NEW METHOD FOR DOSING LIQUID MIXTURE'S COMPONENTS BY MEANS OF OVERPRESSURE
/
METODA NOUĂ DE DOZARE A COMPONENTELOR AMESTECURILOR LICHIDE CU UTILIZAREA SUPRAPRESIUNII

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ABSTRACT
The results of the bibliographic and theoretical studies on methods of dosing liquid substances using hydropneumatic systems are presented in this article. Based on these studies, the multicomponent continuous dosing method and installation were developed in order to obtain high quality liquid mixtures (including biofuels) at minimal cost. In the proposed installation "Biomixt-Pres" the flow of liquid components is ensured by overpressure in the dispenser tank. Theoretical analysis and experimental research of this installation allowed to argue the values of constructive and hydrodynamic parameters (overpressure in the working tank Δp = 0.2- 0.5 MPa; diameter of the working tank $D \approx 0.625\ H$ (H is the height of the tank), liquid level and the installation height of the maximum, minimum liquid level transducers in the working tank), which ensures the required ratio of components with the error $\delta \leq 0.2\%$.

REZUMAT
În prezentul articol sunt prezentate rezultatele studiilor bibliografice și teoretice privind metode de dozare a substanțelor lichide cu utilizarea sistemelor hidropneumatice. În baza acestor studii au fost elaborate metoda și instalația de dozare continuă multicomponentă, cu scopul de a obține amestecuri lichide (inclusiv, biocombustibili) de înaltă calitate cu cost minim. În instalația propusă „Biomixt-Pres”, curgerea componentelor lichide este asigurată de suprapresiune în rezervorul dozatorului. Analiza teoretică și cercetările experimentale ale acestei instalații au permis argumentarea valorilor parametrilor constructivi și hidrodinamici (suprapresiunea în rezervorul de lucru Δp=0,2-0,5MPa; diametrul rezervorului de lucru $D \approx 0,625H$ (H este înălțimea rezervorului), nivelul lichidului și înălțimea instalării traductoarelor de nivel maxim / minim al lichidului în rezervorul de lucru), care asigură raportul necesar al componentelor cu eroarea $\delta \leq 0,2\%$.

INTRODUCTION
Obtaining high-quality, reasonably priced liquid mixtures, including biofuels, is an important technical-scientific problem in various branches of the world economy (chemical, pharmaceutical, energy, food, etc.). Therefore, methods and equipment for dosing and mixing liquid components are the subject of research of many specialists (*Bașta et al., 2010; Băieșu, 2012; Bezmenov, 2011; Cori-Fill TM, 2020; Gheorghişor, 2012; Globin and Krasnov, 2012; Mațumura Takehico and Utino Iosihico, 2014*). The known liquid mixing dosing machines in most cases provide the high dosing accuracy of each component, which increases the complexity of these machines. In many technological processes it is important to obtain liquid mixtures with a high precision of the ratio between the components.

In order to streamline the technological process of dosing-mixing liquid components in a mixture, for example, biofuel, a method and an installation with the name “Biomixt” were developed (*Cerempei and Molotcov, 2019; Hăbășescu et al., 2011*). The proposed method is based on the flow of liquid components through holes or calibrated individual pipes, under the action of a negative pressure difference Δp (aspersion) at the inlet to the metering pump. In the Biomixt installation, the multichannel dosing with common electronic control of the actual process is performed.

The long-term tests of the Biomixt installation have shown that it ensures a relatively high accuracy of the ratio between the components of the mixture ($\delta \leq 0.5\%$). However, the mentioned installation, having some

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advantages (constructional simplicity, small dimensions), ensured the necessary precision under certain conditions. In reality, liquid mixtures, including biofuels, are produced under various conditions, respectively their production is characterized both by different productivity and by the composition of the mixture, dosing accuracy, etc. Achieving these goals is possible due to certain constructive peculiarities. In order to deal with this situation, the analysis of the hydrodynamic parameters that influence the liquid flow process and, implicitly, the precision of the dosing of the components was performed.

