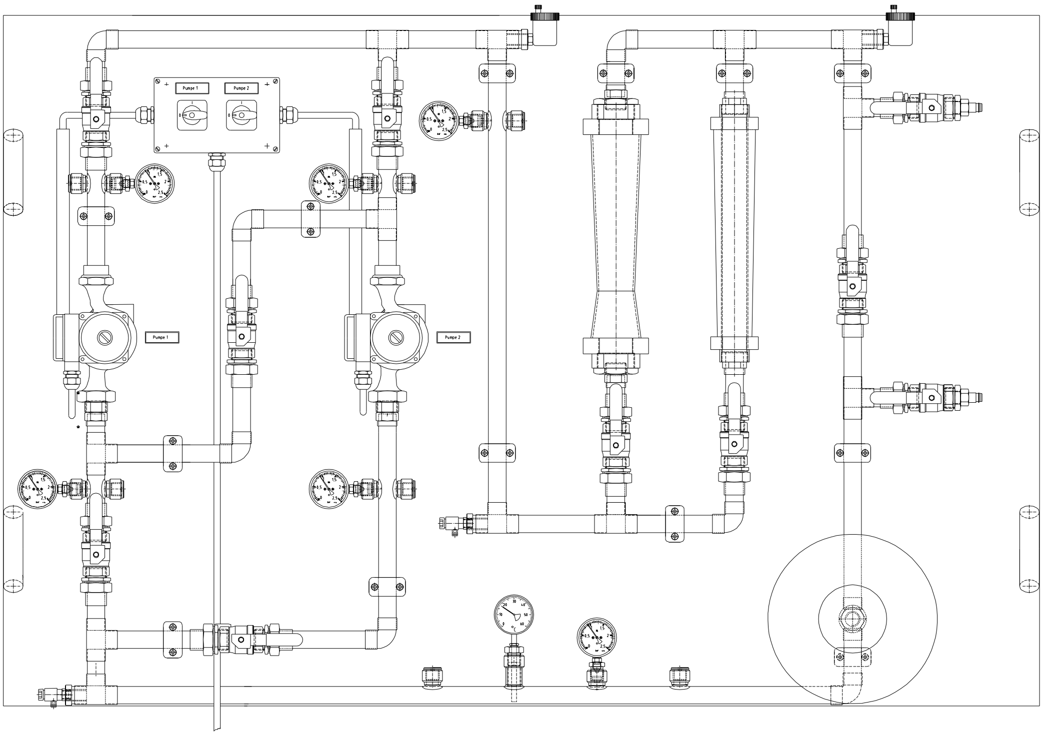
Experiment Instructions

HL 107 Circulating Pumps Training Panel



Experiment Instructions

This manual must be kept by the unit.

Before operating the unit:
- Read this manual.
- All participants must be instructed on handling of the unit and, where appropriate, on the necessary safety precautions.

Table of Contents

1 Introduction

On the HL 107 Circulating Pumps Training Panel commercially available circulating pumps are to be investigated in respect of their characteristic curves and the effect of series and parallel connection on the flow rate and the capacity. The following topics can be investigated in detail on the training panel:

- Determination of pump curves at different rotational speeds
- Determination of pipework characteristic curves
- Determination of operating points
- Series connection of 2 circulating pumps
- Parallel connection of 2 circulating pumps
- Pump capacity matching
- Comparison of experiment and calculation
- Observation of the effects of faults.

In addition the student gains skills in the preparation and performance of series of experiments, and knowledge on the use of pressure and flow rate measuring equipment. Measuring glands provided also enable a PC data acquisition system to be connected (not included).

The Appendix to this instruction manual contains working sheets that ease the methodical evaluation of the experiments.

The experimental setup is fitted to a rear wall that can easily be suspended in the HL 100 Universal Stand for Training Panels or the HL 090 Supply Bench for Training Panels.

The system, once filled, can be used independent of the water mains in different locations, also in training and seminar rooms, and lecture theatres.

1.1 Intended Use

The unit is to be used only for teaching purposes.

2 Safety

2.1 Structure of the Safety Instructions

The signal words DANGER, WARNING or CAUTION indicate the probability and potential severity of injury.

An additional symbol indicates the nature of the hazard or a required action.

Signal word	Explanation
DANGER	Indicates a situation which, if not avoided, will result in death or serious injury.
WARNING	Indicates a situation which, if not avoided, may result in death or serious injury.
CAUTION	Indicates a situation which, if not avoided, may result in minor or moderately serious injury.
NOTICE	Indicates a situation which may result in damage to equipment, or provides instructions on operation of the equipment.

Symbol	Explanation
	Electrical voltage

2.2 Safety Instructions

⚠ WARNING

Reaching into the open switch box can result in electric shocks.

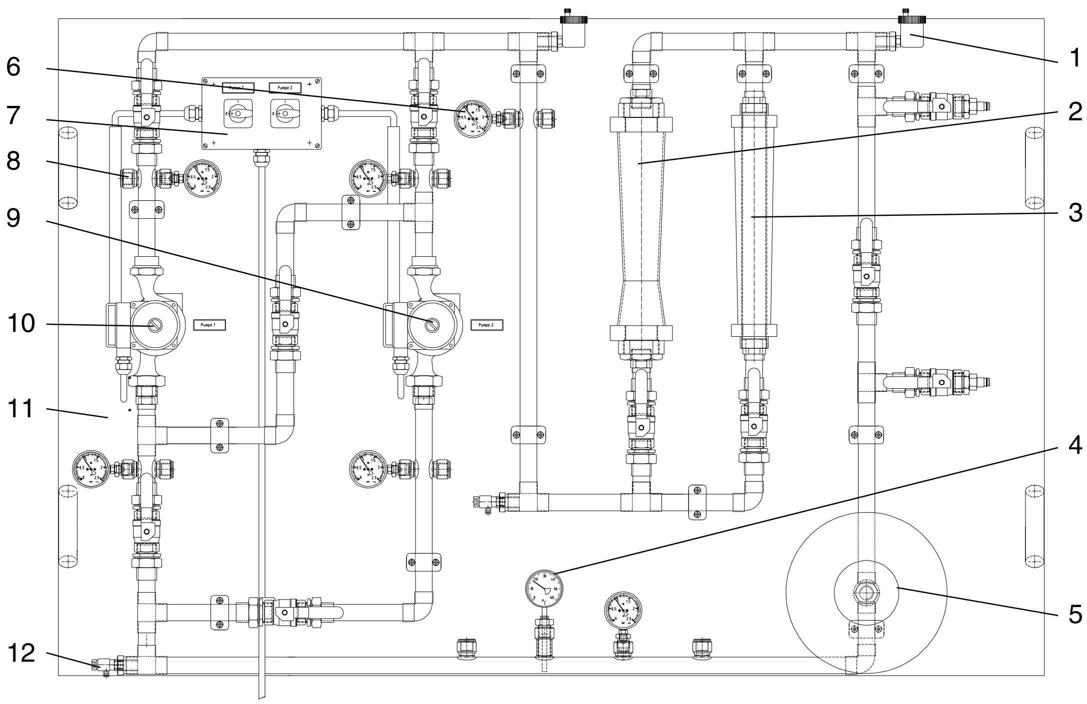
- Disconnect from the mains supply before opening.
- Work should only be performed by qualified electricians.
- Protect the switch box against moisture.

