the entire dehydration cycle that includes mash distillation, rectification, and water adsorption in molecular filters.

The available energy consumption calculations for mash distillation indicate that both technologies have common functional technology beginning node, but bioethanol dehydration concept does not include that. This approach is applied by world renown traditional bioethanol technological facility manufacturer Katzen (USA), which indicates that heating vapour consumption for rectification and dehydration in molecular filters is from 1.8 to 2.5 kg [7]; however, Wiegand (Germany) and Vogelbusch (Austria) indicate respectively 1.5 and 1.2 kg to one produced litre of bioethanol [5]. It should be mentioned that the company Vogelbusch as energy consumption of traditional technology indicated 3.5 $kg \cdot l^{-1}$, pointing out its decrease in partly integrated system to 2.0 $kg \cdot l^{-1}$, but in fully integrated system to 1.25 $kg \cdot l^{-1}$ [8].

The new bioethanol dehydration technology [1] and facility [2] that are based on bioethanol semi-dry congruent dehydration principle when both stages are combined together, where water separation from spirit takes place simultaneously in the process of water adsorption and rectification were used in the performed researches [3]. Energy consumption is equal to heating vapour consumption to one produced bioethanol volume unit and the number of separated water units.

Continuing the previously started researches of the technological facility of the new bioethanol dehydration method [4], we have performed researches of bioethanol dehydration technological facility adsorbent node energy consumption researches for heating vapour per one produced bioethanol volume unit and per separated water amount unit.

The performed energy consumption researches are based on facility's operation principle that water separation from spirit takes place simultaneously in way of water adsorption and rectification, in cohesion less, downwards moving wet adsorbent granule layer, continuously renewing it by adding fresh active adsorbent granules at its top part which in downwards movement gradually saturate with water, absorbing it from the injected dehydratable spirit vapour in the middle part, but from the lower part of the layer discharge overworked granules saturated with water. Complete research facility principal construction scheme has been depicted in Fig. 1.

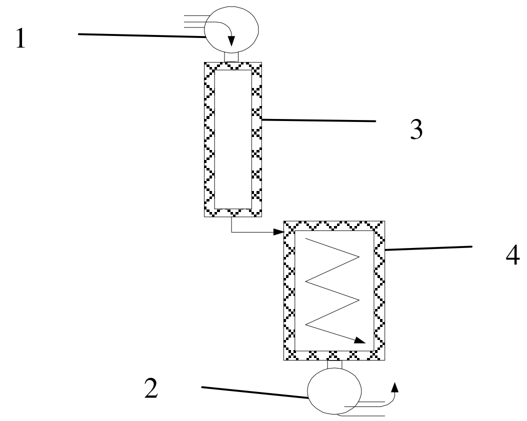

Fig. 1. **A principal general view of the experimental equipment:** 1 – the sealing/dosing units; 2 – the dosing units for the water adsorbent granules, 3 – the bioethanol dehydration column; 3 – the regenerator for the water adsorbent granules

Experimental facility structure used for the research of granule regeneration process can be figuratively divided into four layers where the necessary temperature is maintained automatically (Fig. 2). Electrical heaters that provide the necessary energy supply for granule regeneration are inserted in layers 2–2 and 4–4. The calculated regenerator heating surface area is 2.02 m^{-2}.

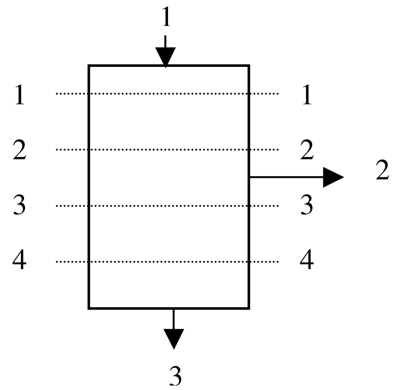

Fig. 2. **Scheme of experimental facility's water adsorption granule regenerator:** 1 – inlet; 2 – vapour extraction; 3 – discharge

Materials and methods

Water adsorbent regeneration node is filled with granules of defined humidity (Table 2, 3). Automatically adjusting heating regime to temperature of 300 ºC is set in regenerator. Simultaneously starting automatic granule temperature registration in the levels of the facility indicated in Fig. 2. In the defined time period part of adsorbent granules is discharged from the facility, replacing them by granules with specified humidity (Table 2, 4). Time is calculated from the first added portion of granules up to regenerator discharge of water adsorption granules. With this moment automatic parameter control and registration of all testing process regimes is started: granule portion discharge and adding time intervals, mass of discharged and added granule portion, humidity of discharged granules, temperature of granules in various levels of facility, amount of electrical energy used for heating.

