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Subject	**Fluid Mechanics**	
Measurement	A	
Day	**Tuesday 14-16**	
Week	**Even**	
Date of the measurement	**2023. 11. 07**	
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MEASUREMENT REPORT

Measurement Nr M09.
DETERMINATION OF THE CHARACTERISTICS OF A DIFFUSER

Group: 2	**NEPTUN code**
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Validation Code: QFR5R2-M09-11-1.05-467.53-853.54-633.18-0.733-dd94ca6bcad8e2ccb0298212774d4c79

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

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Measurement Location: BME Department of Fluid Mechanics, Theodore von Kármán Wind Tunnel Laboratory
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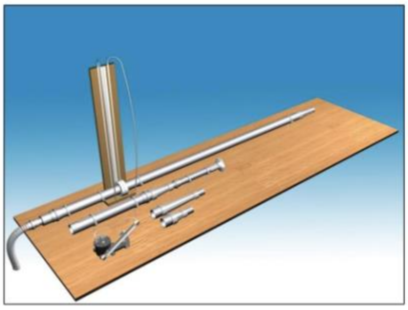
The lab report must be uploaded with this cover! Please fill out only the red sections!

AIM AND OBJECTIVES OF THE MEASUREMENT

It is necessary to ascertain the diffuser efficiency (η_{diff}) during the laboratory testing. Plotting the results in diagrams, the efficiency must be examined as a function of the diffuser angle (α) and the volume flow rate (qv). The measuring setup were included one Borda-Carnot element and two distinct diffusers with angles of 6° and 30° (The 15° diffuser cannot be used due to inappropriate function). Both the volume flow rate through the system and the length of the flow straightener segment that comes after the built-in components can be adjusted.

DESCRIPTION OF THE MEASUREMENT SET-UP



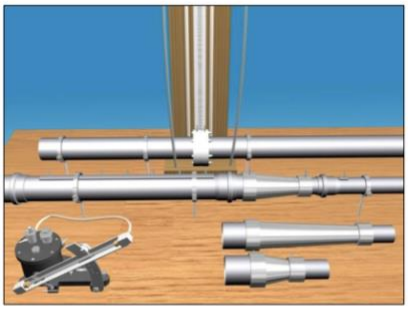


Figure 1 displays the measurement device's sketch. The calibration of the inlet orifice plate was created by the help of a built-in standardized orifice plate (6) and the use of calibration section. The real measurement started after the entrance orifice plate (5) has been calibrated and built into the lower measurement section.

INLET ORIFICE PLATE CALIBRATION

A radial fan integrated within the table (1) that is attached to the calibration component (7) is used to supply air to the device. By monitoring the pressure differential on the standard built-in orifice plate and the inlet orifice plate simultaneously, we may utilize the standardized orifice plate (6) to find the flow number of the inlet orifice plate. The standard orifice plate can be used to determine volume flow rates, which can then be substituted into the equation that describes the inlet orifice plate. In this case, the flow number will be the only unknown. If the corresponding pressure differences are noted and shown in a diagram, a calibration diagram can be created.

DIFFUSER EFFICIENCY MEASUREMENT

The fan's suction tube and inlet orifice plate need to be attached to the measurement section (3). The diffusers (4) were placed between the measurement section and the inlet orifice plate. With the help of the recorded calibration diagram, the flow rate can be computed using the pressure differences. By using a pressure transducer to detect the pressure rise on the pressure taps before and after the diffuser, the efficiency of the diffuser can be determined. To prevent measuring the pressure in the separated flow, there are numerous pressures taps on the measurement section after the diffuser.

Figure 1: Calibration section

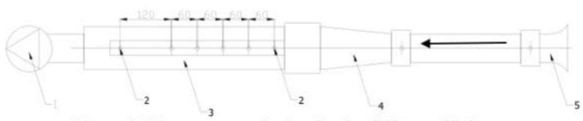


Figure 2: Measurement device for the diffuser efficiency

MEASUREMENT ASSIGNMENTS – M09 A

- Measure the lab temperature and the atmospheric pressure! - 2 data
- Calibrate the inlet orifice No.1 at three essentially different velocities! - 3x2 data
- Measure the efficiency characteristic of the 3 diffusers and the Borda Carnot diffuser using three essentially different velocities! - 3x4x8 data
- Measure the lab temperature and the atmospheric pressure! - 2 data
- Check your calculation results at www.ara.bme.hu/lab web page!

