Equipment for Engineering Education

Experiment Instructions

WL 377 Natural Convection & Heat Apparatus

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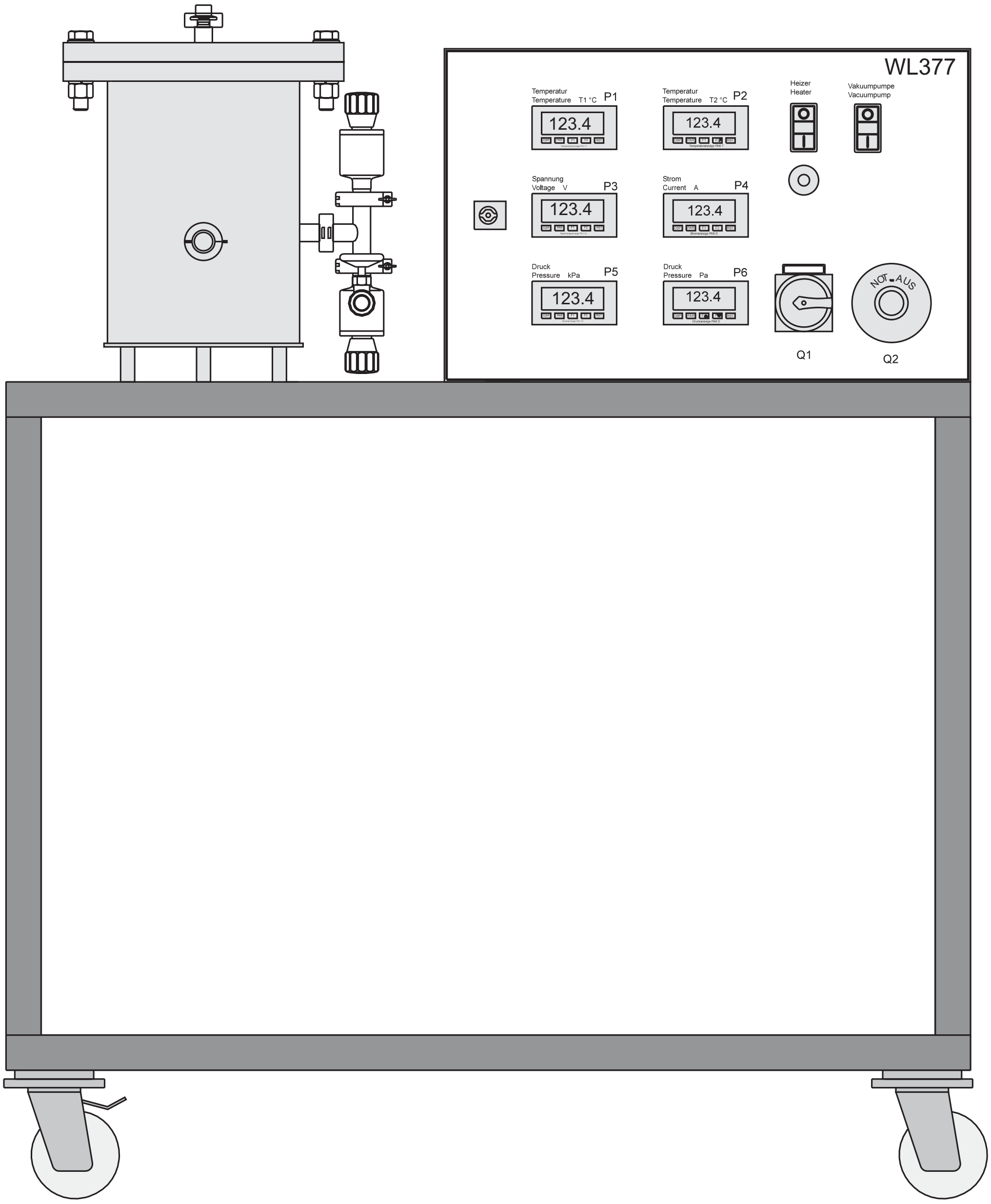
WL 377 NATURAL CONVECTION & HEAT APPARATUS



Experiment Instructions

Please read and follow the safety regulations before the first installation!

