EXPERIMENTAL INVESTIGATION OF HEAT CARRIER FLOW EFFICIENCY

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Abstract
In order to state the amount of heat energy produced by a solar collector or consumed by a heated floor, usually the heat transfer medium flow intensity as well as its inflow and outflow temperatures is to be measured. But these parameters are changeable during an operation. Therefore with a view to obtain more precise data, to automate the data acquisition process, the produced or consumed power and its character, the amount of produced or consumed energy at a certain period of time, the energy transformation ratio and other parameters, as well as to increase the attained data accuracy and credibility, a new heat carrier flow intensity meter has been developed and produced. Setting it with some data collecting device it is possible to determine the produced or consumed power as a function of time, and the produced or consumed heat energy in a certain time interval. The technical performance of the heat carrier flow metering system is given. Experimental investigation of the produced heat energy by the solar collector with a canal absorber, and the consumed heat energy by the heated floor panel, has been carried out using the newly developed method and some of the obtained results presented.
Key words: solar collector, panel, flow, efficiency, metering.

Introduction

When carrying out an experimental investigation of heat energy produced by a solar collector or consumed by the heated floor, it is important to state the efficiency of the heat source or heat consumer. Usually for this heat meters are used. For an experimental determination of the heat energy produced by a solar collector, a heat transfer medium meter usually is used, and the inflow and outflow heat carrier temperature has to be measured (Harcenko, 1991). The deficiency of this methodology is that it is hard to automate the process and to record the obtained data. It is possible to get only an average heat carrier circulation pump efficiency, but it is variable in time due to inconsistency of electric voltage, heat carrier temperature changes, circulation pump torque, and some accidental factors. For the scientific investigation of solar collectors and heated floor panels, where more precise data would be obtained, the measuring and data recording process has to be improved by using automated data metering and acquisition possibilities. In order to eliminate the mentioned shortcomings, to automate the data acquisition process and to increase the data accuracy and credibility, the heat carrier flow meter has to be equipped with a heat carrier flow intensity metering sensor and a frequency-voltage convertor. Therefore the objective of the research is to automate the data acquisition process and to increase accuracy and credibility of the obtained data. In order to attain the aim, the heat meter was equipped with the heat carrier flow intensity metering sensor and the frequency-voltage convertor. The outgoing from the convertor direct voltage, which numerically is directly proportional to the intensity of the heat carrier flow into the heat meter, was recorded into the data collector. By this the heat meter additionally was supplied by the heat carrier flow intensity metering and recording function.

Materials and Methods

At the experimental investigation of a heated floor or floor panel, more important parameters, which have to be stated, are the consumed power, the surface temperature of the heating element and its evenness along the surface. Designing the construction of the heated floor or floor panel, from the economic point of view it is important to minimize the heat losses, so that the coefficient of its efficiency is as high as possible. The evenness of the distribution of the temperature on the heating surface for the newborn piglets has to be about ± 1˚C. In order to establish the momentary power of the producing or consuming devices, it is necessary to know the heat carrier flow intensity, the heat carrier temperature flowing into and out of the device, as well as the heat carrier heat capacity. Then the power of a heat device can be calculated using formula:

$$P_h = g \cdot c_p \cdot (t_1 - t_2), \tag{1}$$

where

- P_h – power of the heat device, W;
- g – intensity of the heat carrier flow into the device, kg s^{-1};
- t_1; t_2 – inflowing and outflowing heat carrier temperature, ˚C;
- c_p – specific heat capacity of the heat carrier (water $c_p = 4.18 \cdot 10^3$ J kg^{-1}°C^{-1}).

