The Control System for the Production of Biodiesel

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Abstract**—**This article describes the control unit for the production of biodiesel from waste material, such as fats or oils. The control system is based on programmable logic controller of PCD2 family and provides dosing of feedstock materials (fat or oil) and other material, temperature reactor control, visualization of process and progress of production. It provides easy setting of the parameters of the technological process – transesterification. It was proposed to use in laboratory or small industrial production. There can be connected touch screen terminal to the control unit or the user can use local area network for the connection with computer with web browser to control the production process. The process of desalting is proposing for the preparation of waste materials (fats from leather industry, it's based on ARM microcontroller from Cortex-M4 family with touch screen LCD (10.4").

Keywords**—**Biodiesel, control unit, pilot plant, PLC, remote access, two-state controller visualization.

I. Introduction

BIODIESEL as alternative fuel for internal combustion engines have several advantages and disadvantages to normal diesel:

- Lower CO_2 emissions
- Production from waste materials
- Increased nitrogen oxide emissions

Part of biodiesel production is more expensive than regular diesel. It is given by the price of catalyst. However, this fact is compensated by very low or zero cost of oil or fat that is used for production of biodiesel. As a usable fat can be used vegetable or animal fat, such as waste grease from tannery industry or restaurants and kitchens as used cooking oil. Next biodiesel parameters are similar to regular diesel, such as solidification temperature is almost equal and it's not suitable for use in extreme cold.

Production from these fats runs via transesterification of unsaturated fatty acids to biodiesel and glycerin with presence of a catalyst. This reaction is detailed investigated in [1]-[3].

Because it's necessary to save the cost of raw materials and energy and reduce time-consuming manual production, there was constructed the control unit that is based on programmable logic controller Saia, type PCD2.M5540. It allows fully automatics operation. However, there are other modes, such as semiautomatic or manual.

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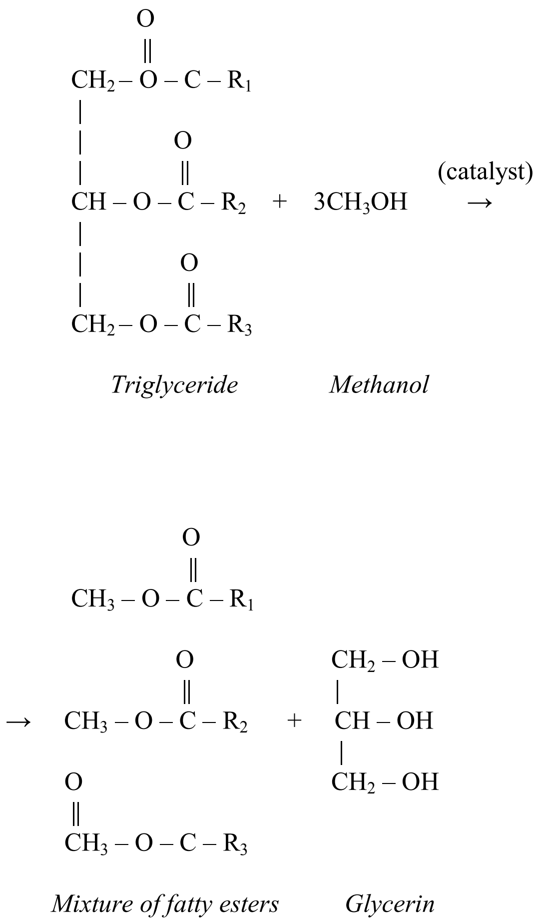
II. Transesterification of Free Fatty Acids

The transesterification of unsaturated fatty acids to biodiesel need a few basic ingredients:

- Free fatty acids – waste vegetable oil or grease from tannery production
- Alcohol, there is mostly methanol
- Acidic or alkaline catalyst, depending on the fat and its properties

In this reaction are created methylesters – biodiesel and glycerin, which can be seen in equation (1). Glycerin can be removed by the separating vessel or centrifuge, because biodiesel is insoluble in glycerin and it has higher density than biodiesel.



(1)

where R_1, R_2 and R_3 are long hydrocarbon chains. It was invented patent for production of biodiesel, where the addition of 1.6 times compared to the theoretical assumptions of methanol with 0.1% - 0.5% potassium hydroxide. If the mixture was heated to 80°C, then the process allowed 98% conversion to alkyl esters and high quality glycerol.

During the oil crisis in the 70 – 80 years was used vegetable oil instead of diesel as an alternative fuel in diesel engines. But it appeared that the oil is not suitable due to its high viscosity, because engines were not prepared to this. However, the viscosity is reduced by the above mentioned transesterification.

