Czech Lectures
on
Fluid Mechanics

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BIOMEDICAL ENGINEERING and BIOMEDICAL ENGINEERS IN CLINICAL PRACTICE

- Discussion

Repairing medical equipment and its maintenance is important but not the only things the biomedical engineers are responsible for and take care about!

Laboratory equipment – its purpose

Several goals:

To understand the physics, fluid mechanics, measurement, construction of medical devices. The tasks should be assembled by students and require some preparation or calculations in advance. It is educational.

To be able to experiment with the equipment, to test your own circuits and systems. It is modular and it has many options.

To facilitate research experiments and equipment design. The systems for measurement, flow generation, etc. can be programmed and can be used easily for many various applications the students and engineers may meet: from measurement of pneumatic components in hospitals to the design of a mechanical lung ventilator.

Pressure (P) and flow rate (Q) essentials

Ambient pressure **Patm = 101.325 kPa = 760 mm Hg**

1 bar = 100 kPa,

1 atm = approx. 1 bar = 100 kPa

1 bar = 100 kPa = 10 m H_2O (9.81 m H_2O), therefore 1 kPa = 10 cm H_2O

1 atm = 1 bar = 100 kPa = 1000 cm H_2O = 760 mm Hg
(1 cm H_2O = 1 mbar)

1 mm Hg = 133.3 Pa

DIY (Do-It-Yourself) No. 1

In tyres of a car, the recommended pressure is 2.3 atm.

A: The absolute pressure in the tyres is ...., the relative pressure is ....

B: This pressure is equal to:

.... kPa

.... MPa

.... bar

.... mbar

.... cm H_2O

.... mm Hg

Pressure (P) and flow rate (Q) essentials

Flow rate

- Volume flow rate:
  - m^3/s
  - L/min (liters per min.), L/s;
  - sLpm (standard liters per min.), sLps
- Mass flow rate
  - kg/s, kg/min

Flow Meters

Flow Meters and Flow Controllers

NEVER LET DUST, OIL DROPS OR MIST AND WATER IN TO THE MASS FLOW METER OR MASS FLOW CONTROLLER!

DIY (Do-It-Yourself) No. 2

A rectangular swimming pool (5 m long, 2 m wide and 1 m deep) can be filled with water in 10 hours. The flow rate in the hose is:

.... m^3/h

.... m^3/min

.... m^3/s

.... L/h

.... L/min

.... L/s

.... kg/h

.... sLpm

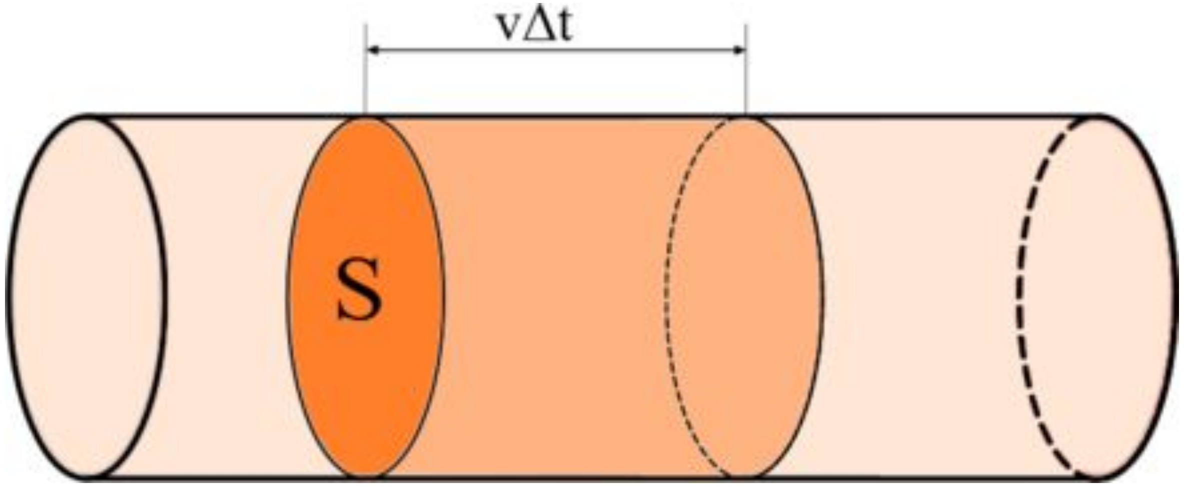
Velocity (v)

Velocity (v) is in m/s

Flor rate (Q) is in **m^3/s**

The crossectional area (S) of a tube is in m^2

$v \cdot S = Q$



DIY (Do-It-Yourself) No. 3

The flow rate in the hose is 20 L/min. The inner diameter of a hose is 3 cm. The velocity of water in the hose is:

.... m/s

.... km/h

Standard and standardized non-standard conditions

In medicine:

- S.T.P.D. Standard temperature (0 °C) and pressure (101,325 kPa), dry
- S.T.P.S. Standard temperature and pressure, saturated
- B.T.P.S. Body temperature (37 °C) and (ambient) pressure, saturated
- A.T.P.S. Ambient temperature and pressure, saturated
- ...

Conditions may be recalculated using **ideal gas law**, also called the **general gas equation**, or the **equation of state**:

$$pV = nRT \qquad R = 8{,}314\ \frac{\mathrm{J}}{\mathrm{mol \cdot K}}$$

DIY (Do-It-Yourself) No. 4

A compressor is able to deliver 300 SLPM.

