EXPERIMENTAL SET-UP OF A HYDRAULIC BENCH

Report of the internship performed between Monday 27th August 2018 and Monday 7th January 2019

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My family and my friends for their support during this internship.

Summary

Introduction

Part I: Internship abroad

According to the context to the international context of this internship, a small presentation of the hosting country, Brazil, could be interesting. Following the presentation of the Brazil and Brasilia, an introduction to the University of Brasilia will be presented.

I.1 presentation of Brazil

Figure I.1 Brazilian flag

Figure I.2 Brazilian position in South America

My internship took place in the **Federal Republic of Brazil** (República Federativa do Brasil) commonly referred as Brazil. With an area of 8 514 876 km², Brazil is the 5th largest country in the world and the first one in South America, Brazil cover 47.3% of the south continent. With at least 209 million citizen, Brazil is the 6th populated country in the world, a vast majority of the population is concentrated in coastal cities like Rio de Janeiro or Fortaleza.

The country is divided in 26 states and one Federal District around the capital. A large portion of the country is covered by the Amazonian Jungle, in the north-west. The main language of the country is the Portuguese thanks to the colonization of the area by Portuguese explorer in 1500, Brazil was a Portuguese colony from 1500 to 1822 with an independence in August 1825.

The local devise is the Brazilian real (R$) with in ISO code of BRL, 1R$ is equal to 0.21€. On the international plan, Brazil acted like a local superpower practicing a leadership in several fields like scientific research, military power and economic power. According to expert on the domain, Brazil is one of the countries which can become a superpower in the next decades. The country is the 7th economic power in the world and is army is 14th largest. The country is part of several international institutions like ONU, BRICS, OMC, WHO.

I.2 Brasilia, capital city of Brazil

The previous capital city of the Brazil was Rio de Janeiro since 1763. In 1956, the Brazilian president Juscelino Kubitschek decided to spread the wealth of the country in the inland, in fact the major of the Brazilian economy was located on the coast especially in the cities of Rio de Janeiro: cultural and political capital, and Sao Paulo: economic capital. In order to also stop the rivalry of the two major cities, the cities of Brasilia, future capital of Brazil was planned to be built.

The yard start in 1957 under the direction of the Novacap Company and the architect Oscar Niemeyer and the urbanist Lucio Costa, the rough conditions of work and the employment promises increase the speed of the yard. The first wave of building took a thousand days to be construct.

The capital city is inaugurated on April 1960, following the inauguration state administrations and foreign embassies moved to the new capital, despite the refusal to move their embassy, foreign countries complied with the Brazilian government thank to diplomatic threatening.

Brasilia is divided in several sector: the Pilot Plan core of the city and home of state administrations has been designed by Niemeyer and Costa, and several satellite cities. Despite the plan of Costa, satellite cities were constructed before the filing of the Pilot Plan, so that the core of Brasilia house less than 500 000 inhabitants (the Pilot Plan was designed for 500 000 inhabitants) and the satellites cities, with not well planned urbanism, house 2 000 000 inhabitants.

Figure I.3 Brasilia from the ISS

figure I.4 heraldry of Brasilia (source: wikipedia.org)

figure I.5 position of Brasilia (red dot)

Figure I.6 Monument axis in Brasilia. From the center-left National Congress, Ministerial building, Cathedral of Brasilia, Cultural Complex of the Republic (Photo taken by the author)

I.3 University of Brasilia

The University of Brasilia (Universidade de Brasília) is a public university. The university has been founded in 1962 by the anthropologist Darcy Ribeiro and the teacher Anísio Teixeira. The main building of the university, the Central Institute of Sciences is a 700m long Niemeyer's design building.

The university had 1757 professor, 2 391 employees and more than 30 000 students. It is in the top five universities in the country and one of the top twenty in South America, the university count 50 departments, 12 institutes and 195 laboratories from scientific research to political research

The university is divided in four campus since 2006: the Darcy Ribeiro campus located in the Pilot Plan and created in 1962, the Planaltina campus created in 2006 focused on natural science, education, agribusiness and environmental management, the Ceilândia campus created in 2008, home of the nursing, pharmacy, physiotherapy, health, and speech therapy. And the Gama campus created in 2008 and home of engineering courses including aerospace, automotive, energy, software, electronic engineering.

Figure I.7 logo of the University of Brasilia

figure I.8 Logo of the Gama Campus (source: fga.unb.br)

My internship took place between Monday 27th August 2018 and Monday 7th January 2019, in the Gama campus of the University of Brasilia. Precisely in the Thermofluids laboratory of the university under the direction of the Professor Lucino Gonçalves Noleto. The laboratory is equipped with numerous bench designed to experiment on fluids mecanics: such as 2 axial fan equipped wind turbine, one designed for great models, the other for small model, one centrifugal fan equipped wind turbine and a bench designed to study the power of water fall.

Figure I.9 Axial wind tunnel (Photo taken by the author)

Figure I.10 Centrifugal wind tunnel in the laboratory

Part II: Presentation of my internship

II.1 Description of my internship

The main goal of my internship in the Gama campus of the University of Brasilia is to set-up a hydraulic bench in the Thermofluids lab of the Gama campus. The bench, a Hidro Didactica HD98B bench will be used for experiment purpose. My objectives here were to design experiment which can be performed on the bench by student and design an automated data acquisition set-up for the same bench.

My internship was divided in several assignments:

1. Review of the theory of basic fluid mechanics;

2. Review of basic instrumentation required for experiments;

3. Measurements and CAD drawings of the hydraulic bench;

4. Formulation of a minimum of 10 experiments that can be performed at the bench;

5. Execution of the experiments of assignment 4 at the bench;

6. Data treatment and analysis for the experiments of assignment 4 using the basic instrumentation;

7. Writing of laboratory scripts for each experiment, containing:

8. Planning of automated data acquisition setup for the experiments at the bench and at the Wind tunnel;

9. Assembly and testing of the data acquisition setup;

The expect result of this internship is a set of ten experiment for the bench and the hydraulic bench ready for teaching purpose by the end of my internship.

II.2 Description of the Bench

The bench used for experiment is a Hidro Didatica HD98B hydraulic bench.

Figure II.1 the HD98B bench

Figure II.1b close view of the flow rate control system

The bench feature nine pipes and is equipped with one venturi tube flow meter, one orifice plate flow meter and a rotameter. One the bench is equipped a 16mm diameter pipe, a 3 section pipe, four 20mm pipes: one mounted with two valves, one with one valve and a T singularity, one simply ribbed and the last one is smooth. The last pipe is equipped with a u,v and n shaped circuit. The water inside the bench is put in motion by a 750W pump. The flow rate is controlled by a valve under the bench, the valve control a pipe that divide the flow rate in two, one flow go to the bench, the other go to the constant level tank. The bench is equipped with two U manometers on each side, one digital manometer and a classic manometers in the center of the bench although, a third manometer can be placed on the center (see annexe XIII for more details).

Figure II.2 close view of central manometer the left one is a Salcaspress digital manometer (in bar) and the right one is a IMB manometer (in water column)

II.3 Internship progress

My internship took place from Monday 27th August 2018 to Monday 7th January 2019. I made a weekly report for my local tutor, professor Noleto, on each Wednesday. And I made a report twice a month for my academic tutor, Professor Menet

The expected progress of my internship was planned to be the following one:

	September	October	November	December
Assignment 1	XX			
Assignment 2	XX			
Assignment 3	XX			
Assignment 4	XX	XX		
Assignment 5	X	XX	XX	X
Assignment 6		XX	XX	XX
Assignment 7		XX	XX	X
Assignment 8			XX	X
Assignment 9			XX	X
Assignment 10			XX	XX

The X (left one) represent the expected achievement and the second (right one) X represent the actual achievement

Activities carried out

Part I: Research on the required topics

My internship required me to research basic theories on specifics topics which would later be related to the rest of my work on the hydraulic bench. For the rest of this report, each pressure noted Px refer to the pressure in the point X in Pa, Ua refer to the fluid speed in A in m/s, Za refer to the altitude of the point A in m, Sa refer to the section in A in m². ΔZab, ΔPab represent respectively the altitude difference and the pressure difference between points A and B.

1) Bernoulli formula

Formulated by the Swiss scientist **Daniel Bernoulli** (1700-1782), the Bernoulli formula is extrapolated from the Bernoulli Principle:

$$\frac{v^2}{2} + g.z + \frac{p}{\rho} = constant \tag{1}$$

With v, speed of the fluid in m/s, g gravitational constant in m/s², z altitude of the point of application in m, p pressure of the fluid in Pa and ρ density of the fluid in kg/m^3

This principle can be applied for, homogeneous, incompressible, Newtonian fluid (the deformation rate of the fluid is proportional to the force applied on it) in a stationary movement between two points A and B:

$$Pa + \frac{1}{2}\rho Ua^2 + \rho gza + \Delta Pmot$$
$$= Pb + \frac{1}{2}\rho Ub^2 + \rho gZb + \Delta Ps + \Delta Pl$$

(2)

A area in m²
h altitude in m
v speed in m/s
Δt short periode of time s

P density of the fluid (kg/m³)

With ΔPmot (Pa) pressure complement given by a pump (or any other similar device), ΔPs (Pa) singular head losses created by singularities in the circuit, ΔPl (Pa) linear head losses in the circuit created by the pipes.

This formula can be demonstrated by integrating Euler's equation,
or it can be demonstrated with the conservation of energy principle if the compressibility of the fluids is neglected.   The following situation is used: situation is used:

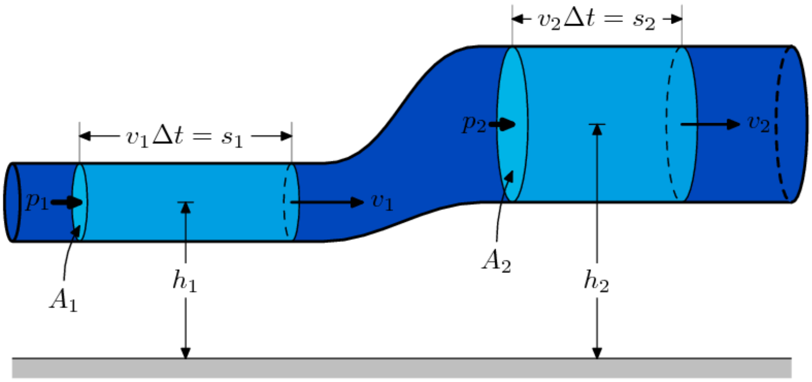


Figure 1 Ssituation used for the demonstration (source: https://fr.wikipedia.org/wiki/Th%C3%A9or%C3%A8me_de_Bernoulli)

The closed system between x1 and x2 at t time and between x1+v1Δt and x2+v2Δt at t+Δt is used.
Being incompressible, the masse Δm (kg) is constant:

$$\Delta t.v1.A1.\rho = \Delta t.v2.A2.\rho$$

(3)

By conservation of the mechanical energy:

$$\Delta Ek + \Delta Epp = W\ (4)$$

(4)

With Ek kinetic energy (J), Epp potential energy (J), and W work (W)

$$\frac{1}{2}\Delta m.(v2^2 - v1^2) + \Delta m.g.(h2 - h1) = p2.A2.(v2.\Delta t) - p1.A1.v1.\Delta t\ (5)$$
$$divided\ by\ \frac{\Delta m}{\rho} = (A1.v1\Delta t) = (A2.v2\Delta t)\ (6)$$
$$P1 + \frac{1}{2}\rho v1^2 + \rho gh1 = P2 + \frac{1}{2}\rho v2^2 + \rho gh2$$

For a real fluid, energy losses from the friction between the fluid and the pipe is added, energy given by a pump is also added:

$$Pa + \frac{1}{2}\rho Ua^2 + \rho gza + \Delta Pmot = Pb + \frac{1}{2}\rho Ub^2 + \rho gZb + \Delta Ps + \Delta Pl \quad (5)$$

The Bernoulli formula is one of the most fundamental formula and principle of the fluid mechanics.

2) Venturi tube

Named after the Venturi effect, a physical effect discovered by the Italian scientist **Giovanni Battista Venturi** (1746-1822), the venturi tube is flow meter comprised of a convergent-divergent tube:

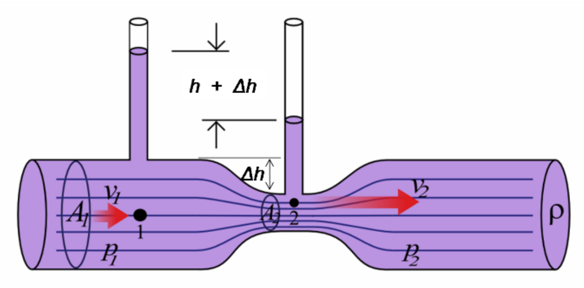


Figure 2 venturi tube (source: https://fr.wikipedia.org/wiki/Effet_Venturi)

The reduction of the section in the middle of the tube lead to a speed increase due to the flow rate conservation:

$$Qv_1 = v1.A1 = v2.A2 = Qv_2 \quad (6)$$

Qv_i flow rate in the point i in m^3/s

According with the Bernoulli formula the increase of speed reduce the pressure in the narrowing section.

Replacing the speed in the Bernoulli formula:

$$Pa + \frac{1}{2}\rho\left(\frac{Qv}{Sa}\right)^2 + \rho gZa = Pb + \frac{1}{2}\rho\left(\frac{Qv}{Sb}\right)^2 + \rho gZb$$

$$Pa - Pb + \rho g(Za - Zb) = \frac{1}{2}Qv^2\rho\left(\frac{1}{Sb^2} - \frac{1}{Sa^2}\right)$$

$$Qv = \sqrt{\frac{2\Delta P}{\rho\left(\frac{1}{Sb^2} - \frac{1}{Sa^2}\right)}} \quad (7)$$

3) Orifice plate

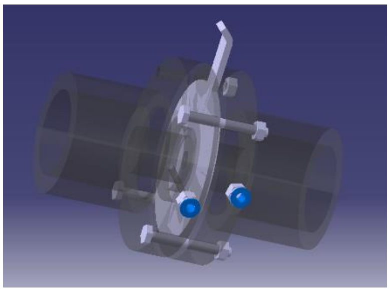


Figure 3 3D model of the orifice plate used on the bench

Alongside with the venturi tube, the orifice plate is a flow meter also based on the venturi effect, the orifice plate consist of a plate with a reduced section in the middle. Like the venturi tube, the flow rate passing through the orifice plate is given by the following formula:

$$Qv = \sqrt{\frac{2\Delta P}{\rho\left(\frac{1}{Sb^2} - \frac{1}{Sa^2}\right)}}$$

With B a point in the center of the reduced section and A a point upstream of B

However due to the form of the flow meter, the orifice plate generate much more disturbance in the circuit than a venturi tube. So, a correction coefficient is introduced:

$$Qv = Sb\sqrt{\frac{2\Delta p}{\rho(1-(\frac{d}{D})^4}} = CdSb\sqrt{\frac{1}{1-\beta^4}} * \sqrt{\frac{2\Delta p}{\rho}}$$

The Cd coefficient, coefficient of discharge (Cd=$\frac{Qvexperimental}{Qvtheoritical}$) is introduced due to the fact that the flow is disturbed by the plate and β=d/D is introduced with d diameter of the orifice (m), D diameter of the pipe (m).

