GAS MIXING PANEL

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ABSTRACT

Nowadays, it is increasingly common that industries and laboratories work with a wide range of gas mixtures to run their businesses; due to the high demand existing, there are many companies engaged in manufacturing and supplying the most frequently gas mixtures. Nevertheless, due to specifications on these gas mixtures, the dependence that industries and laboratories currently have on the provider companies is high. In order to avoid this high dependence, many companies and laboratories have built a gas mixing panel in their installations.
Following the same line, this project’s aim is to carry out the design and the installation of a gas mixing panel, that it will be based on the specifications needed by the current experiments and the ones which are planned to be developed during the next three years. This project is included within the Explore Polygeneration's one, an initiative that will serve as an important tool to promote the application of renewable technologies extending to the future sustainable energy engineering field, developed by the Division of Heat and Power Technology.
ACKNOWLEDGEMENTS

I would like to express my gratitude to the Heat and Power Technology dept. at the Royal Institute of Technology, Stockholm, and to Politecnico di Torino for giving me the possibility to perform this thesis.

Special thanks go to my supervisor in Stockholm, Dr. Anders Malmquist, Mr. Leif Petersson and my supervisor from the Politecnico di Torino, prof. Andrea Carpignano for being a great help during the developing of my thesis, supplying a lot of useful sources of information, patience and time.

Thanks to all my friends for this unforgettable experience in Stockholm.

In closing, I’m deeply grateful to my whole family who has always encouraged me, trusting me even when I didn’t.
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## NOMENCLATURE

### Chemical formulation

<table>
<thead>
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<tr>
<td>$CO_2$</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>$CO$</td>
<td>Carbon monoxide</td>
</tr>
<tr>
<td>$H_2$</td>
<td>Hydrogen</td>
</tr>
<tr>
<td>$CH_4$</td>
<td>Methane</td>
</tr>
<tr>
<td>$N_2$</td>
<td>Nitrogen</td>
</tr>
<tr>
<td>$C_3H_8$</td>
<td>Propane</td>
</tr>
</tbody>
</table>

### Latin Symbols

<table>
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<th>Symbol</th>
<th>Description</th>
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<tr>
<td>$m$, $\dot{m}$</td>
<td>mass flow</td>
</tr>
<tr>
<td>$q$</td>
<td>volume flow</td>
</tr>
<tr>
<td>$v$</td>
<td>speed</td>
</tr>
<tr>
<td>$p$</td>
<td>pressure</td>
</tr>
<tr>
<td>$A$</td>
<td>section</td>
</tr>
<tr>
<td>$D$</td>
<td>diameter</td>
</tr>
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<td>$x$</td>
<td>length</td>
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<td>$h$</td>
<td>enthalpy</td>
</tr>
<tr>
<td>$s$</td>
<td>entropy</td>
</tr>
<tr>
<td>$T$</td>
<td>temperature</td>
</tr>
<tr>
<td>$c_p$</td>
<td>heat capacity at constant pressure</td>
</tr>
<tr>
<td>$c_v$</td>
<td>heat capacity at constant volume</td>
</tr>
<tr>
<td>$R$</td>
<td>gas constant</td>
</tr>
<tr>
<td>$Ma$</td>
<td>Mach value</td>
</tr>
<tr>
<td>$f$</td>
<td>Darcy friction factor</td>
</tr>
<tr>
<td>$k$</td>
<td>heat capacity ratio</td>
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</table>

### Greek Symbols

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
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<tbody>
<tr>
<td>$\rho$</td>
<td>density</td>
</tr>
<tr>
<td>$\tau_w$</td>
<td>wall shear</td>
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</table>
BACKGROUND

The ability to generate gas mixtures with an arbitrary composition will be necessary in different lab rigs involved in the Polygeneration project in order to investigate the performance of the system when using a wide variety of gaseous mixtures as a fuel supply. This will reveal the applicability of the system to exploit different fuel streams that might not be available for testing in the laboratory.

There have been several attempts to build the gas mixing panel with different approaches. The last one started in 2008-2009 when the microturbine was being planned, however, as the responsible person left the department, the build of the gas mixing panel was put on hold.

1 OBJECTIVES

This project involves the conception of a gas mixing panel that will be able to simulate a wide range of gaseous fuels mixtures representative of the output of mainstream gasification and biogas production systems. In order to do this, at least 6 gas streams (H\textsubscript{2}, CH\textsubscript{4}, N\textsubscript{2}, CO, CO\textsubscript{2}, C\textsubscript{3}H\textsubscript{8}), beginning at the gas house (located about 175 meters from the lab), will need to be combined using flow-controllers piloted by a real-time computer program. Ideally, it should also be possible to add a controlled amount of water vapour to the heated mixture to provide a more realistic approximation to real-life fuels with a biological origin.

The system would provide at least 30 to 50 kW of thermal power, to be used as fuel supply in the lab rigs currently available as well as leave a margin for future expansions.

The building of this gas mixing panel needs engineering expertise due to safety requirements. That is the reason why companies specialized in this subject, as AirLiquide or AGA, will participate in this project development.
2 METHOD OF ATTACK

Initially, the main tasks to accomplish the purpose of this project included:

- the inventory of the current available devices,
- the study of the rig needs,
- the study of the actual installation and its limits,
- the design of the system (plumbing, valves, flow controllers, etc.),
- the safety assessment to ensure the compliance with local regulations,
- the programming of the computer software controlling the equipment and the actual assembly of the hardware. The software task will be extensive and will most conveniently be implemented in the LabView environment.
- the contact with suppliers, contractors and consultants in order to perform the design.

Due to the constraints appeared in the development of the thesis, that will be explained later, the initial method of attack has been modified.
3 INVENTORY

Firstly, an overview of the real situation was needed; therefore an inventory of the available parts from the gas mixing panel that had been started three years ago has been made. It is important to take into account that not all the pieces bought before can be used in the build of the gas mixing panel nowadays, as they are already in use in other projects.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Number of pieces</th>
<th>Completed pieces</th>
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</thead>
<tbody>
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<td></td>
</tr>
<tr>
<td>B-45S12MM</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>SS-45YF8</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>SS-45S12MM</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>CHECK VALVES</strong></td>
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</tr>
<tr>
<td>SS-12C-MM-1</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td><strong>TUBE FITTING MALE CONNECTOR</strong></td>
<td>12</td>
<td>10</td>
</tr>
<tr>
<td><strong>T connection</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS-12M0-3-4TTF</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>SS-12M0-3</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td><strong>X connection</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS-12M0-4</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>L connection</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SS-12M0-9</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td><strong>Nuts</strong></td>
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<td></td>
</tr>
<tr>
<td>SS-12M2-1</td>
<td>20</td>
<td>20</td>
</tr>
</tbody>
</table>

*Table 1. Inventory of Swagelok products*
4 SPECIFICATION REQUIREMENTS

All the members of Heat and Power department were interviewed in order to identify the specifications of mixtures they are interested in. In the following table it can be seen the required gases to be provided to each one of rigs.

<table>
<thead>
<tr>
<th></th>
<th>Micro Gas Turbine</th>
<th>Target rig</th>
<th>High Pressure Catalytic Conversion</th>
</tr>
</thead>
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<tr>
<td>Working pressure</td>
<td>50 mbars</td>
<td>5 bars</td>
<td>5 – 40 bars</td>
</tr>
<tr>
<td>Required gases</td>
<td>Mixture CH$_4$ – CO$_2$</td>
<td>Gasified biomass</td>
<td>Gasified biomass and methane</td>
</tr>
</tbody>
</table>

*Table 2. Rigs’ working characteristics*

4.1 Composition of the mixtures

4.1.1 Gasified biomass

Composition (%vol):
4% CH$_4$
18% CO
12% H$_2$
16% CO$_2$
50% N$_2$

Mass flows for each gas have been calculated according to the power delivered (table 3).
<table>
<thead>
<tr>
<th>Total Power (kW)</th>
<th>CH₄ (kg/h)</th>
<th>CO (kg/h)</th>
<th>H₂ (kg/h)</th>
<th>CO₂ (kg/h)</th>
<th>N₂ (kg/h)</th>
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<td>26,65</td>
<td>1,27</td>
<td>37,23</td>
<td>74,04</td>
</tr>
</tbody>
</table>
The data has been obtained from an already existing document, that was elaborated some years ago. The power required in both processes is 100 kW for high pressure catalytic conversion process and 200 kW for the target rig, therefore the mass flow rate has been calculated to give a power from 0 till 200 kW.

The mass flow has been estimated through the low heat value (LHW) for each combustible component, calculating the heat power percentage contribution to the heat total power.

To make it clear, here there is an example of how these calculations have been done:

**C₃H₈:**

From the volume composition, the mass composition has been calculated, and then the power percentage:

\[
\text{Propane mass composition (\%)} = \frac{\text{Propane volume composition(\%)} \times \text{Propane molar mass}}{\sum_{\text{all components}} (\text{Volume composition(\%)} \times \text{Molar mass})} \times 100
\]

\[
\text{Propane power content} = \frac{\text{Propane mass composition(\%)}}{\sum_{\text{combustible components}} (\text{Mass composition(\%)})}
\]

\[
\text{Power (\%)} = \frac{\text{Propane power content}}{\sum_{\text{combustible components}} \text{Power content}} \times 100
\]

When the power percentage is reached, it is easy to get the mass or volume flow: In order to get a total power of 50kW, the power given by the C₃H₈ will be 11,41kW, then using the LHV (45,8 MJ/kg), the mass flow is obtained and arranged by the proper change of units: 0,9 kg/h, that it means 0,48 m³/h.