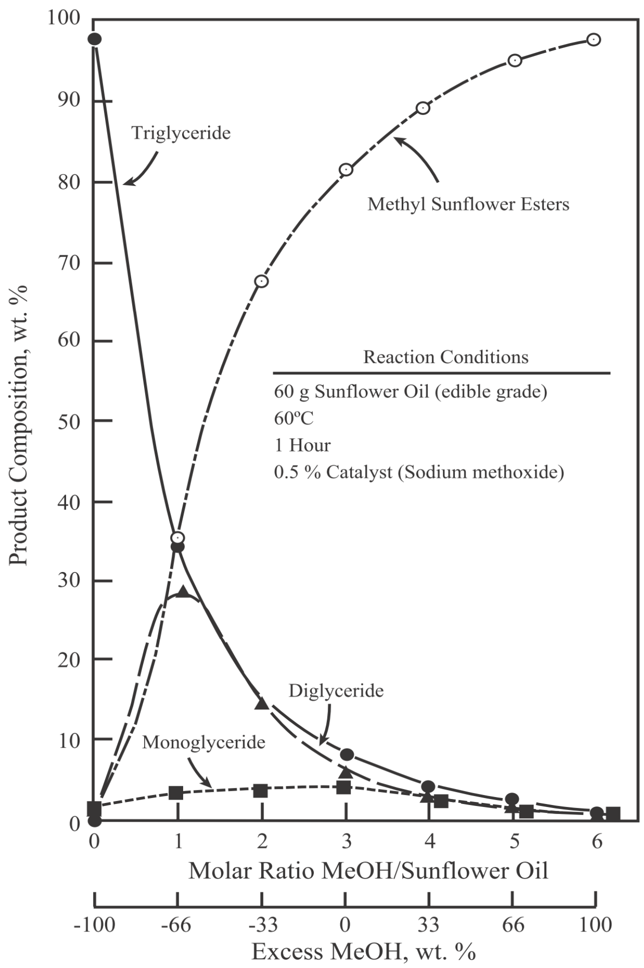


Fig. 1: Effect of alcohol and fat ratio to transesterification

During the development many publications show various results that were achieved in this area. It was found that production is strongly dependent on temperature: at 32 ° C transesterification takes 4 hours, but at 60 ° C approximately 1 hour. Further tests showed the influence of different catalysts and their molar ratios, as showed in Fig. 1 [3].

If the used oil or fat contains unsaturated fatty acids, a special process is required. Vegetable oil usually contains from 2% to 7% unsaturated fatty acids, animal fat from 5% to 30%. Although this, reaction containing more than 5% of unsaturated fatty acids can be carried out with the alkaline catalyst. But it need more, especially to compensate of created potassium soap. It is described in following equation:

$$HO-\overset{\overset{O}{\|}}{C}-R + KOH \rightarrow K^{+}\,{}^{-}O-\overset{\overset{O}{\|}}{C}-R + H_2O \quad (2)$$

fatty acids *potassium soap*
potassium hydroxide *water*

If the content of unsaturated fatty acid is greater than 5%, potassium soup reduces separation of methylesters from glycerin. For these cases it is better to use on catalyst place sulfuric acid, as shown in the following equation:

$$HO-\overset{\overset{O}{\|}}{C}-R + CH_3OH \xrightarrow{(H_2SO_4)} CH_3-O-\overset{\overset{O}{\|}}{C}-R + H_2O \quad (3)$$

fatty acids *sulfuric acid* *water*
methanol *methylesters*

In the Fig. 2 is showed schema of biodiesel production process. As you can see, except the transesterification there's also separation process of glycerin from methylesters and their subsequent purification. During this process is removed toxic methanol also and neutralization and drying methylesters – it creates biodiesel. The removed methanol can be recycled, but water must be removed from it. Also from glycerin must be removed. This glycerin can be cleared up to 99.5% of pure glycerin.

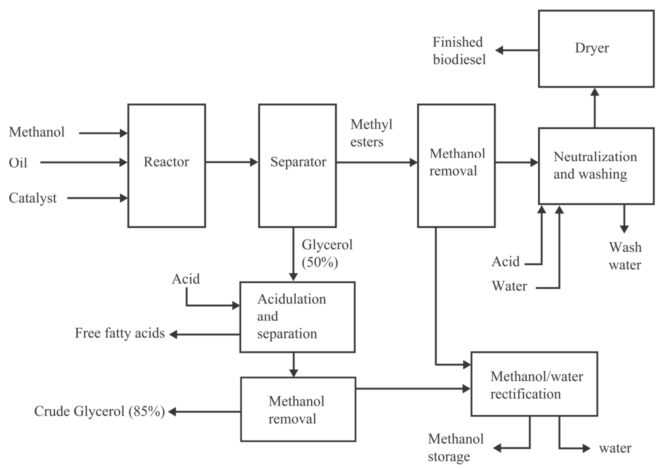


Fig. 2: Schematic representation of the biodiesel production [3]