By introducing the coefficient C, the formula is simplified:

$$Qv = C * Sb0\sqrt{\frac{2\Delta p}{\rho}}\ with\ \mathrm{C} = Cd\sqrt{\frac{1}{1-\beta^4}} \tag{8}$$

C is calculated with the Reader-Harris/Gallagher equation:

$$0.5961 + 0.0261\beta^2 - 0.216\beta^8 + 0.000521\left(\frac{10^6\beta}{REd}\right)^{0.7}$$
$$+ (0.0188 + 0.0063A)\beta^{3.5}\left(\frac{10^6}{REd}\right)^{0.3}$$
$$+ (0.043 + 0.080\exp(-10L1) - 0.123\exp(-7L1))(1 - 0.11A)\frac{\beta^4}{1-\beta^4}$$
$$- 0.031\left(M2' - 0.8M2'^{1.1}\right)\beta^{1.3} + 0.011(0.75 - \beta)(2.8 - \frac{D}{0.0254})$$

(9)

In this equation A= $\left(\frac{19000\beta}{REd}\right)^{0.8}$, M2'= $\frac{2L2\prime}{1-\beta}$ however in the case of a flange taping (the case here) L1=L2'=0.0254/D.

REd is the Reynolds number of the fluid in the pipe (see below).

4) Head losses

When a fluid is flowing through a pipe, or is in contact whit a solid, a friction is created due to the movement of the fluid, energy is dissipated in the form of heat. Head losses can be observed with the resulting pressure losses.

Those linear head losses(also known as major losses) follow the Darcy-Weisbach formula (named after **Henry Darcy** (1803-1858) and **Julius Weisbach** (1806-1871)) and based on the Prony equation (**Gaspard de Prony** (1755-1839):

$$\Delta Pl = \xi * \frac{L}{D} * \frac{1}{2} * \rho * Um^2$$

(10)

With ΔPl pressure loss in Pa, L length of the pipe in m, D diameter of the pipe in m and Um: flow speed in m/s, ξ is the head loss coefficient, it is calculated with 3 formulas:

- For a laminar flow, the Hagen-Poiseuille's law (named after **Jean Léonard Marie Poiseuille (**1797-1869) and **Gotthilf Heinrich Ludwig Hagen**(1797-1884) is used:

$$\xi = \frac{64}{Re}$$

(11)

- In a smooth pipe with a turbulent flow, the Blasius correlation (**Paul Richard Heinrich Blasius** (1883-1970)) is used:

$$\xi = \frac{0.316}{\sqrt[4]{Re}}$$

(12)

- In a rough pipe with a turbulent flow, the Colebrook-White's correlation (**Cyril Franck Colebrook** (1910-1997) and **Cedric Masey White** (1898-1993)) is used:

$$\frac{1}{\sqrt{\xi}} = -2log10\left[\frac{\varepsilon}{3.71D} + \frac{2.51}{Re\sqrt{\xi}}\right] \tag{13}$$

Where ε is the rugosity of the pipe in m.

Those are the 3 mainly used formula.

When a valve, an elbow… generally a singularity is placed in a hydraulic circuit, the interaction between the flowing fluid and the singularity result in energy losses which are characterized by pressure losses upstream and downstream of the singularity. Those singular head losses (also called minor losses) are ruled by the following formula:

$$\Delta Ps = \sum_{i=1}^{n} K_i * \frac{1}{2}\rho Um^2 \tag{14}$$

With K_i the singular head losses coefficient of the i^{th} singularity. And ΔPs singular head losses in Pa and n the number of singularity.

5) Internal flow

The behaviour of a fluid when moving inside a pipe can be characterized with types of flow like the Poseuille flow, the Couet-Plan flow. The main formula used to characterize those type of flows is the Navier-Stocks equation.

Currently, this equation do not have a generic form of solution, the solution we have can only be applied in some particular case, for the rest of the time, CFD software are encoded with the equation and calculate an approximation of the solution.

For a fluid flowing through a pipe, the regime of the fluid is described by the Reynolds number (Osborn Reynold (…)):

$$Re = \frac{\rho VLc}{\mu} = \frac{VLc}{\nu} = \frac{Inertial\ forces}{Viscous\ forces} \tag{15}$$

With Lc characteristic length of the solid (diameter for a pipe) in m, µ dynamic viscosity of the fluid in Pa.s, V speed of the fluid in m/s, ν cinematic viscosity of the fluid in m^2/s.

If the Re of the fluid in a pipe is below 1, the fluid is considered in Stocks flow, inertial forces of the fluid.

For Re below 2000 and greater than 1, the fluid is in a laminar flow: viscous forces are dominant, the fluid is characterized by a constant fluid motion. Energy given to the fluid is used to move particles in the direction of the flow.

For Re between 2000 and 4000, the fluid is in a transition flow: viscous forces are no longer dominant.

For Re greater than 4000, the fluid is in a turbulent flow, inertial forces are dominant, a part of the energy given to the fluid is used to move particles inside the fluid in different directions.

6) Aerodynamic forces

When a solid is moving inside a fluid (air or water for example) two major forces are created one opposed to the movement and another perpendicular to the movement.

The lift force is perpendicular to the movement, it is created by the pressure difference between two face of the same solid. This force is characterized by the following formula:

$$Fl = \frac{1}{2}\rho S V^2 Cl \tag{16}$$

With S wing surface (for an aircraft) or frontal area in m²; V speed of the solid in m/s Cl lift coefficient.

This formula is obtained empirically, the Cl is determined by the experience.

The drag force is opposed to the movement of the solid, its expression have the same shape as the lift force:

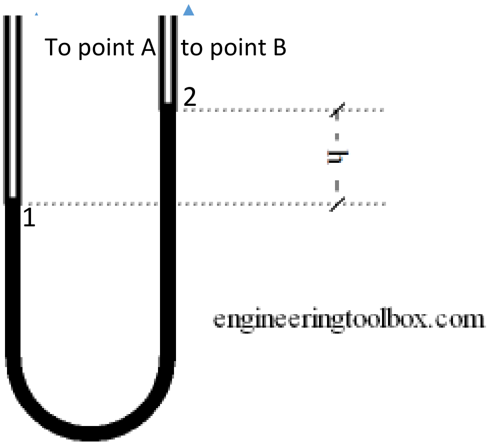
$$Fd = \frac{1}{2}\rho S V^2 Cd \tag{17}$$

This formula is also determined by the experience and Cd, the drag coefficient is determined by the experience.

Cd and Cl depend on the shape of the solid, and other of its physical parameters such as its rugosity.

Part II: review of the instrumentation required.

From the first topic (Bernoulli formula) to the last topic, a pressure difference come in the equations related to the topics, so that, a manometer will be used for each of this topic.
A U-manometer is the simplest manometer usable for the task, it operate by creating an altitude difference between two point of a fluid inside a U shaped pipe, each side of the U pipe is linked to a bench, thereby, when a fluid is flowing, in the pressure difference between the two point of the fluid inside the manometer can be linked to the pressure difference between the two point studied on the bench.



Between A and 1, and B and 1, the fluid is in static so:
$P1 = Pa + \rho g \Delta Za1 \text{ and } P2 = Pb + \rho g \Delta Zb2$

In most case, ΔZ is less than a meter so it can be neglected

Between 1 and 2, it is also static so:

$$\Delta P_{12} = \rho_{12} g \Delta Z_{12} = \Delta P_{ab} + \rho g(\Delta Za1 - \Delta Zb2)$$

In practice, $\rho \ll \rho_{12}$ so $\rho_{12} g \Delta Z_{12} = \Delta P_{ab}$

Figure 4 U manometer

Alongside U manometers, classic manometers will be used

For the topics on internal flows and head losses, alongside the pressure difference in the head losses topic, the speed of the flow is needed for the related formulas. In order to measure the speed of the flow, an axial or radial turbine can be used.
Those speed meters operate as follow: when the fluid encounter the turbine it rotate the turbine, the rotation speed of the turbine can be linked to the axial speed of the fluids. Those devices are quite expensive and can be applied on certain diameter of pipe, so a more economical solution is to use a pitot tube with manometers in order to have access to the speed, however the conception of the hydraulic bench is not compatible with the utilisation of a pitot tube. So the simplest solutions is to use a classic flow meter, with the flow rate formula, the section of the flowmeter, the speed of the fluid and the flowrate are linked together. More a rotameter is currently mounted on the bench in order to survey the flow rate, and an orifice plate and a venturi tube are mounted for experimental purpose, thereby the utilisation of one of those flow meter is the privileged solution.

For the topic on aerodynamic forces, the wind turbine of the laboratory will be used, in order to measure the air speed, like for the hydraulic bench, an axial/radial turbine can be used to measure the air speed, hot wire can also be used. The hot wire is alimented with a fixed current. When placed inside a flow, the hot wire will cool down with the movement of the fluid: its electrical resistance will change and the flow speed can be related to this change. Hot wire are simple and cheap system however they are inaccurate because hot wires are very sensitive to small change in fluid properties. A static Pitot tube (Prandtl tube) is a privileged solution. The Pitot tube work by comparing the static pressure and the dynamic pressure of a fluid, in order to compare the two pressure, a membrane can be used or a U manometer. A Pitot tube work like a U manometer.

Part III: 3D modelling of the bench

The 3D modelling of the wind tunnel originally planned has been deleted due to the fact the wind tunnel was already model when I started my internship.

In order to facilitate further modification of the bench and do theoretical calculation on it, a 3D model of the bench have been created. With this 3D model, any modification can be applied on the 3D model in order to adjust them.

The model have been created with the Dassault Systèmes CAD software CATIA V5. In order to facilitate the creation, the bench have been divided in small part, each part have been modelled on CATIA. Thereby, the virtual assembly of the bench is quite close to the real assembly of the bench and it facilitate and speed up the assembly process, it also make the model highly modular and precise.

The simplest piece of the bench are created from a single bloc of matter, due to the fact that the internal details of the bench are not relevant (like the internal component of a valve), some complex piece can be created from one bloc:

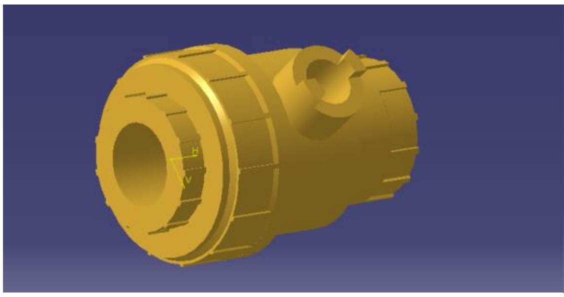


Figure 5A A complex piece in one bloc

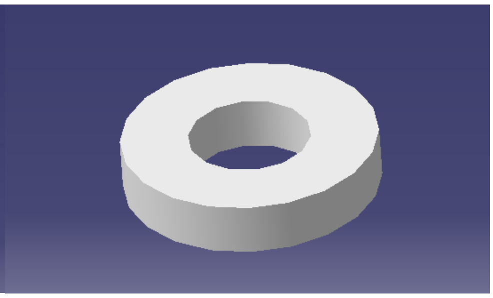


figure 5B A simple piece in one bloc

However some component of the bench are too complex to be reduced in a 1 bloc piece, so part where created in order to maintain the simplicity of the final assembly and also maintain the modularity of the model and its close rendering:

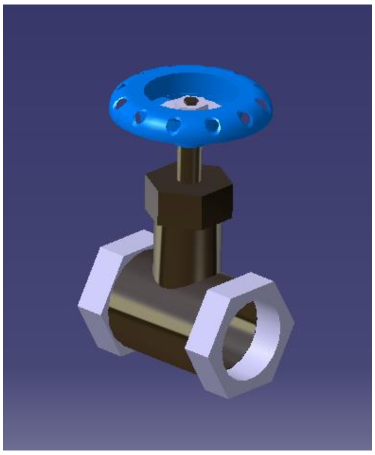


Figure 6 A complex piece of the bench

The final assembly of the bench only require to load every piece on a product file (.CATProduct) and put every constraints between each pieces in order to give a structural integrity to the bench.

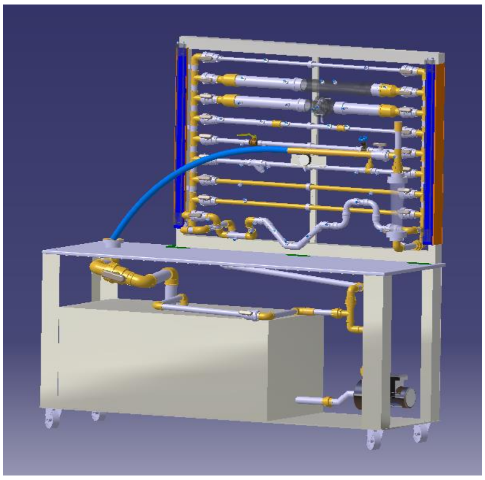


Figure 7 3D model of the bench with modifications

Part IV: Formulation of experiments

In order to make the bench fully operational, experiments have to be designed in order to fulfil its purpose. With the help of Professor Noleto, I designed ten experiments which can be performed on the HD98B bench.

In order to create experiments, I draw inspiration from the experiment created by Professor Menet for the fluid mechanic experiment of the Mechanic and Energy division of the ENSIAME. The experiment were made in order to highlight specific point of fluid mechanic, they are related to the topics listed previously.

