EXPLORATION OF TECHNOLOGICAL EQUIPMENT FOR BIOETHANOL DEHYDRATION

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Abstract. A new bioethanol dehydration method has been developed at the Latvia University of Agriculture (LUA), for which an application has been filed for an EU patent. The equipment which is necessary for the implementation of the technology of the method in this application is given as possible recommendations in the form of draft variants. Experimental equipment is being developed now at the Research Institute of Agricultural Machinery, Latvia University of Agriculture, for testing the possible variants in which testing of all the constituent parts of the equipment is envisaged. The publication presents the data of the already conducted research in thermal insulation of the sealing/dosing units of the water adsorbent granules, the granule regenerator and the rectification column, as well as the resulting consequences. But within the framework of a project, in cooperation with the Institute of Physical Energetics, a device is developed which controls the composition of the products involved in the technological process.

Keywords: bioethanol dehydration, dosing equipment for the adsorbent granules, thermal insulation of the equipment.

Introduction

The technology mostly used at present in the production of bioethanol is an alcohol dehydration technology when, first of all, a part of water is separated in the conventional rectification columns by rectification but the remaining water is then adsorbed with molecular grids [1].

A new bioethanol dehydration method has been developed at the Latvia University of Agriculture (LUA) based on the bioethanol semi-dry congruent dehydration principle [2] for which an application has been filed for an EU patent. On July 13, 2010 it was accepted for consideration under No. 10 169 387.7, and on November 10, 2011 the European Patent Office made a principal decision about granting a patent. A technological block scheme of this method has been presented at the *10th International Scientific Conference "Engineering for Rural Development" which took place at the LUA* Faculty of Engineering on May *26 – 27, 2011* [3].

In order to implement the developed technology and carry out testing of the structural units to achieve optimum solutions, experimental equipment for testing the variants of the bioethanol dehydration technology has been created within the framework of the European Regional Development Fund project "*Innovative bioethanol dehydration technologies and elaboration of the measuring equipment for the determination of its parameters" No.2010/0281/2DP /2.1.1.1.0/10/APIA/VIAA/003* at the Research Institute of Agricultural Machinery, Latvia University of Agriculture, in cooperation with the Institute of Physical Energetics (IPE). It is intended that the developed and tested structure of the equipment will also be filed as a patent application; therefore, details cannot be disclosed to a full extent.

The parameters of the tested parts are evident in the principal general view of the experimental equipment in Figure 1. They are units of the equipment for dosing/sealing the water adsorbent granules (1; 2) and thermal insulation of the granule regenerator and the rectification column (3).

When conducting further tests of the bioethanol dehydration technological process and evaluation of the equipment, control of the composition of the products involved in the process will be necessary in several technological steps. For this purpose a device has been worked out in cooperation with the IPE, allowing detection of ethanol concentration in the mixture of such two dielectric liquids as bioethanol and water, which is based on the difference of the dielectric constants of both components in this mixture. The ethanol concentration changing in such a mixture, there is a corresponding change in its dielectric constant. By means of a capacitive liquid sensor the capacity of which, in its turn, is determined by the dielectric constant of the liquid mixture, measuring devices of ethanol concentration are created on the basis of the measurements of the reactive component of the complex conductivity of the sinusoidal alternating current of such a capacitive sensor.

The measuring device consists of two functional blocks. The sensor block of the measuring device comprises a capacitive sensor and a thermosensor for thermocompensation of the concentration measurements, as well as two synchronised high precision direct digital synthesis controlled generators connected in an original configuration, a synchrodetector, a 24-bit analogue-digital convertor, and other components of the scheme. A microcontroller is used for the control of the measuring device, registration and processing of the results. Another – a distantly placed block for the indication of the measurements – includes an indicator – a display, another microcontroller, an electronic clock and a calendar. It is intended to complete this block with a wireless computer network standard *Bluetooth* which would ensure wireless information exchange with the computer.

