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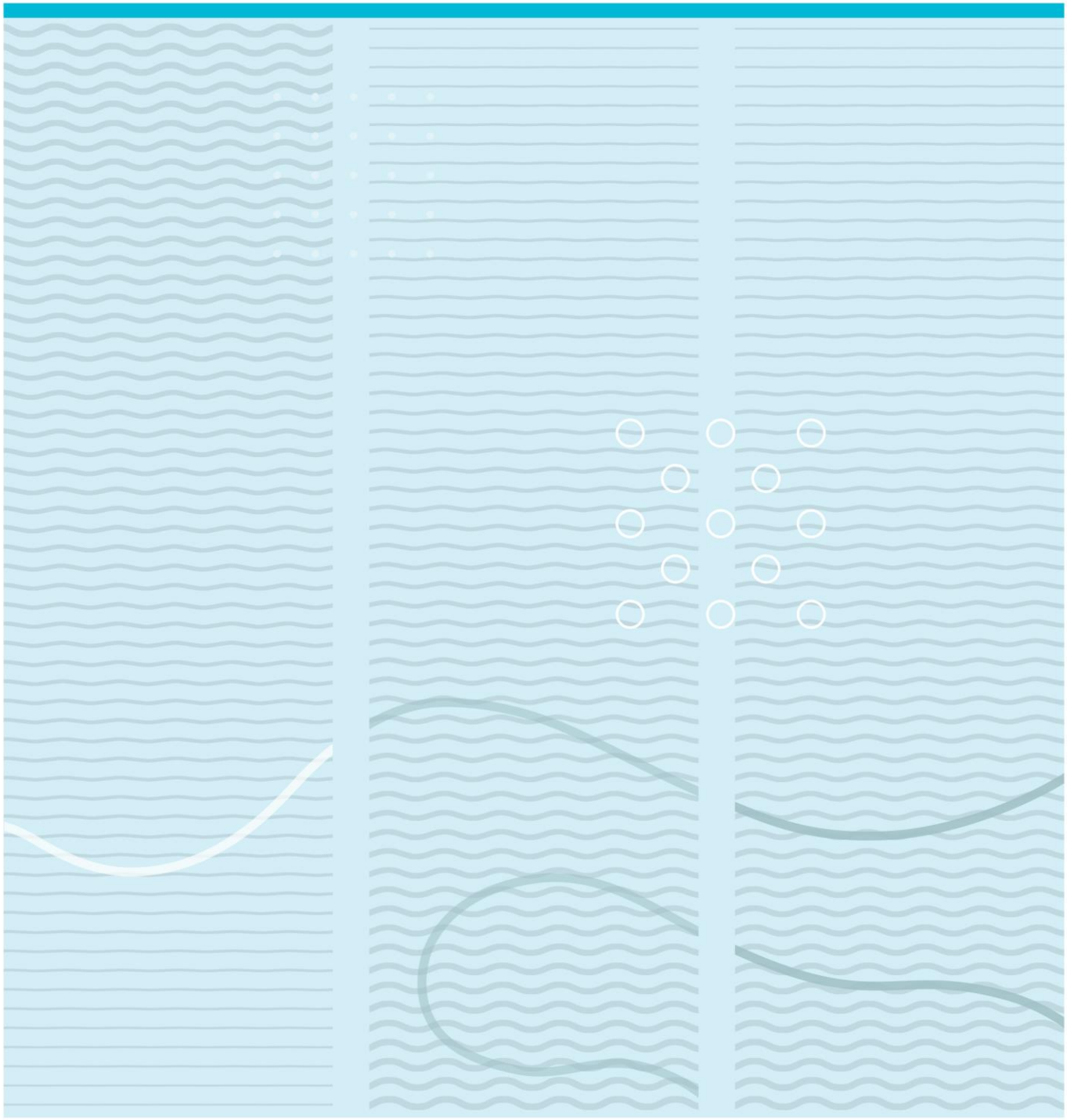
Vyncke Stijn

Process Tomometric Data Fusion with Multimodal Sensor Suite in Multiphase flow studies



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Abstract:

The objective of the thesis is to propose simple tests on raw electrical measurements, using electrical capacitance tomography in order to assess the prevailing flow regime in the test section. This information regarding the flow patterns is useful in itself in many scientific and technological applications: it can be used in computational fluid dynamics (CFD) for fine-tuning the input parameters, increasing safety on site by providing information about dangerous flow patterns such as slug. In electrical tomography, the reconstruction of an image from the electrical measurements is greatly enhanced when one can postulate what approximately the test area looks like in real time (i.e. flow patterns). By using the raw data coming from the sensor, we avoided the image processing and proposed criteria for different flow patterns. Fang and Cumberbatch have proposed to analyse the eigenvalues of the capacitance data matrix in order to identify core annular or stratified flows. They argue that the analysis of eigenvalues collapses the amount of data to be processed and has the advantage that the analysis is rotationally invariant. Their study has been completely based on numerical simulations of the response of an electrical capacitance tomography (ECT) sensor. Based on their work, we have considered the analysis of eigenvalues of the capacitance matrix but obtained the test criteria based on experimental data, gathered during measurement sessions. We have focused on flow regimes occurring in horizontal pipes. Our tests somewhat differ from Fang and Cumberbatch. One criterion differentiates intermittent flows (plug and slug) form static flows (stratified, wavy and annular) based on the standard deviation of the time series set of the capacitance measurements. The second criterion differentiates annular flows from layered flows (stratified and wavy). For intermittent flows, we have found another criterion using the gamma-ray sensor. A Fast Fourier Transform (FFT) was applied to the time series. This gave us the frequency of plugs and slugs. With this criterion, we can identify intermittent flows.

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Contents

Foreword

This thesis assumes basic knowledge of MATLAB. This is used in the chapters were the analysis of the data is discussed and the mapping of the results.

I would like to thank Antoine Dupré for his help with this thesis, Fredrik Hansen for his help with performing the experiments and Saba Mylvaganam for his advice, help and positive spirit. In addition, I would like to thank my girlfriend, friends, family in Belgium and my Norwegian family for their support.

<Porsgrunn, Norway/10.06.2016>

<Stijn Vyncke>

1. Introduction

In this thesis, the goal is to propose simple test for identifying certain types of multiphase flow patterns. The knowledge of the type of flow pattern can be useful in many different applications.

One application could be to make operations safer. In pipelines, a flow pattern called slug can occur. A characteristic of a slug is that is has irregular flows. Liquid accumulates in the pipe and in some cases fill the pipe totally, flows through the pipe and eventually the level in the pipe is low again. This happens in a cyclic behavior. One of the results can be that vibrations occur which can causes severe problems for the whole operation. If a simple test can reveal the flow pattern, actions can be taken in order to prevent the potential problems (e.g. damages to equipment of the process, high level of liquid in multiphase flow separators, floods).

After this introduction, in Chapter 2, 3, 4 and 5, the following topics are discussed: tomography, flow regimes in multiphase flow, the experimental set-up used for the experiments and the data acquisition. This will provide the reader with some general knowledge about the topic.

The Chapters 6, 7 and 8 will describe the methods used to analyze the raw capacitance data, the characterization of the flow regimes and the mapping of the flow regimes using the criteria found for the different flow regimes.

2. Multimodal process tomometry

2.1. Introduction

In this chapter, the tomographic measurement system is described. An enumeration is made of the different types of tomographic sensors and the technique for the electrical capacitance tomography (ECT) is illustrated. In addition, a brief description of gamma-ray densitometry is given.

2.2. Concept of tomography

Industrial process flows consists of complex mixtures of different components. These components can occur in different state of matter: gas, liquid and solid. When the process flows are being controlled and monitored, process tomography gives the operators a real-time flow estimation. This gives the operator a tool to monitor and control flow behavior. This is done mostly non-intrusively using process tomographic systems. The data, coming from the tomographic systems, gives valuable data for:

- Visualization
- Monitoring
- Mathematical model verifications
- Computational fluid dynamics

Due to the complexity of the multiphase process flows, there has been development of tomographic systems, which use multiple electrical properties for generating real-time images. Hence the name, multimodal tomographic systems [Marashdeh et al., 2007].

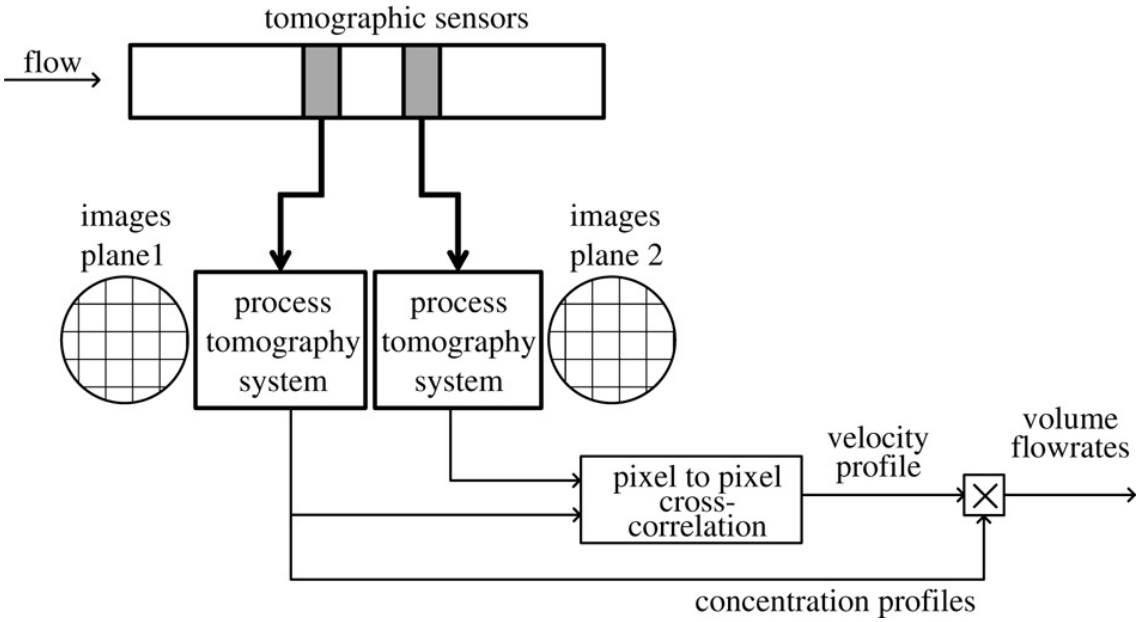


Figure 2-1: Twin plane tomographic measurement system of a multiphase flow [Ismail et al., 2005].

2.3. Tomographic sensors

There are many different types of tomographic sensors used in process tomography. These include ionizing radiation (e.g. X-ray and gamma-ray), optical, positron emission (PET), magnetic resonance imaging (MRI), acoustic, electrical (capacitive, conductive and inductive) and microwave sensors. Due to the different physics involved, there are some sensors more suited for specific work that others. Each of the sensors has its advantages and disadvantages. The objects or processes under investigation will determine which sensors is the most reliable for that specific purpose.

The tomographic techniques that use electrical properties have been extensively studied. There are three different type of techniques:

1. Electrical capacitance tomography (ECT)
2. Electromagnetic tomography (EMT)
3. Electrical resistance tomography (ERT)

One main disadvantage emerges with using electrical techniques. The spatial resolution of the image achieved through these techniques is moderate. The reason behind this is the absence of a direct narrow path between the electrodes [Ismail et al., 2005].

2.3.1. Electrical capacitance tomography

This technique derives from imaging industrial processes that contain dielectric materials. The ECT sensor will give the same capacitance measurement if the distribution of the dielectric material in the pipe is not changing. Once the distribution changes, the sensor will display different capacitance measurements.

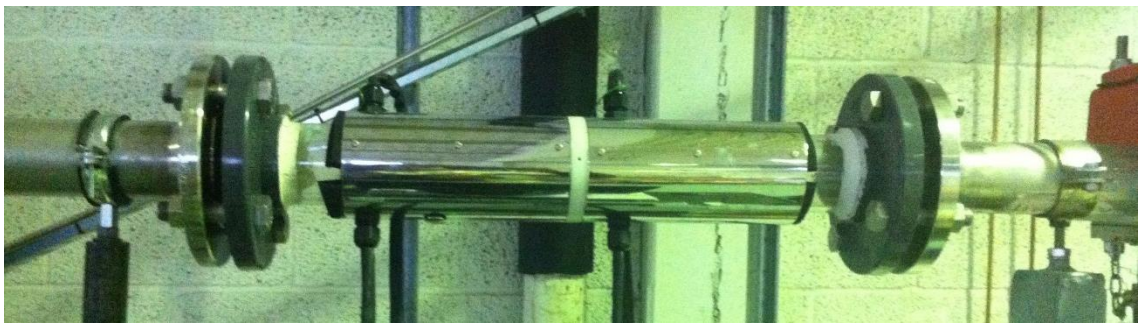


Figure 2-2: Twin plane ECT sensor mounted in the multiphase flow rig located in the process hall at USN, Porsgrunn.

The sensor, that takes these capacitance measurements, is a multi-electrode sensor. The most common setup is an ECT sensor with either 8 or 12 electrodes. These electrodes are mounted on the outside of the pipe.

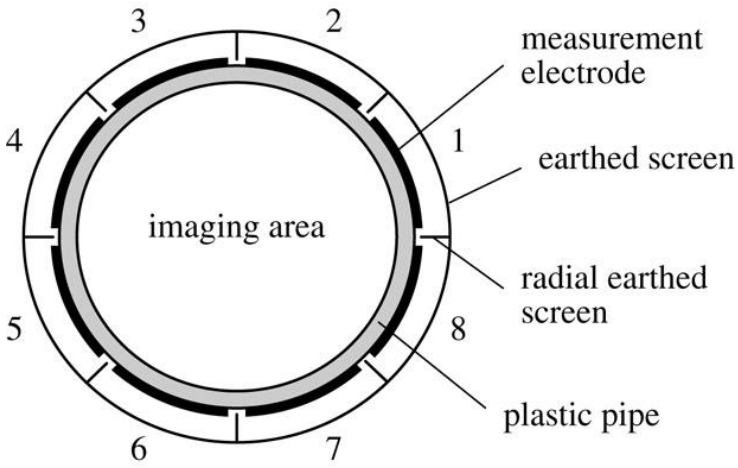


Figure 2-3: Schematic representation of an 8-electrode ECT-sensor [Ismail et al., 2005]

There is a non-linear relationship between the measurements and the permittivity distribution. Therefore, when the measurements are used to reconstruct the image, it requires a complicated algorithm. One of the main advantages the ECT-sensor offers is that it is non-intrusive and non-invasive. This mean that the flow in the pipe is not disturbed in any way by the sensor.

Other advantages of this technique are no radiation, rapid response and sensor withstands high temperatures and moderate pressure. [Ismail et al., 2005]

2.4. Gamma-ray densitometry

With densitometry, the goal is to determine the density of a certain substance, preferably online with nonintrusive sensors. In this study, gamma-rays are sent through the sample and its absorption is used in estimating the density. Here, absorption means any physical interaction between the radiation and the material that reduces the intensity of the incident radiation while penetrating the sample [Schlieper G, 2000].

Figure 2-4: Gamma-ray sensor mounted in the multiphase flow rig in the process hall.

3. Flow regimes in multiphase flow

3.1. Introduction

When dealing with multiphase flows, there are some design difficulties in planning the layout of the pipelines used. Process mechanisms, energy transfer rates, mass and momentum are sensitive towards the geometric distribution or topology of the components within the flow. The understanding of this complex phenomenon is quite challenging. The next chapter discusses the geometric distribution or flow patterns in horizontal pipes. [Brennen C. E, 2005]

3.2. Multiphase flow patterns

Usually, the identification of the flow patterns happens by visual inspection. Sometimes, the conditions in the pipe make it impossible to do a visual inspection. For instance, if the forces in the pipe are too high, it is possible that a transparent piece of the pipe will become a weak spot and the pipe will break there. This results in the pipe not having any transparent section. To determine which flow patterns is present in the pipe different methods can be used (e.g. gamma-ray densitometry, electrical capacitance tomography). Furthermore, if the identification is done visually, the interpretation can differ from person to person. Very often, the pipe sections are not accessible for process personnel. The characteristics of the different patterns depend on various parameters. One of the parameters is the distribution of fluid phases in space and time. These can change over time and are usually uncontrollable for the operator.

The main goal is to determine how the flow pattern is affected by different parameters such as component volume fluxes, pipe angle and fluid properties (i.e. density, viscosity, surface tension). Many studies have focused on horizontal pipes. Typically, a flow regime map displays the results (Figure 3-1). Different areas of the map present different flow patterns. Where they show up in the map relates to the component flow rates. The flow rates, used in the flow regime map, depend on the author of that map, e.g. volume fluxes, mass fluxes, momentum fluxes or other similar quantities.

The transition region in the flow regime map shown in Figure 3-1 between the different types determine where the flow patterns will change.

The flow regime becomes unstable when it reaches the region. The instability will continue until the formation of another flow pattern.

The range in which two flow regimes changes into each other varies and is hard to predict. The boundaries are rather a vaguely defined transition zone than a line. Therefore, the multiphase flow regimes change smoothly into each other rather than rapid changes, which would indicate sharp boundaries. The dashed lines in Figure 3-1 display the transition zones [NFOGM, 2005].

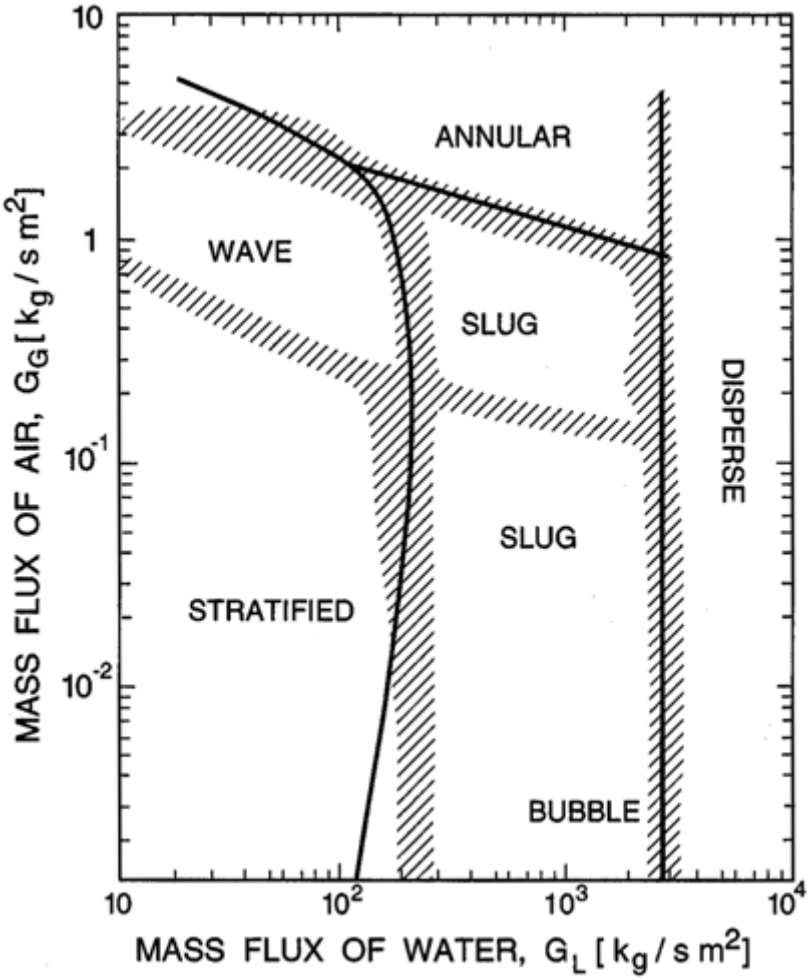


Figure 3-1: Example of a flow regime map for a horizontal pipe. Hatched regions: observed boundaries zones, continuous lines: theoretically predicted boundaries. [Brennen C. E., 2005]

3.2.1. Flow regime maps

A problem that occurs with flow regime maps is that they are only valid for a specific pipe, pressure and a specific multiphase flow (i.e. water-air, water-oil). Once one of these parameters change the flow regime map is no longer the same. The transition zones will move around depending on an increase or decrease of the pipe and pressure or switch of the multiphase flow. [NFOGM, 2005]

3.2.2. Forming mechanisms of different flow regimes

The components of the mechanism playing an important role in determining which flow pattern develops in the pipe are [NFOGM, 2005]:

- Transient effects: these effects are the result of changing system boundary conditions; e.g., opening and closing valves.
- Geometry and terrain effects: when the pipe changes geometry or has bends, the flow pattern will be affected. This effect can have severe implications in downstream of sea-lines. The flow regimes generated by these effects can go on for several kilometers; e.g., severe riser slugging.
- If none of the above effects is present, the flow rates, fluid properties, pipe diameter and inclination determine the flow pattern. These flow patterns will occur in horizontal pipes. All the flow patterns combined, formed in these conditions, are called hydrodynamic flow patterns. These patterns are fully developed because they are generated in a horizontal pipe and there is no other external effect that can influence the pattern. In this thesis, the hydrodynamic flow patterns are the ones that will be discussed.

3.2.3. Flow pattern classifications

The main characteristic of a multiphase flow pattern is the way in which the liquids and gasses distribution happens along the pipes axial and radial directions. Every flow regime is a member of one three main groups of flow types or a combination of them. The three groups are:

- Dispersed flow: the distribution of the phase is uniform in radial and axial direction; e.g., bubble and mist flow.
- Separated flow: here, the distribution is non-continuous in the radial direction. In the axial direction, the distribution is continuous; e.g., stratified and annular.
- Intermittent flow: non-continuous distribution in the axial direction. Due to this kind of distribution, the flow shows unsteady behavior; e.g., elongated bubble, also known as a plug flow, and slug flow.

There is another way of classifying multiphase flow. This classification uses Gas Volume Fractions (GVF). This method is relevant to multiphase flow metering but irrelevant for this thesis because the aim is to determine the flow pattern, and not the gas volume fractions of the flow. Therefore, the GVF classification is irrelevant [NFOGM, 2005].