The experiments were designed according to the requirement given by Professor Noleto, each experiment feature the following sections:

- Presentation, a short paragraph were the goal of the experiment is explained;
- Theories, all of the theories needed in the experiment are reported in this section;
- Material, this section feature every tools and systems required for the experiment;
- Protocol, a series of instruction aimed to guide the experiment;

Ten experiment were made for the hydraulic bench:

1) Flow meter comparison
   see annexe I

The goal of this experiment is to criticize the use of one flow meter over another one. In this experiment, the three flowmeters equipped on the bench are compared in terms of singular head losses in order to determine which one is the best suited.

2) Head losses
   see annexe II

In this experiment, is quite simple and is designed to show the phenomena of head losses. 3 pipes are used, the pressure losses in each pipes is measured in order to determine head losses inside it. After that the head losses of each pipes are compared.

3) Hydraulic resistance
   see annexe III

The purpose of this experiment is to show the effect of hydraulic resistance: $Rh = \frac{\Delta P}{Qv}$ (18) with Rh the hydraulic resistance of the pipe in $Pa.m^{-3}.s^{-1}$. In practice the more high the hydraulic resistance is, the more difficult the fluid will flow through the pipe. In this experiment hydraulic resistance of different pipes are compared. A comparison between the experiment and the theory for a Poiseuille flow is also conducted in this experiment.

4) Comparison of experimental head losses and theoretical ones
   see annexe IV

The experiment require the student to measure head losses in pipes of different diameters and extract the head losses coefficient of each pipe and compare it to the theoretical one following the Blasius formula, the Poiseuille formula and the Colebrook-White formula depending the type of pipe used and the flow regime of the fluid.

5) Technical solution comparison
   see annexe V

The goal of the experiment is to show the different impact of similar devices on a hydraulic circuit. The experiment require to measure head losses for different singularity that achieve the same goal: An n shaped part of the circuit, a v shaped one and a u shaped one.

6) Valve authority
   see annexe VI

This experiment show authority of a valve on a regulated pipe, the authority of a pipe is defined by: $\frac{head\ losses\ valve}{head\ losses\ vale + head\ losses\ pipe}$. (19)

In order to be effective, a valve shall have an authority close to 0.5 or higher: head losses generated by the valve have to be the same as the on generated by the regulated pipe. An authority below 0.25 is unacceptable, between 0.25 and 0.5 the valve is effective.
In this experiment, different valve's authority are compared with the pipe they are equipped one and other pipe.

7) Singular head losses for laminar and turbulent flow
see annexe VII

The goal of the experiment is to show the difference between singular head losses in a laminar flow and in a turbulent flow. The venturi tube and the orifice plate are used because they are made of a transparent material that allow to visually check the flow regime of the fluid.

8) Flow meter behaviour in turbulent and laminar flow
see annexe VIII

The aim of the experiment is to highlight the behaviour of the venturi tube and the orifice plate in a turbulent flow, the value given by the flow meter are compared to the ones given by the rotameter which are supposed to be the true value.

9) Power of the pump
see annexe IX

This experiment has been designed to determine the power of the pump used on the bench, depending of the altitude of the used pipe. In order to do so, different pipes are opened, one at the time and the pressure entry of the pipe is measured. The power of the pump used to move the fluid can be determined by using the Bernoulli formula (the required requirement are supposed to be valid):

$$Pa + \frac{1}{2}\rho Ua^2 + \rho gza + \Delta Ppump = Pb + \frac{1}{2}\rho Ub^2 + \rho gZb + \Delta Ps + \Delta Pl$$
$$\Delta Ppump\ is\ the\ pressure\ \text{given}\ by\ the\ pump, thereby$$
$$Ppump\ used = \Delta Ppump * Qv$$

Ppump is the power of the pump in W (20)

10) Critical Reynolds number
see annexe X

This experiment attempt to determine the Reynolds number critical for the fluid: this number is reached when the laminar flow become a transition flow. To do so, student have to measure the pressure difference in the venturi tube in order to achieve a laminar flow and then increase the flow rate in order to reach the critical Reynolds number. The transparent materials of the venturi allow to visually check the regime of the fluid.

PART V: modification of the bench

In order to realise some of the experiments, the HD98B Hydraulic bench have to be modified. The changes are mostly additions of pressure connectors in order to gain access to certain pressure in the hydraulic bench.

The first modification was the additions of two pressure connectors on the venturi tube, in order to measure the head losses induced by this device. In order to achieve that, the pressure connector have been placed upstream and downstream of the venturi tube, another pressure connector has been placed in order to measure head losses of the 40mm diameter pipe, it has been placed at a certain distance of the entry valve in order to not include turbulence from this singularity.

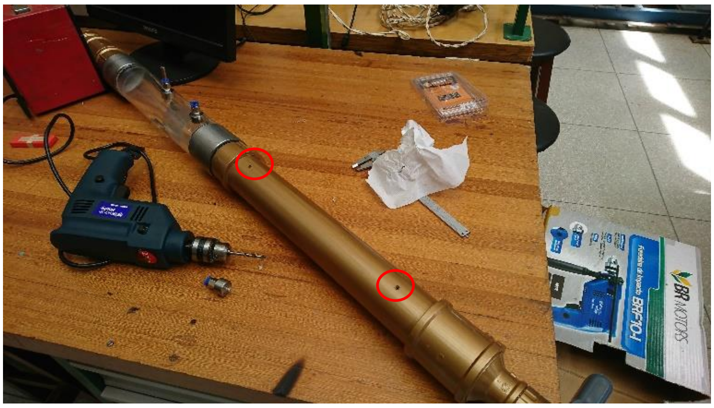


Figure 8 change on the venturi tube pipe note the connector's hole circled in red

The second modification operated on the bench was quite similar to the first one, the goal was to measure the head losses of the orifice plate. Two pressure connector were installed upstream and downstream of the orifice plate in order to achieve the same goal as the ones on the venturi tube pipe.

Figure 9 changes on the orifice plate pipe, the connector's hole are circled in red

Pressure connectors are also placed on the upstream pipe in order to replace the one on the venturi tube if the tube was malfunctioning.

The last modification was the addition of a pressure connector downstream the rotameter in order to measure the head losses created by this device.

PART VI: Set up of automated measure

1) Automated measure on the hydraulic bench

In order to facilitate the measure on the hydraulic bench, an automated measure device can be placed alongside the bench for experimental purpose.

The device used is PASCO PS-2164 quad pressure sensor, this device was already used in the laboratory for experiment on venturi effect. The device is a pressure sensor with four entry, it is linked to a computer by USB cable. The USB cable is used to transfer information between the computer and the pressure sensor, and it also used to power the sensor.

Figure 10 PASCO PS2164 quad pressure sensor

In order to operate the sensor, the PASCO Capstone software is used. This software allow the operator to collect measure from the quad pressure sensor and put them in a table, it also allow to operate different operations on those readings. More, the software is the only way to calibrate the quad pressure sensor. Due to the fact that the sensor is powered by the computer, the calibration must be done every time the sensor go offline.

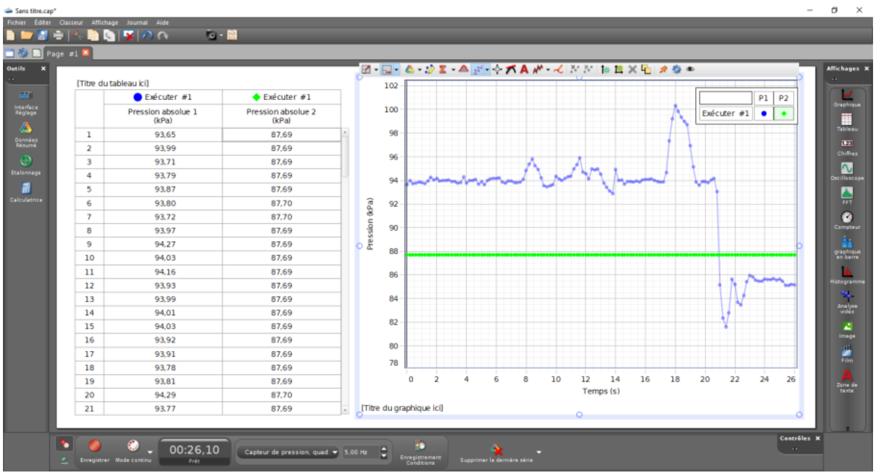


Figure 11 PASCO Capstone software

The quad pressure sensor allow more precise measure of the pressure, the quad pressure sensor is connected to the bench with the standard tube equipped with a pressure connector. This simple method allow an easy plug-in of the bench tubes and assure a good sealing between the two tubes.

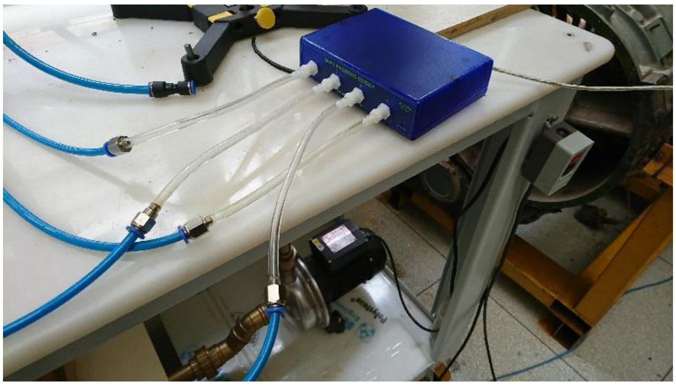


Figure 12 quad pressure sensor connected to the bench

2) Automated measure on the wind tunnel

For the wind tunnel, the measure needed are the air speed inside the wind tunnel, the pressure and the couple lift and drag force of the model tested inside the wind turbine.

In order to measure the air speed inside the wind tunnel, the overall speed in each section can be determined with the flow rate conservation. The wind tunnel only have a switch on the motor so the overall speed is independent of the model tested. By measuring the angular speed of the fan, we can determine the overall speed in each section. To be more precise, the speed in a particular point can be determine with a Pitot tube, this tube can be linked to the quad pressure sensor in order to automate the measure and the readings.

The pressure measure inside the wind turbine will also rely on the quad pressure sensor. However, in order to measure the pressure and the speed a modification of the wind turbine is needed: an aperture must be created in order to pass cable of the quad pressure sensor inside the wind turbine. Specific model have to be designed in order to incorporate the pressure sensor inside.

The lift force and the drag force do not require the quad pressure sensor. This two force can be measured with a bench designed for it: the measure systems is comprised of an iron bench in the shape of a U, a metal rod cross the support, it is used to support any model. This metal rod is fixed to two metal bloc free of movement, those two blocs are linked to the metal support by strain gauges.

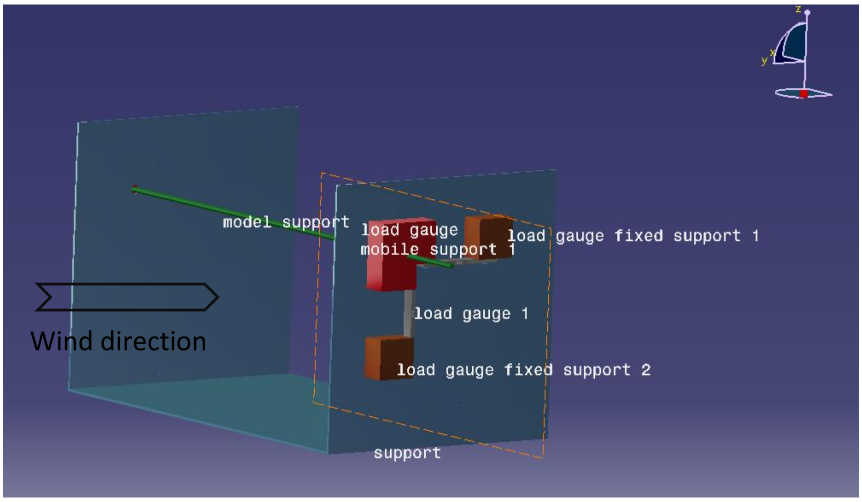


Figure 13 3D model of the sensor

One of the drawbacks of this device is it can't measure the lift force and the drag force at the same time, in fact, when the lift forces strain gauges are put in place they prevent the translation of the model induced by the drag force, and when the drag force strain gauges are put in place, in the same way, the lift force induced translation is prevented by the strain gauges.

The strain gauges uses small resistance glued on a specific support, when the support is stretched, the resistance will become longer or shorter (depending of the deformation applied on the gauge strain support), thereby, the linear resistance of the glued resistance will change according to the Pouillet's law (**Claude Servais Mathias Pouillet** (16 February 1790 - 14 June 1868)):

$$R = \rho \frac{l}{A} \tag{21}$$

With R resistance of the conductor in Ω, l length of the conductor in m, A internal area of the conductor in m², and ρ the electric resistivity in Ω.m.

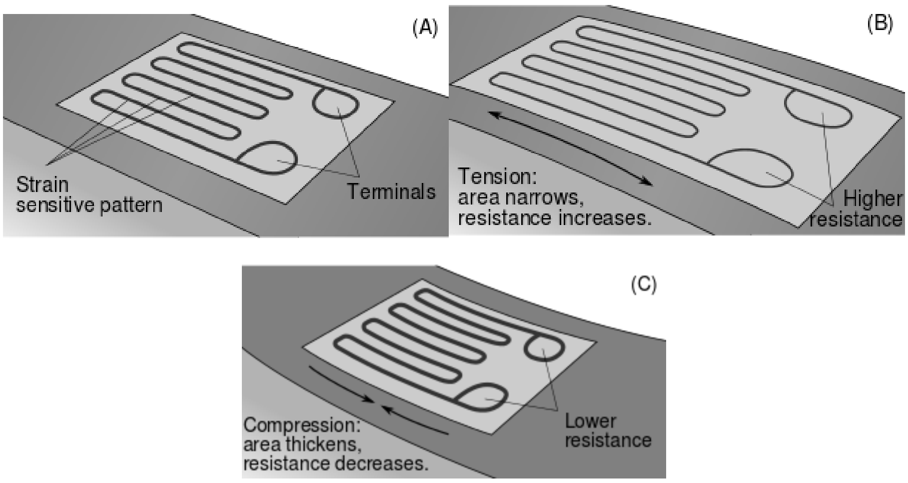


Figure 14 strain gauge principle (source: https://en.wikipedia.org/wiki/Strain_gauge)

The resistance change is usually measured with a Wheatstone bridge. The bridge would be built inside a control unit linked to computer in order to process the data from the strain gauges.