CAS DB–1H scales are used for determining the granule mass released through granule dispenser, where measuring precision is ± 50 g, whereas laboratory scales KERN 440–35N are used for testing the granule humidity where measurement precision is within the boundaries of ± 0.01 g. Electrical heating elements with capacity of 2 kW are used for energy supply.

Precisely regulated temperature is maintained by K series thermo regulators K-31 (Technologic) where temperature is measured by K type thermo pairs that are connected with data logger TC-08 (Pico Technology Ltd., software Picolog) for temperature registration where the measurement range is from -270 ºC to +1820 ºC and the measurement precision is within the boundaries of ± 0.5 ºC.

Registration of consumed electrical energy is performed with aerometer PM-300 whose reading precision is ± 0.01 kWh^{-1} and registration precision is within the boundaries of ± 5 % from the sum.

Three samples (≈ 6 g each) are obtained from each level's places (Fig. 2) for determining granule humidity by weighing and heating up (≈ 250 ºC) each for at least 20 minutes.

Humidity amount calculations are made according to formula (1).

$$m = \frac{m_1 - m_2}{m_1} 100 , \tag{1}$$

where m – granule humidity, %;
m_1 – granule mass before heating, g;
m_2 – granule mass after heating, g.

Results and discussion

Granule temperatures registered in one of the tests in different levels of the facility are provided as an example in Table 1. In remaining tests results were similar that is why they are not repeated. All energy consumption data obtained in all tests are compiled in Table 2.

Table 1

Granule temperature in various levels of facility

Item No.	**Measuring interval, min.**	**Temperature in levels of facility, ºC**				
1	2	3	4	5	6	7
-	-	4–4...	3–3...	2–2	1–1	At discharge
1	00:00:00	236.4	312.1	271.7	296.9	264.....
2	00:10:00	257.8	299.3	223.2	179.4	-
3	00:20:00	267.1	301.6	228.9	198.7	-
4	00:30:00	229.8	302.0	229.7	213.7	256.....
5	00:40:00	246.2	300.5	235.9	226.8	-
6	00:50:00	262.3	296.1	227.2	181.0	-
7	01:00:00	271.4	296.4	235.2	204.0	273......

Table 2

Energy consumption calculation output data and results

No. of test	**Size of granule flow, kg·h^{-1}**	**Granule humidity,%**		**Electrical energy consumption, kWh**		**Amount of separated water, kg·h^{-1}**	**Energy consumption, kJ·kg^{-1}**
		input	**discharg e**	**total**	**net**		
1	2	3	4	5	6	7	8
1	1.5	12.4	2.0	1.02	0.62	0.178	12539
2	3.0	12.4	3.4	1.14	0.74	0.309	8621
3	4.5	13.1	5.7	0.96	0.56	0.384	5250
4	5.6	13.0	4.5	1.43	1.03	0.70	5100

Net electrical energy consumption has been determined from total consumption reducing energy losses in the surrounding environment that were determined in previous tests [4].

Formula (2) is used for the calculation of separated water amount:

$$W = M^1 \frac{M^1(w^1 - w^2)}{100 - w^1}, \tag{2}$$

where: M^1 – mass of granules inserted in the facility, kg·h^{-1};
w^1 – humidity of granules inserted in the facility, %;
w^2 – humidity of granules discharged from the facility, %.

From relation it occurs that energy consumption is 1 kWh = 3600 kJ per one kilogram of the separated water. Results of the calculation show that water adsorption granule regeneration energy efficiency can be expressed by relating to one kilogram of water, separated in the process of dehydration. In traditional technology it is 32311 kJ·kg^{-1} [5] or converting to heating vapour consumption – 14.1 kg^{-1} steam to one kilogram of separated water.

In tests of our experimental device (Table 2, column 8) it was determined that energy consumption for the separation of one kilogram of water is 5100-12539 kJ·kg^{-1}. Consumption differences are defined by both granule feedthrough intensity, as well as general drying process specifics – the smaller the final humidity of the drying material, the higher the specific energy consumption is.