III. Equipment of the Control Unit

The control unit is based on programmable logic controller Saia, type PCD2.M5540. It was chosen due to built-in web

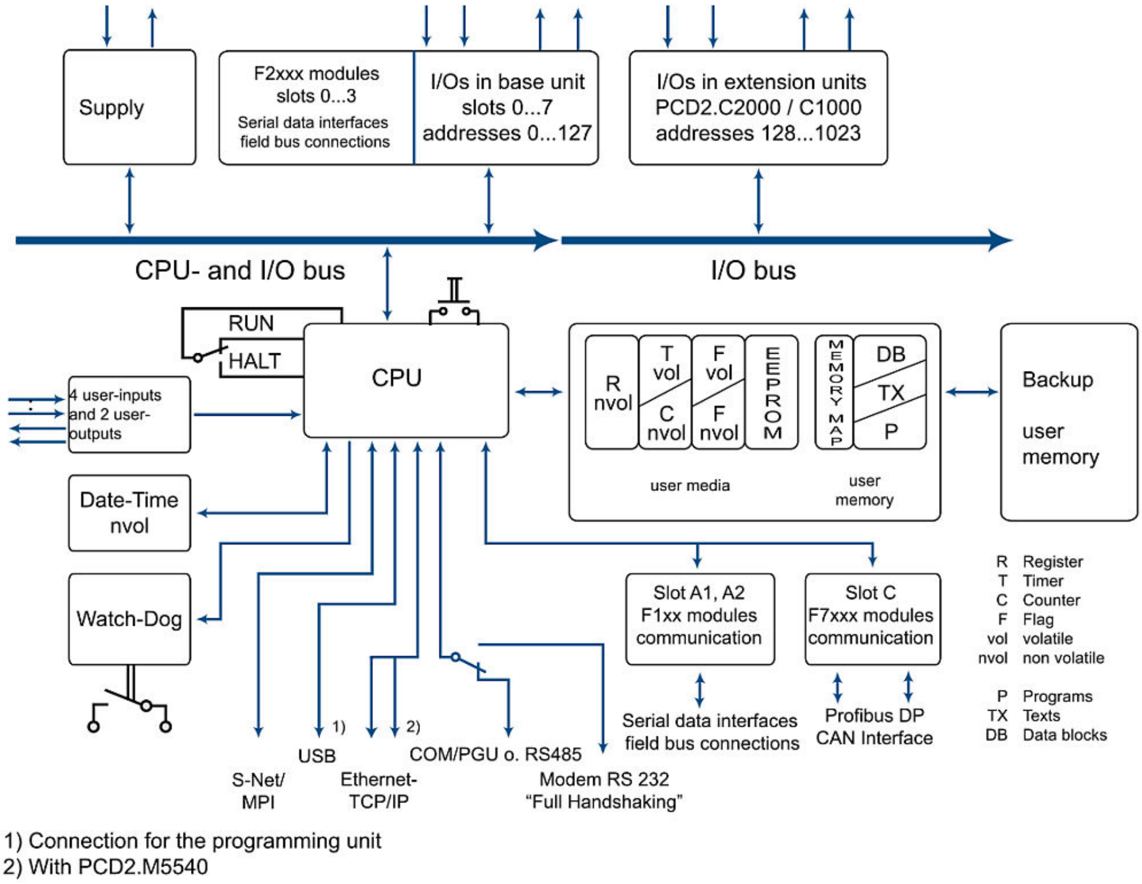


Fig. 3: Structure of PLC SAIA, type PCD2.M5540

server, which is used to visualization of process or remote access. This PLC has a high numbers position for extending modules with inputs and outputs and communication channels. It can be extended up 1024 inputs/outputs. In basic model it has two Ethernet connectors, serial line RS232 or RS485, but in use can be only one. For program code, variables and other data, such as pages of visualization there is 1MB nonvolatile memory that can be upgraded up to 8MB [4] by special industry secure flash card. There is position for two cards at top of body programmable logic controller. In basic configuration there are 4 digitals inputs and 2 digitals outputs.

For connection a lot of inputs and outputs card modules are provided interface between processor in PLC and other components. There is position for 8 modules and connector for connection other base station with these positions. For binary inputs are used PCD2.E166 modules. It is specified for 16 binary inputs and with 24V input level. Each input has typically 0.2 ms delay. All inputs can be connected by a screwless terminal. Module PCD2.A465 is for connecting 16 binary outputs. Outputs are electrically connected, with shortcut circuit protection. Each output has maximum current 500 mA, together all outputs on board have maximum at 8A. Output delay of this module is typically 50 µs, maximally 100µs for resistive load.

