Automatic dosing system for pilot plant production

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***Abstract*—**This paper deals a design of an automatic dosing system for pilot plant. The automatic dosing of raw materials in production is important to reach of accurate amount of dosed raw materials and it saves time. The accurate amount is important to get correct result of the production or laboratory tests. The dosing systems can work with a very small amount of materials in the laboratories or huge amount of raw materials in industry production. It can work slower and more accurate in the laboratory than in an industry production, where is important fast dosing. Combination of these parameters must be chosen and used in a pilot plant. Low price, fast and cheap reconfigurations of systems are important when tests are doing. These dosing systems can work independently or they can be controlled by main unit in production system. For these purposes an automatic dosing system was designed on the base of an ultrasonic or capacitive amount measurement in liquids reservoirs. It has density temperature compensation for the higher accuracy of dosing. It saves time that is needed to manual dose of liquids, and it doses specified amount in each time when it is used.

***Keywords*—**ARM, automatic dosing, microprocessor, pilot plant, raw material,ultrasonic measurement.

I. Introduction

THEpurpose of the automatic dosing systems is accurate measurement of dosing raw materials on the base of user requirements or the supervisor control system requirements. These systems have to be easy to operation. They can include operation interface on the place where raw materials are dosed or it can be controlled by remote access depending on the type. Here can be used some kind of industry Ethernet protocol or wireless connection.

Due to deployment of these systems, it’s not necessary to use systems with huge amount of computing performance and they can be realized with use of microcontrollers which price is lower in comparison with industrial computers. Apart from this price, they have advantages in low power consumption, small dimensions, and easy hardware modification to the controlled system. The worse changing the firmware functions and lower computing performance (in some extra cases) can be as disadvantages, but it can be eliminated by the choice of an appropriate microcontroller, adequate development tools and a proper design of the dosing system.

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A lot of attributes are required on these systems. These requirements are speed of dosing (in industry production) and accuracy with raw materials are dosed. Mostly these parameters are excluding each other, therefore it is necessary choice their compromises. The line of raw materials from reservoir to place of consumption is still important to be short and fast. The degradation of material or permanent change of some parameters should occur or temperature changes which increases the costs of the production.

These systems must measure and evaluate effects of environment for fulfillment of all parameters, especially accuracy. Most important is measurement of temperature and compensation of it. It’s necessary for dosing materials which volume is strongly depending on temperature and it is necessary dose it in weight units and simultaneously weighing is not available.

This paper is dealing with raw materials dosing in the pilot plant unit in the production of biodiesel. There are chemical aggressive liquids which are dosed in small amount due to the range of pilot plant unit. Small automatic dosing system was design for purpose of the acceleration of production and elimination of manual work with aggressive chemicals.

II. Production of Biodiesel

The biodiesel as an alternative fuel for combustion engines has some advantages and disadvantages in compare [1] to normal diesel:

- Lower CO2 emissions
- Production from waste materials or renewable resources
- Increases nitrogen oxide emissions

Some parts of biodiesel production are more expensive than a regular diesel. It’s given by the high price of the catalyst. On the other hand, it is compensated by a very low or zero price of the main raw material – oil or fat. Here can be used a vegetable oil (cooking oil) or an animal fat. Biodiesel parameters are very similar to a regular diesel, such as solidification temperature is almost equal and it’s not suitable for use in extreme cold.The production from these fats and oils go through transesterification of free fatty acids to the biodiesel and glycerin [1] – [3].

A. Transesterification of Unsaturated Fatty Acids

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

- Free fatty acids – oil or fat
- Alcohol
- Acidic or alkaline catalyst, depending on the fat and its properties

Methylesters – biodiesel and glycerin are created in transesterification [1] – [3] which is written in equation (1). Glycerin is insoluble in biodiesel and it can be removed from a mixture by the centrifuge or a separating vessel.

O (1)
||
CH_2 – O – C – R_1
|
| O
| || (catalyst)
CH – O – C – R_2 + 3CH_3OH →
|
| O
| ||
CH_2 – O – C – R_3

TriglycerideMethanol

O
||
CH_3 – O – C – R_1

OCH_2 – OH
|| |
→ CH_3 – O – C – R_2 + CH – OH
|
CH_2 – OH
O
||
CH_3 – O – C – R_3

Mixture of fatty estersGlycerin

where R_1, R_2 and R_3 are long hydrocarbon chains.