MEASUREMENT PROCEDURE

Equipment and tools used:

- 6° diffuser
- 30° diffuser
- Borda Carnot
- Calibrated digital manometer (EMB-001)
- Betz manometer

Measurement steps:

Part 1

- Arrange the Inlet Orifice Plate (IOP) calibration unit, where consist of the IOP, one straight long pipe with a pressure tap, one pipe with a standardized orifice plate, two pressure taps, and one connection-pipe for the fan.
- Turn on the fan, then measure the pressure at the inlet orifice plate (IOP) towards the surrounding and two sections of the standardized orifice plate (SOP).
- Repeat those pressure measurements at three level of volume flow rates (qv): at minimum, maximum, and in between.

Part 2

- Prepare the set-up for the diffusers testing. The suction tube of the fan and the inlet orifice plate were connected to the measurement section.
- Between the measurement section and the inlet orifice plate (IOP), placed the diffuser that need to be measured.
- Measure the pressure difference at the IOP and the diffuser, as well as the pressure drop at all seven pressure taps on the measurement section. Calculate the downstream distance between the reference point and all seven pressure taps.
- Repeat these steps for every diffuser that need to be used in this laboratory.

Part 3

- Calibrate the digital manometer with the assist of the Betz Manometer and a syringe. The calibration is an important process that need to be done to ensure the accuracy of the pressure measurements.

LABORATORY DATA

- Initial Temperature (T_0) = 293,85 [K]
- Initial atmospheric pressure (P_0) = 99810,00 [Pa]
- Final temperature (T_f) = 292,20 [K]
- Final atmospheric pressure (P_f) = 99810,00 [Pa]

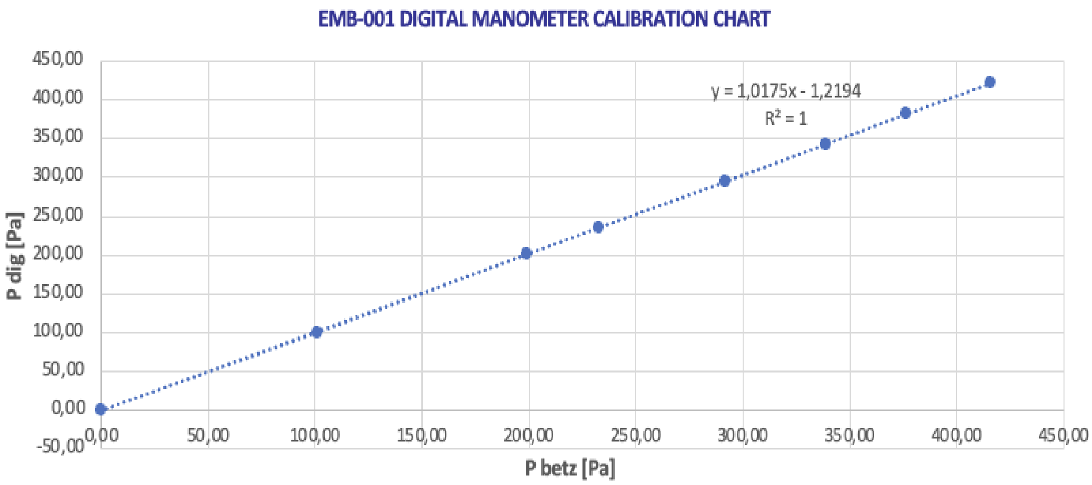
DATA ANALYSIS AND CALCULATIONS

I. Manometer Calibration

- Data collected: $1\ [mmH_20] = 9{,}80665\ [Pa]$, g = 9,808369 m/s2

Digital Manometer Calibration		
Betz [mmH2O]	P dig [Pa]	P betz [Pa]
0,00	0,00	0,00
10,20	100,90	100,05
20,50	198,90	201,07
24,00	232,30	235,40
30,00	291,50	294,25
35,00	338,55	343,29
39,00	376,12	382,53
43,00	415,67	421,76