As an example, Phidget CZL616C load gauge can be used, those gauges have a maximum weight capacity of 780g, according to the constructor. Using the gravitational force formula: $\vec{F} = m\vec{g}$ with F in N, m in kg and g in m.s^{-2}, the maximum force supported by those gauges is 7.6518N. For a model of wing, this type of gauge are sufficient, however, if stronger gauges are required, Phidget produce gauges supporting up to 50kg in maximum weight, the maximum force is 490.5N.
The Phidget 1046 Bridge can be used to control the load gauges. A control software from Phidget is also required in order to control the equipment from a computer.

Figure 15A Phidget 1046 bridge (www.phidgets.com)

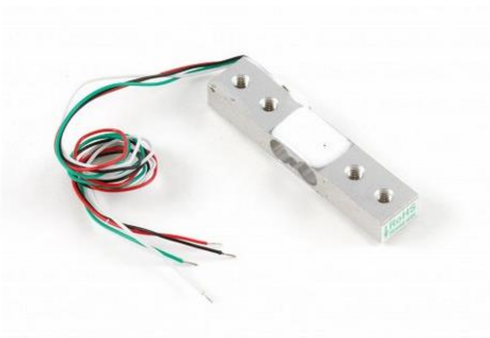


Figure 11B Phidget CZL616C load gauge (www.phidgets.com)

PART VII: Result of the experiment on the bench

Two set of experiment were made on the hydraulic bench, one with the already equipped U manometers and the other one with the PASCO PS-2164 unit. This two set were made in order to prove that the experiment were achievable on the bench. It also served as a test for the every devices used for the bench.

1. flow meter comparison

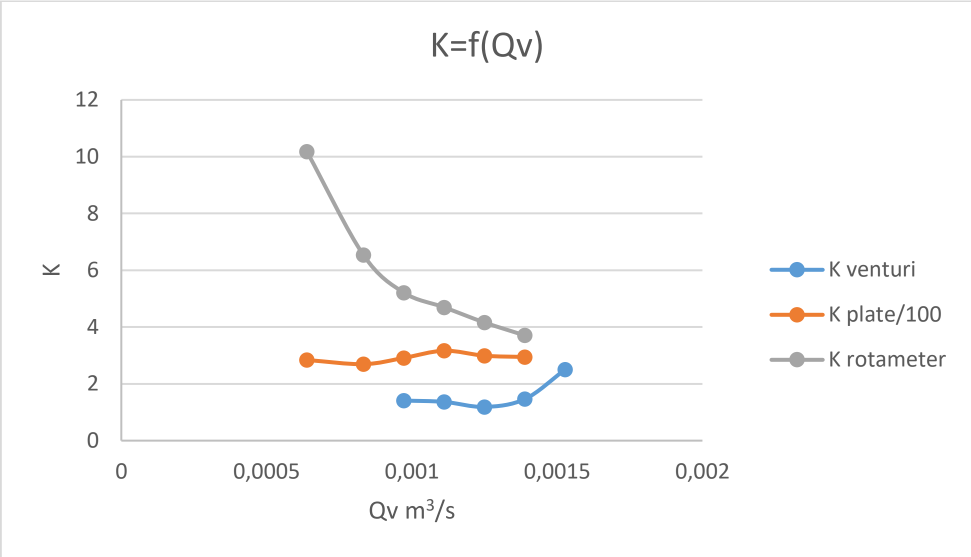


Figure 16 flow meter comparison with the quad pressure sensor

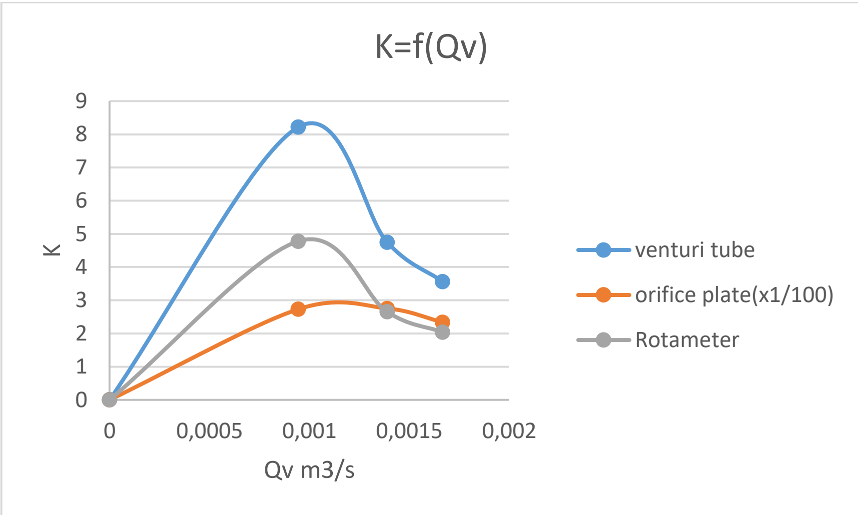


Figure 17 flow meter comparison with the embedded instrumentation

The comparison between the flow meter prove that the venturi tube have a smaller impact on the circuit, the rotameter is in second place, the third place for the orifice plate could have been predicted due to the shape of the flowmeter itself: the plate reduce considerably and abruptly the flow of water. For the experience realized with the U manometers, the head losses of the flow meter is reduced when the flow rate increase, despite multiple attempt of the experiment, the same result happen. In the other and, the quad pressure sensor show are more logical result (except for the rotameter) the head losses of the flow meters seems to be constant. Those results came from the pressure connector, affected by the close presence of singularity (close presence of a T singularity)

2. Head losses

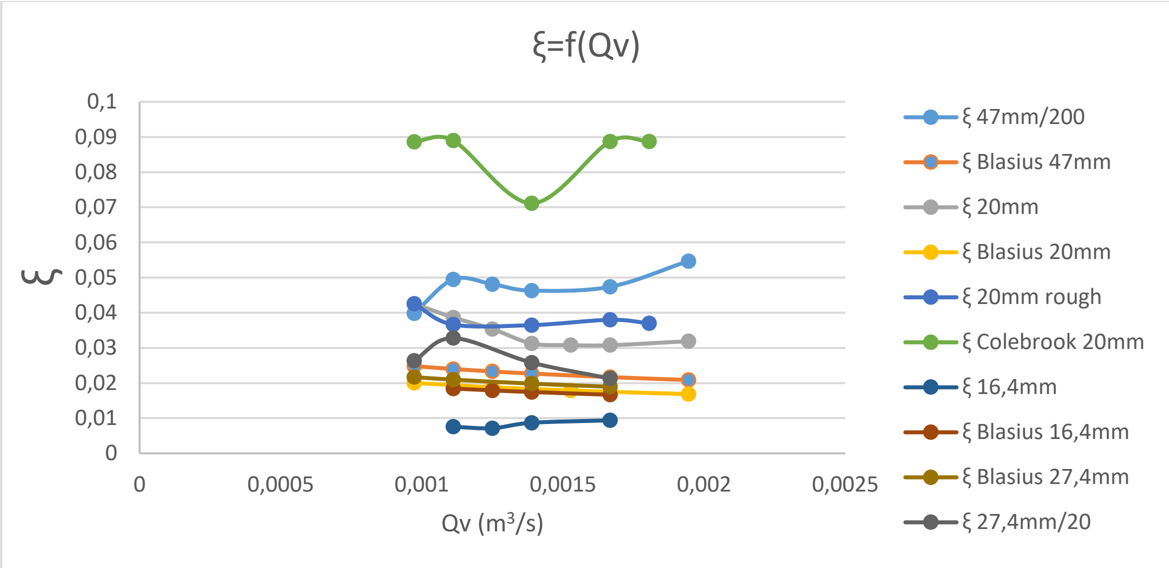


Figure 18 linear hed losses coefficient measured with embeded devices

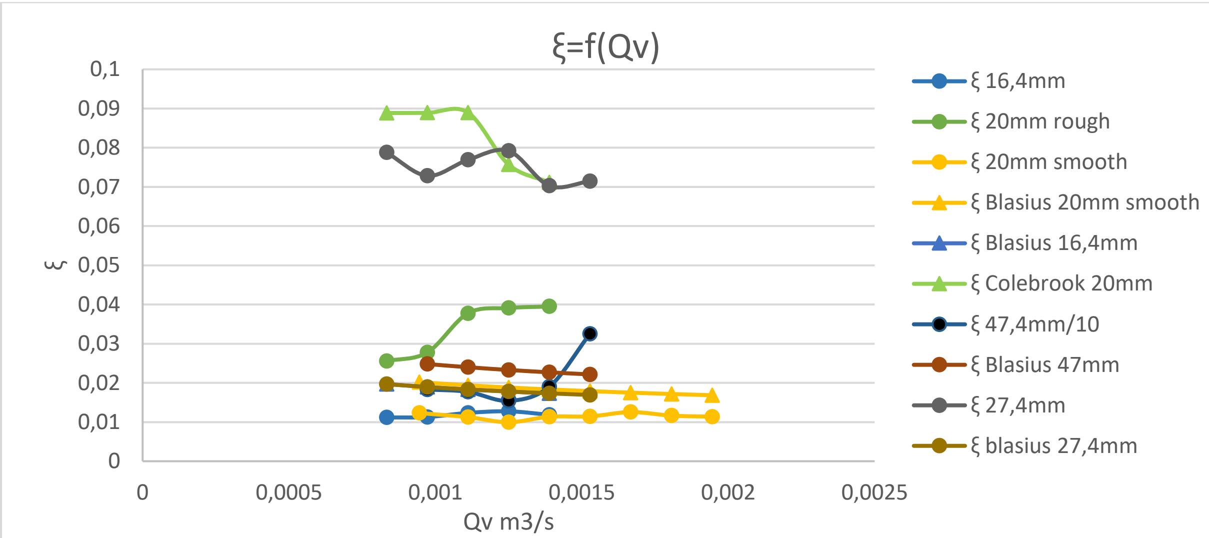


Figure 19 linear head losses comparison with quad pressure sensor

Whit this result, we can see that the 47.4mm pipe is in violation of the Blasius formula with each device, the 27.4mm pipe is also in the same condition. This can be a result of the placement of the pressure connector, the proximity with a singularity (the entry valve for the 27.4mm pressure connector and the pipe enlargement for the 40mm pressure sensor) can be altering the flow in this way. This theory can be supported by the fact that the 27.4mm pipe and the 47.4mm pipe are the only pipes with this pressure captor placement.

The second conclusion on the comparison of the two measuring systems is that the U manometers seem the overestimate the pressure losses due to the fact that every experimental ξ coefficient is above the one given by the Blasius formula related.

3. Hydraulic resistance

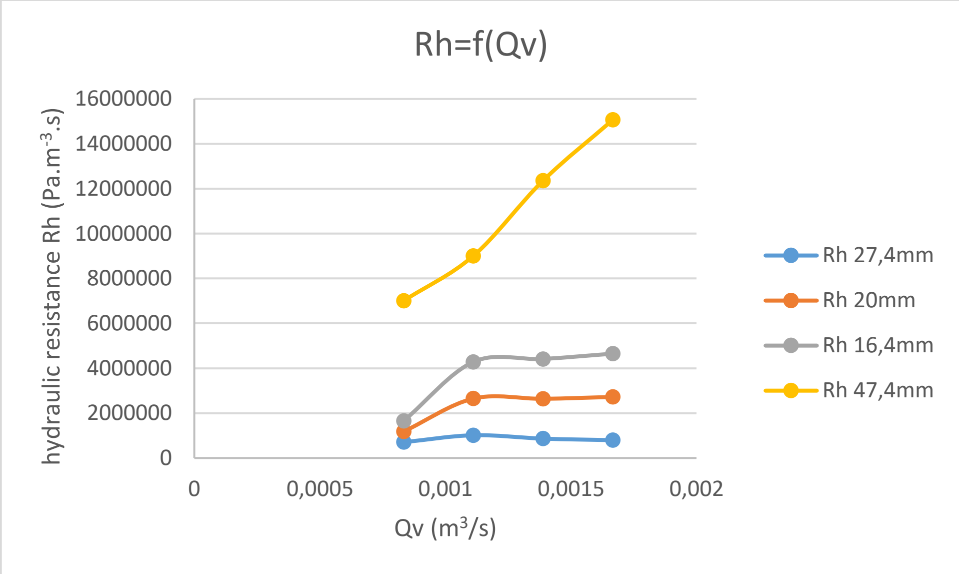


Figure 20 hydraulic resistance comparison of different pipes

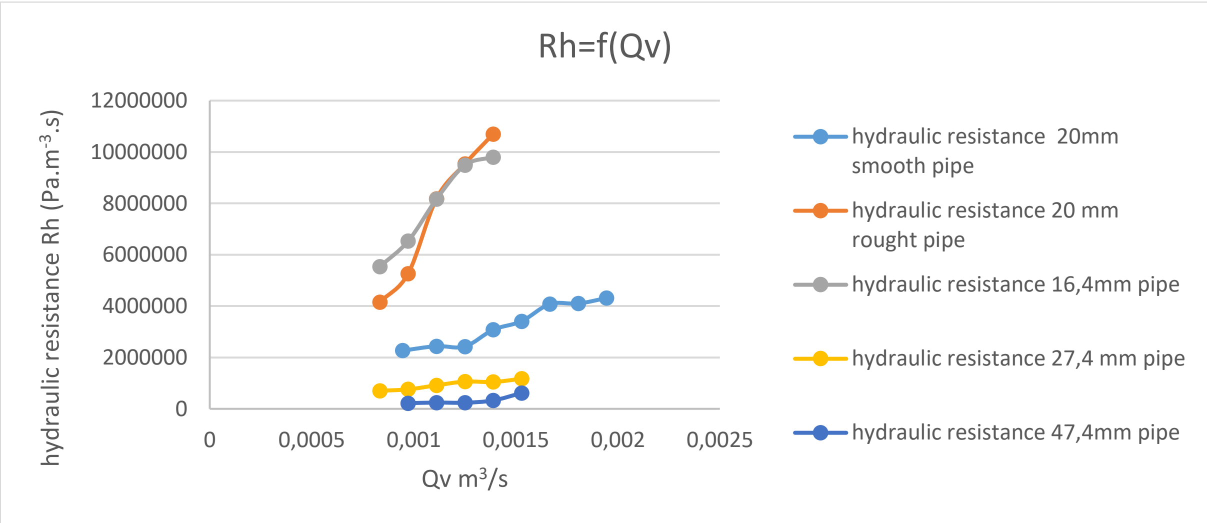


Figure 21 hydraulic resistance comparison with the quad pressure sensor

The measure realised with the quad pressure sensor are close to the expected result: we can see that the more important is the diameter, the lesser is the hydraulic resistance. The measure realised with the embedded equipment does not show this expectation for the 47.4mm pipe. More the values of the experiment made with the U manometer seem a bit overestimated. Thereby, the quad pressure sensor is more appropriate in regard to the conclusion: the expected result are present within the experiment.

