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Subject	**Fluid Mechanics**	
Measurement	A	M13
	B	M05
Day	Tuesday 10-12	2
Week	even	8
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MEASUREMENT REPORT

Measurement N^r M13

MEASUREMENT OF SHEET DIFFUSER PROPERTIES

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IG6JX7-M13-21-0.07-12-614.3-36efdff5576d6598522617edf55414f8

I hereby state that the report was prepared by the previously named group according to the measurement.

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Contents

1. Aim and objectives of the measurement

The aim of this laboratory measurement is to determine the efficiency of sheet diffuser fixed at the end of the pipe (Figure 1). There are several parameters affecting the efficiency of the sheet diffuser. The distance x between the plane of outflow element and the sheet influences outflow area of the diffuser. In this measurement efficiency η will be measured as a function of the distance x.

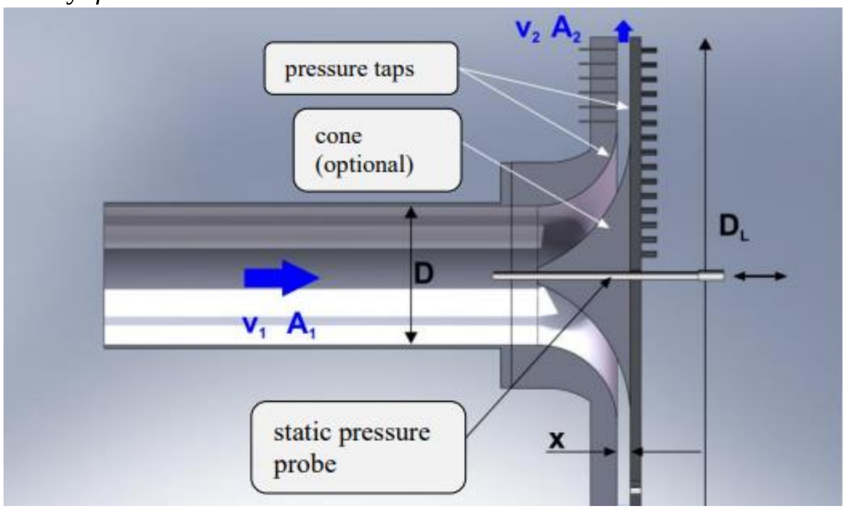


Figure 1: Sheet diffuser

2. Description of the measurement

2.1. Measurement facility

The sheet diffuser is connected to a pipeline located at the delivery side of a radial fan. At the suction side of the fan there is an inlet orifice to measure the volume flow rate. The v_1 and v_2 velocities can be defined by this with the help of the cross-sectional area. The sheet diffuser gap size can be set using the three bolts. Diffuser efficiency can be improved using a cone that can be attached using an M5 bolt. The setup can be seen in Figure 2.

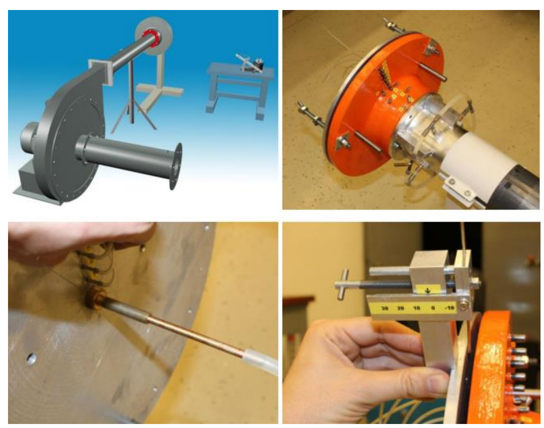


Figure 2: Measurement setup

2.2. Theoretical background of measurement

The flow takes place between cross-sections A_1 and A_2 in the diffuser. A_1 is the circular cross-section of the pipe, A_2 is a cylindrical shell characterized by a diameter D_L and distance x. The facility works as a diffuser if $A_1 < A_2$. Therefore, the first step in measurement is to determine initial gap size x, which must be carried out with caliper in four radial positions to ensure precise result. Gap size will be increased by 1-2 mm till it reaches maximum of 25 mm. To find initial gap size, the following formula will be used:

$$A_1 < A_2$$

where $A_1 = \frac{\pi D^2}{4}$ and $A_2 = \pi D_L \cdot x_{min}$

After this, measurement can be started from x_{min} till x = 25 mm with 1-2 mm increments, and diffuser efficiency will be calculated for every point. The steps to find diffuser efficiency are given below.