3 Unit description

The Training Panel, Circulating Pumps is a completely equipped experimental unit for pressure and flow rate measurements in pipe systems with two circulating pumps in individual, series, and parallel connections. In conjunction with the HL 100 Universal Stand for Training Panels or the HL 090 Supply Bench for Training Panels the HL 107 Training Panel has the following features:

- The complete experimental setup is on a training panel.
- The experimental unit can be moved and is easy to manoeuvre due to four castors.
- Dimensions are such as to permit passage through normal door openings.
- Secure positioning by means of two castors with brakes.
- Once filled, can be operated independent of the water mains.
- Flow rate measurements using two rotameters with different measuring ranges.
- Pressure measurement using Bourdon gauge.
- Measurement of the system pressure using bimetallic dial thermometers.
- Membrane expansion vessel integrated into the pump circuit to compensate for pressure fluctuations and volume changes.
- Individual, series, and parallel connection as well as change of the flow resistance via ball-cocks.

3.1 Layout of the Training Panel



1	Automatic bleed valve	7	Switch box for pump controller
2	Rotameter	8	Measuring glands
3	Rotameter	9	Circulating pump
4	Bimetallic dial thermometer	10	Circulating pump
5	Expansion vessel	11	Training panel
6	Bourdon gauge	12	Drain cock

Fig. 3.1 Explanation of the components

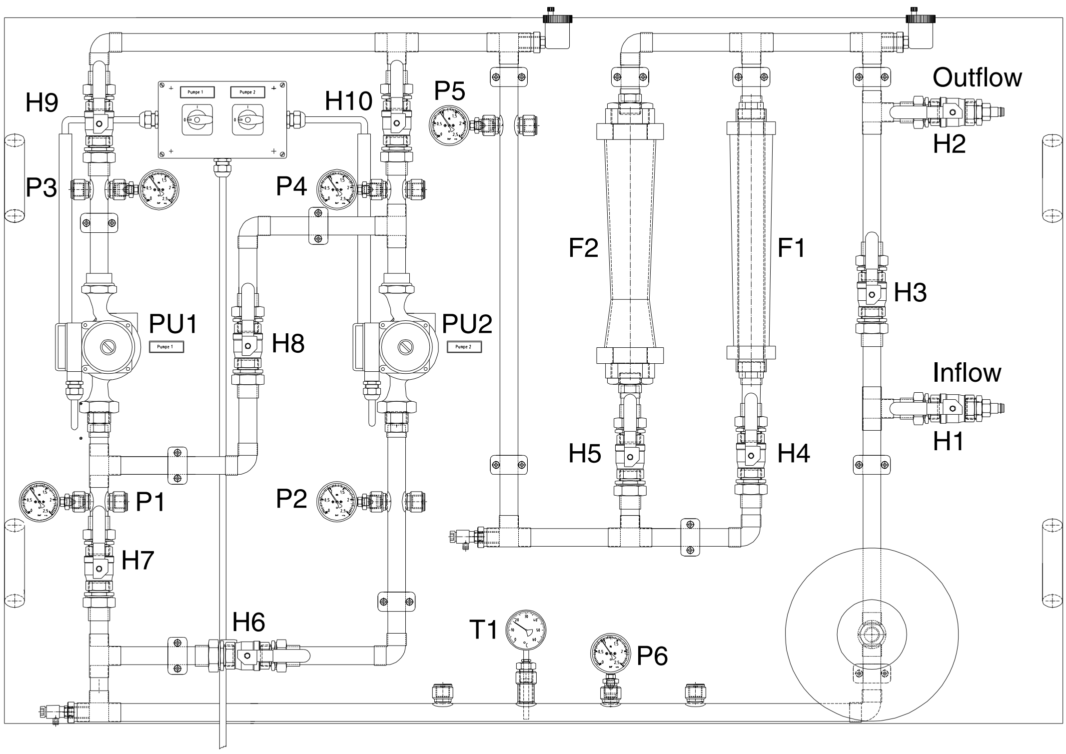


Fig. 3.2 Identification of the measurement points and shut-off points

To be able to consistently and easily describe the circuits in the experiments that follow, the following abbreviations are used:

H1 - H10	Shut-off and regulation points (ball-cocks)
P1 - P6	Pressure measuring points
PU1 - PU2	Circulating pumps
T1	Temperature measuring point