- Analytical graph



II. Calibration of the Inlet Orifice Plate (IOP)

- Recorded data:

Volume Flow Rate	ΔP Inlet Orifice Plate [Pa]	ΔP Standardized Orifice Plate [Pa]
qv Minimum	169,65	467,53
qv Maximum	274,55	853,54
qv In between	213,64	633,18

- Volume flow rate for the Inlet Orifice Plate (IOP)

$$q_v = k\frac{d_i^2\pi}{4}\sqrt{\frac{2}{\rho_1}\Delta p_i}$$

Where:

k : Flow factor [-]
di : Inner diameter of the inlet orifice plate = 3,64 . 10^{-2} [m]
$\rho 1$: Density of air = 1,18 [Kg/m^3]
Δp_i : Pressure drop measured on the inlet orifice plate

- Volume flow rate for the Standardized Orifice Plate (SOP)

$$q_v = \frac{C}{\sqrt{1-\beta^4}}\varepsilon_1\frac{d^2\pi}{4}\sqrt{\frac{2}{\rho_1}\Delta p}$$

Where:

C : Flow coefficient =
β : Measured relation of the cross-section of the inner brim to the diameter of the pipe = 0,6587
ε : Compressibility factor = 1, since the change in the pressure of the fluid is small
d : Hole diameter of the measurement brim = 3,88 . 10^{-2} [m]
Δp : Pressure drop on flow through orifice

Calculation of the flow coefficient (C):

$$C = 0.5961 + 0.0261\beta^2 - 0.216\beta^8 + 0.000521\left(\frac{10^6\beta}{Re_D}\right)^{0.7} + (0.0188 + 0.0063A)\beta^{3.5}\left(\frac{10^6}{Re_D}\right)^{0.3} + 0.011(0.75-\beta)\left(2.8 - \frac{D}{0.0254}\right)$$

Calculation of the Reynold Number (Re_D)

$$Re_D = \frac{vD}{\nu}$$

Where:

D : Diameter before the brim = 5,89 . 10^{-2} [m]
ν : Kinematic viscosity air at 20° C = 1,52 . 10^{-5} [m^2/s]

Calculation of the Factor A

$$A = \left(\frac{19000\beta}{Re_D}\right)^{0,8}$$

- Pressure drop and velocity

$$v_1 = \frac{4 \cdot q_v}{d_{in}^2 \cdot \pi} \qquad v_2 = \frac{4 \cdot q_v}{d_{out}^2 \cdot \pi}$$

Where:

d_{in} : D = 5,89 . 10^{-2} [m]
d_{out} : d = 3,88 . 10^{-2} [m]

- Flow factor

$$k = \frac{q_{V,SOP}}{q_{V,IOP}}$$

Results:

k at qv minimum = 1,30 [-]
k at qv maximum = 1,37 [-]
k at qv in between = 1,34 [-] = $k_{average}$

III. Calculation of the Diffuser Efficiency

- Pressure changes between the pressure tabs and diffusers

Pressure Tabs	Borda Carnot Diffuser		6° Diffuser		30° Diffuser	
	Δds [mm]	ΔP [Pa]	Δds [mm]	ΔP [Pa]	Δds [mm]	ΔP [Pa]
1	110	-30,6	260	280	80	160,2
2	230	29,23	340	287	160	222,73
3	350	80,34	400	294	240	245,64
4	410	105,24	460	298	300	250,9
5	470	110,5	520	295	360	260
6	530	103,97	580	289	420	242,8
7	650	107,2	700	284	540	256,48

Δds : Change in Down Stream Distance
ΔP : Change in Pressure

- Pressure changes between the pressure tabs and the inlet orifice plate from three diffusers

Pressure Tabs	Boda Carnot Diffuser [Pa]	6° Diffuser [Pa]	30° Diffuser [Pa]
1	219,79	207,8	214,91
2	205,12	206,4	212,91
3	202,56	207,9	216,77
4	201,9	205,7	215,9
5	209,96	205,2	216,6
6	201,7	204,2	217,4
7	204,2	205,7	215,4