The same calculations are made to get the CH₄ flow, that in this case is 2,77 kg/h or 4,15 m³/h.

**CO₂:**

As it is not a combustible gas, the calculation method is quite different from the other gases.

The CO₂ mass flow is calculated from the mass percentage of the total flow:

\[
\text{Total flow} = \frac{\text{Propane mass flow}}{\text{propane mass composition (\%)}} \times 100
\]
In conclusion, for the previous example, the mass flow for each gas to get a fuel flow that provides 50kW of power is:

$\begin{align*}
\text{C}_3\text{H}_8 &: 0.9 \text{ kg/h} \\
\text{CH}_4 &: 2.77 \text{ kg/h} \\
\text{CO}_2 &: 0.45 \text{ kg/h}
\end{align*}$

### 4.1.2 Methane

Composition (%vol):

100% CH₄

The mass flow is calculated according to the power delivered (table 4).

<table>
<thead>
<tr>
<th>Total Power (kW)</th>
<th>CH₄ (kg/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0.3593</td>
</tr>
<tr>
<td>10</td>
<td>0.7186</td>
</tr>
<tr>
<td>15</td>
<td>1.0778</td>
</tr>
<tr>
<td>20</td>
<td>1.4371</td>
</tr>
<tr>
<td>25</td>
<td>1.7964</td>
</tr>
<tr>
<td>30</td>
<td>2.1557</td>
</tr>
<tr>
<td>35</td>
<td>2.5150</td>
</tr>
<tr>
<td>40</td>
<td>2.8743</td>
</tr>
<tr>
<td>45</td>
<td>3.2335</td>
</tr>
<tr>
<td>50</td>
<td>3.5928</td>
</tr>
<tr>
<td>55</td>
<td>3.9521</td>
</tr>
<tr>
<td>60</td>
<td>4.3114</td>
</tr>
<tr>
<td>65</td>
<td>4.6707</td>
</tr>
<tr>
<td>70</td>
<td>5.0299</td>
</tr>
<tr>
<td>75</td>
<td>5.3892</td>
</tr>
<tr>
<td>80</td>
<td>5.7485</td>
</tr>
<tr>
<td>85</td>
<td>6.1078</td>
</tr>
<tr>
<td>90</td>
<td>6.4671</td>
</tr>
<tr>
<td>95</td>
<td>6.8263</td>
</tr>
<tr>
<td>100</td>
<td>7.1856</td>
</tr>
</tbody>
</table>

*Table 4. Mass flow for each gas according to the power delivered*
The power required by the High Pressure Catalytic Conversion is 100kW, so the mass flow rate is calculated to give a power from 0 till 100 kW. The calculation procedure is the same than the natural gas’ case, but this time the $\text{CH}_4$ is the only component, so all power is given by it.

### 4.1.3 Natural gas

Composition (%vol):
- 10% $\text{C}_3\text{H}_8$
- 85% $\text{CH}_4$
- 5% $\text{CO}_2$

Mass flows for each gas have been calculated according to the power delivered (table 5).

<table>
<thead>
<tr>
<th>Total Power (kW)</th>
<th>$\text{C}_3\text{H}_8$ (kg/h)</th>
<th>$\text{CH}_4$ (kg/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>0,09</td>
<td>0,28</td>
</tr>
<tr>
<td>10</td>
<td>0,18</td>
<td>0,55</td>
</tr>
<tr>
<td>15</td>
<td>0,27</td>
<td>0,83</td>
</tr>
<tr>
<td>20</td>
<td>0,36</td>
<td>1,11</td>
</tr>
<tr>
<td>25</td>
<td>0,45</td>
<td>1,39</td>
</tr>
<tr>
<td>30</td>
<td>0,54</td>
<td>1,66</td>
</tr>
<tr>
<td>35</td>
<td>0,63</td>
<td>1,94</td>
</tr>
<tr>
<td>40</td>
<td>0,72</td>
<td>2,22</td>
</tr>
<tr>
<td>45</td>
<td>0,81</td>
<td>2,50</td>
</tr>
<tr>
<td>50</td>
<td>0,90</td>
<td>2,77</td>
</tr>
<tr>
<td>55</td>
<td>0,99</td>
<td>3,05</td>
</tr>
<tr>
<td>60</td>
<td>1,08</td>
<td>3,33</td>
</tr>
<tr>
<td>65</td>
<td>1,17</td>
<td>3,60</td>
</tr>
<tr>
<td>70</td>
<td>1,26</td>
<td>3,88</td>
</tr>
<tr>
<td>75</td>
<td>1,35</td>
<td>4,16</td>
</tr>
<tr>
<td>80</td>
<td>1,44</td>
<td>4,44</td>
</tr>
<tr>
<td>85</td>
<td>1,52</td>
<td>4,71</td>
</tr>
<tr>
<td>90</td>
<td>1,61</td>
<td>4,99</td>
</tr>
<tr>
<td>95</td>
<td>1,70</td>
<td>5,27</td>
</tr>
<tr>
<td>100</td>
<td>1,79</td>
<td>5,55</td>
</tr>
</tbody>
</table>

*Table 5. Mass flow for each gas according to the power delivered*

This mixture is supposed to be used by other rigs not defined yet, so it has been supposed a required power of 100 kW.
The calculation procedure is the same than the natural gas’ method. This time, the combustible gases are CH₄, CO and H₂, and the non-combustible gases are CO₂ and N₂.

### 4.1.4 The CH₄ – CO₂ mixture

Composition (%vol):
- 65% CH₄
- 35% CO₂

This mixture is the one required by the gas micro turbine. In this case the calculation procedure is quite different since it starts from the expected compressor speed, instead of starting from the power to be achieved (table 6).

<table>
<thead>
<tr>
<th>Speed (rpm)</th>
<th>CH₄ (kg/h)</th>
<th>CO₂ (kg/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>110000</td>
<td>3,651</td>
<td>5,393</td>
</tr>
<tr>
<td>112500</td>
<td>3,734</td>
<td>5,515</td>
</tr>
<tr>
<td>115000</td>
<td>3,816</td>
<td>5,638</td>
</tr>
<tr>
<td>117500</td>
<td>3,899</td>
<td>5,760</td>
</tr>
<tr>
<td>120000</td>
<td>3,982</td>
<td>5,883</td>
</tr>
<tr>
<td>122500</td>
<td>4,065</td>
<td>6,005</td>
</tr>
<tr>
<td>125000</td>
<td>4,148</td>
<td>6,128</td>
</tr>
<tr>
<td>127500</td>
<td>4,231</td>
<td>6,251</td>
</tr>
<tr>
<td>130000</td>
<td>4,314</td>
<td>6,373</td>
</tr>
<tr>
<td>132500</td>
<td>4,397</td>
<td>6,496</td>
</tr>
<tr>
<td>135000</td>
<td>4,480</td>
<td>6,618</td>
</tr>
<tr>
<td>137500</td>
<td>4,563</td>
<td>6,741</td>
</tr>
<tr>
<td>140000</td>
<td>4,646</td>
<td>6,863</td>
</tr>
<tr>
<td>142500</td>
<td>4,729</td>
<td>6,986</td>
</tr>
<tr>
<td>145000</td>
<td>4,812</td>
<td>7,109</td>
</tr>
<tr>
<td>147500</td>
<td>4,895</td>
<td>7,231</td>
</tr>
<tr>
<td>150000</td>
<td>4,978</td>
<td>7,354</td>
</tr>
<tr>
<td>152500</td>
<td>5,061</td>
<td>7,476</td>
</tr>
<tr>
<td>155000</td>
<td>5,144</td>
<td>7,599</td>
</tr>
<tr>
<td>157500</td>
<td>5,227</td>
<td>7,721</td>
</tr>
<tr>
<td>160000</td>
<td>5,310</td>
<td>7,844</td>
</tr>
</tbody>
</table>

*Table 6. Mass flow for each gas according to the speed of the compressor*

After working on the results that were obtained in another experiment, the speed-air mass flow relation has been defined by two points:
1st point:
Speed=0 rpm
Air mass flow= 0 g/s

2nd point:
Speed=160.000rpm
Air mass flow= 110 g/s

A linear relation has been established in order to get the air mass flow data from 110.000 rpm till 160.000 rpm (the micro-turbine’s working range).

At this point, the fuel mass flow can be calculated taking into account that at 160.000 rpm, the fuel flow is 6,5Nm³/h.

Firstly, the fuel flow at 160.000rpm in the working conditions (1,5 bars of pressure and 973,15K of temperature) has been calculated.

Once the fuel flow has been calculated, the proportional fuel amount to the air flow can be obtained from the fuel density (0,93 kg/m³), dividing it by the air mass flow at 160.000 rpm of speed (the fuel mass percentage obtained in that case is 3,32%).

From this, the fuel mass flow for each air mass flow can be calculated. As the volume composition is defined, CH₄ and CO₂ flows are calculated through the mass percentage.