4. Comparison of experimental head losses

With the result displayed in the 3rd experiment, we can see that the Blasius formula is followed however, in laminar flow, the Poiseuille's formula is not respected. This is mainly due to the fact that the laminar flow is not reached, despite the efforts to reduce the flow rate in the pipe, the lowest flow rate reached during the experiment is beyond the maximal flow rate for a laminar flow.

5. Technical solution comparison

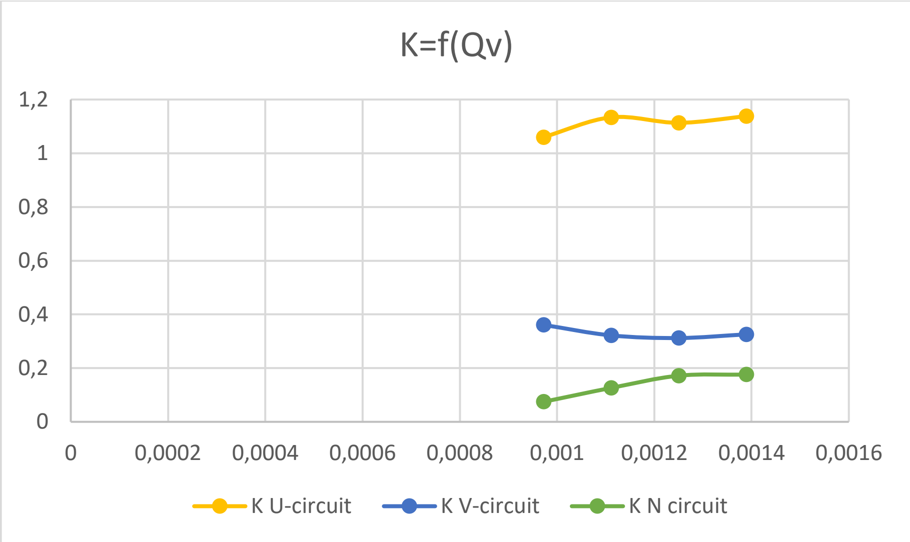


Figure 22 cicuit comparison with the quad pressure sensor

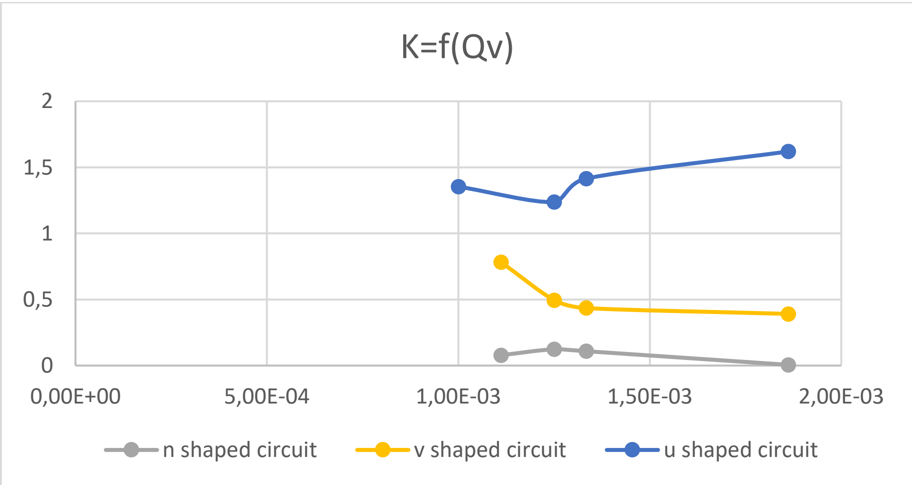


Figure 23 solution comparison with the U manometers

The result indicate that the U shaped circuit generate more head losses in the circuit than the two other circuit.

6. Valves authority
   see annexe XI

Following the realisation of the experiment, the average authority measured for the blue valve was 0.5185 which is quite close to the 0.50 of an efficient valve. For the yellow valve, the average authority is 0.162, not enough for the 20mm pipe where the valve is plugged. The comparison with other pipes showed that this valve is best suited on a 16.4mm pipe (the average authority is 0.443).

7. singular head losses for laminar and turbulent flow
see annexe XII

The two set of experiment resulted in close result for the head losses coefficient of some singularity on the bench for the experience performed with the embedded equipment, the head losses coefficient measured for the 90° elbow, the 135° elbow and the 90° long elbow is respectively: 0.4837, 0.2664, and 0.087. For the other experience, the result are for the same singularity are respectively: 0.3993, 0.1784, and 0.0808.

8. Flow meter behaviour in turbulent and laminar flow

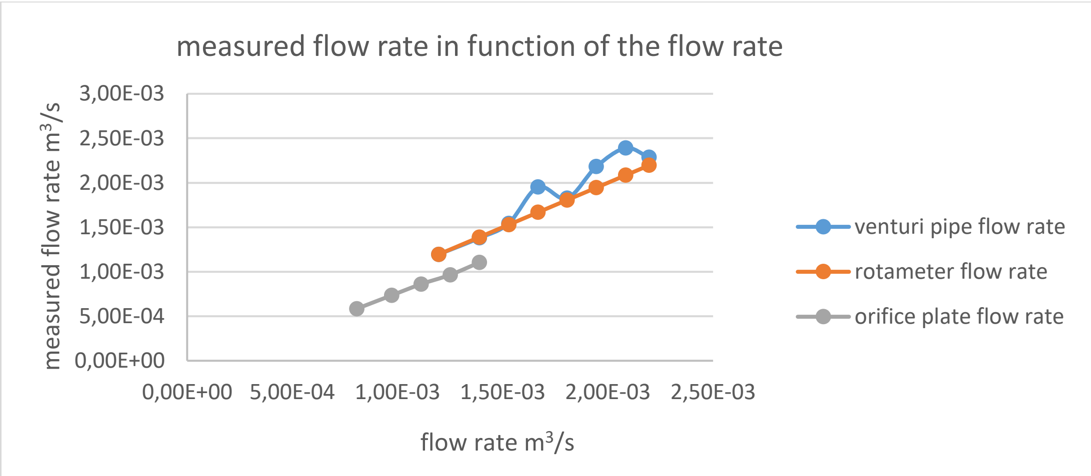


Figure 24 flow rate comparison measured with U manometers

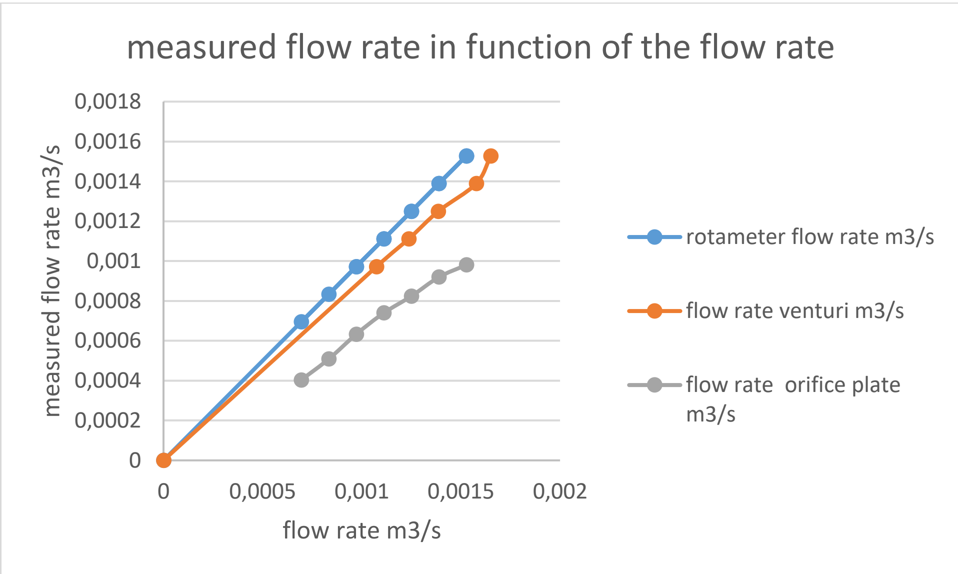


Figure 25 flow rate comparison measured with the quad pressure sensor

The experiment demonstrated in both case that the venturi tube is closer to the rotameter than the orifice plate in terms of accuracy. In both case the orifice plate will underestimate the flow rate. For the experiment performed with the U manometers, the venturi tube seems to overestimate the flow rate when it goes beyond 0.0015m^3/s, the same point on the second graphic indicate the venturi tube stay close to the rotameter. The last point of the experience done with the U manometer, indicate a value close to the one given by the rotameter. Therefore, the overestimated value can be the result of a malfunction of the U manometer, or a misreading.

9. Power of the pump

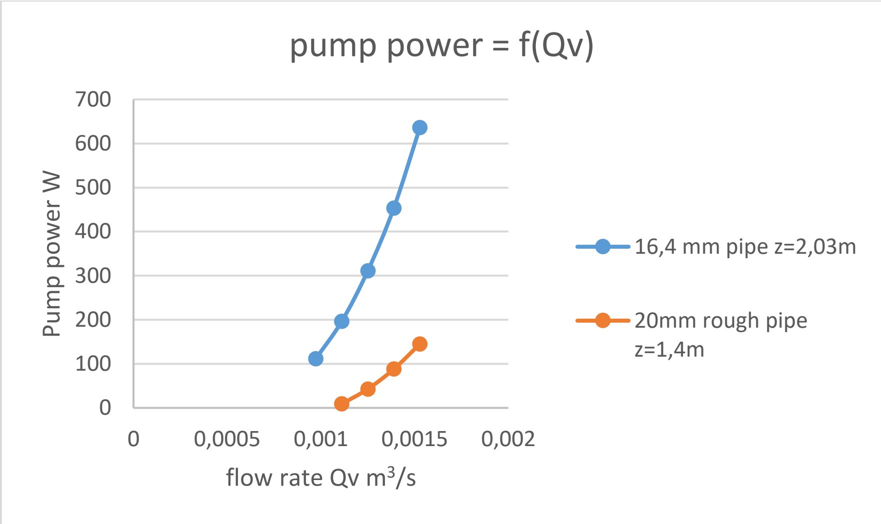


Figure 26 pump power determined with the quad pressure sensor

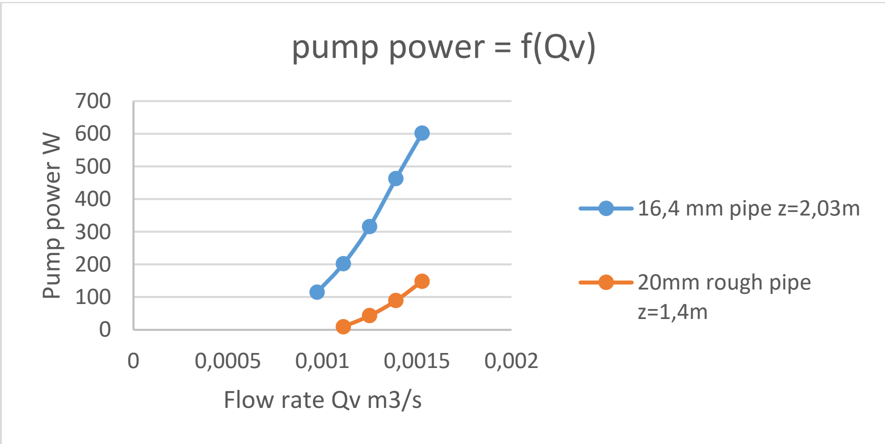


Figure 27 pump power determined with embedded manometers

The two experiment produced the same result, we can conclude that the pump is adapted to the bench due to the fact that the power needed to put in motion the fluid in the higher pipe at a high flow rate is under the power of the pump (750W). As expected, the power increase when the altitude increase. Alongside the more hydraulic resistance there is, the more power is needed.