3.2.4. Different types of flow patterns

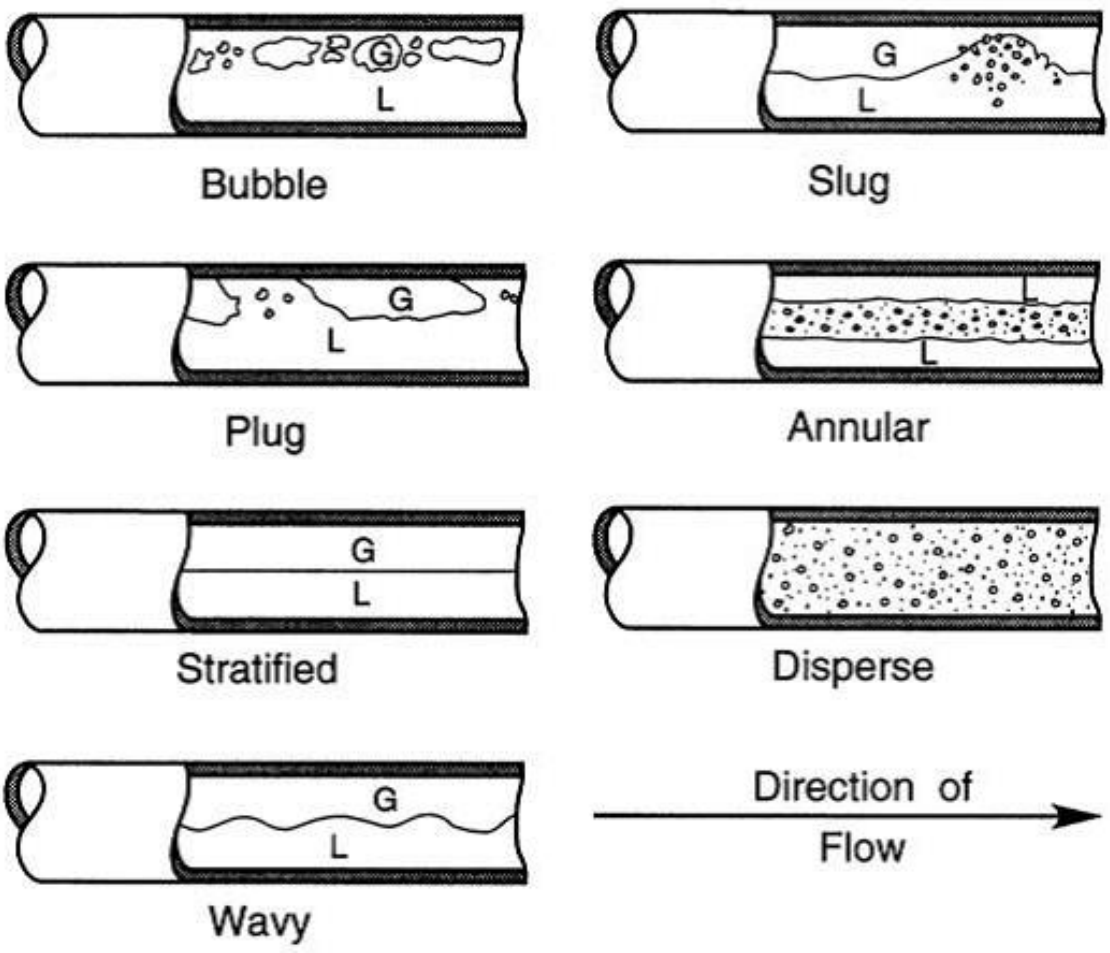


Figure 3-2: Flow regimes for air/water mixture in a horizontal pipe. G is for gaseous phase, L for liquid phase [Brennen C. E., 2005]

Seven different types of flow regimes can occur in horizontal pipes. In Figure 3-2, all different types are sketches. The different flow patterns are listed in Table 3-1.

Table 3-1: Description of the different flow patterns found in horizontal pipes from our experimental studies and [Brennen C. E., 2005].

Bubble	The pipe is filled with clear water for the most part. The bubbles will appear in the top of the pipe.
Slug	With slug flow there is an accumulation of water in the pipe that (most of the time) reaches the top of the pipe. There are bubbles in this accumulation.
Plug	Plug is more or less the same as slug. The difference is that in the accumulation, there are very few bubbles and they are not dispersed. .
Annular	The walls of the pipe are covered with a layer of liquid phase. In the middle of the pipe, water is dispersed in the gas phase. This is because centrifugal forces pushed the most dense phase (water) outwards.
Stratified	Liquid phase at the bottom of the pipe, gas phase on top. The interface between the two phases is flat. The reason behind this is that gravity is separating the phases by difference of density.
Disperse	Fine bubbles (liquid phase) are dispersed in the gas phase
Wavy	Same as stratified but interface is wavy.

4. Experimental set-up of the multiphase flow rig

4.1. Multiphase flow facility

The rig used for experiments consists of many parts. The main components are the horizontal pipe, pumps and separators. A diagram of the rig is displayed in Figure 4-1.

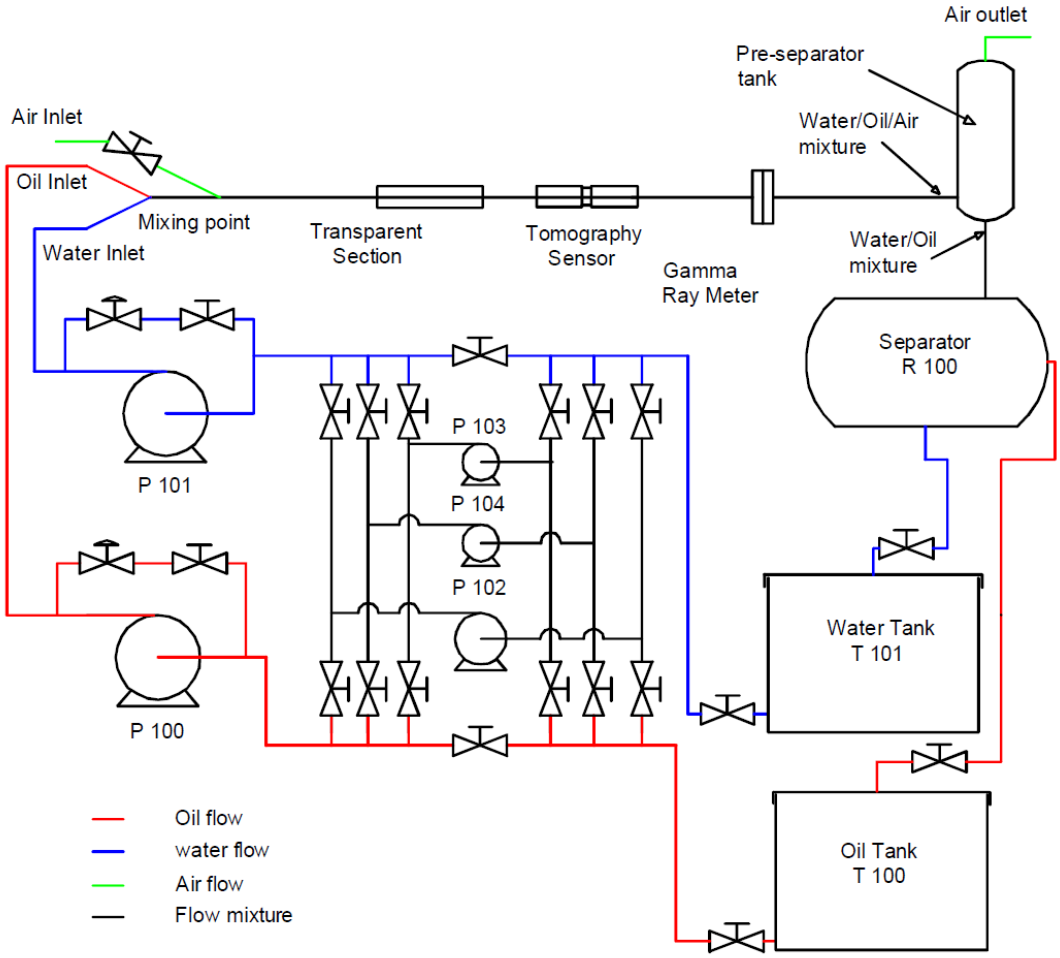


Figure 4-1: Piping and Instrumentation Diagram (PID) of the multiphase flow facility at USN [Pradeep et al., 2014]

The experiments are performed at ambient temperature and room pressure. The two types of liquid that can be used for experiments are distilled water (T101 in Figure 4-1), which might have some contamination, and Exxsol D60 (T100 in Figure 4-1), a transparent mineral oil. These liquids are stored in separate tanks. From there, different pumps transport the liquid to the horizontal pipe. The type of pump used will depend on the volumetric flow rate that is required. The operating ranges of the different pumps are displayed in Table 4-1.

Table 4-1: Pump specifications for different pumps in the flow loop. The specific pump can be found in the diagram using the pump number. [Hansen et al., 2011]

Pump number	Type	Flow rate (L/min)	Fluid flow
P100	Positive displacement	80-428	Oil
P101	Positive displacement	80-542	Water
P102	Centrifugal	1.74-13.9	Water/Oil
P103	Positive displacement	0.158-1.5	Water/Oil
P104	Positive displacement	0.455-4.2	Water/Oil

The oil and water enter the pipe at the same spot. The air is injected a little bit further. The air is originated from compressed air tanks. A valve controls the outlet of air. The different flow rates of the liquids and air are measured with Coriolis meters [Pradeep et al., 2014].

4.2. Description of the tiltable pipe for two-phase flow

The two-phase mixture is injected into the 15 m long horizontal pipe in which the flow pattern develops. The liquid mixes with the air at the beginning of the pipe. The angle of the pipe can be adjusted to study the behavior of the flow patterns with different inclinations. The angles of the pipe can be: 10, 6, 5, 3 and 1. The angle can be applied in negative or positive direction.

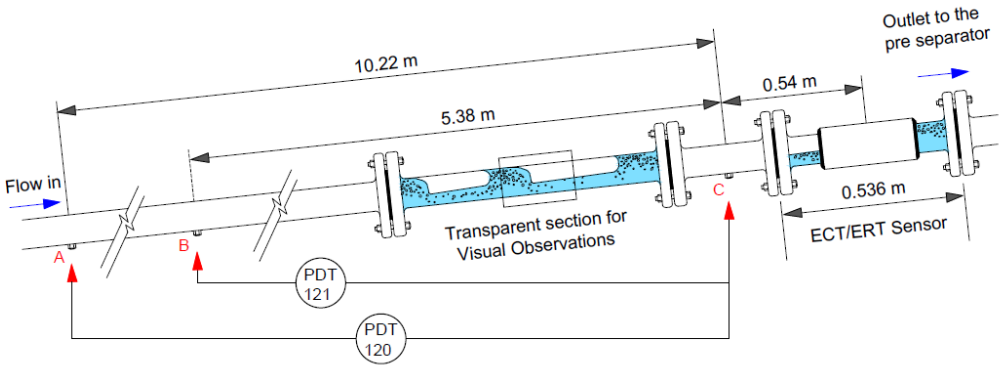


Figure 4-2: Test section with sensor placements as part of the titled pipe with multiphase flow. Transparent section for high-speed camera base studies and visual observations, multimodal tomographic systems at the far right of the pipe. [Pradeep et al., 2014].

In the flow loop, there is a Plexiglas transparent section, situated 10 m from the beginning of the pipe. This section is useful for high-speed camera recordings and visual observations of the different flow patterns. If there is a need for visual validation afterward, the high-speed camera will provide the necessary information. A normal recording is also used as validation. The ECT sensor and gamma-ray sensor are installed behind the transparent section [Pradeep et al., 2014]. In Table 4-2, the dimensions of the pipe are given

Table 4-2: Pipe dimensions in the vicinity of the tomographic systems [Hansen et al., 2011]

Length	Approx. 15m
Inner Diameter	56 mm
Outer Diameter	65 mm

4.2.1. Sensors used for flow pattern characterization

4.2.1.1. Tomographic sensor

The sensor that is used for gathering the electrical capacitance data is an ECT sensor (Figure 2-2). It is a dual plane sensor with an internal diameter of 56 mm. The sensor has 12 electrodes per plane. It operates at an AC electrical field frequency of 1MHz and acquires 100 frames per second.

The 12 electrodes are each 12.7 mm wide and 85 mm long. They are positioned on the outer diameter of the wall made of dielectric material. [Pradeep et at., 2014]

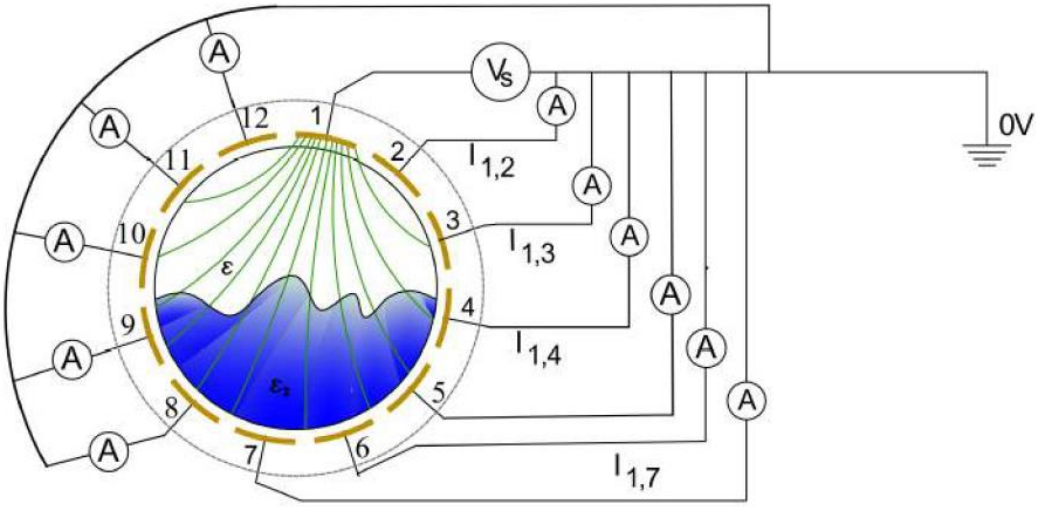


Figure 4-3: Measurement principle of ECT sensor. Electrode 1 is excited with V_s and other electrodes are earthed. [Pradeep et al., 2014]

The capacitance measurements will be taken between two electrodes *i* and *j*. On electrode *i,* the source electrode, an electric potential is applied while electrode *j,* the detector electrode, is kept earthed. The resulting electric charge in electrode *j* is measured. Every electrode is held at zero potential while one is given an excitation. The one that is given the excitation will change so that every electrode will be the source electrode for one frame. Due to the symmetric nature of the measurements ($C_{i,j} = C_{j,i}$), there are 66 independent measurements in a frame for a 12-electrode sensor. These 66 measurements are mutual capacitance measurements for specific pairs of electrodes [Fang and Cumberbatch, 2004].

4.2.1.2. Gamma-ray sensor

The density is measured with this sensor (Figure 2-4). It is also a non-intrusive sensor. The data gathered from this sensor can also be helpful for determining the flow pattern. The gamma-ray sensor is not suited for distinguishing non-intermittent flows but it helps with distinguishing intermittent against other flows. This data is used to characterize the flow-associated parameters (slug frequency, amplitude…) [Johansen, 2015].

4.3. Programs for data logging and analysis

4.3.1. Program for data gathering using tomographic system - ECT32v2

For gathering data from the ECT sensor, the program ECT32v2 is used. With this program, the data, coming from the sensor, will be stored in binary .bcp files. This type of file needs to be converted into ASCII files for further processing with MATLAB. The ECT32v2 also gives real-time tomographic images of the inside of the pipe during the experiments.

4.3.2. Program for data logging and steering of the multiphase rig in LabVIEW

The multiphase flow loop is controlled with LabVIEW. In the interface, valves and pumps can be operated and the desired flow rates of the phases can be changed here. The measurement taken by the pressure sensors and flow rate sensors will be stored in .txt files. The files are generated synchronously with the ECT data (60 seconds). The flow rates and pressures are logged every second.

The gamma-ray sensors data can be viewed in a LabVIEW interface as well. There is a real-time graphic of the density/time. These measurements will be stored in '.xlsx' files and are used for additional information on the types of flow patterns. The rate at which the measurements are taken is 20Hz.

5. Data acquisition at different conditions of flow

In Annex 2, the experiment settings and different types of collectible data are displayed. If the data is gathered for that experiment, the color code is green. Otherwise, it will be red. The data for a particular flow condition can be retrieved by looking for the sample number or the run number.

The flow regime map that is used to predict which flow pattern would be generated is shown in Figure 5-1. Note that this flow regime map is for a horizontal pipe with a diameter of 56mm. The pipe used in the multiphase flow rig is 56mm, so the transition lines will be slightly shifted. This is also used as a guideline to design the experiments sessions. From this map, an indication can be found of the parameters to study certain transitions.

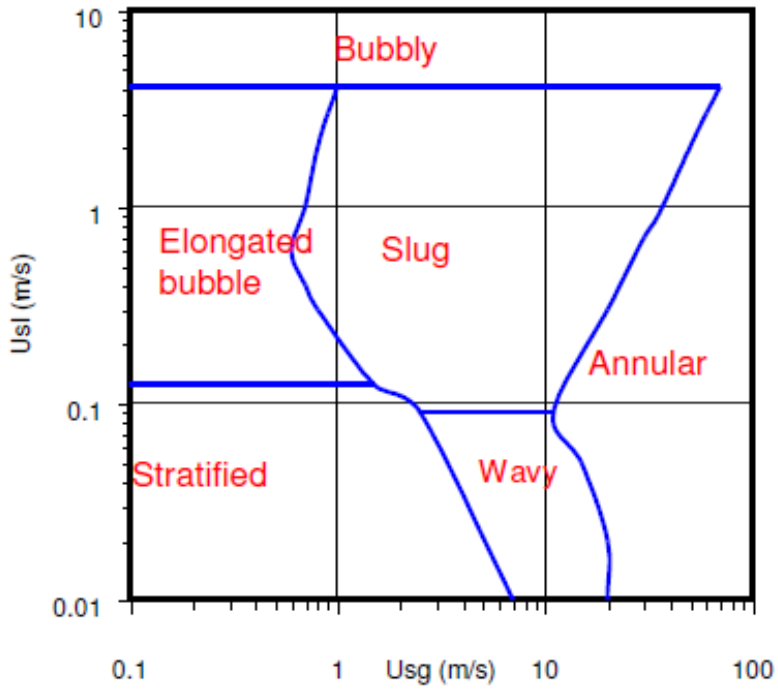


Figure 5-1: Flow regime map for a horizontal 50 mm pipe, air and water 20°C, based on [Mandhane et al., 1974]

The bubbly flow at the top of the flow regime map in Figure 5-1 will not be studied because the rig cannot be operated safely at high water flow rates necessary for this.

6. Data analysis of the capacitance measurements

Further analysis is done after all the data is gathered. In the next paragraphs, the analysis of the raw data is explained. The analysis uses the programs ECT32v2 and MATLAB.

6.1. Electric capacitance tomographic data

6.1.1. Sensor data protocol

During the experiments, the data gathered by the ECT sensor is saved in .bcp files. These files need to be converted with the ECT32v2 software. With this software, ASCII files can be generated and these files will be used for further analysis. There are two different type of ASCII files: absolute capacitance files ('.aac') and normalized capacitance files ('.anc'). In the latter, the capacitances are normalized with the calibration measurements of reference media (pipe full of water and pipe full of air). Two models can be used for this normalization: the series or the parallel model. In this thesis, the parallel normalization model is used. The effect of the geometric setup of the sensor is expected to be reduced by these normalizations [Fang and Cumberbatch, 2005] [Marashdeh et al., 2007].

6.1.1.1. Absolute capacitance file generation

In Figure 6-1, the interface for generating ASCII files is shown. Some parameters need to be changed every time other files are generated:

1. In the Data sources box the .bcp files that will be converted need to be selected as the Capacitance file. Browse to the location of the file. Also, select the calibration file air_water60l.cal in the Calibration box.
2. Next, select the name and the place of the output file in the Output box.
3. Select the Absolute Capacitance radio button in the Converted data type box. In this box, select the desired plane: Plane 1 or Plane 2.
4. Disabled the Include File Comments.
5. If all of the previous steps are done, click Save and the ASCII file will be generated.

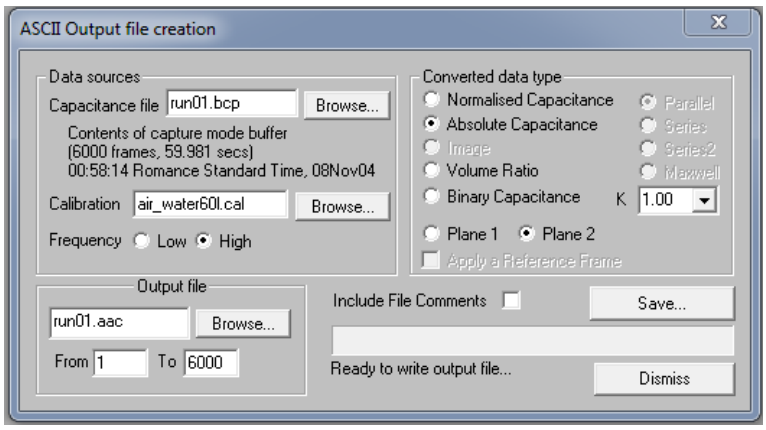


Figure 6-1: Screen capture from ASCII output '.aac' file generation

6.1.1.2. Normalized capacitance file generation

In Figure 6-2, the interface for generating '.anc' files is shown. The steps to generate the files are almost similar for '.aac' files (See 6.1.1.1). The differences are:

- The calibration file in the Data sources box must not be selected.
- The radio button for Normalized Capacitance in the Converted data type box needs to be selected.

After these two steps, the '.anc' files can be generated the same ways as '.aac' files are generated.

