# Statistical Process Control for Depropanizer Column at Petronas Gas Berhad, Kerteh

by

Siti Fariza bt Ahmad

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(Nasser M Ramli)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

April 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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SITI FARIZA BT AHMAD

# ABSTRACT

The final report is made in order to give all the details on the Final Year Project II which is ***"Statistical Process Control for Depropanizer Column at Petronas Gas Berhad (PGB), Kerteh"***. This report is divided into five main chapters which are : Introduction, Literature Review, Methodology, Results & Discussions and Conclusion.

Statistical Process Control (SPC) has a very high demand in industry right now as it provides a way to monitor process behavior and able us to analyze the variations in the process that may affect the quality of the end product. In this project, the focus in on the depropanizer column at Petronas Gas Berhad (PGB), Kerteh. The short term targets are to apply Statistical Process Control on the column stated, to measure and analyze the variation in the processes, to monitor the consistency of processes used to manufacture the product as designed and finally to suggest the best way in controlling all the variables at the column. While for long term is to implement the results in our industry.

Many variables have to be considered in order to complete the project, which are: (a) Calculated data surrounding the depropanizer column which include all the tag names, (b) Tag names and description, (c) Description of the depropanizer column and (d) Flow sheet for the column showing all the tag name surrounding the column. Mainly, two tools are required in executing this project which are (a) SSPS software and (b) LIMS – Laboratory Information Management System (in PGB, Kerteh). From here, an early analysis on all the variables obtained by using Microsoft Excel has been made. Mainly, the discussion is about the input variables that affecting the output variable, which in this case the output variable is the $C_3$ composition. Some problems have been identified during the process of analyzing the data using Microsoft Excel.

Simulation using SPSS software has been completed which includes:

a) Descriptive Statistics
b) Histograms
c) Correlations
d) Scatter Plots

a) Crosstabs
b) One Way Anova
c) Paired T-test
d) Linear Regressions

Analysis has been completed for the results obtained from SPSS, focusing on the critical components inside the overhead product composition which is $C_3$ and some input data that will most probably affect the overhead product composition:

i) Reflux flow (4FC6203.PV)
ii) Energy input inside the column (4TI6231.PV)
iii) Feed conditions (4FY62022.PV, 4TI6009.PV)

It is proven that these four main input variables have a very strong relationship with $C_3$ composition inside the overhead product and they all come from a general population mean. Increasing or decreasing their values will give a great impact to the $C_3$ composition. As the samples proved to come from a general population mean, an optimum operating condition could be produced from the average data, in order to maintain $C_3$ composition within the desired value (98.48 mole%):

| **Input variables** | **Description** | **Optimum operating conditions suggested** |
|---|---|---|
| 4FC6203.PV | Reflux flow | 112.96 $m^3$/hr |
| 4TI6231.PV | Energy input inside the column / Reboiler temperature | 116.03 °C |
| 4FY62022.PV | Feed flowrate | 143.36 $m^3$/hr |
| 4TI6009.PV | Feed temperature | 95.81 °C |

However, these optimum operating conditions suggested must be checked again so that it will not violate the design operating conditions.

This project will not only improve the existing process control of the column but also improve the quality of end product and saving the cost to operate the column.

# ACKNOWLEDGEMENTS

First and foremost, I would like to thank my Supervisor, Mr Nasser M Ramli, who has given me support, providing advice and guidance, making time for consultation and discussion during the completion of the project.

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- Mr. M Feris Halmy Zakaria (Senior Process Plant Engineer)
- All PGB staffs

I would also like to thank Mr M Tazli Azizan, the coordinator for Final Year Project II. With his excellent management and coordination, the flow of this project was seamless.

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# CHAPTER 1 : INTRODUCTION

## 1.1 PROBLEM STATEMENT

Statistical Process Control (SPC) has a very high demand in industry right now as it provides a way to monitor process behavior and able us to analyze the variations in the process that may affect the quality of the end product. In this project, we would be doing the SPC for the depropanizer column at Petronas Gas Berhad (PGB), Kerteh. This title was chosen based on some characteristics which are: (a) Unique – no previous student has done it before, (b) Possible – the project is doable and within the student's capability, and (c) Within time frame – the project can be completed within time frame given (1 year).

The short term target is to achieve all the objectives stated and thus in the end, come up with the best way in controlling all the variables at the column. While for long term is to implement the result in the industry.

## 1.2 OBJECTIVES

- To apply Statistical Process Control on depropanizer column at Petronas Gas Berhad, Kerteh
- To measure and analyze the variation in the processes
- To monitor the consistency of processes used to manufacture the product as designed
- To suggest the best way in controlling all the variables at the column

## 1.3 SCOPE OF STUDY

In doing this project, the scopes of study are:

- Study on Statistical Process Control (SPC)
- Study on fractionation column, mainly on depropanizer column
- Study on SSPS software (a statistical software used to assist in analyzing data)

# CHAPTER 2 : LITERATURE REVIEW

## 2.1 STATISTICAL PROCESS CONTROL (SPC)

Statistical Process Control (SPC) involves using statistical techniques to measure and analyze the variation in processes [10]. Most often used for manufacturing processes, the intent of SPC is to monitor product quality and maintain processes to fixed targets. It provides a way to monitor process behavior for chemical and other processes. SPC is used to monitor the consistency of processes used to manufacture a product as designed. It aims to get and keep processes under control. No matter how good or bad the design, SPC can ensure that the product is being manufactured as designed and intended.

SPC will not improve a poorly designed product's reliability, but can be used to maintain the consistency of how the product is made. Process control engineers use SPC to monitor a process's stability, consistency and overall performance. Quality control engineers use SPC to see if the process is functioning within quality standards. In industry, these two departments work together to monitor a chemical process.

Arguably the most successful Statistical Process Control (SPC) tool is the control chart, originally developed by Walter Shewhart in the early 1920s [11]. A control chart helps you record data and lets you see when an unusual event, e.g., a very high or low observation compared with "typical" process performance, occurs. A marked increase in the use of control charts occurred during World War II in the United States to ensure the quality of munitions and other strategically important products. The use of Statistical Process Control (SPC) diminished somewhat after the war, though was subsequently taken up with great effect in Japan and continues to the present day. Many SPC techniques have been "rediscovered" by American firms in recent years, especially as a component of quality improvement initiatives like Six Sigma [12]. The widespread use of control charting procedures has been greatly assisted by statistical software packages and ever-more sophisticated data collection systems.

The control chart is a graphical representation of certain descriptive statistics for specific quantitative measurements of the manufacturing process. These descriptive statistics are displayed in the control chart in comparison to their "in-control" sampling distributions. The comparison detects any unusual variation in the manufacturing process, which could indicate a problem with the process. Several different descriptive statistics can be used in control charts and there are several different types of control charts that can test for different causes, such as how quickly major vs. minor shifts in process means are detected. Control charts are also used with product measurements to analyze process capability and for continuous process improvement efforts. Control charts attempt to distinguish between two types of process variation:

- Common cause variation, which is intrinsic to the process and will always be present.
- Special cause variation, which stems from external sources and indicates that the process is out of statistical control.

Various tests can help determine when an out-of-control event has occurred. However, as more tests are employed, the probability of a false alarm also increases.

The capability of SPC [25] :

- All forms of SPC control charts
    - Variable and attribute charts
    - Average (X bar)
    - Range (R),
    - Standard Deviation (σ)
    - Shewhart
    - Cumulative Sum (CUSUM) charts : the ordinate of each plotted point represents the algebraic sum of the previous ordinate and the most recent deviations from the target
    - Combined Shewhart-CuSum
    - Exponentially Weighted Moving Average (EWMA) charts : each chart point represents the weighted average of current and all previous

subgroup values, giving more weight to recent process history and decreasing weights for older data.

- Selection of measures for SPC
- Process and machine capability analysis ($C_p$ and $C_{pk}$)
- Process characterization
- Variation reduction
- Experimental design
- Quality problem solving
- Cause and effect diagrams

More recently, others have advocated integrating SPC with Engineering Process Control (EPC) tools, which regularly change process inputs to improve performance.

Some of the benefits of applying SPC in processes are :

- *Effective method of monitoring a process* – A primary tool used for SPC is the control chart, a graphical representation that can be analyzed to detect any unusual variation in the manufacturing process, which could indicate a problem with the process. It is also used with product measurements to analyze process capability and for continuous process improvement efforts.
- *Detects assignable causes of variation* – By collecting data from samples at various points within the process, variations in the process that may affect the quality of the end product or service can be detected and corrected. From here, the pattern can be analyzed and thus preventing the problems to be passed on to the customer. This would also means that by applying SPC, the process can be kept in control.
- *Accomplishes process characterization* – From the pattern, the process characterization required can be achieved. For examples, in operating a distillation column, by doing SPC, the optimum operating conditions can be obtained leading to on-spec product and optimum process.

- *Reduces need for inspection* – With its emphasis on early detection and prevention of problems, SPC has a distinct advantage over quality methods, such as inspection, that apply resources to detecting and correcting problems in the end product or service.
- *Reduce the time required to produce the product* – The SPC data can be used to identify bottlenecks, wait times, and other sources of delays within the process. Process cycle time reductions coupled with improvements in yield have made SPC a valuable tool from both a cost reduction and a customer satisfaction standpoint.

## 2.2 DISTILLATION/FRACTIONATION COLUMN

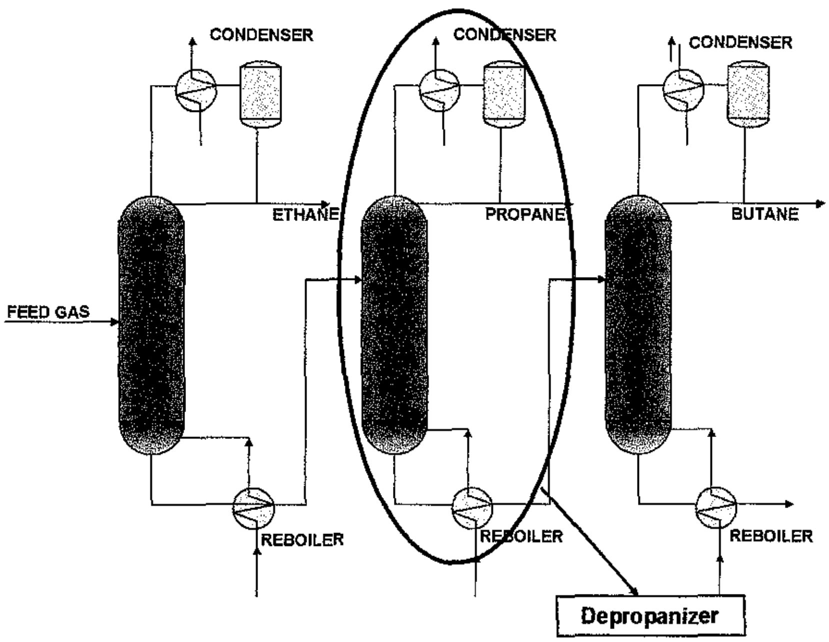



**Figure 1: Process Flow Diagram for Fractionation Trains**

Fractional distillation is one of the unit operations of chemical engineering Fractionating columns are widely used in the chemical process industries where large quantities of liquids have to be distilled. Such industries are the petroleum processing, petrochemical production, natural gas processing, hydrocarbon solvents production and other similar industries but it finds its widest application in petroleum refineries.

Industrial distillation is typically performed in large, vertical cylindrical columns known as "distillation towers" or "distillation columns" with diameters ranging from about 65 cm to 6 m and heights ranging from about 6 m to 60 m or more. Industrial distillation towers are usually operated at a continuous steady state. Unless disturbed by changes in feed, heat, ambient temperature, or condensing, the amount of feed being added normally equals the amount of product being removed [9].

The design and operation of a fractionating column depends on the composition of the feed and as well as the composition of the desired products. Given a simple, binary component feed, analytical methods such as the McCabe-Thiele method or the Fenske equation can be used. For a multi-component feed, simulation models are used both for design, operation and construction.

The Fractionation Column Train in Product Recovery Unit at PGB, Kerteh is an example of a fractionation system designed to separate ethane, propane and butane respectively from demethanizer bottom product streams. Three towers are used to separate ethane, propane and butane from the feed stream. The columns can have multiple feeds coming from various units in the gas plant and entering the columns at different tray locations.

## 2.3 DEPROPANIZER COLUMN

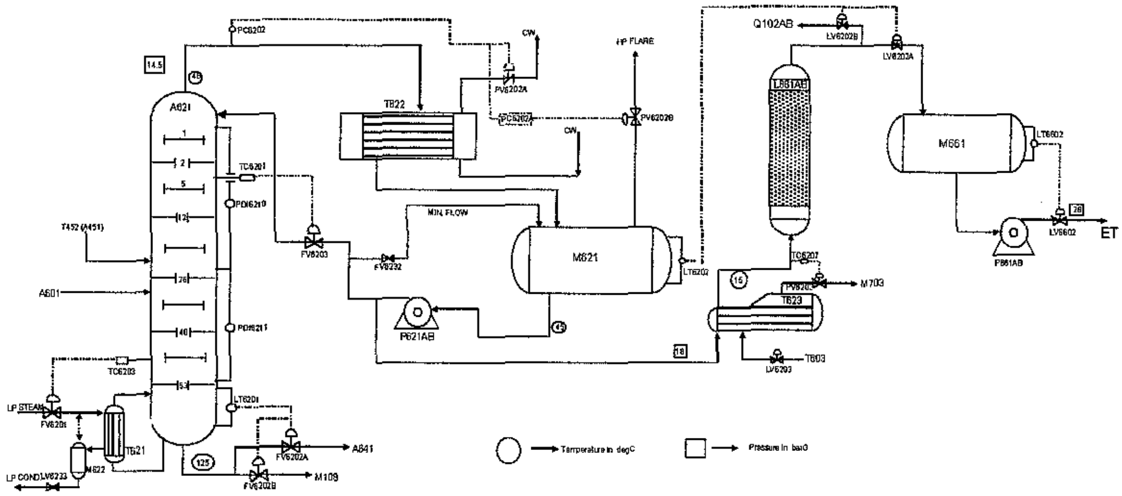



**Figure 2: Process Flow Diagram of Depropanizer Column in Petronas Gas Berhad, Kerteh**

**Table 1: Operating Conditions and Parameters for Depropanizer Column in Petronas Gas Berhad, Kerteh**

| Criteria | Operating conditions |
|---|---|
| Over head pressure (average) | 14.5 barG |
| Over head temperature | 46°C |
| Bottom temperature | 120 – 135°C |

A depropanizer column is a one type of fractionation/distillation column which function to remove propane from bottom liquid. In PGB, the equipment number for depropanizer is A-621 with 53 number of trays, height of 32.3 m with diameter of 3.2 m. The propane that extracted by the depropanizer is sent to the Export Terminal and/or MTBE Plant. The bottoms from A-621 are $C4_{+}$, which flow to the debutanizer, A-641 [3].

# CHAPTER 3 : METHODOLOGY

## 3.1 FLOWCHART OF METHODOLOGY

*(See APPENDIX A for FYP2 Gantt Chart)*

Do the literature review and research regarding the project

↓

Study on :

a. Statistical Process Control
b. Fractionating Column (focus on depropanizer)
c. SSPS software

↓

Plant visit to Petronas Gas Berhad, Kerteh (To collect all the data on the process variables)

a) Calculated data surrounding the depropanizer column which include all the tag names
b) Tag names and description
c) Description of the depropanizer column
d) Flow sheet for the column showing all the tag name surrounding the column.

↓

Transfer all the data into Microsoft Excel and analyze them

↓

Transfer all the data and info obtained into SSPS software and analyze them

↓

Produce the final results and conclusions

**Figure 3: Flowchart of the Methodology**

## 3.2 TOOLS REQUIRED

- SSPS software – A statistical software that can ease the process of analyzing the data. It can be used to generate control charts, regression analysis, descriptive statistics and etc.
- LIMS – Laboratory Information Management System (in PGB, Kerteh)

# CHAPTER 4 : RESULTS & DISCUSSIONS

On the 27th and 28th of August 2008, a visit to Petronas Gas Berhad (PGB), Kerteh has been done for the purpose of data requisition. The data obtained comprises of:

a) Calculated data surrounding the depropanizer column which include all the tag names
b) Tag names and description
c) Description of the depropanizer column
d) Flow sheet for the column showing all the tag name surrounding the column.

See Appendix B for samples of data obtained. See also Appendix C which includes all the graphs on all the data obtained for each variable/tag number which are compositions, flow, temperature, pressure and level.

Process data is the cornerstone of all data driven modelling techniques [6], thus the quality of process data used in developing the SPC is crucial to the success of the application. These are some useful questions when collecting data for modelling purpose:

*a) What is considered 'normal' process operation?*

- In our cases, the 'normal' process operation is considered when the plant is in its daily operation, without any turnaround or plant shutdown.

*b) How much data is available and how much should be used?*

- The data can be extracted for any time of the year as long as the data is still inside the Laboratory Information Management System (LIMS) in PGB, Kerteh and also the PI system. For this project, the data needed is for two years period with an interval of one hour.

*c) What is the quality of the process data?*

- For the data that has been taken from PGB, it can be said that it is good enough for the purpose of this project. As the data is taken directly from PI system, supposedly they are all correct for each tag/variables, means that the data is solely coming from each respective tag/analyzer.

*d) How noisy is the collected process data?*

- There are certain periods whereby all the tags show "No Good Data For This Time", this indicates that at that time, the plant is going through a plant turnaround or sudden shutdown. This creates a small hole in the data; however, as the data was taken for two years, there are still enough data to be manipulated.

## 4.1 ANALYSIS ON THE DATA/VARIABLES USING MICROSOFT EXCEL

**Table 2: Analysis on the Variables obtained using Microstf Excel**

| Variables / Tag | Description | Unit | Average | Maximum | Minimum | Range |
|---|---|---|---|---|---|---|
| $C_1$ | Composition of $C_1$ in Overhead Product | mole % | 0.077 | 1.460 | 0.000 | 0 - 0.4 |
| $C_2$ | Composition of $C_2$ in Overhead Product | mol e% | 0.546 | 3.420 | 0.000 | 0 - 1.5 |
| $C_3$ | Composition of $C_3$ in Overhead Product | mol e% | 98.482 | 99.970 | 93.870 | 97 - 99.5 |
| $iC_4$ | Composition of $iC_4$ in Overhead Product | mol e% | 0.871 | 5.620 | 0.000 | 0 – 2 |
| $nC_4$ | Composition of $nC_4$ in Overhead Product | mol e% | 0.022 | 1.390 | 0.000 | 0 - 0.05 |
| 4FY62022.PV | TOTAL DEPROPANIZER FEED | M3/H | 143.359 | 179.480 | 32.751 | 120 – 170 |
| 4FC6002.PV | A601 BTM TO A621 | M3/H | 124.854 | 155.134 | 22.602 | 110 – 150 |
| 4FI6202.PV | A 621 TO A 641 | M3/H | 67.017 | 118.038 | 0.001 | 50 – 90 |
| 4FC6203.SP | DEPROPANIZER REFLUX | M3/H | 112.757 | 165.000 | 51.755 | 90 – 140 |
| 4FC6203.PV | DEPROPANIZER REFLUX | M3/H | 112.956 | 165.057 | 0.001 | 90 – 140 |
| 4TI6009.PV | A601 BTM | DEGC | 95.807 | 124.045 | 22.352 | 94 – 99 |
| 4TI6204.PV | A621 OVHD | DEGC | 45.001 | 51.248 | 26.699 | 44 – 46 |
| 4TI6205.PV | A 621 BOTTOM | DEG C | 115.761 | 134.362 | 27.671 | 110 – 128 |
| 4TC6231.SP | T621 TO A621 | DEG C | 127.418 | 150.000 | 112.303 | 120 -150 |
| 4TC6231.PV | T621 TO A621 | DEGC | 132.166 | 155.000 | 112.307 | 120 -155 |
| 4TI6231.PV | T621 TO A621 | DEGC | 116.033 | 128.572 | 32.556 | 110 – 124 |
| 4TI6214.PV | A621 TRAY 5 | DEGC | 47.801 | 56.332 | 28.609 | 45 – 51 |
| 4TI6213.PV | A621 TRAY 13 | DEGC | 54.278 | 69.188 | 29.000 | 46 – 62 |
| 4TI6202.PV | A621 TRAY 39 | DEGC | 69.649 | 87.605 | 28.384 | 64 – 75 |
| 4TI6203.PV | A621 TRAY 44 | DEGC | 101.097 | 107.087 | 31.907 | 98 – 105 |
| 4PC6202.SP | A621 OVERHEAD | KPAG | 1450.620 | 1459.984 | 1428.579 | 1445 – 1455 |
| 4PC6202.PV | A621 OVHD | KPAG | 1450.157 | 1558.965 | 1262.336 | 1445 – 1455 |
| 4LC6201.PV | A621 | PCT | 44.510 | 85.824 | 1.319 | 35 – 65 |
| 4LT6201.PV | A621 | PCT | 44.509 | 85.830 | 1.369 | 35 – 65 |

*Note : A601 = deethanizer, A621 = depropanizer, T621 = depropanizer reboiler*

**Table 3: The Product Specifications for $C_3$**

| Components | Specifications |
|---|---|
| $C_2$ | $\leq 2.0$ mol% |
| $C_{4+}$ | $\leq 3.4$ mol% |

In this project, the focus is only on the overhead product composition. This is mainly due to unavailability of data for the bottom product compositions. The composition data obtained is from 24th October 2007 until 31st July 2008. These data were extracted using Laboratory Information System (LIMS) at PGB, Kerteh. Data older than 24th October 2007 is not available due to the process of upgrading the system and the older data have been removed. Total, there are around 600 numbers of samples to be analyzed for each variable. On the graphs made, x-axis is the sample number as for y-axis is the variables (i.e., compositions, temperature, pressure, level).