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

During the development many publications show various results that were achieved in this area. It was foundedthat the productionis strongly dependenton temperature: at 32°C transesterification takes 4 hours, but at 60°C approximately1 hour.Further testsshowedthe influence of differentcatalystsand theirmolarratios, as showed in Fig. 1 [1].

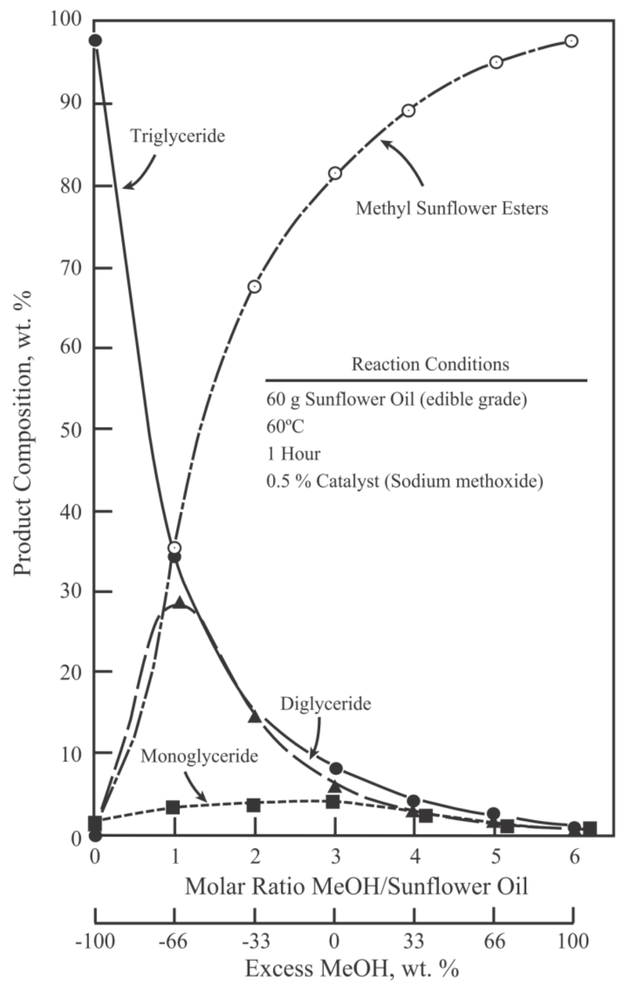

Fig. 1: Effect of the alcohol and the fat ratio to the transesterification

Also tests were conducted without catalyst, but it was necessary to reach a temperature 300°C – 350°C and molar ratio 42:1 of methanol to oil.

B. Process with unsaturated fatty acids

A special process is required, if the used oil or fat contains unsaturated fatty acids. 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 compensation of created potassium soap. It is described in following equation:

O O
|| ||
HO – C –R + KOH → K^{+-}O – C – R + H_2O (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. It is better to use on catalyst place sulfuric acid for these cases, as shown in the following equation:

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

fatty acids *sulfuric acid* *water*
methanolmethylesters

If we want to achieve maximum yield in the production, we must strictly observe ratios of individual substances, temperature and reaction time [1] – [4].

III. Conception of the System

The proposed system is designed to dispense two ingredients - alcohol and a catalyst in a user-given rate and amount. The system will measure the dosed amount of raw materials indirectly by the change of liquid level in the tank. It will be provided by using of capacitive level sensors for this measurement; possibly it can be used ultrasonic sensors which can have bigger differences between real level and measured level. It is given by spread speed of ultrasonic signal at different temperatures of air (if it isn't compensated) and surface liquid waves. It's necessary to measure the temperature to compensation of thermal expansion of the fluid and convert volume, because the requirement was dosage in the weight units. Normal solenoid valves with higher resistance against aggressive chemicals are used in this system.