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1 Introduction

Heat transfer is used in industry in many processes. A differentiation is made between the following types of heat transfer:

- Thermal conduction in bodies and materials
- Convection between fixed and moving media
- Thermal radiation, which occurs without a physical carrier

As these individual effects are subject to different laws, they must be addressed separately.

For calculations in thermal engineering, it is always important to know the properties of the transport of heat. With the **G.U.N.T. WL 377 Natural Convection & Heat Apparatus** basic laws and parameters on convection and radiation can be determined experimentally.

For this purpose a heater is installed in a sealed chamber. The air can be evacuated using a vacuum pump so that only heat transmission due to radiation is measured. For the measurement of the convective contribution the chamber is again filled with air. Pressure, temperature, and for the heater voltage and current are displayed on the unit.

The unit is mounted on a trolley on castors. Only a mains electricity supply is necessary for providing power to the unit.

2 Unit Description

2.1 Unit Layout

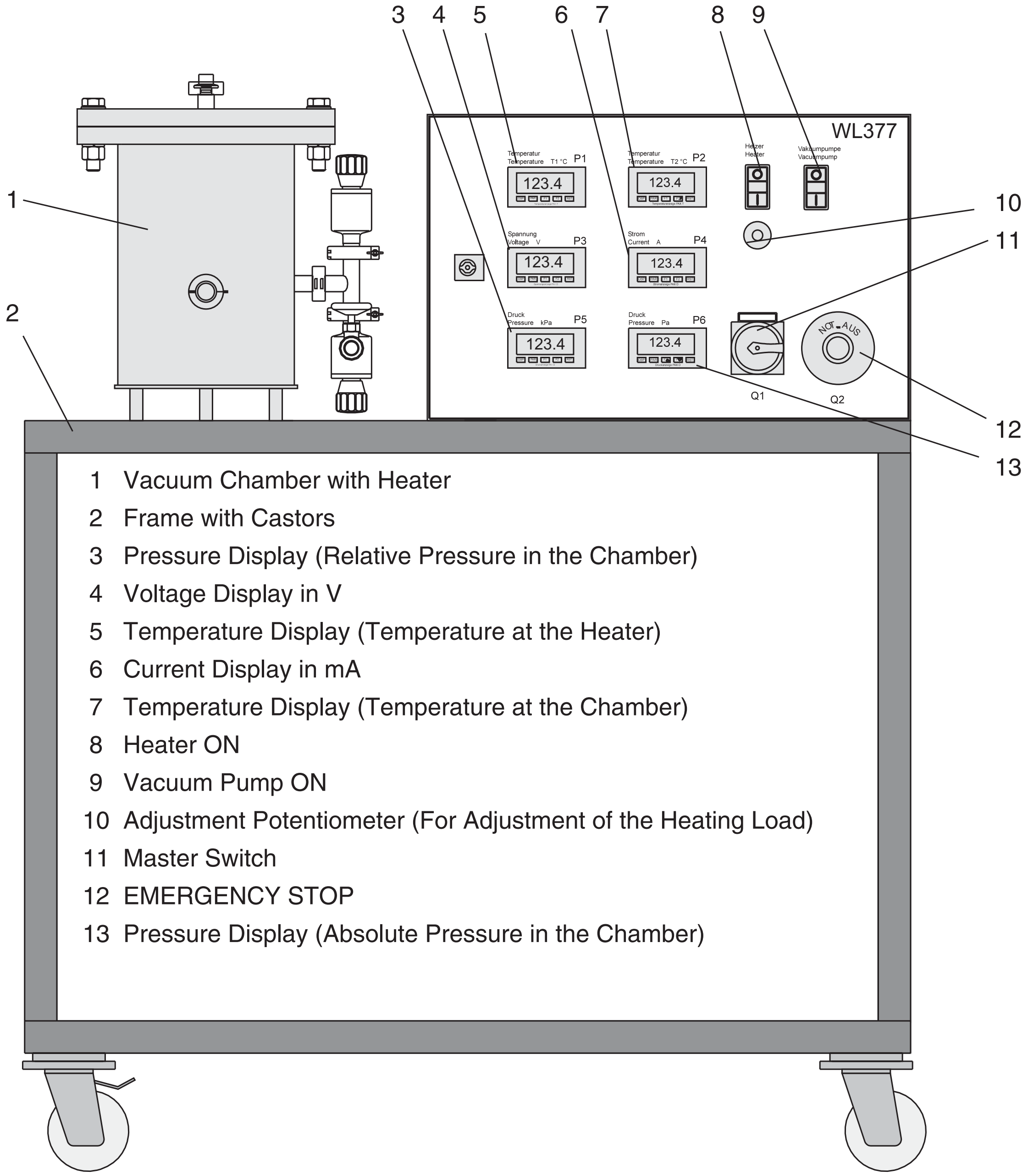

Fig. :2.1 General View WL 377

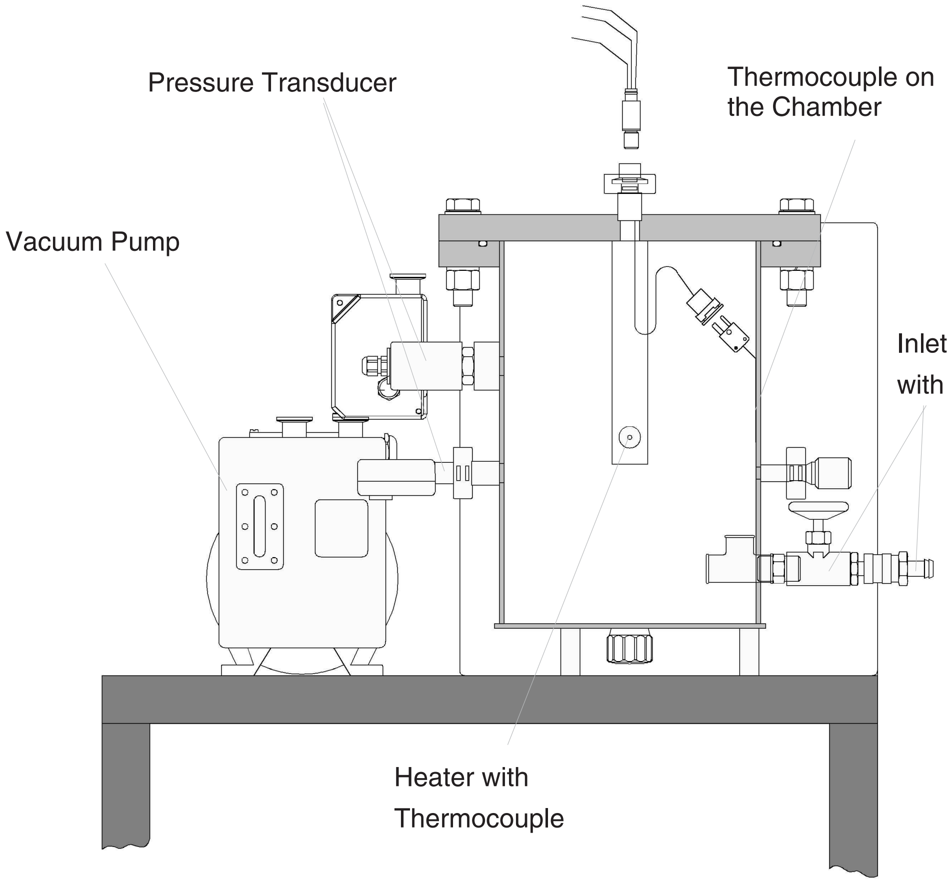

Fig. 2.1 View of Chamber

The experimental unit is fitted to a frame (2) on castors. It comprises a switch housing (Fig. 2.1) that has all the necessary displays for measured values on its front panel; all the switches for operating the unit are also fitted here. Beside the switch housing is the vacuum chamber with the heater, pressure measuring devices and thermocouples. The vacuum pump is behind the switch housing. A section through the chamber can be seen in Figure 2.2 for clarification of the positions of the measuring devices.