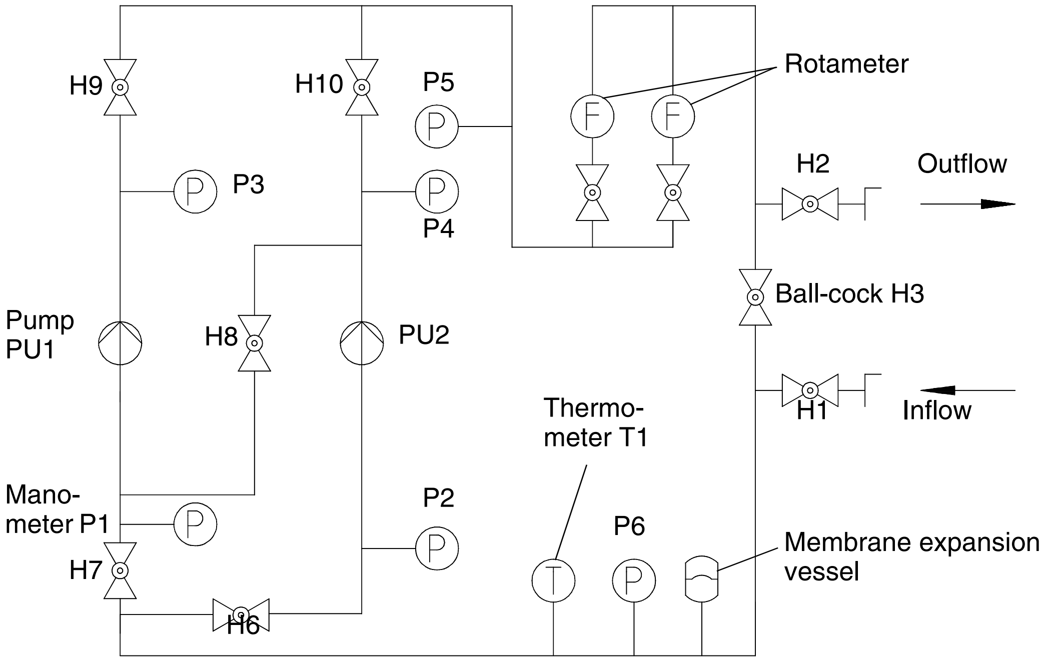


Fig. 3.3 Function principle of the unit

3.2 Function of the Training Panel

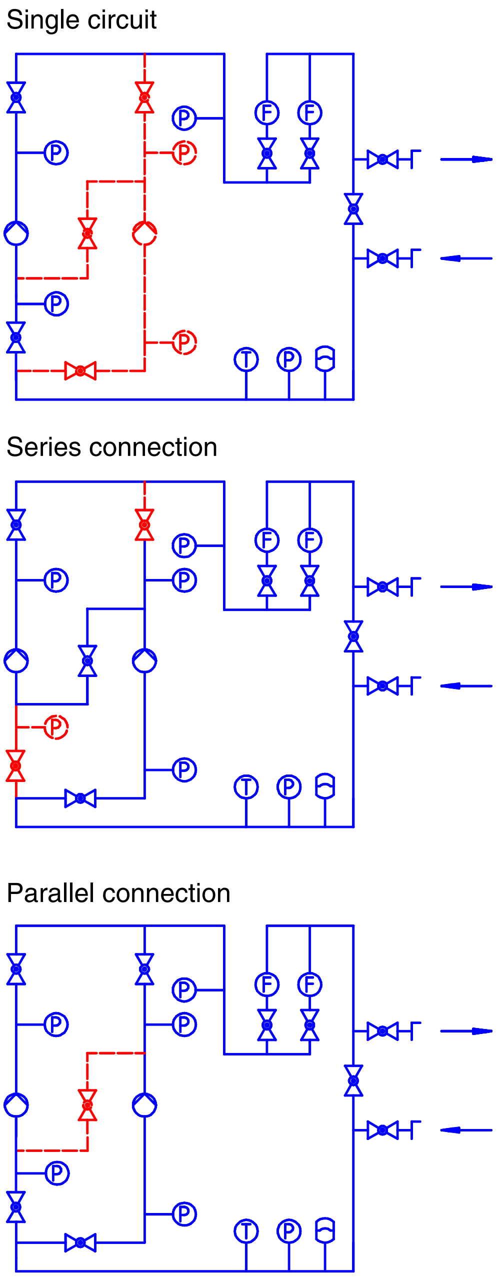


Fig. 3.4 Principles of operation

The system comprises a sealed circuit with two circulating pumps. By means of different settings on the ball-cocks, the pumps can be operated individually, or in a series or parallel connection.

Pressure measuring points with Bourdon gauges are installed on the intake and delivery side. Two automatic bleed devices keep the system free of air during operation and thus free of inaccuracies in measurements due to air bubbles circulating in the pipe system.

Using two rotameters with different measuring ranges, also with ball-cocks, the actual flow rate can be read.

A membrane expansion vessel compensates for temperature changes and volume changes and keeps the system pressure constant.

The system temperature can be read on a bimetallic dial thermometer.

4 Performing the experiment

4.1 Commissioning

- Place training panel in the HL 100 Universal Stand for Training Panels and secure this against rolling away by locking the brakes.
- Choose a flat, water-resistant surface (on bleeding the pumps PU1 and PU2 water can escape in small amounts).
- Connect water supply to cock H1 using quick-action coupling (H1 closed).
- Connect outflow to cock H2 using quickaction coupling.
- Connect to electrical supply.

4.2 Filling the System

- Open all cocks except H1 and H3 (lever in the direction of flow – cock open, lever at 90° to the direction of flow – cock closed).
- Slowly open H1 and leave system to flush for a few minutes, to clear air out of the system.
- Open H3 periodically and close again, to also clear the air between H1 and H2 from the system.
- The system must be flushed until no more air bubbles rise up through the rotameters F1 and F2 after briefly closing and opening all ball-cocks.
- Close H2.

- Leave H1 open until a system pressure of 1 bar can be read on manometer P6, then close.
- The system pressure can be set very precisely by opening and closing the ball-cocks H1 and H2.
- Now, if H1 and H2 are closed, the water supply and the water outflow hose can be removed. The training panel is now independent of the water mains.

4.3 Bleeding the Pumps

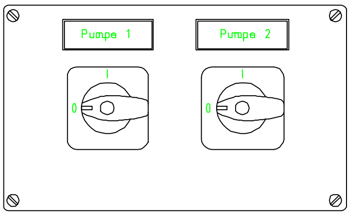


Fig. 4.1

- Open ball-cock H3 and close H8.
- Set pumps PU1 and PU2 to speed n = 3 and using switches on the switch box for the pump controller for pumps PU1 and PU2.
- Undo bleed screws on the pumps, until water escapes.
- Close bleed screws.
- The training panel is now ready for use.

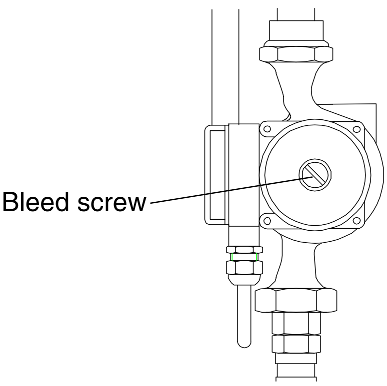


Fig. 4.2

4.4 Flow Rate Measurement

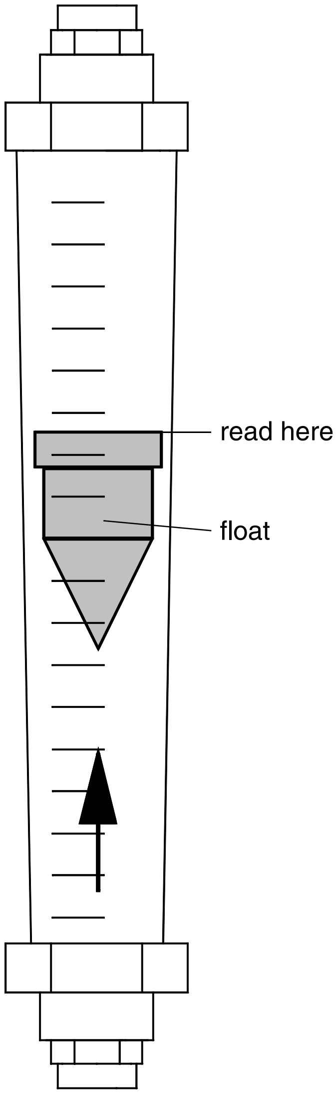


Fig. 4.3

To measure the flow rate two rotameters with different measuring ranges and the following features are used.