The dosing error δ of each component and the ratio between them in a liquid mixture can be expressed by the formula (*Cerempei and Molotcov, 2019*):

$$\delta = \frac{Q - Q_r}{Q} \cdot 100\% = \left[1 - \sqrt{1 + \frac{\Delta h}{h + \frac{\Delta p}{\rho g}}} \right] \cdot 100\% \tag{1}$$

where:

Q and Q_r are the flow rates, respectively, the nominal and the real ones (for the constant values of the working section S of the pipe and of the flow coefficient μ), [m^3/s];

h - height of the liquid column at the inlet of the outlet hole, [m];

Δh - variation range of the height h, [m];

Δp- the pressure difference at the inlet and outlet of the dosing system ($p_1 > p_0$), [Pa];

g - gravitational acceleration, [m^2/s];

ρ - density of the dosed liquid, [kg/m^3].

Therefore, in practice, the dosing error δ of each component and of the ratio of components in the fuel mixture depends on the accuracy of maintaining the height of the liquid column (Δh), the difference in pressure Δp at the inlet and outlet of the dosing system, and the height h. At present there are high capacities for decreasing the fluctuation of the height of the liquid h, i.e. it is possible that $\Delta h \rightarrow 0$ (*Băieșu, 2012; Bezmenov, 2011*). For economic reasons, it is not rational to increase the height h of the liquid in the working tank. Therefore, there is only one rational way left: to increase the value of the pressures difference Δp. However, in the Biomixt installation there are limited possibilities to increase Δp, because in this case the pressure difference consists in difference between the atmospheric pressure p_0 in the working tank and the inlet pressure -p_1 at the inlet to the dosing pump.

Thus, analysing formula (1) it was found that in order to increase the dosing accuracy it is necessary to increase the difference Δp between the inlet pressure and the outlet pressure in the outlet. This condition can be achieved if the liquid flows from an airtight tank with a pressure of $p_1 > p_0$. Generally, installations operating according to the mentioned principle are known (*Bașta et al., 2010; Bezmenov, 2011; Cori-Fill TM, 2020; Globin and Krasnov, 2012; Mațumura Takehico and Utino Iosihico, 2014; Nistoran et al., 2007*). The typical functional diagram is shown in Figure 1.

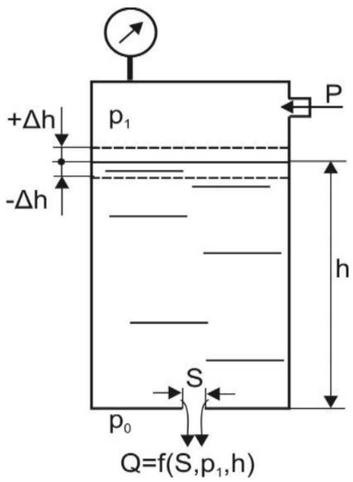


Fig 1 - Functional diagram of the liquid flow dispenser through the calibrated hole with section S

In the working tank, the required pressure (($p_1 \pm \Delta p_1$) is maintained with the help of compressed air from the pneumatic system. In order to achieve the described conditions, it is necessary that the flow rate Q through the orifice calibrated with section S be in the range $Q \pm \Delta Q$, where ΔQ represents the error of the flow rate.

The results of the monographic researches show that in the existing installations for continuous dosing of liquids (fig.1), there are difficulties in the simultaneous regulation of the liquid level in the tank $h \pm \Delta h$ and of the pressure in the tank $p_1 \pm \Delta p_1$. One of the causes of the difficulties is that with the completion of the liquid in the working tank in the dosing process, the overpressure Δp can increase uncontrollably, exceeding the set value. Therefore, in this case, the flow rate Q also increases, so that additional dosing errors occur simultaneously.

Therefore, existing liquid dosing facilities have certain shortcomings and a narrow field of use, the information from existing bibliographic sources is not sufficient for the design and use in production of the installation with continuous dosing of several liquid components, especially for the production of biofuels. Therefore, it is necessary to carry out a complex of theoretical and experimental research activities, with the aim of developing the method and installation to ensure the continuous and concomitant dosing of several liquid components with precise compliance of the ratio between them and the minimum cost of the mixture production.