2.2.1. Calculation of the diffuser performance

A diffuser's efficiency is defined as ratio of the real pressure growth $(p_2 - p_1)_{real}$ to the pressure growth in ideal case $(p_2 - p_1)_{ideal}$,which can be calculated from Bernoulli equation.
The Bernoulli-equation between cross-sections "1" and "2" is:

$$(p_2 - p_1)_{ideal} = \frac{\rho}{2} \cdot (v_1^2 - v_2^2) \qquad (1)$$

So the diffuser efficiency is:

$$\eta_{diff} = \frac{(p_2-p_1)_{real}}{(p_2-p_1)_{ideal}} = \frac{(p_2-p_1)_{real}}{\frac{\rho}{2}(v_1^2-v_2^2)} \qquad (2)$$

2.2.2. Determination of flow velocity by volume flow rate measurements

v_1 and v_2 velocities can be calculated from the pressure measured by the orifice plate at every diffuser setting, i.e. at every distance x, using digital manometer. To define the volume flow rate, the pressure of the pressure outlet at the inlet orifice must be compared to the atmospheric pressure, with this Δp_{or} the volume flow rate of the device can be calculated:

$$q_V = \alpha \cdot \varepsilon \cdot \frac{d^2 \cdot \pi}{4} \sqrt{\frac{2 \cdot \Delta p_{or}}{\rho}} \qquad (3)$$

where "d" is the inner diameter of the orifice, "ρ" is density of the air and α=0.6 in case of a suction orifice. (ε=1). Density of the air can be found as follows:

$$\rho = \frac{p_0}{R \cdot T} \qquad (4)$$

where p_0 is the atmospheric pressure, R = $287\frac{J}{kg \cdot K}$ and T is the actual temperature of the air in K.
The velocity in cross-section "1" entering the diffuser is:

$$v_1 = \frac{q_V}{A_1} = \frac{4 \cdot q_V}{D^2 \cdot \pi} \qquad (5)$$

where D is the inner diameter of the pipe at the suction side of the fan. The average velocity of the air leaving the sheet diffuser is:

$$v_2 = \frac{q_V}{A_2} = \frac{q_V}{D_L \cdot \pi \cdot x} \qquad (6)$$

The change in gap size and the resulting pressure change might affect the operating state of the fan; therefore the volume flow rate has to be measured for every gap size.

3. Measurement procedure

Firstly, environmental conditions (atmospheric pressure - p_0 , temperature – T) must be measured, as they affect the density of the air, which is crucial in the calculations of efficiency.

3.1. Measurement of the real pressure difference

The p_1 pressure can be measured in the sidewall static pressure measurement point in cross-section A_1, while p_2 pressure is the atmospheric pressure p_0, since the outlet of the sheet diffuser enters the atmosphere at p_0. Thus, it is enough to measure p_1 as compared to the atmospheric pressure and the result is the real pressure difference.

3.2. Measurement of the diffuser sidewall pressure distribution

13 pressure taps on the inner side and 15 on the outer side of the diffuser allow the measurement of pressure distributions inside the diffuser. Besides them, there is a static pressure probe in the diffuser axis. Pressure distributions must be recorded as specified by the measurement task. These profiles provide useful information about different flow phenomena: separations, stagnation points etc.

3.3. Outflow symmetry

In case of a symmetric setting on a given radius no flow properties change along the circumference. This is to be checked in one measurement case, i.e., one gap setting. The outflow velocity profile must be measured along the diffuser circumference using the Pitot probe and its stand using 30° steps.

3.4. Outflow velocity profile

The outflow velocity profile is to be measured in along one radius for one gap size setting. The Pitot probe stand is to be attached to the diffuser surface using a bolt. The velocity profile can be measured using a step size of 1 mm between the two diffuser plates.

3.5. Devices used in the measurement.

Device	**Type**	**Serial number**
Digital manometer	EBM-001	000011507 (BME 225303)
Wall pressure gauge	103	94322418
Wall thermometer	LW Immersion total	914
Betz Manometer	ARA_BETZ-01	000011507 (BME 225303)