Here there is an example to make it clear:
At 160.000 rpm

\[ \text{Air mass flow} = 110 g/s \]

\[ \text{Fuel flow (normal conditions)} = \frac{6,5Nm^3}{h} \]

\[ \text{Fuel flow (working conditions)} = \frac{6,5 \times 973,15}{h1,5 \times 273,15} = 15,44m^3/h \]

\[ \text{Fuel mass flow} = \text{Fuel flow} \times \text{density} = 14,36kg/h \]

\[ \text{Fuel (\%)} = \frac{\text{Fuel mass flow} \times \frac{1000}{3600} \times 100}{\text{Air mass flow}} = 3,63\% \]

\[ \text{Methane mass flow} = \text{Fuel mass flow} \times \text{Methane mass composition(\%)} \times \frac{1}{100} \]

\[ = 14,34 \times 40 \times \frac{1}{100} = 5,8kg/h \]
5 SAFETY REQUIREMENTS

All gas mixing operations require the normal safety procedures, practices and controls which are followed when producing standard industrial gases. Additional controls are required when using electrical equipment in a Flammable Gas Zone. For this reason, great care is necessary during the design of the gas mixing panel to ensure that no dangerous situations take place.

This chapter is inspired by the CERN Flammable Gas Safety Code, which defines the rules which must be followed in the use of flammable gas at CERN, but applicable to this case as well. It takes into account ATEX directive and some EIGA documents.

It is important to take into account that a failure mode, effects and critically analysis (FMECA) should be scheduled and completed concurrently as an integral part of the design process. The FMECA would help the team to identify potential failure modes based on past experiences with similar products or processes, enabling the team to design those failures out of the system with the minimum effort and resource expenditure, thereby reducing development time and costs.

Besides, this document is also useful when system is working, since more real information is available; then, the analysis should be updated in order to provide the most benefit.

5.1 System definition and functional breakdown

The process to be analyzed is the gas mixing panel construction. This is a part of the Explore polygeneration project.

The gas mixing panel’s goal is to create mixtures of gases that are stored in the gas house and provide them to the rigs, which are situated in the laboratory. Therefore, the considered parts of the process should start at the gas house and end when the mixture is done in the laboratory.

As the piping installation is already working, safety measures related to it have been defined, so in this document just a description of the installations have been included, whereas the gas mixing panel must be designed from the beginning, a discussion of how it should be, according to safety requirements has been made.

A functional and reliability block diagram representing the operation, interrelationships and interdependencies of functional entities of the system, has been constructed.

![Block diagram of the system](image)

Every block involve several devices to be noted in the design of the safety requirements as regulators, valves, filters, mass flow controllers, etc.
The goal of establishing the safety requirements is to minimize hazards that can occur in the system. There have been designed three steps to achieve hazard control:
  1. Recognize the hazards (chemicals and failure modes).
  2. Define and select preventive actions in order to eliminate the hazard or reduce its level.
  3. Provide safety devices, warnings and protective equipments.

5.2 Ground rules

5.2.1 ATEX directive

ATEX (“Atmosphères Explosibles”) is a directive outlining the standards for equipment and protective systems that must be carried out for controlling explosive atmospheres. It combines two European Directives related to equipment used and people working in potentially explosive atmospheres.

The functionality of these norms is to define the degree of protection required by the devices involved in the installation, in order to render it explosion proof when the working area has been defined as explosive atmosphere.

An explosive atmosphere for the purpose of ATEX Directive is defined as a mixture of flammable substances in the form of gases, vapors, mists or dusts; with air; under atmospheric conditions, in which, after ignition, the combustion spreads to the entire unburned mixture (it has to be noted that not always the whole quantity of the combustible material is consumed by the combustion).

An atmosphere, which could become explosive due to local and/or operational conditions, is called a potentially explosive atmosphere.

This chapter covers equipment and protective systems, which may be used in the gas mixing panel area and its surroundings.

This equipment includes any item which contains or constitutes a potential ignition source and which requires special measures to be incorporated in its design and/or installation in order to prevent the ignition source from initiating an explosion in the surrounding atmosphere. Also included in the term “equipment” are safety or control devices installed outside the hazardous area but having an explosion protection function.

- Definition of the areas. Zone and category

According to the ATEX guidelines the zones can be classified as explained in the table 7.

| Zone 0 | Area in which an explosive gas/vapor atmosphere is present continuously or for long periods or frequently, (e.g. 1000 hours or more per year). It is only Category I* equipment that can be used in Zone 0. |
| Zone 1 | Area in which an explosive gas atmosphere is likely to occur in normal operation occasionally, (e.g. 10-1000 hours/year). It is only Category I and II* equipment can be used in Zone 1. |
| Zone 2 | Area in which an explosive gas atmosphere is not likely to occur in normal operation and if it does occur, is likely to do so only infrequently and will exist for a short period only, (e.g. less than 10 hours/year). Category I, II and III* can be used in Zone 2. |
**Category I** equipment are equipments with a very high level of protection. **Category II** equipment are equipments with a high level of protection. **Category III** equipment are equipments with a normal level of protection.

*Table 7. Zone description*

The whole laboratory is not ATEX class; nowadays, the gas store and the closet where chemical products are stored are the only ones to be considered in ATEX guidelines, but the gas mixing panel will have to be as well, and it should belong, as the gas store does, to the zone 1, which is intended for products designed to be capable of remaining within its operational parameters and ensuring a very high level of protection for its intended use in areas in which explosive atmospheres caused by mixtures of air and gases, vapors, mists or air/dusts mixtures are highly likely to occur and are present continuously, for long periods of time or frequently.

Therefore, the electrical apparatus within the gas mixing panel should conform to ATEX requirements for the category that they belong; the main problem is that mass flow controllers which are ATEX class are priced very high.

### 5.2.2 AFS Directive ("Arbetsmiljöverkets författningssamling")

The AFS directive is a list of all existing regulations and guidelines which are issued by the Swedish Work Environment Authority pursuant to section 18, SFS 1977:1166. The installation has been built in the compliance of these. The directives taken into account are:

- **AFS 1999:4.**
  These regulations apply to pressure equipment and assemblies with the manufacturer specified maximum allowable pressure, PS, is higher than 0.5 bar.

- **AFS 1997:7.**
  These regulations apply to all activities for which gas is handled.

- **AFS 1985:14.**
  These regulations apply to protection against accidents during the testing of technical equipment with overpressure or vacuum.

- **AFS: 2002:1.**
  These Provisions apply to the professional use of pressure retaining devices, storage tanks, low-pressure gas containers and vacuum vessels. However, some specific sections are applicable to gas cylinders.

- **AFS 1992: 09.**
  These regulations apply when working with fusion welding and thermal cutting of metallic materials.

### 5.3 Assumptions

In the development of this chapter, not all possible situations can be counted on. There are a lot of possible gas mixtures whose consequences are unknown that at a higher level of study must be considered because of the fact they could be created by accident by a mechanical/electronic failure. This would be the purpose, among others, of the FMECA study.

Despite not doing such an accuracy study, a FMEA example was made in the chapter 6.9 referred to the micro turbine.
When working in an experimental environment there are many limitations at the moment to arrange a detailed plan. An initial plan is always done, but it can change as often as it requires, furthermore even the experiments can be re-planned in a different way, i.e. the amount of gases cannot be planned for long periods as this is based on the experiments that are taking place in the lab for a specific period and the specifications of the required gases can change at any moment.

5.4 Hazards

5.4.1 Electrical hazards

Electricity and electrical equipment create or contribute to a number of hazards; the most common ones are electric shock, heat, fire and explosion. Many fires are caused when more current flows through conductors than their designed capacity, causing excessive heating that can ignite surrounding materials. Arcing in the presence of an atmosphere containing combustible dust or flammable vapors may cause an explosion. To control this type of hazards, there are different options to be considered, such as physical controls, switching devices, grounding and bonding, ground fault circuit interrupters, and procedures.

5.4.2 Pressure hazards

Pressurized gases and fluids can cause injury or rupture tissues. Corrosion or physical damage from handling may create a weak point. The cylinders can reach pressures too high; consequently, the cylinders may leak slowly or suddenly.

5.4.3 Chemical hazards

This hazard recognition notes that three items of information about an agent must be known to determine if it is hazardous:

- Agent properties
- Concentration
- Duration and form of exposure

The main hazards of chemicals are health effects, fires and explosions and reactivity with other materials, but it depends on the working gases. In order to satisfy the specification requirements, the gas mixing panel will work with \( \text{N}_2 \), \( \text{CH}_4 \), \( \text{C}_3\text{H}_8 \), \( \text{CO} \), \( \text{CO}_2 \) and \( \text{H}_2 \), so the gas categories which these gases belong to are inert, flammable and toxic gases. Inert gases, as \( \text{CO}_2 \), are the ones that do not react with other materials. If released in a confined space, they will reduce the oxygen level to a point that asphyxiation could occur.