MATERIALS AND METHODS

After conducting bibliographic studies, as well as experimental research of the Biomixt installation (*Cerempei and Molotcov, 2019*), technical solutions were submitted aimed at streamlining the dosing process of liquid mixtures, including biofuels, which require theoretical and experimental research to achieve the stated goal. Therefore, the following activities were performed:

1. Design, development of the method and installation for the dosing and mixing of components in order to obtain high quality liquid mixtures. Verification of the conformity of the functional parameters of the installation presented for tests to those established in the design phase;

2. Carrying out the theoretical analysis of the hydrodynamic parameters, which influences the dosing error δ of the components in the liquid mixture. Determining the flow rate dependence of the components depending on the pressure in the dispenser working container. Estimation of possible dosing errors, resulting from the theoretical calculation, and their comparison with the real ones obtained on the pilot installation.

3. Long-term testing of the procedures for adjusting the ratio between the components of the liquid mixture.

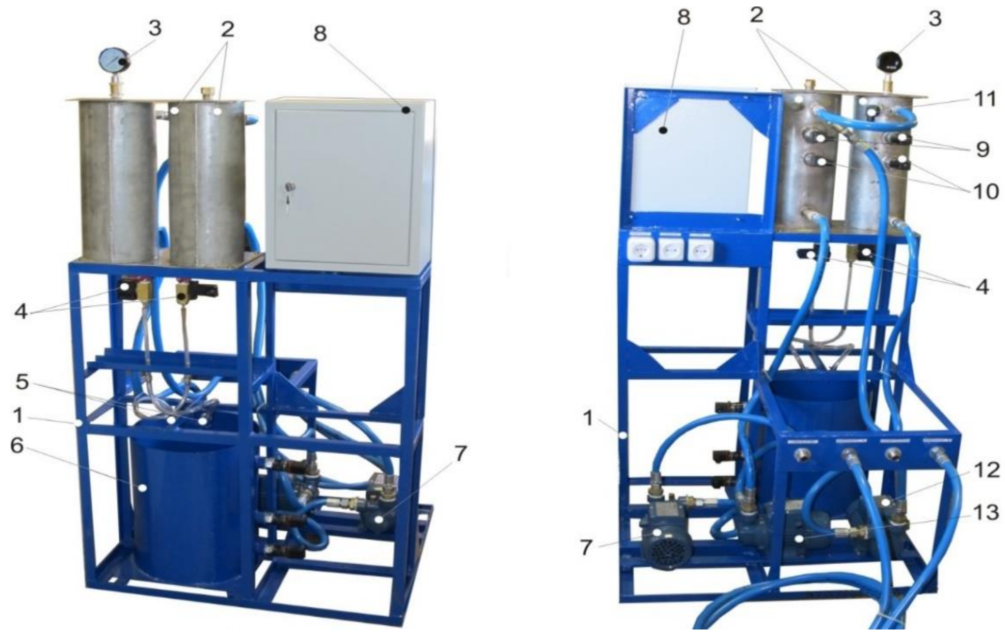
As a result of the activities from the first stage, the method and installation "Biomixt-Pres" for the preparation of liquid mixtures was developed (fig.2) (*Hăbășescu et al., 2011, 2014*).

The experimental installation (fig.2) works in the following way.

After connection, pumps *12* and *13* initiate the supply of liquid to the working tanks *2* of the dispensers. The pressure inside the pumps starts to increase and after reaching the installed value, the pressure transducer *11* sends the signal of the electronic command and control system SECC with panel *8*, which controls the opening of the distributors *4* in the exhaust channels. The process of continuous dosing of the *A*, *B* components of the liquid mixture starts. Transducers *9* and *10* monitor the level of components *A, B* in the tanks *2*, and transducer *11* monitors the value of the working pressure in the pneumatic system.

The pressure in the working tanks *2* is automatically maintained by supplying the liquid components in the respective working containers or by pumping the compressed air by a compressor. Each component (A, B, etc.) of the liquid mixture, passing through the fixed section of the discharge nozzle *5*, under the action of the overpressure Δp in the working container, flows with the flow given in the storage tank *6*. Due to the fact that the nozzles of the mixing device are inclined towards each other, the diffused jets merge into one, forming the expected mixture. It is then sent to the storage container from where it is delivered to the consumer with the special pump *7*.