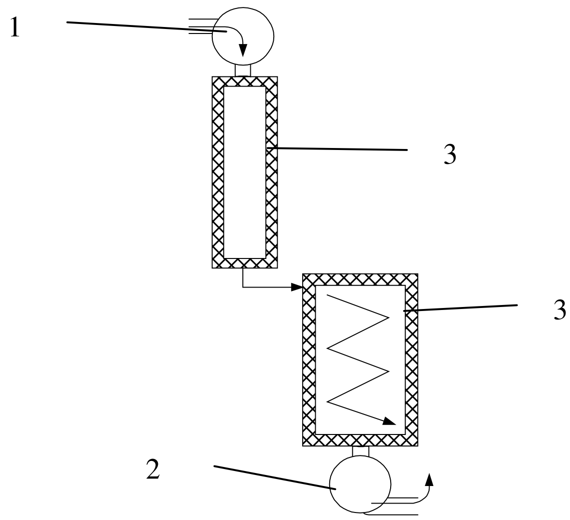

Fig. 1. **Principal general view of the dosing/sealing units and thermal insulation of the experimental equipment:** 1; 2 – dosing/sealing units for the water adsorbent granules, 3 – thermal insulation of the bioethanol dehydration column and the granule regenerator

Materials and methods

Experimental equipment was designed and made for technical pre-research of the developed and patented congruent bioethanol dehydration technology intended for the implementation of the technological process and testing its structural units.

The dosing/sealing units for water adsorbent granules. Testing of the dosing/sealing units for the water adsorbent granules of the experimental equipment in order to evaluate their compliance with the requirements of the technological process was one of the pre-research objects.

Testing the dosing/sealing units of the granules was carried out by means of a granular synthetic material on zeolite base Sylobead MS 564 used in the bioethanol production for dehydration.

Testing of thermal insulation of the granule regenerator and the column. The envisaged testing of the produced equipment provides for the detection of the energy consumption required for the process of congruent bioethanol dehydration. The most essential part of the consumed energy is related to the regeneration of the water adsorbent granules. It proceeds at up to 400°C increased temperature. At such temperature considerable losses of heat are inevitable.

The losses of heat in the experimental equipment were determined at two temperature conditions: 1 – when the maximum temperature on the bottom inside the granule regenerator was maintained 300° (on the level 1-1), and 2 – when temperature of 400 ºC was maintained. In each condition the temperature was measured on three levels of the regenerator (Fig. 2).

The temperature inside the regenerator on the level 1-1 was ensured by setting the corresponding capacity of the heater but on the levels 2-2 and 3-3 it set in due to the heat transfer by means of air convection and heat conduction of the material the structure is made of. In its turn, the required temperature in the column was achieved by creating a current of hot air in it. The conditions of the necessary temperature on every level were controlled and fixed automatically by means of a computer.

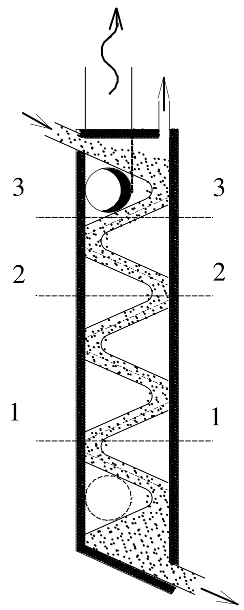

Fig. 2. **Distribution of the cross section of the regenerator by levels to fix the temperature and losses of heat**

By maintaining stable definite temperature in the lower part of the equipment, temperatures were fixed on the thermally insulated external surface of the casing of the equipment on its various levels (Fig. 2). During a stabilised temperature condition an amount of electric energy consumed for heating was determined.

A theoretical estimate of thermal insulation of the experimental equipment. When designing the experimental equipment, it was predetermined that the technological process of bioethanol dehydration would require a 1900 W flow of heat. Assuming that the losses of heat in the equipment will be 15 %, the flow of heat Q (1), will be:

$$Q = \frac{1900 \cdot 15}{100} = 285 \text{ W} \tag{1}$$

Knowing the flow of the losses of heat, the area of the external surface and the temperature difference, one can calculate the heat transfer coefficient k (2):

$$k = \frac{Q}{F} \cdot \Delta T \tag{2}$$

where k – heat transfer coefficient, $W \cdot m^{-2} \cdot K$;
Q – flow of the losses of heat, W;
F – entire area of the external surface of the equipment, m^2;
ΔT – difference of temperatures inside the equipment and the surrounding environment, ºC.