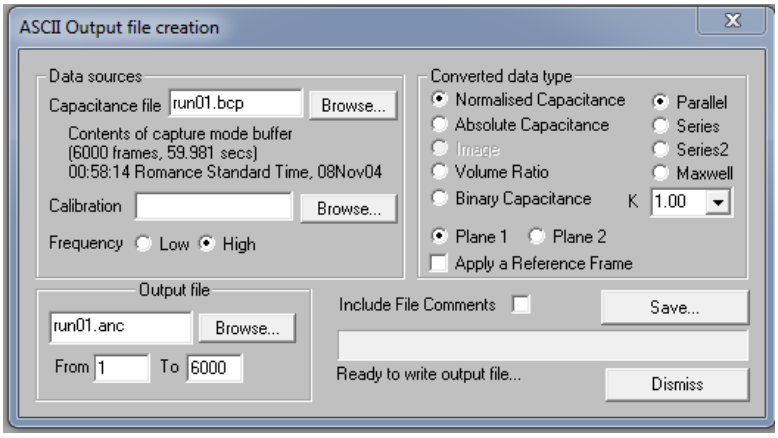


Figure 6-2: Screen capture of ASCII output '.anc' file generation

6.1.2. Processing of the ASCII files

The generated ASCII files need to be processed. These files contain 6000 tomographic data sets that are collected over a period of 60 seconds. This means that the ECT sensor acquires 100 frames per second. One set of data consists of 66 mutual capacitance measurements (see 4.2.1.1). The totality of these sets of tomographic data will be called a time series.

6.2. The 12x12 capacitance matrix

Each frame of the time series that is acquired by the ECT sensor will be converted to a 12x12 matrix for further processing.

Table 6-1: Normalized capacitance data from the second plane of the ECT sensor run 001.

Electrode	1	2	3	4	5	6	7	8	9	10	11	12
12	1.056	1.069	1.016	1.080	1.159	1.045	1.017	1.026	1.040	1.041	1.256	
11	1.090	1.010	1.066	1.147	1.033	1.004	1.010	1.022	1.022	1.046		
10	1.071	1.110	1.187	1.067	1.033	1.039	1.051	1.048	1.073			
9	1.098	1.153	1.028	0.996	1.000	1.009	1.008	1.029				
8	1.355	1.098	1.058	1.055	1.064	1.058	1.083					
7	1.347	1.160	1.153	1.154	1.152	1.171						
6	1.077	1.050	1.051	1.047	1.063							
5	1.041	1.031	1.022	1.036								
4	1.064	1.034	1.047									
3	1.077	1.062										
2	1.100											
1												

The data in Table 6-1 will be received from the ASCII-files after generating them. This is only one frame. The total files contains 6000 of these data sets.

The first step in the conversion is to mirror the values along the diagonal term. This is possible because the capacitance measurements are symmetric, meaning that the capacitance measurement between electrode 1 and 12 is the same as the capacitance measurement between 12 and 1. The mirroring is done by a MATLAB code (Annex 3) and is discussed later in this chapter.

Table 6-2: Normalized capacitance data from run001. The initial data is mirrored around the diagonal term.

Electrode	1	2	3	4	5	6	7	8	9	10	11	12
12	1.056	1.069	1.016	1.080	1.159	1.045	1.017	1.026	1.040	1.041	1.256	
11	1.090	1.010	1.066	1.147	1.033	1.004	1.010	1.022	1.022	1.046		1.256
10	1.071	1.110	1.187	1.067	1.033	1.039	1.051	1.048	1.073		1.046	1.041
9	1.098	1.153	1.028	0.996	1.000	1.009	1.008	1.029		1.073	1.022	1.040
8	1.355	1.098	1.058	1.055	1.064	1.058	1.083		1.029	1.048	1.022	1.026
7	1.347	1.160	1.153	1.154	1.152	1.171		1.083	1.008	1.051	1.010	1.017
6	1.077	1.050	1.051	1.047	1.063		1.171	1.058	1.009	1.039	1.004	1.045
5	1.041	1.031	1.022	1.036		1.063	1.152	1.064	1.000	1.033	1.033	1.159
4	1.064	1.034	1.047		1.036	1.047	1.154	1.055	0.996	1.067	1.147	1.080
3	1.077	1.062		1.047	1.022	1.051	1.153	1.058	1.028	1.187	1.066	1.016
2	1.100		1.062	1.034	1.031	1.050	1.160	1.098	1.153	1.110	1.010	1.069
1		1.100	1.077	1.064	1.041	1.077	1.347	1.355	1.098	1.071	1.090	1.056

The capacitance data is mirrored around the diagonal term. This results in a 12x12 matrix with the diagonal term empty. This diagonal term needs to be calculated.

6.2.1. Calculating diagonal term

The diagonal term represents the self- capacitance of the electrode that is excited at that point in time. Self-capacitance is the amount of electric charge that must be added to an isolated conductor to raise its electric potential by one unit. This characteristic needs to be calculated for each electrode and is done with formula (6-1).

$$C_{i,i} = -\sum_{j \neq i} C_{i,j} \tag{6-1}$$

The sum of all non-diagonal terms on each line is taken. The diagonal term will be calculated using MATLAB. Then, the matrix will be calibrated using the calibration vectors of water and air. After the calculation, the capacitance matrix C is complete and will have the following form:

$$C = \begin{pmatrix} C_{1,1} & \cdots & C_{1,12} \\ \vdots & \ddots & \vdots \\ C_{12,1} & \cdots & C_{12,12} \end{pmatrix} \tag{6-2}$$

This is described by [Fang and Cumberbatch, 2005].

6.3. Compressing the 12x12x6000 matrix

The matrix calculated in 6.2 is a matrix for one frame. In the time series, there are 6000 frames and that results in 6000 matrices. This makes that the time series consist of a 12x12x6000 matrix. This series is represented by formula (6-3) where N = 6000.

$$C = \begin{pmatrix} C_{1,1\,[n]} & \cdots & C_{1,12\,[n]} \\ \vdots & \ddots & \vdots \\ C_{12,1\,[n]} & \cdots & C_{12,12\,[n]} \end{pmatrix}, n = 1,2,\dots,N \tag{6-3}$$

The matrix needs to be condensed for further analysis. This is done by calculating the mean (6-4) and standard deviation (SD) (6-5) capacitance matrices.

$$C_{mean} = \begin{pmatrix} mean(C_{1,1\,[n]}) & \cdots & mean(C_{1,12\,[n]}) \\ \vdots & \ddots & \vdots \\ mean(C_{12,1\,[n]}) & \cdots & mean(C_{12,12\,[n]}) \end{pmatrix} \tag{6-4}$$

$$C_{SD} = \begin{pmatrix} SD(C_{1,1\,[n]}) & \cdots & SD(C_{1,12\,[n]}) \\ \vdots & \ddots & \vdots \\ SD(C_{12,1\,[n]}) & \cdots & SD(C_{12,12\,[n]}) \end{pmatrix} \tag{6-5}$$

The mean and the standard deviation operators are calculated using respectively formulas (6-6) and (6-7).

$$mean(x[n]) = \frac{1}{N} * \sum_{n=1}^{N} x[n] \tag{6-6}$$

$$SD(x[n]) = \sqrt{\frac{1}{N} * \sum_{n=1}^{N} \big(x[n] - mean(x[n])\big)^2} \tag{6-7}$$

6.3.1. Eigenvalues of the capacitance matrix

Next, the eigenvalues are calculated. The eigenvalues of the mean and standard deviation matrices are worked out using MATLAB. The eigenvalues are represented in a 12-element array. The algorithm, to see which flow pattern is present in the pipe, will be applied on the eigenvalues of the mean and standard deviation matrices.

The eigenvalues that will be calculated from these matrices will be rotationally invariant. That means that the sensors can be rotated without changing the eigenvalues. [Fang and Cumberbatch, 2005]

With this analysis procedure, a 12x12x6000 matrix is condensed into two 12-element arrays: eigenvalues of mean matrix and eigenvalues of standard deviation matrix. The eigenvalues will be used for characterizing the flow regimes.

6.4. MATLAB code for data analysis

The calculations, described in the previous paragraphs of this chapter, are done with the MATLAB code ECTMeasurementAnalysis (Annex 3). This code can process multiple '.anc' and '.aac' files in one run.

6.4.1. Calibration, multiple inputs and zero matrix building

In the first part of the code, two calibration vectors are shown. Before executing the code, the right calibration vector must be 'uncommented'. This depends on the type of ASCII file used. If the files are '.anc' files, the normalized calibration vector needs to be used. These lines of code can be found in Annex 3.

After this, the multiple files directory will be used. This will locate all the files with the correct file type. This type of file needs to be changed the type of file that will be used. It needs to be the same as the calibration vector file type. Otherwise, errors will occur.

```
number_of_electrode=12;
%%% Multiple input
files = dir('*.anc');
%%% Eigenvalues_SD matrix
Eigenvalues_SD_matrix=zeros(length(files),number_of_electrode);
%%% Eigenvalues_mean matrix
Eigenvalues_mean_matrix=zeros(length(files),number_of_electrode);
```

Figure 6-3: Multiple files directory load and building of the eigenvalue matrices for all the eigenvalue vectors of the different runs

Two zero matrices are created in Figure 6-3. The number of columns and rows will depend on the number of electrodes and the number of files that will be processed. Therefore, the number of electrodes used in the specific sensor must be known. The experiments in this thesis are all done with a sensor consisting of 12 electrodes.

6.4.2. Reading the data, making the matrices and calculating the eigenvalues.

The data from the ASCII files are imported into MATLAB using the textscan command. For the full code, see Annex 3. All of the 6000 capacitance measurements are combined in a 66000x11 matrix. The measurements, as shown in Table 6-1, have a triangular form. In the 66000x11, every element without a value will be assigned with [NaN] so that every element exists.

Table 6-3: Two sets of the 6000 capacitance data processed by the MATLAB code. This is a part of the 66000x11 matrix, called matrix1 in the MATLAB code.

0,607	-0,025	0,03	0,009	-0,004	0,012	0,014	0,03	0,012	0,072	1,351
0,465	0,02	0,022	-0,015	-0,016	0,02	0	-0,027	0,011	0,026	NaN
0,449	-0,012	0,007	-0,027	-0,008	0,017	-0,015	0,027	0,009	NaN	NaN
0,415	0,009	0,037	-0,031	0,055	0,011	-0,017	-0,019	NaN	NaN	NaN
0,674	0,014	-0,034	0,044	0,002	0,034	-0,031	NaN	NaN	NaN	NaN
0,717	-0,005	0,001	0,023	-0,013	-0,013	NaN	NaN	NaN	NaN	NaN
0,73	0,049	0,068	0,005	-0,024	NaN	NaN	NaN	NaN	NaN	NaN
1,346	0,992	0,579	0,091	NaN	NaN	NaN	NaN	NaN	NaN	NaN
1,368	1,356	0,341	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
1,347	0,55	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
1,339	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
0,608	-0,025	0,03	0,009	-0,004	0,012	0,018	0,037	0,022	0,079	1,351
0,464	0,02	0,022	-0,015	-0,016	0,02	0,001	-0,025	0,012	0,024	NaN
0,45	-0,012	0,007	-0,027	-0,008	0,018	-0,014	0,028	0,007	NaN	NaN
0,416	0,009	0,037	-0,031	0,056	0,013	-0,016	-0,021	NaN	NaN	NaN
0,682	0,014	-0,034	0,046	0,003	0,036	-0,032	NaN	NaN	NaN	NaN
0,721	-0,006	0,003	0,025	-0,01	-0,013	NaN	NaN	NaN	NaN	NaN
0,725	0,062	0,077	0,014	-0,021	NaN	NaN	NaN	NaN	NaN	NaN
1,346	1,126	0,71	0,165	NaN	NaN	NaN	NaN	NaN	NaN	NaN
1,368	1,356	0,535	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
1,347	0,807	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN
1,339	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN	NaN

The matrix generated by the MATLAB code is called matrix1.

The next step is to convert the 66000x11 matrix into the 12x12x6000 matrix. In the first line of code, shown in Figure 6-4, the zero matrix is created.

```
matrix=zeros(12,12,N);
for i=[1:12]
    for j=[i+1:12]
        matrix(i,j,:)=matrix1(i:11:i+(N-1)*11,j-i);
        matrix(j,i,:)=matrix(i,j,:);
    end
end
for k=[1:N]
    matrix(:,:,k)=matrix(:,:,k)-diag(sum(matrix(:,:,k),2));     %diagonal term
    matrix(:,:,k)=(matrix(:,:,k)-calibration_air)./(calibration_water-calibration_air);  %calibration
end
```

Figure 6-4: Generation of 12x12x6000 matrix including the calculation of the diagonal term and the calibration

In the first part of the code, the capacitance data is mirrored around the diagonal term. The diagonal term is calculated in the second half of the code (see %diagonal term in Figure 6-4) and after that is done, the calibration is applied. Then the 12x12x6000 matrix is complete.

```
matrix_mean=mean(matrix,3);
eigenvalues_mean=transpose(eig(matrix_mean));
matrix_SD=std(matrix,0,3);
eigenvalues_SD=transpose(eig(matrix_SD));

Eigenvalues_SD_matrix(i_files,:)=eigenvalues_SD;
Eigenvalues_mean_matrix(i_files,:)=eigenvalues_mean;
Eigenvalues_CopyMeanRE = horzcat(Eigenvalues_mean_matrix, Eigenvalues_SD_matrix); %copy excel
```

Figure 6-5: Calculating the mean matrix, standard deviation matrix and their eigenvalues. These values will be written into the zero matrices created in the first part of the code (6.4.1)

The mean matrix, matrix_mean, and the standard deviation matrix, matrix_SD, are calculated using the 12x12x6000 matrix. This results in 12x12 matrices. From these matrices, the eigenvalues are calculated and transposed. Now the eigenvalues are written in the zero matrices, Eigenvalues_mean_matrix and Eigenvalues_SD_matrix. In the last line of the code, the two matrices are put beside each other so that on one line of the matrix the mean eigenvalues and the standard deviation values are displayed for one run.

This calculation will repeat until every file in a specific folder is done. Then the matrix Eigenvalues_CopyMeanRE contains all the eigenvalues of the mean and standard deviation matrix of every run. This matrix will be copied to Excel for further analyzing.

7. Characterization of flow regimes

The eigenvalues that are calculated will be used for the characterization of the different flow regimes. The eigenvalues are copied from MATLAB into an Excel sheet (see Annex 4). This is more convenient to make different plots and give the values a color code. In the next paragraphs, the algorithm used to determine the flow pattern is discussed. The criteria are found by trial and error. First, we attempt to identify a significant parameter for a given type of flow pattern. When the parameter is found, the threshold would be fine-tuned until the best results are obtained, Figure 7-1.

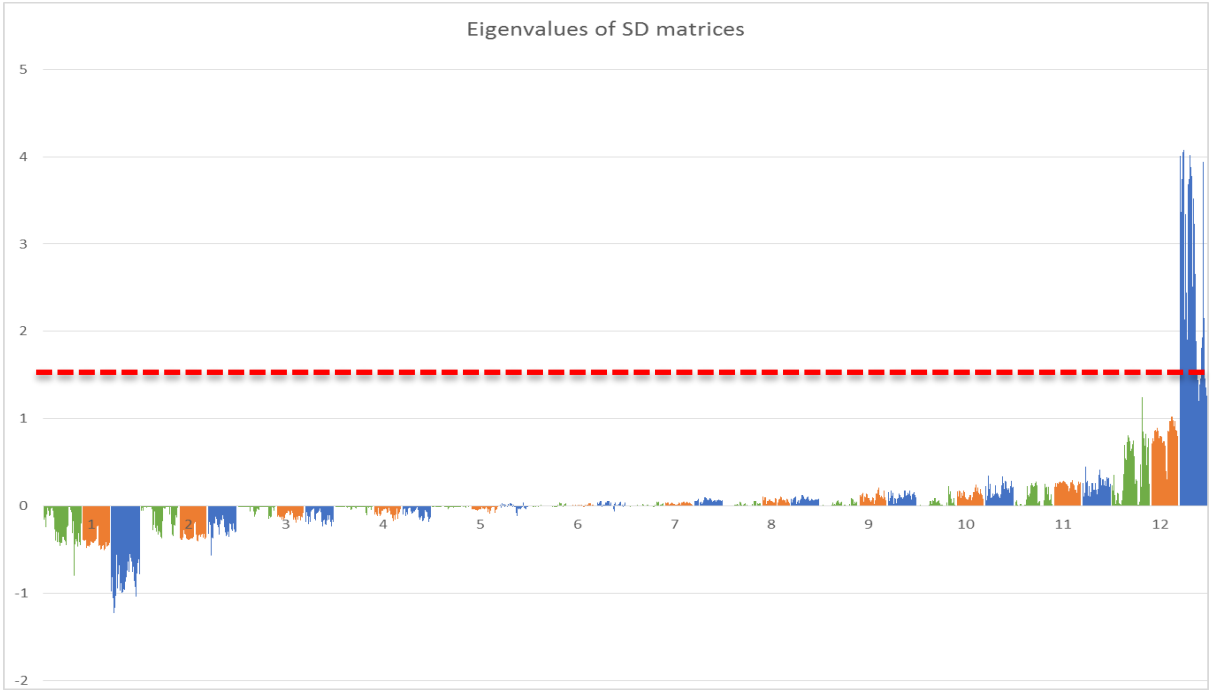


Figure 7-1: Eigenvalue graph of standard deviation matrices. Green represents stratified and wavy flows, orange represents annular flow and blue represents slug and plug flows.

The 12th eigenvalues of the standard deviation matrices varies significantly for different types of flow patterns. The blue lines, intermittent flows, have a much higher value than the other ones. This parameter was then chosen to identify the intermittent flows and the threshold was set at 1.5 (see dashed line in Figure 7-1). Afterward, the threshold was fine-tuned to have better results.

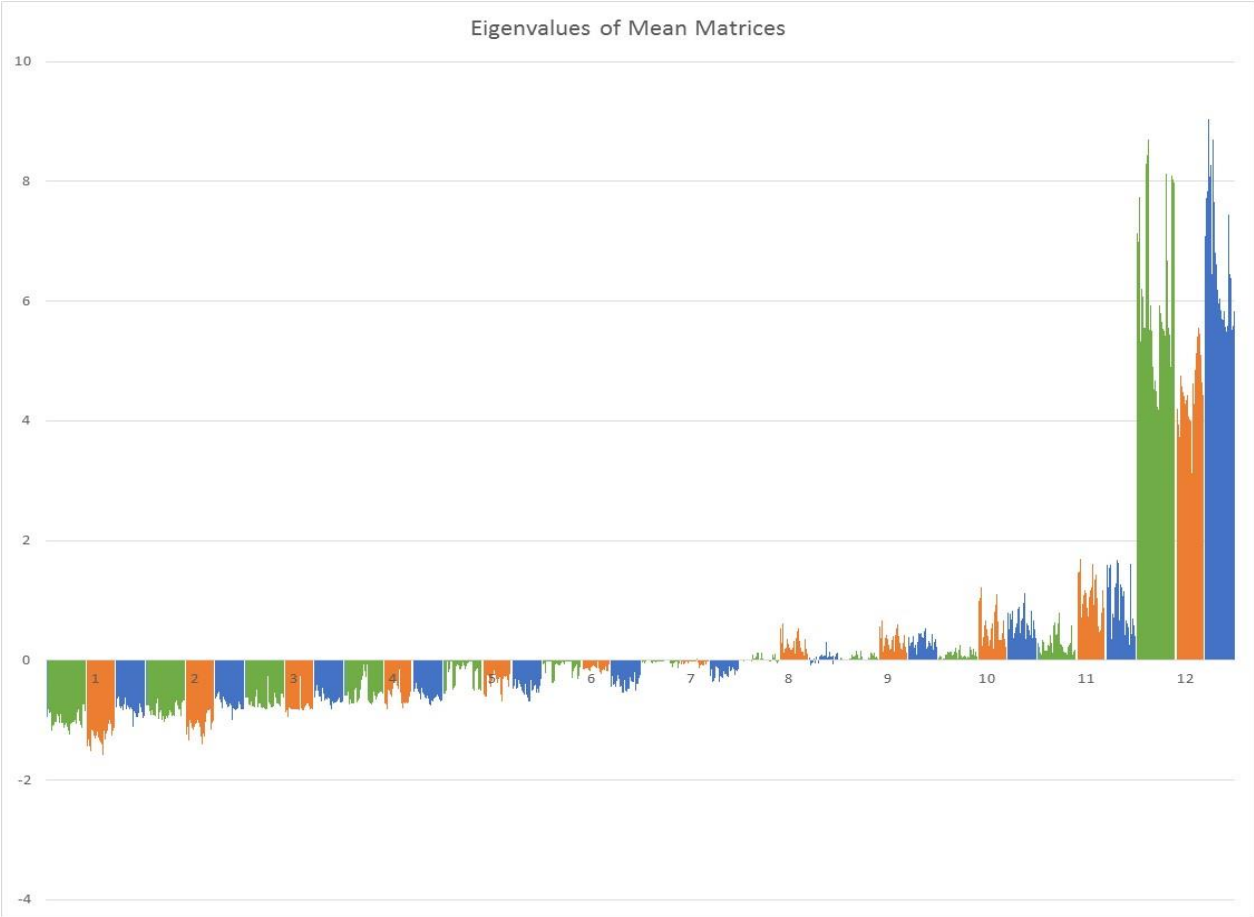


Figure 7-2: Eigenvalue graph of mean matrices. Green represents stratified and wavy flows, orange represents annular flow and blue represents slug and plug flows.

7.1. Intermittent flows

The first criterion used in the algorithm is to determine if the flow is an intermittent flow. This is a group of flow patterns that include plug and slug flows (see 3.2.3). The algorithm uses the 12^{th} eigenvalue form the C_{sd} matrix. In addition, the gamma-ray sensor can be used to determine this type of flows.

