Determining the electric work of an immersion heater using an AC power meter

Objects of the Experiment

- Determining the electric work W_{el} of an immersion heater using an AC power meter
- Determining the electric work W_{el} measuring the voltage U, the current I and the time t
- Determining the change of thermal energy E_{th}

Principles

Electrical work is the work done on a charged particle by an electric field. In this experiment, electrical work is used to change the thermal energy of water. The supplied electrical work W_{el} is converted into thermal energy E_{th} in the heating coil of an immersion heater. This leads to a temperature rise of the water.

The supplied electrical work is determined by:

$$W_{el} = U \cdot I \cdot t \qquad (1)$$

U: voltage
I: current
t: time

According equation (1) the electrical work W_{el} can be determined by measuring the voltage U, the current I and the time t. In addition, the electrical work can be measured directly by an AC meter (alternating current meter).

The change in thermal energy E_{th} is determined by:

$$E_{th} = c_W \cdot m \cdot (\vartheta_2 - \vartheta_1) \qquad (2)$$

ϑ_1: temperature at start
ϑ_2: temperature at end
c_W: specific heat capacity of water
m: mass of water

According to equation (2), measuring the temperature ϑ_1 at the start and ϑ_2 at the end of the experiment allows to determine the thermal energy E_{th}.

The supplied electrical work and the thermal energy can be determined quantitatively in units of wattsecond (Ws) and Joule (J) so that their numerical equivalence can be demonstrated experimentally: $W_{el} = E_{th}$.

In the experiment the amount of electrical work W_{el} is determined that is required to bring 1 liter of water from room temperature to a boil. Three different measuring methods are applied:

a) by noting the meter reading M_1 of a electricity meter before beginning experiment and the meter reading M_2 when the water boils,

b) by counting the number of revolutions of the electricity meter disc during the heating process.

Fig. 1: Experimental setup for method c

c) by measuring the voltage U, the current I and the time t during the heating process.

The change in thermal energy E_{th} is determined from the temperature change between beginning and end of the heating. The resulting values are compared.

Apparatus

1 Alternating current meter	560 331
1 Pair of stand feet	301 339
1 Immersion heater	303 25
1 Plastic beaker, 1000 ml	590 06
1 Thermometer, -10 to +110 °C	382 34
1 Multimeter LDanalog 20	531 120
1 Multimeter LDanalog 30	531 130
1 Stop-clock I	313 07
4 Safety connecting lead 50 cm black	500 624

CS-1006

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Safety notes

Use caution when experimenting with dangerous contact voltages:

- Connect the device in circuits only when the mains plug is unplugged from the mains.
- Only connect the device to the AC mains using the power cable
- Connect voltage and current meters to the device using only safety connecting leads (500 420 ff) and only at the safety connection sockets.
- When no ammeter is connected, use only the safety bridging plug supplied with the AC meter to jumper the socket pair to the right.
- Observe the notes contained in the instruction sheet of the alternating current meter (560 331) and the immersion heater (303 25).

Setup

- Set up the alternating current meter on the pair of stand feet.
- Jumper the safety socket pair to the right (above the mains socket for the consumer) with the safety bridging plug.
- Connect the alternating current meter to the AC mains (230 V / 50 Hz).
- Pour 1.0 liter water in the plastic beaker.
- Put the immersion heater in the plastic beaker.

Note:
The immersion heater is equipped with an overheating protection. **Never** use immersion heater with less water than the minimum immersion level indicated in the operation instructions! Otherwise the heater will permanently fail to work.

Carrying out the experiment

Method a)

- Measure the temperature ϑ_1 of the water.
- Note meter reading M_1 from the counter value display.
- Connect the immersion heater to mains socket for the consumer of the alternating current meter. The immersion heater starts heating the water.
- Heat water till it boils and withdraw mains plug.
- Measure the temperature ϑ_2 of the water.
- Note meter reading M_2.

Method b)

- Measure the temperature ϑ_1 of the water.
- Connect the immersion heater to mains socket for the consumer of the alternating current meter. The immersion heater starts heating the water.
- Count the number n of revolutions of the meter disc during the heating process.
- Heat water till it boils and withdraw mains plug.
- Measure the temperature ϑ_2 of the water.

Method c)

- Withdraw the main plug of the alternating current meter.
- Connect the multimeter LDanalog20 as voltmeter to the safety sockets on the left side of the alternating current meter.
- Remove the safety bridging plug on the right side and connect the multimeter LDanalog30 as ammeter.
- Connect the alternating current meter to the AC mains (230 V / 50 Hz).
- Measure the temperature ϑ_1 of the water.
- Connect the immersion heater to the mains socket for the consumer of the alternating current meter and simultaneously start stop watch.
- Read off applied voltage U and current I.
- Heat water till it boils.
- Withdraw mains plug and simultaneously stop stop watch.
- Measure the temperature ϑ_2 of the water.

Measuring example and evaluation

Method a)

- Meter reading M_1: 12.70 kWh
- Meter reading M_2: 12.78 kWh
- Temperature ϑ_1: 32 °C
- Temperature ϑ_1: 100 °C
- Specific heat capacity of water: $c_W = 4.18\ \frac{\text{kJ}}{\text{kg}\cdot\text{K}}$
- Mass of 1.0 liter water: 1.0 kg

The electrical work W_{el} is calculated from the difference $M_2 - M_1 = W_{el}$ = 0.08 kWh = 288 kWs

The change in thermal energy E_{th} is determined according equation 2: $E_{th} = c_W \cdot m \cdot (\vartheta_2 - \vartheta_1)$ = 284 kJ

Method b)

- Number of revolutions of the meter disc n: 47
- Meter constant k: 600 $\frac{\text{revs.}}{\text{kWh}}$
- Temperature ϑ_1: 32 °C
- Temperature ϑ_1: 100 °C

The electrical work W_{el} is calculated from the number n of revolutions and the meter constant k:

$W_{el} = \frac{n}{k}$ = 0.078 kWh = 282 kWs

The change in thermal energy E_{th} is determined according equation 2: $E_{th} = c_W \cdot m \cdot (\vartheta_2 - \vartheta_1)$ = 284 kJ

Method c)

- Voltage U: 220 V
- Current I: 4.1 A
- Time t: 5 min 24 s = 0,09 h
- Temperature ϑ_1: 32 °C
- Temperature ϑ_1: 100 °C

The electrical work W_{el} is calculated according equation 1:

$W_{el} = U \cdot I \cdot t$ = 0.081 kWh = 292 kWs

The change in thermal energy E_{th} is determined according equation 2: $E_{th} = c_W \cdot m \cdot (\vartheta_2 - \vartheta_1)$ = 284 kJ

Comparison of the experimental results:

Electrical work W_{el}:

Method 1: W_{el} = 288 kWs

Method 2: W_{el} = 282 kWs

Method 3: W_{el} = 292 kWs

Change in thermal energy E_{th}:

E_{th} = 284 kJ

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