10. Critical Reynolds number

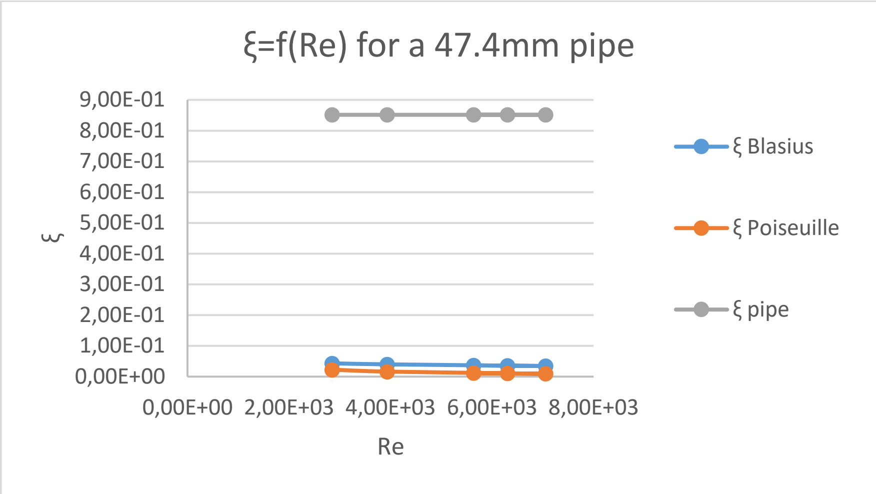


Figure 28 Critical Reynolds number determination with the quad pressure sensor

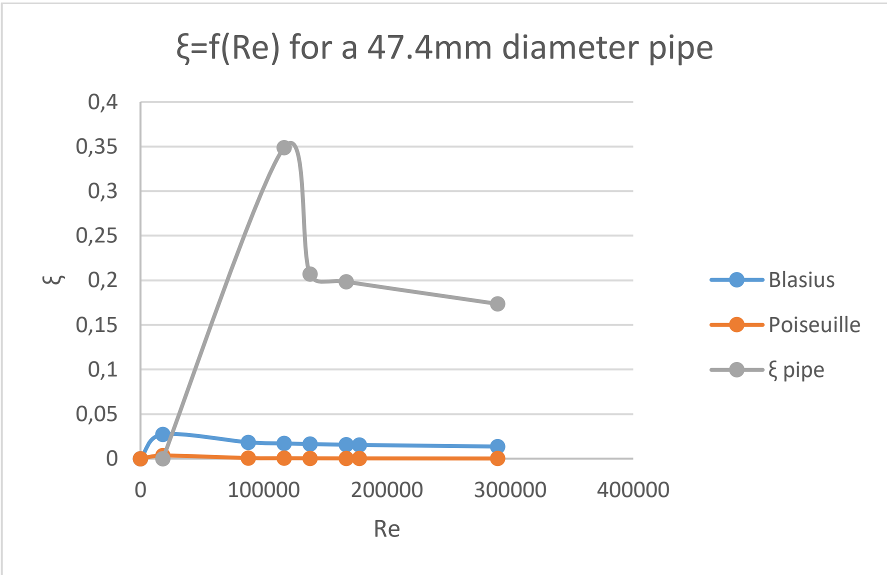


Figure 29 determination of the critical Reynolds number with U manometers

In both case the critical Reynolds number is not found with the measure however a visual check of the venturi tube placed downstream the 40mm pipe indicate a laminar flow for the lowest flow rate. Therefore we can suppose that the critical Reynolds number for this pipe is around 2850.

Part VIII: Conclusion of the results

At the light of the precedent result, the quad pressure sensor is clear for utilization on the bench, the results found with U manometers and the other manometers on the bench are close to the ones given by the quad pressure sensor. Thereby its utilization seems to be better, contrary to the U manometers, the sensor is not disturbed by the initial filling of the tested pipe by water. For the U manometers, some water go inside the linking tube of the manometer and alter the results. The only drawback of the quad pressure sensor is that it need a computer to run and a specific software. The proximity to the bench and therefor water projection will imply to take precautions. More the software used with the quad pressure sensor is not free of charge, so a license have to be bought in order to use it (a trial version of Capstone was used during the internship).

The vast majority of the experiment designed previously can be performed on the bench. However the experiment involving the critical Reynolds number seems to be more complicated to properly realise. For the problems encountered on the venturi tube's pipe, the problems come from the position of the pressure connector: to close to a singularity. This problems could have been prevented by placing the pressure connector away from the singularity however, by doing so the length between the two pressures connectors needed to measure the head losses of the pipe would have been reduced. Therefore, the head losses inside the pipe would have been very low and could have been impossible to measure with U manometers or could have been too low for a good reading with the quad pressure sensor. Indeed a too low pressure losses reading would have been parasitized by the electronic noise of the quad pressure sensor.

A laminar flow inside the 47.4mm pipe is created by opening another pipe and closing the entry valve of the 47.4mm pipe. This increase greatly the perturbation generated by the entry valve, this perturbation maybe a factor of the wrong pressure measure. A solution to this is to completely open the entry valve and reduce the flow rate inside the 47.4mm pipe by opening other pipe in order to divide the flow rate at the entry of the hydraulic bench. This solution was the first one tested, even with all the 9 pipes of the bench fully open, the flow rate needed at the hydraulic bench entry is about 2400 liter per hour, which is too low for the pump.

The flow rate can be controlled at the exit of the hydraulic bench by using a control valve. However doing so increase the overall pressure inside the bench and disturb the readings of the U manometers and those of the quad pressure sensor leading to false results. Therefore, the regulation of the flow rate by using the entry valve of the studied pipe is the more suitable solution for creating a laminar flow inside a pipe.

The utilization of an electronic device like the quad pressure sensor provide more reliable and precise result. The U manometers in their current form are not suitable for experiment involving high Reynolds number, the for example, in the 16.4mm pipe a to high flow rate leads to a high pressure losses, this entails the filling of the manometer by water (fluid currently used on the hydraulic bench). An alternative to using the quad pressure sensor is to fill the manometers with a heavier liquid (like mercury). Likewise, experiment involving too low pressure losses cannot be performed with U manometers due to the fact that the pressure losses will not be measured by the manometer. A solution is to fill the manometer with a lighter fluid (like oil). However those to solution specialize the manometer so it would be wise to let the manometer in the current form and use alongside embedded manometers and the quad pressure sensor.

Chapter III: General conclusion

Part I: Conclusion of the experimental set up

After 4 months working on the bench, the experimental set up of the bench is now finally complete.

The hydraulic bench has been set up following the following steps:

- A research of the basic theories needed in order to perform any work on the bench, and create content related to the bench;
- The creation of a 3D model in order to modify the bench without any cost and study the feasibility of the proposed modification;
- The creation of 10 experiment which can be performed at the bench.

In order to continue the work already performed one the bench, one can thing about a modelization of the internal flow inside the 47.4mm pipe. More in order to make the creation of a laminar flow, one can work on the implementation of a regulation on the water pump.

The added value of this work to the UnB Gama, is now the hydraulic bench will be useful and will help teachers to illustrate basic of fluid mechanics. It could also be used to conduct more specific experiment.

Part II: Personal conclusion

This internship helped me develop my communication skills, by working with other student and presenting my advancement and my ideas to my industrial tutor. My redaction skills were also developed, by writing this report and several advancement report to my academic tutor. All the work was performed by myself with advises and review by Professor Noleto, so I was able to learn about the complexity of such project and assume every aspect of it from the successes to the failures in the end it helped me become more autonomous. It was also a good way to directly apply my knowledge of fluids mechanics and see how the reality respond and why the theory was wrong. This internship helped me refine my professional project to a more conception oriented one.

The difficulties I encountered where principally made of a language boundary between me and other actors, some of the persons that helped me during the internship were not English speakers so I was forced to adapt to this situation. The resources needed for my work were sometimes not available in the laboratory, so I was forced to think twice for some of my problems in order to find solution inside the laboratory and avoid expenses.

The most important difficulty was to create a laminar flow on the bench despite my best effort, I wasn't able to correctly measure the pressure when the fluid was in a laminar flow due to the previously cited problems with the 47.4mm pipe.

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Table of annexes

Annexe I:

Experiment n°1:

Flowmeters comparison

Objective

The purpose of this experiment is to compare three different solutions for the measurement of a flow rate. The fluid used here is water,

The three flowmeter are: a venturi tube, an orifice plate and a rotameter.

Singular head losses of each flowmeter will be determined.

Description of the installation

The installation used is the HD98B hydraulic bench. Only two pipe will be used: the one with the venturi tube and the one equipped with the orifice plate.

The hydraulic circuit is supplied by water from the tank. The water goes first in the vertical part of the bench, then in the venturi tube or the orifice plate (depending of the pipe used), and finally goes in the rotameter.

The venturi tube is a flowmeter based on the venturi effect, it is basically a convergent pipe linked to a divergent pipe.

The orifice plate is a plate white a hole in the center that allow the fluid to pass it.

The rotameter is a graduated tube similar in shape to a venturi tube, inside the rotameter is a float shaped like whirligig, the ascending flow maintain the float at a certain altitude and give it a rotational movement. The shape of the tube and also the weight, the shape and the dimensions of the float are combined in order to maintain the head losses only a function of the flow rate. The reading is conducted at the top of the float.

Theories

The flow is supposed permanent, adiabatic and incompressible. Between two point 1 and 2 in a pipe we can apply:

- Flow rate conservation:

$$Qv=S_1U_1=S_2U_2$$

- Bernoulli formula:

$$P1+\frac{1}{2}\rho U1^2+\rho gz1+\Delta Ppump=P2+\frac{1}{2}\rho U2^2+\rho gz2+\Delta Ps+\Delta Pl$$

- Head losses:
  Head losses are consequences of the actions between the water and pipe, the friction between the water and the pipe result in a loss of pressure. The formula used to calculate singular head losses (minor losses) is:
  $\Delta Ps=K*\frac{1}{2}\rho Um^2$ K singular head losses coefficient.

Experiments

a) Purge the pipes liking the bench to the manometers;

b) Check if the exit valve (large valve below the bench) is open;

c) Open the flow control valve;

d) Open the two valve of the desired pipe;

e) Connect the manometers to the pressure connectors upstream and downstream of the flow meter;

f) Activate the pump;

h) Change the flow rate by opening or closing the small valve below the bench

Pick up the value of Δh and determine the head losses coefficient of each flow meter.

Conclude on the efficiency of each solutions

Annexe II:

Experiment n°2

Head losses comparison

Objectives

This experiment is designed to highlight head losses in pipe. 3 pipe will be used, the pipe n°1, 7 and 8. Linear head losses will be determined for each pipe in laminar and turbulent flow and the correspondence with the following laws will be stressed.

Description of the installation

The three pipes are different each other: the first pipe has a diameter of 16mm and is a smooth pipe, the n°7 pipe is a 20mm diameter, ribbed pipe. The n°8 pipe is a 20mm smooth pipe. The distance between the two pressure connector is about 77 cm.

Theories

The fluid is supposed in a permanent flow, adiabatic and incompressible. Between two points 1 and 2 in a pipe, head losses can follow the Darcy-Weisbach formula:

$$\Delta Pl = \xi * \frac{L}{D} * \frac{1}{2} * \rho * Um^2$$

The coefficient ξ depend on the flow of the fluid:

Laminar flow: $\xi = \frac{64}{Re}$ Poiseuille Formula

-Turbulent flow in a smooth pipe: $\xi = \frac{0.316}{\sqrt[4]{Re}}$ (Blasius fromula)

-Turbulent flow in a rough pipe: $\frac{1}{\sqrt{\xi}} = -2log10\left[\frac{\varepsilon}{3.71D} + \frac{2.51}{Re\sqrt{\xi}}\right]$ (Colebrook formula)

The flow regime is defined by the Reynold’s number: $Re = \frac{\rho UD}{\mu} = \frac{UD}{\nu}$ U average speed in the pipe (m/s), D diameter of the pipe (m).

In hydraulic, linear head losses i is used: i=$\frac{\Delta h}{L}$ L length of the pipe

If head losses are noted Δh_{12}, the linear head losses coefficient is defined by:

$$\xi = \frac{\Delta h12}{\frac{1}{2}\rho U^2 \frac{L}{D}} = 2i\,\frac{gD}{U^2}$$

Experience demonstrated that in a laminar flow regime, i is proportional to U; in a turbulent flow regime, i is proportional to U^n.

Material

U tube manometers

Experiment

a) Purge the pipes liking the bench to the manometers.
b) Check if the exit valve (large valve below the bench) is open
c) Open the flow control valve
d) Open the two valve of the desired pipe
e) Open the rotameter control valve
f) Connect the manometers to the pipes
g) Activate the pump.

For laminar flow, open another pipe and close the entry valve of the studied pipe.

Pick up the results in the following board:

Qv m^3/s	ΔP	ξ

Conclude on the head losses coefficient between the different pipes

Annexe III:

Experiment n°3: Hydraulic resistance

Objective

The purpose of this experiment is to show the hydraulic resistance of different pipe and compare them to the theoretical value.

Theories

The hydraulic resistance is a characteristic value of a pipe, it allow the calculate head losses. However those two notions are not the same.

Hydraulic resistance is defined by:

$$R_h = \frac{\Delta p}{Qv}$$

With Δp, pressure difference in Pa and Qv flow rate in m^3/s. this relation is valid in a stationary flow.

For a laminar flow in a circular pipe, the case of a Poseuille flow, the speed is given by the following formula:

$$v(r) = \frac{R^2}{4\mu}\frac{\Delta p}{L}\left(1 - \frac{r^2}{R^2}\right)$$

With R radius of the pipe in m, µ dynamic viscosity of the fluid in Pa.s, L length of the pipe in m.

$$Qv = \int_0^R 2\pi v(r) r dr = \frac{\pi R^4}{8\mu L}\Delta p$$

In this case the hydraulic resistance is defined by: $R_h = \frac{8\mu L}{\pi R^4}$

Material

U shaped manometers;

Pipes of 20, 16.4, 47.4, 24mm;

Meter;

Protocol

a) Check the opening of the exit valve (large valve below the bench);
b) Open one of the pipe,
c) Connect the manometer to the pipe;
d) Activate the pump;
e) Change the flow rate and pick up the values of the manometer;

For the laminar comparison:

a) Open the pipe 2 with the venturi tube, it will allow to check the laminar state of the fluid;
b) Open the pipe number 8 it will allow to make a laminar flow in the pipe n°2;

c) Connect the manometer to the pipe n°2;
d) Activate the pump;
e) Pick up the value of the manometer;
f) Change the flow rate by closing the entry valve of the pipe n°2

Annexe IV:

Experiment n°4

Comparison of experimental and theoretical head losses

Objective

The main goal of this experiment is to confront the theories established with experiment performed on the bench in the Hydrodynamic Lab

Description

The bench used is the HD98B hydraulic bench, precisely the pipes n°1, 2, 4, 5, 7, 8.

The n°1 pipe is a 77cm long pipe with a diameter of 16mm, the n°2 pipe is a 47.4mm diameter and 29.5 cm long pipe. The pipe n°4 is 3 section pipe, each section is 30 cm long the diameter of each section is 27.4mm, 20mm, 16mm. The number 5 pipe is a 20mm diameter and 77 cm long rough pipe, the ε is about 0.0015. The pipe n°8 is a 20mm diameter pipe.

Theories

When a fluid flows in a pipe, friction due to the contact between the fluid and the pipe, appear.

