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:

\[ P_h = g \cdot c_p \cdot (t_1 - t_2), \]  

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\(^{-1}\)).
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:

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

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:

$$Q = m \cdot c_p (t_1 - t_2). \tag{3}$$

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 и 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 carrying 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 toothed 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).

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

<table>
<thead>
<tr>
<th>$T$, °C</th>
<th>$\rho$, kg m$^{-3}$</th>
<th>$c_p$, kJ kg$^{-1}$ °C$^{-1}$</th>
<th>$T$, °C</th>
<th>$\rho$, kg m$^{-3}$</th>
<th>$c_p$, kJ kg$^{-1}$ °C$^{-1}$</th>
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<td>4.183</td>
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<td>4.179</td>
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<tr>
<td>30</td>
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<td>4.174</td>
<td>70</td>
<td>977.8</td>
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<tr>
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<td>4.179</td>
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</tr>
<tr>
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<td>977.8</td>
<td>4.187</td>
<td>110</td>
<td>951.0</td>
<td>4.233</td>
</tr>
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</table>
heat carrier flow turbine which, by means of magnetic clutch, is connected with a teethed rotor. Above the rotor, which is hermetically separated from the heat carrier space, the heat carrier flow intensity sensor with a photo-electric converter is located, which itself is electrically connected with frequency-voltage converter. To the frequency-voltage converter the flow intensity indicator and data register, 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 – VD1, and 2 – VD2. They are placed on the division circumference of the teethed rotor (Fig. 4). The diode VD1 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 VD2, 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 VD2 does not appear. The diode VD2 through the condenser C1 (Fig. 5) is connected to the incoming snap of the operational intensifier IC1. At the intensifier IC1 outgoing voltage snap 6, an overcharge condenser C2 is connected. To another snap of the condenser C2, through the diode VD4 the voltage accumulation condenser C3 is connected. The condenser C3 through the voltage fluctuation filter R5C4R7 is connected to the direct incoming snap of the integral intensifier IC2. The outgoing voltage snap of the intensifier IC2 is connected to the heat carrier flow intensity indicator PA, data register HOBO, and to the corrector R10 of the transformation coefficient K. To the intensifier IC2 snaps 1 and 8, zero value adjustment corrector R12 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 (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 VD2 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.
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 $C_1$ charges and discharges into the condenser $C_2$. By each charge the voltage in the condenser $C_1$ increases. In order the voltage on the condenser $C_1$ 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 $C_1$ 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 $C_1$ 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 $C_1$ with resistors $R_4$ and $R_5$ is led on the operational intensifier’s IC$_2$ 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 $K=1+ (R_9+R_{10})/R_6$. 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

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

where

- $g$ – amount of liquid flown out during the time $t_s$, dm$^3$;
- $t_s$ – 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
Flow intensity meter testing results

<table>
<thead>
<tr>
<th>No.</th>
<th>flow Indicator</th>
<th>Heat meter</th>
<th>PicoLog table</th>
<th>1 litre - flowing out time</th>
<th>Mean value</th>
<th>Max. deviation %</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>150</td>
<td>153</td>
<td>153.3</td>
<td>150.5</td>
<td>151.7</td>
<td>± 1.09</td>
</tr>
<tr>
<td>2</td>
<td>109</td>
<td>112</td>
<td>110.6</td>
<td>106.3</td>
<td>109.47</td>
<td>± 2.6</td>
</tr>
<tr>
<td>3</td>
<td>44</td>
<td>45</td>
<td>43.8</td>
<td>42</td>
<td>43.7</td>
<td>± 3.4</td>
</tr>
<tr>
<td>4</td>
<td>31</td>
<td>31</td>
<td>31.4</td>
<td>29.3</td>
<td>30.67</td>
<td>± 3.4</td>
</tr>
</tbody>
</table>

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Figure 9. Experimental results of the temperature distribution in the heated floor panel using the invented device: $T_o$ – surrounding air temperature, $T_{\text{min}}$ and $T_{\text{max}}$ – the lowest and the highest temperature on the panel’s surface, $T_{\text{ins}}$ – temperature inside the panel, $T_{\text{in}}$ and $T_{\text{out}}$ – 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 divisor 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 metering sensor and frequency-voltage convertor more precise experimental data have been obtained.

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.

References

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