The conformity check of the developed installation was performed by comparing the initial design requirements with the actual parameters of the installation, determined by visual examination and measurements. Water was used as the initial stage dosing component. To test the safety of the installation, the control valves of the exhaust channels *4* were positioned arbitrarily, then the installation was started. When the pressure set in the containers was reached, the solenoid valves of the exhaust channels opened and a stable jet of both liquids formed in the storage container. Each experiment lasted at least 20 minutes.



a) front view **b) rear view**

Fig. 2 - Biomixt-Pres installation for the preparation of liquid mixtures (*Hăbășescu et al., 2011, 2014*)
1 - frame; 2 - working tanks; 3 - control manometer; 4 - hydraulic distributors; 5 - exhaust nozzles; 6 - storage tank; 7 - pump for taking the ready liquid mixture; 8 - control panel; 9 - maximum level transducers; 10 - minimum level transducers; 11 - pressure transducer; 12 - pump for supplying component A; 13 - pump for supplying component B.

To evaluate the dosing accuracy of the components, the installation worked continuously for 15 min, in each experiment. This period ensured the stabilization of the operating regimes of all component systems. The control valve in the drain of the base component was fully opened (Q_A = max), and the valve of the drain of the component B for each experiment was positioned so as to ensure the following ratios of the constituents of the mixture: Q_B / Q_A = 10/90; 20/80; 30/70; 40/60; 50/50.

The accuracy of the Q_i flow rate measurement of each component was ensured by using calibrated fuel measurements and by repeating the measurements 10 times according to the standard SM 226: 2002- “Automotive gasoline used in the Republic of Moldova. Technical conditions for conformity assessment”.

Using the stopwatch, the time required to fill the container to the mark line was measured and the flow rate Qi (l/min) was calculated for each channel in the following relationship:

$$Q = \frac{60 \cdot V}{\tau} \tag{2}$$

where:

V is the volume of the calibrated container, [l]; τ - the filling time of the container, [s].

Based on the measurement results, the average value of the flow rate was determined:

$$Q_m = \frac{1}{n} \sum_{i=1}^{n} Q_i \quad \text{[l/min]} \tag{3}$$

where:

Q_i is the result of the measurement and flow rate, [l/min]; n - number of experiments performed.

Next, the deviation Δ_i was calculated for each measurement of Q_i from Q_m, taking into account the sign. This allowed the determination of the relative dosing error for each measured flow rate:

$$\delta_i = \frac{\Delta_i}{Q_m} \cdot 100 \quad [\%] \; . \tag{4}$$

The evaluation of the reproducibility of the established flow rates was performed, repeating one of the experiments described above for 96 hours, without changing the position of the control valve. In this case, for each series of long-term experiments the mean value of the flow rate Q_{mi} was calculated and was compared with the overall mean value Q_m previously obtained according to formula (2).

RESULTS

The analysis of formula (1) shows that the accuracy of the component dosing and the error value of the flow rate ΔQ are determined by the sum of the errors that occur when maintaining the overpressure Δp and the level Δh. The degree to which Δp and Δh influence the dosing accuracy can be determined from the analysis of formula (1), from which it follows that the relative dosing error decreases with decreasing Δh and increasing Δp. So, $\lim\limits_{p_1 \to \infty} \delta = 0$

Theoretical calculations based on formula (1) and the results of experimental research with the Biomixt installation, allowed to establish the dependence of the dosing error δ depending on the pressure drop Δp in the working tank for different heights of the liquid column h and the deviation Δh with a fixed value (fig. 3).