As there are only the specifications for $C_2$ and $C_{4+}$, the overhead product should be expected to have 0 mole% for $C_1$ composition. However, referring to graph for $C_1$ composition, the range is between 0 – 0.4 mole%. This indicates that at certain times, exist a small amount of $C_1$ in the $C_3$ product, although this phenomena should not be happened after all. At one point, the $C_3$ product even have 1.46 mole% of $C_1$ inside it. For $C_2$, $iC_4$ and $nC_4$, seeing the average data, most of the time, they obey the specifications restricted.

## 4.2 FACTORS AFFECTING OVERHEAD PRODUCT COMPOSITION

Some of the main factors to be considered when investigating the overhead product composition:

**Table 4: Factors Affecting Overhead Product Composition and their Effects**

| Factors | Descriptions | Effect to the Overhead Composition |
|---|---|---|
| *Reflux* | It is a technique involving the condensation of vapors and the return of this condensate to the system from which it originated [11]. In this case, the system is the depropanizer. The reflux ratio is the ratio between the boil up rate and the | From the data obtained, it can be seen that when the reflux is low, between 50 – 80 m3/h, the mole% for $C_3$ decreased. It results in low purity of the product. Most of the time, the values fall within the range |

| | | |
|---|---|---|
| | take-off rate. The reflux can be used in controlling the purity of the overhead product while maintaining a fixed reboiler duty. | of 90 – 140 m3/h. |
| *) Energy input nside the column* | Basically, this is the heat supplied by the reboiler. In this case, it is the heat supplied from T621 (Depropanizer Reboiler).The composition of the overhead product can be controlled by manipulating the heat supplied to the fractional distillation column. Energy input will determine the vapor rate or vapor traffic inside the column and also the degree of separation that column can achieve [13]. High energy input will increase the reflux, resulting in increment of vapor/liquid traffic inside the column and less impurities in the overhead product composition [14]. As energy supplied increase, the degree of separation of the light and heavy components will also increase. | From the data obtained for the Depropanizer Reboiler, it can be seen at samples number 520 to 524, when the return temperature to the column is low, the purity of $C_3$ in the product is very low. |
| *Feed onditions<br>- Feed mperature<br>- Feed pressure* | Both are some of the vital things that will effect the overhead composition greatly and must be supplied at the optimum conditions. Here, we can only consider the feed temperature owing to the *unavailability data on the feed pressure*. However, theoretically, if the feed is from a source at a pressure higher than the distillation column pressure, it is simply piped into the column. Otherwise, the feed is pumped or compressed into the column [13]. The feed may be a superheated vapor, a saturated vapor, a partially vaporized liquid-vapor mixture, a saturated liquid (i.e., liquid at its boiling point at the column's pressure), or a sub-cooled liquid [11]. | For the temperature, the optimum condition based on the data obtained, is around 94 – 99 °C. In the situation of the supply feed temperature is lower than expected; it will effect the overhead product composition. Low purity of $C_3$ product will be produced, and more $C_1$, $C_2$ and $C_{4+}$ will be found in the overhead composition. Referring to samples number 520 to 524, whereby the feed temperature is lower, varies from 22 – 68 °C; the composition of $C_3$ inside the overhead product is only 53 – 87 mole% only. This will give PGB an off-spec $C_3$ product and will lead to customer complaints. |

And why do these three factors affect the overhead product composition greatly:

**Table 5: Why the Factors Affect Overhead Product Composition**

| Factors | Why does it affect the Overhead Composition |
|---|---|
| *) Reflux* | Reflux is the ratio between the amount of reflux that goes back down the distillation column and the amount of reflux that is collected in the receiver (distillate/overhead composition) [11]. Low flow of reflux results in low purity of the product. When the reflux flow is low, it means that the boil-up (return to distillation column) rate is higher than the take-off (overhead product) rate. The low amount that goes back to the distillation column will result in less amount of product composition inside the column compare when the reflux flow is higher. When the reflux flow is higher, it will result in more amount of product composition inside the column, leading to higher purity of overhead product. Plus, higher reflux will also lead to higher vapor/liquid traffic inside the column, resulting in less impurities in the overhead product. However, too high reflux can force the column to handle heat duties that are much higher than they should be, and this is where the importance of finding the optimum conditions coming in. |
| *) Energy ıput inside ıe column* | Energy input is the factor that will determine the vapor rate or vapor traffic inside the column and also the degree of separation that column can achieve [13]. High energy input will increase the reflux, resulting in increment of vapor/liquid traffic inside the column and less impurities in the overhead product composition [14]. Higher energy input or in this case when the return temperature from Depropanizer Reboiler is higher, the vapor traffic will also increase, leading to more contact between the liquid and the vapor. This will then increase the performance of the column and also purity of the product. |
| *) Feed onditions - Feed mperature - Feed essure* | As these two variables (temperature and pressure) are linked to each other greatly (increment in temperature will cause increment in pressure too), so we can focus to the feed temperature. When the feed is at low temperature or is not being preheated, it will not have enough energy for the vapor-liquid contact inside the column. This situation will lead to poor performance of the column, and thus the purity of the product. |

For multicomponent separations, tray temperatures do not uniquely determine the product composition. This is because the tray temperatures are affected by the feed temperature and the energy input. Nevertheless, it can be seen that when the tray temperatures are higher, the purity of the product also increased.

Next, for the overhead variables, the overhead pressure which is given from tag 4PC6202.PV, the average is 1450.157 kpaG which is near to the operating conditions stated in the theory previously (1450 kpaG). The range also falls within the value of operating conditions (1445 – 1455 kpaG). As for the overhead temperature, the average is

45.001 °C and the data falls within the range of 44 – 46 °C. The given operating condition for the overhead temperature is 46 °C.

For tag 4TI6205.PV, which is for the depropanizer bottom temperature, the average is 115.761 °C. And the data falls within the region of 110 – 128 °C.

As for the level inside the depropanizer, it is controlled by using the control valve at the bottom product. This means that the opening of the valve will be set by the level inside the column. If the level is less than requirement, the opening of the control valve will also be lessen and vice versa. From the data obtained, at samples number 559 and 564; when the level inside the column is slightly lower (25 – 30 PCT), the purity of $C_3$ inside the product also decreased. This shows that the level inside the column also give an affect towards the purity of the overhead product.

## 4.3 PROBLEMS FACED

However, there are some problems that might cause the analysis to be inaccurate:

a) Some of the tag/analyzer/indicator did not exist previously. This cause unavailability of the older data.

b) The data includes the plant shutdown period. This gives a period whereby there is no invalid data for all the variables.

c) Some of the tag/analyzer/indicator suddenly did not give a reading for a period of time. This also gives a period whereby there is no invalid data for all the variables. It may be broken or in maintenance during that time.

## 4.4 ANALYSIS ON THE DATA/VARIABLES USING SPSS SOFTWARE

### 4.4.1 Descriptive Statistics

**Table 6: Overall Descriptive Statistics**

| | N | Range | Minimum | Maximum | Mean | | Std. | Variance | Skewness | | Kurtosis | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Statistic | Statistic | Statistic | Statistic | Statistic | Std. Error | Statistic | Statistic | Statistic | Std. Error | Statistic | Std. Error |
| C1 | 570 | 1.46 | .00 | 1.46 | .0791 | .00724 | .17291 | .030 | 4.493 | .102 | 25.797 | .204 |
| C2 | 570 | 3.42 | .00 | 3.42 | .5499 | .02033 | .48540 | .236 | 1.761 | .102 | 5.961 | .204 |
| C3 | 570 | 6.10 | 93.87 | 99.97 | 98.4765 | .03715 | .88692 | .787 | -1.210 | .102 | 3.221 | .204 |
| iC4 | 570 | 5.62 | .00 | 5.62 | .8780 | .03147 | .75140 | .565 | 1.842 | .102 | 6.260 | .204 |
| nC4 | 569 | 1 | 0 | 1 | .02 | .005 | .125 | .016 | 8.429 | .102 | 77.259 | .204 |
| 4FY62022.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 371.318 | -1.653 | .102 | 4.911 | .203 |
| 4FC6002.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 311.275 | -1.465 | .102 | 3.948 | .203 |
| 4TI6009.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 39.750 | -9.403 | .102 | 102.952 | .203 |
| 4TI6204.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 1.842 | -9.299 | .102 | 113.818 | .203 |
| 4PC6202.SP | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 13.443 | -.936 | .102 | 2.616 | .203 |
| 4PC6202.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 153.712 | -7.703 | .102 | 130.393 | .203 |
| 4TI6205.PV | 572 | 107 | 28 | 134 | 115.76 | .688 | 16.449 | 270.565 | -4.525 | .102 | 20.514 | .204 |
| 4FI6202.PV | 572 | 118 | 0 | 118 | 67.02 | .744 | 17.797 | 316.732 | -1.385 | .102 | 4.763 | .204 |
| 4LC6201.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 67.402 | .357 | .102 | 5.147 | .203 |
| 4LT6201.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 67.386 | .358 | .102 | 5.146 | .203 |
| 4FC6203.SP | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 242.031 | -.498 | .102 | 1.330 | .203 |
| 4FC6203.PV | 573 | 165 | 0 | 165 | 112.96 | .675 | 16.167 | 261.381 | -1.345 | .102 | 8.123 | .204 |
| 4TC6231.SP | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 126.529 | 1.233 | .102 | -.046 | .203 |
| 4TC6231.PV | 215 | 43 | 112 | 155 | 132.17 | .956 | 14.011 | 196.315 | .654 | .166 | -1.152 | .330 |
| 4TI6231.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 56.296 | -7.385 | .102 | 73.120 | .203 |
| 4PDI6210.PV | 564 | 2 | -1 | 1 | -.53 | .014 | .343 | .117 | 3.724 | .103 | 15.290 | .205 |
| 4PDI6211.PV | 564 | 37 | -5 | 32 | -4.80 | .077 | 1.821 | 3.316 | 15.443 | .103 | 299.840 | .205 |
| 4TI6214.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 6.260 | -.758 | .102 | 9.375 | .203 |
| 4TI6213.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 25.500 | -.422 | .102 | 1.567 | .203 |
| 4TI6202.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 19.914 | -4.217 | .102 | 34.215 | .203 |
| 4TI6203.PV | 577 | ******** | ******** | ******** | ******** | ******** | ******** | 36.481 | -9.564 | .102 | 100.174 | .203 |
| Valid N (listwise) | 213 | | | | | | | | | | | |

The Descriptive Statistics are used to describe the central tendency and variability of variables measured at the interval level. The most common measure of central tendency is the mean, while the standard deviation is typically used to describe variability. These measures provide concise summaries of the data without all the detail from frequency analysis [21].

For this project, the focus will be on the most critical composition for overhead product of a depropanizer column which is propane or $C_3$ and the input data that will most probably affect the $C_3$ composition:

i) Reflux flow (4FC6203.PV)

ii) Energy input inside the column (4TI6231.PV)

iii) Feed conditions (4FY62022.PV, 4TI6009.PV)

. Referring to Table 6 which shows the Descriptive Statistics for all the variables, some measures that can be analyzed are: Minimum, Maximum, Mean, Standard Error of Mean, Standard Deviation, Variance, Skewness and Kurtosis. The table below will summarize all the information on $C_3$ and the other variables.

**Table 7: Summarize of Descriptive Statistics**

| 'ariables | Range | Min | Max | Mean | S.E. of Mean | Std. Dev. | Variance | Skewness | Kurtosis |
|---|---|---|---|---|---|---|---|---|---|
| | 6.10 | 93.87 | 99.97 | 98.48 | 0.03715 | 0.88692 | 0.787 | -1.21 | 3.221 |
| :6203.PV | 165 | 0 | 165 | 112.96 | 0.675 | 16.167 | 261.381 | -1.345 | 8.123 |
| 6231.PV | - | - | - | - | - | - | 56.296 | -7.385 | 73.12 |
| '62022.PV | - | - | - | - | - | - | 371.318 | -1.653 | 4.911 |
| 6009.PV | - | - | - | - | - | - | 39.75 | -9.403 | 102.952 |

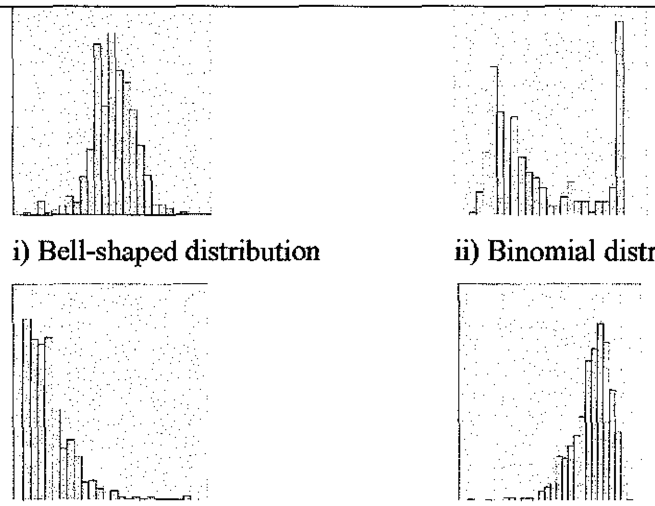
The range is simply the difference between the minimum and maximum value, which are 93.87 mole% and 99.97 mole % respectively. The average or the mean of $C_3$ is calculated to be 98.48, so generally, it can be seen that the composition of $C_3$ on the overhead product is quiet good. S.E. mean identifies the standard error of mean. This statistics provides an indication on how well the samples mean represent the population mean. The smaller the value is, the less error will be in the sample and therefore, the sample mean provides a better estimation on the population mean. The value of S.E.

mean is 0.03715. This indicates that the two years data will give a good analysis of the equipment itself. The two years sample does not varied a lot due to a small value of standard deviation which is 0.88692. The variance is calculated by squaring the standard deviation, 0.787 (=$0.88692^2$).

There are two additional measures reported in this SPSS output that describe the shape of the distribution, skewness and kurtosis. The closer these values are to 0, the more likely that it is that the variables follow a normal distribution. The skewness for $C_3$ is -1.21, which shows more extreme scores at the lower part of the distribution. It can also be said that that the sample is negatively skewed. Another type of measure is the kurtosis. Positive value of kurtosis indicates a pointy distribution whereas negative values indicate a flat distribution[23]. The kurtosis value is 3.221 which shows a taller distribution. A positive kurtosis also indicates that the distribution is slightly taller than what can be expected in a normal distribution. These two properties are easier to understand through a graph of distribution. A histogram would be used later to display the distribution.

### 4.4.2 Histograms

Histogram offers a nice pictorial representation of distributions, and these graphs are normally summarized with descriptions of their shapes. There are four common shapes:



i) Bell-shaped distribution ii) Binomial distribution

iii) Positively skewed distribution iv) Negatively skewed distribution

**Figure 4: Histograms of Normal, Skewed and Bimodal Distributions** [22]

i) *Bell-shaped distribution* – symmetric, both sides look pretty much the same. It has the highest frequencies taper off at the high and low ends of the distribution, creating "tails" with few cases.

ii) *Positively skewed distribution* – looks like a bell-shaped distribution that has been shoved to the left side, with a tail that points in the positive direction of the horizontal axis. There are many cases with low values of the variables and few cases with high values.

iii) *Negatively skewed distribution* – the opposite of a positively skewed. These distributions show many cases with high values and few cases with low values.

iv) *Bimodal distribution* – symmetric, but the highest frequencies are at both ends, with few cases in the middle.

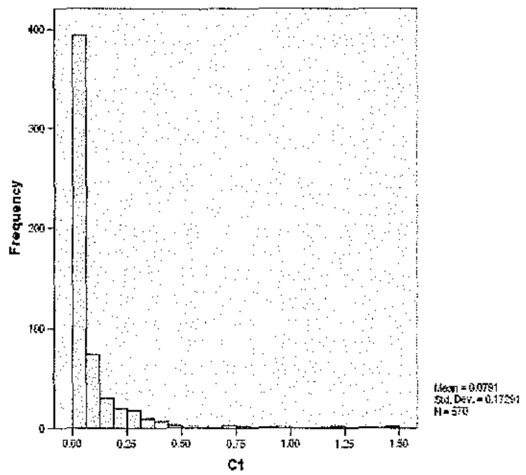



**Figure 5: Histogram of $C_1$ Composition at the Overhead Product**

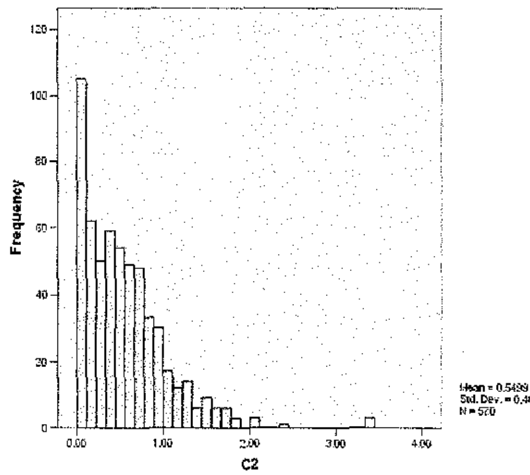



**Figure 6: Histogram of $C_2$ Composition at the Overhead Product**

Both histogram above show positively skewed distributions where there are many cases with low values of the variables and few cases with high values. The skewness for $C_1$ and $C_2$ are 4.493 and 1.761 respectively, which show that most of the extreme scores are at the upper part of the distributions. As for the kurtosis, the values are 25.797 and 5.961 for $C_1$ and $C_2$ respectively. Both components have a very high value of kurtosis which show their distributions are taller than what can be expected in a normal distribution.

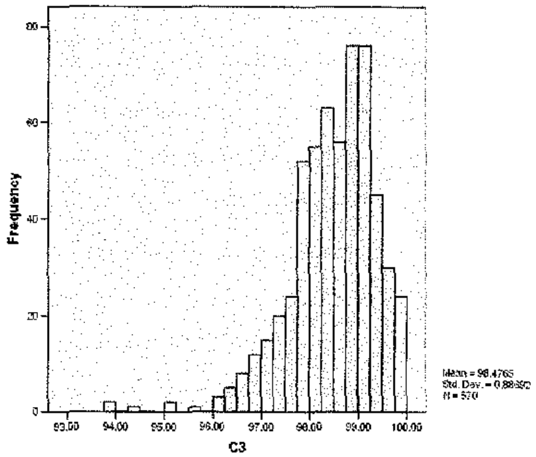
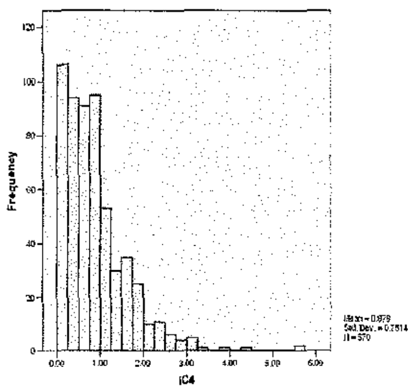



**Figure 7: Histogram of $C_3$ Composition at the Overhead Product**

Figure above shows the histogram of $C_3$ composition at the overhead product. The histogram is negatively skewed as discussed before where the skewness is -1.21. Most of the extreme scores are at the lower part of the distribution. The kurtosis is 3.221 which indicates that the distribution is slightly taller than what can be expected in a normal distribution.



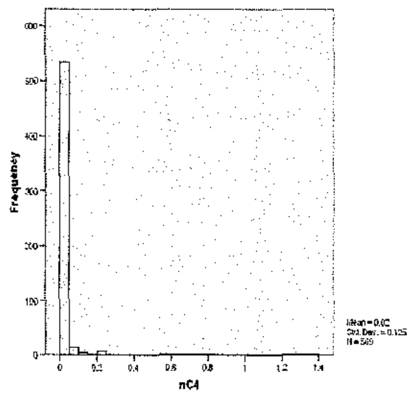




**Figure 8: Histogram of $iC_4$ Composition at the Overhead Product**

**Figure 9: Histogram of $nC_4$ Composition at the Overhead Product**

Both histograms above are positively skewed which shows there are many data with low values of the variables and few data with high values. The skewness are 1.842 and 8.429 for $iC_4$ and $nC_4$ respectively. The difference in their values of skewness can be seen here in the histograms where $nC_4$ which has a higher skewness, has most of its data on the upper part of the distribution. As for $iC_4$, there are some amounts of data which lies towards the middle of the histogram. For the kurtosis, the value for $iC_4$ is 6.260 which indicates that the distribution is taller than what can be expected in a normal distribution. And for $nC_4$, the value of kurtosis is 77.259, a very high value which shows the distribution is much taller than what can be expected in a normal distribution.

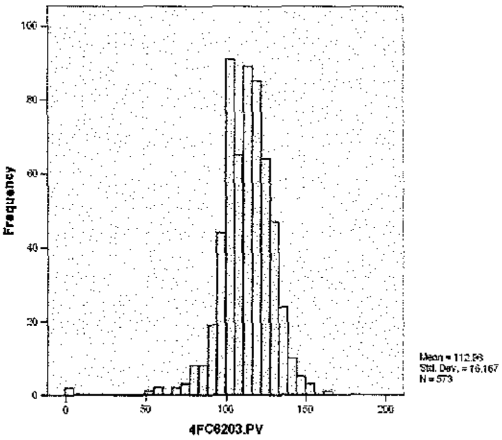



**Figure 10: Histogram of Data from 4FC6203.PV**

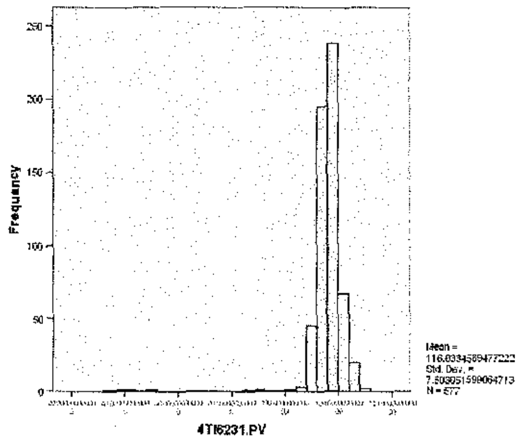



**Figure 11: Histogram of Data from 4TI6231.PV**

For 4FC6203.PV, the histogram shows a bell-shaped distribution. It has the highest frequencies taper off at the high and low ends of the distribution, creating "tails" with few cases. Although the value of skewness for 4FC6203.PV is -1.345, the histogram is more to a bell-shaped distribution. The value of kurtosis for 4FC6203.PV is 8.123, which indicates a pointy distribution. While for 4TI6231.PV, the histogram is negatively skewed. The histogram also has a pointy distribution with the value of kurtosis is 73.12.