7.1.1. Criteria for intermittent flows using eigenvalues

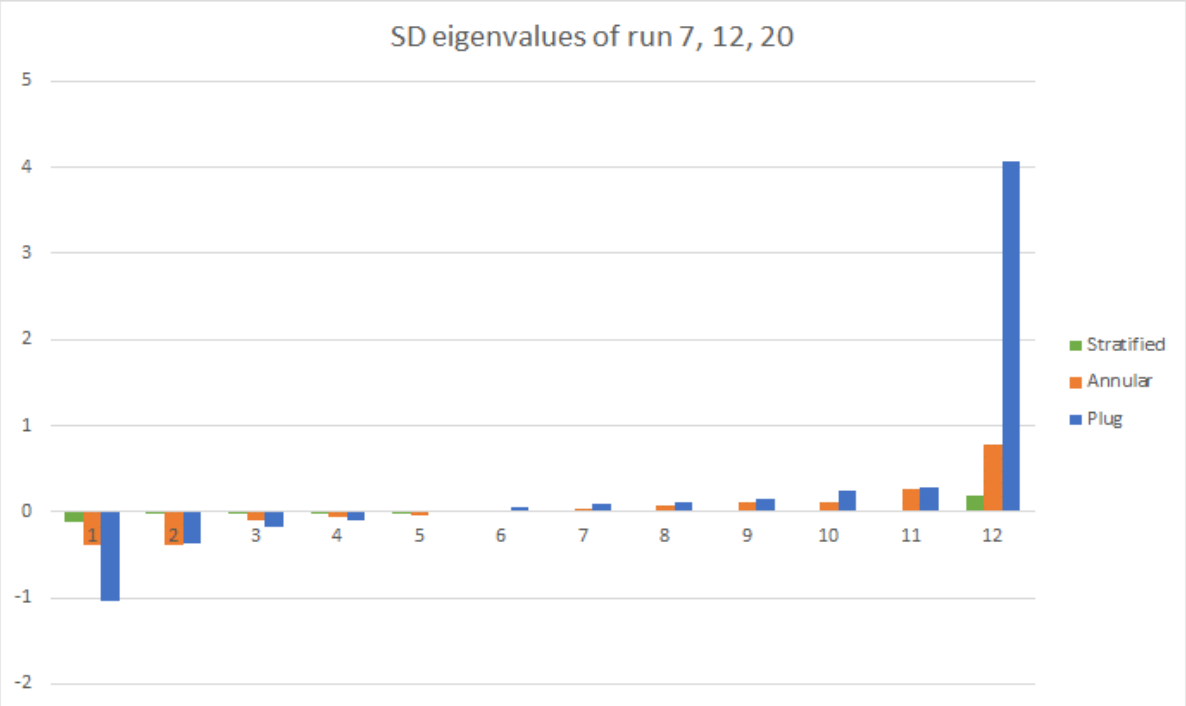


Figure 7-3: Eigenvalues of the standard deviation matrix of measurements 7, 12, 20. Data taken from '.anc' plane 2

In Figure 7-3, three series of eigenvalues are displayed. One set is taken from a plug flow (measurement 20), the other from an annular flow (measurement 12) and the last one from a stratified flow (measurement 7).

It is clear that there is a significant difference between the values of the 12^{th} eigenvalue. The value for the plug in this example is near five. The reason for the high value of the standard deviation is the great amplitude fluctuations in the signals.

$$FlowPattern = Intermittent\ if\ 12^{th}\ Eigenvalue\ of\ SD > 1{,}15 \quad (7\text{-}1)$$

The algorithm will help determining whether the flow pattern is intermittent or not. The first criterion for the intermittent flow was set at 1.5. After comparing the result from the algorithm and the observations, we have decided to lower the value. The value 1.15 gives the best results. The criterion to separate plug from slug flows is not yet found.

7.1.2. Criteria for intermittent flows using gamma-ray data.

The gamma-ray sensor takes density measurements. These can be used to determine if a flow is intermittent.

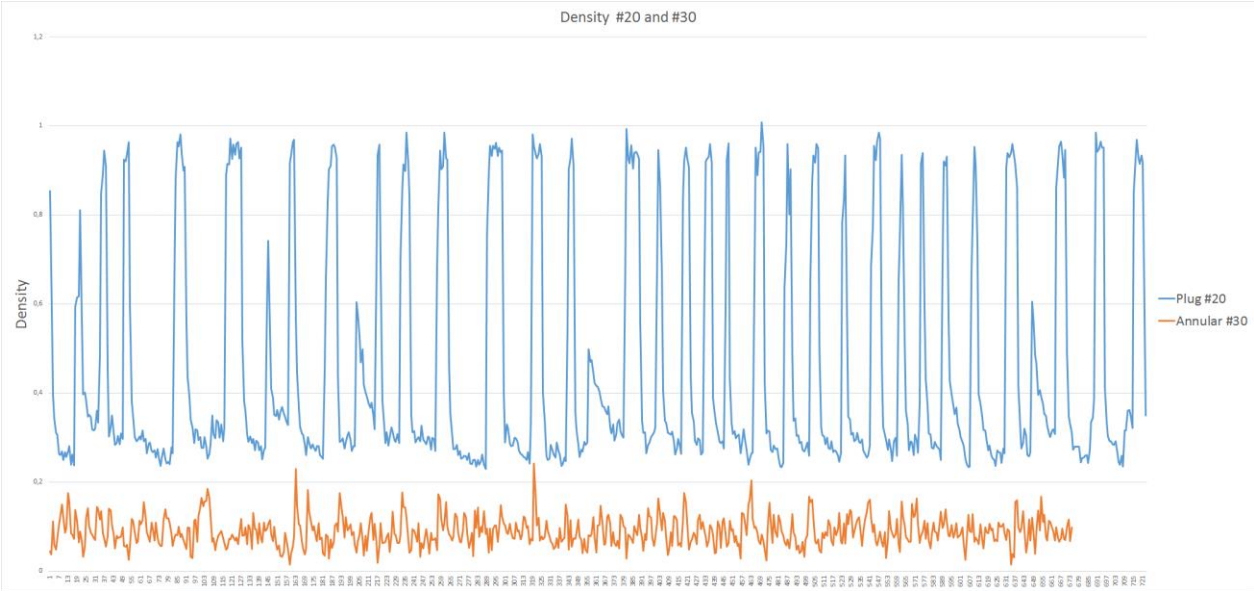


Figure 7-4: Density chart of run 20 and 30. Blue line is plug flow run 20, orange is an annular flow run 30.

In Figure7-4, some density measurements are plotted. The blue line represent run 20 and is a plug flow, the orange line is run 30 and it shows the density measurements of an annular flow. In the graph, it is clear that the density measurements for the plug flow has many peaks. The peaks represent the plugs that flow through the pipes. If the plug passed the sensor, the level in the pipe will decrease, as shown by the density measurements. The annular flow has a lower density and does not have the peaks the plug flow has. Because an annular flow has a continuous distribution in the axial direction (see 3.2.3). For further analyzing, a FFT is applied on the time series data for density from the gamma ray measurements.

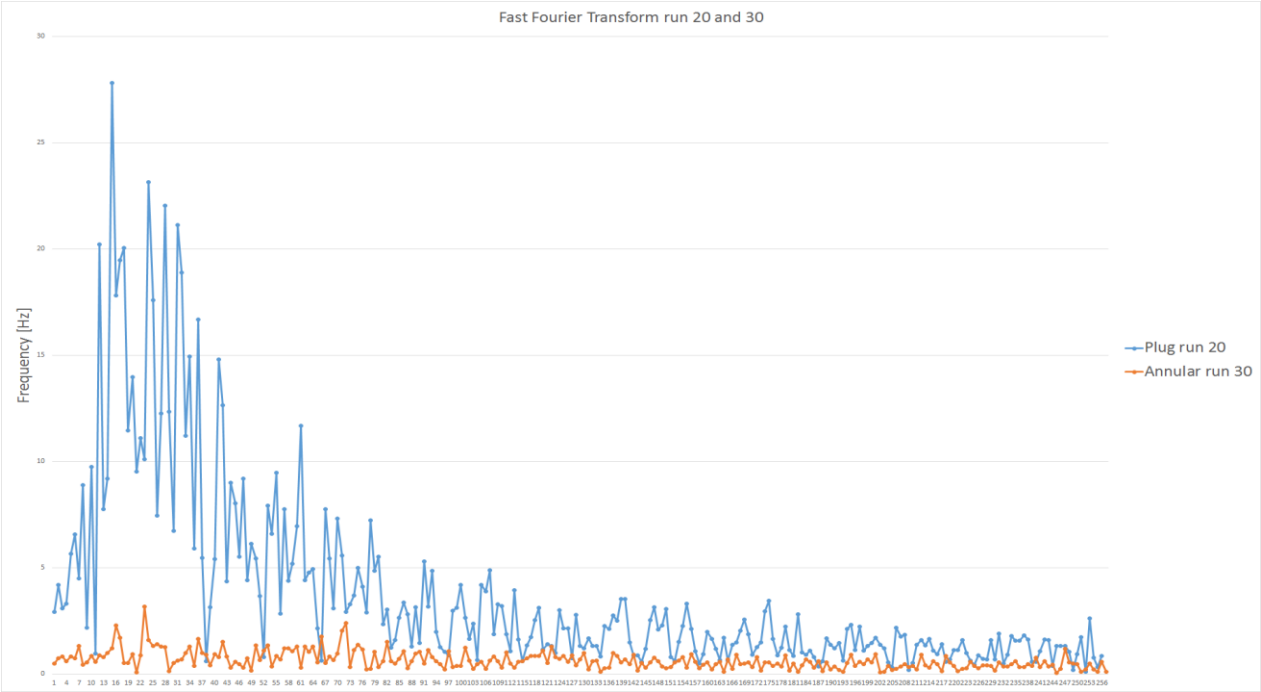


Figure 7-5: FFT of the density chart in Figure 7-4. Blue is plug flow, orange is annular flow.

Figure 7-5 shows the chart for the second to 256th frequencies coming out of the FFT. The dominance of low frequencies over the high frequencies seems to characterize intermittent flow (e.g. run 20 illustrated in Figure 7-5). As a result, in order to determine if the flow is an intermittent flow, the following parameter is used

$$Ratio_{FFT} = \frac{\sum_{2}^{111} y_{freq}}{\sum_{111}^{256} y_{freq}} \quad (7\text{-}2)$$

The ratio of the sums of the frequencies values is calculated. The sum is taken of the second until the one hundred and tenth-frequency value. This sum is then divided by the sum of the following 145 values. The following threshold is proposed:

$$Flow\ pattern = intermittent\ flow\ if\ Ratio_{FFT} > 2 \quad (7\text{-}3)$$

7.2. Annular and Wavy/Stratified flows

For the annular and wavy/stratified flow patterns, the data from the ECT sensor is used. The gamma-ray sensor data do not give enough information for the identification of the flow patterns. The difference between the flow patterns are very often of geometric nature, which can be obtained using tomographic systems.

The criterion for identification of annular flow regime is based on the ratio of the 11th eigenvalue with the 1st eigenvalue of the mean matrix. The eigenvalue vector is sorted from the smallest to the largest, as seen in Figure 7-3.

$$\varsigma = -\frac{(11^{the} Eigenvalue\ of\ Mean\ Matrix)}{(1^{th}\ Eigenvalue\ of\ Mean\ Matrix)} \quad (7\text{-}4)$$

Typically, the transition from stratified or wavy to annular flow is not a sharp boundary but more a transition area. Therefore, the parameter ς will gradually increase. In order to set the threshold value, the video recordings of different runs were analyzed. If the top of the pipe were wetted, the flow pattern would be considered annular.

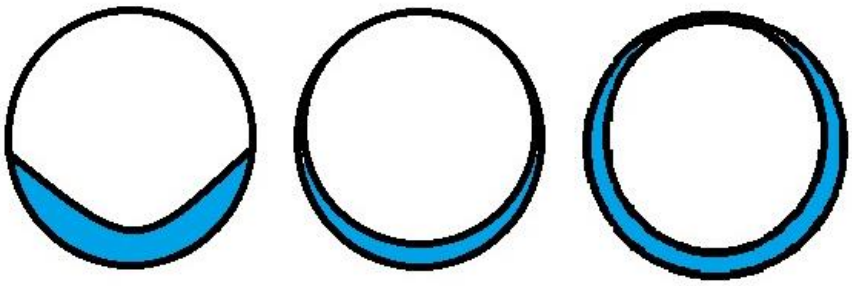


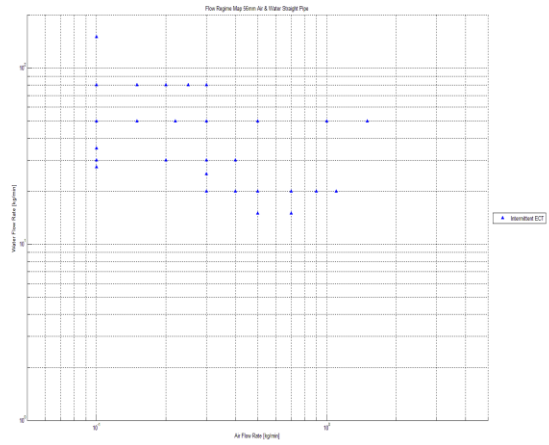
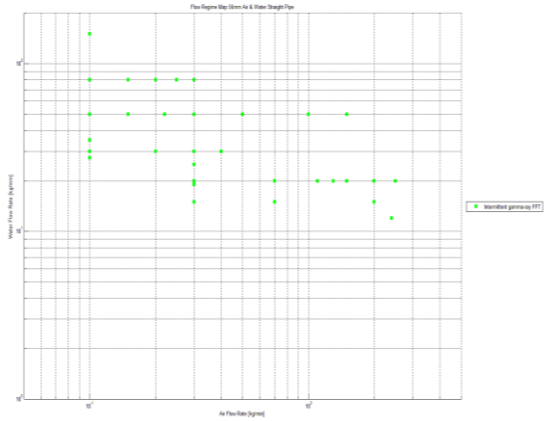
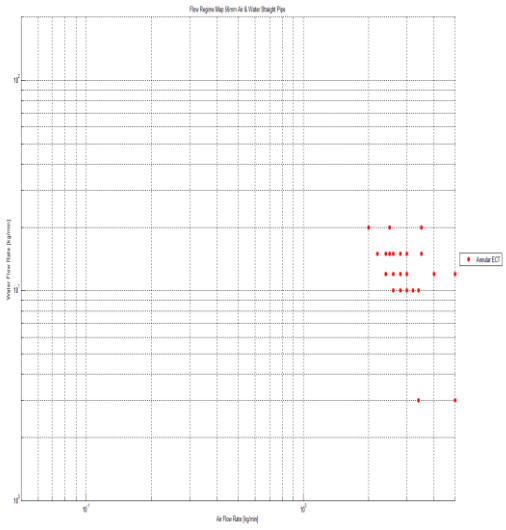
Figure 7-6: Transition from stratified or wavy to annular. The water touches the top of the pipe in the right circle.

In Figure 7-6, the transition is schematically shown. In the left circle, the water is starting to be pressed onto the wall of the pipe. The circle in the middle shows that the water is becoming a thin layer around the whole pipe but it does not yet touch the top of the pipe. The water touches the top of the pipe in the last circle. The last circle is considered annular, the other two are not. The parameter threshold for annular flow is found to be around $\varsigma_{thresh} = 0.20$.

Note that intermittent flows usually would be mistaken as annular flows using this criterion, but since the criterion for identification of intermittent flows is tested first, this confusion can be avoided.

In the algorithm, if the flow pattern is neither intermittent nor annular, it is classified as a wavy/stratified flow. A criterion for this flow patterns has not been found yet.

Table 7-1: The criteria found for the different flow patterns and their formulas

Flow regime	*Criterion*	*Flow regime map*
Intermittent (ECT sensor)	$12^{th}\ eigenvalue\ of\ SD\ > 1{,}15$	
Intermittent (gamma-ray sensor)	$Ratio_{FFT} = \frac{\sum_{2}^{111} y_{freq}}{\sum_{111}^{256} y_{freq}}$ $Ratio_{FFT} > 2$	
Annular (ECT sensor)	$\varsigma = -\frac{\left(11^{the} Eigenvalue\ of\ Mean\ Matrix\right)}{\left(1^{th}\ Eigenvalue\ of\ Mean\ Matrix\right)}$ $\varsigma_{thresh} > 2$	

7.3. Success/fail test of the algorithm.

During the experiments, observations were made for the actual flow pattern. This was done by filming the transparent section of the pipe (see Figure 4-2) and by visual inspection. After the calculations are done and the algorithms have determined which flow pattern the flow was, a comparison is made between the observed flow pattern and the determined flow pattern. In this test, FFT test using gamma-ray signals is left out.

Table 7-2: Success/fail test table, the measurements done with horizontal pipe and inclined pipe are separated.

	Normalized Plane 1	*Normalized Plane 2*	*Absolute Plane 1*	*Absolute Plane 2*
Total	137	137	137	137
Wrong FP	35	15	49	26
Percentage Wrong	25,5%	10,9%	35,8%	19,0%
Straight Pipe	115	115	115	115
Wrong FP	27	7	36	18
Percentage Wrong	21,7%	6,1%	31,3%	15,7%
Angled Pipe	22	22	22	22
Wrong FP	8	8	13	8
Percentage Wrong	36,4%	36,4%	59,1%	36,4%

From Table 7-2, one can conclude that the best results are derived from the data out of the normalized plane 2 measurements. A possible reason for this is that, during the experiments bubbles were present in the front of the sensor. This was visible on the tomographic image of plane one in the ECT32v2 software. Therefore, data from plane 1 includes bubbles, which possibly influenced the measurements. In addition, it shows that the highest percentage of wrong flow patterns is found with inclined pipes.

In those experiments, the flow patterns did not behave as suspected, with high amplitude waves difficult to attribute to intermittent flows or wavy flows.

Additionally, the criteria have been derived from sets of experiments not including measurements with inclined pipes. This needs further investigation.

Furthermore, the wrong identification of the flow pattern for the horizontal pipes are usually flows that are near or in a transition area between two flow patterns. I.e. run 43 is determined to be an annular flow. In the visual observation, the flow pattern is determined to be a wavy flow. In run 44, the flow is determined to be an annular flow and was recognized as an annular flow. The difference between run 43 and 44 is that in run 44 the airflow rate was 0.2 kg/min higher than in run 43. Therefore, it is difficult to say if the observer made a wrong identification of the flow pattern or the algorithm did not work as desired. The transition between some of the flow patterns is very difficult to observe because it takes place in a transition area and is not a rapid shift between two flow patterns. It gradually changes (see Figure 3-1). Despite the intrinsic difficulty to draw a line between the different zones on the flow regime map that is obtained by the measurements (Figure 7-6), the similarity between the transition zones in the flow regime map generated, corresponds to the one found in the literature (Figure 5-1, for slightly smaller pipe diameter. 50mm). Because the diameters are not the same, it is expected that the transitions will shift for higher air and water velocities.

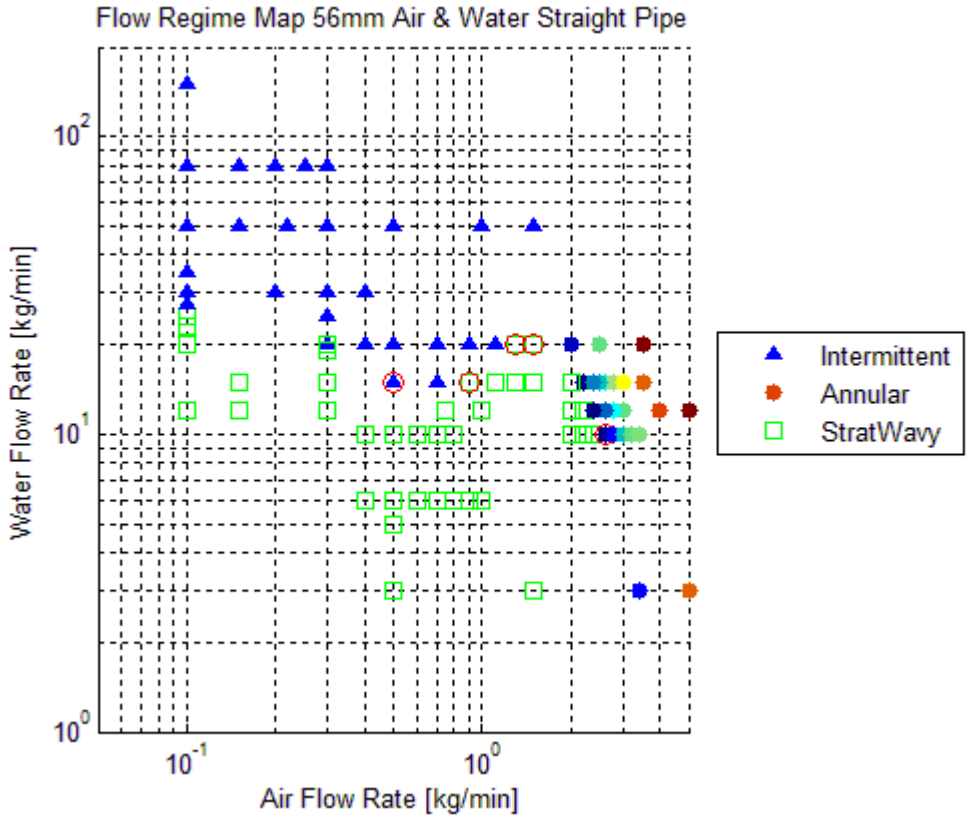


Figure 7-7: Flow regime map with the flow pattern identification of a horizontal 56 mm pipe. The points on the plot with red circle around are the flow patterns that are false, according to the success fail test. The generation of this map is explained in Chapter 8. Based on analyzing 115 different measurements performed on the multiphase rig.

8. Flow regime mapping

The results from the flow pattern algorithm (Chapter 7) will be used for making a flow regime map of the experiments performed. In the next paragraphs, the MATLAB code FlowRegimeMapping.m used for making the mapping is explained. Full code is found in Annex 5.

8.1. Data export from Excel to MATLAB

The data that will be used is imported from an Excel file. In the Excel file, a specific tab is made for the measurements taken with a horizontal pipe. This is important because the measurement from horizontal pipes cannot be mixed with measurements from inclined pipes.

```
%% Get data out the excel file
Measurements = xlsread('Flow_regime_identification.xlsx','horizontal_pipe');
```

Figure 8-1: MATLAB code for importing data out of Excel sheets

In the code that is presented in Figure 8-1 the name of the Excel file can be change according to which file is needed. The values that are used come from the normalized eigenvalues in plane 2. (Chapter 6 for explanation)
Once the Excel-sheet is imported in MATLAB, the desired column will be selected. This is done using the following code.

```
%% Mapping with FP results
figure
Intermittent = Measurements(1:end,4);
Annular = Measurements(1:end,5);
StratWavy = Measurements(1:end,6);
SuccessorFail = Measurements(1:end,7);
Flow_rates=Measurements(1:end,1:2);
```

Figure 8-2: Importing the desired columns into a vector

The columns containing the 0 and 1 values, coming from the flow pattern algorithm are stored into columns with specific names. The flow rates and the success/fail test result are stored.