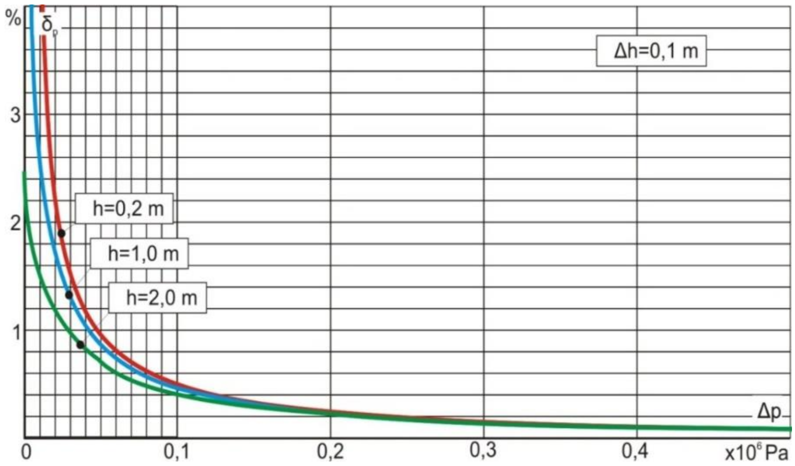


Fig. 3 – Dosing error δ depending on the overpressure Δp in the working tank for different heights h of the liquid column

The graph shows that, for Δp > 0.2MPa, the initial height of the liquid column h practically does not influence the error δ, which becomes dependent only on the absolute values Δp and Δh (fig. 4).

For comparison, the dependence formula δ = ***f*** (Δh) for Δp = 0 is presented, ie for the case when the pressure in the working tank is equal to the atmospheric pressure. In this case the size δ depends a lot on Δh and can be determined from the relation:

$$\delta \backsimeq 49\ (\Delta h / h)\ \ [\%] \tag{5}$$

Increasing the pressure drop Δp to 0.2MPa, this dependence becomes much lower, namely:

$$\delta \backsimeq 2.3\ (\Delta h / h)\ \ [\%] \tag{6}$$

At pressure drop Δp = 0.5 MPa:

$$\delta \backsimeq 1\ (\Delta h / h)\ \ [\%] \tag{7}$$

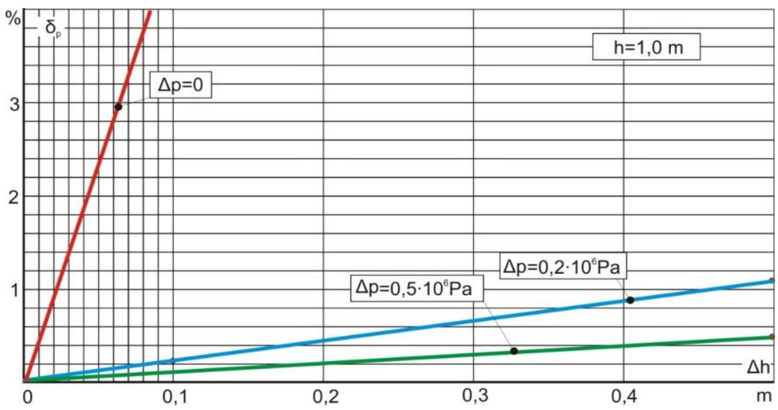


Fig. 4 – Influence of deviations of the liquid column height (Δh on the dosing error δ, for different values of the overpressure Δp in the working tank

Therefore, it can be said that with increasing pressure, the dependence $\delta = \boldsymbol{f}(\Delta h)$ becomes smaller and when $\Delta p \rightarrow \infty$ the relative dosing error $\delta \rightarrow 0$ and a little depends on the magnitude of the fluctuation Δh. It follows that in the working tank for pressure p_1 with high values (Δp > 0.5 MPa) (fig.3), the dosing error δ depends only on the errors of maintaining the given pressure.

For practically assuring the results obtained from the theoretical and experimental researches, the dispenser was elaborated (fig.5), in which the pressure p_1 is maintained by a combined method, namely by supplying in the working tank the dosed liquid or the compressed air. To switch from one mode to another and to control the liquid level in the tank, maximum and minimum level transducers have been installed on the side wall of the working tank.

Safe operation of the dispenser shown in figs. 2 and 5 is conditioned by the correct choice of geometric parameters and installation coordinates of level transducers.