Table 1

Dependence of some water parameters on water temperature

T, °C	ρ, kg m^{-3}	c_p, kJ kg^{-1} °C^{-1}	T, °C	ρ, kg m^{-3}	c_p, kJ kg^{-1} °C^{-1}	T, °C	ρ, kg m^{-3}	c_p, kJ kg^{-}°C^{-1}
0	999.9	4.212	40	992.2	4.174	80	971.8	4.195
10	999.7	4.191	50	988.1	4.174	90	965.3	4.208
20	998.2	4.183	60	983.1	4.179	100	958.4	4.220
30	995.7	4.174	70	977.8	4.187	110	951.0	4.233

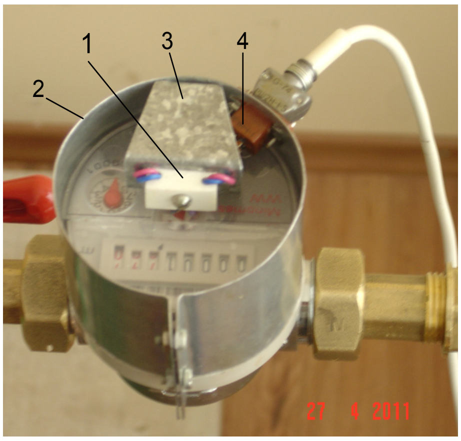


Figure 1. **Heat carrier flow intensity metering sensor**

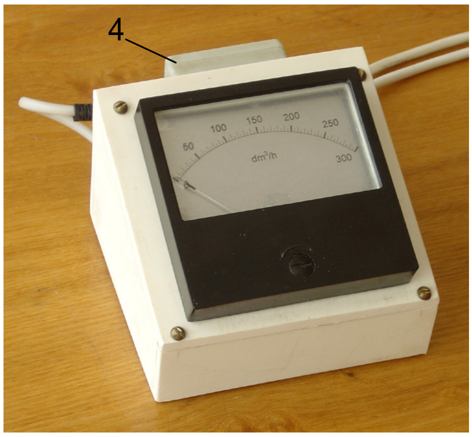


Figure 2. **Frequency-voltage convertor**

If the heat carrier circulation intensity g (kg h^{-1}) is known and if the water as the heat carrier is used, the heating device power can be calculated:

$$P_h = \frac{g \cdot 4.18 \cdot 10^3 (t_1 - t_2)}{3600} = 1.161 \cdot g \cdot (t_1 - t_2) . \quad (2)$$

If the produced heat energy is being accumulated, for instance, stored up in a hot water tank, the amount of produced heat energy can be calculated as following:

$$Q = m \cdot c_p (t_1 - t_2) , \quad (3)$$

where

Q – produced amount of energy, kJ;

m – heat carrier mass, kg.

If performing experimental investigation, where water is used as a heat carrier, it is important to consider the dependence of water parameters on its temperature. For the further calculations the necessary water parameters depending on water temperature in Table 1 are given (Михеев and Михеева, 1977).

Results and discussion

At the agency of the Latvia University of Agriculture Research Institute of Agricultural Machinery a device for solar collectors produced and heated floor panels consumed heat energy metering and recording device was developed for caring out the experimental investigation of heated floor panels for newborn piglets resting places. The device consists of two parts: self-made heat carrier flow intensity meter, and industrially produced data recording devices.

The heat carrier flow intensity metering sensor consists of a clamp 2, clenching the water meter (Fig. 1). In the clamp, a holder 3 is fixed. On the second end of the holder above the circumference of the heat meter's teethed rotor, a photo-electric convertor 1 in a plastic body is placed. In the clamp 2, a plug 4 is fixed, through which the sensor's plug by means of a cable is connected with frequency-voltage convertor 4 (Fig. 2).

On the front panel an indicator of the heat carrier flow meter is located, which limb is graduated in the range of 0-300 dm^3 h^{-1}. At the rear side of the body, a pocket 4 is made, where the data collector (HOBO Data Logger) is placed. The scheme of the electric circuit is located on a plate and installed into the plastic body of the frequency-voltage convertor.