2.2 Commissioning

2.2.1 General

– Connect the unit to the mains electricity supply

2.2.2 Switch on Procedure

1. Unlock EMERGENCY STOP button (12) by pulling the red knob.
2. Turn master switch (11) to (I).
   (The measuring point indicators should now light.)
3. Close the inlet valve in the Figure 2.2, open the top valve on the chamber and switch on the vacuum pump by operating switch (9).
   (The pressure on displays (3) and (13) must fall.)
4. Switch on heater using switch (8) and set a heater power using the potentiometer.
   (Temperatures in the measuring displays (5) and (7) should rise)

The unit is ready for the measurement when the pressure no longer changes noticeably.

3 Safety

3.1 Health Hazards

The following is to be taken into account in relation to health and safety when using the **WL 377 Natural Convection & Heat Apparatus**:

DANGER! Caution on opening switch housing, and on making changes to all other electrical circuits. There is a risk of electric shock. It is therefore imperative to unplug the unit from the mains first. Only have work performed by a suitably qualified person.

Attention!

First vent chamber before the lid is removed.

The vacuum pump must be switched off before the lid of the measuring chamber is opened.

DANGER! Do not touch hot surfaces on the heater and chamber! There is a risk of burns. Allow unit to cool down first. If necessary dismantle specimen using gloves or a cloth.

3.2 Hazards for Unit and Function

There is a risk of overheating. Do not operate experimental unit at more than 200°C. Plastic parts may be damaged.

Prior to disconnecting or connecting power cables or data cables, first switch off the unit at the master switch. The temperature sensors and transducers may be irreparably damaged.

4 Theoretical Principles

4.1 Convection

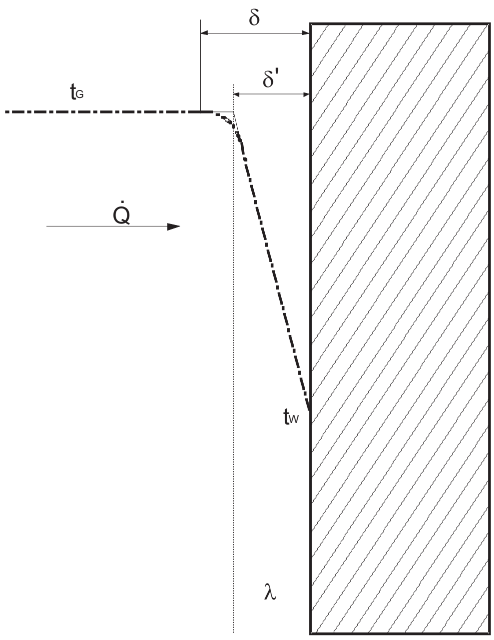

Fig.: 4.1 Convection

In the case of heat transfer by means of convection the heat is transferred to flowing liquids or gas particles. This energy is carried along by the particles as a flow. If the flow is itself caused by the transfer of heat, as for example in the case of air flowing past a central heating radiator, the movement is termed free convection. If the movement is due to pumps or fans independent of the heat transfer, e.g., for the cooling of an engine, the movement is termed forced convection.

The heat transferred by convection is referred to the area of the material to which the heat is transferred. If, for example, the heat is transferred from a gas like air to a solid medium like a wall, then the heat flow can be calculated as follows:

$$\dot{Q} = \alpha \cdot A \cdot (t_G - t_W) \qquad (4.1)$$

Here:

$\dot{Q}$ The heat flow transferred

α The coefficient of heat transfer

A The area of the wall

t_G The temperature of the gas

t_W The temperature of the wall

The coefficient of heat transfer α can be calculated as:

$$\alpha = \frac{\lambda}{\delta'} = \left[\frac{W}{m^2K}\right] \qquad (4.2)$$

Here:

λ Thermal conductivity ($\lambda_{L20°C} = 0{,}026 \frac{W}{mK}$)

δ' Thickness of the boundary layer (Fig.: 4.1)

From the relationship of equation 4.2 and 4.1, the heat flow transferred by convection can be calculated as:

$$\dot{Q} = \frac{\lambda}{\delta'} \cdot A \cdot (t_G - t_W) \qquad (4.3)$$

The coefficient of heat transfer depends on a complex relationship of a wide range of factors that are defined by the physical properties and flow state of the fluid, as well as the geometrical shape of the heated areas. In the following a few general figures for coefficients of heat transfer are given.