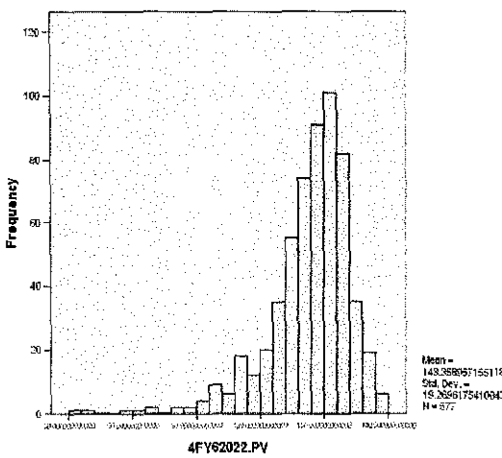



**Figure 12: Histogram of Data from 4FY62022.PV**

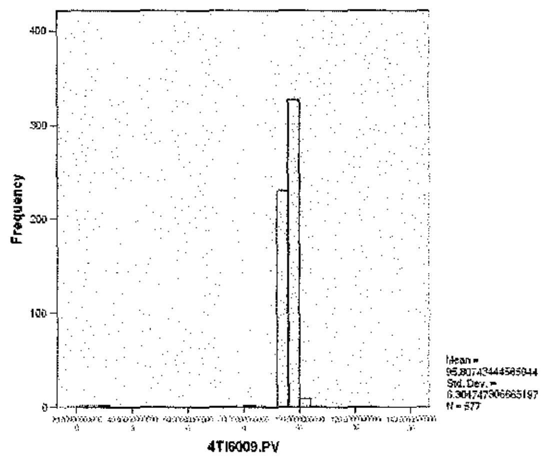



**Figure 13: Histogram of Data from 4TI6009.PV**

Both histograms above show a negatively skewed distribution with thevalues of skewness are -1.653 and -9.403 for 4FY62022.PV and 4TI6009.PV respectively. 4FY62022.PV has a value of kurtosis 4.911 which shows the distribution is slightly taller than what can be expected in a normal distribution. 4TI6009.PV has a very high value of kurtosis which is 102.952. It can be seen from the pointy distribution of the histogram.

### 4.4.3 Correlation

Correlation is a measure of covariation [21]. It is a simple and effective way of summarizing the degree to which values in two variables correspond with each other. In other words, the more two variables vary together, the stronger the correlation is between them.Pearson's correlation coefficient measures the strength of the linear relationship between two variables. Other types of possible relationship are curvilinear, "U" shaped and inverted "U" shaped relationship. Another term used to describe the relationship between two variables is covariance. A covariance is simply a measure of association which has not been standardized. Correlation coefficient range from -1.0 to +1.0, whereas the range of covariance depends on the variability of the variables being correlated and the number of data in the sample. However, this dependence makes covariances difficult to interpret and compare. The comparison of variables and their relationship become easier when the variables have been standardized. Therefore, correlation of coefficient will be used to describe the relationship between the variables. As discussed earlier, the discussion will focus to $C_3$ composition and the three input data: 4FC6203.PV, 4TI6231.PV, 4FY62022.PV and 4TI6009.PV.

**Table 8: Summarize on the Relationship between $C_3$ and the Input Data**

| | 4FC6203.PV | 4TI6231.PV | 4FY62022.PV | 4TI6009.PV |
|---|---|---|---|---|
| **$C_3$** Pearson's Correlation Coefficient | -0.070 | -0.030 | -0.0137 | 0.017 |

From the table above, it can be seen the linear relationship between $C_3$ and the input data that will most probably affect the $C_3$ composition at the overhead product. For 4FC6203.PV (Depropanizer Reflux), 4TI6231.PV and 4FY62022.PV, the correlation are

–0.070, -0.030 and -0.0137 respectively. These values show that all these three input variables have a very weakly negative linear relationship with $C_3$ composition. As for 4TI6009.PV, the value for correlation is 0.017, which is a weakly positive linear relationship. It can be concluded from these four values that none of them have real linear relationship with $C_3$ composition at the overhead product. However, this does not indicate that there are no relationship at all between them. There might be another type of relationship exists (i.e.: curvilinear, "U" shaped and inverted "U" shaped relationship). It will be discussed next in the scatter plots.

### 4.4.4 Scatter Plots

Scatter Plots graph the relationship between two numerical variables [22]. The values of independent variable are listed on the horizontal axis (X axis) and the values of the dependent variable are listed on the vertical axis (Y axis). Each case is then placed on the graph at the intersection of its values for the two variables. In this project, the dependent variable is the most critical component at the overhead product which is $C_3$ and the independent variable is the input data from any tag that would affect the composition of $C_3$. Again, the focus will be on the factors that affect the overhead product composition (i) Reflux flow – 4FC6203.PV, ii) Energy input inside the column – 4TI6231.PV and iii) Feed conditions – 4FY62022.PV, 4TI6009.PV).

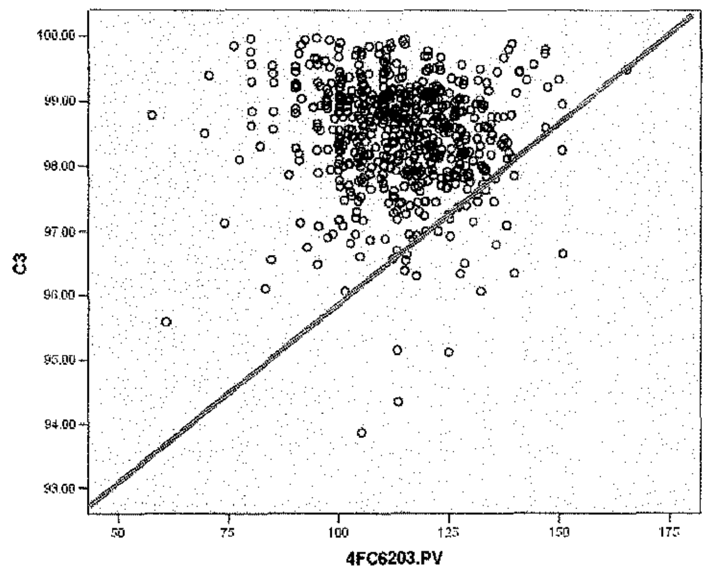



**Figure 14: Scatter Plot of $C_3$ Composition by 4FC6203.PV**

4FC6203.PV is the tag that shows the flow of reflux for the depropanizer column. From the scatter plot, it can be seen that almost all the points are grouped tightly together. This shows a very strong relationship between these two variables. The red line was drawn in order to show the relationship between these two variables. Most of the data lies near to this line, and this shows a strong positive relationship between them. However, there are a few outliers in this scatter plot. An outlier is an observation so far removed from the cluster of other observations that it is considered an extreme value. Outliers can have a strong impact on the values of statistics as they can undermine conventional statistical methods. These outliers might be resulting from result of an error or data entry error caused by

i) Some of the tag/analyzer/indicator did not exist previously. This cause unavailability of the older data.
ii) The data includes the plant shutdown period. This gives a period whereby there is no invalid data for all the variables.
iii) Some of the tag/analyzer/indicator suddenly did not give a reading for a period of time. This also gives a period whereby there is no invalid data for all the variables. It may be broken or in maintenance during that time.

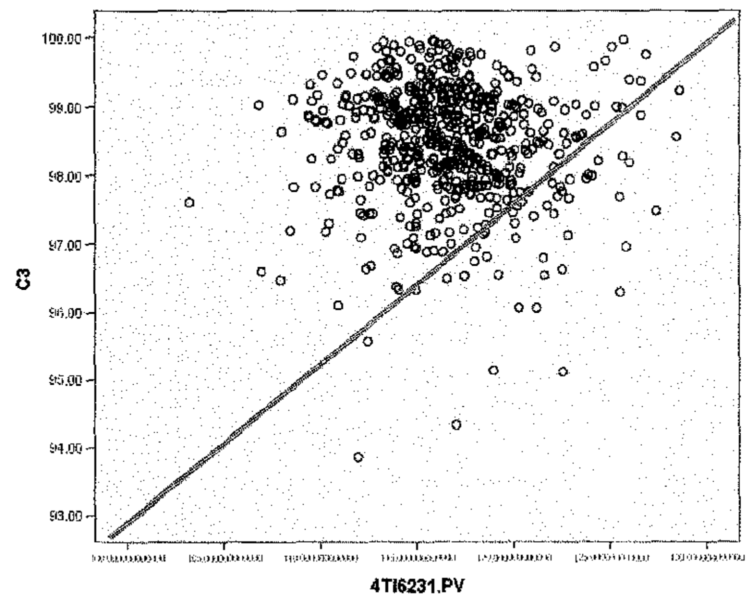



**Figure 15: Scatter Plot of $C_3$ Composition by 4TI6231.PV**

4TI6231.PV is the tag that shows the return temperature from the reboiler to the column or the energy input inside the column. Theoretically, the higher energy input inside the column, the higher concentration of $C_3$ in the overhead product. From the scatter plot, it can be seen that almost all the points are grouped tightly together. This shows a very strong relationship between these two variables. Most of the data lies near to the red line, and this shows a strong positive relationship between them. However, same as the scatter plot from 4FC6203.PV, there are also a few outliers in this scatter plot.

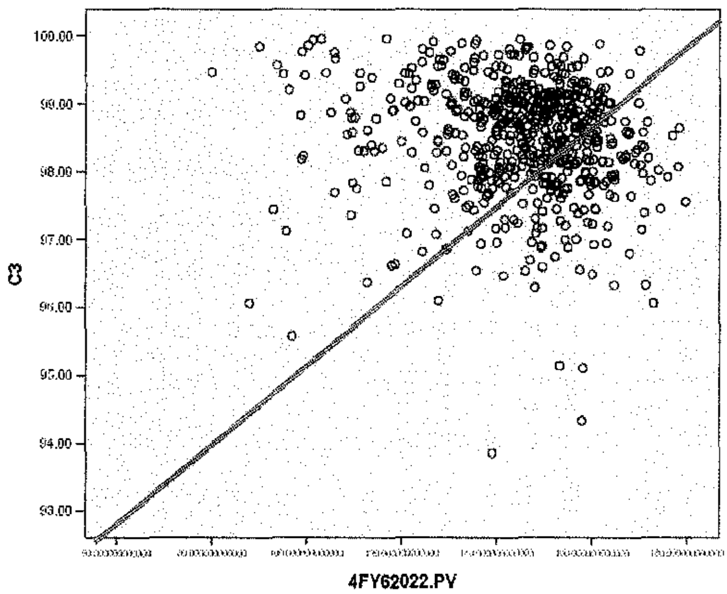



**Figure 16: Scatter Plot of $C_3$ Composition by 4FY62022.PV**

4FY62022.PV is the tag that shows the total flow of depropanizer feed. All the points are grouped tightly together, which shows a very strong relationship between these two variables. Most of the data lies near to this line, and this shows a strong positive relationship between them. The increment in the total depropanizer feed will also affect or increase the $C_3$ concentration inside the overhead product composition.

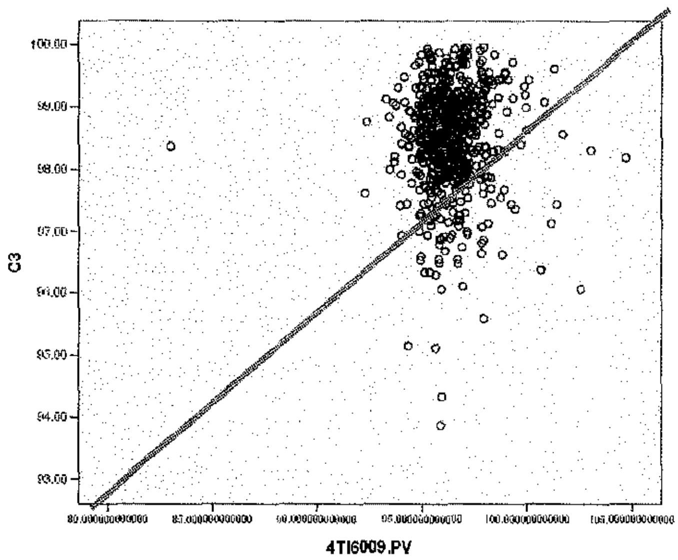



**Figure 17: Scatter Plot of $C_3$ Composition by 4TI6009.PV**

This scatter plot shows the relationship between 4TI6009.PV and $C_3$ composition inside the overhead product. Comparing this scatter plot with the other three previously shows that almost all of the points are grouped together and this scatter plot has less outliers from the other three previously. 4TI6009.PV is a tag that shows the temperature of feed entering the column. From the scatter plot, it can be seen that there is a strong positive relationship between them. This shows that the higher temperature of feed entering the column, the higher purity of $C_3$ inside the overhead product.

### 4.4.5 Crosstabs

Crosstabs are a simple and highly effective means of showing the association between two categorical variables [22]. A cross tabulation is a grid of all possible combinations of the values for two categorical variables. When the cells of this grid are filled with frequency of occurrence of the intersecting values, the association becomes apparent. Shown next are the results from crosstabs using SPSS software. The relationship between $C_3$ and the four main variables that will most probably affect $C_3$ composition in the overhead product are to be examined.

The degrees of freedom (df) are the same for all the crosstabs which is 153408. The formula used to calculate the df is (number of rows – 1) x (number of columns – 1). Since a vast amount of data are being used, it caused the df to be big.

Chi-Square Tests

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| **Pearson Chi-Square** | 153279.000(a) | 153408 | .592 |
| **Likelihood Ratio** | 6150.343 | 153408 | 1.000 |
| **Linear-by-Linear Association** | 2.744 | 1 | .098 |
| **McNemar-Bowker Test** | . | . | .(b) |
| **N of Valid Cases** | 567 | | |

a 154245 cells (100.0%) have expected count less than 5. The minimum expected count is .00.

b Computed only for a PxP table, where P must be greater than 1.

Symmetric Measures

| | | Value | Asymp. Std. Error(a) | Approx. T(b) | Approx. Sig. |
|---|---|---|---|---|---|
| **Nominal by Nominal** | **Phi** | 16.442 | | | .592 |
| | **Cramer's V** | .997 | | | .592 |
| | **Contingency Coefficient** | .998 | | | .592 |
| **N of Valid Cases** | | 567 | | | |

a Not assuming the null hypothesis.

b Using the asymptotic standard error assuming the null hypothesis.

c Based on normal approximation.

d Kappa statistics cannot be computed.They require a symmetric 2-way table in which the values of the first variable match the values of the second variable.

**Figure 18: Crosstabs between 4FC6203.PV and $C_3$**

Chi-Square Tests

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| **Pearson Chi-Square** | 153279.000(a) | 153408 | .592 |
| **Likelihood Ratio** | 6150.343 | 153408 | 1.000 |
| **Linear-by-Linear Association** | .511 | 1 | .475 |
| **McNemar-Bowker Test** | . | . | .(b) |
| **N of Valid Cases** | 567 | | |

a 154245 cells (100.0%) have expected count less than 5. The minimum expected count is .00.

b Computed only for a PxP table, where P must be greater than 1.

Symmetric Measures

| | | Value | Asymp. Std. Error(a) | Approx. T(b) | Approx. Sig. |
|---|---|---|---|---|---|
| **Nominal by Nominal** | **Phi** | 16.442 | | | .592 |
| | **Cramer's V** | .997 | | | .592 |
| | **Contingency Coefficient** | .998 | | | .592 |
| **N of Valid Cases** | | 567 | | | |

a Not assuming the null hypothesis.

b Using the asymptotic standard error assuming the null hypothesis.

c Based on normal approximation.

d Kappa statistics cannot be computed.They require a symmetric 2-way table in which the values of the first variable match the values of the second variable.

**Figure 19: Crosstabs between 4TI6231.PV and $C_3$**

Chi-Square Tests

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| **Pearson Chi-Square** | 153279.000(a) | 153408 | .592 |
| **Likelihood Ratio** | 6150.343 | 153408 | 1.000 |
| **Linear-by-Linear Association** | 10.567 | 1 | .001 |
| **McNemar-Bowker Test** | . | . | .(b) |
| **N of Valid Cases** | 567 | | |

a 154245 cells (100.0%) have expected count less than 5. The minimum expected count is .00.

b Computed only for a PxP table, where P must be greater than 1.

Symmetric Measures

| | | Value | Asymp. Std. Error(a) | Approx. T(b) | Approx. Sig. |
|---|---|---|---|---|---|
| **Nominal by Nominal** | **Phi** | 16.442 | | | .592 |
| | **Cramer's V** | .997 | | | .592 |
| | **Contingency Coefficient** | .998 | | | .592 |
| **N of Valid Cases** | | 567 | | | |

a Not assuming the null hypothesis.

b Using the asymptotic standard error assuming the null hypothesis.

c Based on normal approximation.

d Kappa statistics cannot be computed.They require a symmetric 2-way table in which the values of the first variable match the values of the second variable.

**Figure 20: Crosstabs between 4FY62022.PV and $C_3$**

Chi-Square Tests

| | Value | df | Asymp. Sig. (2-sided) |
|---|---|---|---|
| **Pearson Chi-Square** | 153279.000(a) | 153408 | .592 |
| **Likelihood Ratio** | 6150.343 | 153408 | 1.000 |
| **Linear-by-Linear Association** | .159 | 1 | .690 |
| **McNemar-Bowker Test** | . | . | .(b) |
| **N of Valid Cases** | 567 | | |

a 154245 cells (100.0%) have expected count less than 5. The minimum expected count is .00.

b Computed only for a PxP table, where P must be greater than 1.

Symmetric Measures

| | | Value | Asymp. Std. Error(a) | Approx. T(b) | Approx. Sig. |
|---|---|---|---|---|---|
| **Nominal by Nominal** | **Phi** | 16.442 | | | .592 |
| | **Cramer's V** | .997 | | | .592 |
| | **Contingency Coefficient** | .998 | | | .592 |
| **N of Valid Cases** | | 567 | | | |

a Not assuming the null hypothesis.

b Using the asymptotic standard error assuming the null hypothesis.

c Based on normal approximation.

d Kappa statistics cannot be computed.They require a symmetric 2-way table in which the values of the first variable match the values of the second variable.

**Figure 21: Crosstabs between 4TI6009.PV and $C_3$**

Figure 18 – 21 show the crosstabs between 4FC6203.PV, 4TI6231.PV, 4FY62022.PV and 4TI6009.PV with $C_3$. The first information that can be obtained is the chi-square test. Chi-square is used to test for the significance of relationships between variables cross-classified in a bivariate table. The chi-square test results in a chi-square statistic that tells the degree to which the conditional distributions (the distribution of the

dependent variable across different values of the independent variable) differ from what expected under the assumption of "statistical independence." The reported value of Pearson chi-square is 153279 and it is the same for all the input variables used.

The significance level reported for the Pearson chi-square test is also the same for all the input variables used, which is 0.592. It is listed under 'Asymp. Sig. (2-sided)' heading. The significance level is interpreted as a probability. This probability indicates the extent to which the observed and expected frequencies differ by chance. A value of 0.592 is medium (value of higher than 0.7 is assume high), meaning that it would be expected the observed and expected frequencies to differ as much as they do by chance about 59 times out of 100. This indicates that it is unlikely that these frequencies differ by chance. It might be caused by the relationship between them. This will support the hypothesis that there are strong relationship between the output variables used (4FC6203.PV, 4TI6231.PV, 4FY62022.PV & 4TI6009.PV) and $C_3$ composition.

### 4.4.6 One-way Analysis of Variance (ANOVA)

One-way ANOVA tests how much the mean values of a numerical variable differ among the categories of a categorical variable [22]. It is called one-way ANOVA because there is only one independent variable.

ANOVA

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| C3 | Between Groups | 422.602 | 564 | .749 | .985 | .637 |
| | Within Groups | 1.522 | 2 | .761 | | |
| | Total | 424.124 | 566 | | | |

**Figure 22: One-way ANOVA for $C_3$**

Figure 22 shows the summary of ANOVA table for $C_3$. The sum of squares (SS) represents the sum of the squared deviations from the mean. The SS represents the extent to which each values vary from the overall grand mean. The total SS is further divided in between-group and within-group resources. The SS for between groups (442.60) represents the variability of the group means from the overall grand mean, and the SS within groups (1.522) represents the variability of each values from the their group mean.

Mean squares (MS) is the estimate of population variance, computed by dividing SS by df. In this case the MS for between groups is 0.749 while the MS for within groups is 0.761. Both values are quite the same. The MS value for between groups should be larger in order to maximize the variation between groups.

The F ratio is also reported. The F ratio is computed by dividing the MS (between groups) by the MS (within groups). In this case, the reported F ratio is 0.985 with the probability of 0.637. With this probability, the chances of being wrong when rejecting the null hypothesis are about 637 times in 1000, which is very high (null hypothesis = all the groups come from the general population). This means that the null hypothesis must be accepted and it shows that all the groups or variables used come from the general population.