What flow rate is able to deliver continuously with the output pressure of 5 atm?

Respect (High) Pressure

What is it a high pressure?

Respect (High) Pressure

What is a high pressure?

Low pressures:

underpressure in the lungs during spontaneous ventilation: 0.2 kPa

maximum positive pressure in the lungs during mechanical ventilation: typically 3.5 kPa, max. 5 kPa

systolic pressure 260 mm Hg: 21 kPa

High pressures:

working pressures inside the lung ventilators: e.g. 80 kPa

medical air supply system: 300 – 700 kPa (3 – 7 bar)

gases (O_2, air, N_2) in the cylinders: 15 – 300 MPa (150 – 300 bar)

Respect (High) Pressure in a high volume

Rupture of a narrow house made of soft plastic at 10 bars: only unpleasant noise, but minor threat.

Respect (High) Pressure in a high volume

Rupture of a glass container at 1 bar may shoot glass pieces very far; acts as a grenade or bomb due to the high accumulated energy.

ALWAYS USE OVERPRESSURE SAFETY VALVES where is a danger of high-pressure gas influx into a system that is not designed for it!

Pressure measurement

Pressure meaters:

- absolute pressure (“0” on the scale is 0 Pa, i.e. vacuum)
- differential pressure
  1. “0” on the scale is 1 atm (ambient pressure) – the sensor has one input port
  2. “0” means there is no pressure difference between two input ports
- partial pressure (later... ☺️)

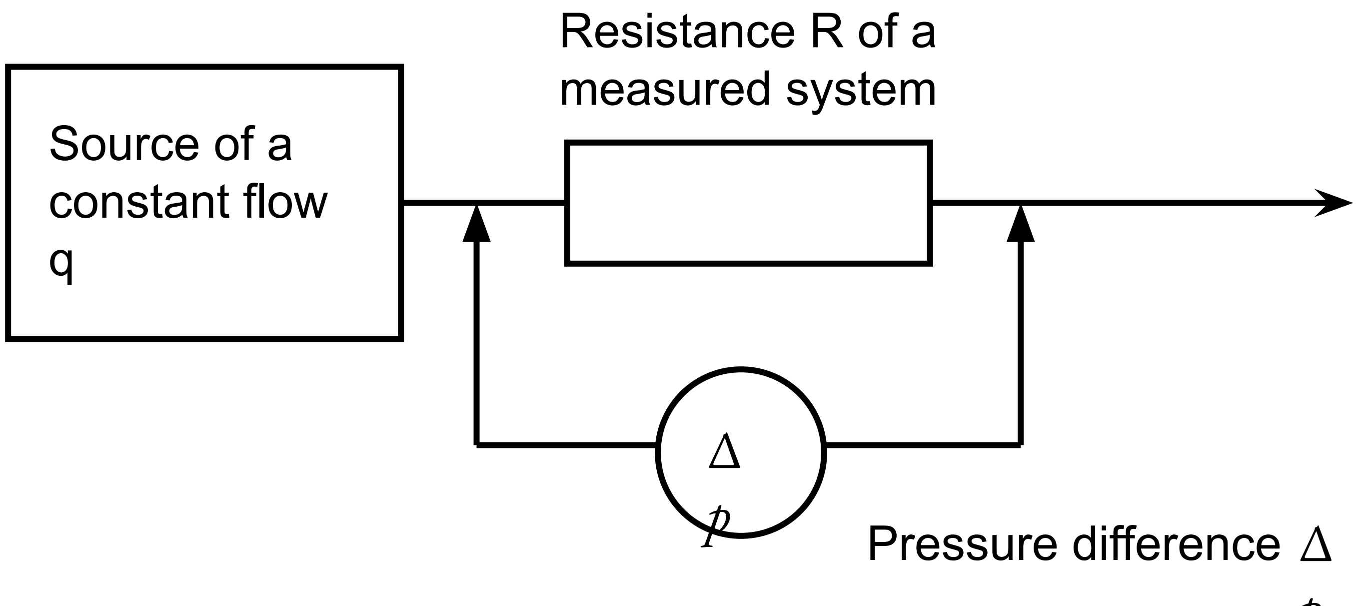
Definition of (airflow) resistance

Equivalent to the Ohm's law U=R.I:

$$R = \frac{\Delta p}{q}$$

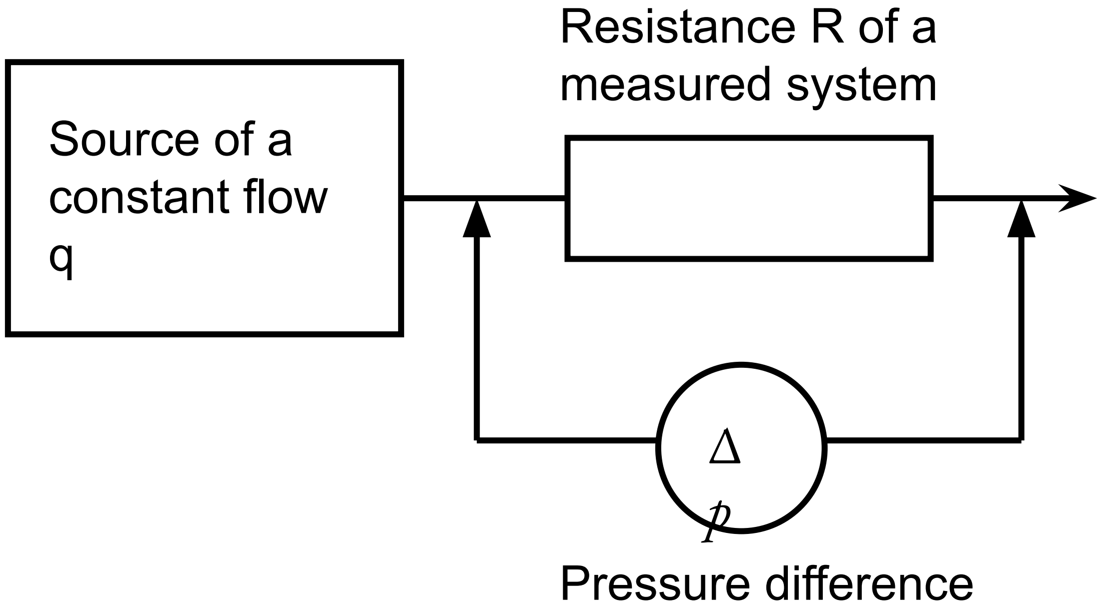
Units: Pa.s/L which is Pa/(L/s) (**never write Pa/L/s**)