The area F of the external surface of the equipment determined by its design measurements was 7.5 m^2. The maximal average temperature inside the equipment will be 300 ºC. If the temperature of the surrounding environment in winter is assumed as being 0 ºC, then it turns out that the temperature difference ΔT will be 300 ºC.

If from this we calculate the heat transfer coefficient k, it is 0.127 $W \cdot m^{-2} \cdot K$. On the basis of this estimate and assuming that the heat transfer coefficient, when the internal surface α_1 of the equipment is 20 $W \cdot m^{-2} \cdot K$, the heat transfer coefficient, when the external surface α_2 of the equipment is 5 $W \cdot m^{-2} \cdot K$, the heat conduction coefficient λ of the rock wool insulation is 0.04 $W \cdot m^{-2} \cdot K$, the thickness of the rock wool insulation layer β can be calculated from k in formula (3):

$$k = \frac{1}{(1/\alpha_1 + \beta/\lambda + 1/\alpha_2)} \qquad (3)$$

where k – heat transfer coefficient, W·m^{-2}·K;
α_1 – heat emission coefficient at the internal surface of the equipment, W·m^{-2}·K;
α_2 – heat emission coefficient at the external surface of the equipment, W·m^{-2}·K;
λ – heat conduction coefficient of the rock wool insulation, W·m^{-2}·K;
β – thickness of the rock wool insulation layer, m.

After the calculation is finished, β = 0.348 m.

Results and discussions

The research results of the granule dosing/sealing units of the equipment. The granule dosing/sealing units of the equipment must ensure the throughput regulation of the water adsorbent granules in the equipment, and simultaneously prevent escaping of alcohol vapour into the surrounding environment.

The results of the conducted research confirm the fact that by using the granule dosing/sealing unit with a spherical core and varying the revolutions of its core it is possible to change the intensity of the granule motion in the equipment. Increasing the revolutions of the dosing unit, its throughput increased (Table1). But, after multiple passing of the granules through the doser, an undesirable by-effect was observed – splitting of the granules, which makes one think that the design of the doser has to be changed.

Table 1

Throughput of the adsorbent granule dosing/sealing unit depending on the revolutions of its core

Revolutions of the core, min^{-1}	Throughput, kg·h^{-1}
16	11.8
5	3.9
4	3.2

Data analysis of the experiments conducted to determine the losses of heat in the equipment. The data of experiments are summed up in Figure 3. The data of the graph show that at the end of the first heating condition a 280 W flow of heat losses set in which is close to the previously estimated value (see the description of the methodology). During the second heating condition the flow of heat losses of 390 W is more intense because of a greater temperature difference ΔT.

The obtained data of the experiments provide a possibility to check the value of the heat emission coefficient $\alpha_2$at the external surface, using a formula:

$$\alpha_2 = \frac{Q}{F \cdot \Delta t} \qquad (4)$$

where α_2 – heat emission coefficient, W·m^{-2}·K;
Q – flow of heat losses, W;
F – entire area of the external surface of the equipment, m^2;
Δt – difference between the temperatures on the external surface of the equipment and the surrounding environment, K.

During the experiments the temperature of the surrounding environment was 4 ºC. The surface temperatures are evident in the established data. Using them, one can calculate that in the first condition Δt is 7.3 K but in the other – 14.1 K. When α_2 is determined for the first condition, it is 5.1 W·m^{-2}·K but for the second – 3.6 W·m^{-2}·K. It results from this that the value α_2, which was assumed as 5 W·m^{-2}·K in the above calculations (description of the methodology), is close to the estimated one.

The data obtained during the experiments indicate a logical result: the higher the temperature inside the equipment, the higher is the temperature on the external surface of the casing, and the higher are the losses of heat of the equipment. The obtained concrete values of the heat losses will be applicable in the technological calculations of energy consumption.