### 4.4.7 Linear Regression

Model Summary(b)

| Model | R | R Square | Adjusted R Square | Std. Error of the Estimate | Change Statistics | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | R Square Change | F Change | df1 | df2 | Sig. F Change |
| 1 | .070(a) | .005 | .003 | .86430 | .005 | 2.753 | 1 | 565 | .098 |
| a Predictors: (Constant), 4FC6203.PV | | | | | | | | | |
| b Dependent Variable: C3 | | | | | | | | | |
| 1 | .137(a) | .019 | .017 | .85828 | .019 | 10.749 | 1 | 565 | .001 |
| a Predictors: (Constant), 4FY62022.PV | | | | | | | | | |
| b Dependent Variable: C3 | | | | | | | | | |
| 1 | .030(a) | .001 | -.001 | .86602 | .001 | .511 | 1 | 565 | .475 |
| a Predictors: (Constant), 4TI6231.PV | | | | | | | | | |
| b Dependent Variable: C3 | | | | | | | | | |
| Model Summary(b) | | | | | | | | | |
| 1 | .017(a) | .000 | -.001 | .86629 | .000 | .159 | 1 | 565 | .690 |
| a Predictors: (Constant), 4TI6009.PV | | | | | | | | | |
| b Dependent Variable: C3 | | | | | | | | | |

Coefficients(a)

| Model | | Unstandardized Coefficients | Standardized Coefficients | t | Sig. | 95% Confidence Interval for B | Correlations | Collinearity Statistics |
|---|---|---|---|---|---|---|---|---|

| | | B | Std. Error | Beta | | | Lower Bound | Upper Bound | Zero-order | Partial | Part | Tolerance | VIF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | (Constant) | 98.953 | .286 | | 345.440 | .000 | 98.391 | 99.516 | | | | | |
| | 4FC6203.PV | -.004 | .003 | -.070 | -1.659 | .098 | -.009 | .001 | -.070 | -.070 | -.070 | 1.000 | 1.000 |
| a Dependent Variable: C3 | | | | | | | | | | | | | |
| 1 | (Constant) | 99.502 | .313 | | 317.690 | .000 | 98.887 | 100.117 | | | | | |
| | 4FY62022.PV | -.007 | .002 | -.137 | -3.279 | .001 | -.011 | -.003 | -.137 | -.137 | -.137 | 1.000 | 1.000 |
| a Dependent Variable: C3 | | | | | | | | | | | | | |
| 1 | (Constant) | 97.536 | 2.375 | | 41.075 | .000 | 92.872 | 102.200 | | | | | |
| | 4TI6009.PV | .010 | .025 | .017 | .398 | .690 | -.039 | .058 | .017 | .017 | .017 | 1.000 | 1.000 |
| a Dependent Variable: C3 | | | | | | | | | | | | | |
| 1 | (Constant) | 99.322 | 1.176 | | 84.455 | .000 | 97.012 | 101.632 | | | | | |
| | 4TI6231.PV | -.007 | .010 | -.030 | -.715 | .475 | -.027 | .013 | -.030 | -.030 | -.030 | 1.000 | 1.000 |
| a Dependent Variable: C3 | | | | | | | | | | | | | |

**Figure 23: Summarize of Linear Regression between $C_3$ and the Main Variables (4FC6203.PV, 4FY62022.PV, 4TI6009.PV & 4TI6231.PV)**

Linear regression is used to make predictions based on a linear relationship between the dependent and independent variables [23]. These predictions are made using an equation to estimate a line that best fits the relationship. The linear relationship has been discussed earlier in *Section 4.4.3 Correlation.* Here, the discussion is mainly on the regression equation that can be extracted from the results obtained in SPSS.

a) $C_3 = -0.004(4FC6203.PV) + 98.953$
b) $C_3 = -0.007(4FY62022.PV) + 99.502$
c) $C_3 = 0.010(4TI6009.PV) + 97.536$
d) $C_3 = -0.007(4TI6231.PV) + 99.332$

Shown above are the regression equation that describes the relationship between $C_3$ composition and the main variables that will most probably affect it. It can be seen

Paired Samples Test

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 3 | C3 - 4TI6009.PV | 2.111004922997993 | 1.700228724507021 | .071402894872606 | 1.970757920175778 | 2.251251925820207 | 29.565 | 566 | .000 |

Paired Samples Test

| | | Paired Differences | | | | | t | df | Sig. (2-tailed) |
|---|---|---|---|---|---|---|---|---|---|
| | | Mean | Std. Deviation | Std. Error Mean | 95% Confidence Interval of the Difference | | | | |
| | | | | | Lower | Upper | | | |
| Pair 3 | C3 - 4TI6231.PV | -18.158362395937500 | 3.739561772348833 | .157046832730143 | -18.466828146974920 | -17.849896644900080 | -115.624 | 566 | .000 |

**Figure 24: Summarize of Paired T-test between $C_3$ and the Main Variables (4FC6203.PV, 4FY62022.PV, 4TI6009.PV & 4TI6231.PV)**

For each test, a t-value, degrees of freedom (df) and a 2-tailed significance is reported. For each test, the df reported is 566 because each test is based on a sample of 567 data. The lowest t-value (t = -115.624) is given by the pair $C_3$-4TI6231.PV, while the highest t-value (t = 29.565) is given by the pair $C_3$- 4TI6009.PV. In all four pairs, the reported 2-tailed significance is 0.000. This means that these results will be expected less than 1 time in 1000 ($p < 0.001$) if the null hypothesis is true.

Because the probability of these results occurring is very low, the null hypothesis is rejected for each test. This indicates that the two population means are not equal and this is true because for each test, both variables are very different although they have strong relationship. The independent and dependent variables will have different population means.

# CHAPTER 5 : CONCLUSION & RECOMMENDATION

This project "Statistical Process Control on the Depropanizer Column at Petronas Gas Berhad, Kerteh" has been completed fulfilling the requirement of CAB 4614 : Final Year Project II.

Simulation using SPSS software has been completed which includes:

a) Descriptive Statistics
b) Histograms
c) Correlations
d) Scatter Plots
e) Crosstabs
f) One Way Anova
g) Paired T-test
h) Linear Regressions

And analysis has been done for the results obtained from SPSS, focusing on the critical components inside the overhead product composition which is $C_3$ and some input data that will most probably affect the overhead product composition:

a) Reflux flow (4FC6203.PV)
b) Energy input inside the column (4TI6231.PV)
c) Feed conditions (4FY62022.PV, 4TI6009.PV)

Before analyzing the relationships between the input and output variables, a check within and between the variables have been done in order to ensure that the two years data used come from a general population mean and to know whether they follow a normal distribution or not. The check was being done using:

a) Descriptive Statistics
b) Histograms
c) Paired T-test
d) One Way Anova

It is proven that these four main input variables have a very strong relationship with $C_3$ composition inside the overhead product. Increasing or decreasing their values will give a great impact to the $C_3$ composition. The relationship has been analyzed through these analyses:

a) Histograms
b) Correlations
c) Scatter Plots
d) Crosstabs
e) Linear Regressions

As the samples proved to come from a general population mean, an optimum operating condition could be produced from the average data, in order to maintain $C_3$ composition within the desired value (98.48 mole%):

**Table 9: Optimum Operating Conditions Suggested**

| **Input variables** | **Description** | **Optimum operating conditions suggested** |
|---|---|---|
| 4FC6203.PV | Reflux flow | 112.96 $m^3$/hr |
| 4TI6231.PV | Energy input inside the column / Reboiler temperature | 116.03 °C |
| 4FY62022.PV | Feed flowrate | 143.36 $m^3$/hr |
| 4TI6009.PV | Feed temperature | 95.81 °C |

However, these optimum operating conditions suggested must be checked again so that it will not violate the design operating conditions.

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# APPENDICES

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**APPENDIX A – FYP2 Gantt Chart**

**FYP2 Gantt Chart**

| No. | Detail/ Week | 1 | 2 | 3 | 4 | 5 | 6 | 7 | | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Project Work Continue | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| 2 | Submission of Progress Report 1 | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| 3 | Project Work Continue | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| 4 | Submission of Progress Report 2 | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| 5 | Seminar (compulsory) | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| 5 | Project work continue | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| 6 | Poster Exhibition | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| 7 | Submission of Dissertation (soft bound) | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| 8 | Oral Presentation | | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | | | |
| 9 | Submission of Project Dissertation (Hard | | | | | | | | | | | | | | | |

Suggested milestone

Process

# APPENDIX B – Samples of the Data obtained

| | M3/H TOTAL DEPROPANIZER FEED -FV62022.PV | M3/H A601 BTM TO A621 -FC6042.PV | DEGC A601 BTM -TI6009.PV | DEGC A621 OVHD -TI6204.PV | KPAG A621 OVERHEAD -PC6202.SP | KPAG A621 OVHD -PC6202.PV | DEG C A2 621 BOTTOM 2TI6205.PV | M3/H A2 621 TO A2 641 2FI6202.PV | PCT A621 -LC6201.PV | -LT6201.PV | M3/HR DEPROPANIZER REFLUX -FC6203.SP | M3/H DEPROP/ REFL -FC62( |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-Nov-07 00:00:00 | 152.6927185 | 133.383499 | 96.0612106 | 44.89682 | 1445.043 | 1445.14209 | 121.0227 | 43.54222 | 44.995762 | 45.013264 | 106.3721085 | 106.31 |
| 01-Nov-07 01:00:00 | 156.3392487 | 136.092133 | 95.3352356 | 45.41821 | 1446.037 | 1446.20251 | 117.5872 | 55.31287 | 48.314304 | 48.306614 | 118.2884903 | 118.4 |
| 01-Nov-07 02:00:00 | 156.1583862 | 135.625031 | 94.9005585 | 45.22388 | 1445.097 | 1444.95642 | 116.1979 | 51.00071 | 50.24818 | 50.222706 | 122.0334625 | 121.84 |
| 01-Nov-07 03:00:00 | 153.6270905 | 135.365631 | 95.4891663 | 44.9472 | 1445.035 | 1445.06567 | 120.6052 | 38.32404 | 54.484966 | 54.469662 | 117.2271652 | 117.16 |
| 01-Nov-07 04:00:00 | 152.9840851 | 135.14502 | 95.3943329 | 44.84604 | 1445.796 | 1445.77417 | 121.642 | 39.11098 | 51.282108 | 51.272823 | 108.8434067 | 109.1 |
| 01-Nov-07 05:00:00 | 152.2232666 | 135.166077 | 95.2738647 | 44.83311 | 1445.086 | 1444.88135 | 119.2163 | 49.89167 | 55.538635 | 55.538807 | 107.0186081 | 107.0 |
| 01-Nov-07 06:00:00 | 155.3352509 | 136.167923 | 94.3844757 | 45.2792 | 1448.413 | 1448.41602 | 115.7774 | 57.89136 | 55.167088 | 55.178486 | 121.7437744 | 121.46 |
| 01-Nov-07 07:00:00 | 153.2041168 | 132.704895 | 94.3252792 | 44.57655 | 1445.002 | 1445.0033 | 116.2268 | 52.03412 | 51.067417 | 51.070377 | 112.9181976 | 113.15 |
| 01-Nov-07 08:00:00 | 154.0132446 | 133.101517 | 95.5653305 | 45.07154 | 1445 | 1444.94482 | 117.9124 | 46.97624 | 52.848953 | 52.834503 | 138.790863 | 138.77 |
| 01-Nov-07 09:00:00 | 150.8891754 | 129.988708 | 97.663475 | 44.83835 | 1445 | 1445.06104 | 122.2783 | 40.66962 | 56.892342 | 56.923824 | 138.8748627 | 138.91 |
| 01-Nov-07 10:00:00 | 149.146347 | 128.491608 | 98.4425507 | 44.88677 | 1445.211 | 1444.95007 | 120.5856 | 40.92438 | 55.379223 | 55.361156 | 132.150528 | 131.97 |
| 01-Nov-07 11:00:00 | 154.4525757 | 135.077118 | 96.668129 | 44.83747 | 1445.077 | 1445.2207 | 118.5751 | 46.02605 | 56.455734 | 56.477798 | 121.2039948 | 121.47 |
| 01-Nov-07 12:00:00 | 160.0706635 | 140.528381 | 95.5276947 | 45.11472 | 1445.205 | 1445.45251 | 117.978 | 43.28532 | 56.133274 | 56.123085 | 137.6242676 | 137.14 |
| 01-Nov-07 13:00:00 | 154.7674408 | 141.056152 | 94.9272766 | 44.78223 | 1447.301 | 1447.27148 | 117.494 | 45.71428 | 62.72274 | 62.716686 | 117.092186 | 117.09 |
| 01-Nov-07 14:00:00 | 149.5262146 | 138.368408 | 95.6228104 | 45.25834 | 1448.335 | 1448.39026 | 117.366 | 50.50385 | 60.82526 | 60.855968 | 126.1567688 | 126.19 |
| 01-Nov-07 15:00:00 | 139.0497589 | 128.245987 | 96.5189896 | 44.88701 | 1447.583 | 1447.56006 | 118.5973 | 55.50901 | 58.20916 | 58.202587 | 128.084198 | 128.00 |
| 01-Nov-07 16:00:00 | 137.957489 | 128.614029 | 96.4355087 | 44.80751 | 1446.947 | 1446.74292 | 119.6839 | 53.66763 | 45.574692 | 45.562065 | 112.9255905 | 112.90 |
| 01-Nov-07 17:00:00 | 150.9815369 | 133.550659 | 96.0068436 | 44.69436 | 1446.664 | 1446.73035 | 120.9951 | 52.5921 | 50.871231 | 50.878162 | 105.0942154 | 105.03 |
| 01-Nov-07 18:00:00 | 149.4823303 | 134.703735 | 93.4569702 | 44.63808 | 1448.942 | 1448.84937 | 121.1292 | 57.03492 | 58.041737 | 57.999676 | 103.3236694 | 103.85 |
| 01-Nov-07 19:00:00 | 145.0749207 | 136.824188 | 93.4642639 | 45.2717 | 1452.545 | 1452.59009 | 120.1412 | 64.73555 | 55.928028 | 55.927544 | 115.4829102 | 115.8 |
| 01-Nov-07 20:00:00 | 134.9229431 | 131.333099 | 96.0574646 | 44.77113 | 1454.127 | 1453.99829 | 114.6973 | 80.02668 | 28.864773 | 28.826563 | 120.380043 | 120.4 |
| 01-Nov-07 21:00:00 | 137.1988831 | 122.216232 | 98.9949417 | 45.18055 | 1452.302 | 1452.53809 | 114.0672 | 60.98597 | 64.204216 | 64.208206 | 126.4035568 | 126.28 |
| 01-Nov-07 22:00:00 | 142.6994934 | 129.275299 | 97.8942947 | 45.09514 | 1452.671 | 1452.65015 | 126.6496 | 33.28025 | 70.00621 | 69.999321 | 116.4609604 | 116. |
| 01-Nov-07 23:00:00 | 108.0300369 | 100.626503 | 96.8702316 | 45.2365 | 1453.753 | 1453.55994 | 125.6904 | 62.11195 | 57.614151 | 57.60062 | 110.0555725 | 110. |
| 02-Nov-07 00:00:00 | 149.0470581 | 138.450668 | 94.7595291 | 45.11971 | 1454.881 | 1454.84241 | 118.1186 | 59.50872 | 43.342602 | 43.344265 | 110.8259354 | 110.91 |

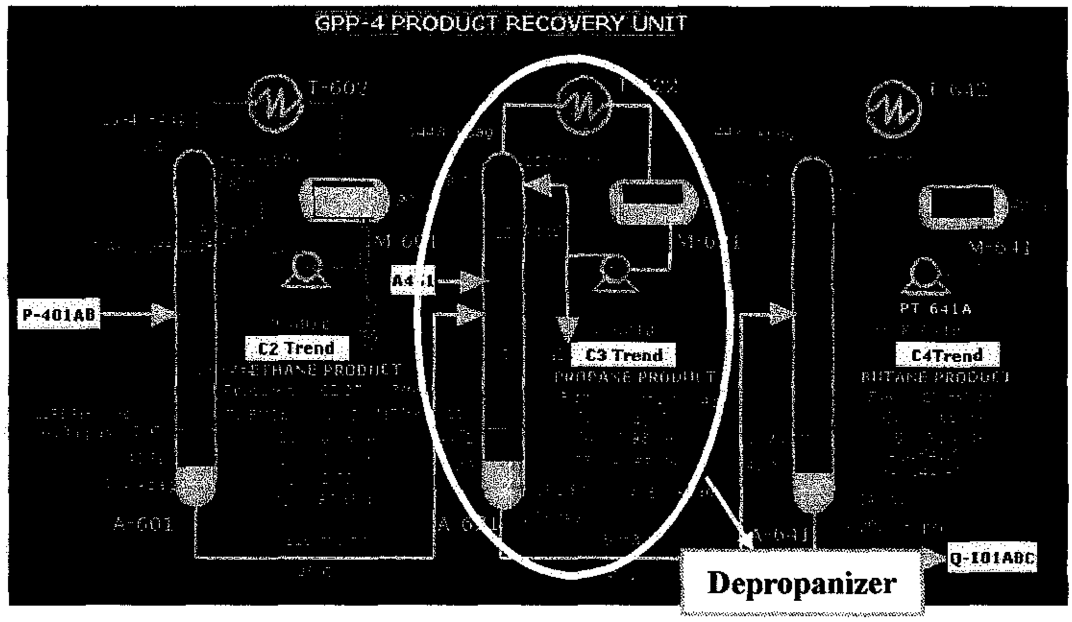
## Sample of Calculated Data Surrounding the Depropanizer Column

| | % Mole Propane - Methane SP-46601C1 | % Mole Propane - Ethane SP-46601C2 | % Mole Propane - Propane SP-46601C3 | % Mole Propane - Methane SP-46601CC | % Mole Propane - Ethane SP-46601CC | % Mole Propane - Propane SP-46601CC | Kg/L Propane - Density @ 15 C SP-46601CD | % Mole Propane - Neo-Pentane SP-46601CE | % Mole Propane - i-Butane SP-46601CIC | % Mole Propane - i-Pentane SP-46601CIC | % Mole Propane - n-Butane SP-46601CIN | % Mole Propane - n-Pentane SP-46601CIN | Kg/L Propane - Density @ 15 C SP-46601DS |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 01-Jan-06 06:00:00 | 0 | 0.23 | 98.38 | 0.03 | 0.82 | 98.23 | 0.505 | 0 | 0.86 | 0 | 0.06 | 0 | 0.509 |
| 01-Jan-06 07:00:00 | 0 | 0.23 | 98.38 | 0.03 | 0.82 | 98.23 | 0.505 | 0 | 0.86 | 0 | 0.06 | 0 | 0.509 |
| 01-Jan-06 08:00:00 | 0.02 | 1.51 | 96.05 | 0.02 | 0.87 | 98.26 | 0.507 | 0 | 0.75 | 0 | 0.1 | 0 | 0.507 |
| 01-Jan-06 09:00:00 | 0.02 | 1.51 | 96.05 | 0.02 | 0.87 | 98.26 | 0.507 | 0 | 0.75 | 0 | 0.1 | 0 | 0.507 |
| 01-Jan-06 10:00:00 | 0.02 | 1.51 | 96.05 | 0.02 | 0.87 | 98.26 | 0.507 | 0 | 0.75 | 0 | 0.1 | 0 | 0.507 |
| 01-Jan-06 11:00:00 | 0.02 | 1.51 | 96.05 | 0.02 | 0.87 | 98.26 | 0.507 | 0 | 0.75 | 0 | 0.1 | 0 | 0.507 |
| 01-Jan-06 12:00:00 | 0.02 | 1.51 | 96.05 | 0.02 | 0.87 | 98.26 | 0.507 | 0 | 0.75 | 0 | 0.1 | 0 | 0.507 |
| 01-Jan-06 13:00:00 | 0.02 | 1.51 | 96.05 | 0.02 | 0.87 | 98.26 | 0.507 | 0 | 0.75 | 0 | 0.1 | 0 | 0.507 |
| 01-Jan-06 14:00:00 | 0.02 | 1.51 | 96.05 | 0.02 | 0.87 | 98.26 | 0.507 | 0 | 0.75 | 0 | 0.1 | 0 | 0.507 |
| 01-Jan-06 15:00:00 | 0.02 | 1.51 | 96.05 | 0.02 | 0.87 | 98.26 | 0.507 | 0 | 0.75 | 0 | 0.1 | 0 | 0.507 |
| 01-Jan-06 16:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 01-Jan-06 17:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 01-Jan-06 18:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 01-Jan-06 19:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 01-Jan-06 20:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 01-Jan-06 21:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 01-Jan-06 22:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 01-Jan-06 23:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 02-Jan-06 00:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 02-Jan-06 01:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 02-Jan-06 02:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 02-Jan-06 03:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 02-Jan-06 04:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 02-Jan-06 05:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 02-Jan-06 06:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |
| 02-Jan-06 07:00:00 | 0.01 | 0.2 | 98.61 | 0.06 | 0.08 | 98.91 | 0.507 | 0 | 0.9 | 0 | 0.04 | 0 | 0.507 |

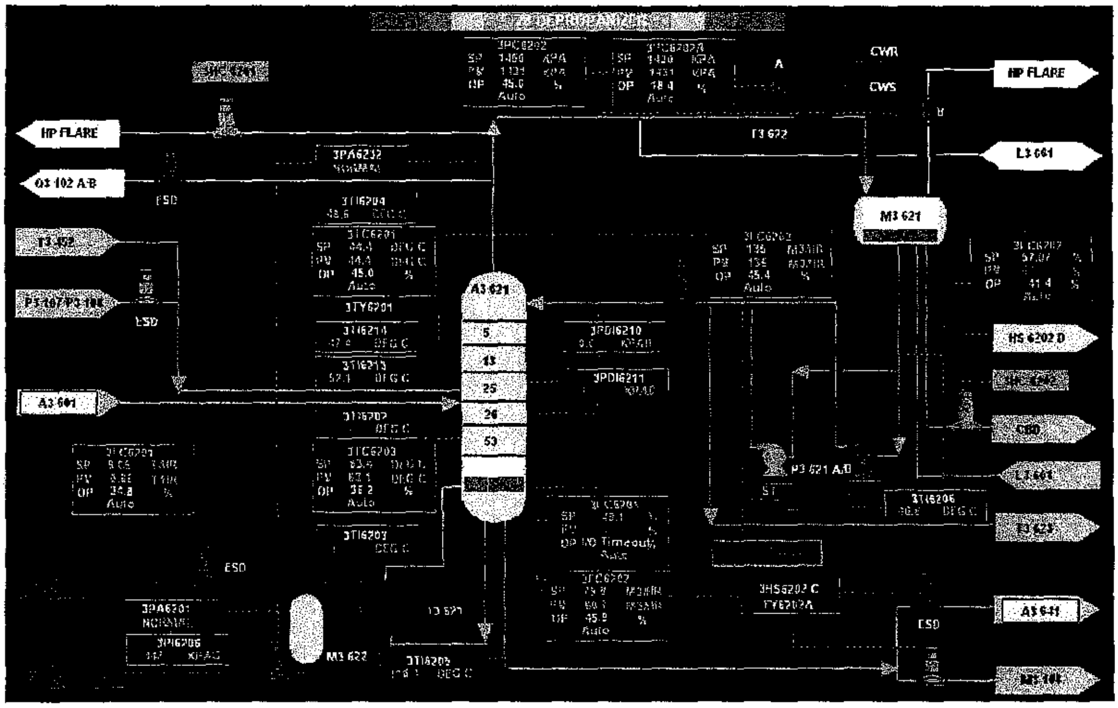
## Sample of Data on Composition of Overhead Product at the Depropanizer Column