Table 1:Used measurement devices

4. Measurement results and calculations

4.1. Calibration

To assure precise results it is important to do calibration of the digital manometer. This can be done with the help of Betz manometer. It can be done in a following way: 2 pressure gauges must be connected to the same medium, and using a syringe pressure can be adjusted. Afterwards, the pressure on calibrated manometer and the height of the water column from Betz manometer must be read which then can be converted to pascals using the following formula:

$$p = \frac{(\rho_w - \rho_{air}) g h_w}{1000} \qquad (7)$$

,where $\rho_w - water\ density$, $\rho_{air} - air\ density, h - water\ column\ height.$

h_w [cm]	$p_{device1}$ [Pa]	$p_{device2}$[Pa]	p_{water} [Pa]
-2.7	-6.6	-8.7	-26.41
2.5	28.8	26.5	24.45
3.7	40.2	37.6	36.19
4.7	49.4	46.6	45.97
5.5	57.69	54.6	53.80
6.2	64.5	61.7	60.64
7.9	81.3	78.1	77.27
8.7	81.9	85.5	85.10
9.5	96.8	93.1	92.93
10.3	104.9	101.1	100.75
11.3	114.5	110.5	110.53

Table 2: Calibration data

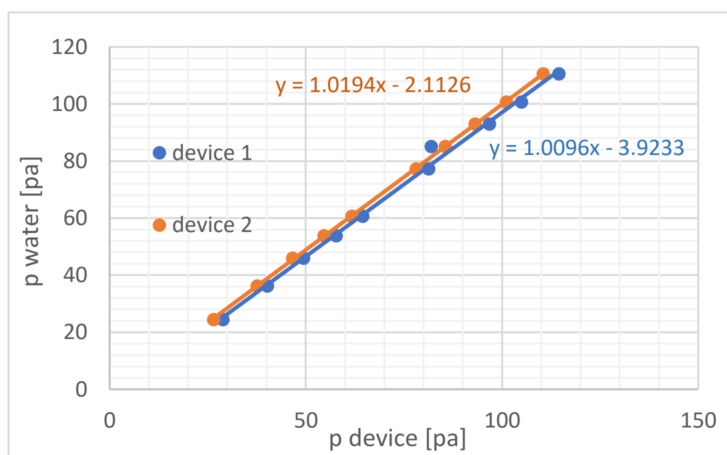


Figure 3: Calibration chart

4.2. Environment conditions measurement

Afterwards, the environmental conditions and diffusers parameters were measured as follows:

T_0 [k]	19.5
p_0 [Pa]	100300

d_{or} [m]	0.1
D [m]	0.105

D_L [m]	0.36
α [-]	0.6

Table 3: environment conditions and diffuser parameters

4.3. Measurements to find sheet efficiency

Next, main parameters were measured which are x – sheet distance, $\Delta p_{orifice}$ – gauge pressure of orifice, Δp_{real} – real pressure difference. The measured values are given with “red” color and the calculated values are given with the “green” color in the table below:

Point	X[m]	$\Delta p_{or}[Pa]$	Δp_{real}[Pa]	$q_V[m^3/s]$	v_1[m/s]	v_2[m/s]	$\Delta p_{ideal}[Pa]$	$\eta[-]$
1	0.008	529.20	-157.70	0.14	16.20	15.50	13.18	-11.97
2	0.009	539.40	-130.50	0.14	16.35	13.91	44.14	-2.96
3	0.010	581.50	-31.20	0.15	16.98	13.00	71.27	-0.44
4	0.012	614.30	41.36	0.15	17.45	11.13	107.88	0.38
5	0.014	627.60	81.60	0.15	17.64	9.65	130.29	0.63
6	0.016	644.10	111.60	0.15	17.87	8.55	147.08	0.76
7	0.018	649.50	125.20	0.16	17.94	7.63	157.56	0.79
8	0.020	653.10	130.50	0.16	17.99	6.89	165.08	0.79
9	0.022	655.50	131.10	0.16	18.03	6.27	170.63	0.77
10	0.025	650.10	125.20	0.16	17.95	5.50	174.48	0.72

Table 4: measurement to determine efficiency

The formulas used to determine calculated parameters in the table:

$$q_V = \alpha \cdot \varepsilon \cdot \frac{d^2 \cdot \pi}{4}\sqrt{\frac{2 \cdot \Delta p_{or}}{\rho}},\ v_1 = \frac{q_V}{A_1} = \frac{4 \cdot q_V}{D^2 \cdot \pi},\ v_2 = \frac{q_V}{A_2} = \frac{q_V}{D_L \cdot \pi \cdot x},\ \Delta p_{ideal} = \frac{\rho}{2} \cdot (v_1^2 - v_2^2),\ \eta_{diff} = \frac{\Delta p_{real}}{\Delta p_{ideal}}$$