Flammable gases, when combined with air or oxidizers, will form a mixture that will burn or possibly explode if ignited. Flammable mixtures have a range of concentration below which they are too lean to be ignite, and above which the mixture is too rich to burn; the limits of this range are known as Lower Explosive Level (LEL) and Upper Explosive Level (UEL). The toxic gases, as \( \text{CO} \), will harm human tissue by contact or inhalation.
Also the produced mixtures have to be considered from a the safety point of view; these mixtures will be considered as flammable as they contain at least one flammable gas component. The one which contain CO will be considered toxic as well. Summary of the main hazardous characteristics for each gas is listed in the table 8.
### Table 8. Hazardous characteristics of the working gases

<table>
<thead>
<tr>
<th>Toxic by inhalation</th>
<th>H₂</th>
<th>CH₄</th>
<th>C₃H₈</th>
<th>CO</th>
<th>CO₂</th>
<th>N₂</th>
</tr>
</thead>
<tbody>
<tr>
<td>Burns with an invisible flame.</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>High pressure gas.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Compressed liquefied gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Can cause rapid suffocation.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extremely flammable.</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Extremely flammable liquefied gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May form explosive mixtures in air.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Vapors may spread long distances and ignite.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Immediate fire and explosion hazard exists when mixed with air at concentrations exceeding the lower flammability limit (LFL).</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High concentrations that can cause rapid suffocation are within the flammable range and should not be entered.</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Do not breathe gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Avoid breathing gas</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct contact with liquid can cause frostbite</td>
<td></td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Self contained breathing apparatus (SCBA) may be required</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

### 5.5 Safety requirements in the gas store

In order to avoid the risks that could happen in the gas store there are several measures to be applied:

- Its walls should have a fire resistance of one hour.
- Its roof is of light material with a low fire contribution⁷ and doesn’t have any visible wooden components, its framework is fireproofed.
- The floor must be horizontal and made of material with a "minimal" fire contribution¹ (asphalt). It is at the same level as the surrounding ground.
- The door is made of a material of minimal fire contribution¹. It opens outwards and is kept locked, in order that only authorized personnel can access to it.
- Piping is metallic, except where flexibility is required.
- The vessels and pipes are identified properly by the warning labels.
- As there are flammable gases, there is a risk of fire and/or explosion if a leak of flammable gas occurs, thus all electrical equipment, as it is noticed in the label situated in the wall of the gas house, conforms to the requirements of ATEX guidelines (as the light switch which doesn’t spark).
- Normal electrical apparatus are accepted if they have a specific protection such as inert-ion or over-pressurization.
- As there is liquefied gas, it has to be noted that it cannot be heated by a naked flame. The cylinder which contains this kind of gas is heated by electrical heating completely Ex (ATEX class).
- There is a regulator located in the gas store which reduces a variable high inlet pressure to a constant lower outlet pressure. It must be rated for the highest

¹ See table 9
possible working pressure. A relief valve, between the regulator and the first shutoff valve in the system, is used to protect the system from overpressure. The relief valve set point should be set to 25 percent over working pressure at a safe figure because the system test pressure is 50 percent over working pressure.

- A flow limit shutoff valve automatically shuts off the flow from the cylinders if that flow rate exceeds a limit.
- Pressure gauges are provided in the system to indicate the pressure within each line.
- An oxygen detector is installed to detect the lack of oxygen due to the presence of other gases, when the oxygen level is below 19.5%, it activates a visual and auditory alarm which cuts the gas supply and opens a chimney located on top of gas storage, this chimney is in charge of sucking out all the gases in the line.
- There are two sensors, one located on the top of the wall and the other at the bottom; the one on the top is for detecting the gases whose density is lower than the air, and the sensor on the bottom is for detecting heavier gases.
- All metallic equipment must be grounded.
- Fire detectors are installed in the gas store. A high level fire alarm shall activate the same actions as the oxygen detection alarm.
- The system shall shut down automatically in the case of failure of services (electricity, compressed air, water, etc.).
- The distribution of the cylinders inside allows the rapid evacuation of them in the case of a fire in the nearby. A dry powder extinguisher is available near the door, this is the most versatile of all fire extinguishers and can be used on class A, B and C fires and fires involving electrical equipment (see table 10).
- The cylinders are stored in a vertical position and are securely attached to a bank to prevent them from falling. Empty cylinders are stored separately from full cylinders. They must be appropriately labeled to indicate that they are empty.
- Cylinders must be handled in the proper way.
- The gas store must be kept clean and tidy and free from all combustible waste material. In particular, they must be kept free of paper, rags, dry grass and leaves.
- Smoking and the use of naked flames or incandescent apparatus is forbidden.
- The temperature cannot rise above 50ºC, there is no heat detector because it is considered unnecessary as the range of temperatures during the year is from -20ºC till 30ºC.
- All maintenance and repair of gas cylinders is forbidden within a store and its protection zone.
### 5.6 Safety requirements in the piping

The piping is about 175 m long, and brings the gases from the gas store till the lab through an underground corridor. There are as many pipes as different gases, in addition to the exhaust lines which work in case of failure. The safety measures to be applied are the following:

- The gas distribution must be carried out at pressures lower than the one of the cylinders. Nowadays, the highest pressure that the piping can resist is about 60-65 bars.
- All parts that are used in the piping (valves, regulators, pipelines, etc.) are suitable for the type of gas being handled. They must be checked regularly, and in case any of them exhibits signs of substantial wear must be discarded and replaced for another one also recommended by the supplier.
- It is important to take into account that even when other non-standard devices can be physically used to make connections, their use may cause serious leaks and catastrophic failure.
- Individual gas lines are equipped with non-return valves to prevent the back flow of gas from higher pressure systems to those at lower pressure and safety valves to protect the piping from overpressure resulting from a pressure regulator fault which transmits full cylinder pressure to the system. There is an indication on each pipe to its contents and the direction of flow of the gas.
- All piping is at least 50 cm from cable trays with electrical conductors.
- All piping in the distribution system is metallic. It has to be noted that there is no soft soldering because of its low resistance to vibration and heat.
- Like the gas store, this area is equipped with detectors and extinguishers which are connected to the chimney system.
- Before a pipe is going to be filled with a flammable gas, it must be purged of air with nitrogen in order to avoid explosions. It’s the same when a system is being shut down after operating with flammable gas, it must be purged of its gas filling before air is allowed to enter.
- The whole system, also the gas store, shall be tested for leaks at least once per year as part of their regular maintenance. Nowadays, in the system, leak testing is

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimal</td>
<td>It is usually determined, in the different countries, by a combustibility test based on International Standards. This class is subdivided to enable totally inorganic building materials to be differentiated from those with low (usually &lt; 1%) organic content such as mineral fiber panels containing binders.</td>
</tr>
<tr>
<td>Low</td>
<td>It’s a measure of its behavior in an initiating fire. This class is made up of the materials which usually start to participate at a later stage of the fire.</td>
</tr>
<tr>
<td>Normal</td>
<td>It’s a measure of its behavior in an initiating fire. It’s made up of those which resist medium and low intensity ignition sources for a short time (of the order of minutes).</td>
</tr>
<tr>
<td>High</td>
<td>It’s a measure of its behavior in an initiating fire. It’s made up of those which are set on fire by practically any ignition source and are therefore not permitted to be used as building materials.</td>
</tr>
</tbody>
</table>

*Table 9. Classification of the fire performance of building materials, elements and components*
carried out when changing bottles, hoses or any other equipment that could leak and also before each run.

- All maintenance suggested by the manufacturer must be carried out.

5.7 Safety requirements in the laboratory

The safety measures to be applied in the laboratory are the following:
- All piping arriving at the lab is connected to pressure regulators to get a constant pressure without fluctuations.
- These pressure regulators are located in a cabinet with a ventilation extraction system. This ventilation system is provided with gas detectors checking the oxygen level and flammable gases. Since there is no electrical device inside, it is not ATEX class.
- The door has a lock which only authorized personnel can open; however if the door remains open longer than a certain time a visual alarm warns about it and minutes later, if the door is still open, an auditory alarm system is activated and chimney system as well; this measure is to avoid possible overpressure in the gas piping.
- All flammable products are closed in a cabinet, which is ATEX class and has a ventilation system.
- As sensitive electrical equipment is situated in the lab, carbon dioxide extinguishers are used which leave no residue. The carbon dioxide extinguishers are filled with non-flammable carbon dioxide under extreme pressure as a gas or liquid. They work by reducing the oxygen content of air and by cooling. It is also useful, but less effective, extinguishing Class A fires because they may not be able to displace enough oxygen to successfully put the fire out. Class A materials may smolder and re-ignite.
- There are first-aid supplies in strategic locations.
- An Emergency Stop button is provided in the lab.
- All maintenance must be done according manufacturer specification.