8.2. Mapping of flow regimes

After the different datasets are imported, they can be used for mapping the flow regimes. The MATLAB code makes two plots. One from all the measurements taken without distinguishing which flow pattern it is and the other one with the distinction.

8.2.1. Mapping all measurements without flow pattern identification

With this scatterplot, all the measurements taken with the horizontal pipe are plotted using the following code:

```
%% Mapping All Measurements
Water = Measurements(1:end,1);
Air = Measurements(1:end,2);
figure
scatter(Air,Water);
grid on
set(gca,'xscale','log');
set(gca,'yscale','log');
title('Measurements taken with Multiphase flow rig Air & Water Straight Pipe');
xlabel('Air Flow Rate [kg/min]'); % x-axis label
ylabel('Water Flow Rate [kg/min]') % y-axis label
axis([0.05 5 1 200]);
```

Figure 8-3: MATLAB code for scatterplot all measurements

The scatterplots have logarithmic scale in the two axes. The two axes both have a determined length. This is done so all the mapping generated will have a similar look.

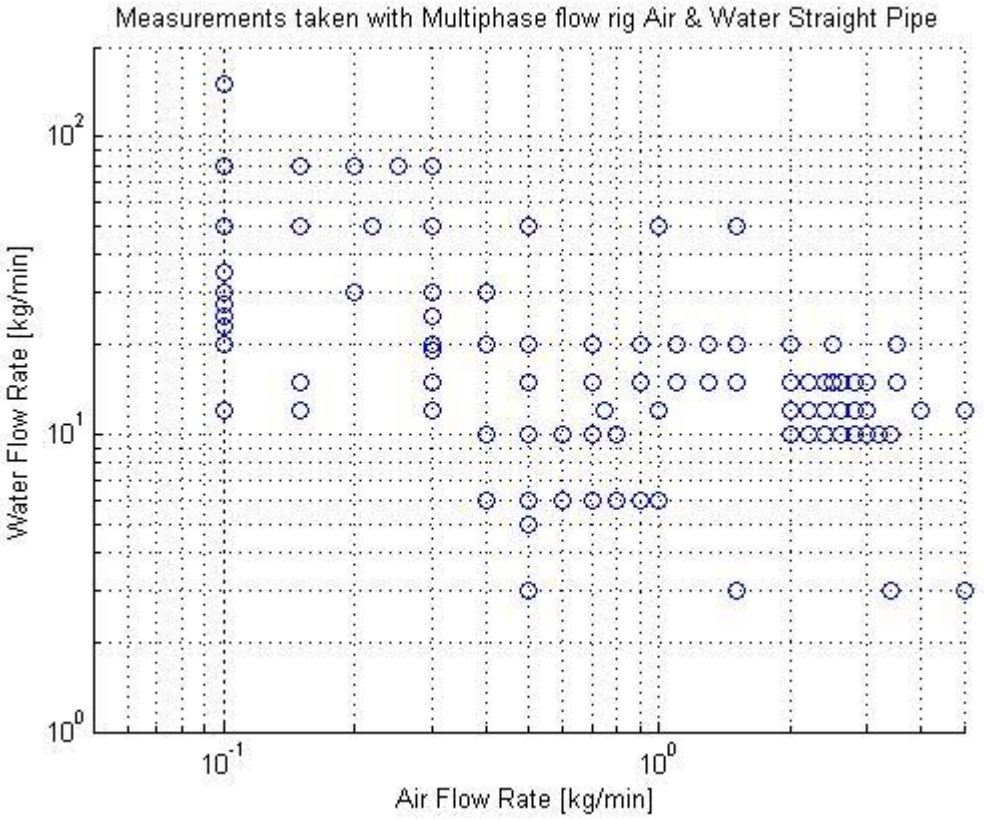


Figure 8-4: Mapping of all measurements taken with horizontal pipe.

In this plot, some measurements are not presented properly, because they have the same values of air and water velocity. The points overlap and there is no indication of the double point. This problem has not been solved yet.

This plot can be helpful to decide in which region more measurements needs to be taken. In addition, this plot can be made before the measurements are taken. This will perhaps help to design experiment sessions.

8.2.2. Mapping the flow regimes

The next mapping will be a flow regime map. This mapping will have the same points as the one shown in Figure 8-5. The difference will be a number of different colors and symbols to represent the flow pattern or a group of flow patterns. As of now, the algorithms splits the flow patterns into three different groups: intermittent flow (Plug and slugs), annular, stratified/wavy. The algorithm used in the Excel sheets determine which flow pattern it is. For giving the different points in the scatterplot the right coded color and symbols, these values are used. They are imported and stored into the vectors Intermittent, Annular and StratWavy (Figure 8-2).

The values of the flow rates and the success or fail test are stored as well. The assignment and plotting of the different points is done by following MATLAB code.

```
for i_index=1:length(Flow_rates)
selectedRow = i_index;
    if Intermittent(selectedRow,1) == 1;
    scatter(Flow_rates(selectedRow,2),Flow_rates(selectedRow,1),'^','b','filled')
    elseif Annular(selectedRow,1) ~= 0;
    scatter(Flow_rates(selectedRow,2),Flow_rates(selectedRow,1),40,Annular(selectedRow,1),'filled','o'
    elseif StratWavy(selectedRow,1) == 1;
    scatter(Flow_rates(selectedRow,2),Flow_rates(selectedRow,1),'s','g')
    end
    hold on
    if SuccessorFail(selectedRow,1) == 1;
    scatter(Flow_rates(selectedRow,2),Flow_rates(selectedRow,1),80,'o','r')
    end
    hold on
end
```

Figure 8-5: Assigning the flow patterns and plotting the different points in flow regime map

In the MATLAB code, presented in Figure 8-5, the code will determine which flow pattern it is by searching for the columns that possesses a value equal to 1. Then the values of the velocities are plotted with a specific color and symbol code. The result is shown in Figure 8-6.

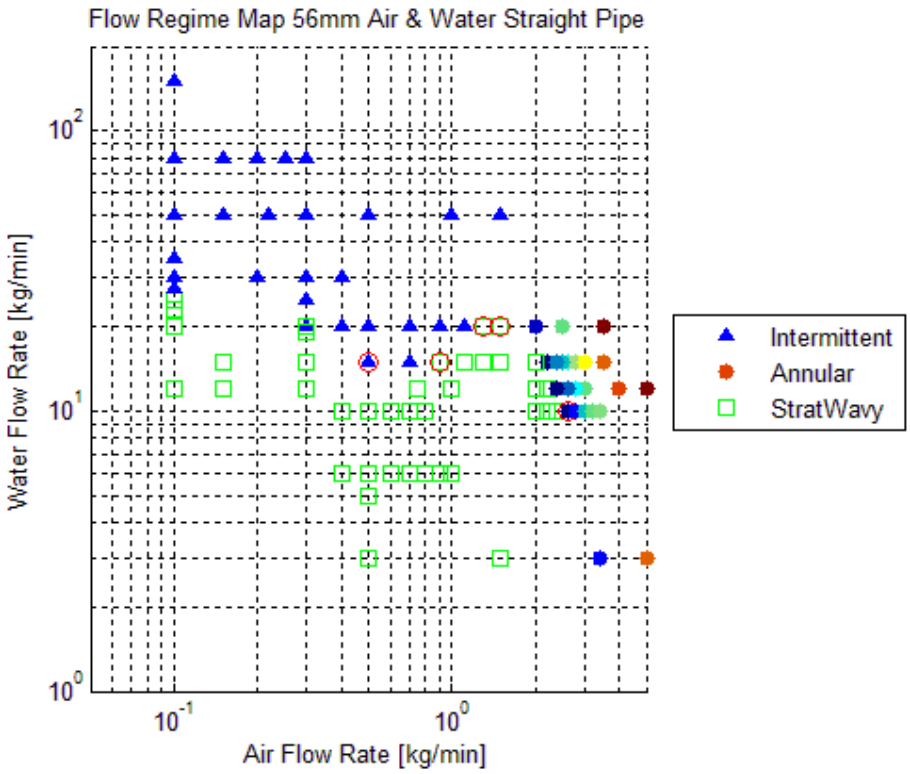


Figure 8-6: Flow regime map with flow pattern identification of horizontal pipe 56 mm, based on 115 experiments runs in the multiphase rig.

The legend in the plot explains which symbol is which flow pattern. If this flow regime map is compared with Figure 5-1, the imaginary lines between the different regions Intermittent, Annular and StratWavy have the same shape as the lines presented in this flow regime map given in [Mandhane et al., 1974], the straight line between StratWavy and SlugPlug for low air flow rate, the parabolic line between StratWavy and SlugPlug for medium air flow rate and the declining straight line between StratWavy and Annular.

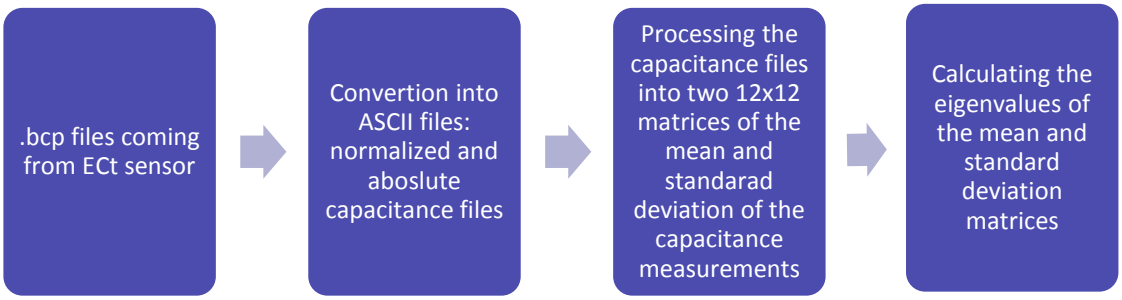
The color of the annular points of the flow regime map gradually change. The meaning behind this is that the blue annular points are the least annular flows. The 'annularity' of the flow gradually increases if the air flow rate is increased. The points on the mapping will go from blue (low annularity) to red (high annularity), according to Figure 7-6.

In Figure 8-6, five red circles are present. This is derived from the success/fail test of the flow pattern identification. This means that if a point in the map is red circled, the flow pattern that is observed varies from the flow pattern calculated with the algorithm. These points will need to be studied further. Also notice that in Table 6-2 there are seven wrong flow patterns found and in the mapping only five. This is because 4 runs that have wrong flow patterns are the same: run111/127 and run 112/run126.

9. Conclusion and future work

9.1. Conclusion

All the experiments performed use a horizontal pipe combined with water and air as the two different phases. The raw data, gathered from these experiments, needs to be processed in order to analyze it. There are a couple of different data sets gathered: the ECT sensor data, gamma-ray sensor data, flow rates and differential pressure sensor data. The ECT sensor data will be processed using following steps:



Once all the eigenvalues are calculated, a parameter is searched that best characterizes the flow regime. For this, the gamma-ray sensor data and camera footage is used to see when a flow pattern goes over into another. This helps to set the threshold that best fits the algorithm.

Three criteria are found for flow patterns. Two criteria are found for intermittent flow patterns, one criterion is found for annular flows. Intermittent flow patterns include slug and plug flows. One criterion is found by using the eigenvalues of the standard deviation matrix, originating from the ECT sensor.

$$FlowPattern = Intermittent\ if\ 12^{th}\ Eigenvalue\ of\ SD \geq 1{,}15$$

Another criterion is found by applying a FFT on the gamma-ray sensor data.

$$Ratio_{FFT} = \frac{\sum_{2}^{111} y_{freq}}{\sum_{111}^{256} y_{freq}}$$

The ratio of the sums of the frequency values is calculated. The sum is taken of the second until the one hundred and tenth-frequency value. This sum is than divided by the sum of the following 145 values. If the ratio is bigger than two, the flow pattern will be identified as an intermittent flow.

The third criterion that came out of the analysis is a criterion for annular flow. This uses eigenvalues of the mean matrix.

$$\varsigma = -\frac{(11^{the}\, Eigenvalue\ of\ Mean\ Matrix)}{(1^{th}\ Eigenvalue\ of\ Mean\ Matrix)}$$

If ς is bigger equal to or bigger than 0.2, the flow will be an annular flow. Note that intermittent flows usually would be confused with annular flows with this criterion. However, since the criterion for identification of intermittent flows is tested first, they can be discarded.

With these criteria, the fast recognition of flow patterns is possible. A criterion for wavy and stratified flows has not been found yet. Nevertheless, as in the experiments, if only three type of low patterns (intermittent, annular, strat/wavy) are examined, only two criteria are needed.

The algorithm for flow recognition can be used to obtain flow regime maps, specific for a given flow rig. In this project, a large number of measurements have been analyzed with varying input mass flow rates and obtained the following flow regime map.

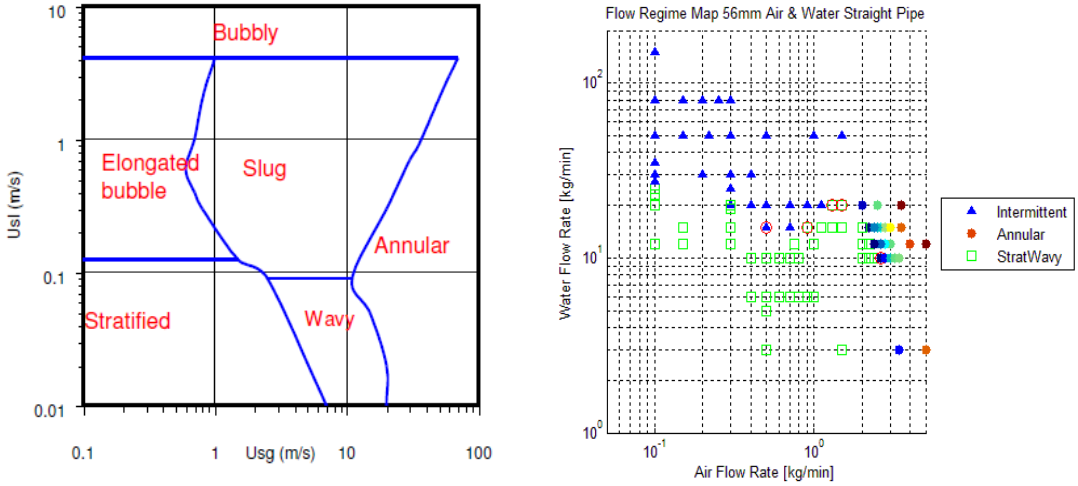


Figure 9-1: Mandhane map [Mandhane et al., 1974] on the left and the flow regime map generated for flow rig at USN, Porsgrunn on the right

There is a slight but noticeable difference with the Mandhane map (Figure 9-1 on the left), so the reader will realize the potential of such flow regime identification techniques for generating flow regime maps specific for a given installation.

The transition criterion between the different flow patterns are not found in this thesis. It is hard to determine when a specific flow pattern starts to transition into another one.

In this thesis, some experiments are taken with an inclined pipe. The algorithm was tested on the data sets but the result were not promising. The success/fail rate of the flow pattern was high.

9.2. Future work

- Finding the transition criteria for the different flow patterns.
- Validating the criteria with different sensors and pipe diameters.
- Studying the behavior of flow patterns in angled pipes and trying to fine-tune the criteria to give better results.
- Combining the analyzing method and flow pattern criteria to get a direct recognition of the flow pattern out of the sensors. Also, combine the criteria, coming from the ECT data and gamma-ray data, for intermittent flows.
- Perform similar test with other modalities, i.e. ERT, EIT etc.

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List of tables and figures

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Annexes

Annex 1: <Master thesis description.>

Campus Porsgrunn/Faculty of Technology
Department of Electrical Engineering, IT and Cybernetics

FMH 606 Master's Thesis

Title: Process Tomometric Data Fusion with Multimodal Sensor Suite in Multiphase flow studies

USN supervisor: Saba Mylvaganam, Kjell Joar Alme (only on need basis),

External partner: Professor Geir Elseth, STATOIL / PhD Research Fellow Antoine DUPRE, CEA Cadarache, Institut Fresnel (France)

Task description:

Focus in this project is the multimodal tomometry (ECTm and ERTm) in studying various features of multi-phase flow, but bypassing image processing and incorporating time series data from high-speed camera, gamma meter and some conventional sensors. This means that the focus will be on exploiting patterns in the actual time series of raw data from the array of multimodal sensors or their other mathematical properties. Considerable work has been done earlier at USN. The present thesis should strive to add value to existing results and findings achieved particularly by students and staff at USN. Real times processing of time series, data mining approach, wavelets, and matrix methods are some keywords associated with this project. The goals for the present thesis project are the following:

(1) Survey of multimodal process tomometry with focus on its application to multi-phase flow
(2) Understanding and describing the basic features of the process multimodal systems in the Sensor Lab at TUC including the programs developed by TUCs collaborators and PhD students.
(3) Generating data sets using multi-phase flow rigs at TUC and analysing them for flow regime, bubble and slug studies
(4) Online data acquisition and processing with multi-modal sensor suite
(5) A brief survey of flow regimes in multiphase flow in tabular form with own sketches and at least some own photos/videos using TUC flow rigs.
(6) Analysis of data with focus on slug and bubble characterization and means of studying wavy flow
(7) Characterization of plug vs slug flow
(8) Criteria for identification of transition from stratified to wavy flow. Validation with high speed camera
(9) Mapping of the flow regimes for the USN flow rig, with gradual transitions based on criteria found in (8)
(10) Submitting a report using the guidelines and template of USN with systematically archived data sets and software

Task background:

Multimodal sensor suites for multiphase flow is found increasingly in the oil and gas & process industries. TUC has the latest equipment on multimodal and capacitance based tomography. Recently, a modern Gamma ray based measurement system has been added to the sensor suite on the multiphase flow rig. There will be close collaboration with manufacturers of process tomographic equipment in the UK. Currently, USN is conducting a measurement campaign in collaboration with University of Stavanger.

Student category:

This work is suitable for both SCE/PEM students with some interest in mathematical techniques. *As the work entails continuous lab work and program development, students need to be at USN throughout the term. It is mandatory that students have weekly meeting with at least one the supervisors in the lab.*

Practical arrangements:

Necessary hardware and software will be provided by USN. Work will be performed in Sensor Lab and Process Hall where the multiphase flow facilities are available. However, possible interaction with process tomography research groups in Norway and abroad is also envisaged. Students need to familiarise themselves with the earlier work done at USN and USNs collaborators in the field. Some data sets from real industrial measurements may be available in the final stages of the thesis work.

Signatures:

Student (date and signature): Stijn Vyncke
12.02.2016

Supervisor (date and signature):
12.02.2016

Annex 2: <All measurements taken during sessions, colour code green means data represented for that column is taken, red means it is not taken>

Sample	Water Flow Rate	Air Flow rate	Flow regime		ECT	Process parameters	Gamma	High-Speed Camera
#1	80	0	Full	1_01	05.02.2016			
#2	80	0,15	Plug	1_02				
#3	12	4	Annular	1_03				
#4	12	2	Wavy	1_04				
#5	12	1	Wavy	1_05				
#6	12	0,1	Stratified	1_06				
#7	12	0,15	Stratified	2_01	10.02.2016			
#8	12	0,3	Stratified	2_02				
#9	12	0,75	Wavy	2_03				
#10	12	1	Wavy	2_04				
#11	12	2	Wavy	2_05				
#12	12	3	Annular	2_06				
#13	12	4	Annular	2_07				
#14	12	5	Annular	2_08				
#15	15	0,15	Stratified	2_09				
#16	35	0,1	Plug	2_10				
#17	50	0,1	Plug	2_11				
#18	150	0,1	Plug	2_12				
#19	80	0,1	Plug	3_01	17.02.2016			
#20	80	0,15	Plug	3_02				
#21	80	0,2	Slug	3_03				
#22	80	0,25	Slug	3_04				
#23	80	0,3	Slug	3_05				
#24	30	0,1	Plug	3_07				
#25	30	0,2	Plug	3_08				
#26	30	0,3	Slug	3_09				
#27	30	0,4	Slug	3_10				
#28	15	2	Wavy	3_11				
#29	15	2,2	Annular	3_12				
#30	15	2,4	Annular	3_13				
#31	15	2,6	Annular	3_14				
#32	15	2,8	Annular	3_15				
#33	15	3	Annular	3_16				
#34	12	3	Annular	3_17				
#35	12	2,8	Annular	3_18				
#36	12	2,6	Annular	3_19				
#37	12	2,4	Annular	3_20				

Sample	Water Flow Rate	Air Flow rate	Flow regime		ECT	Process parameters	Gamma	High-Speed Camera
#38	12	2,2	Wavy	3_21				
#39	12	2	Wavy	3_22				
#40	10	2	Wavy	4_01	18.02.2016			
#41	10	2,2	Wavy	4_02				
#42	10	2,4	Wavy	4_03				
#43	10	2,6	Wavy	4_04				
#44	10	2,8	Annular	4_05				
#45	10	3	Annular	4_06				
#46	10	3,2	Annular	4_07				
#47	10	3,4	Annular	4_08				
#48	3	3,4	Annular	4_09				
#49	3	5	Annular	4_10				
#50	3	1,5	Wavy	4_11				
#51	3	0,5	Stratified	4_12				
#52	5	0,5	Stratified	4_13				
#53	10	0,4	Stratified	5_01	26.02.2016			
#54	10	0,5	Stratified	5_02				
#55	10	0,6	Wavy	5_03				
#56	10	0,7	Wavy	5_04				
#57	10	0,8	Wavy	5_05				
#58	6	0,4	Stratified	5_06				
#59	6	0,5	Stratified	5_07				
#60	6	0,6	Stratified	5_08				
#61	6	0,7	Wavy	5_09				
#62	6	0,8	Wavy	5_10				
#63	6	0,9	Wavy	5_11				
#64	6	1	Wavy	5_12				
#65	30	0,3	Plug	5_13				
#66	25	0,3	Plug	5_14				
#67	20	0,3	Plug	5_15				
#68	19	0,3	Wavy	5_16				
#69	20	0,1	Stratified	5_17				
#70	23	0,1	Stratified	5_18				
#71	25	0,1	Stratified	5_19				
#72	27,5	0,1	Plug	5_20				
#73	27,5	0,1	Slug	6_1	04.03.2016			
#74	25	0,1	Slug	6_2				
#75	23	0,1	Slug	6_3				
#76	15	0,1	Slug	6_4				
#77	12	0,1	Slug	6_5				
#78	12	0,3	Slug	6_6				