In the right side of the frequency-voltage corrector's body, a frequency-voltage character line's corrector is installed. During the calibration of the device, the corresponding value of the heat carrier flow's intensity for the voltage convertor coefficient K has to be adjusted. The functional scheme of the device is shown in Fig. 3. It includes the circulation pump 1, the

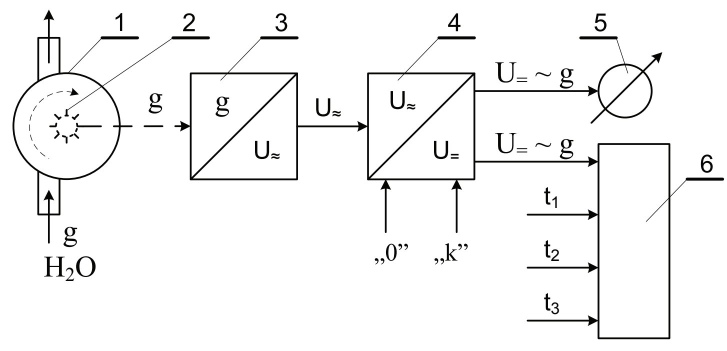


Figure 3. **Functional scheme of the device**

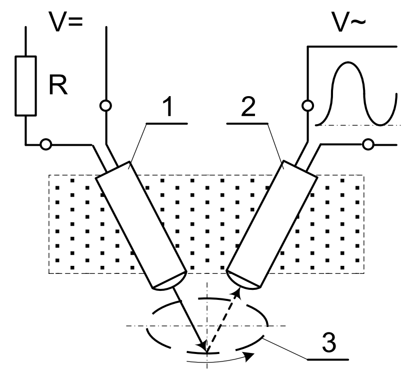


Figure 4. **Infrared irradiative diodes: 1 – VD1; 2 – VD2**

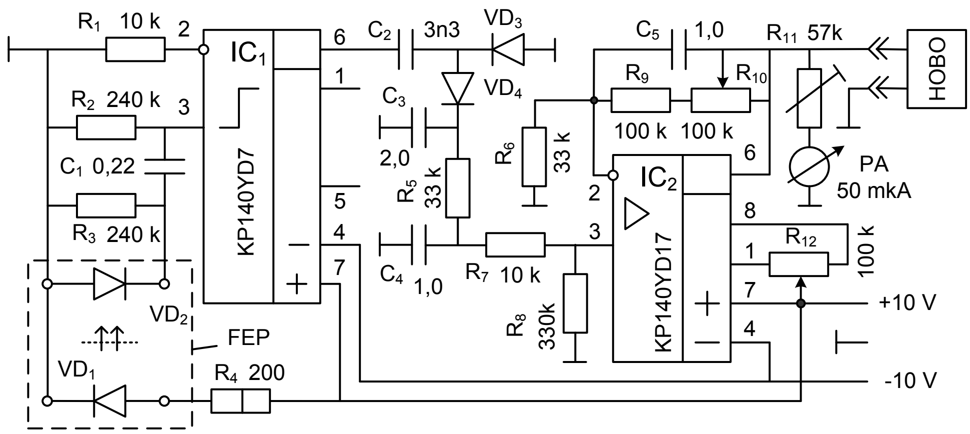
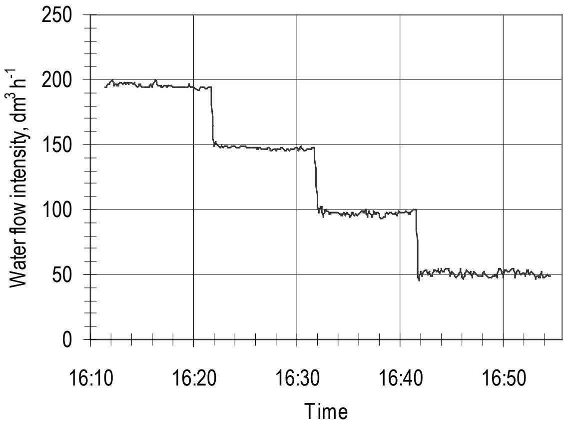


Figure 5. **Electric circuit scheme**

heat carrier flow turbine which, by means of magnetic clutch, is connected with a teethed rotor 2. Above the rotor, which is hermetically separated from the heat carrier space, the heat carrier flow intensity sensor with a photo-electric converter 3 is located, which itself is electrically connected with frequency-voltage convertor 4. To the frequency-voltage convertor 4 the flow intensity indicator 5 and data register 6, for instance, HOBO Data Logger U12-006, are joined.