<table>
<thead>
<tr>
<th>Class A</th>
<th>Class A fires involve ordinary combustibles (wood, paper, cloth, rubber, plastics). Extinguishment is caused by cooling or smothering</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class B</td>
<td>These fires involve flammable and combustible liquids, flammable gases, greases, and oils. Extinguishment is accomplished by inhibiting the release of combustible vapors or the development of the hydroxyl radical</td>
</tr>
<tr>
<td>Class C</td>
<td>Electrical equipment fires are class C fires. Extinguishment agents for electrical fires must not conduct electricity</td>
</tr>
<tr>
<td>Class D</td>
<td>Class D fires involve combustible metals. Extinguishment agents must absorb heat and not react with the metals</td>
</tr>
</tbody>
</table>

Table 10. Fire classes

5.8 Safety requirements for the gas mixing panel

The safety measures to be applied to the gas mixing panel are the following:

---

2 See table 10
- Its location must be separated from the gas storage area and be near the experiment or test area provided.
- It must be installed in a gas cabinet according to the ATEX directive and classified as a Flammable Gas Zone, then implement the required security measures to minimize hazards from compressed and/or flammable gases in the event of a fire external or internal to the gas cabinet.
- The door will be fitted with a lock and with a visual and auditory alarm which will work like the alarm of the pressure regulators cabinet.
- It has to be located in a ventilated area and provided with a ventilation system.
- Equipment and protective systems shall be designed and manufactured after the analysis of possible operating faults in order to avoid dangerous situations (FMECA study), i.e. all apparatus (mass flow controllers, switches,...) must be ATEX class. If they cannot be obtained, equivalent national standards or improvised protection may be employed (like pressurization method).
- The gas type and temperature ratings should be communicated to the supplier that provides the apparatus.
- There will be ball-valves to shut down the system manually.
- Gas filters will be used in order to separate dust and other particles such as oils, waxes, etc., and protect the system.
- Written instructions to shut down the gas mixing system manually and in a safe manner shall be available beside it, as well as a placard with instructions for emergency response and emergency contact numbers.
- An operating manual containing an accurate flow diagram of the complete system shall be available near the gas mixing panel.
- All written instructions shall be up-dated as necessary and particularly after modifications to the system or to the operating procedures.
- The personnel involved in the system should be trained in the proper way, as well as an emergency plan must be traced.

More detailed information about this subject (emergency planning, handling measures, personnel training...) can be found in the documents specified in the references.
### 5.9 FMEA Study example

<table>
<thead>
<tr>
<th>ITEM NUMBER</th>
<th>ITEM FUNCTIONAL ID</th>
<th>POTENTIAL FAILURE MODES</th>
<th>FAILURE MECHANISM</th>
<th>LOCAL EFFECTS</th>
<th>NEXT HIGHER LEVEL</th>
<th>END EFFECTS</th>
<th>DETECTION METHOD</th>
<th>SEVERITY CLASS</th>
<th>OCCURRENCE RATING</th>
<th>DETECTION CLASS</th>
<th>RISK PRIORITY NUMBER</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.0</td>
<td>MFC of methane/Supply methane to the mixture at the sequent</td>
<td>Provide higher methane flow</td>
<td>Sequent mistake (human error)</td>
<td>Too high flow for the piping</td>
<td>System doesn't run</td>
<td>System doesn't run</td>
<td>System stops</td>
<td>4</td>
<td>2</td>
<td>10</td>
<td>80</td>
</tr>
<tr>
<td>100.1</td>
<td></td>
<td>Higher power level of the mixture</td>
<td></td>
<td>Explosion</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>10</td>
<td>1</td>
<td>10</td>
<td>100</td>
</tr>
<tr>
<td>100.2</td>
<td></td>
<td>Working temperature increases</td>
<td>None effects</td>
<td>Temp sensor</td>
<td>1</td>
<td>4</td>
<td>1</td>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>100.3</td>
<td></td>
<td>Breakdown</td>
<td>Temp sensor</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>84</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The Risk Priority Number (RPN) methodology is a technique used to analyze the risk associated with potential problems identified during a Failure Mode and Effects Analysis (FMEA).

This method rates each potential problem according to three scales:
- **Severity**, which rates the severity of the potential effect of the failure.
- **Occurrence**, which rates the likelihood that the failure will occur.
- **Detection**, which rates the likelihood that the problem will be detected before it reaches the end-user/customer.

Rating scales have a range from 1 to 10, with the higher number representing the higher risk (see tables 11, 12 and 13).

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Effect</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>None</td>
<td>No reason to expect failure to have any effect on Safety, Health, Environment or Mission.</td>
</tr>
<tr>
<td>2</td>
<td>Very low</td>
<td>Minor disruption to facility function. Repair to failure can be accomplished during trouble call.</td>
</tr>
<tr>
<td>3</td>
<td>Low</td>
<td>Minor disruption to facility function. Repair to failure may be longer than trouble call but does not delay Mission.</td>
</tr>
<tr>
<td>4</td>
<td>Low to moderate</td>
<td>Moderate disruption to facility function. Some portion of Mission may need to be reworked or process delayed.</td>
</tr>
<tr>
<td>5</td>
<td>Moderate</td>
<td>Moderate disruption to facility function. 100% of Mission may need to be reworked or process delayed.</td>
</tr>
<tr>
<td>6</td>
<td>Moderate to high</td>
<td>Moderate disruption to facility function. Some portion of Mission is lost. Moderate delay in restoring function.</td>
</tr>
<tr>
<td>7</td>
<td>High</td>
<td>High disruption to facility function. Some portion of Mission is lost. Significant delay in restoring function.</td>
</tr>
<tr>
<td>8</td>
<td>Very high</td>
<td>High disruption to facility function. All of Mission is lost. Significant delay in restoring function.</td>
</tr>
<tr>
<td>9</td>
<td>Hazard</td>
<td>Potential Safety, Health or Environmental issue. Failure will occur with warning.</td>
</tr>
<tr>
<td>10</td>
<td>Hazard</td>
<td>Potential Safety, Health or Environmental issue. Failure will occur without warning.</td>
</tr>
</tbody>
</table>

Table 11. Possible qualitative severity rankings (S).

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Failure Rate</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1/10000</td>
<td>Remote probability of occurrence; unreasonable to expect failure to occur</td>
</tr>
<tr>
<td>2</td>
<td>1/5000</td>
<td>Very low failure rate. Similar to past design that has, had low failure rates for given volume/loads</td>
</tr>
<tr>
<td>3</td>
<td>1/2000</td>
<td>Low failure rate based on similar design for given volume/loads</td>
</tr>
<tr>
<td>4</td>
<td>1/1000</td>
<td>Occasional failure rate. Similar to past design that has had similar failure rates for given volume/loads.</td>
</tr>
</tbody>
</table>
Table 12. Possible qualitative occurrence rankings (O).

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Detection</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Almost Certain</td>
<td>Current control(s) almost certain to detect failure mode. Reliably controls are known with similar processes.</td>
</tr>
<tr>
<td>2</td>
<td>Very High</td>
<td>Very high likelihood current control(s) will detect failure mode</td>
</tr>
<tr>
<td>3</td>
<td>High</td>
<td>High likelihood current control(s) will detect failure mode</td>
</tr>
<tr>
<td>4</td>
<td>Moderately High</td>
<td>Moderately high likelihood current control(s) will detect failure mode</td>
</tr>
<tr>
<td>5</td>
<td>Moderate</td>
<td>Moderate likelihood current control(s) will detect failure mode</td>
</tr>
<tr>
<td>6</td>
<td>Low</td>
<td>Low likelihood current control(s) will detect failure mode</td>
</tr>
<tr>
<td>7</td>
<td>Very Low</td>
<td>Very low likelihood current control(s) will detect failure mode</td>
</tr>
<tr>
<td>8</td>
<td>Remote</td>
<td>Remote likelihood current control(s) will detect failure mode</td>
</tr>
<tr>
<td>9</td>
<td>Very Remote</td>
<td>Very remote likelihood current control(s) will detect failure mode</td>
</tr>
<tr>
<td>10</td>
<td>Almost Impossible</td>
<td>No known control(s) available to detect failure mode</td>
</tr>
</tbody>
</table>

Table 13. Possible qualitative detection rankings (D).

The RPN for each issue is calculated by multiplying severity, occurrence and detection.
The RPN is used to rank and identify the concerns or risks associated with the operation due to the design. This number will provide a means to prioritize which components should be evaluated by the team in order to reduce their calculated risk through some type of corrective action or maintenance efforts. However, when severity is at a high level, immediate corrective action may be given regardless of the resultant RPN.
RPN ratings are relative to a particular analysis. Therefore, an RPN in one analysis is comparable to other RPNs in the same analysis but it may not be comparable to RPNs in another analysis.
6 CIRCUIT LAYOUT

The first design of a possible gas mixing panel was made with Microsoft Visio software.

The considerations to take into account in order to design the gas mixing panel are both, the economic cost and the accuracy of the results provided by the panel.

The problems that appeared when designing this panel were two:

- On the one hand, the gases belonging to the same mixture cannot share one mass flow controller simultaneously, so at least, the gas mixing panel will have to work with 5 controllers, since the gasified biomass has 5 components.

- On the other hand, two gases that have different behavior in front of physical changes cannot share the same controller because of the limitations explained in the chapter 7. So if there was the possibility that a controller worked with two different gases, it was rejected because they had too much different physical proprieties.

Those are the reasons why so many controllers have been involved in this theoretical design, increasing the cost of the gas mixing panel.

- Moreover the panel must be ATEX class, so the meters should be Ex-proof (apparatus very expensive).

A solution in order to reduce the high costs when building the gas mixing panel would be the use of mechanical meters, which use a small ball as an indicator in a variable-area vertical tube, but this option has been rejected because when the system conditions deviate from the calibration of a particular meter, the gases might expand and contract thereby changing density and viscosity, as a consequence, the meters’ accuracy can quickly degrade.

The theoretical proposal for the gas mixing panel has been designed to work with controllers calibrated with the working gas (see figure 2 and 3).