Coefficients of heat transfer α for air vertical to the metal wall.	Unit in $\frac{W}{m^2K}$
Stationary	**3,5.....35**
Moving gently	**23.....70**
Moving strongly	**58.....290**

For the calculation of the heat transfer by convection, the coefficient of heat transfer for stationary air is to be assumed. These values assume dry air, as α changes with the moisture content of the air.

4.2 Radiation

Temperature radiation is termed heat radiation or thermal radiation. There are two approaches for the theoretical description of the emission, transmission and absorption of radiation: the classic theory of electromagnetic waves and the quantum theory of photons.

Where:

Electromagnetic waves: $c = \lambda \cdot \vartheta$ (4.4)

Quantum theory of photons: $e_{Ph} = h \cdot \nu$ (4.5)

The radiation addressed here can be explained as the sum of the contributions of many small amounts of energy emitted. Although the movements and the position of the individual photons cannot be given, the behaviour of a large number can be described as an electromagnetic wave. We will address radiation by means of its wave character.

The waveband for thermal radiation is between: $\lambda = (0{,}35 - 10)\mu m$

The radiation incident on a body divides into three parts:

$$a + r + d = 1 \qquad (4.6)$$

Here:

a Coefficient of absorption

r Coefficient of reflection

d Permeability or coefficient of transmission

4.2.1 Black Body

For a black body a = 1, for a white body r = 1. Both bodies are theoretical boundary cases, the black body can however be realised approximately by means of a hollow space with small openings; the radiation entering the openings is completely absorbed. Solid and liquid bodies as a rule only allow a small amount of radiation to pass through (d=0).

The majority of bodies are grey; they absorb the same portion of all wavelengths of the radiation (a<1). Here the capacity of a body to emit is the same as it capacity to absorb (*Kirchhoff's law*).

$$\varepsilon = a \qquad (4.7)$$

In the following a few coefficients of emission are listed for the angle $\varphi = 90°$:

Surface	Temperature in °C	ε_n
Copper (polished)	20	0,030
Aluminium (bright rolled)	170	0,039
Iron (polished)	20	0,24
Iron (rusty)	20	0,85
Radiator paint	100	0,925
Black paint, matt	80	0,970

Table 4.1

The flow of energy radiated from a black body into the half-space from Stefan-Bolzmann's law:

$$\dot{E} = \sigma \cdot T^4 \qquad (4.8)$$

Here:

$\dot{E}$ The energy per unit area

σ Stefan-Bolzmann constant $5{,}67 \cdot 10^{-8} \dfrac{W}{m^2K}$

T Temperature of the medium (to the fourth power)

As the majority of radiation is emitted from grey bodies, the reduction in the radiation is taken into account with the coefficient of emission. Furthermore, by rearranging the Stefan-Bolzmann constants the radiation constants are found as:

$$C_s = 10^8 \cdot \sigma = 5{,}67 \frac{W}{m^2K} \quad (4.9)$$

For equation (4.8) and (4.9) the following is found:

$$\dot{E} = \varepsilon \cdot Cs \cdot \left(\frac{T}{100}\right)^4 \quad (4.10)$$

In the table on page 12 the coefficients of emission for the direction of $\varphi = 90°$ are given. To arrive at the total radiation as described in equation (4.10), the following must be set:

$$\dot{E} = \pi \cdot \dot{E}_n \quad (4.11)$$

Two bodies of different temperatures that exchange heat in the form of radiation are now considered. Here the total radiation comprises emitted and reflected radiation.