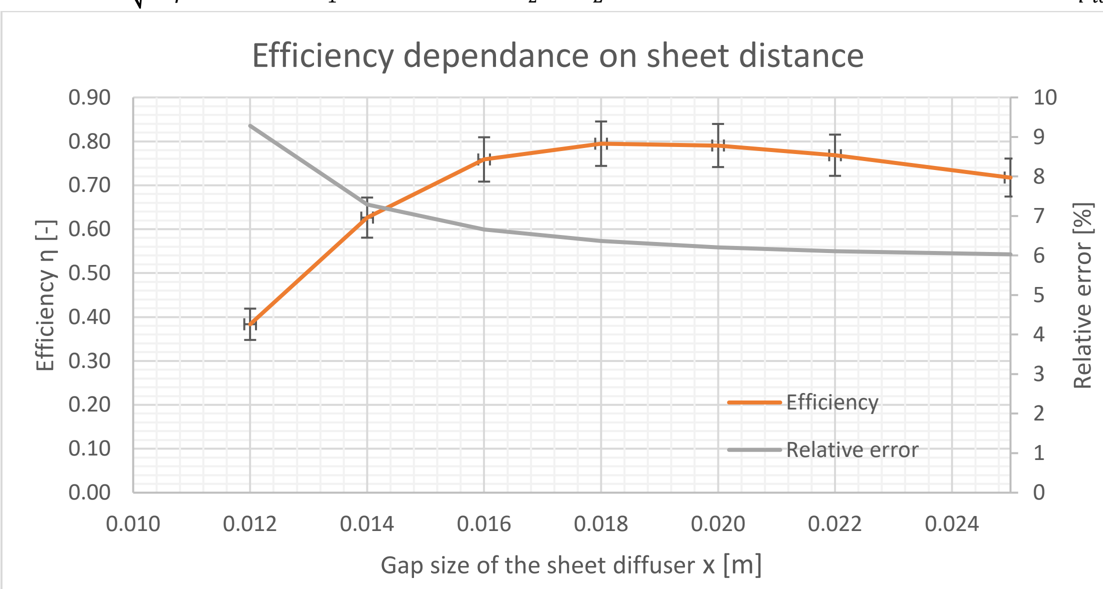


Figure 4:Efficiency and relative error dependance on x (calculation of relative error is given in Error calculation chapter

4.4. Velocity symmetry measurements

The results for the measurement of velocity symmetry are given below:

Angle [°]	Pressure (p) [Pa]	Velocity (v) [m/s]
0	55.42	9.63
30	55.63	9.65
60	55.50	9.64
90	55.49	9.63
120	55.57	9.64

Angle [°]	Pressure (p) [Pa]	Velocity (v) [m/s]
150	55.74	9.65
180	55.53	9.64
210	55.55	9.64
240	54.42	9.54
270	55.50	9.63
300	55.08	9.60
330	55.23	9.61
360	56.09	9.68

Figure 5: Velocity symmetry measurement

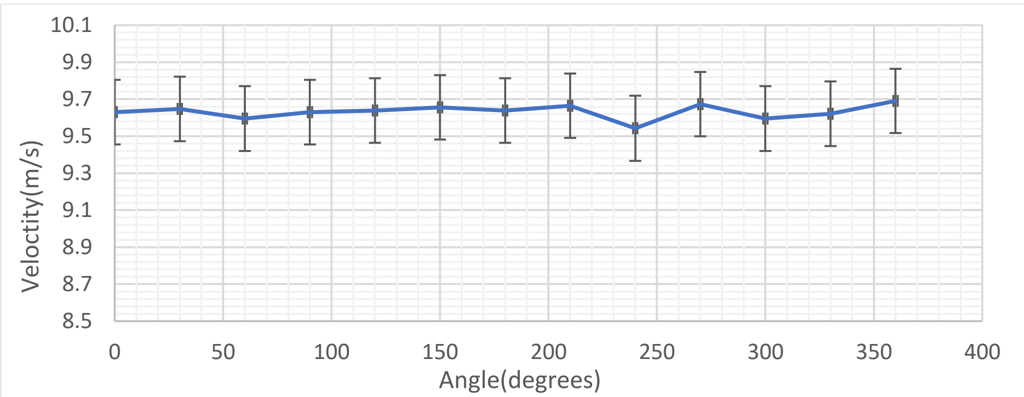


Figure 6: Velocity symmetry diagram

It can be seen from table and the graph that velocity is very symmetric along the circumference. Some deviations are always present which are due to human factor. The formula used to find velocity here is:

$$v = \sqrt{\frac{2 \cdot p}{\rho_{air}}}$$

4.5. Pressure distribution through radial distance

Points	R[m]	$p_{out}[Pa]$	R[m]	$p[Pa]$
1	0.016	351.30	0.053	137.20
2	0.027	350.60	0.053	94.78
3	0.038	347.20	0.065	131.30
4	0.049	331.60	0.066	197.56
5	0.060	306.50	0.077	198.30
6	0.071	265.70	0.091	94.98
7	0.082	206.60	0.100	0.30
8	0.093	121.10	0.112	-93.50
9	0.104	11.50	0.124	-210.47
10	0.115	-99.10	0.135	-180.30
11	0.126	-179.80	0.146	-128.30
12	0.137	-169.90	0.158	-78.20
13	0.148	-128.50	0.170	-46.20
14	0.159	-85.60		
15	0.170	-74.40		

Table 5: Pressure distribution for point x = 8 mm

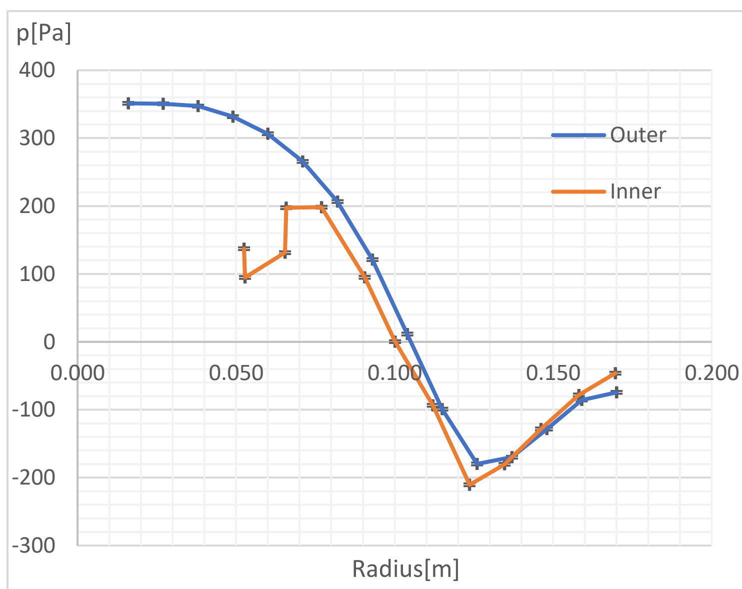


Figure 7: Pressure distribution for point x = 8mm

Points	R[m]	$p_{out}[Pa]$	R[m]	$p_{in}[Pa]$
1	0.016	166.80	0.053	-118.50
2	0.027	162.60	0.053	-169.90
3	0.038	155.10	0.065	-104.60
4	0.049	140.90	0.066	-47.30
5	0.060	110.80	0.077	-35.33
6	0.071	70.40	0.091	-46.17
7	0.082	26.50	0.100	-71.70
8	0.093	-16.30	0.112	-83.90
9	0.104	-51.20	0.124	-93.90
10	0.115	-71.90	0.135	-70.40
11	0.126	-74.70	0.146	-47.40
12	0.137	-64.30	0.158	-29.70
13	0.148	-46.30	0.170	-14.10
14	0.159	-31.20		
15	0.170	-28.50		