Head losses follow the following laws:

Darcy-Weisbach formula: $\Delta Ps = \xi * \frac{L}{D} * \frac{1}{2} * \rho * Um^2$ ξ regular head lose coefficient

For laminar flow:

$$\xi = \frac{64}{Re}$$

For turbulent flow in a smooth pipe:

$$\xi = \frac{0.316}{\sqrt[4]{Re}}$$ (Blasius fromula)

For turbulent flow in a rough pipe, the Colebrook formula have to be used:

$$\frac{1}{\sqrt{\xi}} = -2log10\left[\frac{\varepsilon}{3.71D} + \frac{2.51}{Re\sqrt{\xi}}\right]$$ (Colebrook formula)

Material

Manometer,

From up to down: pipes 1 (16.4mm), 2, 4, 5, 7, 8

Experiment

a) Check the opening of the exit valve (large valve below the bench);
b) connect the manometer to the desired pipe;
c) pick up the value of the manometer

Pick up the value of manometer in the following table:

Qv m^3/s	U m/s	ξ measured	Re	(ξ Blasius/Poiseuille)	(ξ Colebrook)

Compare the value measured to the theoretical ones, conclude.

Annexe V:

Experiment n°5

Head losses comparison for different technical solutions

Objective

The aim of this experiment is to highlight singular head losses in a hydraulic circuit.

Description of the installation

The HD98B Hydraulic bench is used for this experiment. Pipe n°9(16.4mm).

Theories

Head losses follow the Darcy-Weisbach formula:

$$\Delta Ps = \xi * \frac{L}{D} * \frac{1}{2} * \rho * Um^2$$

For head losses induced by a single component in the circuit (singular head losses) the formula is:

$\Delta Ps = K * \frac{1}{2}\rho Um^2$ K singular head losse coefficient

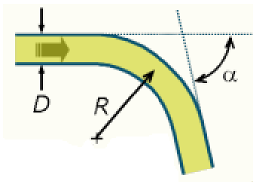
This formula is applicable for one singularity in the circuit, for example: if a circuit is equipped with 2 elbows and one valve, the formula is

$$\Delta Ps = (2Kelbow + Kvalve) * \frac{1}{2}\rho Um^2$$

For a singularity in the circuit, the coefficient K is given by the following formulas:

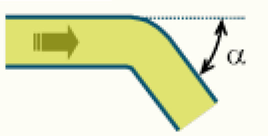
Rounded elbow:

K=$\frac{\alpha}{\pi}[0.131 + 1.847 * (\frac{D}{R})^{7/2}$



Elbow:

K=$(\sin\alpha)^2 + 2\,(\sin\frac{\alpha}{2})^4$



Rough entry:

K=0.5

Material

- U manometers;
- Pipe n°9 (n, v and u shaped circuit)

Experiment

a) Check the opening of the exit valve (large valve below the bench);
b) Connect the U-shaped manometer to the desired singularity;

c) Adjust the flow rate by opening another pipe and closing the entry valve of the used pipe;
d) Pick up the value of the manometer;

Fill the following table:

Qv m^3/s	h1 mm	h2 mm	Δh m	K measured	K theoretical

Image source: http://res-nlp.univ-lemans.fr/NLP_C_M02_G02/co/Contenu_32.html

Annexe VI:

Experiment n°6

Balancing of a hydraulic circuit

Objective

The goal of this experiment is to compare two valve in order to see if they fit for the balancing of the circuit where they are used.

Description

The HD98B bench is used, pipes n°6 (yellow valve) and 5 (blue valve) are used for this experiment.

Theories

In a hydraulic circuit (like a water circuit in a building) the higher you are, the lower the flow rate is. In order to prevent this the circuit must be balanced. In order to balance the singular head losses can be adjusted.

Theories for head losses:

Linear head losses (major losses):

Darcy-Weisbach formula: $\Delta Pt = \xi * \frac{L}{D} * \frac{1}{2} * \rho * Um^2$ ξ regular head lose coefficient

Laminar flow: $\xi = \frac{64}{Re}$

Turbulent flow in a smooth pipe: $\xi = \frac{0.316}{\sqrt[4]{Re}}$ (Blasius fromula)

Turbulent flow in a rough pipe: $\frac{1}{\sqrt{\xi}} = -2log10\left[\frac{\varepsilon}{3.71D} + \frac{2.51}{Re\sqrt{\xi}}\right]$ (Colebrook formula)

Singular head losses (minor losses): $\Delta Ps = K * \frac{1}{2}\rho Um^2$ K singular head losses coefficient

In a hydraulic circuit, a poorly balanced circuit induce problems for example, the heat circuit of a building have to be balanced, if not the closet heaters from the heat generator will receive too hot water, and the most distant one will receive too cold water, that will oblige the user to either waste energy in order to cool down the room or use more energy in order to warm up the room (with portable heater for example).

In a hydraulic circuit, the authority of a valve is defined by:

authority=$\frac{head\ losses\ valve}{head\ losses\ vale+head\ losses\ pipe}$

In order to be the more effective, the authority of a valve have to be close to 0.5: head losses generated by the valve should be close to the head losses generated by pipe.

Materials

- Central manometers or quad pressure sensor (require a PC)

Experiment

a) Check the opening of the exit valve (large valve below the bench);
b) Connect the central manometers to the pipe and to the valve used (do not use U-manometers);
c) Open the valves of the used pipe;
d) Activate the pump;
e) Wait in order to establish the regime;
f) Pick up value in the following table;
g) Measure head losses for different pipes;
h) Compare the authority of the yellow valve on other pipes and justify which pipe can be balanced with the yellow valve.

Δp valve Pa	Δp pipe Pa	Qv m^3/s	Authority

Annexe VII:

Experiment n°7

Singular head losses for laminar and turbulent flow

Objective

The aim of this experiment is to highlight the differences between singular head losses in a laminar and in turbulent flow. The evolution of the K coefficient will be studied here.

Theories

A singularity in a hydraulic circuit create a singular head losses, singular head losses are ruled by the following formula:

For singular head losses (minor losses): $\Delta Ps = K * \frac{1}{2}\rho Um^2$ K singular head losses coefficient.

Description of the installation

The HD98B Hydraulic Bench is used here. The n°9 pipe (with elbow and different circuits) is used the pipe simulate an hydraulic circuit with different singularity

Material

Manometers

Experiment

a) Check the opening of the exit valve (large valve below the bench);
b) Open the desired pipe;
c) Connect the manometers to the used pipes
d) Activate the pump;
e) Pick up values of the manometers in the following table

Qv m^3/s	U m/s	K	Measure differences (%)

Annexe VIII:

Experiment n°8

Evaluation of the performances of manometers in turbulent and laminar flow

Objective

The aim of this experiment is to highlight the different measure of a same manometer in a laminar flow and in a turbulent flow in order to decide which manometer is the more suited for the task.

Theories

Bernoulli formula $Pa + \frac{1}{2}\rho Ua^2 + \rho gZa = Pb + \frac{1}{2}\rho Ub^2 + \rho gZb$

Flow rate equality: $Qv = UaSa = UbSb$

For the venturi tube:

$$Pa - Pb = \frac{1}{2}\rho * (Ub^2 - Ua^2) \Leftrightarrow \frac{2}{\rho}(Pa - Pb) = Qv^2\left(\frac{1}{Sb^2} - \frac{1}{Sa^2}\right) \Leftrightarrow Qv = \sqrt{\frac{2\Delta P}{\rho\left(\frac{1}{Sb^2} - \frac{1}{Sa^2}\right)}}$$

For the orifice plate:

$$Pa - Pb = \frac{1}{2}\rho * (Ub^2 - Ua^2) \Leftrightarrow \frac{2}{\rho}(Pa - Pb) = Qv^2\left(\frac{1}{Sb^2} - \frac{1}{Sa^2}\right) \Leftrightarrow Qv = \sqrt{\frac{2\Delta P}{\rho\left(\frac{1}{Sb^2} - \frac{1}{Sa^2}\right)}} =$$

$Sb\sqrt{\frac{2\Delta p}{\rho(1-(\frac{d}{D})^4}} = CdSb\sqrt{\frac{1}{1-\beta^4}} * \sqrt{\frac{2\Delta p}{\rho}}$ introducing the Cd coefficient (because it is not a perfectly laminar flow) and the β=d/D, d diameter of the orifice (m), D diameter of the pipe (m)

$Qv = CSb0\sqrt{\frac{2\Delta p}{\rho}}$ Introducing C= $Cd\sqrt{\frac{1}{1-\beta^4}}$ Sb0 area of the orifice

Coefficient of discharge can be calculated with the Reader-Harris/Gallagher equation:

C=$0.5961 + 0.0261\beta^2 - 0.216\beta^8 + 0.000521\left(\frac{10^6\beta}{REd}\right)^{0.7} + (0.0188 + 0.0063A)\beta^{3.5}\left(\frac{10^6}{REd}\right)^{0.3} + (0.043 + 0.080\exp(-10L1) - 0.123\exp(-7L1))(1 - 0.11A)\frac{\beta^4}{1-\beta^4} - 0.031\left(M2' - 0.8M2'^{1.1}\right)\beta^{1.3} + 0.011(0.75 - \beta)\left(2.8 - \frac{D}{0.0254}\right)$

A=$\left(\frac{19000\beta}{REd}\right)^{0.8}$

M2'=$\frac{2L2}{1-\beta}$

L1=L2=0

Description

The HD98 bench is used, alongside pipes n°2, 3. Pipe n°2 is equipped with a venturi tube, a flow meter device based on the venturi effect. Pipe n°3 is also equipped with a venturi effect based flow meter: an orifice plate. The circuit use a rotameter (which will be considered the reference here).

Material

Manometers

Experiment

a) Check the opening of the exit valve (large valve below the bench);
b) Calculate the flow rate maximal for a laminar flow in each flowmeter
c) Open one pipe;
d) Connect manometers to the desired pipes;
e) Activate the pump;
f) Open other pipe and close the entry valve of the studied pipe in order to reduce the flow rate;
g) Pick up values of the manometers in the following table;
h) Compare each flowmeter to the rotameter;
i) Conclude

Qv m^3/s	Qv venturi tube m/s	Qv orifice plate m/s	U m/s	Re

Annexe IX:

Experiment n°9

Experimental determination of the power of the pump

Objective

The goal of this experiment is to determine the power of the pump used to move the fluid.

Description

The HD98B bench is comprised of different pipes, at different altitude, the different altitude of pipes will be used to determine the power of the pump.

Theories

This are the basic theories one head losses:

-linear head losses (major losses):

Darcy-Weisbach formula: $\Delta Pt = \xi * \frac{L}{D} * \frac{1}{2} * \rho * Um^2$ ξ regular head lose coefficient

-Laminar flow: $\xi = \frac{64}{Re}$

-Turbulent flow in a smooth pipe: $\xi = \frac{0.316}{\sqrt[4]{Re}}$ (Blasius fromula)

-Turbulent flow in a rough pipe: $\frac{1}{\sqrt{\xi}} = -2log10\left[\frac{\varepsilon}{3.71D} + \frac{2.51}{Re\sqrt{\xi}}\right]$ (Colebrook formula)

- Singular head losses (minor losses): $\Delta Ps = K * \frac{1}{2}\rho Um^2$ K singular head losse coefficient

The Bernoulli formula will be used here:

$$Pa + \frac{1}{2}\rho Ua^2 + \rho gza + \Delta Ppump = Pb + \frac{1}{2}\rho Ub^2 + \rho gZb + \Delta Ps + \Delta Pl$$

With ΔPpump, pressure given by the pump, here, $Ppump\ used = \Delta Ppump * Qv$

Qv flow rate in m^3/s, Ppump used in W

Material

The HD98B Hydraulic Bench will be used with all of its pipes

Manometers

Experiment

a) Check the opening of the exit valve (large valve below the bench)
b) Open one of the pipe;
c) Connect the manometers to the bench
d) Measure the head losses
e) Determine the power of the pump
f) Repeat this protocol for different pipes

g) Conclude on the power of the pump and its characteristic

Annexe X:

Experiment n°10

Determination of the critical Reynolds number

Objective

The aim of this experiment is to find the critical Reynolds number in different pipes and see the effect on the fluid.

Description

In order to find the critical Reynold number in a pipe, head losses will be measured and head losses coefficient will be compared to the theoretical head losses coefficient given by the Poiseuille and Blasius formula, the comparison of the coefficients will allow to find the critical Reynolds number.

Theories

The type of the flow is determined by the Reynolds Number: $Re_D = \frac{\rho U D}{\mu} = \frac{UD}{\nu}$

The transition between laminar and turbulent flow is for a Re beyond 2000

For a venturi tube, the basic theories is:

Bernoulli formula $Pa + \frac{1}{2}\rho Ua^2 + \rho gZa = Pb + \frac{1}{2}\rho Ub^2 + \rho gZb$

Flow rate equality: $Qv = UaSa = UbSb$

$$Pa - Pb = \frac{1}{2}\rho * (Ub^2 - Ua^2) \Leftrightarrow \frac{2}{\rho}(Pa - Pb) = Qv^2(\frac{1}{Sb^2} - \frac{1}{Sa^2}) \Leftrightarrow Qv = \sqrt{\frac{2\Delta P}{\rho(\frac{1}{Sb^2} - \frac{1}{Sa^2})}}$$

Material

The HD98B bench is used with the pipe n°2. This pipe is equipped with a venturi tube in transparent material in order to observe the flow inside the pipe and see the behaviour of this flow.

Manometers

Experiment

a) Check the opening of the exit valve (large valve below the bench);
b) Open the n°2 pipe;
c) Connect one of the two manometers;
d) Open another pipe in order to reduce the flow rate in the pipe n°2
e) Activate the pump;
f) Close the entry valve of the pipe n°2 in order to reduce the flow rate;
g) Pick up the values of the manometer in the following table;

Qv venturi m^3/s	ΔP Pa	ξ	ξ Blasius	ξ Poiseuille	U m/s	Re	State of the fluid

Conclude on the valour of the critical Reynolds number in this pipe, conclude on the state of the fluid depending the Reynolds number.