Sample	Water Flow Rate	Air Flow rate	Flow regime		ECT	Process parameters	Gamma	High-Speed Camera
#79	12	1,5	Slug	6_7				
#80	12	1,7	Annular	6_8				
#81	12	1,9	Annular	6_9				
#82	12	2,2	Annular	6_10				
#83	12	2,5	Annular	6_11				
#84	12	3	Annular	6_12				
#85	30	0,1	Wavy	6_13				
#86	30	1	Wavy	6_14				
#87	30	1,5	Wavy	6_15				
#88	30	2	Slug	6_16				
#89	30	2,5	Slug	6_17				
#90	30	3	Slug	6_18				
#91	50	0,1	Plug	7_1	14.03.2016			
#92	50	0,15	Plug	7_2				
#93	50	0,22	Slug	7_3				
#94	50	0,3	Slug	7_4				
#95	50	0,5	Slug	7_5				
#96	50	1	Slug	7_6				
#97	50	1,5	Slug	7_7				
#98	15	0,3	Wavy	7_8				
#99	15	0,5	Wavy	7_9				
#100	15	0,7	Slug	7_10				
#101	15	0,9	Slug	7_11				
#102	15	1,1	Wavy	7_12				
#103	15	1,3	Wavy	7_13				
#104	15	1,5	Wavy	7_14				
#105	15	2	Wavy	7_15				
#106	15	2,5	Annular	7_16				
#107	15	3,5	Annular	7_17				
#108	20	3,5	Annular	7_18				
#109	20	2,5	Annular	7_19				
#110	20	2	Annular	7_20				
#111	20	1,5	Annular	7_21				
#112	20	1,3	Annular	7_22				
#113	20	1,1	Slug	7_23				
#114	20	0,9	Slug	7_24				
#115	20	0,7	Slug	7_25				
#116	20	0,5	Slug	7_26				
#117	20	0,3	Slug	7_27				
#118	80	0,2	Slug	8_1	05.04.2016			
#119	19	0,3	Wavy	8_2				
#120	20	0,3	Wavy	8_3				

Sample	Water Flow Rate	Air Flow rate	Flow regime		ECT	Process parameters	Gamma	High-Speed Camera
#121	20	0,3	Wavy	8_4				
#122	20	0,4	Slug	8_5				
#123	20	0,7	Slug	8_6				
#124	20	0,9	Slug	8_7				
#125	20	1,1	Slug	8_8				
#126	20	1,3	Annular	8_9				
#127	20	1,5	Annular	8_10				
#128	20	2	Annular	8_11				
#129	15	3	Annular	8_12				
#130	15	2,4	Annular	8_13				
#131	15	0,7	Slug	8_14				
#132	15	0,3	Wavy	8_15				
#133	12	2,4	Annular	8_16				
#134	12	1,5	Slug	8_17				
#135	30	2	Slug	8_18				
#136	30	2,5	Slug	8_19				
#137	30	3	Slug	8_20				

Annex 3: <MATLAB code for analysing the data coming from the ECT sensors ASCII files.

This generates the different matrices and calculates the eigenvalues of those matrices.

This MATLAB code is saved as ECTMeasurementAnalysis.m>

```
clear all;clc

%% READ DATA, BUILD MATRIX
%%% absolute measurements (aac files)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% filename='run01.aac';
% calibration_water=[-5740.61120500007 1104.93015833342
578.206006666639 481.232186666647 406.355483333323 353.644813333306
352.605391666659 357.763081666664 384.640628333341 451.410149999991
588.803305000067 681.020000000017;1104.93015833342 -7559.07732333367
1299.48617166666 810.362080000008 625.370739999967 513.058311666700
484.744071666695 467.783123333348 477.668788333364 527.632586666688
627.754101666745 620.287190000072;578.206006666639 1299.48617166666 -
7347.90160500000 1335.20949833334 763.173566666673 563.090226666692
498.133773333329 452.341148333332 436.337711666664 455.154606666652
505.979474999986 460.789420000030;481.232186666647 810.362080000008
1335.20949833334 -7826.97055499986 1412.62997833339 772.895656666576
618.214194999976 525.936063333293 478.352739999989 471.182953333323
495.105005000026 425.850198333295;406.355483333323 625.370739999967
763.173566666673 1412.62997833339 -7659.36638000003 1190.79000000003
787.418996666641 610.129170000021 515.832126666686 480.245294999975
475.745119999972 391.675903333342;353.644813333306 513.058311666700
563.090226666692 772.895656666576 1190.79000000003 -7235.76800499989
1199.96999999994 744.835111666662 574.089573333295 494.925571666685
465.359303333329 363.109436666672;352.605391666659 484.744071666695
498.133773333329 618.214194999976 787.418996666641 1199.96999999994 -
7497.51443999983 1320.91779999994 750.645384999980 588.422390000049
515.007984999955 381.434451666668;357.763081666664 467.783123333348
452.341148333332 525.936063333293 610.129170000021 744.835111666662
1320.91779999994 -7541.27703833319 1305.25303666669 749.779951666596
594.665198333314 411.873353333330;384.640628333341 477.668788333364
436.337711666664 478.352739999989 515.832126666686 574.089573333295
750.645384999980 1305.25303666669 -7436.95151166671 1288.63949500004
750.673913333304 474.818113333368;451.410149999991 527.632586666688
455.154606666652 471.182953333323 480.245294999975 494.925571666685
588.422390000049 749.779951666596 1288.63949500004 -7432.52085500004
1312.84366500000 612.284190000041;588.803305000067 627.754101666745
505.979474999986 495.105005000026 475.745119999972 465.359303333329
515.007984999955 594.665198333314 750.673913333304 1312.84366500000 -
7442.33155333333 1110.39448166663;681.020000000017 620.287190000072
460.789420000030 425.850198333295 391.675903333342 363.109436666672
381.434451666668 411.873353333330 474.818113333368 612.284190000041
1110.39448166663 -5933.53673833347];
% calibration_air=[-1266.09402666661 575.521314999964 27.7267666666646
31.6006933333351 14.5850299999988 6.39741833333366 10.7852833333325
11.1080816666677 11.8748249999994 13.8192800000007 66.2163916666654
496.458941666645;575.521314999964 -1396.21729999995 630.367421666656
56.3067266666697 30.6402800000014 3.84743000000025 0.108226666666669
16.0893499999989 4.88212666666638 -3.80102833333343 27.2640399999993
54.9914116666630;27.7267666666646 630.367421666656 -1390.44603333336
613.208341666704 33.2459533333351 20.1670249999984 -1.69430000000002
4.93107833333347 12.5205366666667 1.19008999999994 25.3355783333337
23.4475416666660;31.6006933333351 56.3067266666697 613.208341666704 -
1447.88082500009 615.228403333387 45.5864116666623 39.5137283333377 -
3.83307000000008 32.6297699999972 11.6608616666670 0.681909999999952
5.29704833333372;14.5850299999988 30.6402800000014 33.2459533333351
```

```
615.228403333387 -1414.12270500001 609.148511666623 50.1784016666669
1.64375666666657 30.9904750000002 7.15161333333287 21.5660233333340 -
0.255743333333322;6.39741833333366 3.84743000000025 20.1670249999984
45.5864116666623 609.148511666623 -1371.11389499992 605.372493333298
40.5484133333362 17.9543916666686 16.0216733333319 -0.179221666666656
6.24934833333332;10.7852833333325 0.108226666666669 -1.69430000000002
39.5137283333377 50.1784016666669 605.372493333298 -1421.67688499997
633.807343333334 48.5661533333360 33.9140933333340 -0.184899999999999
1.31036166666662;11.1080816666677 16.0893499999989 4.93107833333347 -
3.83307000000008 1.64375666666657 40.5484133333362 633.807343333334 -
1396.54035833333 636.322559999987 31.2720666666692 14.9900316666674
9.66074666666586;11.8748249999994 4.88212666666638 12.5205366666667
32.6297699999972 30.9904750000002 17.9543916666686 48.5661533333360
636.322559999987 -1458.54037499994 620.901019999954 39.2311016666645
2.66741500000008;13.8192800000007 -3.80102833333343 1.19008999999994
11.6608616666670 7.15161333333287 16.0216733333319 33.9140933333340
31.2720666666692 620.901019999954 -1421.25349833332 633.289686666697
55.8341416666675;66.2163916666654 27.2640399999993 25.3355783333337
0.681909999999952 21.5660233333340 -0.179221666666656 -
0.184899999999999 14.9900316666674 39.2311016666645 633.289686666697 -
1429.73831666670 601.527675000004;496.458941666645 54.9914116666630
23.4475416666660 5.29704833333372 -0.255743333333322 6.24934833333332
1.31036166666662 9.66074666666586 2.66741500000008 55.8341416666675
601.527675000004 -1257.18888833331];
%%% normalized absolute measurements (anc files)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% filename='run01.anc';
calibration_water=[-12.1191911666668 1.09318599999992 1.09433183333337
1.02727783333336 1.09491200000002 1.23082716666660 1.05654733333319
1.02777033333335 1.03956116666664 1.05448216666672 1.05729533333324
1.34299999999989;1.09318599999992 -11.6956126666672 1.12630833333346
1.01750000000002 1.07901599999995 1.21202416666684 1.03699233333336
1.00503933333342 1.01407066666673 1.02526816666659 1.02490533333328
1.06130233333326;1.09433183333337 1.12630833333346 -12.1308506666665
1.11052466666666 1.14189716666658 1.26785966666668 1.08305999999991
1.04500883333339 1.05100950000009 1.06066283333333 1.05709566666654
1.09309216666658;1.02727783333336 1.01750000000002 1.11052466666666 -
11.6346560000000 1.14535749999998 1.23257350000011 1.03808299999995
1.00072500000010 1.00528633333339 1.01131683333329 1.00788433333330
1.03812699999996;1.09491200000002 1.07901599999995 1.14189716666658
1.14535749999998 -12.3764226666660 1.35599999999994 1.13451766666674
1.08448533333329 1.07709683333348 1.08212333333341 1.07293650000007
1.10808033333343;1.23082716666660 1.21202416666684 1.26785966666668
1.23257350000011 1.35599999999994 -13.8005053333339 1.34799999999996
1.24583816666672 1.22929000000000 1.22048149999995 1.21426916666666
1.24334200000007;1.05654733333319 1.03699233333336 1.08305999999991
1.03808299999995 1.13451766666674 1.34799999999996 -12.0921883333329
1.12481333333331 1.07325466666670 1.06468449999994 1.05499633333338
1.07723916666681;1.02777033333335 1.00503933333342 1.04500883333339
1.00072500000010 1.08448533333329 1.24583816666672 1.12481333333331 -
11.7495996666667 1.08653333333342 1.04889033333330 1.03102866666663
1.04946700000004;1.03956116666664 1.01407066666673 1.05100950000009
1.00528633333339 1.07709683333348 1.22929000000000 1.07325466666670
1.08653333333342 -11.8001608333337 1.10664733333332 1.05042150000011
1.06698950000000;1.05448216666672 1.02526816666659 1.06066283333333
1.01131683333329 1.08212333333341 1.22048149999995 1.06468449999994
1.04889033333330 1.10664733333332 -11.8676095000001 1.11100133333327
1.08205116666674;1.05729533333324 1.02490533333328 1.05709566666654
1.00788433333330 1.07293650000007 1.21426916666666 1.05499633333338
1.03102866666663 1.05042150000011 1.11100133333327 -11.8209775000004
1.13914333333341;1.34299999999989 1.06130233333326 1.09309216666658
1.03812699999996 1.10808033333343 1.24334200000007 1.07723916666681
```

```
1.04946700000004 1.06698950000000 1.08205116666674 1.13914333333341 -
12.3018340000004];
calibration_air=[-0.161968000000000 0.0421210000000019 -
0.0309658333333366 0.0294759999999995 0.0109780000000009 -
2.50000000000000e-06 0.0148890000000004 0.0119320000000004
0.00499316666666640 -0.0141861666666666 0.0260275000000009
0.0667058333333347;0.0421210000000019 -0.114099333333337
0.0561765000000006 0.0146806666666670 0.0220570000000017 -
0.0138876666666667 -0.0150225000000005 0.0200264999999989 -
0.00604050000000019 -0.0320140000000018 0.00904983333333361
0.0169524999999995;-0.0309658333333366 0.0561765000000006 -
0.0643469999999987 0.0511351666666615 -0.0160815000000008
0.00800183333333379 -0.0264314999999998 -0.00689550000000001
0.0130823333333339 -0.0192893333333343 0.0260033333333343
0.00961149999999994;0.0294759999999995 0.0146806666666670
0.0511351666666615 -0.183153666666665 0.0549093333333381
0.00382700000000015 0.0365135000000026 -0.0296778333333337
0.0521573333333347 0.00743716666666676 -0.0187505000000015 -
0.0185541666666682;0.0109780000000009 0.0220570000000017 -
0.0160815000000008 0.0549093333333381 -0.124811500000002
0.0398688333333307 0.00640066666666683 -0.0324128333333324
0.0420155000000015 -0.00384250000000016 0.0319840000000019 -
0.0310650000000034;-2.50000000000000e-06 -0.0138876666666667
0.00800183333333379 0.00382700000000015 0.0398688333333307 -
0.0399319999999975 0.0291814999999989 -0.00798600000000044 -
0.000737666666666635 0.0131776666666671 -0.0189998333333350 -
0.0125111666666671;0.0148890000000004 -0.0150225000000005 -
0.0264314999999998 0.0365135000000026 0.00640066666666683
0.0291814999999989 -0.0908238333333324 0.0559170000000003
0.00605350000000019 0.0295763333333331 -0.0202584999999994 -
0.0259951666666674;0.0119320000000004 0.0200264999999989 -
0.00689550000000001 -0.0296778333333337 -0.0324128333333324 -
0.00798600000000044 0.0559170000000003 -0.0333484999999991
0.0510816666666609 -0.0182576666666675 -0.00380866666666683 -
0.00657016666666680;0.00499316666666640 -0.00604050000000019
0.0130823333333339 0.0521573333333347 0.0420155000000015 -
0.000737666666666635 0.00605350000000019 0.0510816666666609 -
0.157067166666666 0.0387729999999959 -0.00666483333333344 -
0.0376463333333372;-0.0141861666666666 -0.0320140000000018 -
0.0192893333333343 0.00743716666666676 -0.00384250000000016
0.0131776666666671 0.0295763333333331 -0.0182576666666675
0.0387729999999959 -0.0663678333333313 0.0406636666666643
0.0243296666666679;0.0260275000000009 0.00904983333333361
0.0260033333333343 -0.0187505000000015 0.0319840000000019 -
0.0189998333333350 -0.0202584999999994 -0.00380866666666683 -
0.00666483333333344 0.0406636666666643 -0.147841833333342
0.0825958333333377;0.0667058333333347 0.0169524999999995
0.00961149999999994 -0.0185541666666682 -0.0310650000000034 -
0.0125111666666671 -0.0259951666666674 -0.00657016666666680 -
0.0376463333333372 0.0243296666666679 0.0825958333333377 -
0.0678533333333320];

number_of_electrode=12;
%%% Multiple input
files = dir('*.anc');
%%% Eigenvalues_SD matrix
Eigenvalues_SD_matrix=zeros(length(files),number_of_electrode);
%%% Eigenvalues_mean matrix
Eigenvalues_mean_matrix=zeros(length(files),number_of_electrode);
%%
for i_files=1:length(files)
    fprintf('Running file %s\n',files(i_files).name)
```

```
   fileID = fopen(files(i_files).name); data = textscan(fileID,'%f %f
%f %f %f %f %f %f %f %f %f'); fclose(fileID);
N=length(data{1,1})/11;
matrix1=horzcat([data{1,1}],[data{1,2};[nan]],[data{1,3};[nan]],[data{
1,4};[nan]],[data{1,5};[nan]],[data{1,6};[nan]],[data{1,7};[nan]],[dat
a{1,8};[nan]],[data{1,9};[nan]],[data{1,10};[nan]],[data{1,11};[nan]])
;
matrix=zeros(12,12,N);
for i=[1:12]
    for j=[i+1:12]
        matrix(i,j,:)=matrix1(i:11:i+(N-1)*11,j-i);
        matrix(j,i,:)=matrix(i,j,:);
    end
end
for k=[1:N]
    matrix(:,:,k)=matrix(:,:,k)-diag(sum(matrix(:,:,k),2));
%diagonal term
    matrix(:,:,k)=(matrix(:,:,k)-calibration_air)./(calibration_water-
calibration_air);  %calibration
end
matrix_mean=mean(matrix,3);
eigenvalues_mean=transpose(eig(matrix_mean));
matrix_SD=std(matrix,0,3);
eigenvalues_SD=transpose(eig(matrix_SD));

Eigenvalues_SD_matrix(i_files,:)=eigenvalues_SD;
Eigenvalues_mean_matrix(i_files,:)=eigenvalues_mean;
Eigenvalues_CopyMeanRE = horzcat(Eigenvalues_mean_matrix,
Eigenvalues_SD_matrix); %copy excel

end
```

Annex 4: < Eigenvalues calculating using MATLAB code in Annex 3. The first table are the eigenvalues of the mean matrix. The second are from the standard deviation matrix.>

Sample	Mean											
	1	2	3	4	5	6	7	8	9	10	11	12
#1	-0,08569	-0,07169	-0,04927	-0,02519	-0,00779	0,004997	0,020663	0,024642	0,035611	0,050162	0,09601	11,72556869
#2	-0,78158	-0,64085	-0,62455	-0,52467	-0,47793	-0,44891	-0,25435	0,040777	0,39784	0,799687	1,596206	7,081661216
#3	-1,43025	-1,23151	-0,86237	-0,71234	-0,57809	-0,15286	-0,06322	0,541539	0,570363	1,000725	1,46247	3,964613468
#4	-1,05116	-0,98018	-0,78629	-0,25523	-0,10712	-0,05636	-0,01189	0,094551	0,10297	0,143875	0,417518	4,6612343
#5	-0,89949	-0,86033	-0,72181	-0,69436	-0,0814	-0,06968	-0,01402	0,028261	0,062717	0,104468	0,131599	5,520028648
#6	-0,94091	-0,75006	-0,62648	-0,58732	-0,55491	-0,03109	-0,01693	0,010009	0,021936	0,054073	0,28655	6,964043921
#7	-0,81512	-0,75577	-0,6202	-0,59099	-0,54919	-0,07055	-0,04134	0,006641	0,045926	0,086962	0,184267	7,138680405
#8	-0,88015	-0,74911	-0,61902	-0,58603	-0,54494	-0,04521	-0,02011	0,002723	0,030111	0,065334	0,230673	6,985641333
#9	-1,04012	-0,8328	-0,70185	-0,66263	-0,06793	-0,04536	-0,02895	0,008949	0,065118	0,077753	0,288556	5,930062797
#10	-0,92119	-0,83887	-0,72137	-0,64278	-0,08927	-0,06848	-0,01801	0,032958	0,06636	0,101448	0,122103	5,501772913
#11	-1,04163	-0,99709	-0,79137	-0,2608	-0,07357	-0,03371	-0,00738	0,059741	0,075127	0,137618	0,453363	4,62382781
#12	-1,31648	-1,10246	-0,82435	-0,4731	-0,34758	-0,14358	-0,01931	0,29012	0,365392	0,534822	1,139838	4,201241099
#13	-1,43955	-1,24519	-0,87188	-0,73326	-0,60265	-0,15129	-0,0652	0,568555	0,597066	1,046548	1,487861	3,934391489

#14	-1,52203	-1,33741	-0,94073	-0,80864	-0,60253	-0,1243	-0,05202	0,614695	0,66072	1,227146	1,698451	3,722281444
#15	-0,85971	-0,66184	-0,60402	-0,54839	-0,49867	-0,20552	-0,05591	-0,0096	0,033472	0,063593	0,124866	7,741692966
#16	-0,63391	-0,6065	-0,48626	-0,47587	-0,4426	-0,26195	-0,14966	-0,0789	0,067018	0,257039	0,81158	7,721441482
#17	-0,60099	-0,5611	-0,49824	-0,44343	-0,43193	-0,41507	-0,35178	-0,05602	0,238409	0,528115	1,225799	7,843715391
#18	-0,76157	-0,54835	-0,40371	-0,37479	-0,31265	-0,28838	-0,26784	-0,04021	0,294434	0,786396	1,549069	9,036720346
#19	-0,68757	-0,52661	-0,51065	-0,47313	-0,4043	-0,38869	-0,33707	-0,04026	0,310234	0,685811	1,449542	8,085435656
#20	-0,7929	-0,64585	-0,61065	-0,52102	-0,47743	-0,44895	-0,29056	0,027238	0,399266	0,822759	1,593014	7,291654306
#21	-0,80802	-0,68673	-0,66135	-0,57601	-0,5362	-0,50626	-0,26878	0,07138	0,457808	0,867389	1,670004	6,608724464
#22	-0,7451	-0,73175	-0,63387	-0,59438	-0,56482	-0,53814	-0,28111	0,080091	0,442521	0,837285	1,592649	6,29227289
#23	-0,78658	-0,77811	-0,65925	-0,61788	-0,57115	-0,53188	-0,29991	0,101954	0,462644	0,894935	1,630054	6,197053937
#24	-0,76534	-0,6536	-0,52909	-0,48739	-0,45248	-0,33916	-0,09678	-0,0424	0,095365	0,223997	0,358774	8,270202358
#25	-0,79724	-0,70808	-0,59695	-0,56075	-0,32548	-0,25035	-0,11206	0,012351	0,214191	0,367876	0,788158	6,459017692
#26	-0,83595	-0,79515	-0,67853	-0,65327	-0,38815	-0,31691	-0,11805	0,059225	0,265457	0,45203	0,719895	5,736028437
#27	-0,81168	-0,76965	-0,65475	-0,63057	-0,39968	-0,32443	-0,11773	0,041058	0,264809	0,452475	0,673579	5,969538188
#28	-1,13105	-0,92294	-0,76679	-0,49633	-0,14817	-0,08368	-0,01206	0,123269	0,151604	0,216886	0,59131	4,898293248
#29	-1,12819	-0,99543	-0,78271	-0,48982	-0,13759	-0,08538	-0,00473	0,128034	0,147659	0,247095	0,723678	4,752036423