- Corrosion-resistant and fracture-resistant due to the usage of PVC and Trogamid.
- Adjustable setpoint markers.
- Directly readable scales.
- Measuring range F1: 150...1600 l/h.
- Measuring range F2: 400...4000 l/h.

The flow rate is to be read at the top edge of the cylindrical shoulder.

If both cocks H4 and H5 are open, then the flow rates add together. By reducing the flow rate at one of the cocks H4 or H5, an exact reading is possible.

5 Experiments

In this section some experiments are described as examples of the experiments that can be performed with the training panel. The range of experiments makes no claim to completeness, instead it is intended to serve as a stimulus for own experiments.

The descriptions of the experiments are divided into a section on basics and the actual performance of the experiment with the recording of measured values and plotting of the characteristics.

The measured results given are not to be seen as valid under all circumstances. Depending of the individual components used and skill, smaller or larger variations can occur.

The related settings for the ball-cocks H1 to H10 for the individual circuits are given in tabular form so that they are easy to retrace.

5.1 Pump Characteristic Curves

5.1.1 Basic Principles

In the following experiment the pump characteristic curves for pump PU1 is to be drawn for all three speeds. Measured values were not taken for pump PU2 because the two pumps are identical, and it is assumed that the measured values are then almost exactly the same.

The pump characteristic curve, also called the regulation curve, indicates how the delivery pressure of a centrifugal pump changes with the flow rate. In general the pump head reduces with increasing flow rate. The delivery pressure of the pump is related to the resistance of the water in the pipe system. If the flow rate in a system of pipes is reduced, e.g., by closing a valve, then the delivery pressure increases. For each pump head (back-pressure in the system) there is a specific flow rate. The shape of this characteristic curve for centrifugal pumps is essentially defined by the magnitude of the speed. For a circulating pump with three different adjustable speeds, three characteristic curves are produced.

5.1.2 Performing the Experiment

	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	F1	F2	PU1	PU2
on, open			X	X			X		X		X	X	X	
off, closed	X	X			X	X		X		X				X

Tab. 5.1 Connection pump characteristic curves (regulation curve)

First the system pressure p_6 is measured and recorded by means of a calibration experiment, as is the static pressure on the intake side of the pump p_{10} and the static pressure on the delivery side of the pump p_{30}. The two pressures p_{10} and p_{30} are used in the calculation of the differential pressure Δp to compensate for head variations and the related pressure differences due to the design, and also to compensate for differences in the indications on the manometers. For this purpose no pumps are to be in operation. Now the pump is switched on and various flow rates set at cock H3. The pressure at the intake side of pump P1 and the pressure at the delivery side of pump P3 are recorded in the table shown below. The differential pressure Δp is defined by the flow losses in the pipe system and is the pressure that the pump PU1 must produce to establish a flow through the pipe system

$$\Delta p = (p_3 - p_{30}) - (p_1 - p_{10}) \tag{5.1}$$

The head of the pump h is then calculated as

$$h = \frac{\Delta p}{\rho \cdot g} \tag{5.2}$$

and is also recorded in the table.

Flow rate $\dot{V}$ in m³/h	Suction pressure p_1 in bar	Delivery pressure p_3 in bar	Pressure difference Δp in bar	Head h in m
0	2,02	2,05	0,07	0,7
200	2,02	2,04	0,06	0,6
400	2,02	2,02	0,04	0,4
600	2,02	2,01	0,03	0,3
800	2,02	2,00	0,02	0,2
840	2,02	2,00	0,02	0,2

Tab. 5.2 Measurement results Characteristic curve for pump PU1 at **speed 1**
System pressure p_6 = 2,0 bar
Static pressure suction side p_{10} = 2,02 bar
Static pressure delivery side p_{30} = 1,98 bar

Flow rate $\dot{V}$ in m³/h	Suction pressure p_1 in bar	Delivery pressure p_3 in bar	Pressure difference Δp in bar	Head h in m
0	2,02	2,21	0,23	2,3
200	2,02	2,19	0,21	2,1
400	2,02	2,16	0,18	1,8
600	2,02	2,14	0,16	1,6
800	2,02	2,12	0,14	1,4
1000	2,02	2,08	0,10	1,0
1200	2,02	2,06	0,08	0,8
1400	2,02	2,02	0,04	0,4
1520	2,02	2,02	0,04	0,4

Tab. 5.3 Measurement results Characteristic curve for pump PU1 at **speed 2**
System pressure p_6 = 2,0 bar
Static pressure suction side p_{10} = 2,02 bar
Static pressure delivery side p_{30} = 1,98 bar

Flow rate $\dot{V}$ in m³/h	Suction pressure p_1 in bar	Delivery pressure p_3 in bar	Pressure difference Δp in bar	Head h in m
0	2,02	2,36	0,38	3,8
200	2,02	2,32	0,34	3,4
400	2,02	2,30	0,32	3,2
600	2,02	2,28	0,30	3,0
800	2,02	2,26	0,28	2,8
1000	2,02	2,24	0,26	2,6
1200	2,02	2,22	0,24	2,4
1400	2,02	2,20	0,22	2,2
1600	2,02	2,18	0,20	2,0
1800	2,02	2,16	0,18	1,8
2000	2,02	2,12	0,14	1,4
2200	2,02	2,10	0,12	1,2
2400	2,02	2,08	0,10	1,0
2440	2,02	2,06	0,08	0,8

Tab. 5.4 Measurement results Characteristic curve for pump PU1 at **speed 3**
System pressure p_6 = 2,0 bar
Static pressure suction side p_{10} = 2,02 bar
Static pressure delivery side p_{30} = 1,98 bar

The calculated heads can now be plotted against the flow rate.

5.2 System Characteristics

5.2.1 Basic Principles

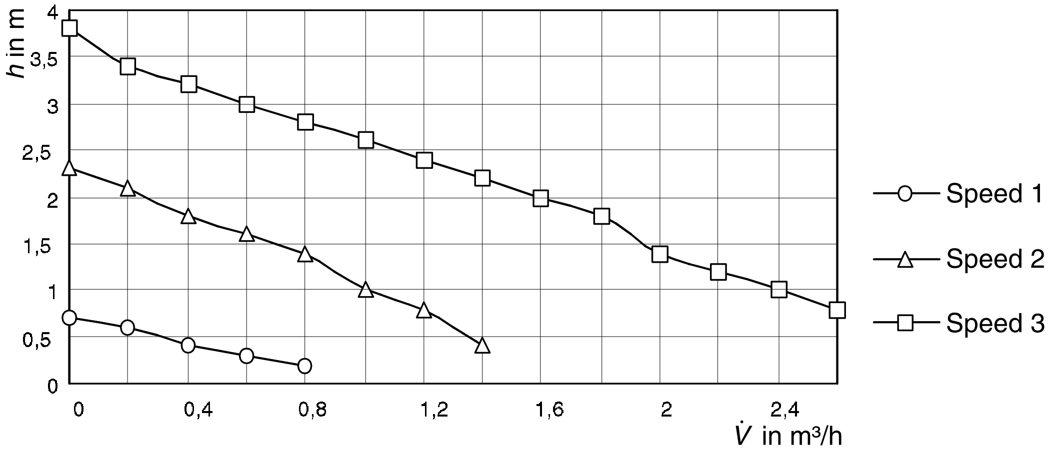


Fig. 5.1 Pump characteristic curves

When water flows through a pipe system, resistance is produced due to pipe friction due to the roughness of the walls and changes in direction. The flow resistance is dependent on the length of the pipe, the pipe cross-section, and the number and type of changes in direction. However, essentially it is dependent on the flow speed of the water. The pipe flow losses increase proportional to the square of the flow rate, in accordance with the formula