For mixing feedstock and other materials in the reactor the stirrer is used. It's made from stainless steel and it is connected to the 1-phase asynchronous motor. It has 180 W power and it is placed under the reactor chamber. Because the motor has too high speed, the 1-phase motor driver must be used to control it. It's connected to programmable logic controller via binary signals to basic control and through analog signals to set the proper speed. However, the driver can communicate by a serial line and it's designed to maximal power output up to 370 Watts. It's powered from 230V/50Hz electric network.

For heating is used electrically powered heater with 1700 watts. It must be precisely controlled. For this purpose there are placed two Pt1000 thermometers. The first of them is standard thermometer that measures temperature in the reactor chamber, it is made in class A precision and it measures in range from -25°C to +250°C. The second temperature is smaller than usually. It measures temperature near the heater to avoid local overheating of the feedstock mixture and looks like M12x1.5 screw. But the temperature from this thermometer is not too accurate, because this thermometer is screwed in the body of reactor. However, the precision temperature is sufficient for our purpose.

These thermometers are connected to PLC by analog module card PCD2.W525. It has four inputs and two outputs that can be configured in five modes [5]. Each input is configurable by the DIP-switch on module card. The modes and setting of switches are showed on next picture:

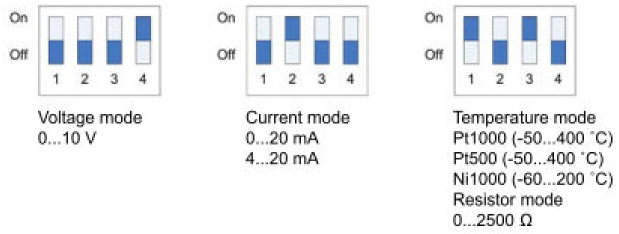


Fig. 4: Configuration of DIP-switch for analog inputs

Also the motor driver is connected by this module to control the speed and to digital output module to start/stop the motor.

Fig. 5: Used 1-phase motor driver

For switching the heater, pumps and siren are used solid state relays. These have several advantages opposite to standard relay with mechanical contact:

- No burning contact
- Speed of switching
- Low interference
- Switching loads when the supply voltage crosses zero value

On the other hand, they needs cooling for high currents and do not electrically isolate the connected equipment from power supply, if they are switched off. The first two advantages are important in the case of this control unit, becasuse the relay switches the main power for electric heater in PWM mode. There is shortest period time 50ms for 1% of power and 5s period for the 100% of power. In this case the mechanical relay would be destroyed and/or damaged after few hours of operation. These relays (totally 8 pcs) are conneced direct to the programable logic controller, because each of this are galvanicaly isolated from the power supply, that take only less than 12mA and there are place on aluminium heatsink for better heat dissipation.

IV. The Reactor Temperature Control

For the proper setting of the temperature controller, we must know the step response of the regulated system and we need know that the system is linear. For this purpose was measured static characteristic three times for each measurement point. You can see the measured points in the next table and static characteristic in (4).

Table 1: The measured values of static characteristic

Measurement No.	Heating power [W]	Temperature [°C]
1	68	61.4
2	85	69.0
3	102	76.0

$$y = 0.4294x + 32.3 \tag{4}$$

Low power values of electrical heating were chosen due to avoid overheat and damage of the reactor and the mixture.

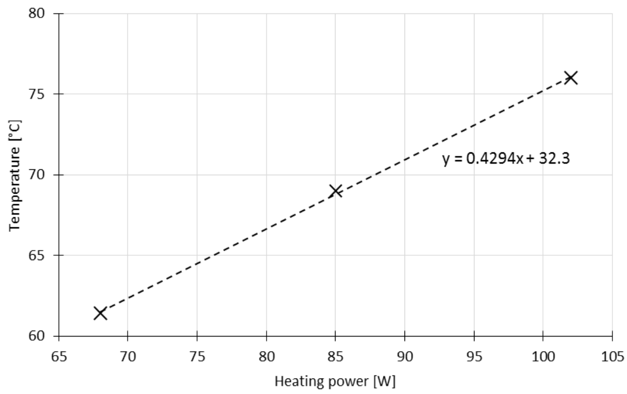


Fig. 6: Static characteristic with linear extrapolation

Next for this regulated system was measured step response. Measurement was made for the same three points that you can see in table1. The final step response (5) is average from all measurement (three times between each point and from cold state).

$$G(s) = \frac{8.808}{12185.3s + 1} \tag{5}$$

It was designed the PI regulator (6) for this step response by the inverse dynamics method [6], [7], but the regulation process was too long and slow.

$$G_R(s) = k_r\left(1 + \frac{1}{T_I s}\right) \tag{6}$$

PI regulator has next parameters:

- T_I = 12185.3 s
- k_r = 1.3834

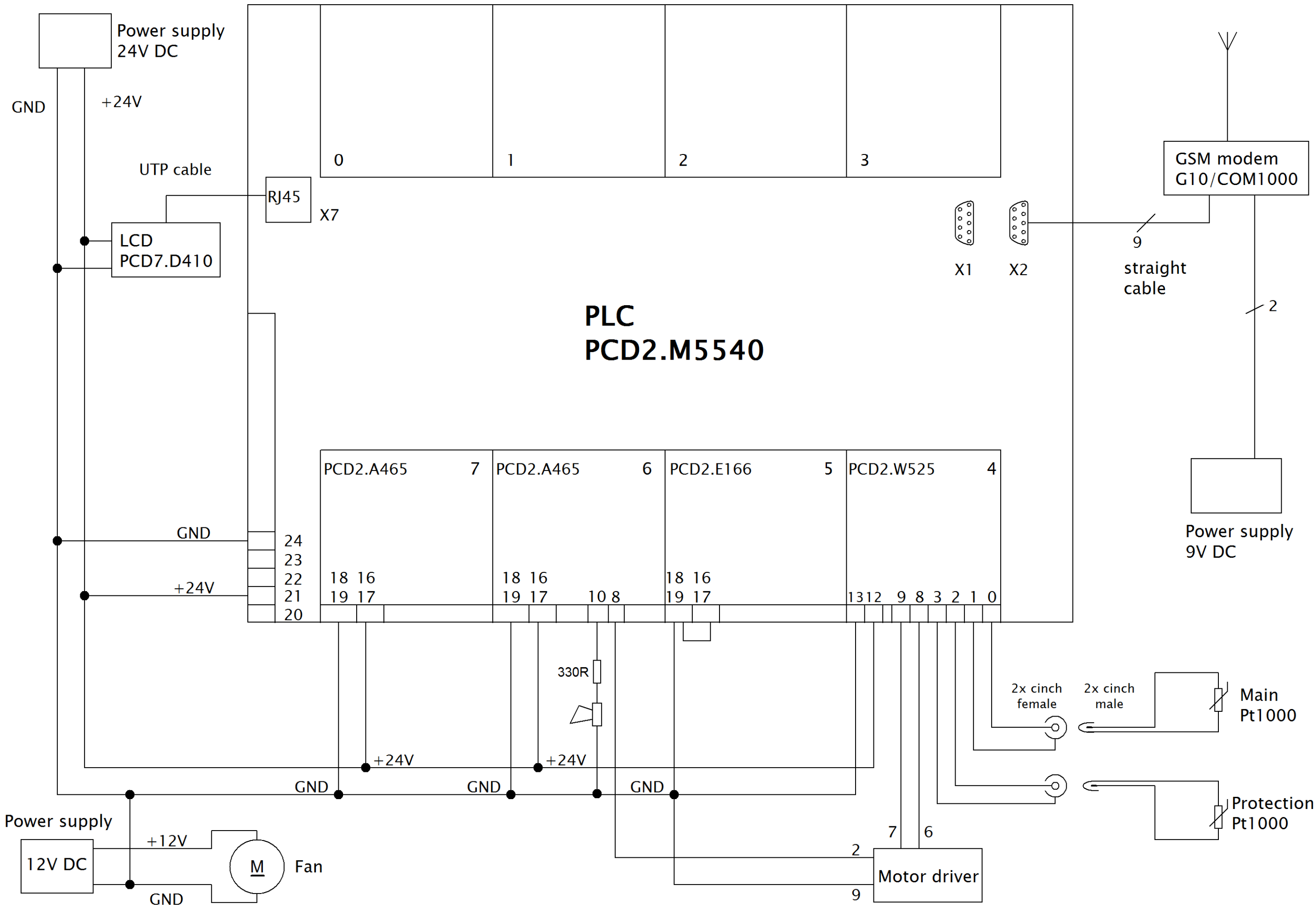


Fig. 7: Part of low voltage section of the control unit

In the fig. 8 you can see simulation of control process. Regulation time is huge, but there isn't overshoot or instability of the regulated temperature.