cm $H_2$0.s/L = mbar.s/L, kPa.min/m^3 and many others

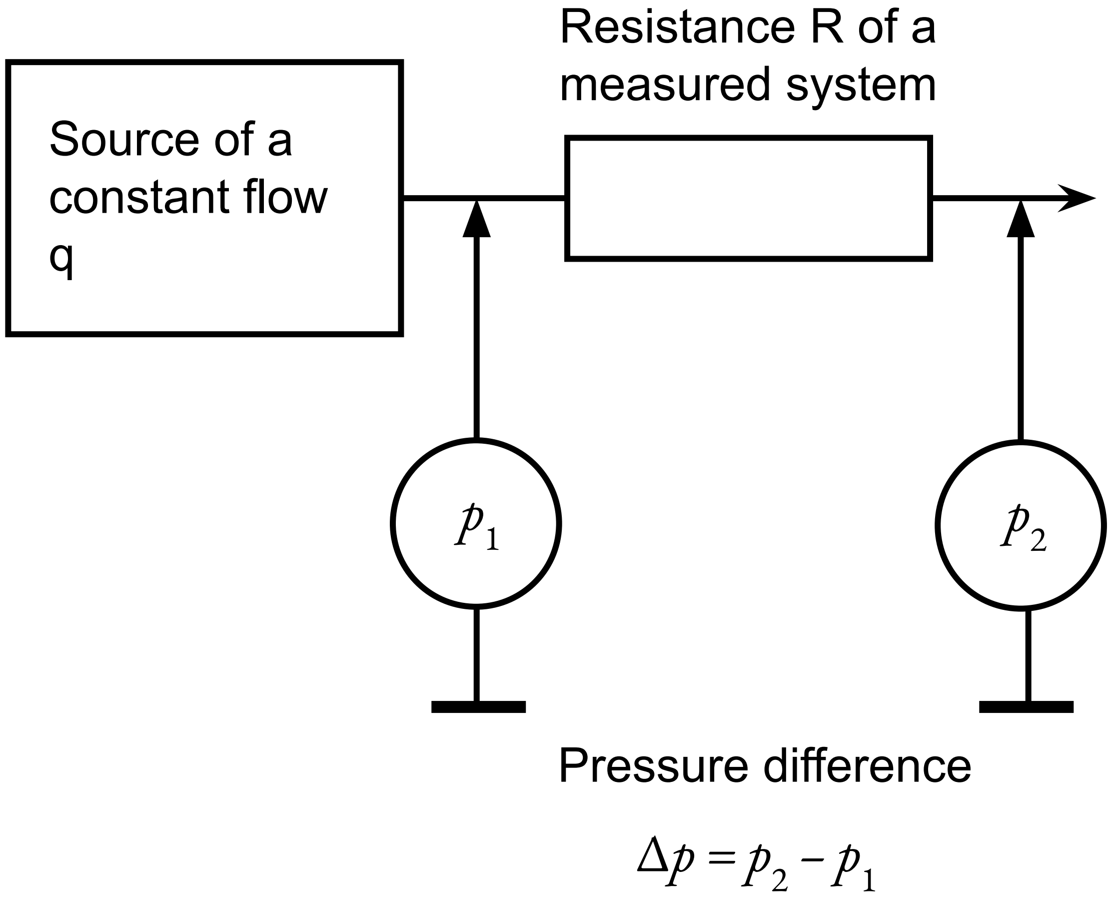


Pressure measurement

One differential pressure meater or pressure sensor

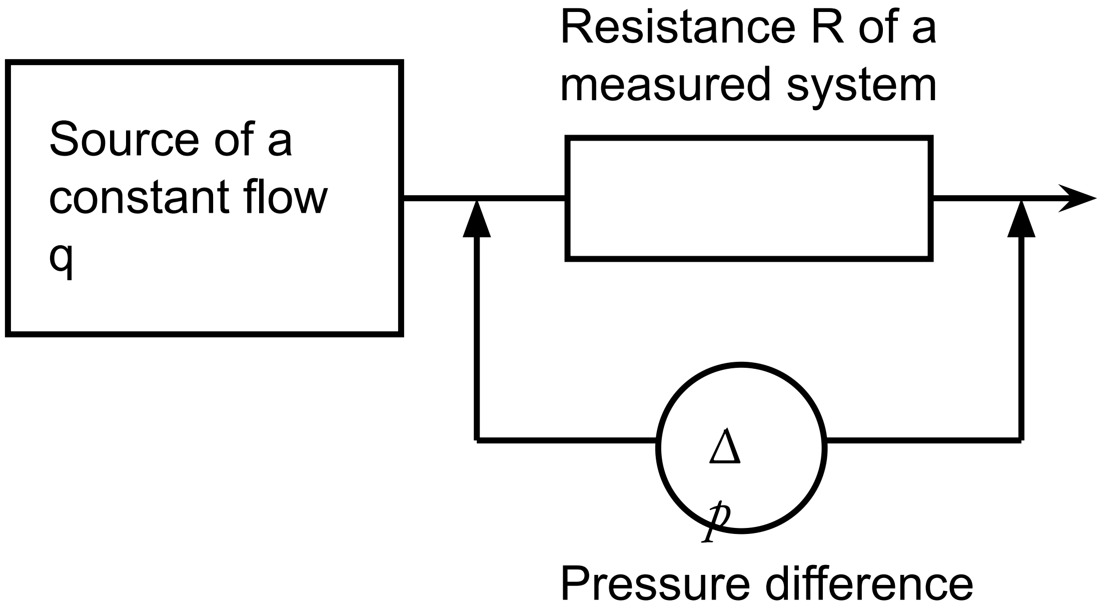


Two absolute pressure meaters or sensors

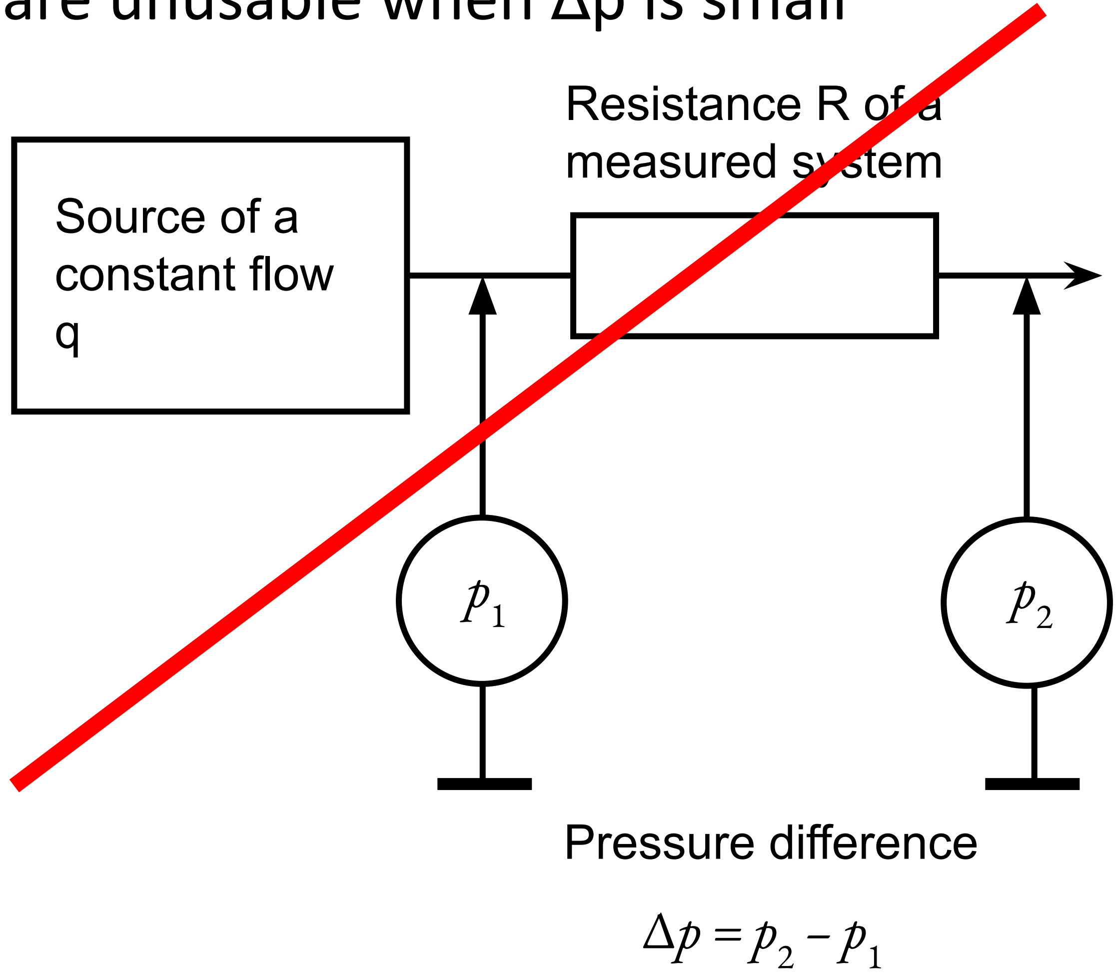


Pressure measurement

One differential pressure sensor



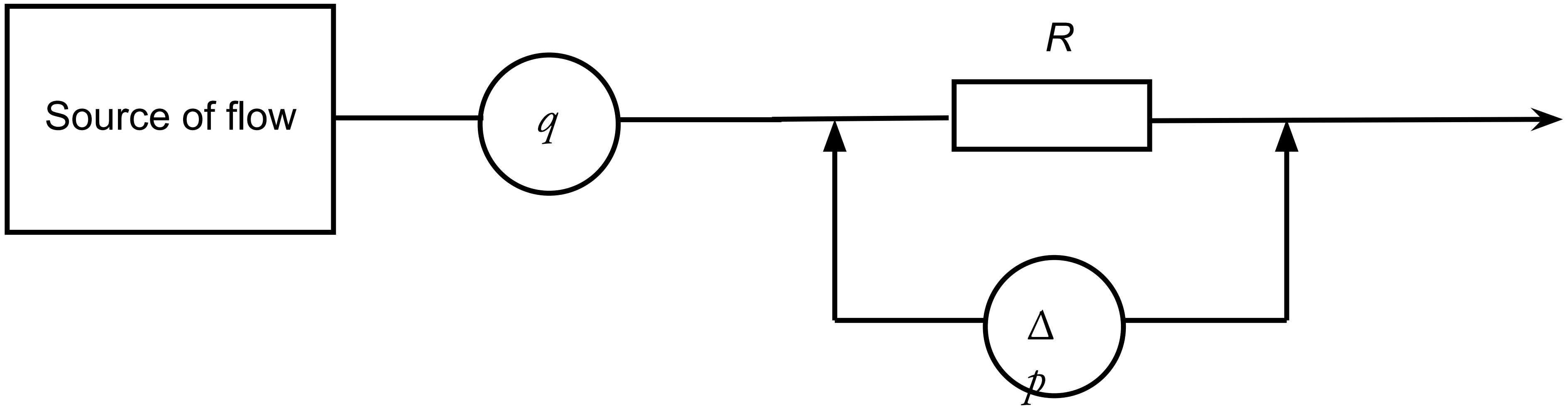
Two absolute pressure meters/sensors are unusable when Δp is small



Definition of (airflow) resistance

Equivalent to the Ohm‘s law U=R.I:

$$R = \frac{\Delta p}{q}$$



Pressure measurement

Range!