$$\frac{p_1}{p_2} = \frac{\dot{V}_2^2}{\dot{V}_1^2} \tag{5.3}$$

If a point on the pipe system characteristic curve is known, the entire pipe system characteristic curve can be drawn as part of a parabola.

5.2.2 Performing the Experiment

	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	F1	F2	PU1	PU2
on, open			X	X	X	X		X	X		X	X	X	X
off, closed	X	X					X			X				

Tab. 5.5 Connection system characteristics

First the system pressure p_6 is measured and recorded by means of a calibration experiment, as is the static pressure on the intake side of the pump PU2 p_{20} and the static pressure p_{50}. The two pressures p_{20} and p_{50} are used in the calculation of the differential pressure Δp to compensate for head variations and the related pressure differences due to the design, and also to compensate for differences in the indications on the manometers. For this purpose pump PU1 and pump PU2 must not be in operation. Pump PU1 and pump PU2 are operated in series at speed 3. Now the flow rate is reduced to 1600 l/h at cock H3 to simulate a longer pipe system. Different flow rates are now set at cock H9 and pressure p_2 and pressure p_5 recorded in Tab. 5.6. The differential pressure Δp is defined by the flow losses in the pipe system and is the pressure that the pumps PU1 and PU2 must produce to establish a flow through the pipe system.

$$\Delta p = (p_5 - p_{50}) - (p_2 - p_{20}) \tag{5.4}$$

The head h of the pumps PU1 and PU2 is then calculated from

$$h = \frac{\Delta p}{\rho \cdot g} \tag{5.5}$$

and the values are also recorded in the table.

Flow rate $\dot{V}$ in m³/h	Suction pressure p_2 in bar	Delivery pressure p_5 in bar	Pressure difference Δp in bar	Head h in m
1600	2,02	2,40	0,42	4,2
1200	2,02	2,22	0,22	2,2
800	2,02	2,08	0,10	1,0
400	2,02	2,00	0,02	0,2
0	2,02	1,98	0,00	0,0

Tab. 5.6 Measurement results
System characteristics for pump PU1 and PU2 in series configuration at speed 3
System pressure $p_6 = 2{,}0$ bar
Static pressure suction side $p_{20} = 2{,}02$ bar
Static pressure delivery side $p_{50} = 1{,}98$ bar

The calculated heads can now be plotted over the flow rate.

In addition the calculated system characteristic curve is plotted on the diagram. The initial value for this calculation is the head calculated at 1600 l/h of 4,2 m. As can be seen, the measured values are in reasonable agreement with the calculated values for the parabola.

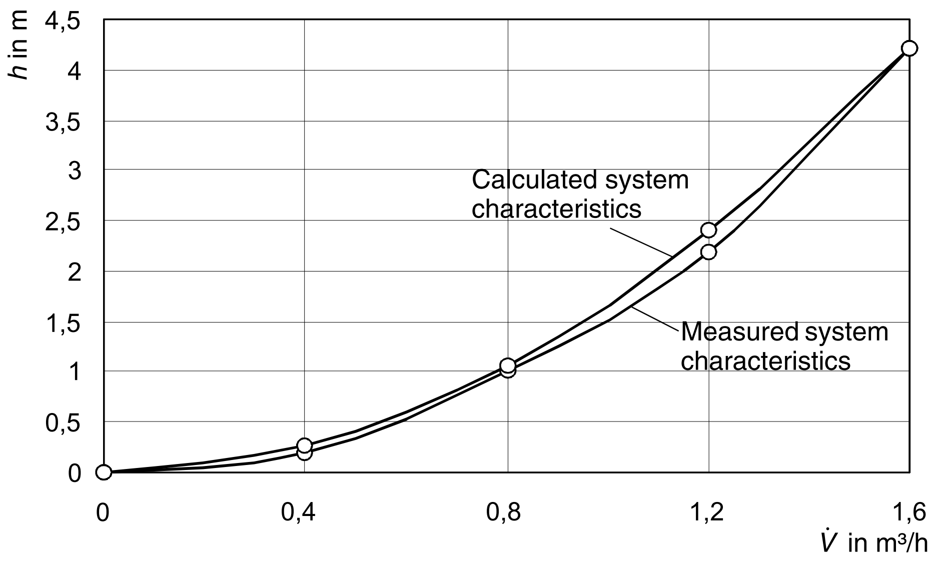


Fig. 5.2 System characteristics

5.3 Operating Point

5.3.1 Basic Principles

To circulate water at a specific flow rate, the max. pump pressure of the pump must be greater than the pipe resistance. At this flow rate the operating point of the pump is at the point where the head of the pump is the same as the pipe resistance. The operating point is the intersection of the pump characteristic curve and the pipe system characteristic curve. By varying the pipe system characteristic curve, e.g., by means of a regulator valve, the operating point can be moved along the pipe characteristic curve. By changing the pump speed, the operating point can be moved along the pipe system characteristic curve. In the case of the series connection of the pumps in systems with only one pipe, the heads of the individual pumps add together for constant flow rate.