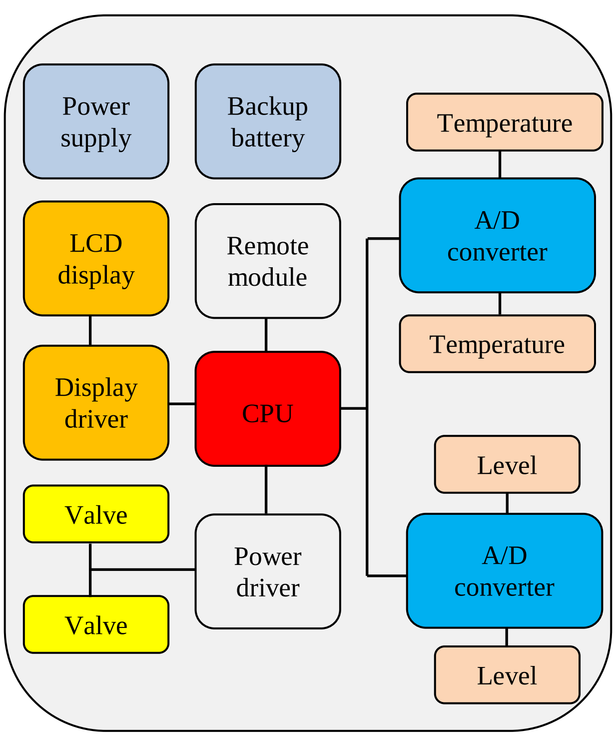

Fig. 2: Conception of the dosing system

The concept of the system tries to approach to state, which is showed in fig. 2, where significant individual blocks for specific purposes are showed.

The core of the system is based on microcontroller. It was chosen 32-bit ARM microcontroller(STM32F407VGT6) with Cortex-M4F core which contains 1MB flash memory and 192kb RAM with 168 MHz speed of core and 1.25DMIPS/MHz performance [5], because a development kit with this microcontroller is on the market. It was chosen for its high power, due to the requirement of easy operation with the touch screen graphic display and possibility of future expansion.

A. Core of the system

As it was told higher, the STM32F4 microcontroller was chosen. It is a powerful microcontroller with high speed of core. It includes a 16-stream DMA (Direct Memory Access) for fast communication between peripherals without participation of processor. This microcontroller has got parallel interface for communication with display in 8080 or 6800 modes and next serial interfaces. The development kit STM32 discovery board is used to easy development of hardware and software. This kit is described in [6] and includes standard features for development of various applications (LEDs, buttons, USB connectors). On-board ST-LINK/V2interfaceorJTAG interface can be used to debugging.

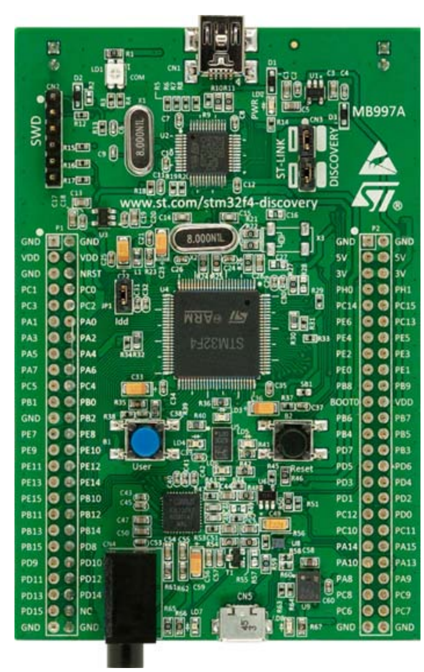

Fig. 3: STM32F4 discovery kit

Some recommended toolchains (Altium True Studio, Keil and IAR) or some other freeware under GNU/GPL license can be used to development the software.

B. Communication

Serial or parallel interface can be used to communication with superior system. The microcomputer includes peripheral units for implementation of most of them.

1) RS232

RS232 is simplest serial interface that can be used. To use this interface it just add converter from 3.3V logic level to ±15V levels. For this purpose, a MAX13235 is used in a lot of applications. Microcomputer achieves data rates up to 10.5Mbit/s itself. However, the converter speed is only about 3Mbit/s [7]. This does not matter, because most of equipment doesn't work with these very fast devices. Generally used speeds are up to 115200baud/s. Speed limits can be increased by the parameters of a transmission line. According to the standard, 15meters length or a maximum capacitance of the lines up to 2500pF is limiting the speed [8].