Never use a pressure sensor without checking its range!

Especially the differential pressure sensors/meters used in medicine may have a very small range of pressures!

Medical air supply sytems

Medical Quality Air (simply „Air“ used in hospitals) is a farmaceutical.

To produce Air the proper equipment must be used and the process must meet the ISO standards and other requirements.

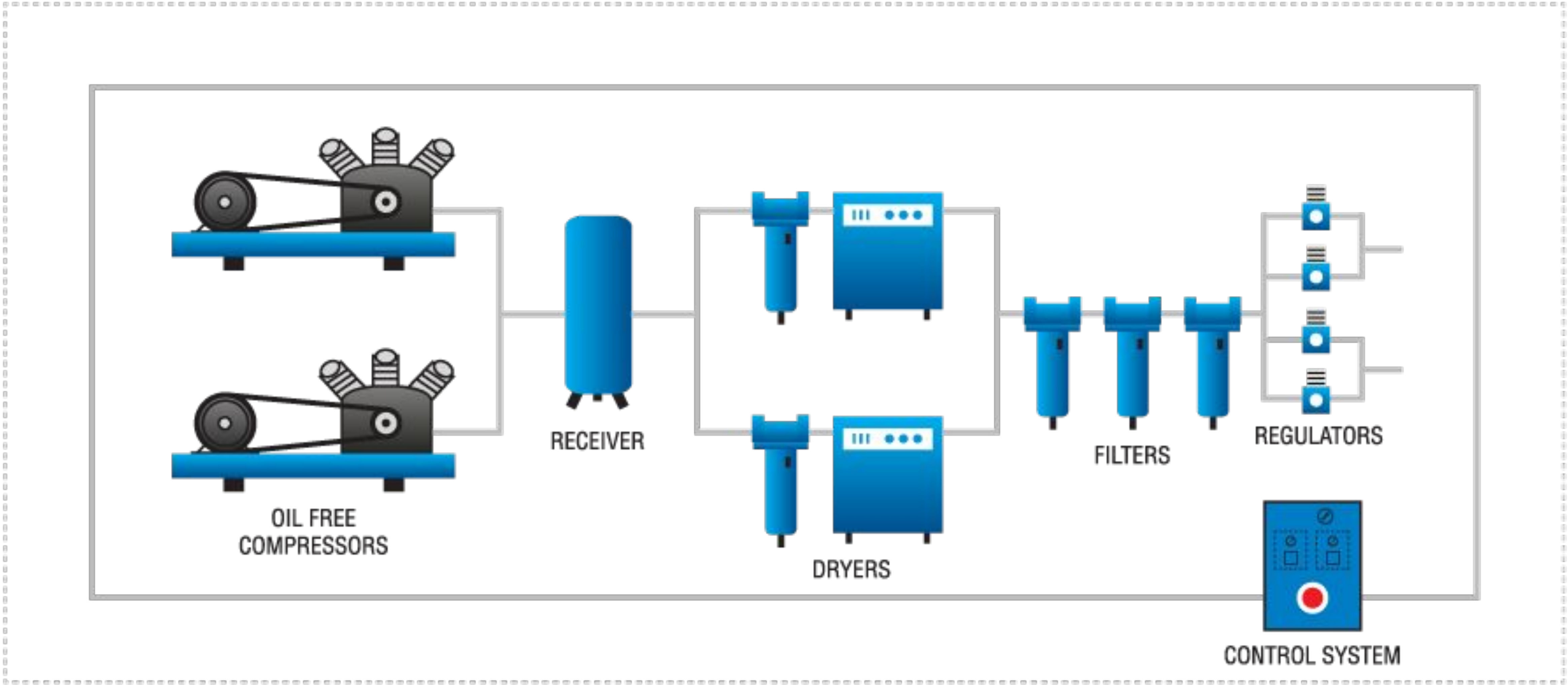
Water, water vapor, oil droplets and oil mist damages the medical equipment and can kill the patient (oil in lungs leads to ARDS – acute respiratory distress syndrome)