The calculation method used is the same as the one used in the chapter 4, “Specification requirements”, when the flow was calculated for each gas.
Figure 2 Circuit layout proposal
Figure 3 Circuit layout legend
7 LIMITS OF THE MASS FLOW CONTROLLER

There have been identified some limitations associated to the use of the mass flow controllers:

- The abundance of thermal mass flow controller manufacturers constitutes an additional complication to their use, as these instruments generally have different and specific designs and performance, so they are not interchangeable.
- The standards written to address the specifications of the instruments cannot eliminate the systematic errors in the original calibration of the mass flow controllers done by manufacturers. Moreover, the mass flow controllers that are used to measure the process gases are generally calibrated with N\textsubscript{2} or air and “corrected” for other gases, but the correction factors are not really reliable, as they are calculated in specific conditions, and pretty often they are misunderstood. Thus it is important to understand how mass flow controllers perform under conditions that differ from the laboratory conditions where they were calibrated.
- As mass flow controllers are used with multiple gases, it is a common practice to calibrate the instrument with one gas, such as N\textsubscript{2}, and employ “generic” correction factors to estimate the flow with other gases. Unfortunately, these correction factors are instrument specific and may vary by as much as 10% between instruments of different designs. Additionally, the correction factors may be a function of flow and not constant at all. Errors in the measured flow are also incurred when the temperature or pressure of the gas differs from their calibrated values as it has been commented before. Manufacturers usually report an estimated uncertainty due to these effects, but the accuracy of these estimations is unknown.
- The main part of the thermal mass flow controller is the sensor that consists of a stainless steel capillary tube with thermometer elements. A part of the gas flows through this bypass sensor, and is warmed by heating elements. Consequently the measured temperatures T\textsubscript{1} and T\textsubscript{2} drift apart; this temperature difference is directly proportional to mass flow through the sensor (see figure 4).
Although the temperature difference is normally linearly dependent on mass flow, nonlinearities may be introduced in several ways: gas temperature is normally measured by measuring the temperature of the capillary wall, which may be different from the gas stream temperature, so it would introduce errors; the heat capacity of the gas may be temperature dependent, which may introduce nonlinearities into the flow measurement; other heat loss mechanism, such as heat losses, may introduce additional nonlinearities;...

7.1 Orientation effects

The mass flow controller works by means of measuring heat transfer to the gas, so anything that influences the heat transfer process will influence the measurement of the mass flow. Mounting affects the heat transfer by changing the amount of natural convection that takes place. This will have most noticeable result in zero changes, particularly when the sensing tube is rotated from perpendicular to parallel to gravity. The manufacturers recommend that the mass flow controllers are re-zeroed after an orientation change.

7.2 Pressure effects

The sensitivity of these meters depends slightly on the upstream pressure. Manufacturers typically give uncertainties due to changes in pressure of approximately 0.75% per MPa. Increasing the upstream pressure (for a given
temperature and mass flow) will cause the average velocity in the sensing tube to decrease. This velocity change may cause small changes in the sensitivity of the mass flow controller due to changes in the amount of heat transfer between the heated capillary and the gas. Moreover, a constant pressure is necessary for accurate measuring, that’s why a regulator must be installed upstream of the mass flow controller.

7.3 Temperature effects

The effect of temperature depends on the working gas. Usually only one generic specification for a particular test gas is given which may overestimate or underestimate these effects.

7.4 Low flow performance

The manufacturers specify that instruments measure and control flow down to 2% of their full scale value. All of them meet this specification when new, but it may change after a few months of operation.

In short summary, each instrument has been calibrated and adjusted for specific process conditions and gases. Throughput and accuracy of flow meters may be tremendously affected if physical fluid properties such as heat capacity and viscosity change due to changing process conditions.
8 NEW GAS MIXING PANEL SITUATION

According to the safety requirements, a proposal of the situation in the lab would be the one suggested by the following pictures (see figures 5 and 6) The principles on which the location is based are that it has to be situated in a ventilated area and the nearest possible to the rigs that it has to provide mixtures for.
Figure 5 Overview of the laboratory
Figure 6 New panel situation proposal
9 TEST OF THE ACTUAL FLOW RATE

A test of the flow rate has been done in order to check the flow capacity of the pipelines. This is the most important step in the thesis because this establishes the viability of achieving the specification requirements. The working gas is $\text{N}_2$.

9.1 Theoretical mass flow

A first attempt to determine the flow capacity of the pipelines was made using a theoretical approach which is detailed in the following lines. The purpose of this calculation is to get an approximation of the mass flow that should be obtained during the experiment. Since the flow through a duct is given by a pressure difference, all gas flow is compressible, i.e. the flow of gases can involve significant changes in density due to variations of the pressure. However the compressibility can be ignored in specific situations when fluids flow in long ducts at relatively low velocities ($\text{Ma}<0.3$); but in this case, compressibility becomes important and use of incompressible flow formulae can lead to serious errors. Unfortunately, the flow of a compressible fluid is further complicated by the fact that the fluid density depends on the temperature as well as on the pressure. In such systems, temperature may vary according to thermodynamic principles. As a consequence, in order to analyze the gas flow thermodynamics, motion and continuity laws must be considered. In order to make calculations possible, some hypotheses have been done (otherwise this study had been discarded as complex procedures would have been needed). A separated study for each part of the line is required (see figure 7).
Figure 7 Layout of the experiment
9.1.1 Gas house regulator

There are two regulators in the piping from the gas storage room till the laboratory. The primary function of a pressure regulator is to match the flow gas through the regulator with the demand for the gas placed in the storage room. The first regulator is located in the storage room, which is manufactured by CONCOA industry: 4922802-89-000. According to the specifications provided by CONCOA industry, the theoretical maximum flow of N$_2$ through the 4922802 regulator is 4,19 Nm$^3$/min, it means 251,4 Nm$^3$/h. This is a theoretical value that will never be reached because of safety reasons, but lower levels would not mean a restriction in the system.

9.1.2 Piping

The theoretical maximum flow is 97,83 Nm$^3$/h. It has been calculated forcing the outlet Mach Value equal to 1, as explained in the appendix B.

9.1.3 Lab regulator

The following limit is set by the second pressure regulating situated in the laboratory, manufactured by Linde industry: R200/1-50. According to the specification data sheet, the theoretical maximum flow is between 40 and 50 Nm$^3$/h. This is an approximate number since it has been extracted from a non-detailed chart.

9.1.4 Conclusions

Analyzing the data obtained in the calculations, the maximum mass flow will be the one smaller, i.e. the one imposed by the lab regulator. From this result, the mass flow controller specification has been chosen: its capacity must be higher than 60 kg/h, so the one with 97 kg/h of capacity will be suitable. After calculating the theoretical mass flow, the experiment can be planned.

9.2 Real mass flow. N$_2$ experiment

9.2.1 Software and considerations of the experiment

The used software is LabView, using as DDE server the one provided by Bronkhorst High-Tech industry, FlowDDE. The mass flow controller involved is manufactured by Bronkhorst High-Tech industry; this is calibrated with air so FLUIDAT software is used to do the proper calculation of conversion factor when N$_2$ is used (see appendix A). The best option would be to have the controller calibrated specifically for N$_2$ because the use of a conversion factor for calibration normally introduces a rather huge extra uncertainty to the absolute accuracy of the instrument, but in this case, as N$_2$’s properties (density and heat capacity) are quite similar to the air (see tables 14 and 15), the uncertainty introduced is not significant.
9.2.2 Mounting

The mounting has been done following the software specifications (see appendix C).

9.2.3 Experiment description

According to the considerations mentioned before, a description step-by-step of the experiment was first made (appendix D), however, like all experiments carried out in a laboratory are subject to changes imposed during execution. The method had to be changed because of the limitations of the used devices.

Finally, two experiments were developed:

In the first one, the mass flow was measured when the outlet pressure of the regulator situated in a gas cabinet of the lab was set at 10 bar all the time and the pressure outlet of the regulator situated in the gas storage was set at 10, 20, 30, 40, 50 and 60 bars.
In the second part of the experiment the mass flow of $N_2$ was measured when the outlet pressure of the regulator situated in the gas storage was set at 60bar all the time and the outlet pressure of the regulator situated in the gas cabinet of the lab was set at 15, 20, 25 and 30bar.
10 RESULTS

The results for each experiment were the following:

<table>
<thead>
<tr>
<th>$P_{\text{IN_LINE}}$ (bar)</th>
<th>10</th>
<th>20</th>
<th>30</th>
<th>40</th>
<th>50</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{\text{OUT_LINE}}$ (bar)</td>
<td>10</td>
<td>20</td>
<td>30</td>
<td>39</td>
<td>45</td>
<td>55</td>
</tr>
<tr>
<td>$P_{\text{MFC}}$ (bar) [set]</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>$P_{\text{MFC}}$ (bar) [read]</td>
<td>-</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>$m$ (kg/h)</td>
<td>13.30</td>
<td>21.07</td>
<td>29.20</td>
<td>32.93</td>
<td>35.16</td>
<td>36.04</td>
</tr>
<tr>
<td>$m_{\text{CORRECTED}}$ (kg/h$^3$)</td>
<td>12.87</td>
<td>20.38</td>
<td>28.24</td>
<td>31.85</td>
<td>34.01</td>
<td>34.86</td>
</tr>
</tbody>
</table>

Table 16. Results of the first part of the experiment. Mass flows measured at 20°C and 1 bar of pressure

![Pressure drop vs. mass flow corrected of the 1st part](image)

---

As the mass flow controller involved in the experiment is calibrated with air, the mass flow value read has to be corrected by the Correction Factor (see appendix A)
Table 17. Results of the second part of the experiment. Mass flows measured at 20°C and 1 bar of pressure.