2) CAN

CAN interface can be used to communication over longer distances with higher reliability and with more communicating systems (multimaster topology). This interface in STM32F4 is compatible with 2.0A and 2.0B specification with 1Mbit/s transfer rate.They can receive and transmit standard frames with 11-bit identifiers as well as extended frames with 29-bit identifiers. Communication is implemented on a hardware standard from RS485 norm (twisted pair) with a maximum distance up to 1600 meters [9]. A principle is shown in fig. 4,

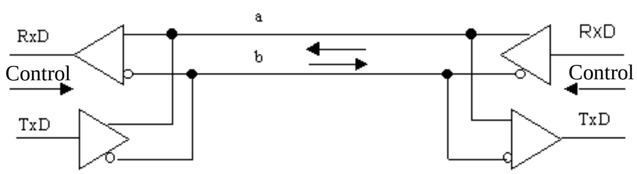

Fig. 4: Principle of RS485

and voltage levels are drawn in fig. 5.

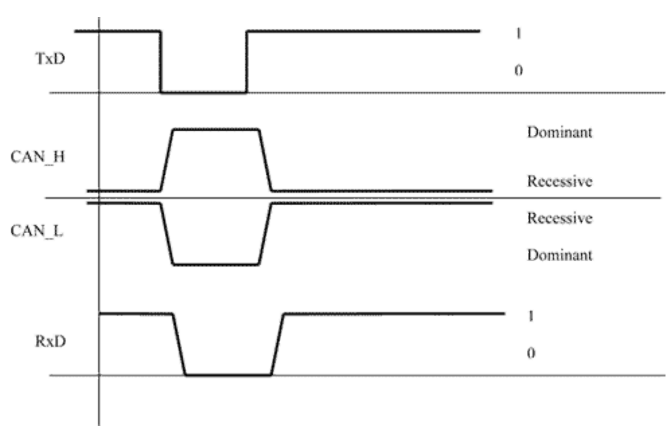

Fig. 5: Example of CAN levels

Next requirements must be fulfilled for functional connection. Individual communication nodes also need a physical connection each other. CAN standard doesn't prescribe either level voltage or physical medium. It is possible to build a network on voltage, current or light principle. When it communicates in speeds as was described in previous paragraph, it is necessary to think on the basic principles of information transmission. It is important to pay attention to impedance matching and protection against radiated out signals. In fact, the number of nodes for communication is unlimited; practically it is limited by possibilities of individual nodes and power load of network. Due to the principle of protocol, it isn't necessary to modify a superiority and priority of each node. This information is encoded in transmitted message. The advantage is in the possibility of modification the constructed network by adding or removing the number of network nodes. An example of this principle is in the shutting down the source of wrong messages or adding a node for a system diagnostic.

3) Ethernet

The Ethernet interface can be used to connect to local area network with support of TCP/IP protocol according to the OSI model. MAC interface with dedicated DMA and IEEE1588 support is implemented in microcontroller. The STM32F407VGT6 includes the following features [5]:

- Supports 10/100Mbit/s rates
- Tagged MAC frame support (VLAN support)
- Half – duplex (CSMA/CD) and full – duplex operation
- MAC control sublayer (control frames) support
- Several address filtering modes for physical and multicast address (multicast and group addresses)
- Supports hardware PTP (precision time protocol) in accordance with IEEE 1588 2008 (PTP v2) with the time stamp comparator connected to the internal timer (TIM2 input)

An external physical interface device (PHY), that provides the transfer between logic voltage level to the transmitted signal through UDP or STP cable, have to be used for a connection to the physical interface. This kind of converter is shown in fig. 6. Circuit DP83848 and integrated transformer in

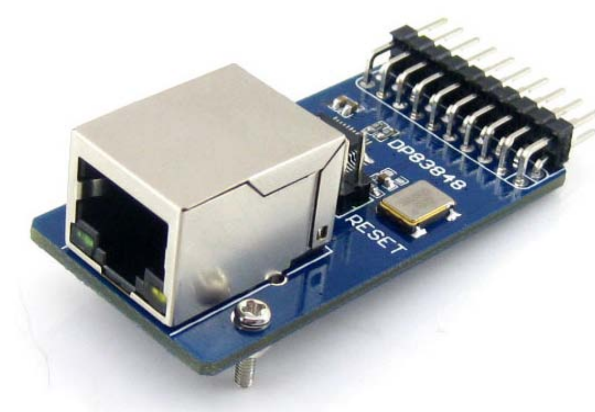

Fig. 6: DP83848 Ethernet physical interface device

RJ45 connector provide the transformation of signals.The DP83848 from Texas Instruments supports automatic cable detection [10] (Auto-MDIX). The maximum allowable cable length is 137 meters. Recommended connection of this circuit is shown in fig. 7.