- Volume flow rate of the inlet orifice

$$q_{v,iop} = k_{avg} \frac{di^2\ \pi}{4} \sqrt{\frac{2\ \Delta P,iop}{\rho}}$$

- Velocity - in front of the diffuser

$$V_{1,\ diff} = \frac{4\ qv,iop}{D^2\ \pi}$$

- Velocity - after the diffuser

$$v_{2,diff} = \frac{4\ q_{v,iop}}{d^2\ \pi}$$

- Ideal pressure difference

$$\Delta P_{ideal} = \frac{1}{2}\ \rho\ ((v1, diff)^2 - (v2, diff)^2)$$

- Efficiency calculation

$$\eta_{diff} = \frac{\Delta P,real}{\Delta P,ideal} = \frac{\Delta Pdiff}{\Delta P,ideal}$$

Results:

η for borda carnot (180°) diffuser = 0,346 [-]

η for 6° diffuser = 0,885 [-]

η for 30° diffuser = 0,733 [-]

- Loss factor calculation

$$\zeta diff = \frac{\Delta P,ideal - \Delta P,real}{\frac{1}{2}\ \rho\ v1^2}$$

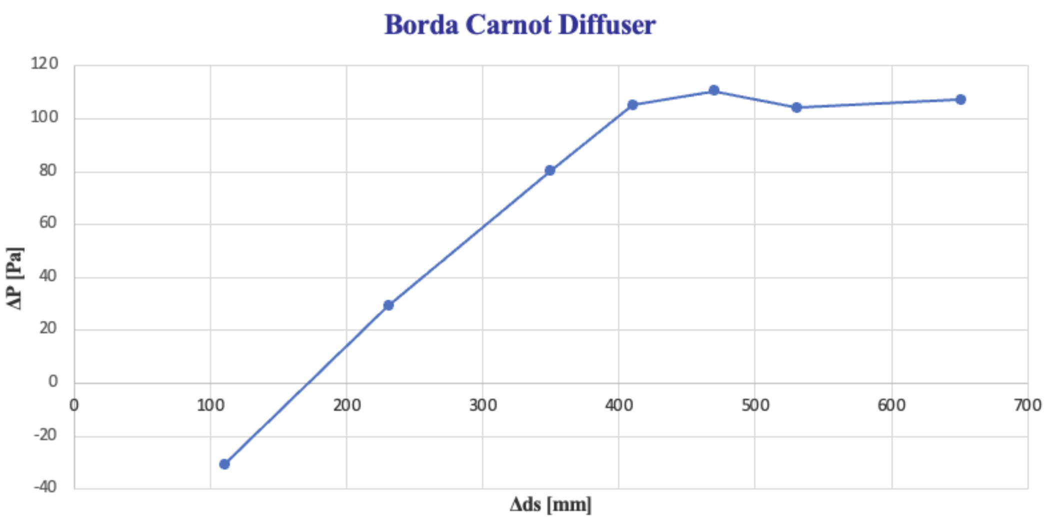
Results:

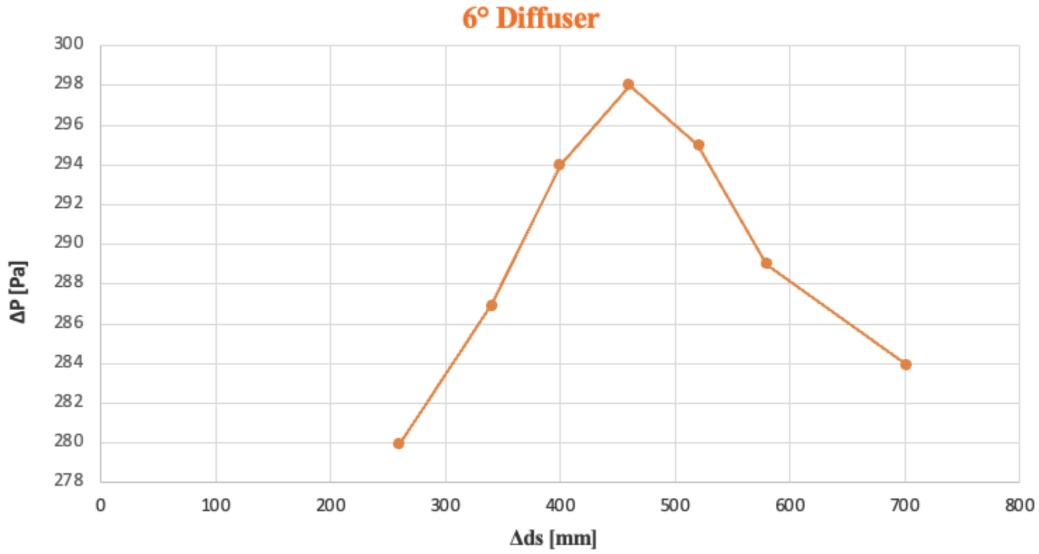
ζ for borda carnot (180°) diffuser = 0,8541 [-]