<table>
<thead>
<tr>
<th>P_{IN_LINE} (bar)</th>
<th>60</th>
<th>60</th>
<th>60</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_{OUT_LINE} (bar)</td>
<td>43</td>
<td>43</td>
<td>40</td>
<td>41</td>
</tr>
<tr>
<td>P_{MFC} (bar) [set]</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>P_{MFC} (bar) [read]</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>m(kg/h)</td>
<td>48.43</td>
<td>49.49</td>
<td>50.15</td>
<td>50.61</td>
</tr>
<tr>
<td>m_{CORRECTED} (kg/h)^3</td>
<td>46.84</td>
<td>47.86</td>
<td>48.50</td>
<td>48.95</td>
</tr>
</tbody>
</table>

![Figure 9 Pressure drop vs. mass flow corrected of the 2nd part](image)

As can be seen in the tables, the outlet pressure in the lab regulator is not the one set, this is due to the fact that the regulator is separated from the open air only by the mass flow controller and few meters of piping and the pressure is set when the valve of the mass flow controller is closed, therefore when the mass flow controller is open, the pressure drops quickly till the atmospheric pressure.
11 DISCUSSION

Looking at the results obtained, the pressure drop is higher when working with higher mass flows. This is an expected effect because pressure drop is the consequence of the frictional forces on the fluid caused by a resistance to flow as the fluid flows through the tube. The main factors impacting resistance to fluid flow are fluid velocity through the pipe and fluid viscosity.

The reached highest flow, when the working gas is $\text{N}_2$, is 48,95 kg/h and it is when the pressure drop in the mass flow controller is about 8 bars.

This limit is caused by the dimensions of the piping. The small diameter forces to have a lower mass flow flowing through the pipe, this means the highest outlet pressure in the gas house regulator is about 65 bars, so the maximum pressure drop that can be reached by a device in the lab is about 60 bars. Therefore the mass flow through the piping has a limit, and if this was exceeded, it would create a dangerous situation in the lab and its surroundings (leaks, damages to the piping, explosions,...).

Because of the previous explanation, the highest mass flows of the gases that will be used by the gas mixing panel are annotated in the table 18.

<table>
<thead>
<tr>
<th>$\text{N}_2$ (kg/h)</th>
<th>CO (kg/h)</th>
<th>$\text{CO}_2$ (kg/h)</th>
<th>$\text{CH}_4$ (kg/h)</th>
<th>$\text{C}_3\text{H}_8$ (kg/h)</th>
<th>$\text{H}_2$ (kg/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>48,95</td>
<td>48,89</td>
<td>57,78</td>
<td>21,51</td>
<td>27,12</td>
<td>3,572</td>
</tr>
</tbody>
</table>

Table 18. Maximum mass flows per each gas measured at 20ºC and 1 bar of pressure.

As a result, this restriction affects to the goals that want to be achieved, specifically when gasified biomass is the working mixture: only 110kW of power will be able to be reached, instead of 200kW of power that are required by the target rig.
12 REQUEST QUOTATION

Gas mixing systems shall be designed by competent personnel with the relevant experience and knowledge to ensure that the systems are safe and effective. The relevant documentation has been compiled to make a request quotation and get the estimates from AGA and AirLiquide industries (appendix F). The proposal made by AirLiquide industry is to build a gas mixing panel which will work, at least to start, with three gases (N₂, CH₄ and C₃H₈) and will be able to make either a mixture to provide a high power level for the rigs, or another to provide a low power level for them, or anything between.
13 CONCLUSIONS AND FUTURE WORK

As previously explained on this project, the gas mixing panel is useful in terms of:
- The capacity to define different mixtures containing different gases and compositions depending on the purpose of the mixtures without depending on external companies
- Cost savings due to own manufacturing of the gas mixtures to be used by lab rigs, instead of purchasing them to gas mixtures providers

After developing this project, there have been identified several limitations on the benefits that would be obtained through the build of a gas mixing panel to be used in the lab rigs.

The main limitations detected are the following:
- The high price to build the gas mixing panel, as in order to accomplish the safety requirements explained during this project it must be ATEX class; therefore, devices to be used will be very expensive.
- The limitations imposed by the pipelines connecting the gas house and the lab: as they are thin, the biggest pressure they admit at the exit of the gas house is about 60bar, considering the pressure drop due to friction losses, pressure could descend until 40 bar; this pressure is too low to be considered useful, so it must be needed to invest money in redesign the existing pipelines or build another installation.
- The proposal of AirLiquide, the company that might build the installation (the only one that has answered to the request of information) according to the available budget will work only with three gases, combining them in order to obtain different mixtures to be delivered at a different power covering a range from a low to high level. This is not interesting to most of the lab team because this panel would not allow any detailed composition of gas.

Nevertheless, in case it is built, it still has to be studied the possibility of expanding this panel in the future to use a larger number of gases. In any case, the installation would be obsolete for future work/experiments within a short time due to the restricted physical characteristics of the gases.
- It has to be noted the importance of a FMECA study in order to design out the failures that could occur and to carry the maintenance out in a proper way according to the different hazardous situations that could happen. Since the aim of this study is to get the highest accuracy level, it must be made by expertise personnel.

In summary, despite all the benefits that the gas mixing panel could provide, due to technique and economical constraints, they cannot be totally achieved in the current situation (existing installations and budget), so its build should be discarded for the moment (that is the reason why the last planned steps of the “method of attack” chapter, as programming of the computer software, haven’t been run.)
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APPENDIX A

CORRECTION FACTOR CALCULATION

FLUIDAT software enables to calculate accurate conversion factors, not only at 20°C/1atm but at any temperature/pressure combination.

The theoretical conversion factor can be defined as the division factor to calculate the normal mass flow quantity of air that should be applied to a thermal mass flow instrument in order to obtain the same output signal as it would read when applying the final operation fluid for the target instrument.

In principle the conversion factor between two fluids is a multiplying flow factor of which the value depends on the flow measuring principle.

For a thermal mass flow meter the conversion factor is proportional to the Heat Capacity ($C_p$) and the Normal density ($D_n$) of the fluids for which the flow factor is calculated and thus related to volume flow units referenced to normal conditions only.

This factor is not a constant value; it may vary with temperature and pressure of both operation fluid and calibration fluid.

The formula to get the conversion factor ($CF_v$) is:

$$CF_v = (C_{p,1} \times D_{n,1}) \div (C_{p,2} \times D_{n,2})$$

In which:

- $C_p =$ heat capacity at constant pressure in [J/kg·K]
- $D_n =$ normal density in [kg/m³], at 0 °C and 1 bar.

The indices apply to the operation fluid (Fluid1) and the calibration fluid (Fluid2).

As the mass flow for a thermal mass flow meter is directly proportional to ($D_n \times C_p$), the formula for the converted flow shows like:

$$F_2 = F_1 \div CF_v$$

In which:

- $F_1 =$ instrument flow using Fluid1 in normal volume flow units
- $F_2 =$ calibration flow using Fluid2 in normal volume flow units
APPENDIX B  MASSFLOW CALCULATION IN THE PIPING

In this part of the calculation a compressible gas is flowing through a constant section-duct. The basic assumptions are:

• Steady one-dimensional adiabatic flow
• Perfect gas with constant specific heats
• Negligible shaft-work and potential-energy changes
• Friction factor is given by Darcy’s equation

This is the system:

\[ \rho V = \frac{\dot{m}}{A} = G = \text{const} \]

\[ \frac{d\rho}{\rho} + \frac{dv}{v} = 0 \]

\[ p \cdot A - (p + dp) \cdot A - \tau_w \cdot \pi \cdot D \cdot dx = \dot{m}(v + dv - v) \]

\[ dp + \frac{4 \cdot \tau_w \cdot dx}{D} + \rho \cdot v \cdot dv = 0 \]

\[ h + \frac{v^2}{2} = h_o = c_p \cdot T_o = c_p \cdot T + \frac{v^2}{2} \]

\[ c_p \cdot dT + v \cdot dv = 0 \]

As there are more unknowns than equations, two additional relations are needed:

![Figure 10 Elemental volume control for flow in a constant section pipe](image)
Perfect gas law

\[ p = \rho \cdot R \cdot T \]

Or

\[ \frac{dp}{p} = \frac{d\rho}{\rho} + \frac{dT}{T} \]

It’s assumed that wall shear is correlated by Darcy friction factor:

\[ \tau_w = \frac{1}{8} f \cdot \rho \cdot v^2 = \frac{1}{8} f \cdot k \cdot p \cdot Ma^2 \]

If the Mach value definition is taken into account

\[ v^2 = Ma^2 \cdot k \cdot R \cdot T \]

Or

\[ \frac{2 \cdot dv}{v} = \frac{2 \cdot dMa}{Ma} + \frac{dT}{T} \]

Eliminating variables, the following working relations can be obtained:

\[ \frac{dp}{p} = -k \cdot Ma^2 \frac{1 + (k - 1)Ma^2}{2(1 - Ma^2)} f \frac{dx}{D} \]

\[ \frac{d\rho}{\rho} = -\frac{kMa^2}{2(1 - Ma^2)} f \frac{dx}{D} = -\frac{dv}{v} \]

\[ \frac{dT}{T} = -\frac{k(k - 1)Ma^4}{2(1 - Ma^2)} f \frac{dx}{D} \]

\[ \frac{dMa^2}{Ma^2} = kMa^2 \frac{1 + \frac{1}{2}(k - 1)Ma^2}{1 - Ma^2} f \frac{dx}{D} \]

The key parameter in this type of fluids is the Mach number. Whether the inlet flow is subsonic (Ma<1) or supersonic (Ma>1), the duct Mach number always tends downstream toward Ma=1 to satisfy the second law of thermodynamics (entropy increases). It can be shown when equations of dp/p and dρ/ρ and the entropy from the following one are combined (figure 2).

\[ \frac{s_2 - s_1}{c_v} = \ln \left[ \frac{p_2}{p_1} \left( \frac{\rho_1}{\rho_2} \right)^k \right] \]
Then, the maximum mass flow will be able to be reached at the moment that the flow is sonic, i.e. outlet Mach value equal to 1.

\[ \frac{v_2}{c_2} = 1 \]

\[ v_2 = c_2 = \sqrt{R \cdot k \cdot T_2} \]

The outlet temperature is the ambient temperature in the lab, 288 K, thus \( v_2 = 346.01 \text{ m/s} \).