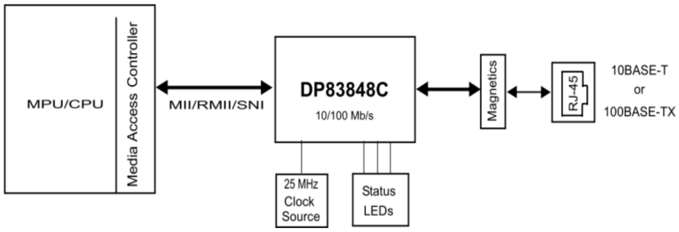

Fig. 7: Typical application of DP83848

4) USB

An USB port is present in the device for possible connection to the host system or for storage some data on flash discs. USB2.0 and high speed USB2.0 standards are supported. Of course, the back compatibility is guaranteed for older devices. The speed can reach up to 480MB/s. Next, it is also possible to upgrade a firmware of the dosing system through USB, but it hasn't been implemented yet and it is planes for future use and expansion of the system.

C. HMI

LCD panel is used for easy control of the system and for show status parameters. Dimensions of the display active area are 154x86mm at 800x480 pixels resolution; the size of pixel is 0.064x0.18mm. LED backlight was selected due for the purpose of lower power consumption and longer life. Therefore the display has got approximately 2W of electric power consumption. The real used display is shown in fig. 8.

Fig. 8: LCD panel

Display controller with its own memory is used fora connection of the LCD panel with microcontroller, whereas it isn't necessary to use addition memory for microcontroller and control of LCD panel is easier. Therefore it was chosen SSD1963 LCD controller that has enough memory – 1215kbit

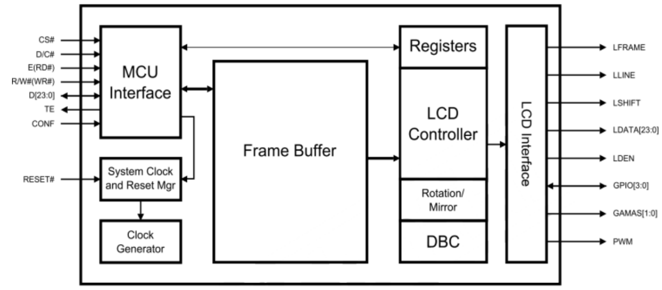

Fig. 9: Block diagram of SSD1963

and supports a maximum resolution of display up to 864x480 pixels. The display is connected via 24-bit parallel interface (8 bits per color) and it provides a dynamic backlight control, hardware rotation of displayed graphics and hardware mirroring. The microcontroller can be connected by use of a parallel interface with 8/9/16/18/24-bits width. The disadvantage of this solution is a need of additional supply voltage for LCD controller core, and therefore it needs a more complex power supply.

A touch layer is added in front of the LCD panel for purpose of touch control of this dosing system. A disadvantage of this construction is a decreased bright and worse color presentation of this display. A display with integrated touch layer would be more suitable.

It was chosen resistive touch panel due to need of control in gloves. Even though, it has got less durability than capacitive touch panels. However, these require control by conductive objects, like finger or metal pens, but the rubber gloves don't fulfill this requirement.

The principle of touched point involves in a sequentially measurements of resistance change of touch layer [11]. The touch panel has got four electrodes, which are located on each side on a sensitive layer. To determine the touch position of X-coordinate, the constant voltage is applied to the X-axis electrodes and the voltage is measured in Y-axis electrodes at the same time. The voltage level gives the position of touched