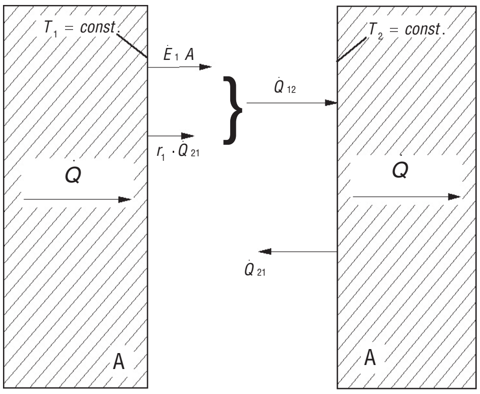

Fig.:4.2 Heat Transfer by Radiation

For body 1 the following applies:

$$\dot{Q}_{12} = \dot{E}_1 A + r_1 \dot{Q}_{21} \quad (4.12)$$

For body 2 the following applies:

$$\dot{Q}_{21} = \dot{E}_2 A + r_2 \dot{Q}_{12} \quad (4.13)$$

If equation (4.12) and (4.13) are now brought together, by rearranging the heat flow is found to be:

$$\dot{Q} = \frac{C_s}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \cdot A \cdot \left[\left(\frac{T_1}{100}\right)^4 - \left(\frac{T_2}{100}\right)^4\right] \quad (4.14)$$

4.2.2 Paths of Radiation in Cylinders

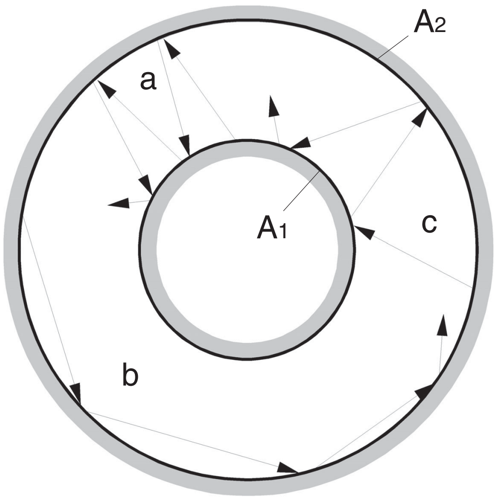

Fig.:4.3 Path of Radiation in the Cylinder

Figure 4.3 shows the path of radiation between two concentric cylinders that reflect like mirrors. The radiation (a) emitted by the inner surface A_1 is incident on the outer surface A_2 and is reflected there by the mirror-like surface such that it is again incident on surface A_1. This is a case of diffuse reflection where the radiation continues to be reflected between the two surfaces until it is completely absorbed. In the case of radiation (b) the surface A_2 is never left and the radiation always moves along the wall. This radiation does not contribute to the exchange of heat. The radiation (c) emitted from surface A_2 is reflected by surface A_1, reduced by the area$_{2-1}$, until it is completely absorbed.

If the outer surface A_2 reflects like a mirror, equation (4.14) becomes:

$$\dot{Q} = \frac{\sigma \cdot \left(T_1^4 - T_2^4\right)}{\frac{1-\varepsilon_1}{\varepsilon_1 A_1} + \frac{1}{A_1} + \frac{1-\varepsilon_2}{\varepsilon_2 A_2}} \qquad (4.15)$$

If in the third resistance of the denominator the area A_2 is replaced by the effective area A_1, the following is found:

$$\dot{Q} = \frac{A_1 \cdot \sigma \cdot \left(T_1^4 - T_2^4\right)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1} \qquad (4.16)$$

From this relationship it can be seen that the outer surface A_2 has no significance for the exchange of radiation.