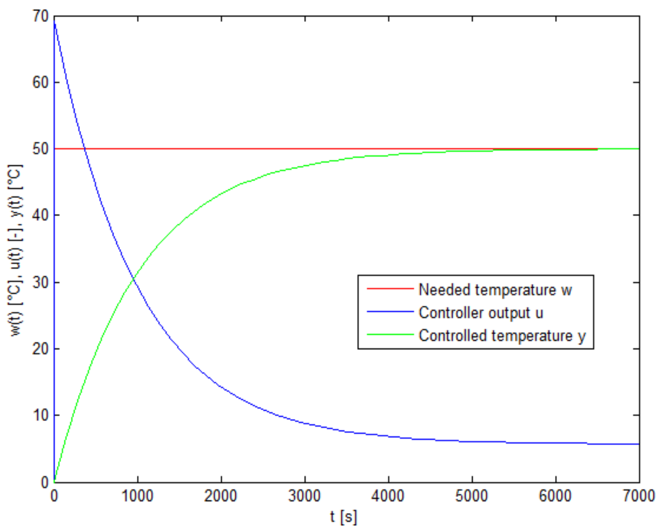


Fig. 8: Temperature controlling by a PI controller

Due to the long time regulation of PI controller, it was replaced by a two – position controller with penalization. To calculate it is used measured static characteristic (4).

Controller parameters are calculated from following equations (7) and (8):

$$k_p = 1 + \left(1 - \frac{w-y}{y} \cdot \frac{1}{\frac{p_p}{2}}\right) \cdot \left(k_{p\max} - 1\right) \tag{7}$$

$$k_{p\max} = \frac{u_{\max}}{u_{str}} \tag{8}$$

where parameters mean:

- k_p penalization constant
- w needed value
- y output
- p_p penalization range
- $k_{p\max}$ maximal value of penalization constant

- $u_{\max}$ maximal value of controller output
- u_{str} value of controller output in operating point

For the first time controller was calculated with p_p=10% for operating value at 60°C. This regulator was simulated and next used on real reactor. In the control process is small overshot, but the time to reach is shorter then was used PI controller. It's showed in fig. 9.

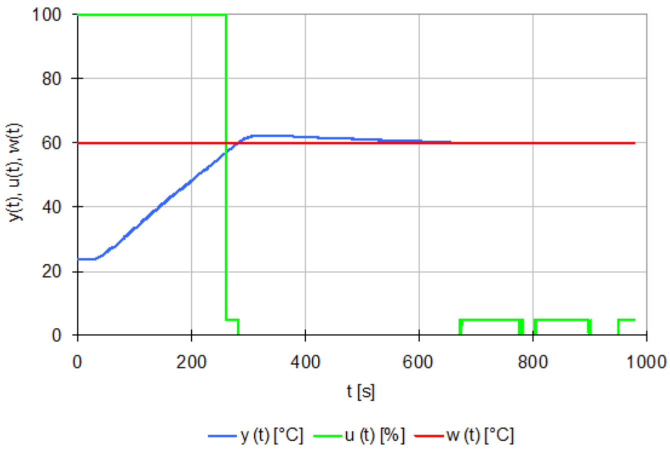


Fig. 9: Controll process of two – position controller for p_p=10%, set temperature at 60°C (w); controller output u; regulated temperature y

Due to the requirement to controll proces without overshot, it was calculated again with p_p=20% for operating value at 60°C. This second two – position controller with penalization was slightly slower than the first, but there is no overshot of regulated temperature. It's showed in fig. 10.

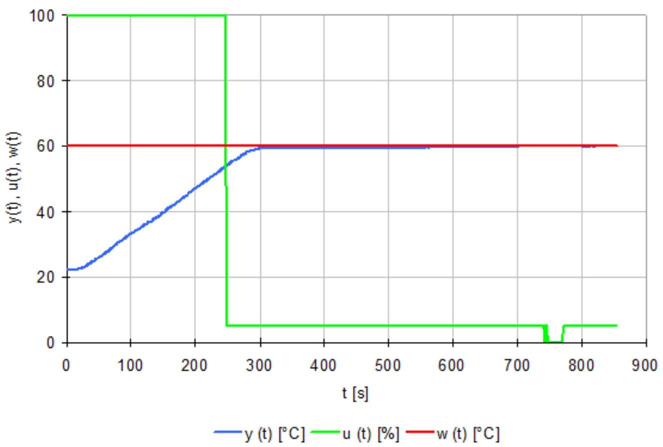


Fig. 10: Controll process of two – position controller for p_p=20%, set temperature at 60°C (w); controller output u; regulated temperature y

This measurement was made few times with full reactor on different temperature in laboratory and the result was still identical – without overshot with very small time differences.

V. Process Visualization

The main function of the control unit is production process control. Due to requirement for changes the parameters of process, intuitive setting and controlling the process with information about it, the visualization was created [10]. It can be accessed on computer with web browser (visualization is based on Java platform) or on the connected terminal.

The programmable logic controller has two RJ45 ports with internal switch, due to this it can be connected to local area network by UTP/STP wire or wireless by Wi-Fi device. On the place of terminal is used micro-browser web-panel PCD7.D410 from Saia company. It's connected by UTP cable to the one of RJ45 port, that's mentioned above. This terminal has 10.4" TFT diagonal screen with 640x480 pixel resolution [11]. This screen is touch resistive for easy setting the process parameters. It's showed on fig. 11.