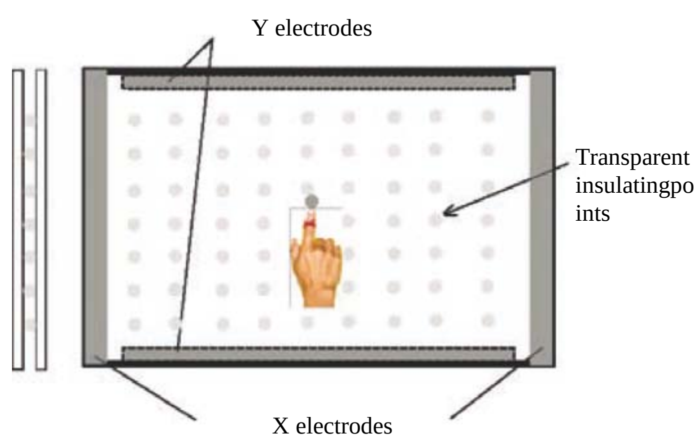

Fig. 10: Principle of resistive touch layer

point. This principle is illustrated in fig. 10. Position of the second axis is determined like the X-coordinate, but witch changed electrodes.

Specialized circuits are produced for these touch interfaces. Their application is preferable than own construction, because they offer complete circuits to evaluation of the contact point. The measured voltage is converted into digital form and the position is sent to a superior microcontroller by a serial line. Due to the mentioned advantages, a AD7843 touch controller was selected, that has got 8 or 12-bits A/D converter with sample rate up to 125kHz [12].

D.Measurement of level in tanks

As mentioned above, the measurement of dosed amount of dosed raw materials uses the indirect measurement of the liquid level in the reservoir and weight of materials is calculated by the change of the liquid level and temperature. There can be used several ways how to measure continuous liquid level. Hydrostatic sensors can be used for measurement in high tanks, but there is disadvantage in the measurement range from 1m to 100m [13],[14], which are unusable in the case of our pilot plant unit. The conductivity measurement can be better in our case, but liquids are highly flammable and an explosive environment may be in tanks – there is a risk of explosion. Other suitable sensor is ultrasonic sensor or capacitive sensor.

1) Ultrasonic measurements

This is a non-contact measurement level method based on a time measuring between transmissions and receptions of ultrasonic signals [15], [18]. The advantages of modern sensors are very highprecision and temperature compensation.

The operating principle is simple. Piezoelectric resonator periodically sends a series of ultrasonic pulses towards to a surface of the material whose height is measured. Material surface work as a reflector and reflected pulses are sent back to the transmitter. Height sensor via the same resonator receives the reflected impulses and calculates the time that elapsed between sending pulses and their reflection.

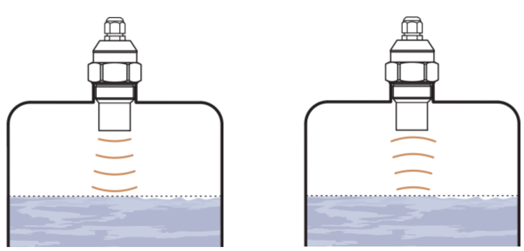

Fig. 11: Principle of ultrasonic level measurement

The measured distance between ultrasonic sensor and material surface is given by equation (2) at a constant speed of sound in the material environment and time:

$$l = \frac{c \cdot T}{2} \qquad (2)$$

where:

c - soundvelocity in the environment [m/s];

T - time between transmissions and receptions of ultrasonic pulses [s].

The prerequisite for sound spread is material elasticity, when compression and dilution particles occur in the air. Locations with air compressions and dilution progress by certain speed, called sound velocity$c$ [16].

Sound speed depends on several parameters and it can be describe by the following equation (3)

$$c = \left(1 + \frac{1}{2}\gamma \cdot t\right)\sqrt{\kappa \frac{p_0}{\rho_0}} \qquad (3)$$

where:

γ - thermal expansion of air [1/K];

t - air temperature [K];

p_0 - air pressure at 0°C [Pa];

ρ_0 - air density at 0°C [kg/m^3];

κ - the Poisson constant [-].

Due to the high price of ultrasonic systems, capacitive measurement of level can be selected. On the other hand, the ultrasonic level measurement is more accurate (temperature deviation 0.04%/K; accuracy 0.15%) [17] than capacitive measurement (temperature deviation 0.05%, nonlinearity 1%) [19].

2) Capacitive level measurement

Capacitive method of level measurement in tanks is often used as method for measurement levels of liquid and solid materials. It can be used for continuous or limit measurement.

The sensing part of the continuous level meter has cylindrical or flat shape of electrode(s). The materials are stainless steel, aluminum or these materials with surface isolation (PTFE, PE). Electrode is directly placed into a tank. The second can be metallic or electrically conductive material of tank wall. On the other hand, the additive second electrode must be used [18].