Sources of air: compressors and cylinders.

Requirements:

1. purity: no water vapor, no water drops, no oil traces, no dust, no CO, ...
2. pressure and its stability: 3 – 7 bars
3. distribution system according to ISO EN 7396-1

Air delivery system for hospitals



https://www.dtcpl.in/medical-air-systems/

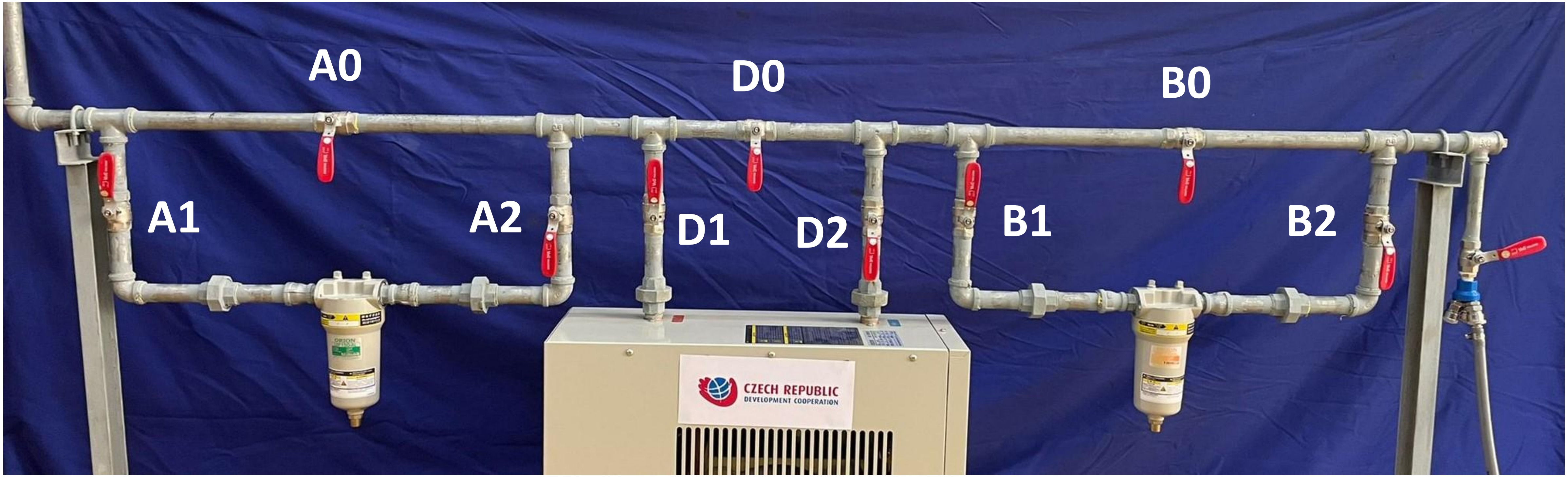
Air delivery system at ITC

Small-size Air Filters: examples at ITC

- **Super line filter LSF series ［Removes solid substance (above 1µm)］**
- **Super mist filter MSF series ［Removes solid substance and oil (above 0.01µm)］**
- Super carbon filter KSF series ［Removes oil and odour (Outlet oil concentration 0.003 wtppm)］