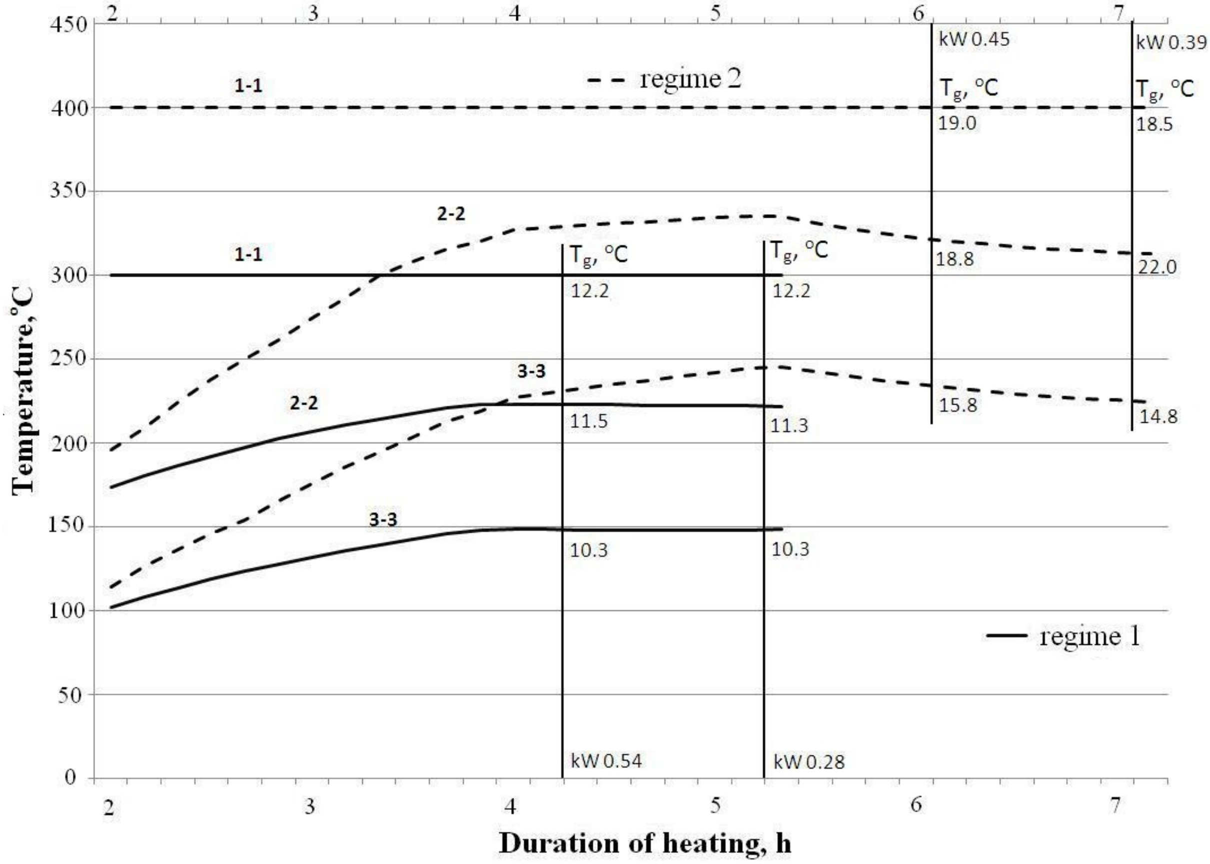

Fig. 3. **Temperature variations inside the regenerator, on the external surface, and the flow of heat losses depending on the heating conditions in various levels of the equipment:**
T_g – temperatures on the external surface of the equipment on the corresponding levels; temperature inside the equipment, ºC addition on the *y* axis

The results of the experiments show that it is possible to ensure a temperature required for the technology on different levels of the regenerator which is close to the temperatures needed for the implementation of the technological process.

Conclusions

1. It was established during the research that, using a granule dosing/sealing unit with a spherical core, varying the revolutions of its core, it is possible to change the intensity of the granule movement in the equipment.
2. Using the granule dosing/sealing unit with a spherical core, after multiple passing of the granules through the doser, an undesirable by-effect was observed – splitting of the granules, which cannot be allowed. Therefore, another solution for dosing granules should be sought.
3. By heating the bottom of the water adsorption granule regenerator in two conditions it was possible to reach a temperature distribution which is close to the temperatures required for the granule regeneration technology on higher levels of the equipment.
4. The data, established in an experimental way, are close to the results of the theoretical estimate.
5. The detected losses of heat in the equipment will allow for more precise estimation of the technological energy consumption to be applied in further experiments, which is necessary for the dehydration of bioethanol.

Acknowledgements

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