The electric circuit scheme is given in Fig.5. The photo-electric convertor of the flow intensity consists of two infrared irradiative diodes: 1 – VD_1, and 2 – VD_2. They are placed on the division circumference of the teethed rotor 3 (Fig. 4). The diode VD_1 in series with the current restriction resistance R is connected to the electric voltage and produces the infrared radiation. When the radiation striking the teethed rotor spokes reflects from them on the diode VD_2, there the electric voltage is produced. If on the way of the infrared beams is a shrink between the rotor's spokes, from which the radiation does not reflect, the voltage on the diode VD_2 does not appear. The diode VD_2 through the condenser C_1 (Fig. 5) is connected to the incoming snap 3 of the operational intensifier IC_1. At the intensifier IC_1 outgoing voltage snap 6, an overcharge condenser C_2 is connected. To another snap of the condenser C_2, through the diode VD_4 the voltage accumulation condenser C_3 is connected. The condenser C_3 through the voltage fluctuation filter R5C4R7 is connected to the direct incoming snap 3 of the integral intensifier IC_2. The outgoing voltage snap 6 of the intensifier IC_2 is connected to the heat carrier flow intensity indicator PA, data register HOBO, and to the corrector R_{10} of the transformation coefficient K. To the intensifier IC_2 snaps 1 and 8, zero value adjustment corrector R_{12} of the transformation character line is connected. According to the functional (Fig. 3) and electric circuit (Fig. 5) schemes, the device is operating as following. When the heat carrier flows through the flow meter, its turbine is rotating and by means of the magnetic clutch turns the teethed rotor 3 (Fig. 4). If the fluid flow in the flow meter is constant, the turbine and rotor rotates continuously, and on the snap of the photo-electric converter diode's VD_2 appears and disappears the voltage. By the shape this voltage is like a sine curve (Fig. 4), which frequency is proportional to the teethed rotor rotation frequency and at the same time it is proportional to the intensity of the fluid flow

a



b

Figure 6. **Test of the flow intensity metering device in operation with the canal type solar collector „a", and its characteristic line at different flow intensity adjustments „b"**

frequency in the fluid flow meter. This voltage through the condenser C_1 is delivered to the direct incoming snap 3 of the operational intensifier IC_1, which when operation in the regime of the intensifier IC_1 at the exit 6 gives the meander shape voltage, by which the condenser C_2 charges and discharges into the condenser C_3. By each charge the voltage in the condenser C_3 increases. In order the voltage on the condenser C_3 remains proportional to the recharge frequency of the condenser C_2, and at the same time to the intensity of the fluid flow into the flow meter, simultaneously is taking place the condenser's C_3 discharge through the connected in parallel to it resistors R_5, R_7 and R_8. The recharge of the condenser goes as following. Condenser C_2 charges through the diode VD_3 from the feeding source, when on the operational intensifier's IC_1 outgoing snaps appears negative voltage (-9 V). During the charge it is disconnected from the condenser C_3 by the diode VD_4. When the voltage on the intensifier IC_1 outgoing snap 6 momentarily changes from negative to positive (+9 V), the condenser C_2 discharges into the condenser C_3 through the diode VD_4. The voltage from the condenser C_3 with resistors R_5 and R_7 is led on the operational intensifier's IC_1 correctors IC_2 direct outgoing snap 3. The voltage led to the snap 3 of the intensifier IC_2 decreases by the adjusted value of the transformation coefficient K=1+ (R9+R10)/R6. The heat carrier flow intensity according to the coefficient K value and parallel to the operational intensifier IC_2 outgoing voltage is adjusted by changing the value of the resistance R_{10}.

As a positive peculiarity of the device is relatively simple and fast control of its accuracy. For this it is necessary to take the time t_s of flowing out of 1 liter heat carrier at a constant regime of the device operation. Then the intensity of the heat carrier flow in $dm^3\ h^{-1}$, which has to be shown by the indicator and recorded by the data logger, can be calculated by formula

$$g = \frac{3600}{t_s}, \tag{4}$$

where

- g – amount of liquid flown out during the time t_s, dm;
- t_s – time of flowing out g amount of liquid g, s.