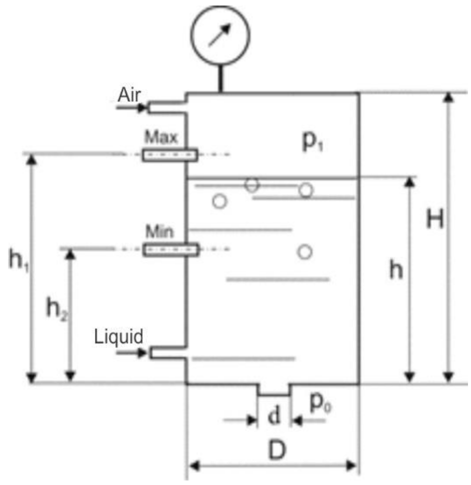


Fig. 5 – Schematic of the combined continuous-acting dispenser for maintaining overpressure in the working tank

The basic dimension H (height of the working tank, fig.5) is required according to the general scheme of the device in which the dispenser will be installed. In this case, the total volume of the tank will be expressed by the formula:

$$V = S_t H = {\pi D^2 H}/{4} \quad [\mathrm{m}^3] \tag{8}$$

where: S_t is the cross-sectional area of the working tank regardless of shape, m^2; D, H - respectively the diameter and height of the working tank, m.

Volume V is occupied by air until the liquid is supplied to the working tank. In this case the pressure inside the tank is equal to the atmospheric pressure $\boldsymbol{p_o}$ (overpressure (Δp = 0). When the liquid is supplied to the tank, the air is compressed to the volume Vg and its absolute pressure p_1 increases according to the Boil-Mariott law ($p_1\ Vg$ = const, for constant values of gas mass and temperature) (*Ratbil, 2010*). However, in this case, if the increase of the compression temperature is neglected, according to the mentioned law, the proportion will take place:

$$\frac{V}{V_g} = \frac{p_1}{p_o} = \frac{\Delta p + p_o}{p_o}, \tag{9}$$

whence:

$$V_g = V \cdot \frac{p_o}{\Delta p + p_o} \quad \text{or} \quad V_g = \frac{V}{\left(\dfrac{\Delta p}{p_o} + 1\right)}, \ [\mathrm{m}^3] \tag{10}$$

where: Vg is the volume of compressed air.

Substituting the value V from formula (8) into formula (9), the following is obtained:

$$V_g = \frac{\pi D^2 H}{4\left(\frac{\Delta p}{p_o}+1\right)} \quad [\mathrm{m}^3] \tag{11}$$

Knowing the volume of compressed air Vg and taking into account the fact that the liquid occupies the rest of the volume of the working tank, the following can be written:

$$V_l = \frac{\pi D^2 H}{4} - V_g = \frac{\pi D^2 H}{4}\left(1-\frac{1}{\left(\frac{\Delta p}{p_0}+1\right)}\right). \quad [\mathrm{m}^3] \tag{12}$$

From expression (12) is determined the height h, at which the liquid rises in the working tank when the given overpressure is reached Δp:

$$h = H\left(1-\frac{1}{\left(\frac{\Delta p}{p_o}+1\right)}\right) \quad [\mathrm{m}] \tag{13}$$

The formula is valid for containers with a constant cross-sectional area.

As shown in formula (13), the level of liquid h in the working tank of the dispenser does not depend on the shape and dimensions of its cross section, but only on the total height of the tank H and the value of the overpressure Δp.

The height h_1 (fig.5), at which the maximum liquid level transducer is installed, is established by adding to the height h (calculated from formula (13)), the size $\Delta = \frac{H-h}{2}$. In this case, the metered liquid acts on the maximum level transducer. This state serves as a signal for the transfer of the control system into operation, in which the working pressure p_1 is maintained due to the supply of metered air in the tank. This excludes overloading the tank and blocking the dispenser.

The height h_2 (fig.5), at which the minimum liquid level transducer is installed, is established, based on the requirement that the duration τ in which the liquid level is lowered from h_1 to h_2 is greater than 10 seconds. Otherwise (τ <10 s) the liquid supply pump in the working tank will operate intermittently, which significantly reduces its working durability.

The results of the monographic research showed that the optimal value is τ > 15 s. In this way, the value of h_2 can be chosen from the condition:

$$h_2 \leq h_1 - {}^{\tau Q}/_{S_t} \tag{14}$$

where S_t is the cross-sectional area of the working container, [m^2].