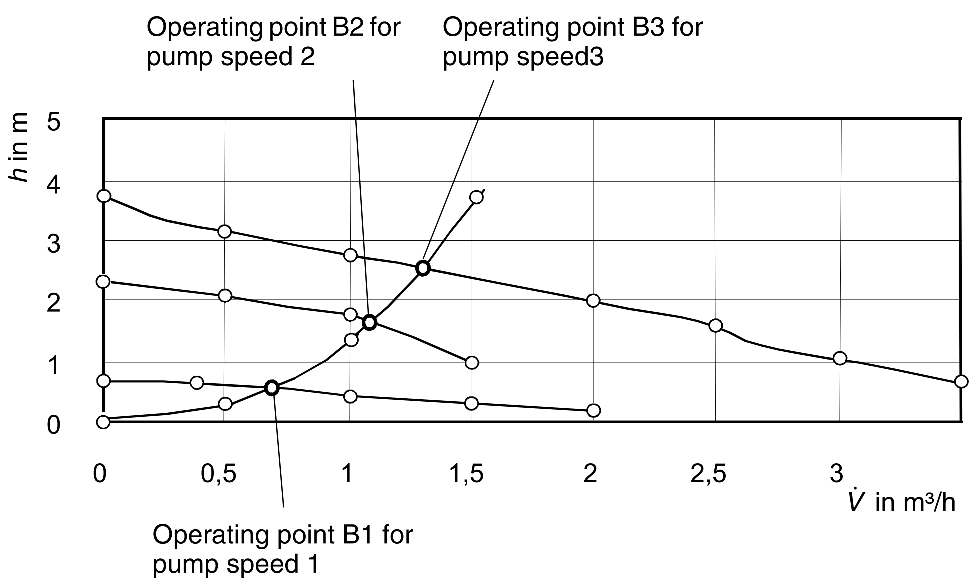


Fig. 5.3 Pump operating points at various speeds
The values are taken from the previous experiments

5.4 Series Connection

5.4.1 Basic Principles

In the case of the series connection of the pumps in systems with only one pipe, the heads of the individual pumps add together for constant flow rate.

5.4.2 Performing the Experiment

	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	F1	F2	PU1	PU2
on, open			X	X	X	X		X	X		X	X	n3	X
off, closed	X	X					X			X				

Tab. 5.7 Connection system characteristic curve

First the system pressure p_6 is measured and recorded by means of a calibration experiment, as is the static pressure on the intake side of the pump PU2 p_{20} and the static pressure on the delivery side of the pump PU1 p_{30}. The two pressures p_{20} and p_{30} are used in the calculation of the differential pressure Δp to compensate for head variations and the related pressure differences due to the design, and also to compensate for differences in the indications on the manometers. For this purpose pump PU1 and pump PU2 must not be in operation. So that all variants of the series connection of pump PU1 and pump PU2 are covered, pump PU1 is operated at speed 3 during all experiments and pump PU2 is connected ahead in series at speed 1 or 2 or 3. As the heads add together, it does not matter which of the two pumps is operated at speed 3 and which with reduced speed. Different flow rates are now set at cock H3 or H9 and pressure p_2 and pressure p_3 recorded in Tab. 5.8. The differential pressure Δp is defined by the flow losses in the pipe system and is the pressure that the pumps PU1 and PU2 must produce to establish a flow through the pipe system.

$$\Delta p = (p_3 - p_{30}) - (p_2 - p_{20}) \tag{5.6}$$

The head h of the pumps PU1 and PU2 is then calculated from

$$h = \frac{\Delta p}{\rho \cdot g} \tag{5.7}$$

and is also recorded in the table.

Flow rate $\dot{V}$ in m³/h	Suction pressure p_2 in bar	Delivery pressure p_3 in bar	Pressure difference Δp in bar	Head h in m
0	2,02	2,58	0,68	6,8
500	2,02	2,45	0,55	5,5
1000	2,02	2,38	0,48	4,8
1500	2,02	2,22	0,32	3,2
2000	2,02	2,15	0,25	2,5
2385	2,02	2,02	0,12	1,2

Tab. 5.8 Measurement results
Series connection of pump PU1 at speed 3 and PU2 at speed 2
System pressure $p_6 = 2{,}0\,\text{bar}$
Static pressure suction side $p_{20} = 2{,}02\,\text{bar}$
Static pressure delivery side $p_{30} = 1{,}98\,\text{bar}$

Flow rate $\dot{V}$ in m³/h	Suction pressure p_2 in bar	Delivery pressure p_3 in bar	Pressure difference Δp in bar	Head h in m
0	2,02	2,65	0,75	7,5
500	2,02	2,60	0,70	7,0
1000	2,02	2,50	0,60	6,0
1500	2,02	2,40	0,50	5,0
2000	2,02	2,26	0,36	3,6
2500	2,02	2,18	0,28	2,8
2830	2,02	2,02	0,12	1,2

Tab. 5.9 Measurement results
Series connection of pump PU1 at speed 3 and PU2 at speed 3
System pressure $p_6 = 2{,}0$ bar
Static pressure suction side $p_{20} = 2{,}02$ bar
Static pressure delivery side $p_{30} = 1{,}98$ bar

The pump heads can now be displayed in a graph over the flow rate.

As can be seen in the diagram, at maximum speed both pumps achieve almost twice the value that was measured in Chapter 5.1.2, Page 15, for one pump at maximum speed. The values for the speed combinations PU1 at speed 3 and PU2 at speed 2, as w ell as PU1 at speed 3 and PU2 at speed 1 can be compared with the values from Chapter 5.1.2 with similar clarity.

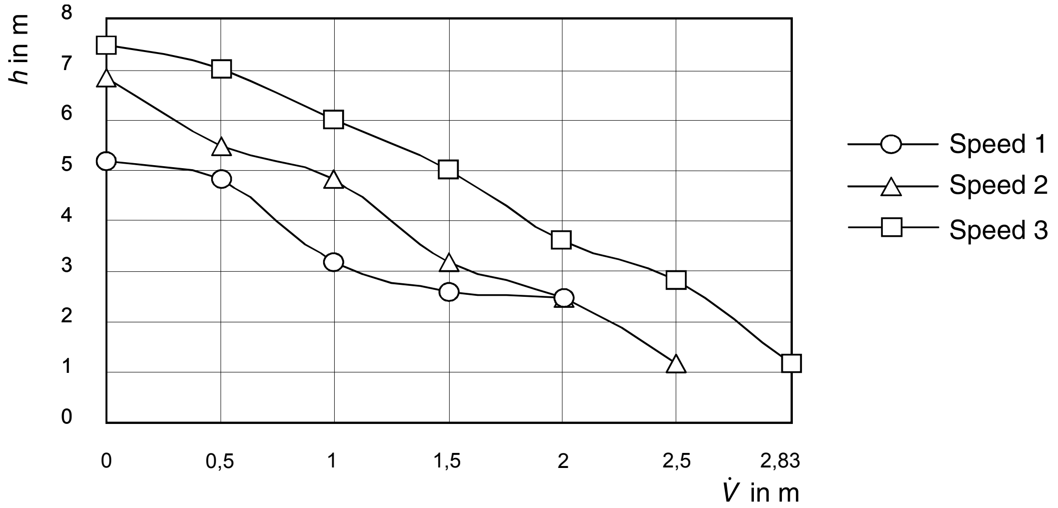


Fig. 5.4 Series connection of the circulating pumps PU1 and PU2 at different speeds for pump PU2

5.5 Parallel Connection

5.5.1 Basic Principles

In this circuit the flow rates of the individual pumps add together at constant head.