It is assumed that bioethanol dehydration energy efficiency is expressed as heating vapour consumption per one kilogram of bioethanol or one kilogram of separated water. Recalculating the consumed energy amounts from our tests into heating vapour, the results are as follows: Test No. 1 – 5.47 kg^{-1}, Test No. 2 – 3.75 kg^{-1}, Test No. 3 – 2.29 kg^{-1} and Test No. 4 – 2.22 kg^{-1} per one kilogram of separated water. In traditional technologies it is 14.1 kg^{-1} of steam vapour per one kilogram of separated water [5].

Conclusion

1. The performed bioethanol dehydration facility water adsorption granule regeneration node researches show that considerable constructive and energy efficiency improvements are possible in the creation of bioethanol producing facilities.
2. Results obtained in experimental facility tests confirm that energy consumption difference for the separation of one kilogram of water is influenced both by granule feedthrough intensity, as well as general drying process specifics – the smaller the final humidity of the drying material, the bigger the specific energy consumption.
3. Taking into account that the greatest part of energy consumption is necessary for regeneration of water adsorption granules and compared to the consumption defined in our researches – 5100-12539 kJ·kg^{-1} – with traditional energy consumption – 32311 kJ·kg^{-1}, considerable improvements of energy efficiency (even up to 70 %) are possible.
4. The final evaluation of the new technology bioethanol dehydration experimental facility construction and energy efficiency will be possible after performing tests of the remaining technological nodes.

Acknowledgements

This research was carried out with the support of European Regional Development Fund project Nr.2010/0281/2DP/2.1.1.1.0/10/APIA/VIAA/003.

References

1. European Patent Application Nr. EP2316549, date of publication: 04.05.2011., EPO Bulletin 2011/18, inventors: Bremers G., Blija A., Skele A., Birzietis G., Danilevics A. Method and device for removing water from bioethanol by combined adsortion and distillation. Available at: https://data.epo.org/publication-server/rest/v1.0/publication-dates/20110504/patents/EP2316549NWA1/document.pdf.

2. European Patent Application Nr. EP 2524722 A1, date of publication: 21.11.2012., EPO Bulletin Nr. 2012/47, inventors: G.Bremers, A.Ruciņš, K.Zihmane-Ritina, G.Birzietis, A.Baltins, A. Skele, J. Bergs. Device for semi-dry congruent dehydration of bioethanol. Available at: https:// data.epo.org/publication-server/rest/v1.0/publication-dates/20121121/patents /EP2524722NWA1/ document.pdf.
3. Bremers G., Birzietis G., Blija A., Skele A., Rucins A., Danilevics A. Evaluation Usability of Water Adsorption and Rectification in Dehydration of Bioethanol. Proceedings of the 9tn International Scientific Conference, Engineering for Rural Development, Jelgava, Latvia, 27-28 May 2010; pp. 154-157, ISSN 1691-5976.
4. Rucins A., Zihmane-Ritina A., Bremers G., Vilitis O., Birzietis G., Baltins A., Skele A., Bergs J. Exploration of Technological Equipment for Bioethanol Dehydration. Proceedings of the 11th International Scientific Conference “Engineering for Rural Development”, Jelgava, Latvia, 2012, pp. 406-411, ISSN 1691-5976.
5. F.O. Licht’s World Ethanol and Biofuels Report, Vol 6, No 12, Feb. 26, 2008. Available at: http://www.gea-wiegand.com/geawiegand/cmsdoc.nsf/WebDoc/ndkw73fbuc.
6. Spravočņik po proizvodsvu spirta. Moskva, Ļegkaja i pišķevaja prom., 1981. - 336 s.5.
7. Katzen Ethanol distillation: the fundamentals. R. Katzen, P.W. Madson and G.D. Moon, Jr KATZEN International, Inc., Cincinnati, Ohio, USA. pp 269-288. Available at: http://pdfsb.com/readonline/6246684666417037576e5a384348356a56413d3d-200984
8. Нові енергоефективні технології для виробництва етанолу. Доповідач: Т.Шульц, Фогельбуш, Австрія. Міжнародна промислова конференція «Біопаливо. Україна – 2008», 2-4 квітня 2008 р., Україна, м.Київ. Available at: http://www.biofuelsukraine.com /2009_en/agenda.html.