**Tag Name and the Descriptions Surrounding the Depropanizer Column**

| Tag Name | Description | Unit |
|---|---|---|
| 4FY62022.PV | TOTAL DEPROPANIZER FEED | M3/H |
| 4FC6002.PV | A601 BTM TO A621 | M3/H |
| 4FI6202.PV | A 621 TO A 641 | M3/H |
| 4FC6203.SP | DEPROPANIZER REFLUX | M3/HR |
| 4FC6203.PV | DEPROPANIZER REFLUX | M3/H |
| 4TI6009.PV | A601 BTM | DEGC |
| 4TI6204.PV | A621 OVHD | DEGC |
| 4TI6205.PV | A 621 BOTTOM | DEG C |
| 4TC6231.SP | T621 TO A621 | DEG C |
| 4TC6231.PV | T621 TO A621 | DEGC |
| 4TI6231.PV | T621 TO A621 | DEGC |
| 4TI6214.PV | A621 TRAY 5 | DEGC |
| 4TI6213.PV | A621 TRAY 13 | DEGC |
| 4TI6202.PV | A621 TRAY 39 | DEGC |
| 4TI6203.PV | A621 TRAY 44 | DEGC |
| 4PC6202.SP | A621 OVERHEAD | KPAG |
| 4PC6202.PV | A621 OVHD | KPAG |
| 4LC6201.PV | A621 | PCT |
| 4LT6201.PV | A622 | PCT |