Annexe XI:

Result of the valve authority experiment

blue valve								
	pipe		valve		pipe	valve		
Qv lph	P1 mce	P2 bar	P1 mce	P2 bar	ΔP Pa	ΔP pa	authority	Average authority
1300	2,5	0,03	3,6	0,04	21525	31316	0,59264586	
1500	4,4	0,03	4,2	0,04	40164	37202	0,48085722	
1700	4,5	-0,03	5,7	0,02	47145	53917	0,53350419	
2000	7	-0,03	6,2	-0,02	71670	62822	0,46710585	0,51852828

yellow valve								
	pipe		valve		pipe	valve		
Qv lph	P1 mce	P2 bar	P1 mce	P2 bar	ΔP Pa	ΔP pa	authority	Average authority
2800	1,9	0,01	0,8	0,01	17639	6848	0,27965859	
3500	3	0,03	0,9	0,05	26430	3829	0,12654086	
4000	4,2	0,07	1,2	0,07	34202	4772	0,1224406	
4500	5,2	0,09	1,6	0,1	42012	5696	0,11939297	0,162008258

other pipes									
	diameters mm					authority (yellow valve)			
Qv lph	16,4	47	20	27,4	ΔP valve Pa	16,4	47	20	27,4
3500	4900	7840	7840	15680	3829	0,43865277	0,32813437	0,328134373	0,19626839
4000	5880	12740	9310	23520	4772	0,44799099	0,27249886	0,338872319	0,16866959
4500		15680	10780		5696		0,26646707	0,345714979	

This experiment was performed with the embedded equipment (U manometer and 2 independent manometers)

Annexe XII:

Head losses coefficient for singularity results

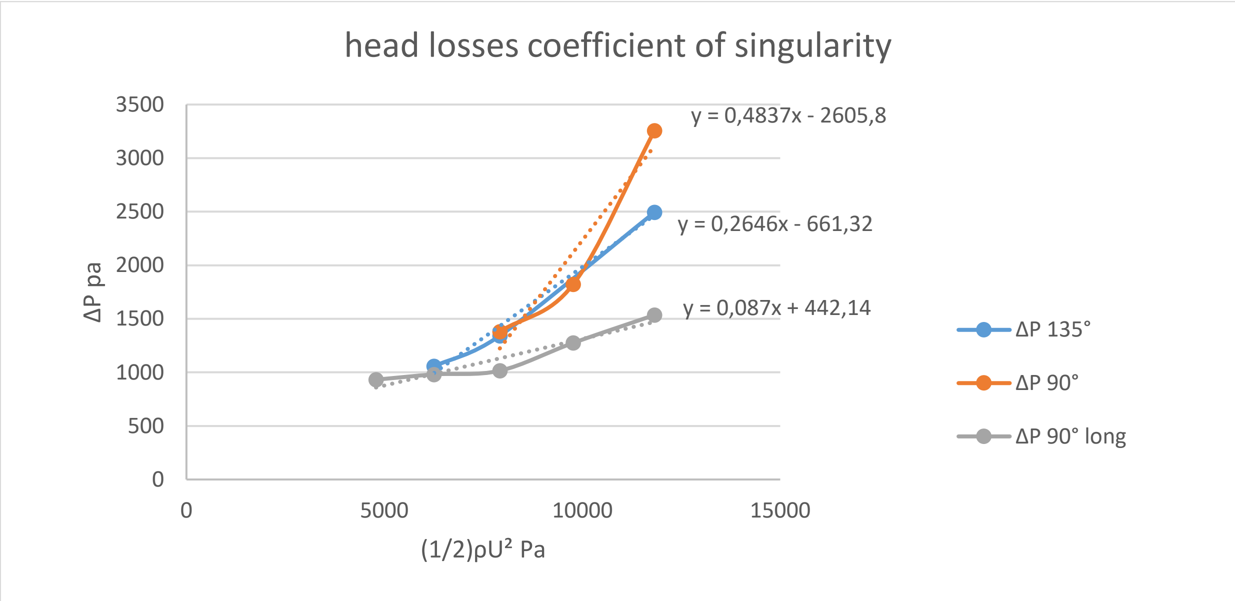


Figure 30 head losses coefficient of singularity measured with embeded manometers

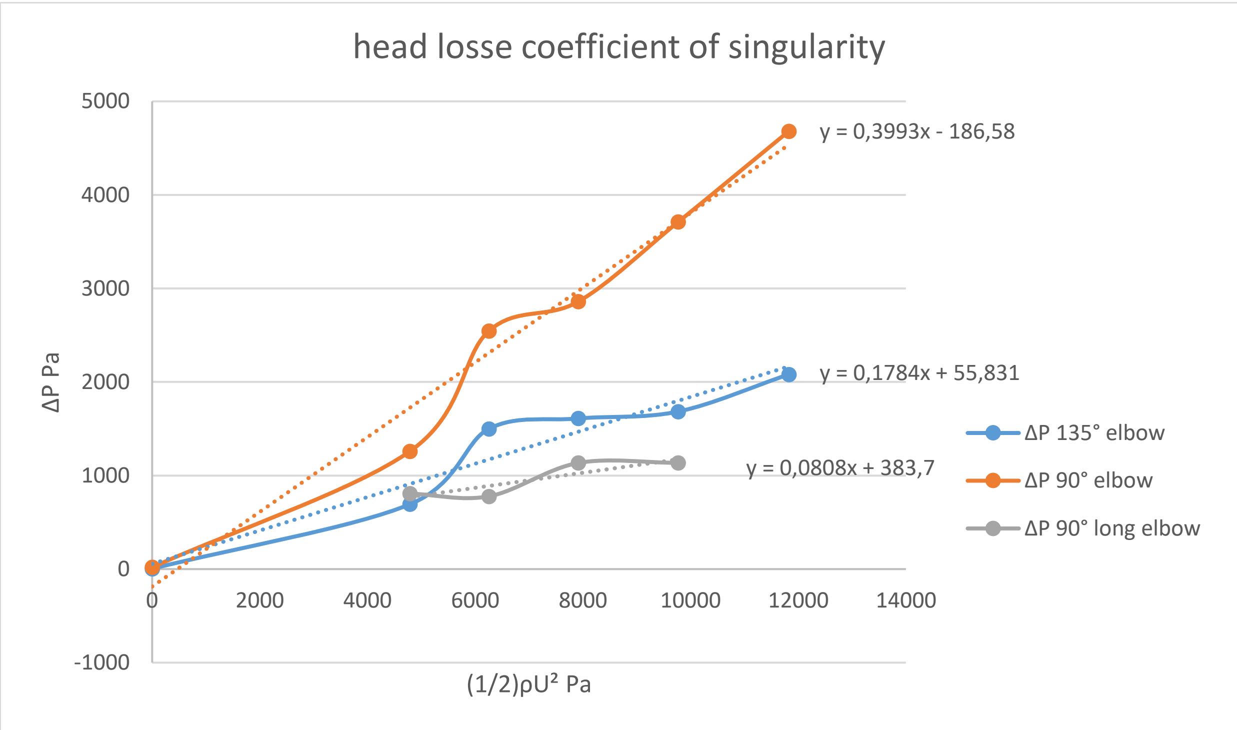
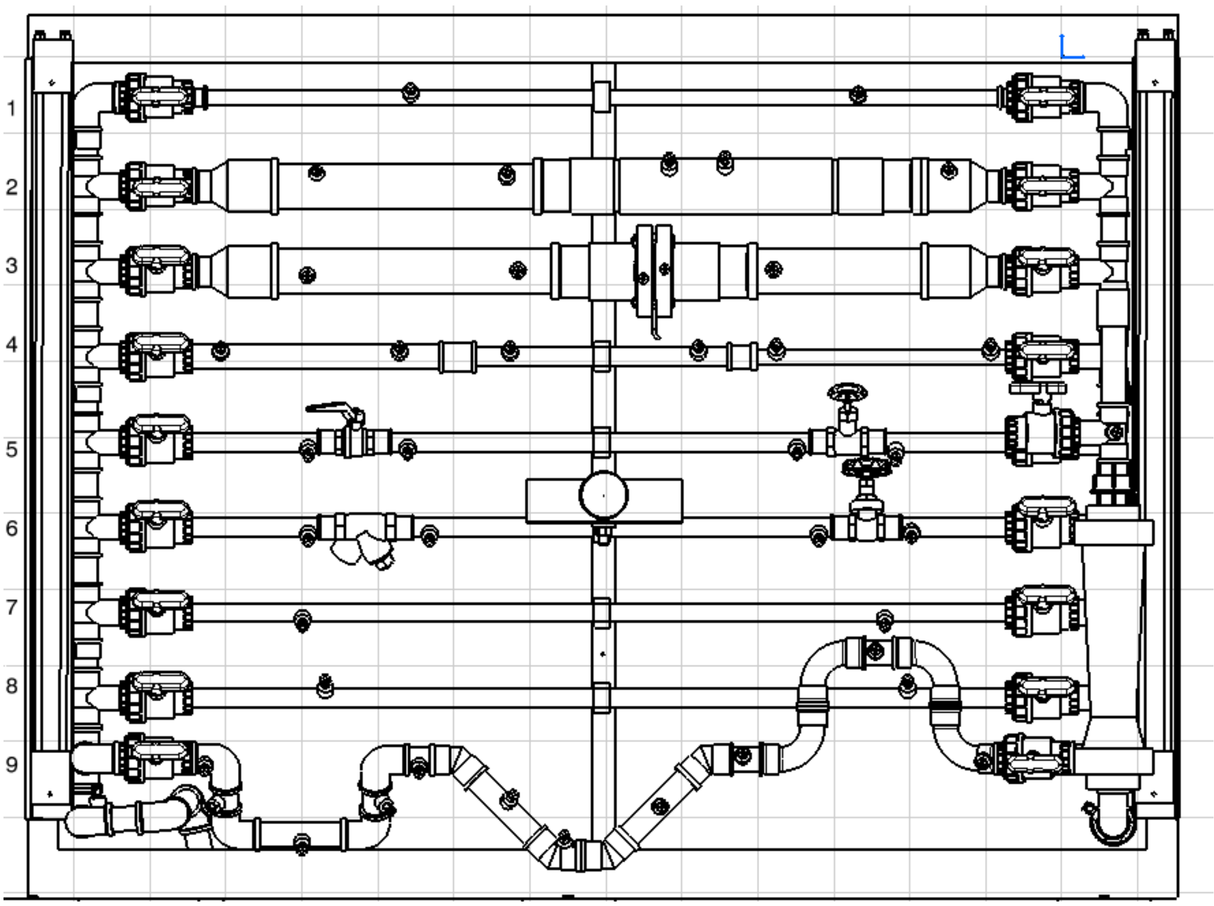


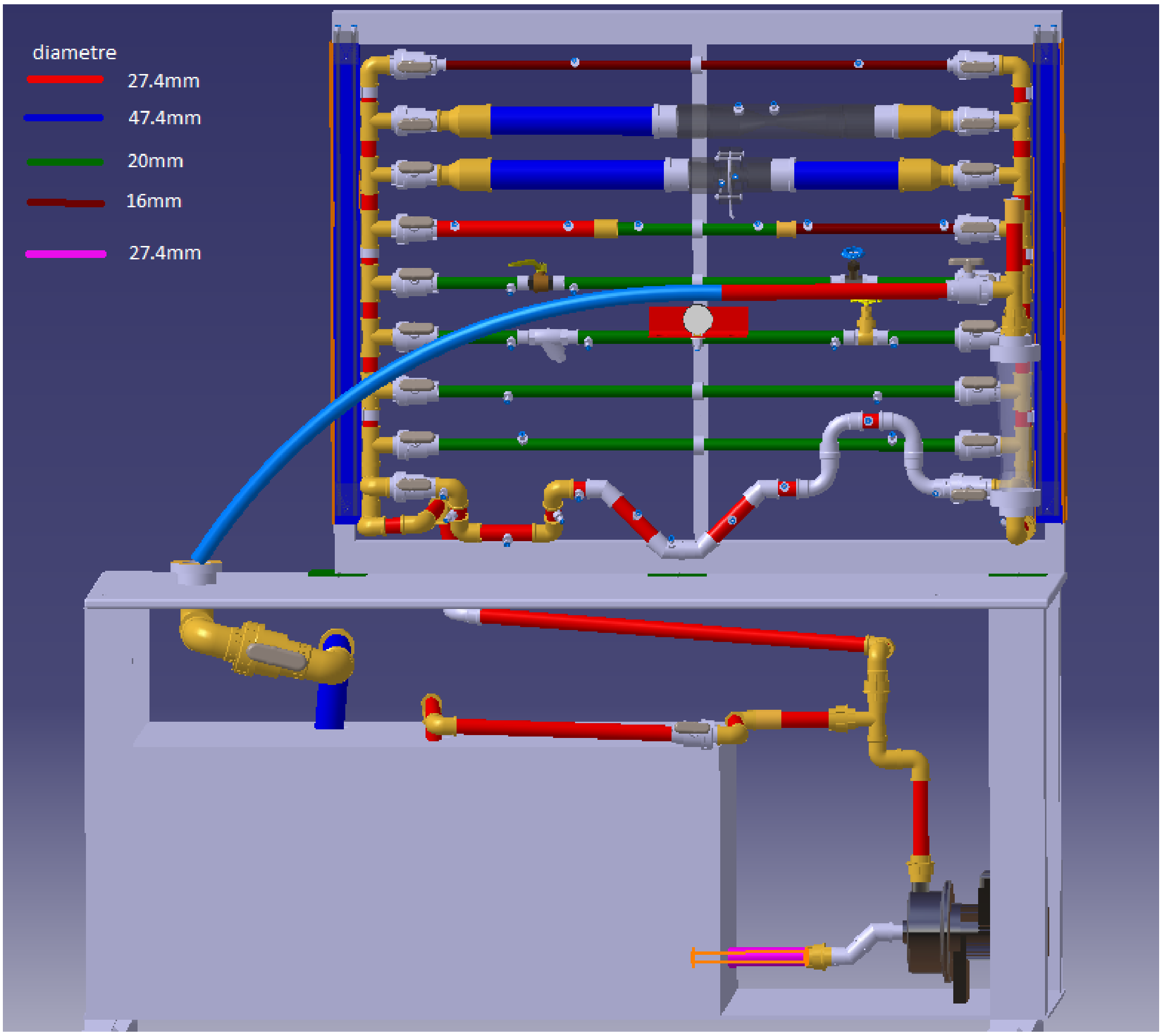
Figure 31 head losses coefficient of singularity measured with the quad pressure sensor

Annexe XIII

Schematic of the Bench



Schematic of the bench with the number designation of each pipe



3D model of the bench featuring the diameter of each pipe solid pipe on the bench.