5.5.2 Performing the Experiment

	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	F1	F2	PU1	PU2
on, open			X	X	X	X			X	X	X	X	n3	X
off, closed	X	X					X							

Tab. 5.10 Parallel connection

First the system pressure p_6 is measured and recorded by means of a calibration experiment, as is the static pressure on the intake side of the circuit p_{60}, which is identical to the system pressure, and the static pressure on the delivery side of the circuit p_{50}. The two pressures p_{50} and p_{60} are used in the calculation of the differential pressure Δp to compensate for head variations and the related pressure differences due to the design, and also to compensate for differences in the indications on the manometers. For this purpose pump PU1 and pump PU2 must not be in operation. So that all variants of the parallel connection of pump PU1 and pump PU2 are covered, pump PU1 is operated at speed 3 during all experiments and pump PU2 is connected in parallel at speed 1 or 2 or 3. As the flow rates add together, it does not matter which of the two pumps is operated at speed 3 and which with reduced speed. Different flow rate are now set at cock H3 and pressure p_5 and pressure p_6 recorded in the table shown below. The differential pressure Δp is defined by the flow losses in the pipe system and is the pressure that the pumps PU1 and PU2 must produce to establish a flow through the pipe system.

$$\Delta p = (p_5 - p_{50}) - (p_6 - p_{60}) \qquad (5.8)$$

The head h of the pumps PU1 and PU2 is then calculated from

$$h = \frac{\Delta p}{\rho \cdot g} \qquad (5.9)$$

and is also recorded in the table.

Flow rate $\dot{V}$ in m³/h	Suction pressure p_6 in bar	Delivery pressure p_5 in bar	Pressure difference Δp in bar	Head h in m
0	2,0	2,18	0,20	2,0
500	2,0	2,12	0,14	1,4
1000	2,0	2,08	0,10	1,0
1500	2,0	2,00	0,02	0,2

Tab. 5.11 Measurement results
Parallel connection for pump PU1 at speed 3 and PU2 at speed 1
System pressure $p_6 = 2{,}0\,\text{bar}$
Static pressure suction side $p_{60} = 2{,}0\,\text{bar}$
Static pressure delivery side $p_{50} = 1{,}98\,\text{bar}$

Flow rate $\dot{V}$ in m³/h	Suction pressure p_6 in bar	Delivery pressure p_5 in bar	Pressure difference Δp in bar	Head h in m
0	2,0	2,22	0,24	2,4
500	2,0	2,25	0,27	2,7
1000	2,0	2,22	0,24	2,4
1500	2,0	2,20	0,22	2,2
2000	2,0	2,18	0,20	2,0
2500	2,0	2,10	0,12	1,2
2920	2,0	2,05	0,07	0,7

Tab. 5.12 Measurement results
Parallel connection for pump PU1 at speed 3 and PU2 at speed 2
System pressure $p_6 = 2{,}0\,\text{bar}$
Static pressure suction side $p_{60} = 2{,}0\,\text{bar}$
Static pressure delivery side $p_{50} = 1{,}98\,\text{bar}$

Flow rate $\dot{V}$ in m³/h	Suction pressure p_6 in bar	Delivery pressure p_5 in bar	Pressure difference Δp in bar	Head h in m
0	2,0	2,38	0,40	4,0
500	2,0	2,34	0,36	3,6
1000	2,0	2,30	0,32	3,2
1500	2,0	2,25	0,27	2,7
2000	2,0	2,22	0,24	2,4
2500	2,0	2,18	0,20	2,0
3000	2,0	2,15	0,17	1,7
3500	2,0	2,05	0,07	0,7

Tab. 5.13 Measurement results
Parallel connection for pump PU1 at speed 3 and PU2 at speed 3
System pressure $p_6 = 2{,}0\,\text{bar}$
Static pressure suction side $p_{60} = 2{,}0\,\text{bar}$
Static pressure delivery side $p_{50} = 1{,}98\,\text{bar}$

The pump heads can now be displayed in a graph over the flow rate.

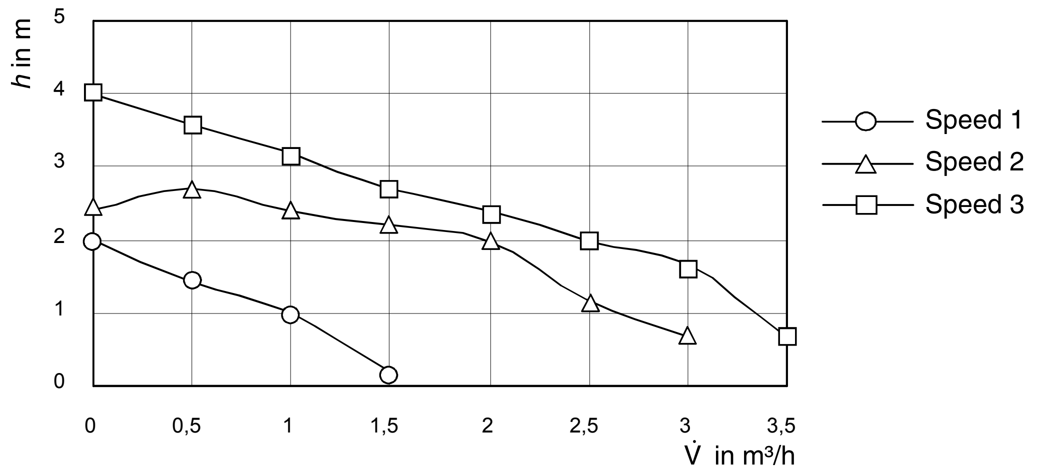


Fig. 5.5 Parallel connection of the circulating pumps PU1 and PU2 at different speeds for pump PU2

As can be seen from the diagram, during the parallel operation of PU1 at speed 3 and PU2 at speed 1, lower heads are achieved than when the pumps are operated individually. This is due to the fact that water is pumped back through pump PU2 because insufficient back-pressure is produced by pump PU2. It can, however, be seen that at the same head, almost twice the flow rate is produced. If both pumps are operated at maximum speed, then at minimum flow rate twice the value for one of the pumps is achieved. With increasing flow rate the doubling of the flow rate is achieved less and less. Here the quadratic increase in the pipe resistance in proportion to the flow rate can be seen.

5.6 Adjustment of Power in the Pump System

5.6.1 Basic Principles

If two or more pumps are installed in a pipe system in a manner such that their configuration can be changed, then this pump system has not just one characteristic curve, but a working range. Within this working range the pump system can be adjusted to suit modified operating conditions.

This adjustment is based on the displacement of the operating point by

- Changing the pipe system characteristic curve, e.g., by means of regulation
- Changing the pump characteristic curve by changing the speed
- Changing the characteristic curve of the pump system by means of the combination of different speeds with a series connection
- Changing the characteristic curve of the pump system by means of the combination of different speeds with a parallel connection.