Table 6:Pressure distribution for point x = 14mm

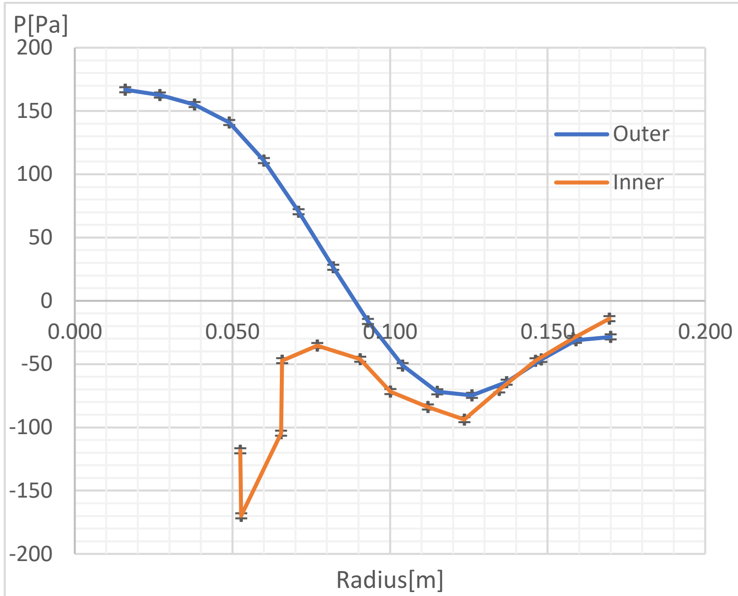


Figure 8:Pressure distribution for point x = 12mm

Points	R[m]	$p_{out}[Pa]$	R[m]	$p_{in}[Pa]$
1	0.016	166.80	0.053	-118.50
2	0.027	162.60	0.053	-169.90
3	0.038	155.10	0.065	-104.60
4	0.049	140.90	0.066	-47.30
5	0.060	110.80	0.077	-35.33
6	0.071	70.40	0.091	-46.17
7	0.082	26.50	0.100	-71.70
8	0.093	-16.30	0.112	-83.90
9	0.104	-51.20	0.124	-93.90
10	0.115	-71.90	0.135	-70.40
11	0.126	-74.70	0.146	-47.40
12	0.137	-64.30	0.158	-29.70
13	0.148	-46.30	0.170	-14.10
14	0.159	-31.20		
15	0.170	-28.50		

Table 7:Pressure distribution for point x = 25mm

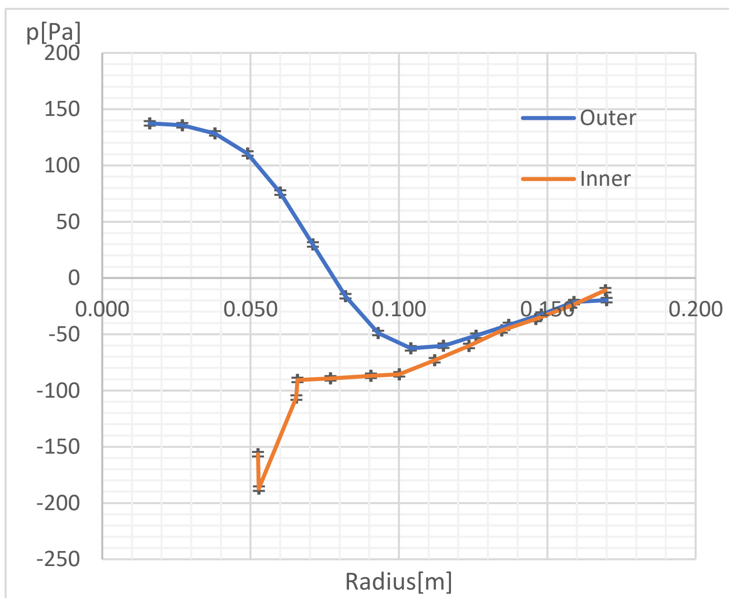


Figure 9:Pressure distribution for point x = 25 mm

It can be seen from the graphs that for first 3-4 points the inner pressure distribution is unpredictable and does not follow any pattern. This happens due to phenomenon called **boundary layer separation.** The kinetic energy of the particles, here slowing down because of the wall shear stress, – especially by the suddenly widening diffuser – is not enough for the energy necessary for the pressure growth induced by the slowing down of the particles further from the wall. Therefore, the particles near the wall are slowing down. They may stop or even flow back. In this case a separation zone develops next to the wall. The inner particles do not follow the widening shape of the pipe and separate from the wall.

5. Error calculation

5.1. Efficiency error calculation

The error of the diffuser efficiency measurement is to be calculated using the following steps. The diffuser efficiency:

$$\eta_{diff} = \frac{\Delta p_{real}}{\Delta p_{id}} = \frac{\Delta p_{real}}{\frac{\rho_{air}}{2}(v_1^2 - v_2^2)} = \frac{\Delta p_{real}}{\alpha^2 \cdot d^4 \cdot \Delta p_{or}\left(\frac{1}{D^4} - \frac{1}{16 D_L^2 x^2}\right)}$$

Absolute error:

$$\delta\eta = \sqrt{\sum_{i=1}^{n} (\delta X_i \cdot \frac{\partial \eta}{\partial X_i})^2}$$

where X_i is the measured quantity and the related measurement error:

$X_1 = \Delta p_{real}$	and the error of measurement is	$\delta \Delta p_{real} = 2Pa$
$X_2 = \Delta p_{or}$	and the error of measurement is	$\delta \Delta p_{or} = 2Pa$
$X_3 = \mathrm{D}$	and the error of measurement is	$\delta \mathrm{D} = 1mm$
$X_4 = \mathrm{D_L}$	and the error of measurement is	$\delta \Delta D_L = 1mm$
$X_5 = \mathrm{d}$	and the error of measurement is	$\delta \mathrm{d} = 1\ mm$
$X_6 = \mathrm{x}$	and the error of measurement is	$\delta \mathrm{x} = 0.2\ mm$