Fig. 11: Touch screen terminal

For easy setting and using of the control unit, three modes were created – automatic, semi-automatic and manual. In full automatic mode the user only set the volume of batch size and then software automatically performs a complete production of biodiesel (dosing, controlling of transesterification and draining to prepared separating vessel). In this mode the user can use emergency stop the process only.

One of the other modes is semi-automatic mode and manual mode. Both modes are protected by password due to avoid abuse and possible damage of reactor, such as overheating the electrical heater or degradation of feedstock and other materials, in extremely case to avoid of fire.

On the following figure is showed setup menu of the control unit (bottom picture) and the selection mode option (top picture). In the setting menu you can set the basic parameters of the process, for example reactor volume, flow rate of pumps and other special parameters, such as parameters of two-position controller with penalization, ratios of composition reaction mixture and password for protection of setting, semi-automatic mode and manual mode.

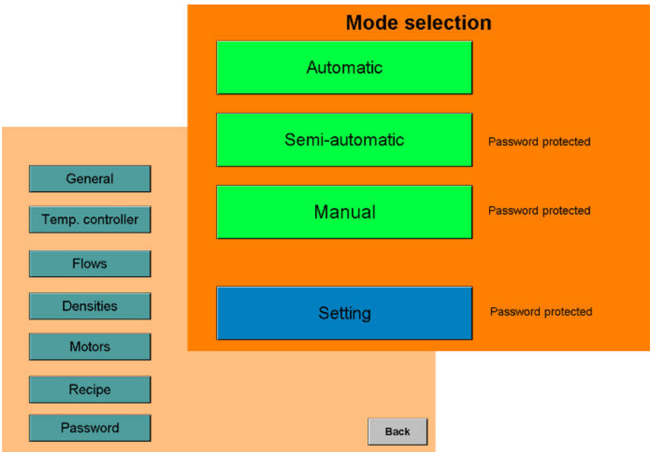


Fig. 12: Menu of the control unit

On the fig. 13 is showed visualization of process in semi-automatic mode. In the center of the image is placed reactor with measured temperature and the stirrer. On the left part is procedure calculator for ratio mixture and information table with feedstock materials volumes in reactor. On the right side of visualization is part with timer and switches for reserve outputs and switch for non-controlled mixing. At the top are showed pumps with possibility of automatic or manual dosing of feedstock. Pumps, stirrer, heater and flow in pipelines are animated depending on the situation.

VI. Conclusion

For the purpose of biodiesel production was made the control unit, based on programmable logic controller PCD2.M5540. This control unit provides precise reactor temperature control by the two – position controller with penalization, automatic dosing of feedstock and other materials according to specified formula and used fats.

Due to the requirements for use in a pilot plant, the unit was equipped with touch screen terminal that is for visualization of technological process and easy setting the parameters and controls each element in manual mode. The