5 Experiments

5.1 Preparation

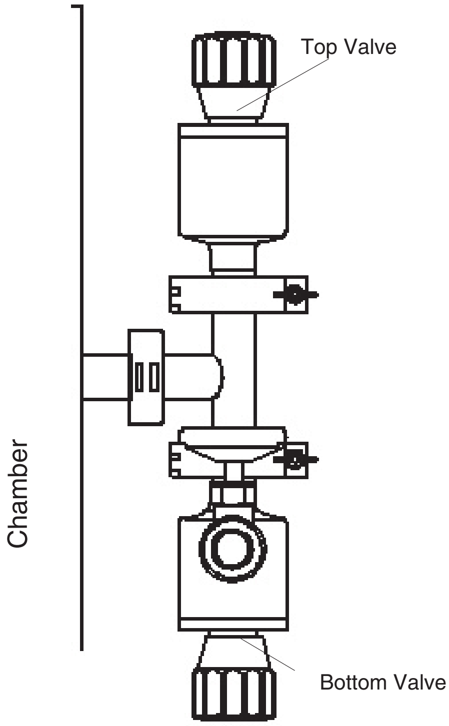

Fig.:5.1 Inlet and Outlet Valves on the Chamber.

- Investigation of heat transfer by means of **radiation**.

1. **Close** the **bottom** valve in Figure (5.1) and **open** the **top** valve.
2. Proceed as described in Section 2.2.2
3. The vacuum pump must remain switched on the entire time.
4. When the indications on the pressure and temperature displays no longer change, the measurement can be started.

- Investigation of heat transfer by means of **convection**.

1. Open the top and bottom valve in Figure (5.1).
2. Proceed as in Section 2.2.2, but skip point 3 of commissioning.
3. When the indications on the temperature displays no longer change, the measurement can be started.

5.2 Performing the Experiment

During the measurement of the heat transfer by convection and radiation, the following procedure is used:

- Preparation as per Section 5.1
- Using potentiometer (10) adjust the heater so that you start the measurement with the smallest heater load.
- Wait until the temperatures on the displays no longer change and then make a note of

the measured values. In the following there is a table that shows a series of measurements with the WL377.

- The heater power is then increased for further measurements and the procedure described above used.

Measurement	U / [V]	I / [A]	t_1 / [°C]	t_2 / [°C]	p_{abs} / bar	p_{rel} / bar
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						

Using the formulas given in Section 4, the heat flows can be calculated for the individual heater powers.

The Appendix contains a working sheet in which all the measured values can be entered. Information on material parameters and other variables for calculations are also entered here.

6 Appendix

6.1 Technical Data

Dimensions:

W x D x H:	1100 x1400 x 650 mm
Weight:	approx. 70 kg

Power Supply nominal 230V / 50Hz
Alternatives optional, see type plate

Thermocouple made of Kapton: Type K
Self-Adhesive Thermocouple: Type K

Heater Element:

Rating	10 W
Voltage	24 V
Diameter	6,5 mm
Length	60 mm

Vacuum Pump:

Nominal Suction Capacity	5 m³/h
Final Pressure	$5 \cdot 10^{-3}$ mbar
Motor Rating	370 W
Speed	1390 min^{-1}

Chamber Internal Sleeve Surface Area:0,20957 m²

Heater Sleeve Surface Area $5{,}6549 \cdot 10^{-3}$ m²

Coefficients of Emission:

Black Paint, Matt ε_n: $0{,}97 \frac{W}{m^2K}$

Iron ε_n: $0{,}24 \frac{W}{m^2K}$

6.2 Working Sheet for Recording Measured Values

Date: . . . .

Parameters:

Coefficients of Emission:

Black Paint, Mat: $\varepsilon_n = 0{,}97 \frac{W}{m^2K}$

Iron, polished: $\varepsilon_n = 0{,}24 \frac{W}{m^2K}$

Stefan-Bolzmann Constant: $\sigma = 5{,}67 \cdot 10^{-8} \frac{W}{m^2K}$

Radiation Surface Area:

Heater Sleeve Surface Area: $A_1 = 5{,}6549 \cdot 10^{-3}$ m²

Chamber Internal Sleeve Surface Area: $A_2 = 0.20957$ m²

Coefficient of Heat Transfer

Air to Iron: $\alpha = 3{,}5...35 \frac{W}{m^2K}$

Measurement	U / [V]	I / [A]	t_1 / [°C]	t_2 / [°C]	p_{abs} / bar	p_{rel} / bar
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						