The relative error is:

$$Relative\ error = \frac{\delta \eta_{diff}}{\eta_{diff}}$$

X[m]	$\delta \Delta p_{real} \frac{\partial \eta}{\partial \Delta p_{real}}$	$\delta \Delta p_{or} \frac{\partial \eta}{\partial \Delta p_{or}}$	$\delta \Delta D_L \frac{\partial \eta}{\partial \Delta D_L}$	$\delta D \frac{\partial \eta}{\partial D}$	$\delta d \frac{\partial \eta}{\partial d}$	$\delta x \frac{\partial \eta}{\partial x}$	δη	Relative error
0.008	0.1517	0.0452	0.7240	-5.4205	0.4786	6.5161	8.5217	-0.7122
0.009	0.0453	0.0110	0.0430	-0.4076	0.1183	0.3441	0.5500	-0.1861
0.010	0.0281	0.0015	0.0034	-0.0403	0.0175	0.0248	0.0579	-0.1322
0.012	0.0185	-0.0012	-0.0015	0.0246	-0.0153	-0.0088	0.0356	0.0928
0.014	0.0154	-0.0020	-0.0015	0.0340	-0.0251	-0.0076	0.0457	0.0729
0.016	0.0136	-0.0024	-0.0013	0.0375	-0.0303	-0.0056	0.0505	0.0666
0.018	0.0127	-0.0024	-0.0010	0.0370	-0.0318	-0.0039	0.0506	0.0637
0.020	0.0121	-0.0024	-0.0008	0.0353	-0.0316	-0.0027	0.0490	0.0620
0.022	0.0117	-0.0023	-0.0006	0.0333	-0.0307	-0.0019	0.0469	0.0611
0.025	0.0115	-0.0022	-0.0004	0.0302	-0.0287	-0.0012	0.0433	0.0603

Figure 10: Efficiency error calculation

5.2. Velocity symmetry error calculation

Similar calculations were carried out to velocity, where:

$$v = \sqrt{\frac{2 \cdot p}{\rho_{air}}}$$

The velocity is affected by the pressure and the density which is affected by temperature and the pressure of the air (T_0 and p_0), as: $\rightarrow\ \rho_{air} = \frac{p_0}{R \cdot T_0}$

Calculating the absolute error in the density we get $\delta \rho_{air} = 0.004255\ \frac{m^3}{V}$. The results of error calculation are shown below:

Angle[°]	Velocity[m/s]	$\delta p \frac{\partial \eta}{\partial p}$	$\delta \rho \frac{\partial \eta}{\partial \rho}$	δv	Relative error
0	9.630	0.174	-0.017	0.175	0.018132
30	9.647	0.174	-0.017	0.174	0.018064
60	9.595	0.174	-0.017	0.175	0.018106
90	9.630	0.174	-0.017	0.175	0.018109
120	9.639	0.174	-0.017	0.175	0.018083
150	9.656	0.173	-0.017	0.174	0.018029
180	9.639	0.174	-0.017	0.175	0.018096
210	9.665	0.173	-0.017	0.174	0.01809
240	9.543	0.175	-0.017	0.176	0.018462
270	9.673	0.173	-0.017	0.174	0.018106
300	9.595	0.174	-0.017	0.175	0.018243
330	9.621	0.174	-0.017	0.175	0.018193
360	9.691	0.173	-0.017	0.174	0.017917

Figure 11: Velocity symmetry error calculation

6. Conclusion

During this laboratory measurement by making calculations and graphs we were able to understand how the efficiency of a sheet diffuser behaves depending on the sheet distance.

- The optimal sheet distance for the diffuser is in 18 mm, with an efficiency of 79.5% ± 0.051%.
- The outflow velocity is very similar all around so the velocity is symmetrical.
- The average relative error in the efficiency calculation is 0.15, and in the velocity calculation is 0.018.

7. References

1. LAJOS, Tamás: Az áramlástan alapjai (Hungarian), Műegyetemi Kiadó, Budapest 2005
2. Departmental Web Site: www.ara.bme.hu
3. BSc_M13_pressure_tap_positions.DW

Fluid Mechanics Laboratory Measurement M13 (Task B).