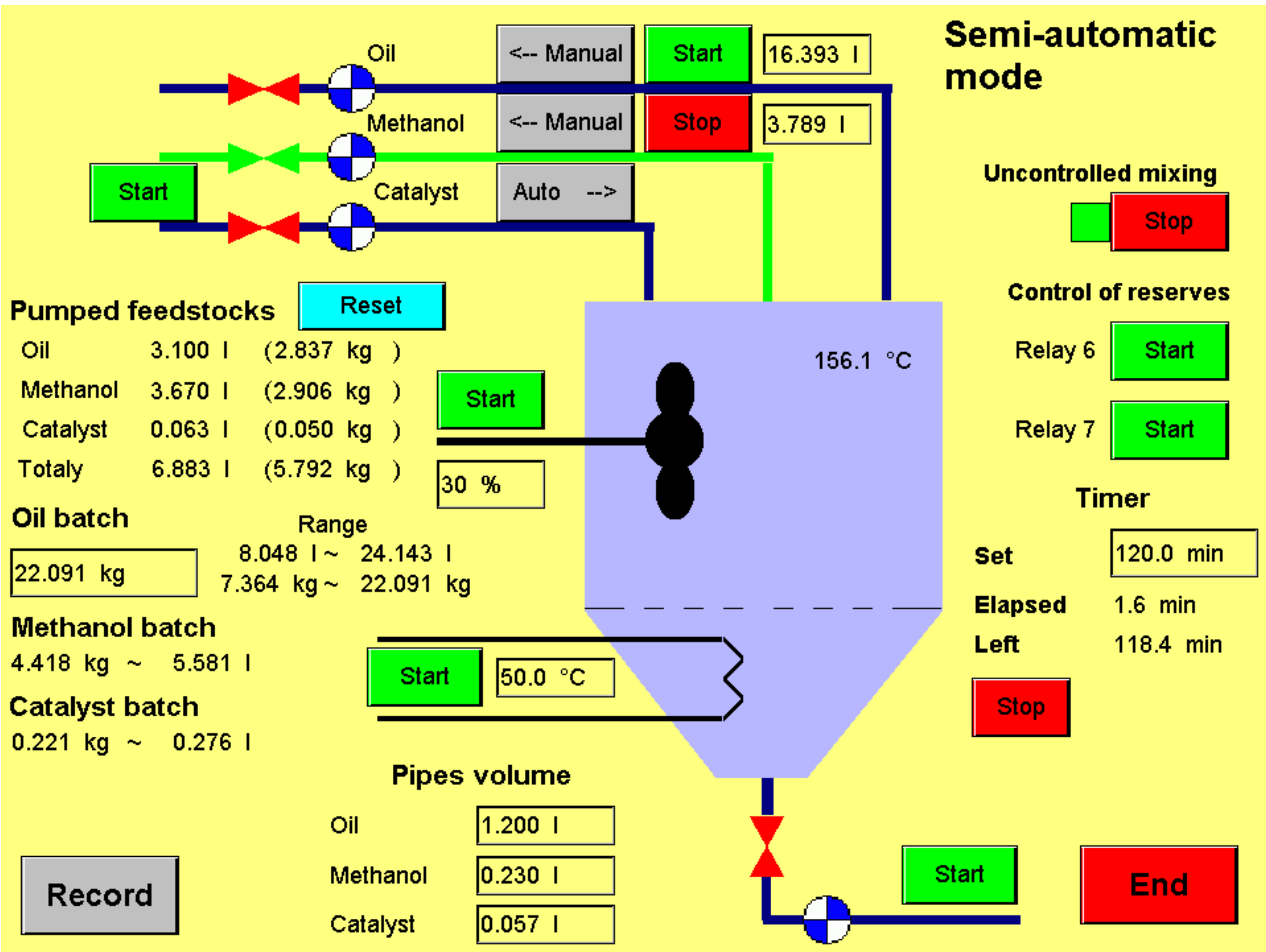


Fig. 13: Process visualization in the semi-automatic mode

device can be controlled remotely through the connection to local area network. For the control the process were created three modes: manual, semi-automatic and fully automatic. For the security reason, the manual and semi-automatic modes are protected by password. Also setup menu is password protected.

With this control unit the time of manual production is reduced, also the feedstock and other materials were saved, as energy for heating.

This unit is prepared for future extending, such as pH controlling of mixture in reactor or extending to control the other parts of production of biodiesel.

This system was build and now is using in the pilot plant production of biodiesel. In the next figure is showed real photo of this system, it is located in factory and it working without any failure.

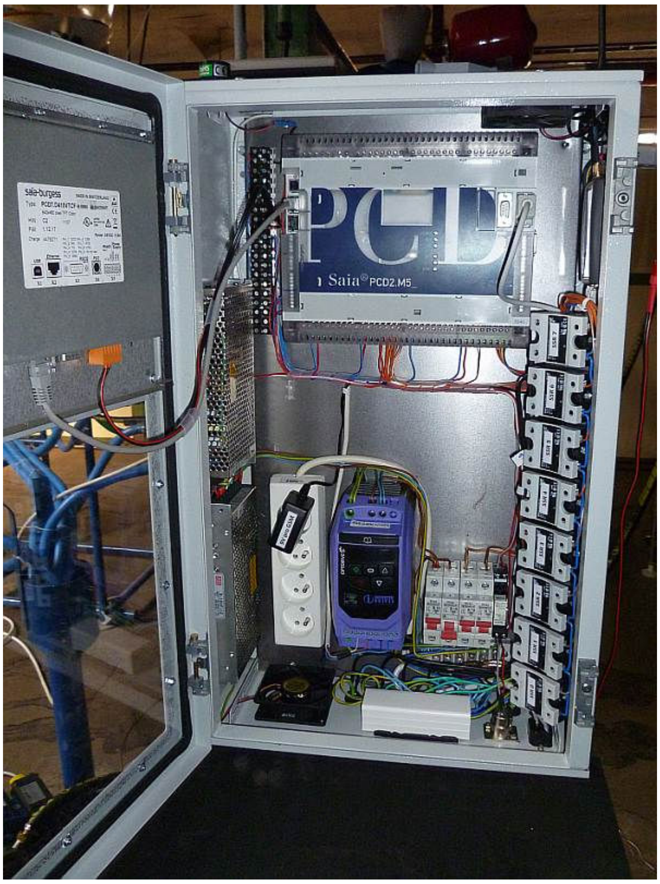


Fig. 14: Photo of real system in pilot plant procedure

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