https://orion-machinery-asia.com/en/industrial/airdryer/al-airfilter-small

Air delivery system at ITC

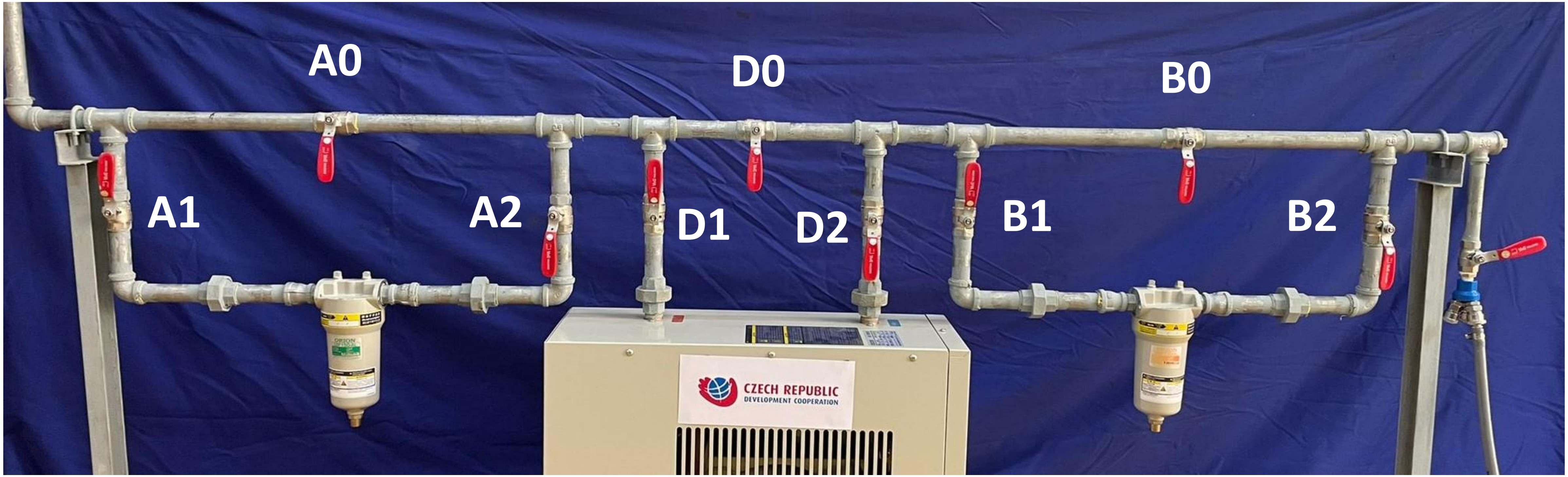


LSF〔solid substance filter〕
A-valves

Air Drayer
D-valves

MSF〔solid substance and oil〕B-valves

Air delivery system at ITC – normal configuration

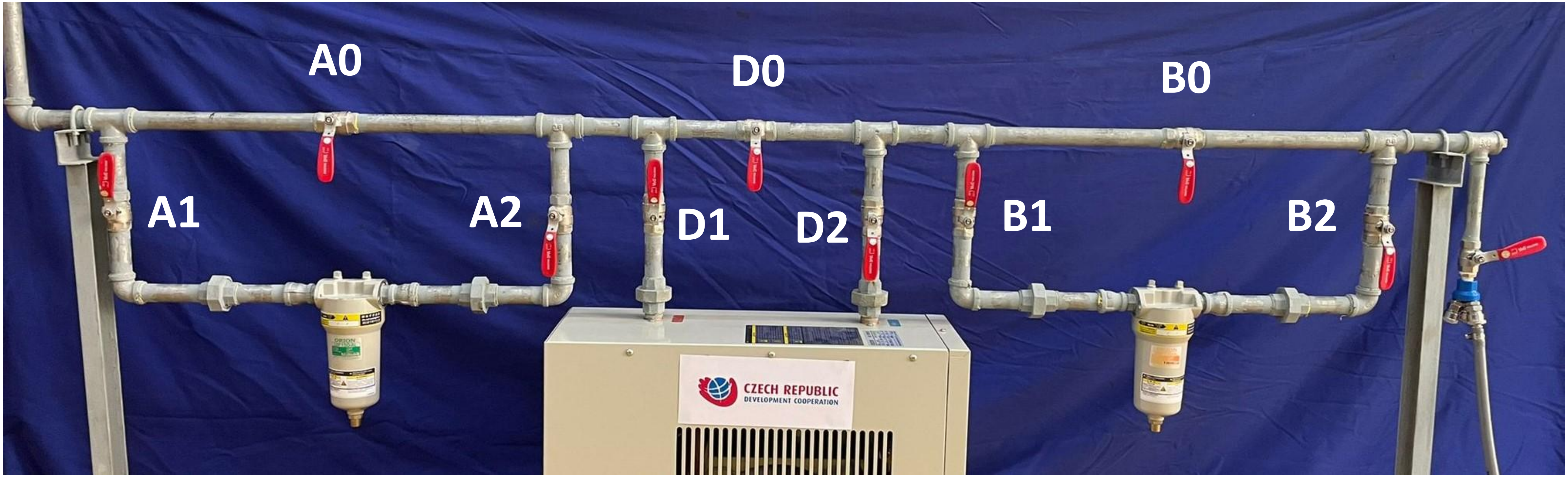


Normal configuration – protects the equipment and/or patients.
No dust, oil or water can get into the pipes.

All A0, D0 and B0 baypass valves are CLOSED
All A1, A2, D1, D2, B1, B2 valves are OPEN

NEVER OPEN ANY BAYPASS FILTER x0 during supplying gas into the pipes and/or equipment!

Air delivery system at ITC – special operations



??? configurations for: humidity measurement, the dryier efficiency measurement, etc.

NEVER ALLOW ABNORMALLY TREATED GAS INTO THE PIPES an/or EQUIPMENT!

After finishing the experiment,
IMMEDIATELY RETURN VALVES INTO THE NORMAL CONFIGURATION!