So the maximum mass flow of N\(_2\) will be:

\[ \dot{m} = \rho \cdot q = \rho_2 \cdot A \cdot v_2 = 0.0323 \frac{kg}{s} = 116.42 \text{ kg/h} \]
APPENDIX C  EXPERIMENT MOUNTING

1. Instruments and connection preparation

- Instrument mounting
  The bottom side of an EL-FLOW Base consists of two mounting holes for stable mechanical fixation of the instrument. The preferred mounting position of EL-FLOW Base mass flow controllers is horizontal. Other mounting positions may introduce a zero shift and/or little gas and pressure dependency of the zero signal. Avoid installation in close proximity of mechanic vibration and/or heat sources.

- Piping requirements
  The piping must be absolutely clean. Do not mount abrupt angles direct on in- and outlet, especially not on high flow rates. At least 10 pipe diameters distance between the angle and the instrument is recommended. Do not mount pressure regulators direct on the inlet of gas flow meters/controllers, but allow some meters of piping (at least 25 pipe diameters).

- Interface
  The MFC instrument is operated by means of Digital RS232 Flowbus interface (connected to COM-port by means of special cable on 38400 Baud).

- Power Supply
  The MFC is powered with +24 Vdc.

- Power and warm up
  Before switching on power, check if all connections have been made according to the hook-up diagram (figure 13).
The MFC should be connected to any of the three 0,5 patch cables. The bus begin terminator 7.03.297 has red color. The end terminator 1.09.240 has black color. It is recommended to turn on power before applying pressure on the instrument and to switch off power after removing pressure. Check fluid connections and make sure there is no leakage. Turn on power and allow at least 30 minutes warming up and stabilizing. When applying pressure to the system, take care to avoid pressure shocks in the system and increase pressure gradually up to the level of the actual operating conditions.

- System purging
  Complete purging is also required to remove such fluids from the system before exposing the system to air.

2. Design application
- Basic RS232 Flowbus operation
  Dynamic Data Exchange (DDE) provides the user a basic level of inter process communication between Windows applications. RS232 Flowbus communication can be used for operating your instrument using the Bronkhorst FLOWDDE server application.

FlowDDE is a DDE server application. Together with a client-application, as LabView, it is possible to create an easy way of data exchange between the flow controller and the Windows application. To use Flow DDE with LabView, the following syntax is used:

- **Server name:** FLOWDDE
- **Topic name:** C(nr)=channel number  
  P(nr)=parameter number
- **Note:** parameter 8 = measured value, parameter 9 = set point wanted value
Parameters 8 and 9: 0-100% ↔ 0-32000
Complete FlowDDE documentation is found in the FlowDDE help in the info menu.
LabView program is designed according to the previous explanation (see screenshots in the appendix E)

- Initializing application
  Double click on the FLOW-BUS DDE server icon
  After a short while the Main window will appear with the BRONKHORST HI-TEC logo in the center.
  The program will not communicate yet with the flow controller, until the Open Communication function is selected from the Communication menu.
  Before selecting Open communication, it's made sure the interface settings are correct at communication settings; this function allows the user to change the communication parameters and to select the interface to FLOW-BUS you want to use.
  Changes made involve both DDE Server and the RS232 communication interface module.
  Open Communication will start the initialization process. During the initialization process the DDE server will automatically configure itself according to the present FLOW-BUS network configuration.
  The FLOW-BUS DDE server is now ready to work and the LabView application may be started.
  The client application will be able to communicate with a virtual system (in the database). This can be useful for application development, demo and test purposes.
  Starting LabView:
  Send a set point to the instrument and check the measured value
  Let the instrument warm-up for 30 minutes for best accuracy
  Then, the mass flow controller is now ready for operation.
PREPARATIONS

1. Installation of flow meter:
   - The mass flow meter has to be on a horizontal position.
   - Connect it at a pipe of 10 inlet diameter, at least 25 cm after the pressure regulating valve in the cabinet at the receiving end.
   - Between regulating valve and the mass flow meter there will be a valve and a filter.
2. The outlet of the flow meter shall be left open pointing to a fume cupboard.
3. Install existing pressure gauges at the sending and receiving ends. Evaluate their accuracy according to their specifications.
4. Check the connections computer-instrument according to the hook-up diagram.

5. Gas bottle of nitrogen situated in the gas house is connected to the appropriate pipe using the normal pressure reduction valve.
6. Open FlowDDE software.
   - Select the correct channel used in the Communication settings menu
   - Open communication
7. Open LabView program

SAFETY

1. Make sure...
   - the piping is absolutely clean
   - there is no leakage in the piping
   - the connections are checked
2. How to act in case of leaks or spills
   - Personal precautions:
Evacuate area. Use breathing apparatus when entering in area unless making sure the atmosphere is safe. Make sure of the adequate air ventilation.

- Precautions for environmental protection:
  - Trying to stop the leak/spill.
- Cleaning methods:
  - Ventilate the area

3. Keep in mind
   Nitrogen is not classified as a dangerous substance, but it's asphyxiating at high concentrations.
   The pressure drop across the MFC shall be at least 2 bars.
   The inlet pressure at which the MFC is calibrated is 10 bars.

**EXECUTION OF TEST**
1. Set the pressure reduction valve in the sending end to 10 bars.
2. Open the valve in the receiving end.
3. Write the setpoint in the Labview program at 97 kg/h (max mass flow) and press “start”.
4. Close the valve in the receiving end.
5. Change the pressure to 7 bars.
6. Repeat steps 2, 3 and 4.
7. Change the pressure to 5 bars.
8. Repeat steps 2, 3 and 4.

**DATA EVALUATION**
Estimate the pressure drop of each regulator and piping as well.
Confront results with theoretical data.
Evaluate differences.
Confront results with specification requirements.
Evaluate differences and establish operating limits for the gas mixing panel.
APPENDIX E
LABVIEW SCREENSHOTS

Front Panel:

Figure 14 LabView Screenshot. Front Panel

Block program:
1. Initializing

Figure 15 LabView Screenshot. Block diagram
2. Displaying mass flow data on screen

![Figure 16 LabView Screenshot. Block diagram](image)

3. Changing set point

![Figure 17 LabView Screenshot. Block diagram](image)
APPENDIX F

DATA PROVIDED TO THE COMPANIES

Specification requirements data

SPECIFICATIONS OF THE RIG’S:

Micro Gas Turbine

- Work pressure: 50 mbar
- Gases used: natural gas and mixture CH₄-CO₂.

Tagget rig

- Work pressure: 5 bar
- Gases used: gasified biomass.

High Pressure Catalytic Conversion

- Work pressure: 5 – 40 bar
- Gases used: gasified biomass and methane

The line pressure is 50 bar

PIPES’ CHARACTERISTICS

- Diameter: (In) 10mm
- (Out) 12mm
- Length: 375-200m

PRESSURE OF SUPPLIES BOTTLES

- Carbon dioxide: 20 – 40 bar
- Carbon monoxide: 200 bar
- Hydrogen: 200 bar
- Methane: 200 bar
- Nitrogen: 200 bar
- Propane: 10 bar

The max pressure that can be reached because of the design constraints is 60 bar.

MIXTURES

- a) Natural gas
  - Composition (% volume):
  

5% Carbon dioxide (10.87% mass)
10% Propane (21.78% mass)
85% Methane (67.35% mass)
Mass flow range: [0-8.23] kg/h

*This mixture is supposed to be used by other rigs not defined yet. So the mass flow rate is calculated to give a power from 0 till 100 kW.

b) Gasified biomass

Composition (% volume):
4% Methane (2.4% mass)
12% Hydrogen (0.9% mass)
16% Carbon dioxide (26.1% mass)
18% Carbon monoxide (18.7% mass)
50% Nitrogen (51.9% mass)
Volume flow range: [0-1.68] kg/h

c) CH₄-CO₂

Composition (% volume):
35% Carbon dioxide (40% mass)
65% Methane (60% mass)
Volume flow range: [9-14] kg/h