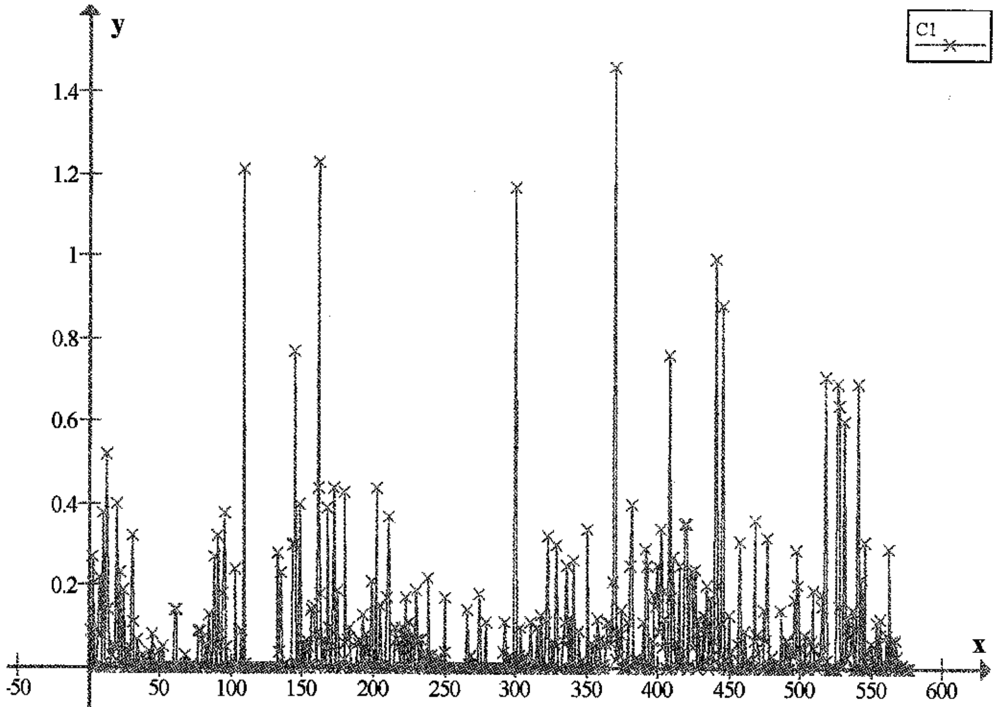

**Flow Sheet for the Product Recovery Unit**



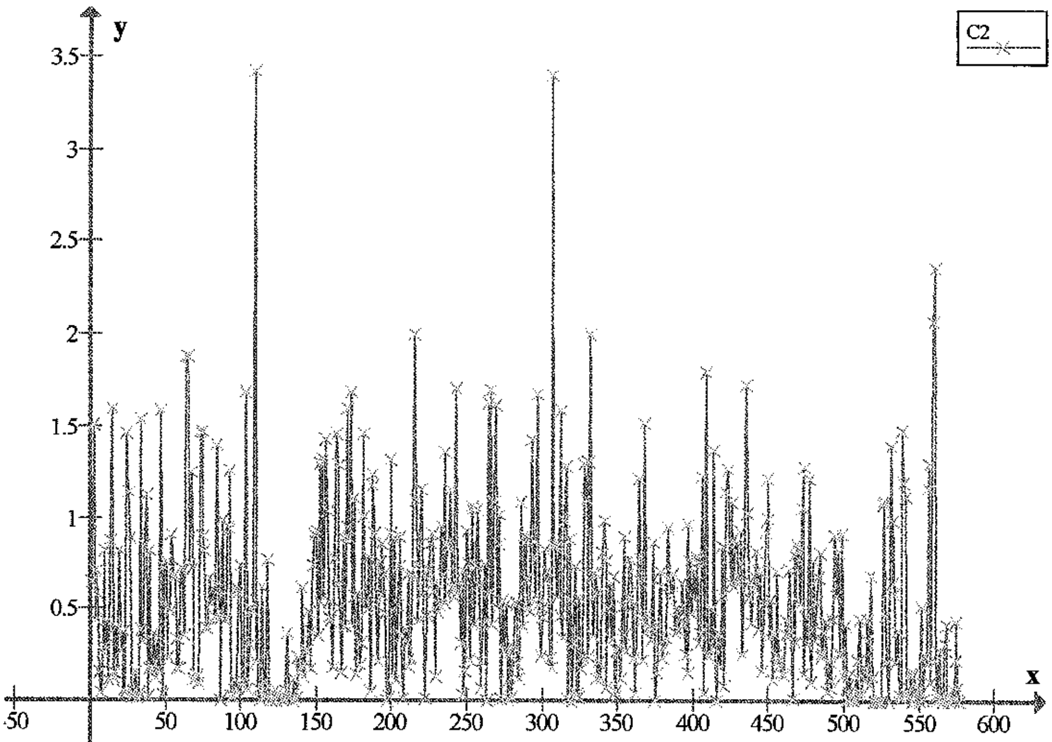

**Flow Sheet for the Depropanizer Column**

## APPENDIX C – Graphs for each Variables/Tag Number

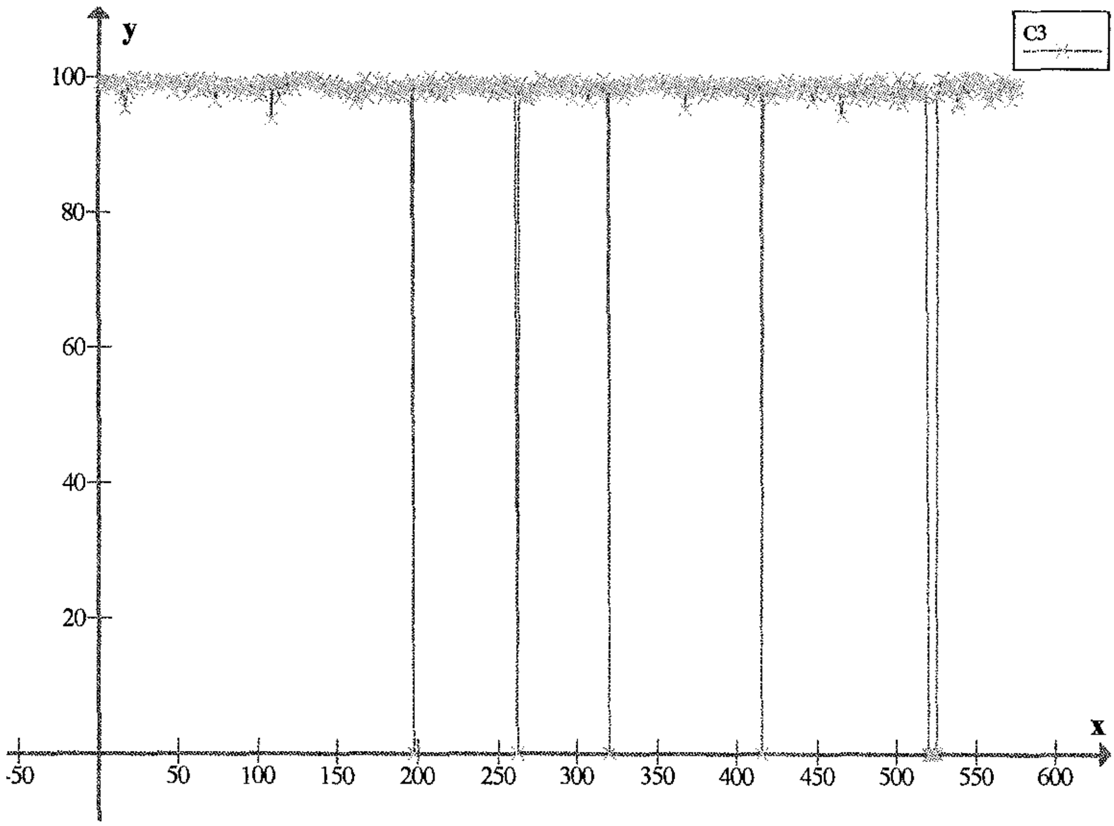
### Appendix C.1 : Composition



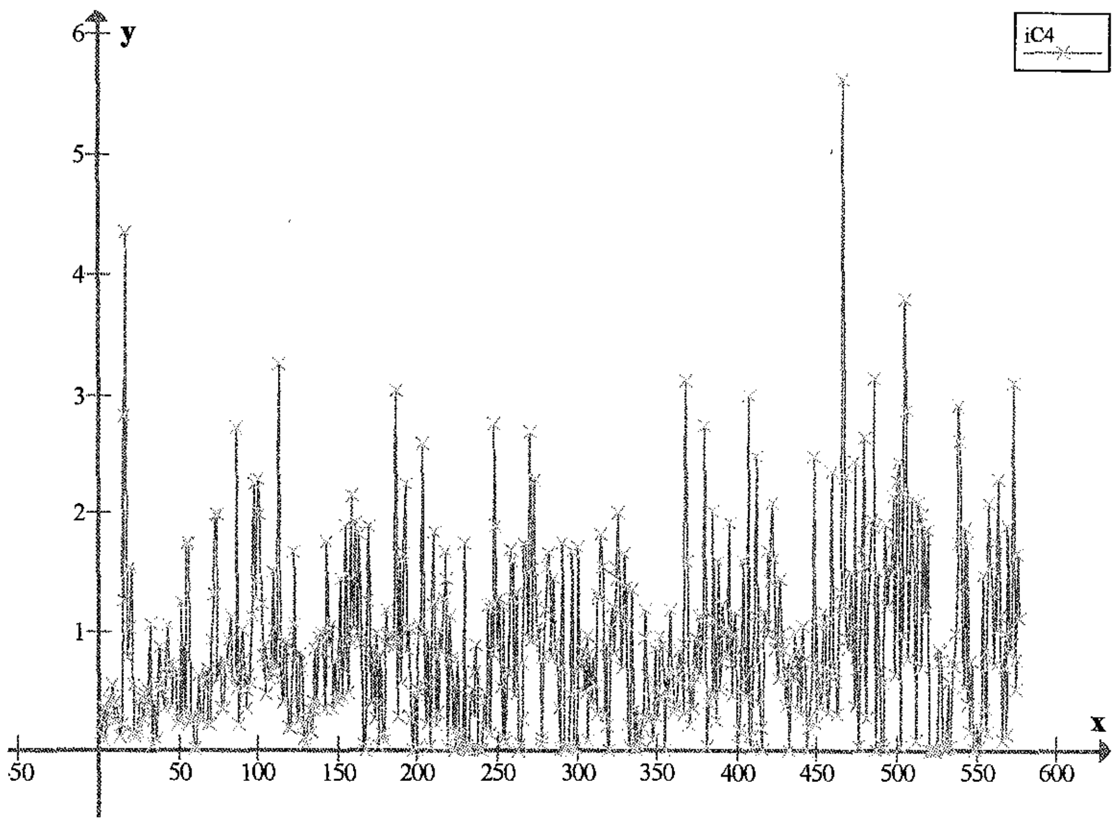

**Graph of $C_1$ Composition at the Overhead Product of Depropanizer**



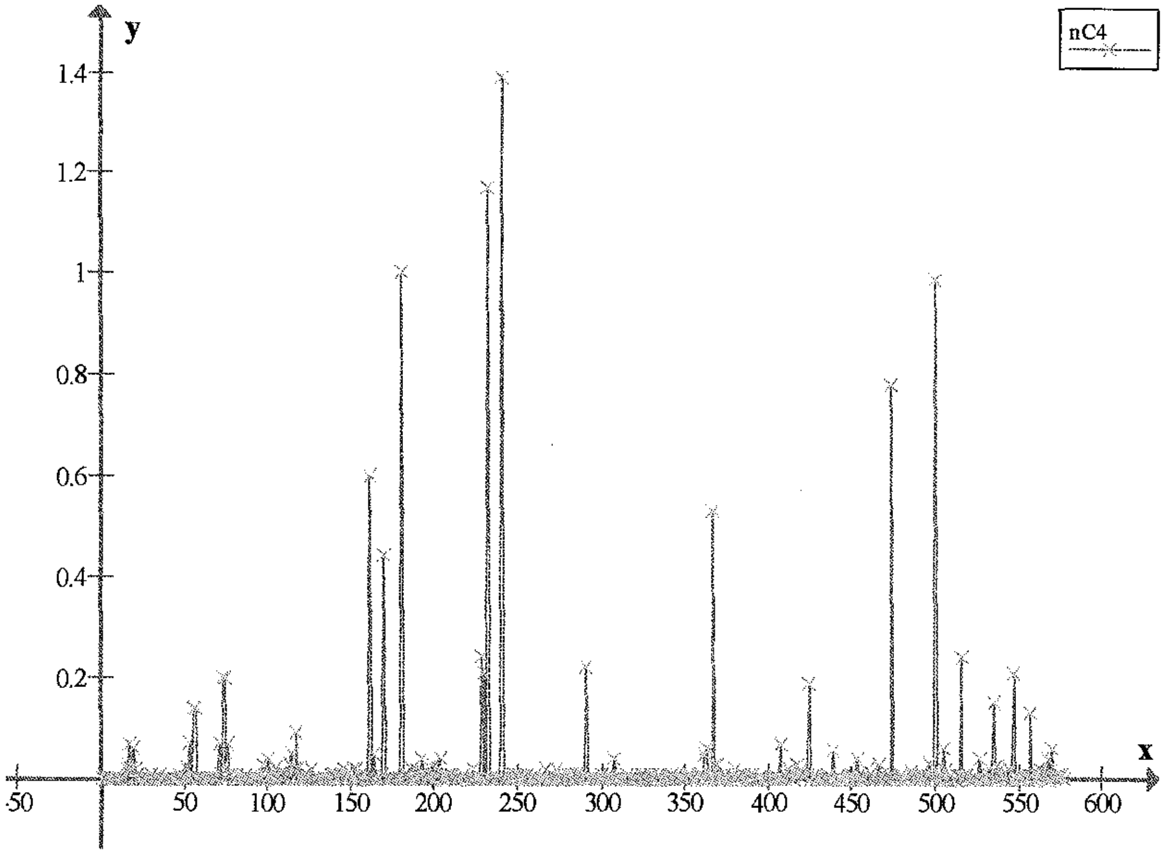

**Graph of $C_2$ Composition at the Overhead Product of Depropanizer**




**Graph of $C_3$ Composition at the Overhead Product of Depropanizer**

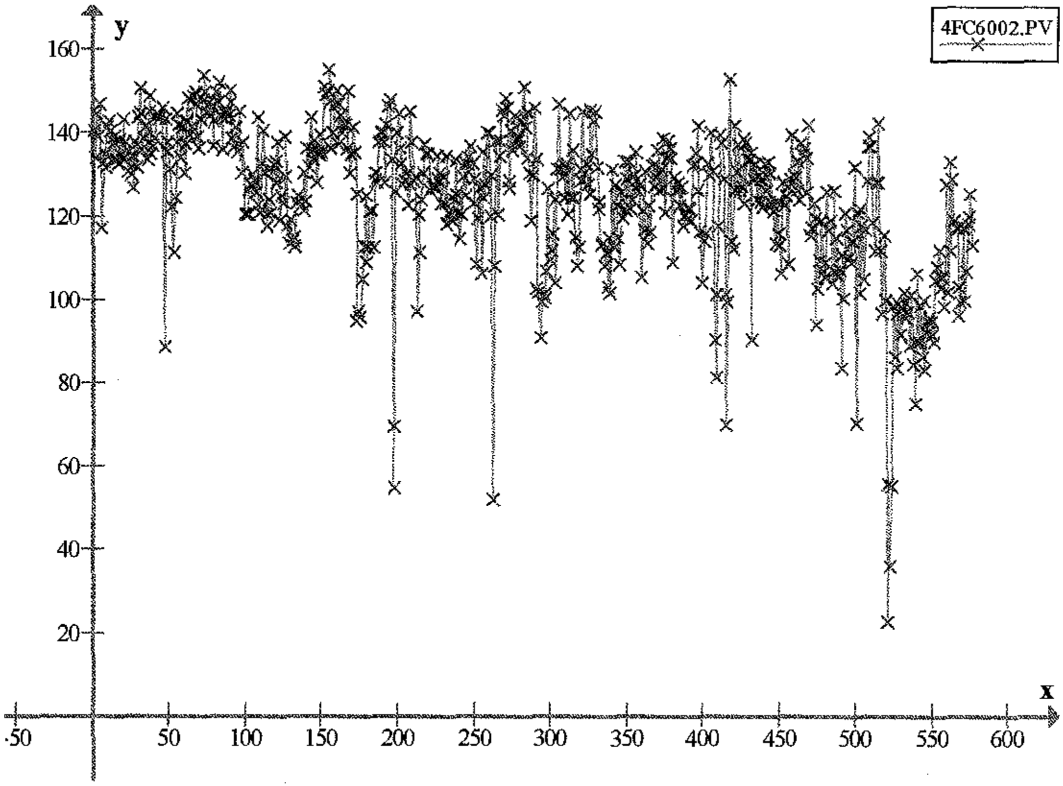



**Graph of $iC_4$ Composition at the Overhead Product of Depropanizer**

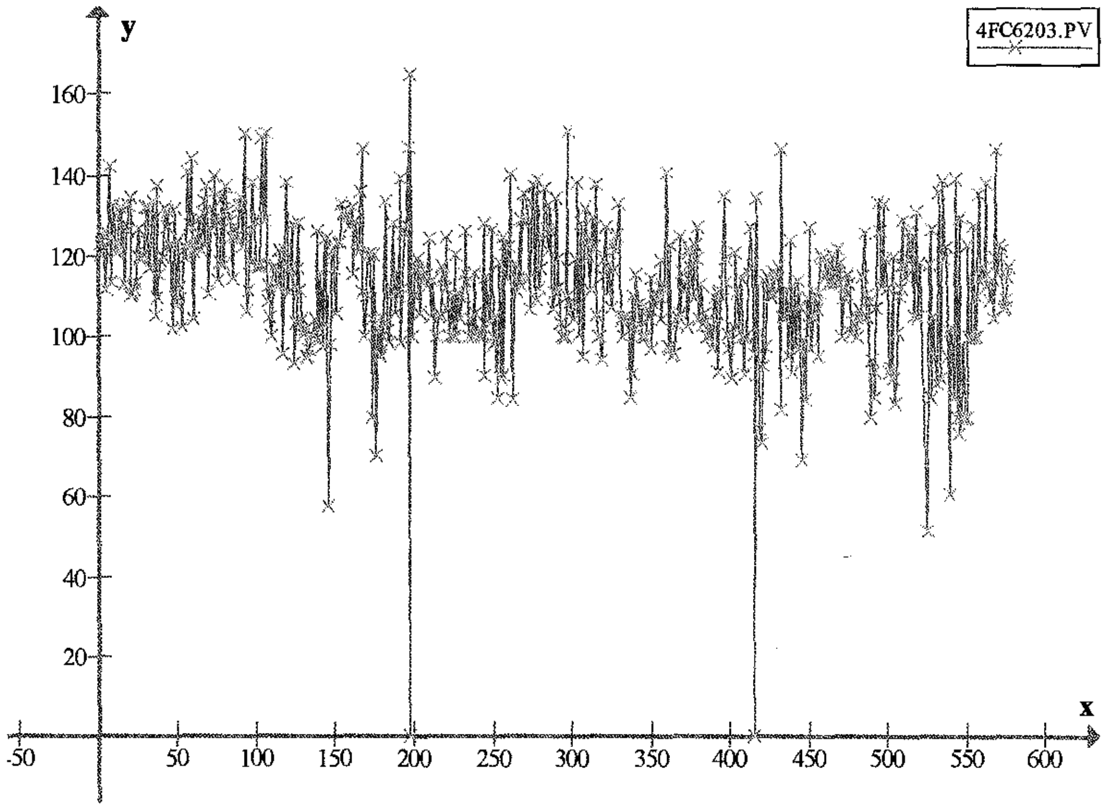



**Graph of $nC_4$ Composition at the Overhead Product of Depropanizer**

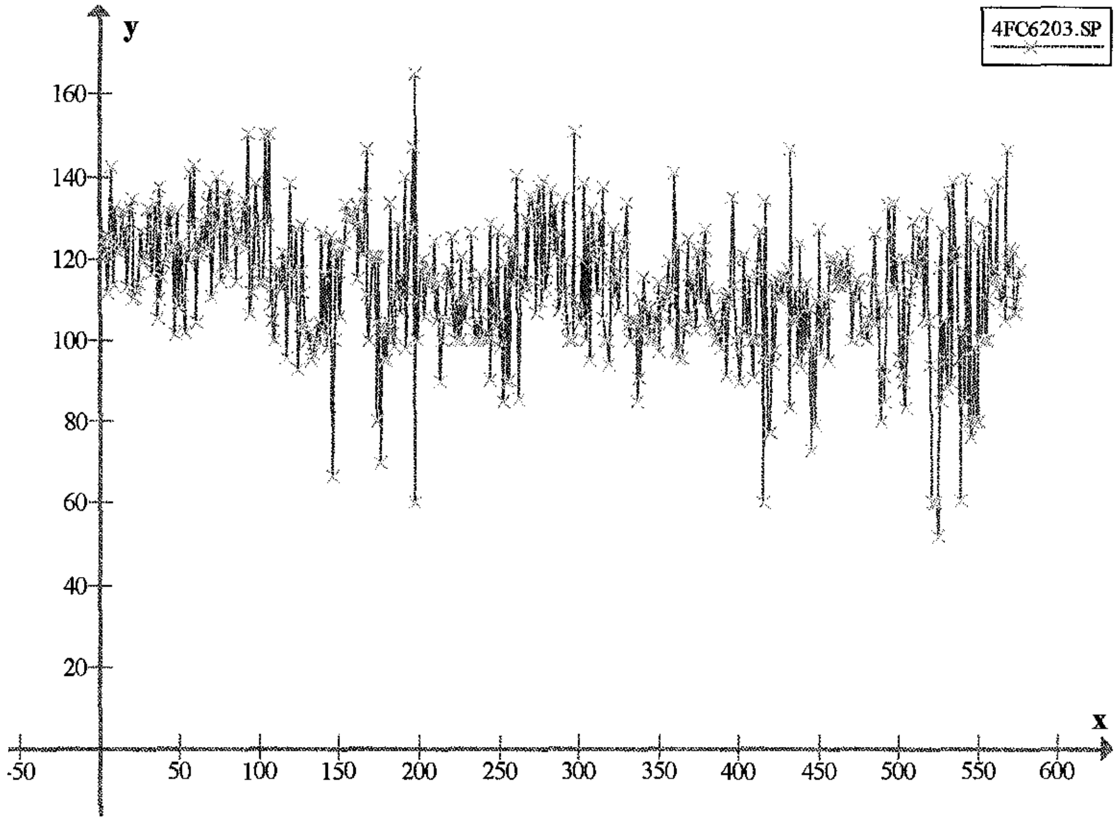
## Appendix C.2 : Flow Variables



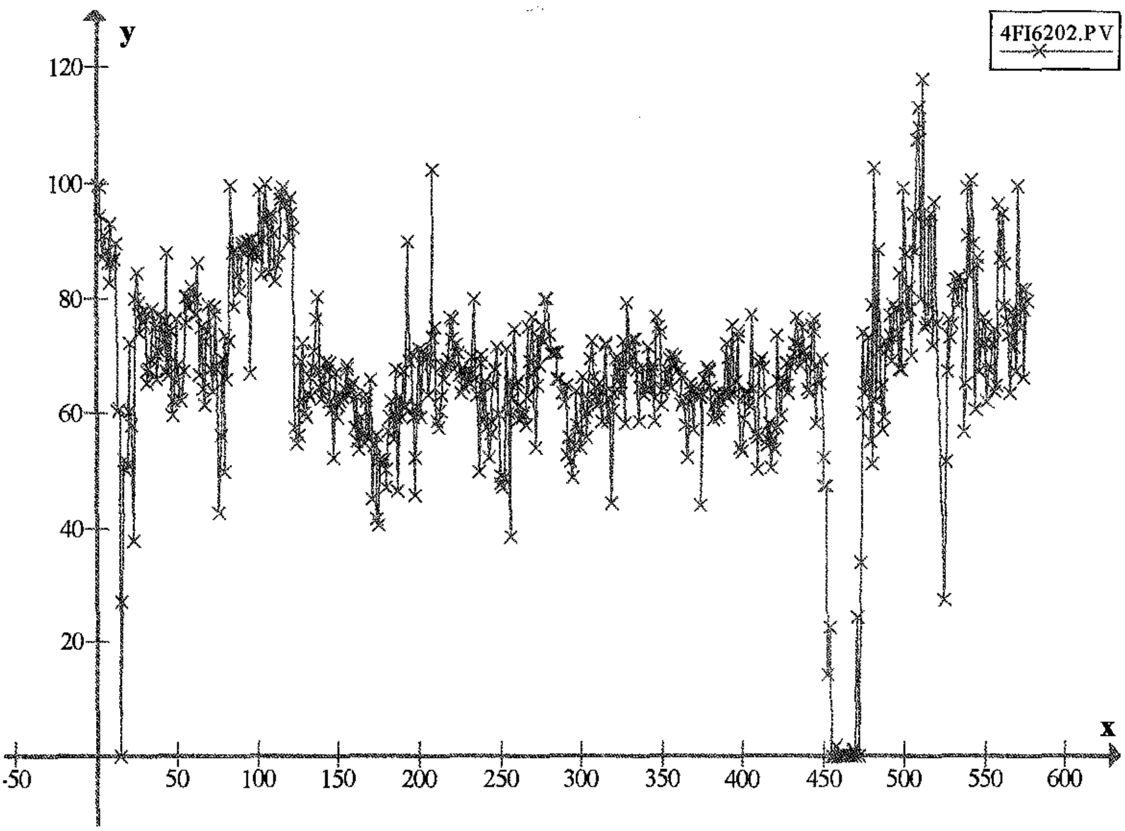

**Graph of Data from Tag 4FC6002.PV**



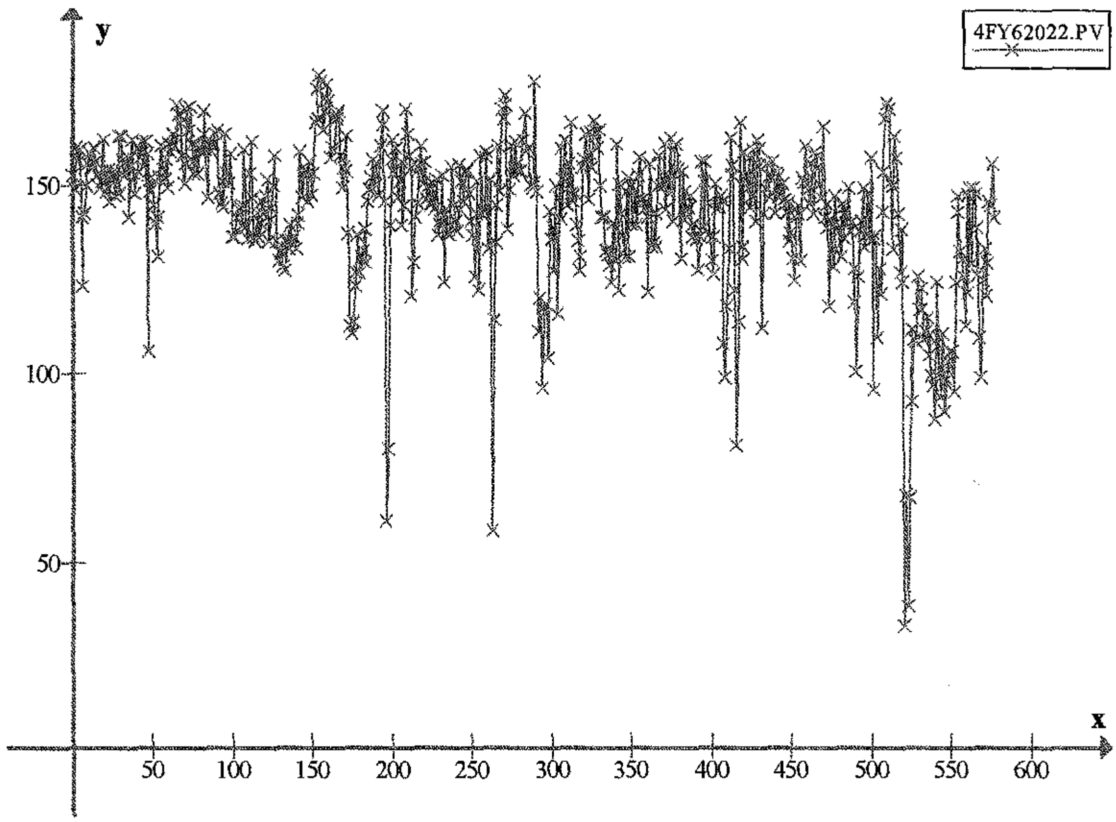

**Graph of Data from Tag 4FC6203.PV**




**Graph of Data from Tag 4FC6203.SP**

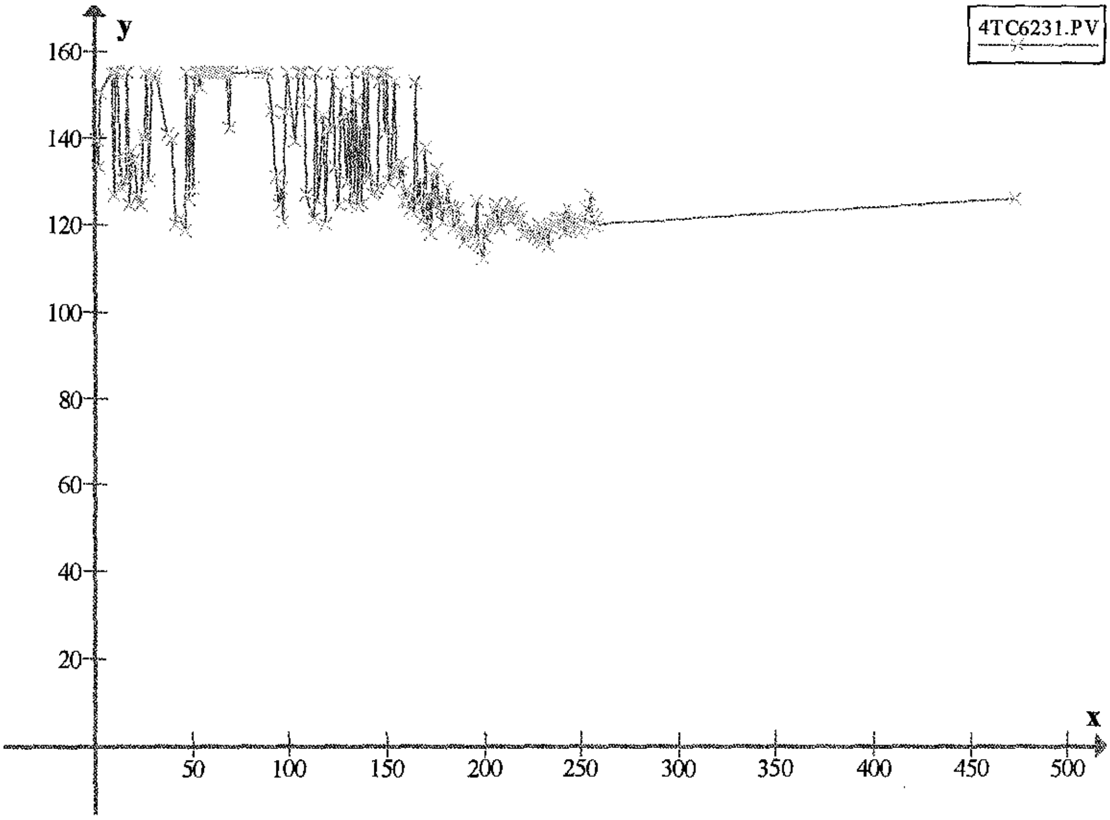



**Graph of Data from Tag 4FI6202.PV**

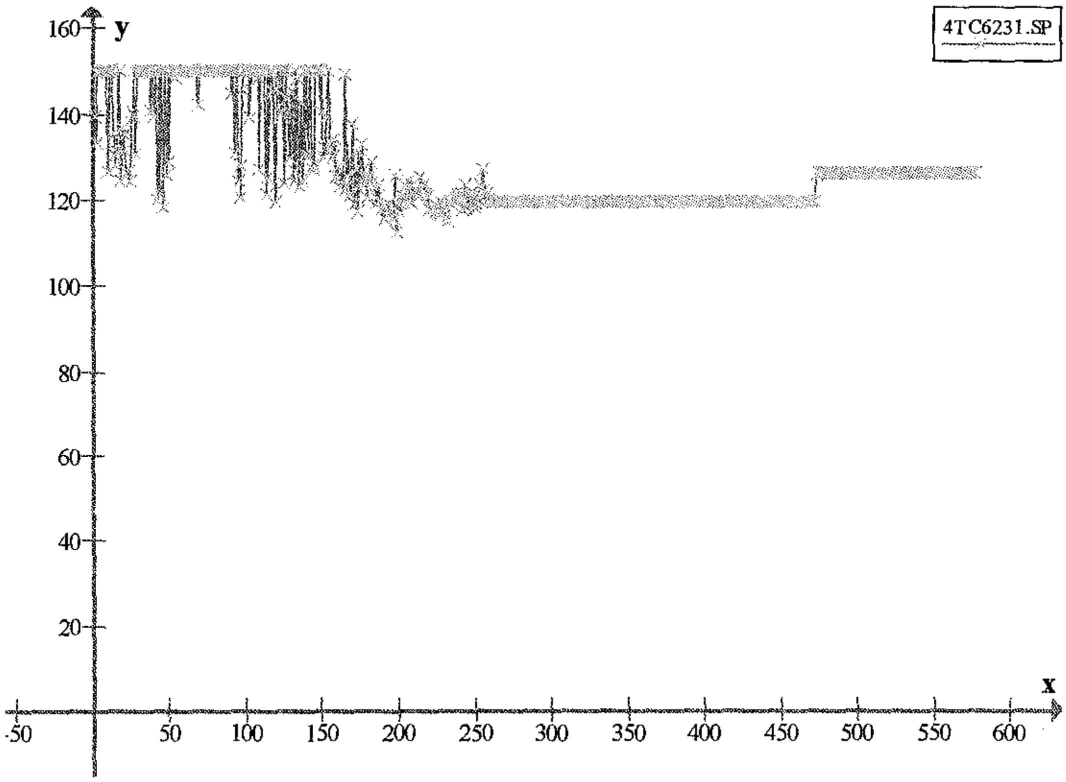



**Graph of Data from Tag 4FY62022.PV**

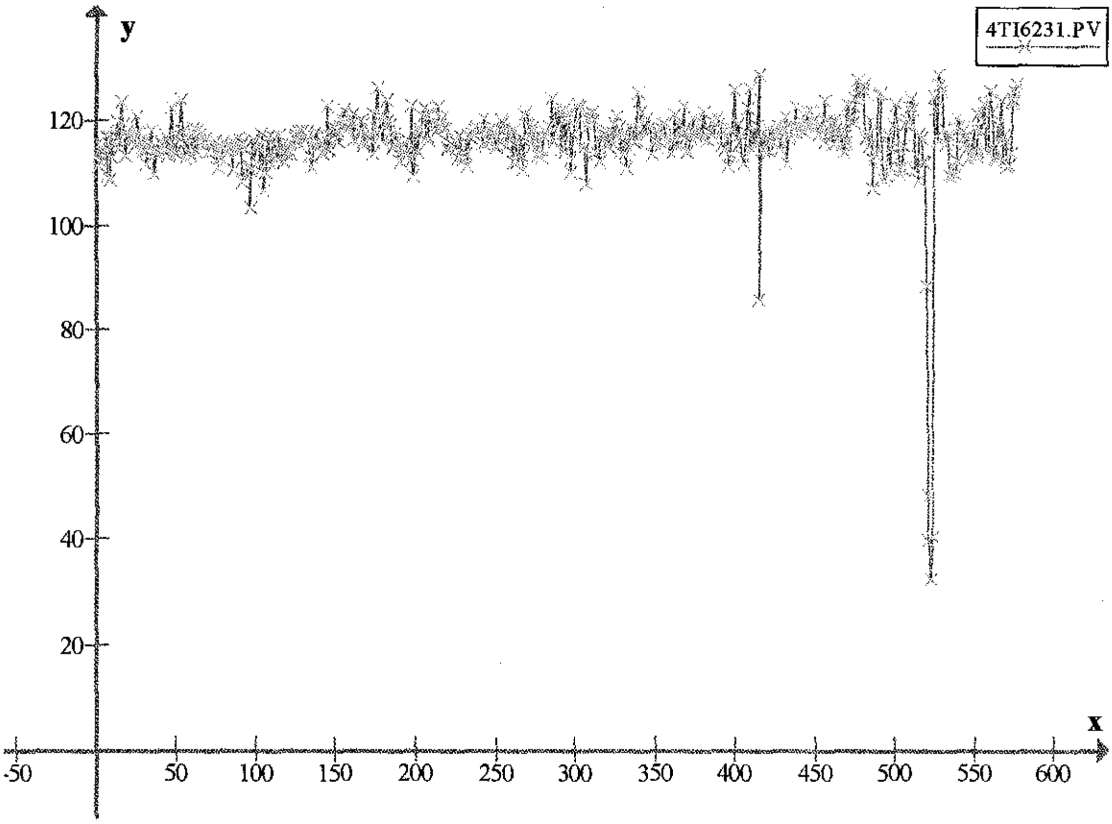
## Appendix C.3 : Temperature Variables



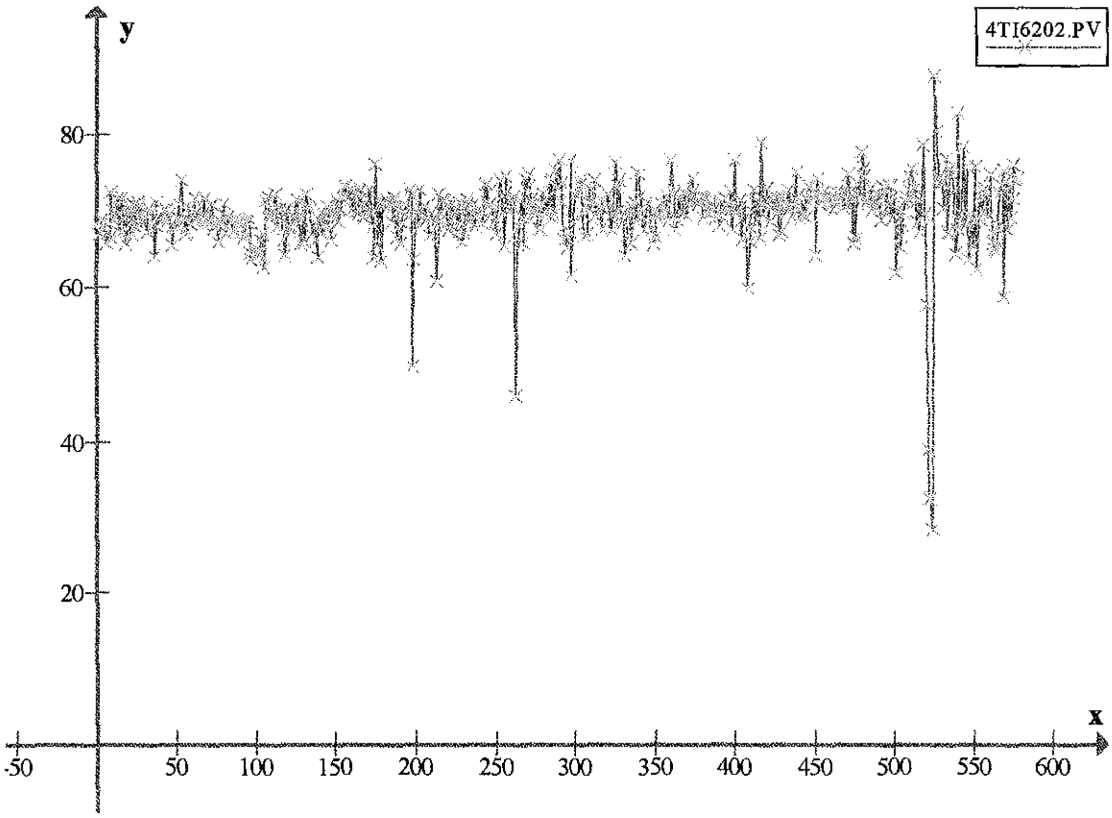

**Graph of Data from Tag 4TC6231.PV**



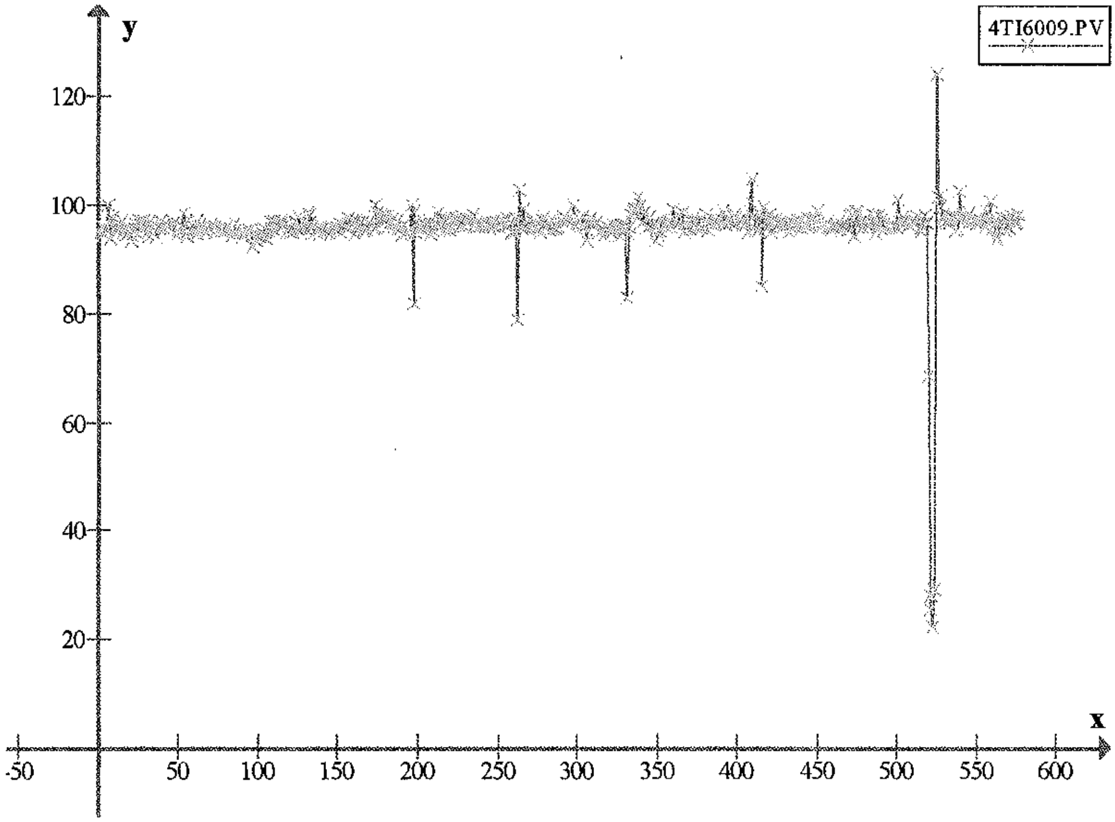

**Graph of Data from Tag 4TC6231.SP**



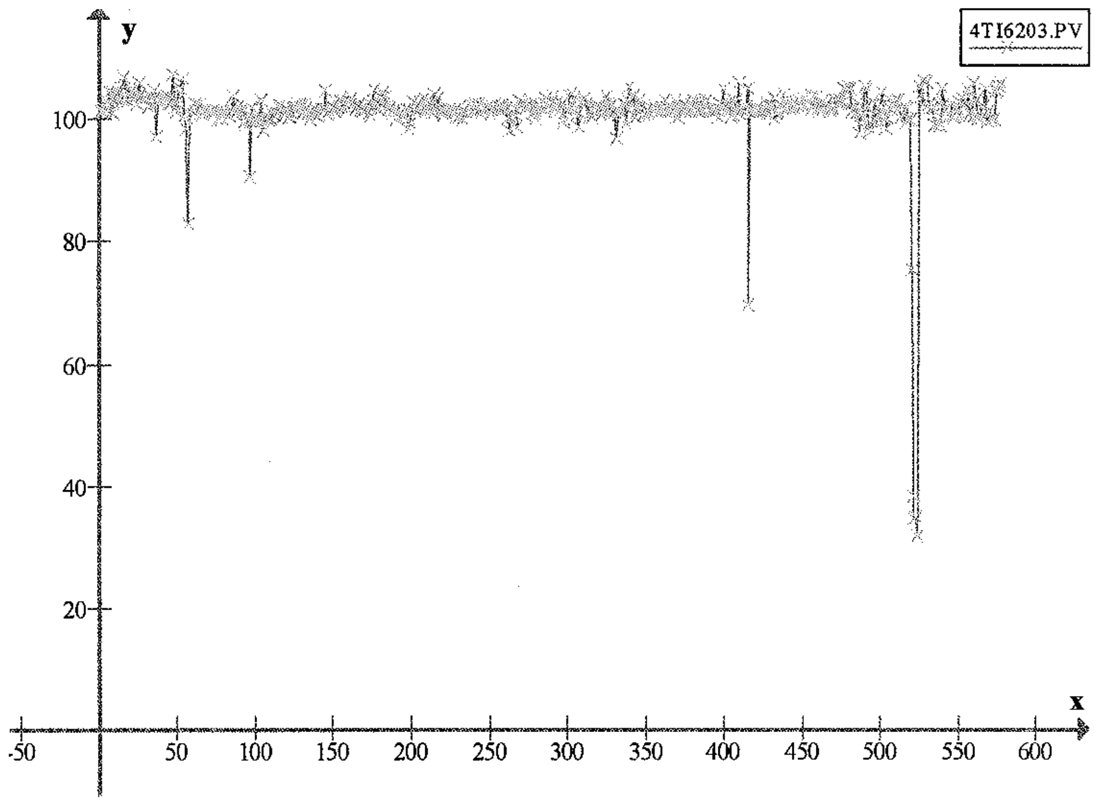

**Graph of Data from Tag 4TI6231.PV**



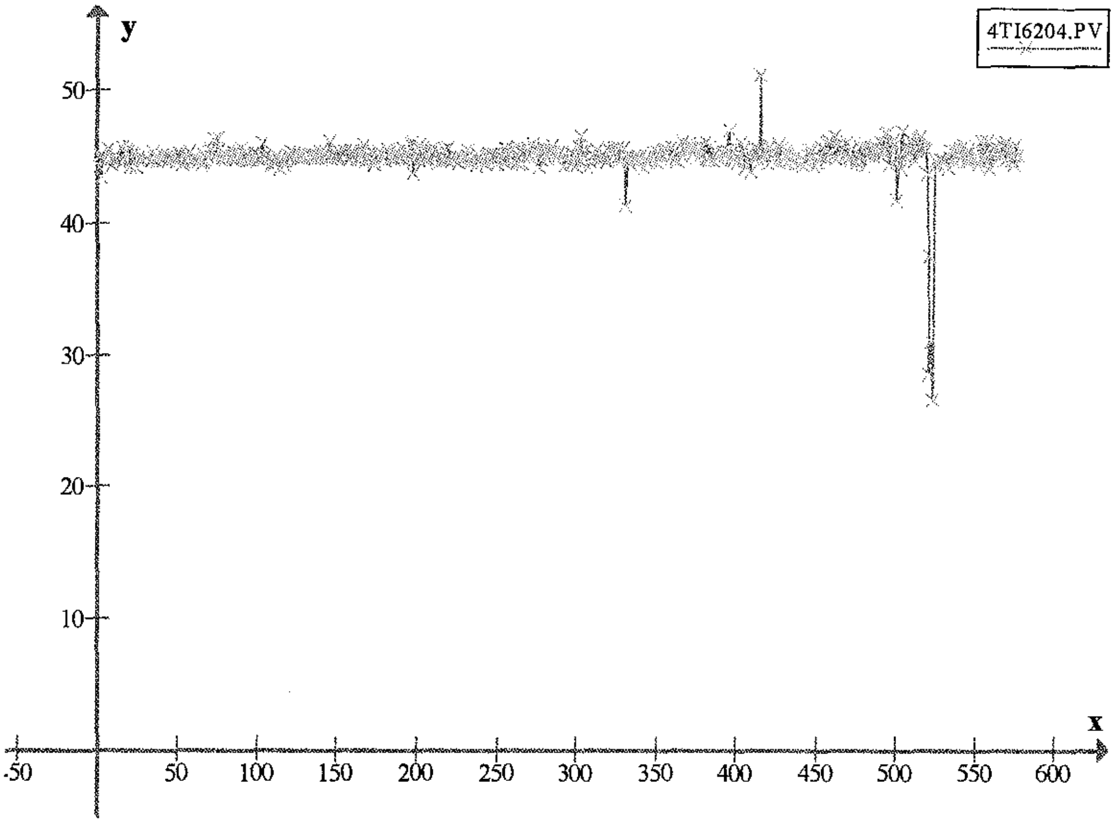

**Graph of Data from Tag 4TI6202.PV**



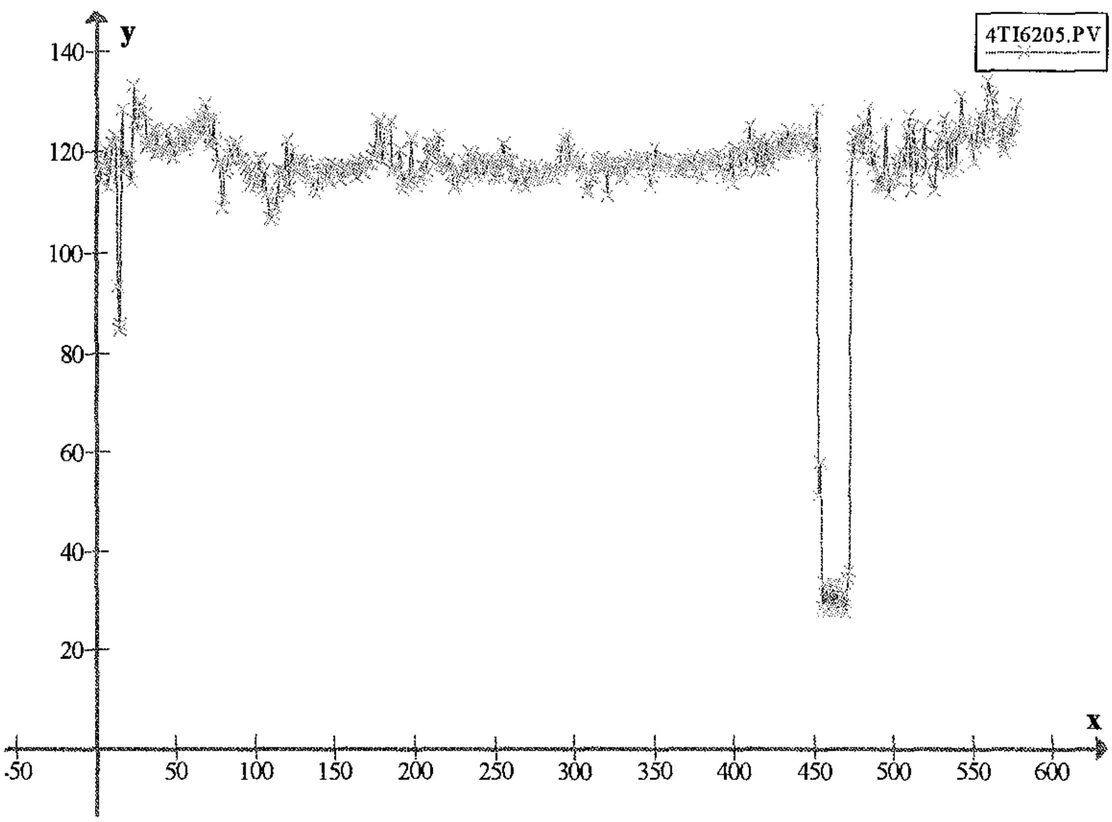