Depending or the level change a ratio of a immersed part of the electrode is changed and capacity of sensor is changed too. The total capacity of the system is a sum of sub-capacities. Electrical parameters of circuit are influenced by leakage resistance in the liquid. It is shown in a next figure,

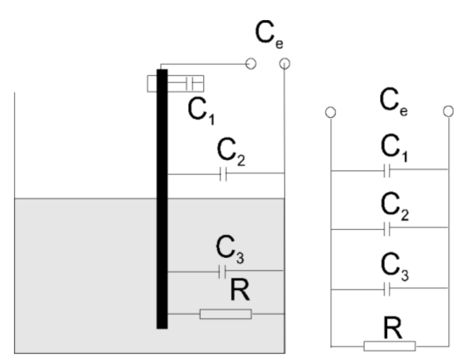

Fig. 12: Capacitive level measurement

where:

C_1 – capacity of electrode mounting
C_2 – air capacity above a liquid surface
C_3 – capacity of liquid
R – leakage resistance

For measurement of conductive liquid are using isolated electrodes. Isolation must be made from chemically resistive material, usually PTFE [18].

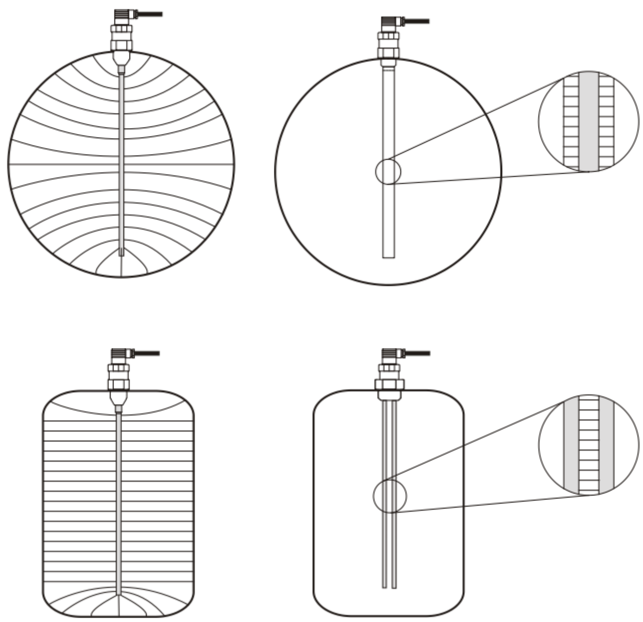

Fig. 13: Examples of compensation for nonlinear capacity change in tanks

The capacity change is nonlinear in the most tanks. It can be compensated by calculation (if you know model of tank) or two electrodes system can be used [19]. The examples are shown in fig. 13.

E. Dosing valves

The tanks with raw materials were placed above of a reactor, because of demand to a low price of the system. Due to this reason, there is low flow of liquids materials into reactor, therefore the pump it is not necessary equipment of the system. Solenoid valves can be used for this low flow of materials (max 5litres/min). Valves were chosen made from PTFE material, because dosed liquids are chemicals aggressive materials. Of course, the stainless steel can be used instead of PTFE. This valve is shown in fig. 14. There is direct controlled 2/2 valve. It has got separating PTFE membrane and itis designed for aggressive chemicals and ozone. It was chosen in model with 24V DC coil (alternate current can be used too), maximal allowed pressure 3bars and k_v factor 9.5litres/min. Time of opening is 5-20ms, closing time is 25-100ms. These valves are produce in IP65 protection class.

Fig. 14: Solenoid valve made from PTFE

IV. Conclusion

Presented text has given the several basic information about biodiesel and its methods of production.

For the purpose of the biodiesel production in pilot plant was designed the automatic dosing system for raw materials to purpose save time by exclusion of manual dosing and it saves materials by more accurately dosing. This system provides dosing of chemical aggressive liquids in user defined weight ratio.

The dosing is based on indirect method thatis the measurement of the liquid level in tanks. Amount of dosed material is calculated on the base of level change and it's compensated by temperature measurement in each tank.

The core is based on 32-bit ARM microcontroller which gives a lot of performance, it's controlled by touch screen LCD and it can be extended by other modules for communication. Of course, the dosing system is easily extendable and upgradable as pilot plant production required.

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