From here, for the round section tank:

$$h_2 \leq h_1 - \frac{4\tau Q}{\pi D^2} \tag{15}$$

where Q is the flow rate of the component, [m^3 s]; D - inside diameter of the working tank, [m];

τ - standby time in the feed pump operation, [s].

From formula (15) results that increasing the diameter D of the working container tank reduces the difference h_2-h_1 and, at the limit, becomes zero. But for small values of D it can happen that the difference on the right side of the formula (15) becomes negative. In this case it is necessary to increase D or decrease τ.

When choosing the working tank diameter D, it must also be taken into account that, for constant values of the difference Δp, increasing the diameter D, for the given flow rate Q, leads to an increase in the working tank volume which, implicitly, increases the time for filling the tank τ.

The pressure, developed by the pump for supplying the metered liquid in the working tank, must be higher than (1.5… 2.0) Δp (Δp the overpressure imposed in the working container). This will allow the pump to maintain Δp at the calculated level, exceeding the resistance of the connecting pipes.

The pump flow rate must be within the range *(4…5)Q*. If this interval is exceeded, in the process of maintaining the given pressure, the phenomenon of significant "over-adjustment"[2] may arise, which may initiate additional dosing errors. At the same time, the lower flow rate can adversely affect the operating speed of the pressure regulating system in the working tank.

The results of the research on the flow of liquid through the calibrated orifice under the action of overpressure, presented in this article, served as a basis for the development of the pilot model of the liquid mixture preparation installation, including biofuels (trade name "Biomixt-Pres") (*Hăbășescu et al., 2011, 2014*).

The Biomixt-Pres installation (fig.6) is composed of the working tanks *1* and *2* of the dispensers of components *A, B*. Through one-way valves SSU 1 and SSU 2; (pos. *3, 4*), the tanks are connected to pumps *5* and *6,* which supply the liquid components *A, B* in a dosed manner. Module *7*, consists of an air filter, an air pressure regulating valve, a manometer and a compressed air distributor block.

In the same time, using the manometer *9* of the air preparation module, the pressure in the working vessels is controlled by means of the pressure transducer *10*, which converts the pressure value into an electrical signal, being transmitted in the automatic control system SAR1.

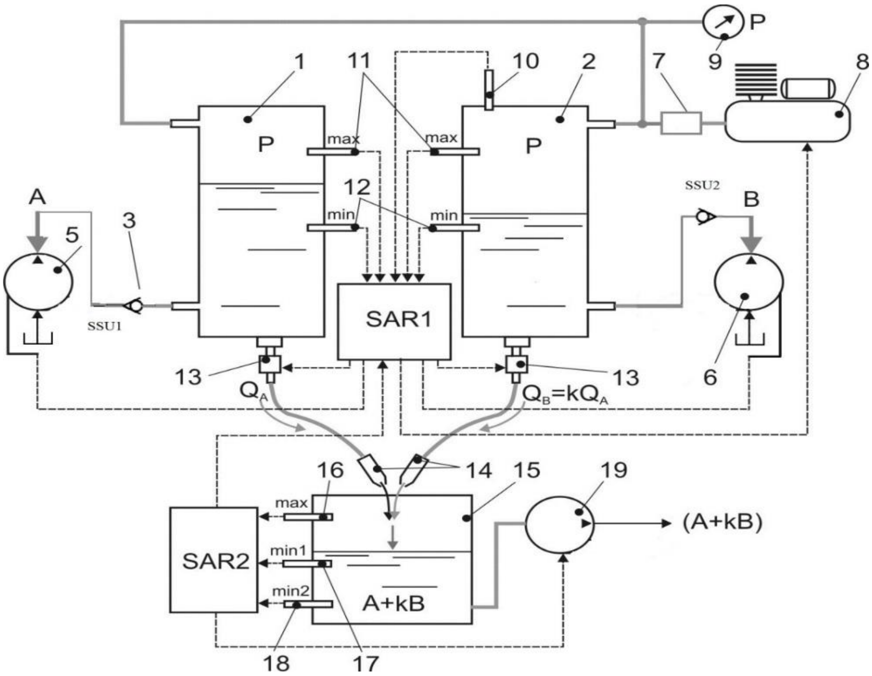


Fig. 6 – Schematic of the "Biomixt-Pres" pilot model for the preparation of liquid mixtures