**Graph of Data from Tag 4TI6009.PV**



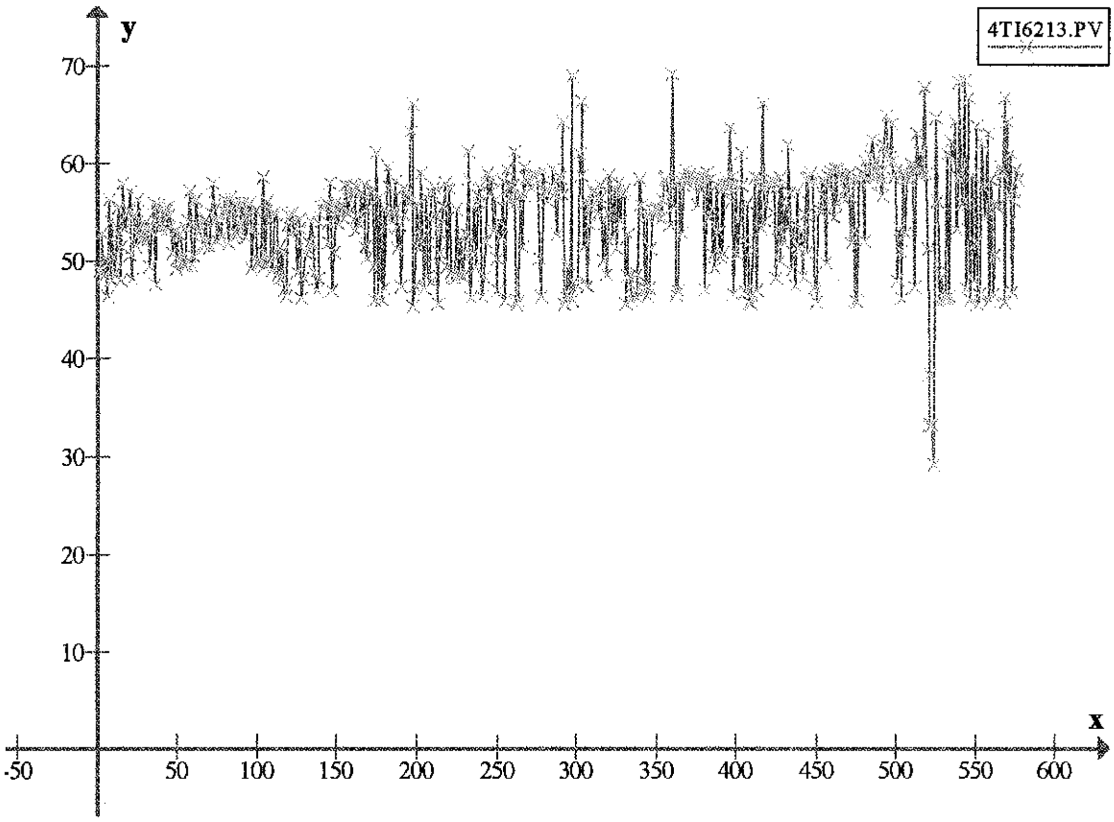

**Graph of Data from Tag 4TI6203.PV**



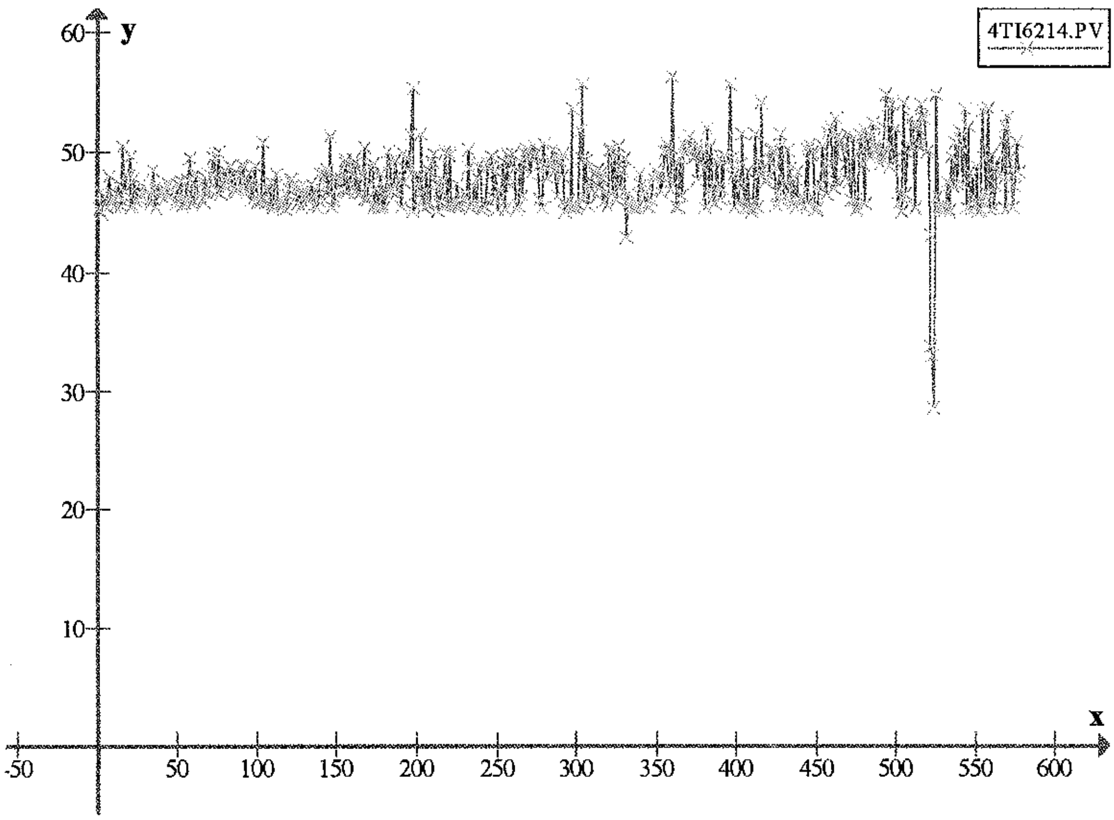

**Graph of Data from Tag 4TI6204.PV**




**Graph of Data from Tag 4TI6205.PV**

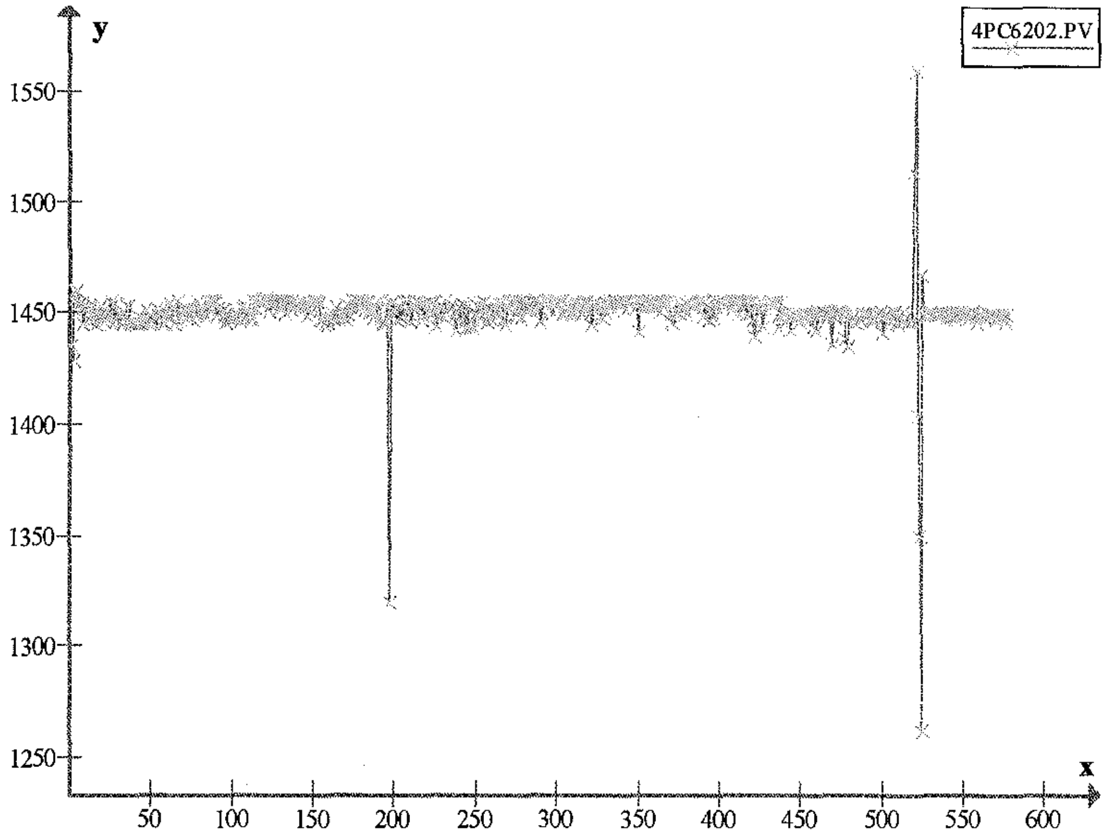



**Graph of Data from Tag 4TI6213.PV**

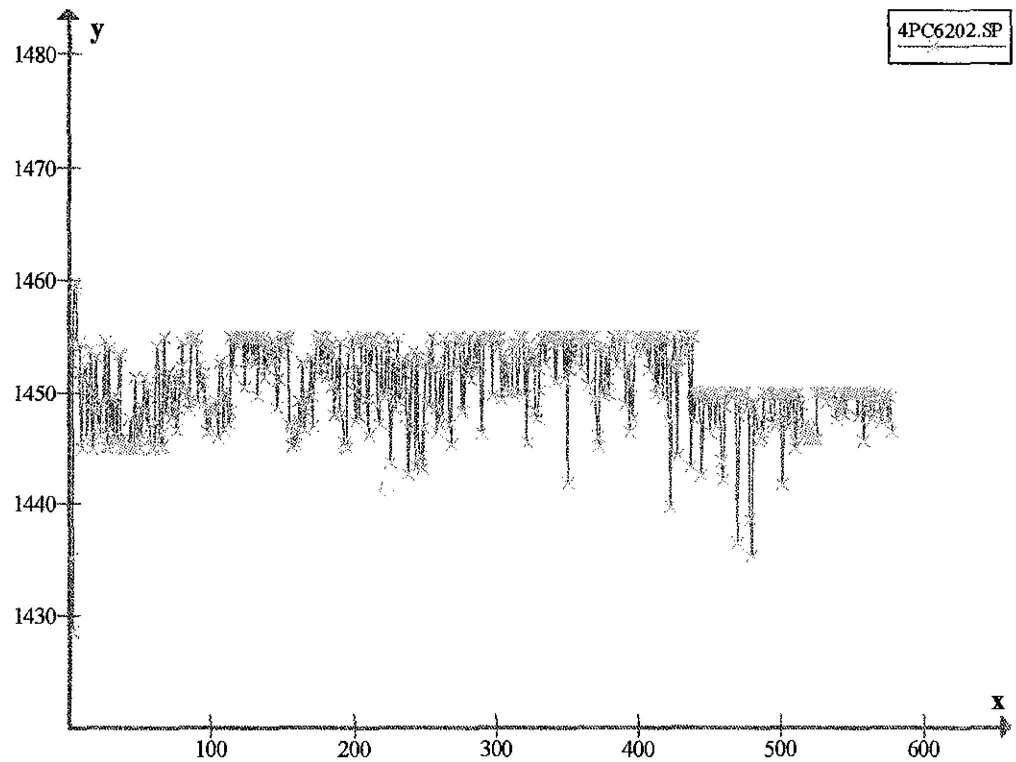



**Graph of Data from Tag 4TI6214.PV**

**Appendix C.4 : Pressure Variables**

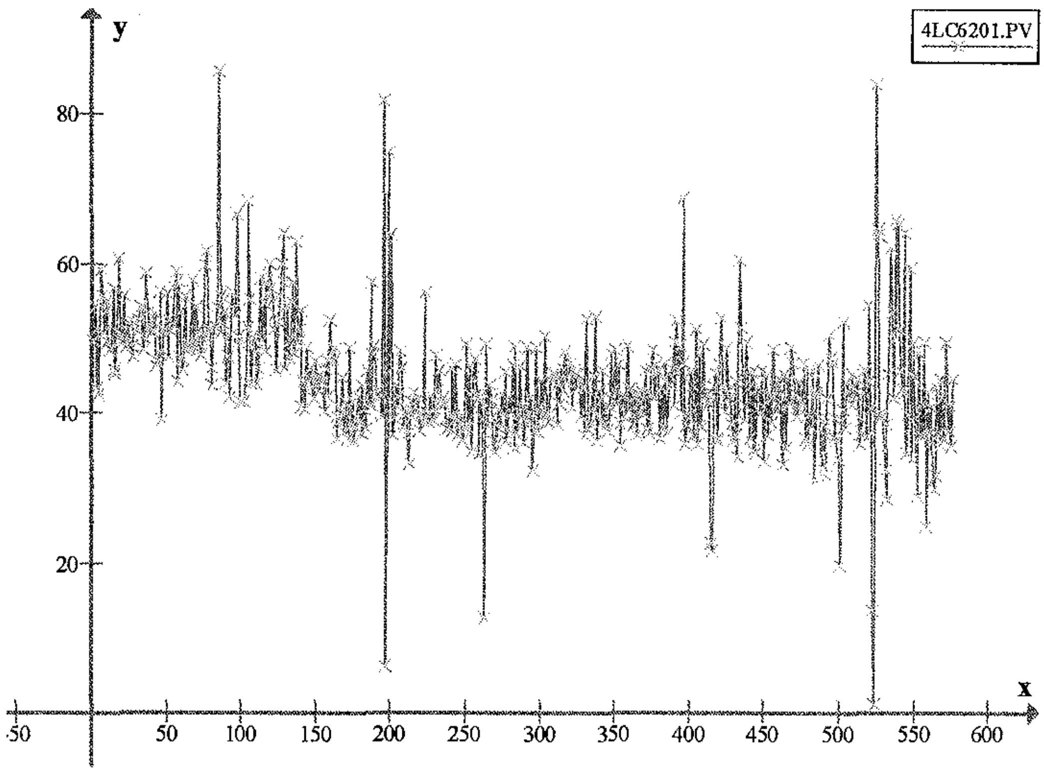



**Graph of Data from Tag 4PC6202.PV**

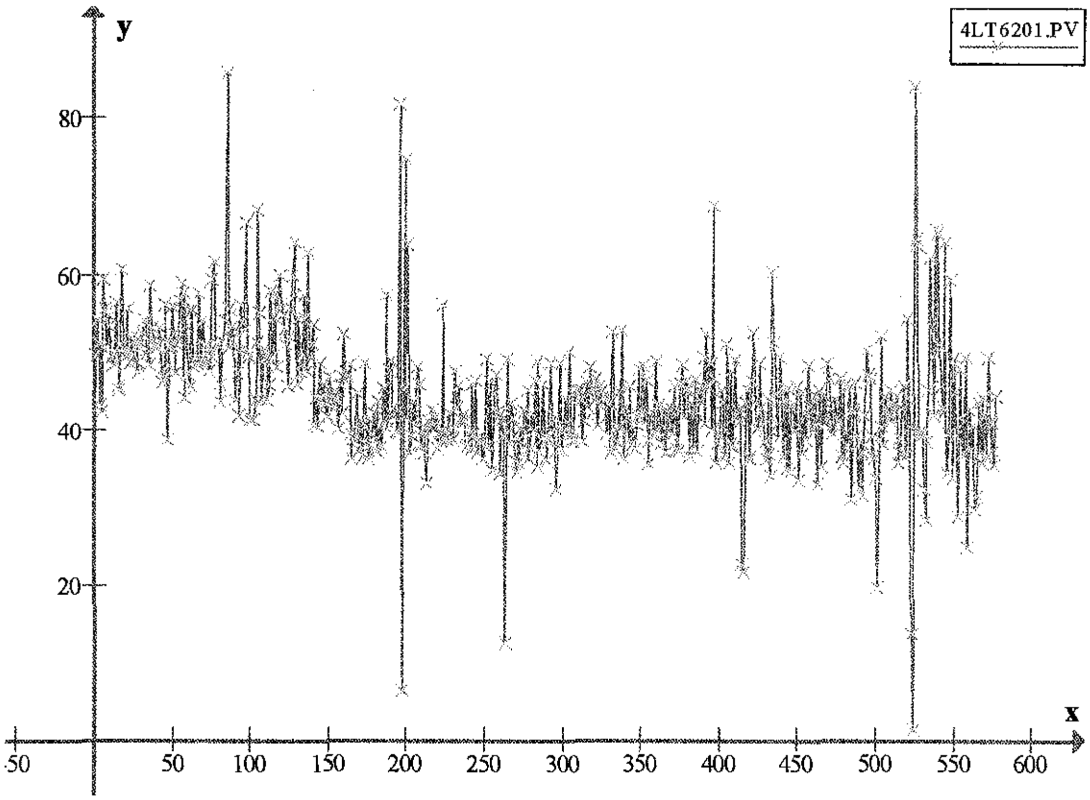



**Graph of Data from Tag 4PC6202.SP**

**Appendix C.5 : Level Variables**




**Graph of Data from Tag 4LC6201.PV**




**Graph of Data from Tag 4LT6201.PV**

**APPENDIX D – Letter Requesting Permission to Visit PGB, Kerteh**

To:

Mrs. Normala Bt Suliman,

Plant Operation Department,

Petronas Gas Bhd,

24300 Kerteh, Kemaman,

Terengganu.

Through:

Mr. Nasser Bin M Ramli

Department of Chemical Engineering ,

University Technology PETRONAS,

Bandar Seri Iskandar,

31750 Tronoh

PERAK

Dear Madam,

**Request for Depropanizer Column Data for UTP, FYP.**

In regard to the subject above, I am writing this letter to request for permission to come to PGB on the 27th and 28th of August 2008 to obtain data on Depropanizer column for my final year project, "Statistical Process Control for Depropanizer Column at PGB, Kerteh".

2. The following are my request:

a. Calculated data surrounding the depropanizer column which include all the tag name

b. Tag name and description

c. Description of the depropanizer column

d. Flow sheet for the column showing all the tag name surrounding the column.

I would like to request for the data from month of January 2006 until July 2008.

Your cooperation in this matter is highly appreciated. Thank you for your commitment and support.