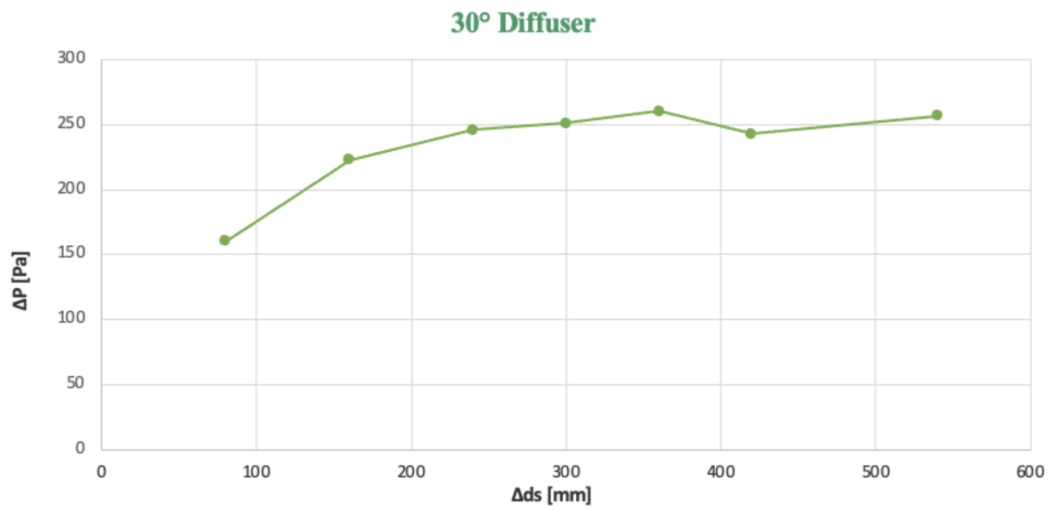
ζ for 6° diffuser = 0,8541 [-]

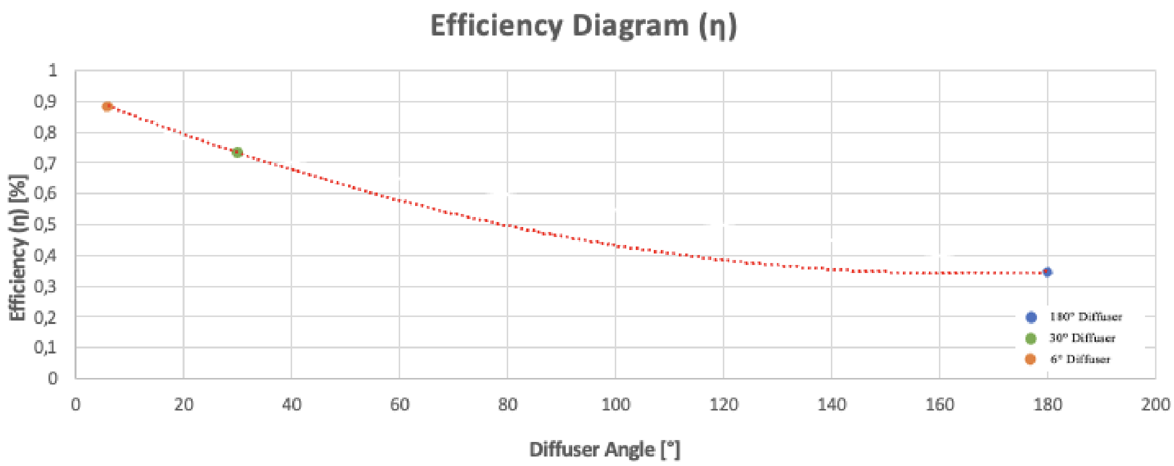
ζ for 30° diffuser = 0,8541 [-]