#30	-1,16274	-1,04555	-0,79348	-0,51067	-0,24017	-0,12932	-0,01754	0,20027	0,24008	0,363889	0,869201	4,649505613
#31	-1,18025	-1,08774	-0,79983	-0,51329	-0,26392	-0,12915	-0,018	0,207693	0,281434	0,397194	0,94798	4,573796658
#32	-1,22708	-1,12776	-0,80799	-0,57088	-0,38448	-0,17181	-0,04234	0,306569	0,377093	0,578851	1,091774	4,485253137
#33	-1,26094	-1,1579	-0,81361	-0,59808	-0,43837	-0,18455	-0,04801	0,361256	0,418289	0,670268	1,17412	4,40879853
#34	-1,30561	-1,10178	-0,82312	-0,4677	-0,34099	-0,14239	-0,0187	0,283318	0,355956	0,517598	1,122846	4,229169674
#35	-1,25066	-1,06591	-0,81921	-0,41769	-0,24215	-0,11	-0,01166	0,204607	0,264684	0,404076	0,996021	4,284414376
#36	-1,19459	-1,04074	-0,81526	-0,37989	-0,22572	-0,10551	-0,00882	0,185355	0,240806	0,331987	0,874441	4,355246482
#37	-1,13068	-1,02525	-0,80954	-0,33771	-0,16016	-0,07574	-0,00482	0,125012	0,181589	0,244902	0,733242	4,435831094
#38	-1,08279	-1,02312	-0,80228	-0,3274	-0,15509	-0,07544	-0,00872	0,129443	0,159359	0,217246	0,640144	4,522917063
#39	-1,05188	-0,98143	-0,78667	-0,26635	-0,10267	-0,05433	-0,00638	0,088605	0,104558	0,133826	0,429803	4,669765458
#40	-1,04219	-0,97713	-0,80296	-0,06894	-0,0225	-0,00922	0,001687	0,018915	0,028976	0,034068	0,293847	4,495212747
#41	-1,11424	-0,93247	-0,81467	-0,10846	-0,02704	-0,00766	-0,00434	0,024984	0,034527	0,082898	0,443259	4,34427216
#42	-1,17979	-0,93119	-0,80965	-0,18412	-0,0875	-0,03344	-0,00671	0,065019	0,10371	0,173669	0,61136	4,240951098
#43	-1,23825	-0,96808	-0,8102	-0,27151	-0,14389	-0,06503	-0,00501	0,129026	0,162311	0,264503	0,798751	4,181954653
#44	-1,28268	-0,99792	-0,81459	-0,31963	-0,18689	-0,07598	-0,01132	0,171931	0,20158	0,342231	0,913728	4,135878047
#45	-1,33619	-1,03936	-0,81565	-0,35888	-0,24322	-0,09585	-0,00778	0,207313	0,272725	0,415105	1,050346	4,065924567

#46	-1,37555	-1,0849	-0,82212	-0,42573	-0,31655	-0,11391	-0,01411	0,277632	0,346365	0,53201	1,168386	4,017782125
#47	-1,40033	-1,10801	-0,82782	-0,4685	-0,37741	-0,12649	-0,01955	0,330104	0,404717	0,61806	1,225408	3,983268344
#48	-1,34331	-1,274	-0,2613	-0,14367	-0,11639	-0,017	0,014387	0,110465	0,151712	0,196693	0,926611	3,130623187
#49	-1,58059	-1,40422	-0,7376	-0,34538	-0,31588	-0,00448	0,032433	0,369524	0,418257	0,815788	1,604612	2,928215352
#50	-1,06216	-0,9078	-0,26488	-0,06287	-0,05223	-0,01531	0,007102	0,028569	0,06968	0,079329	0,167838	3,27333325
#51	-1,16923	-0,8465	-0,74188	-0,51452	-0,00589	-0,00345	-0,00108	0,001845	0,004691	0,013579	0,096226	5,327623623
#52	-1,00031	-0,9155	-0,74328	-0,72981	-0,01218	-0,00277	0,000206	0,003503	0,006691	0,026899	0,116169	5,463244325
#53	-1,09071	-0,82699	-0,6793	-0,64032	-0,20114	-0,01289	0,000845	0,003485	0,008336	0,034002	0,342791	6,210563515
#54	-1,07553	-0,82768	-0,68898	-0,65062	-0,14858	-0,00932	0,000128	0,002843	0,008315	0,036191	0,314168	6,081062517
#55	-1,05794	-0,83279	-0,70296	-0,66416	-0,09254	-0,0039	0,000142	0,002049	0,007292	0,042939	0,278857	5,922615617
#56	-1,05163	-0,83971	-0,71703	-0,67595	-0,05723	-0,00007	0,001069	0,001986	0,006989	0,053413	0,26246	5,797812882
#57	-1,03188	-0,86148	-0,73968	-0,69424	-0,02969	-0,00139	0,00101	0,005317	0,006813	0,070687	0,224029	5,649564133
#58	-1,02432	-0,90626	-0,76766	-0,71291	-0,0196	-0,00155	0,000727	0,005397	0,007925	0,091702	0,167426	5,559984926
#59	-1,02483	-0,91042	-0,76927	-0,71423	-0,01921	-0,00143	0,000908	0,005057	0,00788	0,093288	0,163333	5,555788953
#60	-1,02963	-0,92486	-0,77737	-0,72065	-0,01587	-0,00197	0,000671	0,005016	0,007206	0,088962	0,149817	5,537077266
#61	-1,02875	-0,92469	-0,77968	-0,72449	-0,01358	-0,00234	0,000578	0,004432	0,006909	0,07617	0,138636	5,531016365

#62	-1,02435	-0,91953	-0,78119	-0,72807	-0,01136	-0,0028	0,000222	0,004098	0,005881	0,057337	0,125242	5,526236941
#63	-0,9925	-0,93248	-0,77407	-0,73138	-0,00943	-0,00334	7,58E-05	0,004137	0,005194	0,039931	0,117186	5,50713549
#64	-1,05394	-0,88324	-0,73952	-0,69803	-0,00916	-0,00317	-0,0002	0,003879	0,004171	0,023472	0,121701	5,419249068
#65	-0,83946	-0,7817	-0,68148	-0,65317	-0,41793	-0,34799	-0,12975	0,059715	0,275109	0,486922	0,769873	5,718808038
#66	-0,82122	-0,78336	-0,66575	-0,64242	-0,37143	-0,29838	-0,10462	0,046946	0,258476	0,419486	0,626332	5,840353002
#67	-0,74687	-0,69559	-0,58786	-0,55635	-0,2927	-0,22556	-0,15063	-0,01329	0,109084	0,253586	0,323641	6,755890355
#68	-0,7321	-0,70694	-0,5404	-0,5297	-0,47832	-0,29954	-0,04486	-0,00129	0,045429	0,058376	0,104225	8,123408204
#69	-0,90031	-0,71967	-0,59848	-0,52741	-0,4866	-0,37429	-0,03318	0,01725	0,031682	0,146586	0,169705	8,287484143
#70	-0,92484	-0,65669	-0,52612	-0,48833	-0,45158	-0,37884	-0,02531	0,000651	0,026585	0,135326	0,255268	8,440465382
#71	-0,85183	-0,63173	-0,49328	-0,45537	-0,41978	-0,33835	-0,04498	-0,00239	0,027425	0,144475	0,23818	8,696007807
#72	-0,73076	-0,59633	-0,46242	-0,43152	-0,39834	-0,27242	-0,13031	0,005607	0,102211	0,178195	0,27395	8,706849958
#73	-0,68276	-0,62844	-0,57774	-0,52861	-0,49335	-0,4649	-0,2321	0,063803	0,398892	0,749877	1,601339	6,795358
#74	-0,67837	-0,64839	-0,57911	-0,54083	-0,51113	-0,48215	-0,23891	0,073206	0,408299	0,756424	1,625492	6,618844
#75	-0,65904	-0,6336	-0,57718	-0,52206	-0,50497	-0,47626	-0,21682	0,068179	0,38966	0,716982	1,582881	6,625996
#76	-0,67719	-0,64414	-0,59298	-0,53985	-0,52091	-0,49007	-0,21263	0,066949	0,395318	0,708844	1,542798	6,437301
#77	-0,68276	-0,64873	-0,59168	-0,54359	-0,5229	-0,48709	-0,20419	0,065737	0,38614	0,69876	1,502874	6,416767

#78	-0,88998	-0,82873	-0,74664	-0,64249	-0,56368	-0,32049	-0,12972	0,19579	0,428283	0,760664	0,983846	4,870247
#79	-1,13719	-0,88405	-0,79193	-0,73813	-0,69402	-0,35516	-0,18216	0,30911	0,514237	0,944513	1,021655	5,110629
#80	-1,17998	-0,8925	-0,77552	-0,7289	-0,61735	-0,31146	-0,15616	0,314003	0,466225	0,833767	0,963259	5,080559
#81	-1,16725	-0,98205	-0,77727	-0,67251	-0,55838	-0,25361	-0,12776	0,32152	0,45163	0,777606	0,988644	4,829007
#82	-1,18489	-1,03065	-0,7839	-0,64567	-0,47137	-0,21804	-0,09275	0,312961	0,413978	0,673465	0,996751	4,746572
#83	-1,22501	-1,09902	-0,79525	-0,63217	-0,463	-0,20311	-0,07563	0,34333	0,418503	0,676679	1,086467	4,608058
#84	-1,29584	-1,17532	-0,81857	-0,66277	-0,53228	-0,19262	-0,07544	0,431337	0,494383	0,822776	1,260824	4,339582
#85	-0,98581	-0,87116	-0,72731	-0,68941	-0,06888	-0,05169	-0,00693	0,022572	0,065564	0,105124	0,123384	5,475683
#86	-1,02845	-0,86602	-0,72756	-0,68677	-0,00685	-0,00399	-0,00054	0,00384	0,004939	0,044552	0,137064	5,45813
#87	-1,06193	-0,79415	-0,72911	-0,58671	-0,00745	-0,00341	-0,00052	0,002517	0,012826	0,055969	0,28044	5,359696
#88	-1,2113	-0,88823	-0,78114	-0,71742	-0,40043	-0,22094	-0,0915	0,253447	0,337195	0,567042	0,881815	5,187778
#89	-1,23898	-1,00022	-0,78321	-0,73586	-0,53128	-0,26384	-0,12032	0,349357	0,435547	0,763072	1,068792	5,035394
#90	-1,2604	-1,10352	-0,8132	-0,76201	-0,6139	-0,27306	-0,15137	0,421824	0,504754	0,932658	1,244856	4,895862
#91	-0,62421	-0,59581	-0,5223	-0,46537	-0,44576	-0,43544	-0,35299	-0,04513	0,242403	0,55	1,226563	7,654625587
#92	-0,75228	-0,65626	-0,55817	-0,5317	-0,50398	-0,43127	-0,21598	0,019752	0,313651	0,621395	1,278843	6,806524587
#93	-0,78497	-0,72451	-0,62028	-0,59023	-0,56853	-0,46929	-0,18058	0,065703	0,385966	0,665645	1,274874	6,046397279

#94	-0,7811	-0,71702	-0,63041	-0,61651	-0,59056	-0,50588	-0,22344	0,072166	0,381174	0,70037	1,219294	5,940636292
#95	-0,82011	-0,74727	-0,65962	-0,6402	-0,61898	-0,51859	-0,23521	0,078779	0,396272	0,732627	1,065823	5,844283949
#96	-0,96281	-0,88375	-0,74724	-0,73051	-0,6798	-0,47534	-0,26491	0,187328	0,483776	0,959649	1,067408	5,701674042
#97	-1,10942	-0,99934	-0,81264	-0,75037	-0,68663	-0,47241	-0,28021	0,301117	0,535202	1,130561	1,157106	5,679914452
#98	-0,86517	-0,66427	-0,61637	-0,55477	-0,50681	-0,13161	-0,04422	-0,00452	0,026805	0,046237	0,118094	7,603595455
#99	-0,81116	-0,7506	-0,62865	-0,59355	-0,35989	-0,17386	-0,11504	0,016899	0,125514	0,208448	0,233976	6,683109148
#100	-0,84698	-0,80542	-0,67926	-0,66438	-0,29991	-0,23643	-0,08598	0,052112	0,197582	0,35512	0,379336	5,836619945
#101	-0,88693	-0,8212	-0,70749	-0,6778	-0,32735	-0,27519	-0,10554	0,058107	0,225355	0,388606	0,417978	5,579081524
#102	-0,92175	-0,82109	-0,71193	-0,65597	-0,18287	-0,134	-0,05649	0,066477	0,126537	0,223073	0,255628	5,561920695
#103	-1,01947	-0,80622	-0,72146	-0,60753	-0,15016	-0,09558	-0,04077	0,090943	0,11489	0,185648	0,284632	5,433381061
#104	-1,08277	-0,80854	-0,7298	-0,56153	-0,06823	-0,03748	-0,0086	0,052846	0,073537	0,09432	0,298977	5,301961032
#105	-1,12799	-0,92234	-0,76695	-0,49438	-0,12573	-0,0734	-0,0043	0,109292	0,135258	0,188031	0,586195	4,897921937
#106	-1,18118	-1,06385	-0,7958	-0,53467	-0,28343	-0,1344	-0,02915	0,224069	0,280576	0,418857	0,931582	4,621053145
#107	-1,32126	-1,225	-0,82556	-0,71466	-0,57192	-0,19242	-0,08293	0,482739	0,531788	0,923977	1,346693	4,282283519
#108	-1,28291	-1,27763	-0,83829	-0,80202	-0,69248	-0,23665	-0,13961	0,538866	0,6037	1,107458	1,42789	4,473820704
#109	-1,2244	-1,03336	-0,78133	-0,69182	-0,45541	-0,2278	-0,07765	0,326644	0,400104	0,6499	1,039867	4,854073146

#110	-1,17624	-0,88316	-0,75654	-0,70334	-0,31477	-0,16587	-0,06935	0,206131	0,285786	0,439943	0,787824	5,127250838
#111	-1,05883	-0,80429	-0,74737	-0,71801	-0,25739	-0,15204	-0,07157	0,151866	0,21255	0,344891	0,566101	5,405915243
#112	-0,99084	-0,82515	-0,71649	-0,69992	-0,27156	-0,17018	-0,07936	0,145545	0,196788	0,337314	0,47483	5,557838551
#113	-0,94997	-0,8258	-0,71059	-0,68965	-0,50531	-0,34373	-0,17959	0,139229	0,330549	0,61554	0,665183	5,578297351
#114	-0,94473	-0,79199	-0,7078	-0,63152	-0,48358	-0,35206	-0,16745	0,101681	0,313989	0,580668	0,624794	5,497047564
#115	-0,91138	-0,81309	-0,70298	-0,61616	-0,42667	-0,3556	-0,14515	0,06457	0,288805	0,508328	0,558287	5,571591475
#116	-0,88801	-0,80664	-0,69244	-0,60965	-0,3645	-0,29836	-0,12221	0,056735	0,238595	0,422883	0,549059	5,591566072
#117	-0,72468	-0,68074	-0,56087	-0,52816	-0,40871	-0,19172	-0,14714	-0,07207	0,054172	0,199062	0,258243	7,45281269
#118	-0,77283	-0,68585	-0,65194	-0,57227	-0,5324	-0,50113	-0,25368	0,073831	0,44099	0,831844	1,612799	6,445308178
#119	-0,73868	-0,701	-0,54817	-0,53195	-0,48229	-0,3054	-0,01366	0,002188	0,009602	0,05678	0,097548	8,101738596
#120	-0,73907	-0,67186	-0,54734	-0,52856	-0,47881	-0,26563	-0,07841	-0,01975	0,052962	0,086698	0,139013	8,037497276
#121	-0,73944	-0,66782	-0,55141	-0,52983	-0,48104	-0,24811	-0,12676	-0,04221	0,05621	0,14735	0,174489	7,980744372
#122	-0,7773	-0,73786	-0,62197	-0,59892	-0,34279	-0,27306	-0,14186	0,00946	0,182853	0,365916	0,437133	6,384221051
#123	-0,86195	-0,82099	-0,69532	-0,65998	-0,46653	-0,39247	-0,15826	0,060125	0,312949	0,537428	0,607059	5,655674586
#124	-0,96751	-0,81006	-0,70977	-0,65786	-0,53878	-0,38881	-0,18369	0,105669	0,356006	0,663494	0,701929	5,521090198
#125	-0,93357	-0,8059	-0,70443	-0,67868	-0,43145	-0,29922	-0,14911	0,124281	0,284806	0,527999	0,577964	5,579600888

#126	-1,00038	-0,83242	-0,72017	-0,7027	-0,26277	-0,16415	-0,0775	0,141414	0,185312	0,339914	0,495722	5,558839535
#127	-1,05845	-0,80878	-0,73104	-0,71604	-0,14503	-0,09251	-0,0242	0,0809	0,124891	0,229043	0,494541	5,453983329
#128	-1,16833	-0,89423	-0,76002	-0,69676	-0,3292	-0,18735	-0,06188	0,225662	0,290595	0,457797	0,799903	5,102522345
#129	-1,26003	-1,14996	-0,8127	-0,59769	-0,4346	-0,18189	-0,05062	0,352547	0,420416	0,664771	1,171832	4,40671197
#130	-1,16645	-1,04497	-0,79356	-0,51678	-0,22318	-0,11695	-0,01863	0,186215	0,229635	0,354789	0,881569	4,649707748
#131	-0,84166	-0,81469	-0,6831	-0,66559	-0,31385	-0,25288	-0,08485	0,047715	0,220325	0,369347	0,399647	5,827012914
#132	-0,85558	-0,66584	-0,61562	-0,55746	-0,50956	-0,11435	-0,05503	-0,01115	0,026036	0,063541	0,117785	7,588960803
#133	-1,13057	-1,01512	-0,80957	-0,33266	-0,12054	-0,06268	-0,007	0,109801	0,135408	0,232232	0,725477	4,425232484
#134	-1,07146	-0,88189	-0,77714	-0,73994	-0,63416	-0,33468	-0,1594	0,28817	0,488104	0,869 59	0,976069	4,970853
#135	-1,22505	-0,9005	-0,78501	-0,72064	-0,48762	-0,25802	-0,11416	0,287171	0,394891	0,680795	0,939087	5,162016
#136	-1,2255	-0,99094	-0,77718	-0,72896	-0,47675	-0,24199	-0,10884	0,315058	0,403743	0,695978	1,035721	5,036181
#137	-1,26028	-1,10752	-0,81588	-0,76264	-0,6396	-0,27973	-0,15783	0,43453	0,522098	0,962672	1,259716	4,883081

Sample	SD											
	1	2	3	4	5	6	7	8	9	10	11	12
#1	-0,02473	-0,00054	-0,00051	-0,00039	-0,00014	-2,8E-05	0,000179	0,000525	0,000846	0,000971	0,002071	0,032688823
#2	-0,97587	-0,31454	-0,18486	-0,09624	0,0112	0,038736	0,058964	0,080257	0,157207	0,232304	0,264335	4,0098972

#3	-0,38345	-0,37138	-0,11937	-0,09331	-0,03813	0,00936	0,040013	0,105494	0,129451	0,173294	0,217971	0,718891335
#4	-0,39875	-0,27636	-0,05726	-0,01506	-0,00958	0,003294	0,007968	0,019559	0,040988	0,05947	0,226466	0,698767671
#5	-0,28957	-0,21612	-0,00305	-0,00161	-0,00034	0,001001	0,004599	0,017119	0,017838	0,059716	0,125882	0,498188965
#6	-0,15417	-0,04894	-0,00113	-0,00061	-0,00035	0,000255	0,001377	0,007186	0,008307	0,009135	0,049082	0,234987737
#7	-0,12679	-0,02032	-0,00091	-0,00052	-0,00036	0,000254	0,001434	0,004343	0,005703	0,006638	0,023274	0,181074767
#8	-0,24525	-0,0565	-0,00163	-0,0011	-0,00051	0,000467	0,002401	0,010703	0,011413	0,01222	0,063977	0,356124687
#9	-0,41291	-0,0609	-0,00397	-0,0021	-0,00018	0,002784	0,006718	0,022361	0,023054	0,025555	0,107142	0,544978374
#10	-0,30274	-0,24543	-0,00748	-0,00481	0,000177	0,005558	0,010615	0,017411	0,01877	0,064606	0,14138	0,527078886
#11	-0,41202	-0,29379	-0,0586	-0,00463	-0,0031	0,00105	0,001973	0,0089	0,042887	0,060385	0,236872	0,73616453
#12	-0,39527	-0,38586	-0,10335	-0,06773	-0,03385	0,009547	0,032531	0,067856	0,107834	0,111844	0,264404	0,773449193
#13	-0,39644	-0,38568	-0,12025	-0,09512	-0,03802	0,010533	0,038292	0,104817	0,136143	0,181671	0,21966	0,746575247
#14	-0,38831	-0,36431	-0,13248	-0,11262	-0,0382	0,006956	0,039307	0,097944	0,153243	0,171862	0,265085	0,683346312
#15	-0,09641	-0,0098	-0,0015	-0,00097	0,000266	0,000534	0,003378	0,004739	0,004768	0,004813	0,012907	0,122543685
#16	-0,81248	-0,18106	-0,06647	-0,0358	-0,01816	0,021845	0,025924	0,040327	0,055983	0,06504	0,110107	3,369375804
#17	-1,05651	-0,21206	-0,11459	-0,02639	0,029336	0,040827	0,055478	0,075421	0,090107	0,120278	0,154762	3,741240705
#18	-1,22417	-0,56798	-0,20423	-0,10886	0,005341	0,032983	0,061077	0,093783	0,182102	0,349123	0,448232	4,051475106