* By: - Saif-aldain Aqel QHJ356
- Firuddin Heydarov IG6JX7

* Instruments used during measurement:
- Digital Manometer (14 and 10).
- Pitot probe
- Diffuser
- Caliber

* equation needed for the measurement:
- Diffuser efficiency: $\eta_{dif.} = \dfrac{(P_2 - P_1)_{real}}{\frac{\rho}{2}\left(v_1^2 - v_2^2\right)}$, where $P_2 = P_0$.
- air density: $\rho = \dfrac{P_0}{R.T}$
- Volume flow rate: $q_v = \alpha . \varepsilon \dfrac{d^2 \pi}{4} \sqrt{\dfrac{2 . \Delta P_{or}}{\rho}}$
- Velocities:

$$v_1 = \frac{q_v}{A_1} = \frac{4 . q_v}{D^2 . \pi}$$

$$v_2 = \frac{q_v}{A_2} = \frac{q_v}{D_2 . \pi . X}$$

* Absolute error:

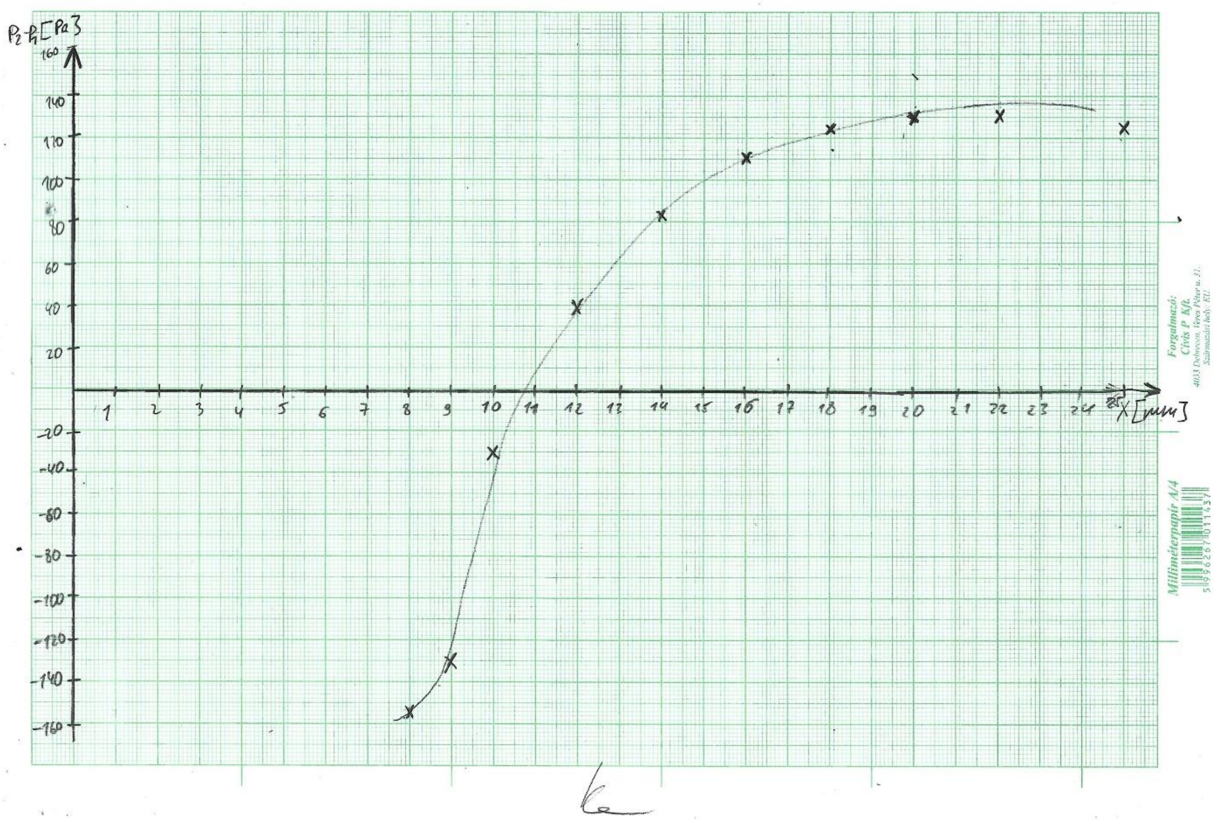
$$\delta \eta_{dif} = \sqrt{\sum_{i=1}^{n} \left(\delta x_i \cdot \frac{\partial \eta_{dif.}}{\partial x_i} \right)^2}$$

* Relative error:

$$\frac{\delta \eta_{dif}}{\eta_{dif.}} =$$

- Supervisor's Signature: ___

KORÉN MÁRTON



p2-p1 [Pa]
x [mm]