If the indication of the indicator does not coincide with the amount of liquid flown out of the device during the certain time, then for the indicator the value, obtained in the experiment, has to be adjusted using the correction coefficient K and by a screwdriver turning the axel in corresponding direction. In order to get the check-up result of high accuracy, instead of the register a high precision digital voltmeter has to be connected.

It has to be considered that 1V of voltage shown on the voltmeter has to correspond to the liquid flow intensity of 1000 dm^3 or 100 l per hour. According to face value (nominal), the intensity of liquid flow metered and recorded has to be in the range from 50 to 250 $dm^3\ h^{-1}$, because the data logger HOBO H08-006-04 is operating at the range of voltage from 0 to 2.5 V. The device after production has been tested at the solar collector with canal absorber (Ziemelis et al., 2007) (Fig. 6). The corresponding adjustment had been made according to the methodology given above with obtained data recording into the data logger HOBO Data Logger H08-007-02. The heat carrier flow intensity in the range of 195, 150, 100 and 50 $dm^3\ h^{-1}$ was adjusted according to the indicator of the device and digital multi-meter Escor 97.

The invented fluid flow intensity metering device (Putans et al., 2011) was used in a set with the temperature metering and recording system Pico TC-08 Thermocouple Data Logger, where for adjusting of the flow intensity meter with the system TC-08 self-made voltage devisor instead of Simple Chanel

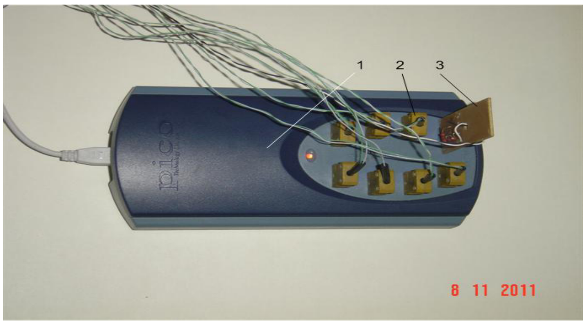


Figure 7. **Pico TC-08 Thermocouple Data Logger**

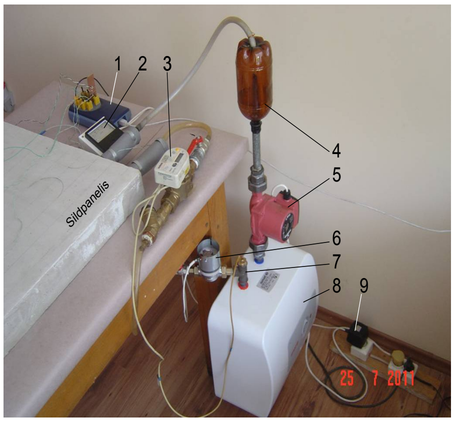


Figure 8. **Stand for an experimental investigation of the newborn piglets' floor heating panels**

Table 2

Flow intensity meter testing results

No	Results according to, l/h				Mean value	Max. deviation %
	flow Indicator	heat meter	PicoLog table	1litre - flowing out time		
1	150	153	153.3	150.5	151.7	± 1.09
2	109	112	110.6	106.3	109.47	± 2.6
3	44	45	43.8	42	43.7	± 3.4
4	31	31	31.4	29.3	30.67	± 3.4