#19	-1,16408	-0,35803	-0,11738	-0,07269	0,02265	0,059977	0,068285	0,098886	0,12217	0,194367	0,270302	4,077110772
#20	-1,02998	-0,37309	-0,18049	-0,09646	0,01881	0,056419	0,087253	0,111998	0,151172	0,251569	0,287933	4,06258675
#21	-0,99691	-0,32952	-0,16176	-0,0765	0,036521	0,059483	0,103252	0,125066	0,144908	0,239395	0,260875	4,021197652
#22	-0,9872	-0,22918	-0,08812	-0,0601	0,035685	0,059213	0,098461	0,123438	0,131312	0,147842	0,188699	3,882164575
#23	-0,95245	-0,20574	-0,08042	-0,06576	0,022851	0,056905	0,094502	0,11246	0,130107	0,15085	0,185745	3,774309871
#24	-0,55432	-0,19454	-0,06048	-0,02455	-0,00999	-0,00189	0,008744	0,025632	0,028161	0,089484	0,119548	2,133886685
#25	-0,94139	-0,19493	-0,04014	-0,00066	0,011327	0,012873	0,038639	0,04866	0,089966	0,098379	0,226098	3,338957842
#26	-0,77787	-0,12134	-0,03335	-0,02111	0,005553	0,017065	0,051342	0,070942	0,08191	0,143761	0,151047	2,448137844
#27	-0,96093	-0,15599	-0,07074	-0,0428	-5,7E-06	0,016216	0,075311	0,079782	0,097477	0,137363	0,261955	2,510838726
#28	-0,45391	-0,2279	-0,11906	-0,04225	-0,03338	0,009157	0,024603	0,046139	0,061156	0,091137	0,2154	0,811883551
#29	-0,47635	-0,27659	-0,11827	-0,02076	-0,01742	0,0034	0,012022	0,027945	0,053577	0,095	0,251792	0,862185457
#30	-0,45647	-0,31433	-0,15255	-0,08582	-0,0447	0,011371	0,028166	0,059234	0,113775	0,149577	0,269543	0,872179329
#31	-0,45583	-0,32464	-0,12546	-0,0647	-0,04726	0,007848	0,032037	0,060709	0,096999	0,122269	0,273455	0,856717204
#32	-0,46125	-0,36632	-0,15732	-0,11211	-0,05008	0,011141	0,040463	0,071934	0,145372	0,177074	0,281228	0,893500544
#33	-0,44976	-0,37418	-0,13545	-0,09732	-0,04446	0,012639	0,035534	0,075329	0,136847	0,15904	0,272327	0,863356099
#34	-0,40044	-0,3837	-0,08806	-0,05261	-0,03167	0,010774	0,025312	0,061562	0,092071	0,098732	0,263308	0,779817337

#35	-0,41453	-0,38524	-0,09568	-0,04886	-0,03461	0,008995	0,027721	0,056938	0,088632	0,097103	0,283497	0,802768553
#36	-0,41795	-0,37646	-0,0795	-0,03281	-0,03202	0,013491	0,015145	0,045397	0,070862	0,080054	0,288209	0,798552532
#37	-0,42291	-0,35771	-0,07533	-0,03222	-0,01336	0,006555	0,012055	0,037681	0,052405	0,078867	0,280236	0,79340551
#38	-0,42465	-0,3261	-0,09601	-0,03785	-0,02057	0,008079	0,015533	0,039571	0,066918	0,095316	0,263537	0,787560023
#39	-0,42327	-0,28261	-0,06133	-0,00901	-0,00605	0,002526	0,005596	0,013407	0,041533	0,06059	0,23355	0,739471873
#40	-0,35013	-0,29995	-0,01917	-0,00426	-0,00159	0,000893	0,001783	0,00638	0,027501	0,042361	0,218471	0,633026246
#41	-0,35449	-0,3224	-0,02647	-0,01044	-0,00151	0,000915	0,002604	0,013875	0,030992	0,048531	0,230493	0,65951724
#42	-0,38591	-0,35117	-0,03814	-0,01625	-0,00584	0,000721	0,012017	0,020463	0,041224	0,058191	0,260594	0,711709811
#43	-0,40777	-0,37185	-0,04423	-0,02318	-0,01837	0,003025	0,01889	0,032991	0,049776	0,066081	0,278686	0,751271407
#44	-0,40039	-0,36574	-0,049	-0,02948	-0,02515	0,012823	0,015439	0,044918	0,050977	0,075579	0,272017	0,725821419
#45	-0,39842	-0,37149	-0,05727	-0,03477	-0,02798	0,010765	0,020483	0,046304	0,062643	0,098855	0,255569	0,738426983
#46	-0,38515	-0,37248	-0,10661	-0,07761	-0,03969	0,012244	0,039359	0,096263	0,102454	0,128134	0,242394	0,738503123
#47	-0,37623	-0,35099	-0,09272	-0,06675	-0,02973	0,008531	0,031229	0,083207	0,090726	0,127619	0,23272	0,687491921
#48	-0,23099	-0,19972	-0,05629	-0,01856	-0,00851	-0,00391	0,007282	0,0111	0,025083	0,069728	0,169316	0,401442498
#49	-0,22162	-0,18491	-0,07614	-0,05279	-0,02862	-0,00618	0,015069	0,037958	0,066092	0,101465	0,204062	0,30629612
#50	-0,44455	-0,17692	-0,00518	-0,00353	-0,00149	0,000789	0,002966	0,004337	0,007879	0,0309	0,234682	0,572792583

#51	-0,0184	-0,00123	-0,00048	-0,00037	-0,00034	-0,00017	-3,4E-05	0,00021	0,000341	0,001478	0,002693	0,022189944
#52	-0,05274	-0,00514	-0,00062	-0,00048	-0,00027	-4,3E-05	0,000136	0,000588	0,000662	0,000845	0,00583	0,063378904
#53	-0,11304	-0,01475	-0,00088	-0,00063	-0,00028	0,000149	0,002133	0,006851	0,006994	0,007759	0,021768	0,152343586
#54	-0,1066	-0,01314	-0,00058	-0,0004	-0,00014	-2,2E-05	0,001658	0,006236	0,006335	0,007143	0,0206	0,142233478
#55	-0,19499	-0,01748	-0,00066	-0,00042	-0,00032	-0,0001	0,002126	0,010163	0,010431	0,01202	0,032106	0,254610619
#56	-0,23806	-0,02546	-0,00075	-0,00044	-0,00037	9,1E-06	0,002152	0,012362	0,012795	0,014675	0,045682	0,309857697
#57	-0,22201	-0,03067	-0,0006	-0,00045	-0,00023	-3,3E-05	0,001953	0,011059	0,011944	0,013124	0,060161	0,2849871
#58	-0,0238	-0,00188	-0,00053	-0,00027	-4,6E-05	0,000119	0,000836	0,001264	0,001308	0,001621	0,003834	0,030502168
#59	-0,01899	-0,00152	-0,00067	-0,00024	-0,0002	0,000124	0,000597	0,001018	0,001126	0,00148	0,003509	0,024408432
#60	-0,00938	-0,00115	-0,00049	-0,0004	-0,00031	-0,00017	0,000488	0,000588	0,000759	0,001427	0,002152	0,012369367
#61	-0,0132	-0,00182	-0,00032	-0,0003	-0,00026	-0,00017	0,000847	0,0009	0,000952	0,001415	0,003233	0,016963689
#62	-0,01095	-0,00193	-0,00049	-0,00035	-0,00013	0,000105	0,0003	0,000597	0,000774	0,001259	0,002971	0,013460747
#63	-0,04037	-0,00797	-0,00074	-0,00035	-0,00029	-0,00016	-0,00011	0,000727	0,001124	0,001562	0,009219	0,049024707
#64	-0,06672	-0,00834	-0,00054	-0,00036	-0,00034	-0,00027	-0,00016	0,00066	0,001231	0,001831	0,008663	0,079993653
#65	-0,79934	-0,08683	-0,04848	-0,02776	-0,00137	0,014 13	0,061785	0,076071	0,087723	0,117943	0,173	2,500349328
#66	-0,95421	-0,12928	-0,07945	-0,05205	0,011873	0,033899	0,075627	0,081241	0,099662	0,143412	0,240632	2,43713061

#67	-1,07085	-0,24116	-0,14353	-0,06991	-0,05753	0,005414	0,081499	0,089995	0,138248	0,169999	0,376435	2,301314189
#68	-0,31271	-0,09531	-0,00207	-0,00167	0,003733	0,0139	0,019064	0,022008	0,02575	0,039335	0,066634	0,481037936
#69	-0,05348	-0,01129	-0,00074	-0,00035	0,001135	0,002113	0,002175	0,002283	0,002515	0,003427	0,013628	0,070209883
#70	-0,13085	-0,00482	-0,00145	9,96E-05	0,002325	0,0061	0,006169	0,006246	0,006495	0,00706	0,019552	0,174591623
#71	-0,26376	-0,03681	-0,00232	-0,00095	0,003772	0,014155	0,01433	0,014489	0,014816	0,017622	0,076933	0,36272701
#72	-0,67424	-0,14603	-0,02536	-0,01652	-0,00035	0,012929	0,02176	0,031976	0,036429	0,091352	0,112861	1,90799751
#73	-1,06709	-0,34068	-0,1828	-0,07249	0,055891	0,06444	0,102838	0,115174	0,161712	0,244424	0,284126	4,30498
#74	-1,06336	-0,3366	-0,17239	-0,06139	0,061925	0,072963	0,10648	0,119004	0,156859	0,23986	0,277539	4,276222
#75	-1,0644	-0,33225	-0,17284	-0,06215	0,059704	0,069751	0,106795	0,119216	0,160457	0,245184	0,274541	4,290729
#76	-1,04959	-0,29025	-0,13677	-0,05636	0,061326	0,0688	0,108104	0,120681	0,15124	0,214808	0,238937	4,158356
#77	-1,04122	-0,27651	-0,1273	-0,05572	0,055703	0,066638	0,106036	0,117986	0,144434	0,208209	0,22491	4,100184
#78	-0,54474	-0,29243	-0,05518	-0,05018	-0,04341	-0,01177	0,007789	0,046787	0,106999	0,128863	0,200683	2,558326
#79	-0,54419	-0,33678	-0,26291	-0,20927	-0,06591	-0,03458	0,039351	0,095405	0,168239	0,336581	0,376301	1,378991
#80	-0,45341	-0,33915	-0,22168	-0,19976	-0,07759	-0,00313	0,040192	0,08682	0,168676	0,29689	0,31478	1,15183
#81	-0,48388	-0,35995	-0,20608	-0,20547	-0,10171	-0,00549	0,039391	0,104026	0,206026	0,282111	0,322872	1,177681
#82	-0,46908	-0,35041	-0,20619	-0,17027	-0,11231	0,019223	0,047725	0,105344	0,224699	0,237939	0,262979	1,037525

#83	-0,44201	-0,34536	-0,19248	-0,15251	-0,09941	0,01994	0,043825	0,101143	0,212358	0,227764	0,26276	0,889158
#84	-0,42777	-0,39919	-0,13927	-0,10801	-0,05811	0,016248	0,043469	0,090597	0,153459	0,170383	0,266215	0,864204
#85	-0,07153	-0,03604	-0,00164	-0,00108	-0,00013	0,00112	0,001434	0,001959	0,002239	0,00831	0,029505	0,09407
#86	-0,10529	-0,04273	-0,00061	-0,00037	-0,00023	1,64E-05	0,000739	0,001769	0,004483	0,007258	0,039153	0,146071
#87	-0,40614	-0,24871	-0,00735	-0,00177	-0,00065	-5,9E-05	0,003414	0,028919	0,039717	0,059855	0,107025	0,741762
#88	-0,49146	-0,33714	-0,16022	-0,09819	-0,01038	0,006571	0,0478	0,075359	0,133373	0,172027	0,233749	1,025596
#89	-0,50931	-0,35841	-0,195	-0,15261	-0,04648	0,003335	0,04886	0,115627	0,19698	0,223469	0,289617	1,026116
#90	-0,5058	-0,38456	-0,18447	-0,13914	-0,05671	0,004981	0,045174	0,106836	0,204314	0,218394	0,29616	1,018734
#91	-0,96631	-0,21572	-0,10985	-0,06127	0,020095	0,04244	0,044939	0,063414	0,080804	0,114446	0,162374	3,681372938
#92	-0,88538	-0,24314	-0,14423	-0,08585	0,003346	0,04051	0,06796	0,082049	0,090024	0,137685	0,262436	3,742803172
#93	-0,92381	-0,16504	-0,04949	-0,03057	0,013781	0,043569	0,063065	0,080489	0,097666	0,112425	0,189881	3,517698573
#94	-0,86677	-0,10624	-0,03044	-0,00896	-0,00336	0,010281	0,056519	0,072958	0,087044	0,095166	0,13888	3,231367058
#95	-0,81399	-0,14702	-0,07371	-0,04022	-0,00575	0,007332	0,076969	0,083594	0,098638	0,131991	0,19495	2,654124173
#96	-0,73812	-0,24116	-0,18146	-0,12854	-0,08198	-0,03712	0,09314	0,097278	0,173717	0,241438	0,361781	1,888063019
#97	-0,6304	-0,29788	-0,23581	-0,15672	-0,11024	-0,06088	0,082483	0,109478	0,175934	0,339269	0,414086	1,525530941
#98	-0,16997	-0,01334	-0,00152	-0,00073	0,000495	0,0028	0,007294	0,007524	0,007784	0,009363	0,018542	0,219767084

#99	-0,79726	-0,20827	-0,14834	-0,07222	0,006069	0,04501	0,053354	0,055898	0,095442	0,227387	0,25727	1,249475633
#100	-0,75553	-0,33954	-0,16366	-0,1282	-0,02876	0,020455	0,064519	0,07254	0,117312	0,266099	0,323235	1,439307174
#101	-0,54937	-0,32821	-0,15226	-0,11597	-0,00291	0,044612	0,046114	0,056966	0,129572	0,197549	0,234921	1,065866208
#102	-0,44171	-0,3246	-0,11179	-0,08284	-0,00948	0,033648	0,042766	0,061418	0,084651	0,135476	0,213533	0,856934616
#103	-0,37917	-0,34526	-0,12822	-0,10547	0,000143	0,029068	0,047786	0,060314	0,079092	0,169471	0,217022	0,778667674
#104	-0,40475	-0,21306	-0,01801	-0,0051	-0,00352	0,000379	0,002155	0,00972	0,026957	0,067608	0,137163	0,693805541
#105	-0,46547	-0,22253	-0,12019	-0,02214	-0,01813	-0,00041	0,016616	0,028596	0,051005	0,083157	0,221988	0,826201103
#106	-0,45233	-0,32803	-0,1545	-0,09704	-0,07038	0,017975	0,038109	0,073656	0,139594	0,15712	0,271823	0,86268731
#107	-0,4449	-0,39756	-0,128	-0,09583	-0,0385	0,010261	0,038185	0,086116	0,143616	0,156695	0,272556	0,849898137
#108	-0,49511	-0,40699	-0,15531	-0,14045	-0,0645	0,010347	0,048401	0,108372	0,18765	0,208717	0,295951	0,962333967
#109	-0,49291	-0,33435	-0,1865	-0,1688	-0,08989	0,01501	0,047315	0,103023	0,213849	0,244592	0,257701	0,970822686
#110	-0,4536	-0,32285	-0,11899	-0,10322	-0,05105	0,011244	0,032601	0,066965	0,130283	0,171506	0,19654	0,972793589
#111	-0,4482	-0,35541	-0,15552	-0,15163	-0,01975	0,030089	0,043136	0,071213	0,103488	0,211292	0,239651	1,023596165
#112	-0,50196	-0,33066	-0,11307	-0,1077	-0,00089	0,028995	0,04553	0,066949	0,113849	0,15403	0,190404	1,022355142
#113	-0,59035	-0,29149	-0,20503	-0,17123	-0,03356	0,006673	0,055285	0,066129	0,152689	0,289381	0,302014	1,201219257
#114	-0,63204	-0,35107	-0,21767	-0,16812	-0,02451	0,014692	0,065313	0,084688	0,134794	0,276854	0,30945	1,391106695

#115	-0,75203	-0,19506	-0,16565	-0,14206	-0,03991	0,002396	0,070107	0,07197	0,174271	0,202993	0,287937	1,458043793
#116	-0,69124	-0,20824	-0,10249	-0,06901	-0,01663	0,021936	0,05284	0,064195	0,11548	0,190756	0,239292	1,814224469
#117	-0,85359	-0,26904	-0,08987	-0,04092	-0,00379	0,04071	0,062737	0,063655	0,074886	0,106239	0,28656	1,928323844
#118	-0,92274	-0,28209	-0,15777	-0,0607	0,038105	0,045912	0,0682	0,077295	0,13192	0,199818	0,233502	3,936580736
#119	-0,30959	-0,08882	-0,00214	-0,00149	0,003463	0,014294	0,019281	0,021917	0,024944	0,036036	0,06358	0,470347655
#120	-0,4122	-0,10274	-0,01582	-0,00575	0,008476	0,019811	0,027869	0,030264	0,035548	0,045125	0,077989	0,673812514
#121	-0,44244	-0,13366	-0,05464	-0,04611	-0,00623	0,029949	0,030667	0,033586	0,045948	0,095542	0,132085	0,774791432
#122	-1,03611	-0,19678	-0,10655	-0,07222	-0,02212	0,00994	0,072714	0,076744	0,118933	0,152406	0,333603	2,149229873
#123	-0,77439	-0,19671	-0,18154	-0,1173	-0,02343	0,012663	0,066877	0,071107	0,144099	0,225656	0,31345	1,461556969
#124	-0,65061	-0,26272	-0,22888	-0,1782	-0,03637	-0,00408	0,065879	0,074923	0,157895	0,290223	0,326775	1,354461523
#125	-0,61275	-0,3018	-0,1572	-0,14875	-0,01162	0,015255	0,059498	0,08236	0,12637	0,211887	0,223046	1,265763296
#126	-0,48635	-0,31859	-0,11096	-0,09318	-0,00789	0,03074	0,043531	0,064644	0,101271	0,135748	0,18954	0,984600395
#127	-0,40826	-0,36205	-0,06638	-0,02902	-0,00048	0,006197	0,031054	0,039744	0,080986	0,094317	0,153775	0,913388055
#128	-0,46216	-0,31993	-0,16263	-0,14367	-0,08102	0,019114	0,043498	0,082421	0,175376	0,197203	0,241669	0,9728169
#129	-0,45232	-0,37597	-0,12463	-0,08547	-0,04286	0,013938	0,030067	0,072217	0,122883	0,147507	0,277642	0,868472156
#130	-0,45022	-0,31161	-0,13399	-0,0721	-0,03214	0,006476	0,022025	0,052001	0,098402	0,12817	0,256704	0,863365203

#131	-0,78336	-0,29602	-0,18368	-0,13407	-0,00544	0,044389	0,065666	0,079065	0,10165	0,220693	0,258504	1,536032538
#132	-0,19607	-0,01714	-0,00249	-0,00117	0,000791	0,003889	0,007905	0,008211	0,008551	0,011364	0,021979	0,256281344
#133	-0,42173	-0,3605	-0,08018	-0,03352	-0,01424	0,005223	0,013727	0,032826	0,066006	0,083248	0,275899	0,798940161
#134	-0,56577	-0,34791	-0,24221	-0,19684	-0,11152	-0,02409	0,047589	0,098886	0,160505	0,312226	0,357953	1,467604
#135	-0,51031	-0,32504	-0,19912	-0,17567	-0,01465	0,003499	0,05531	0,099348	0,168509	0,235637	0,273706	1,070774
#136	-0,5126	-0,35355	-0,16779	-0,10838	-0,03644	0,003712	0,042802	0,086494	0,167174	0,196208	0,261011	1,026218
#137	-0,51216	-0,38226	-0,17825	-0,13575	-0,05969	-0,00212	0,045577	0,113689	0,203555	0,213314	0,296793	1,03559

Annex 5: < MATLAB code for making the flow regime map out with the result coming from the flow pattern recognition algorithm. This code is saved as FlowRegimeMapping.m >

```
clc;
clear all;
%%%% Graph for the measurements taken
%% Get data out the excel file
Measurements =
xlsread('Flow_regime_identification.xlsx','horizontal_pipe');
%% Mapping All Measurements
Water = Measurements(1:end,1);
Air = Measurements(1:end,2);
figure
scatter(Air,Water);
grid on
set(gca,'xscale','log');
set(gca,'yscale','log');
title('Measurements taken with Multiphase flow rig Air & Water
Straight Pipe');
xlabel('Air Flow Rate [kg/min]'); % x-axis label
ylabel('Water Flow Rate [kg/min]') % y-axis label
axis([0.05 5 1 200]);
%% Mapping with FP results
figure
Intermittent = Measurements(1:end,4);
Annular = Measurements(1:end,5);
StratWavy = Measurements(1:end,6);
SuccessorFail = Measurements(1:end,7);
Flow_rates=Measurements(1:end,1:2);
for i_index=1:length(Flow_rates)
selectedRow = i_index;
    if Intermittent(selectedRow,1) == 1;

scatter(Flow_rates(selectedRow,2),Flow_rates(selectedRow,1),'^','b','f
illed')
    elseif Annular(selectedRow,1) ~= 0;

scatter(Flow_rates(selectedRow,2),Flow_rates(selectedRow,1),40,Annular
(selectedRow,1),'filled','o')
    elseif StratWavy(selectedRow,1) == 1;

scatter(Flow_rates(selectedRow,2),Flow_rates(selectedRow,1),'s','g')
    end
    hold on
    if SuccessorFail(selectedRow,1) == 1;

scatter(Flow_rates(selectedRow,2),Flow_rates(selectedRow,1),80,'o','r'
)
    end
    hold on
end
%%%%%%%%%% Make up of the plot
grid on
set(gca,'xscale','log');
set(gca,'yscale','log');
title('Flow Regime Map 56mm Air & Water Straight Pipe');
xlabel('Air Flow Rate [kg/min]'); % x-axis label
ylabel('Water Flow Rate [kg/min]') % y-axis label
axis([0.05 5 1 200]);
```

```
legend('Intermittent','Annular','StratWavy',
'Location','eastoutside');
```