Why water filter – where the water comes from

- Cooling the gas containing water vapor
- Compressing the gas containing water vapor

- partial pressure of water vapor: P_{H20}
- (partial) pressure of saturated water vapor: P''_{H20}
- relative humidity:

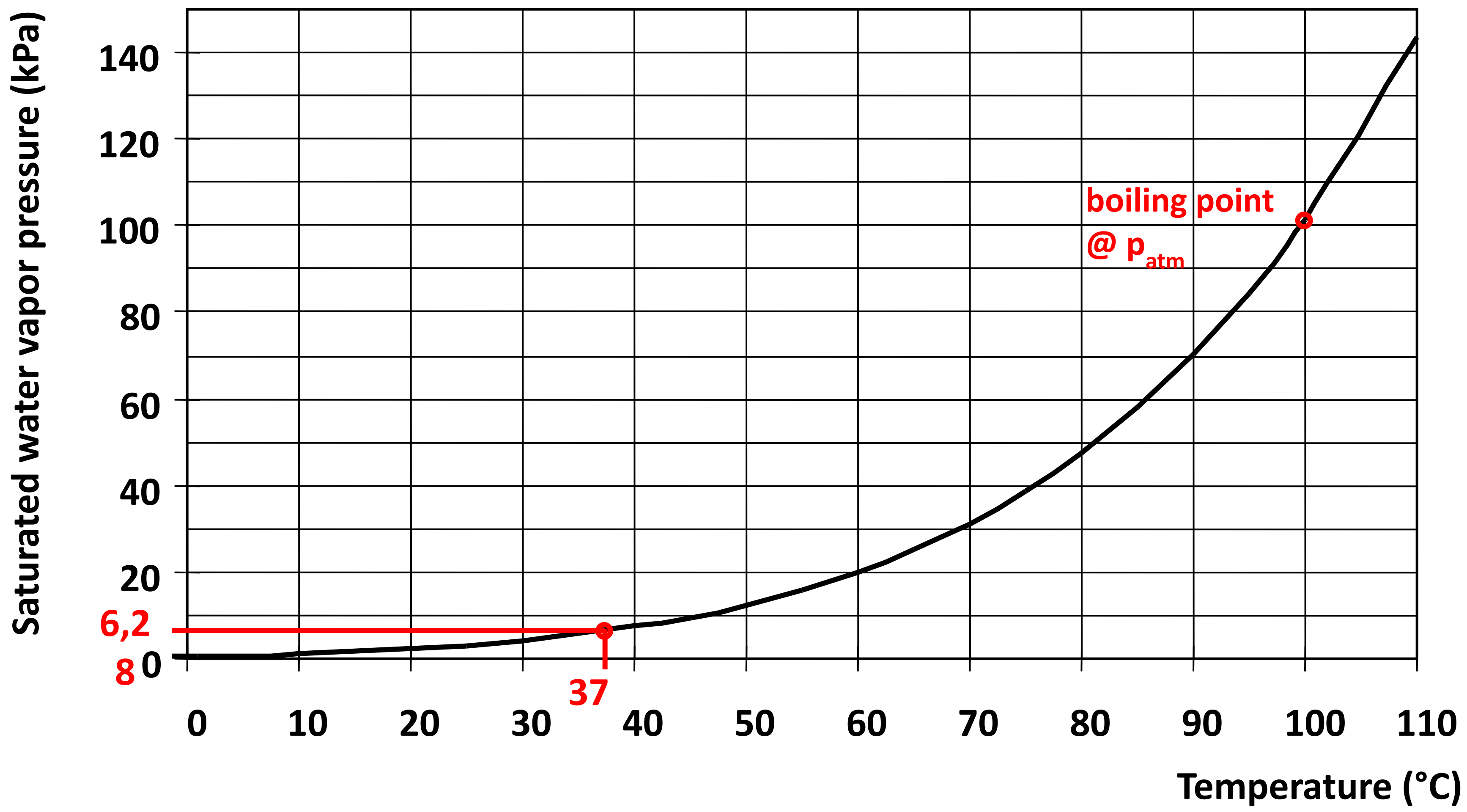
$\varphi = P_{H20} / P''_{H20}$

Dependent on temperature!

Dew point (°C) – is a temperature...

Why they say dew point instead of the relative humidity?

Saturated water vapor pressure



t (°C)	P''_{H20} (kPa)
100	101.325
37	6.28
0	0.611

To remember it...

t (°C)	P''_{H20} (kPa)
100	100
37	$6.28 = 2\pi$ ☺
0	0.6

Why water filter – where the water comes from

- Cooling the gas containing water vapor
- Compressing the gas containing water vapor

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- relative humidity:

$\varphi = P_{H20} / P''_{H20}$

Dependent on temperature!

Dew point (°C) – is a temperature

Why they say dew point instead of the relative humidity?

Calculation of actual water content in the gas using the ideal gas law equation:

$$pV = nRT$$

$$R = 8{,}314 \ \frac{\mathrm{J}}{\mathrm{mol \cdot K}}$$

Humidity measurement

Precise but complicated

„THE GOLD STANDARD" methods

Water vapor absoption in silikagel
ant weighting the difference...

DIY (Do-It-Yourself) No. 5

Listen to SDR (software defined radio) of Twente University (use „SDR Twente" for Google search [http://websdr.ewi.utwente.nl:8901/]). Tune weather information servis for airplains broadcasted from Shannon international airport in Ireland, Europe. The frequency is 5 505 kHz, USB modulation. Listen to current temperature and dew point in Shannon, London or other airport reported.

(Other service: UK Royal Airforce service at 5 450 kHz, USB)

A: Calculate the current relative humidity at the airport.

B: Calculate the current partial pressure of water at the airport.

C: Calculate the relative humidity when the temperature at the airport rises by 10 °C.