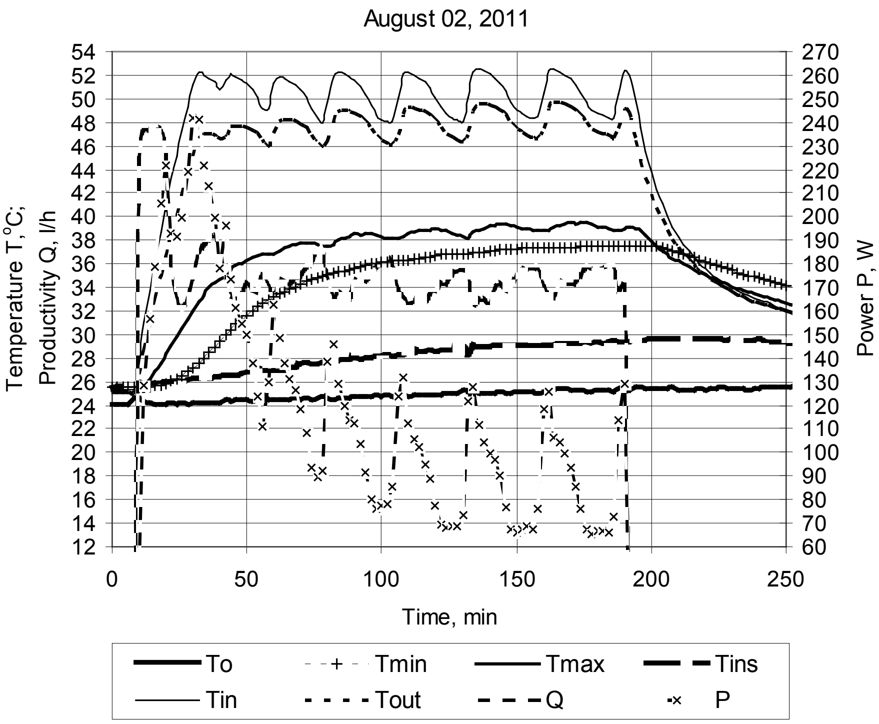


Figure 9. **Experimental results of the temperature distribution in the heated floor panel using the invented device:** To – surrounding air temperature, T_{min} and T_{max} – the lowest and the highest temperature on the panel's surface, T_{ins} – temperature inside the panel, T_{in} and T_{out} – inflow and outflow heat carrier temperature, Q – efficiency of the heat carrier circulation pump, P – heat power consumed by the panel.

Terminal Board is used. The Pico TC-08 Thermocouple Data Logger (Fig. 7) consists of a metering device TC-08 1, thermo-couple plug 2, and voltage devisor 3. To one metering device TC-08 it is possible to contact 8 thermo-couples (or a voltage source with U≤70 mV).

Pico type temperature metering-recording system is used together with the computer, in which the data gathering and processing system PicoLog is installed. The change of the data is going on using the USB interface.

For the experimental investigation of the new born piglets' floor heating panels, a special stand was developed (Fig. 8), which includes Pico TC-08 metering device 1, heat carrier flow metering indicator 2, heat meter M-CAL 0.6 compact 3, drainage vessel 4, heat carrier circulation pump 5, heat carrier meter and flow intensity sensor 6, temperature sensor plug socket 7, electric heat carrier heater (10 litres) 8, and heat carrier intensity meter feeding block 9.

Using the facilities given in Fig. 8, the test on comparing the data obtained by the heat carrier flow intensity meter with the data metered by the heat meter, PicoLog table data as well as the data gained by metering the time during which 1 litre of the heat carrier flew through the fluid consumption was carried out. The obtained results are presented in Table 2.

For the experimental investigation of the heated floor panels, the invented heat carrier flow intensity meter in the set of both the data recorder HOBO Data Logger H08-007-02 and Pico TC-08 Thermocouple Data Logger was used. As more perspective for the heated floor investigation has to be considered Pico TC-08 Thermocouple Data Logger system. Completing it with the worked out heat carrier flow intensity meter it is possible at the same time to meter and record the power and temperature of the heated panel practically in an unlimited number of points both on the panel's surface and inside its body. Example of the obtained results at heated floor panel's experimental investigation when the inflow water temperature is 50˚C in Fig. 9 is presented.

Conclusions

A special device for experimental investigation of heat energy produced by solar collectors or consumed by a heated floor has been developed, produced and tested.

The heat meter is equipped with a liquid heat carrier flow intensity metering sensor and a frequency-voltage convertor.

Using the invented heat carrier flow intensity meter in the set with the heat carrier flow intensity metering sensor and frequency-voltage convertor more precise experimental data have been obtained.

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