1,2- tanks; 3,4-valves; 5.6- supply pumps; 8- air preparation module; 9- manometer; 10- pressure transducer; 11,12,16, 17, 18- level transducers; 13- evacuation devices; 14- nozzles; 15- storage tank; 19- mixture drain pump

On the side walls of the working tank are installed the maximum level *11* and the minimum level *12* transducers, and on the lower bottom of both tanks are connected an outlet channel *13* equipped with a hydraulic distributor which, if necessary, blocks the outlet channel. The section of the outlet channel of component B is adjustable, and that of component A - fixed at the maximum level.

The sizes Δp and Δh are set automatically by a steering system specially designed for this purpose. By modifying the section of the outlet channel of component B, the mixture can be prepared with the necessary composition *A + k B,* where *k*– the coefficient, which determines the ratio of components B and A in the mixture:

$$k = \frac{Q_B}{Q_A}. \tag{16}$$

The components A and B with the given ratio, through the outlet channels *13*, move in the mixing device, which consists of two nozzles *14*, inclined to each other at a certain angle. The *A + k B* mixture reaches the

[2] *Overadjustment - quantitative characteristic of the oscillation property of the system; is denoted by the letter σ and is determined as a percentage in relation to the value stabilized according to the expression (Băieşu, 2012; Bezmenov, 2011):*

storage tank *15*, equipped with the level transducers *16, 17* and *18*, connected to the pump *19* for taking the prepared mixture.

The SAR2 automatic control system manages the operation of pump *19*. It is connected to the SAR1 system, which forms a unique SECC command and control system, which ensures the stable operation of the installation in all working conditions, including accidental one.

Therefore, the research carried out allowed the development of a method and, respectively, of the "Biomixt-Pres" installation that ensures the continuous and concomitant dosing of several liquid components with a high precision: the error of maintaining the ratio between the components δ was less than 0.2 %, which is sufficient in many technological processes in the food, chemical, liquid biofuel production industry (mixtures of monohydric alcohols with gasoline, esters of vegetable oils with diesel).

The tests of the developed method and of the "Biomixt-Pres" installation carried out in the Experimental Center of the Mecagro Institute of Agricultural Technology confirmed the results obtained in the theoretical and experimental research, as well as high values of reliability and durability of the Biomixt-Pres installation.

CONCLUSIONS

✓ Based on the bibliographic study, the analysis of hydrodynamic parameters and experimental research, a method of dosing and mixing the components of liquid mixtures was developed, for the realization of which an installation equipped with a SECC command and control system was developed. Its operation is based on the principle of liquid flow through a calibrated outlet channel (orifice or pipe) under the action of overpressure.

✓ It was theoretically argued and experimentally confirmed the efficiency of using in the "Biomixt-Pres" installation the principle of liquid flow, at controlled overpressures, through holes calibrated with the delivery of components by separate pumps. The flow of liquids in each dosing channel was stable. This minimized the dosing error ($\delta \leq 0.2\%$) for wide ranges of liquid flow rate.

✓ Based on the calculations and researches, the main construction parameters of the "Biomixt-Pres" installation were established, among which are: overpressure in the working tank Δp = 0.2…0.5 MPa; working tank diameter $D \approx 0.625H$ (H is the height of the tank); the level of the liquid in the working tank depending on the pressure p_1 of the liquid in the same tank, the atmospheric pressure p_0 and the height of the tank H; the height of the installation of the maximum and minimum liquid level transducers in the working tank.

✓ The functions of the electronic command and control system SECC for the dosing-mixing installations of liquid mixtures were determined, namely: automatic maintenance of the pressure in the working tank with the indication of the current pressure value; automatic opening and closing of solenoid valves in component exhaust pipes; automatic control of the components delivery pumps and discharge of the prepared mixture from the storage tank; protection against accidental working conditions.

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