- Analytical graph




6° Diffuser
ΔP [Pa]
Δds [mm]
300
298
296
294
292
290
288
286
284
282
280
278
0
100
200
300
400
500
600
700
800


30° Diffuser
ΔP [Pa]
Δds [mm]
300
250
200
150
100
50
0
0
100
200
300
400
500
600


Efficiency Diagram (η)
Efficiency (η) [%]
Diffuser Angle [°]
1
0,9
0,8
0,7
0,6
0,5
0,4
0,3
0,2
0,1
0
0
20
40
60
80
100
120
140
160
180
200
180° Diffuser
30° Diffuser
6° Diffuser

IV. Error Calculations

- Given data

  Δd = 0,001 [m]

  $\delta\Delta p$ = 2 [Pa]

- Efficiency derivation

$$\frac{\delta\eta_{diff}}{\delta X_i}\text{, with } X_{1,2} = d_{IOP}, D_{SOP} \text{ and } X_{3,4} = \Delta p_{\text{ideal}}, \Delta p_{\text{real}}$$

Derivations for every diffuser angle

Diff (6°):		Diff (30°):		Diff (180°):	
$d(\eta)/d(d_{.IOP})$	= -16,6031	$d(\eta)/d(d_{.IOP})$	= -13,7615	$d(\eta)/d(d_{.IOP})$	= -6,4849
$d(\eta)/d(D_{.SOP})$	= 10,2607	$d(\eta)/d(D_{.SOP})$	= 8,5045	$d(\eta)/d(D_{.SOP})$	= 4,0076
$d(\eta)/d(\Delta p_{.Ideal})$	= -0,0042	$d(\eta)/d(\Delta p_{.Ideal})$	= -0,0033	$d(\eta)/d(\Delta p_{.Ideal})$	= -0,0016
$d(\eta)/d(\Delta p_{.Real})$	= 0,0031	$d(\eta)/d(\Delta p_{.Real})$	= 0,0030	$d(\eta)/d(\Delta p_{.Real})$	= 0,0031

- Absolute error

$$\delta\pi diff = \sqrt{\sum_{i=1}^{n}\left(\delta Xi\,\frac{\delta\pi diff}{\delta Xi}\right)^2}$$

Results:

$\Delta\eta$ 6° Diffuser = 0,0222 [-]

$\Delta\eta$ 30° Diffuser = 0,0185 [-]

$\Delta\eta$180° Diffuser = 0,0104 [-]

- Relative error

$$\eta_{rel} = \frac{\delta\eta_{diff}}{\eta_{diff}}$$

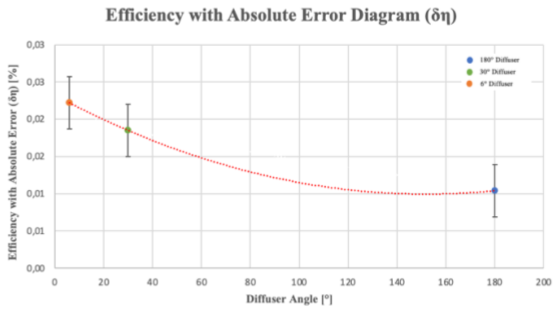
Results:

$\Delta\eta$ 6° Diffuser /η 6° Diffuser = 0,0251 [-]

$\Delta\eta$ 30° Diffuser /η 30° Diffuser = 0,0253 [-]

$\Delta\eta$ 180° Diffuser /η 180° Diffuser = 0,0301 [-]

- Analytical graph



DISCUSSION AND CONCLUSIONS

This fluid mechanics laboratory investigated the efficiency of three different diffusers in a methodical manner. Diffusors with smaller opening angle (6° and 30° diffuser) are often more efficient than those with greater angles (borda carnot diffuser), according to the numerical data and graph. In addition, the pressure diagram illustrates the relationship between the opening angle and the flow separation distance. It is evident that a quick increase in opening angle (diameter) could influenced a greater separation.

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