5.6.2 Performing the Experiment

All the measured values from Chapter 5.1 to Chapter 5.5 are now plotted on a common diagram. The working area of the pump system is very clearly demonstrated here.

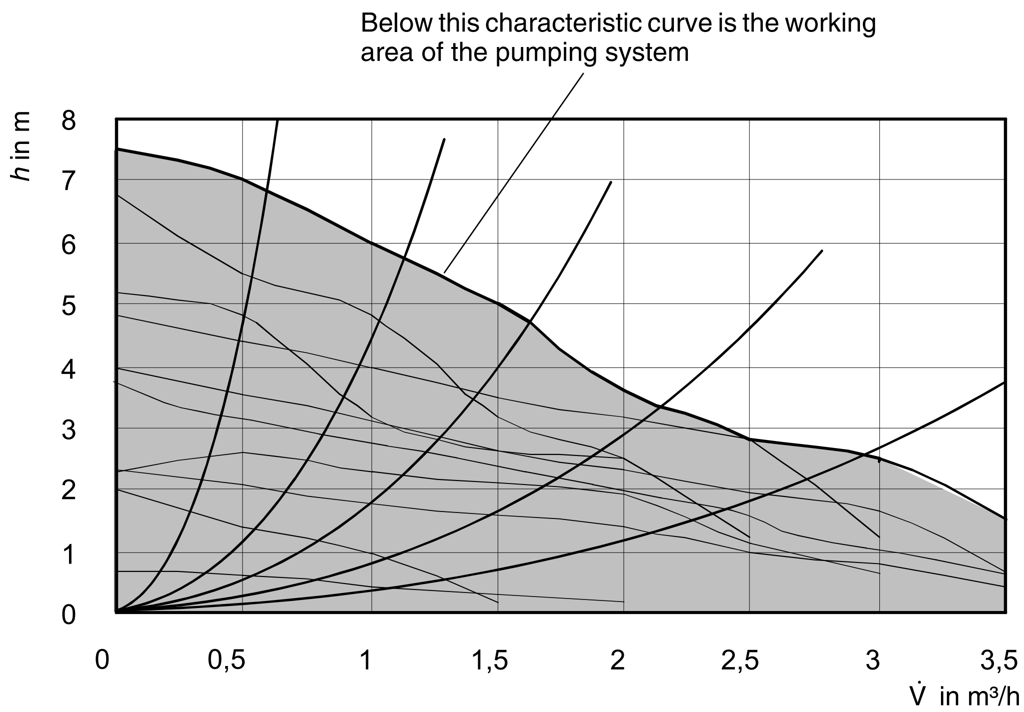


Fig. 5.6 Working area of the pump system

Within the above mentioned area a large number of operating points can be set and compared with the diagram.

6 Appendix

6.1 Work Sheets

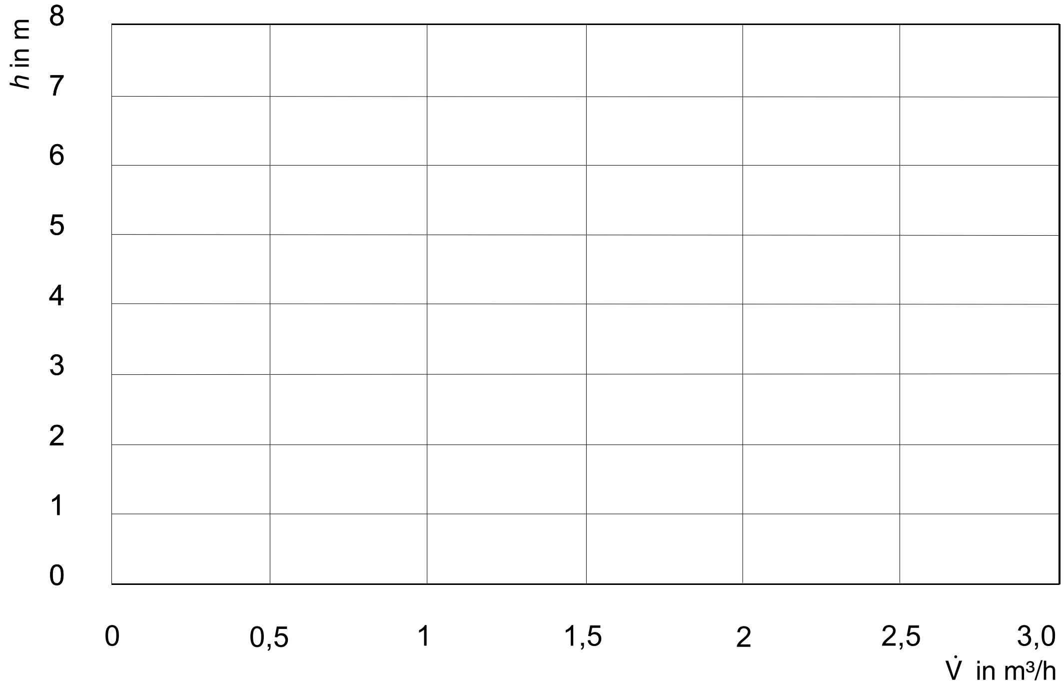
6.1.1 Work Sheet 1: Measured Results

Measurement results

System pressure p_6 = bar
Static pressure suction side p = bar
Static pressure delivery side p = bar

Flow rate $\dot{V}$ in m³/h	**Suction pressure p in bar**	**Delivery pressure p in bar**	**Pressure difference Δp in bar**	**Head h in m**

6.1.2 Work Sheet for Characteristic Curves



6.2 Formula Symbols and Units

$\dot{V}$	Flow rate	m³/h
p	Pressure	bar
Δp	Pressure difference	bar
h	Head	m
g	Acceleration due to gravity	m/s²
ρ	Density	kg/m³

6.3 Technical Data

Overall dimensions of the training panel

Length	1650	mm
Width	1100	mm
Depth	200	mm
Weight	58	kg

Supply

Electrical: Voltage	230 V / 50	Hz

Alternatives optional, see type plate

Connection

Cold water: Quick-action coupling with hose connection

Waste water: Quick-action coupling with hose connection

Circulating pump

Type	UPS 25-40	
Head	4 (0,4	m bar)
Pump capacity	60	l/min
Speed 1	750	min^{-1}
Speed 2	1200	min^{-1}
Speed 3	1850	min^{-1}

Rotameter F1

Measuring range	150...1600	l/h

Precision class 4

Rotameter F2

Measuring range	400...4000	l/h

Precision class 4

Bourdon gauge P1 to P6	
Measuring range	0 - 6 bar
Precision class 1.6	
Bimetallic dial thermometer T1	
Measuring range	0 - 60 °C
Precision class 1.0	

6.4 Index

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