Thank you,

Yours truly,

...............................

Siti Fariza Bt Ahmad
Chemical Engineering Student,
University Technology PETRONAS.

Verified By:

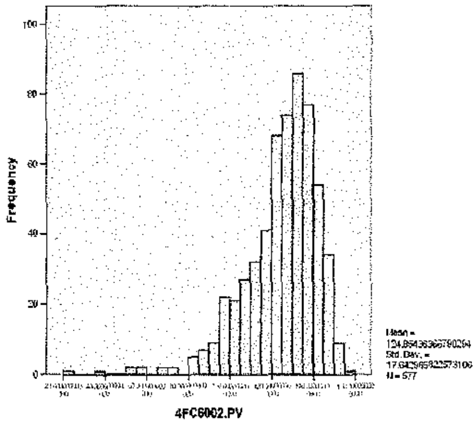
.................................

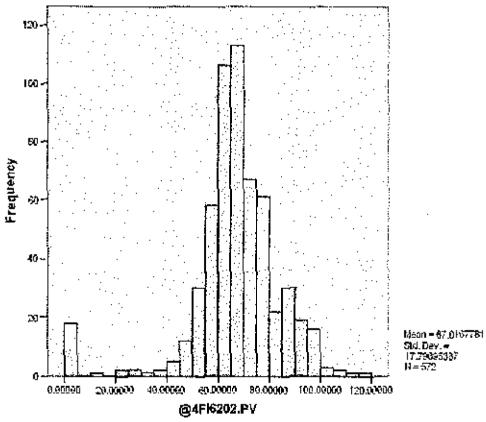
Mr. Nasser Bin M Ramli
Department Of Chemical Engineering,
University Technology PETRONAS

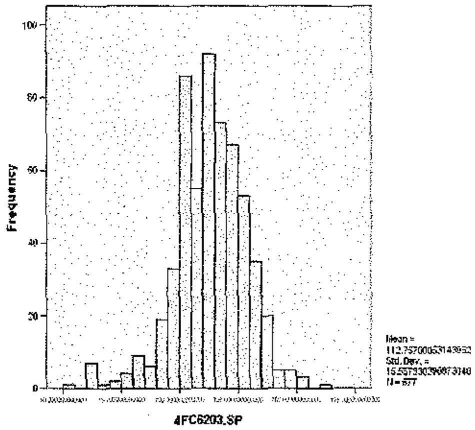
# APPENDIX E

## Appendix E.1 : Histograms

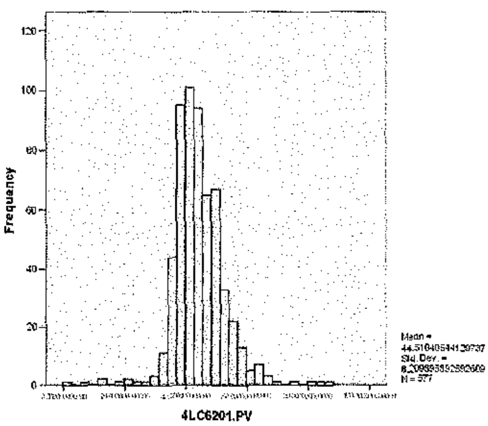
### Flow Variables

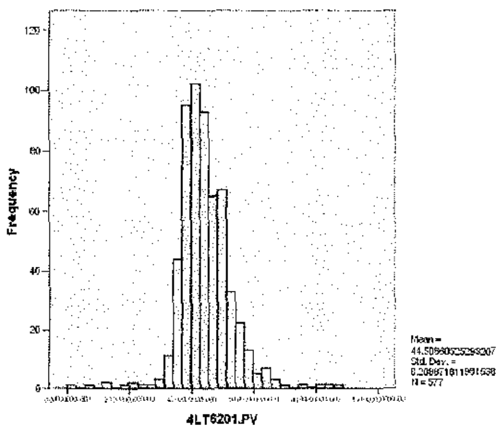


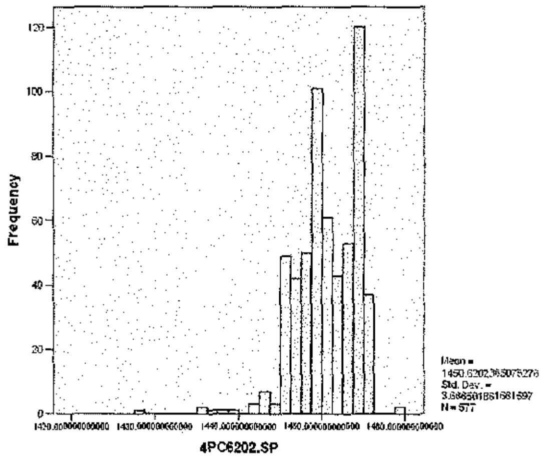



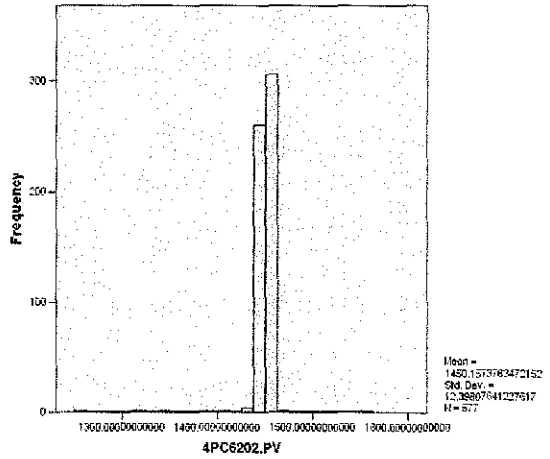

### Level Variables

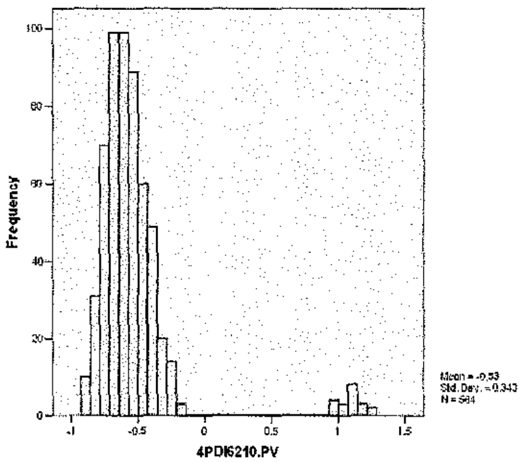


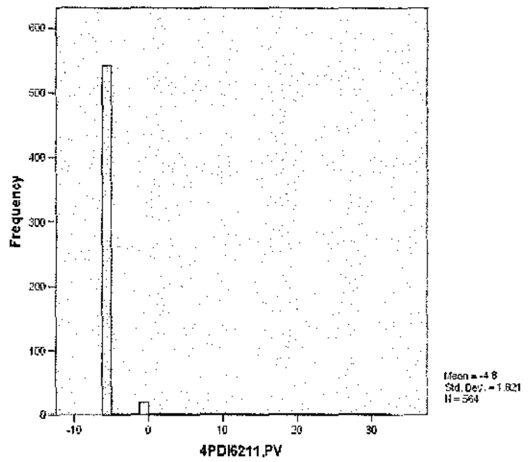



# Pressure Variables

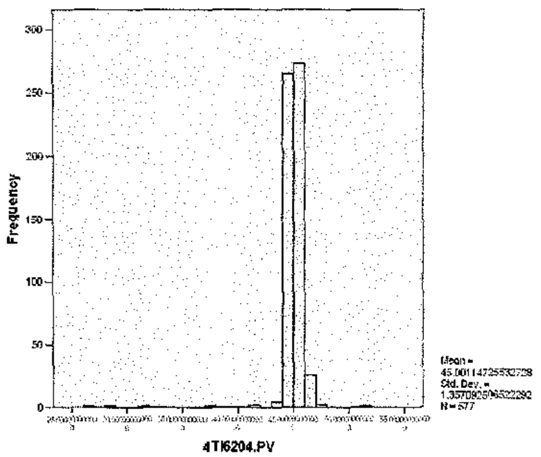


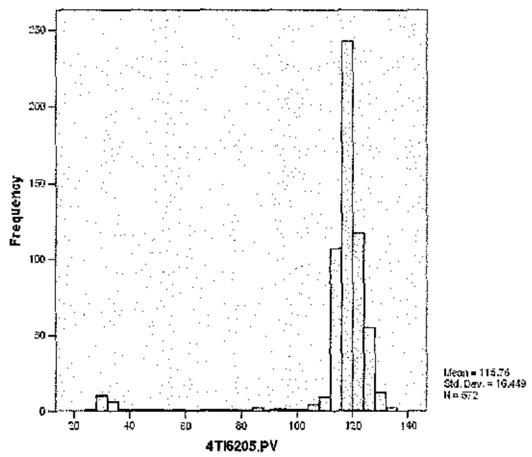



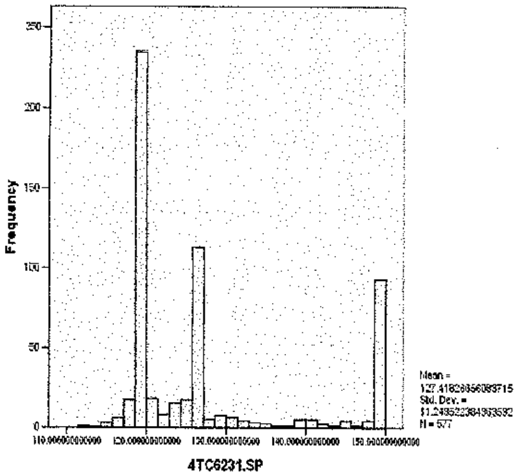



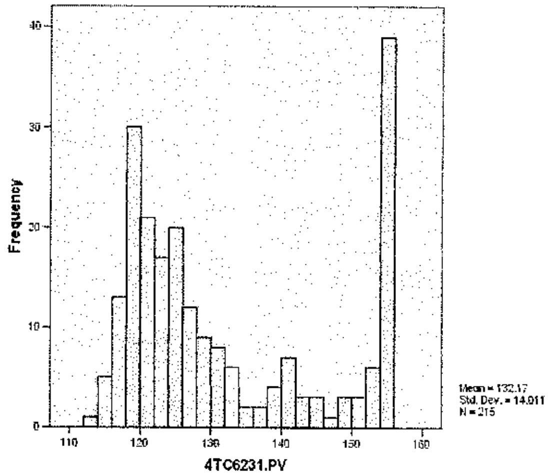



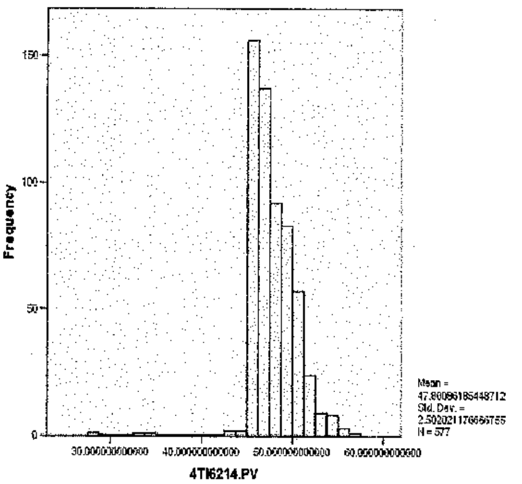

# Temperature Variables

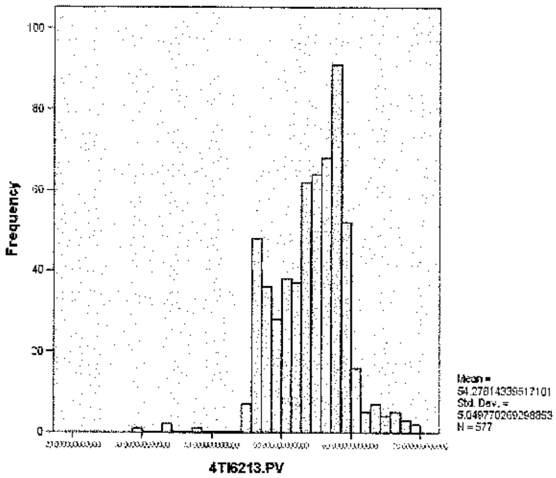


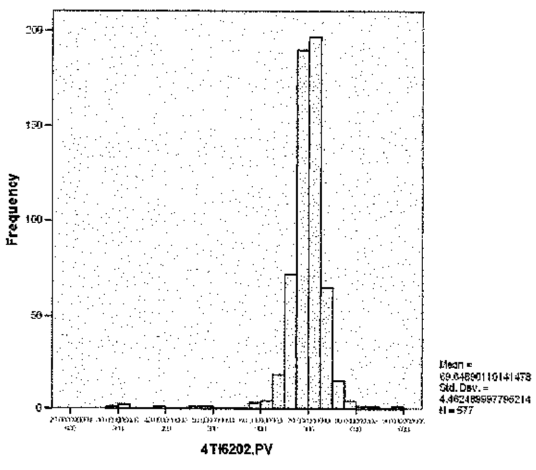



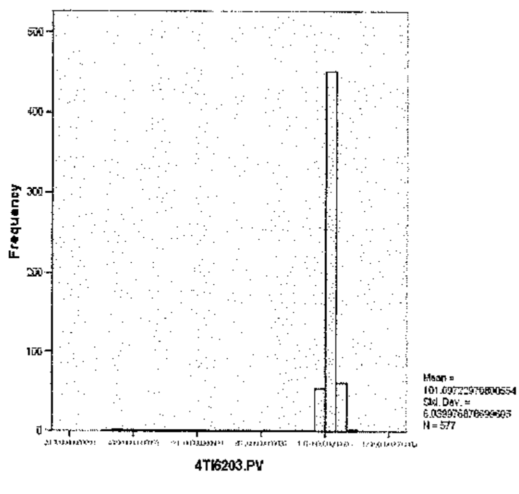

Frequency
250
200
150
100
50
0
110.000000000000
120.000000000000
130.000000000000
140.000000000000
150.000000000000
Mean = 127.41826656083715
Std. Dev. = 11.243522384363592
N = 577
4TC6231.SP


Frequency
40
30
20
10
0
110
120
130
140
150
160
Mean = 132.17
Std. Dev. = 14.011
N = 215
4TC6231.PV


Frequency
150
100
50
0
30.000000000000
40.000000000000
50.000000000000
60.000000000000
Mean = 47.80096185448712
Std. Dev. = 2.502021176666755
N = 577
4TI6214.PV

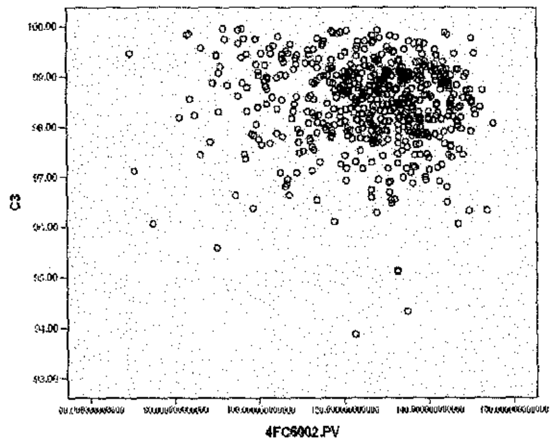

Frequency
100
80
60
40
20
0
Mean = 54.27814339517101
Std. Dev. = 5.049770269298853
N = 577
4TI6213.PV

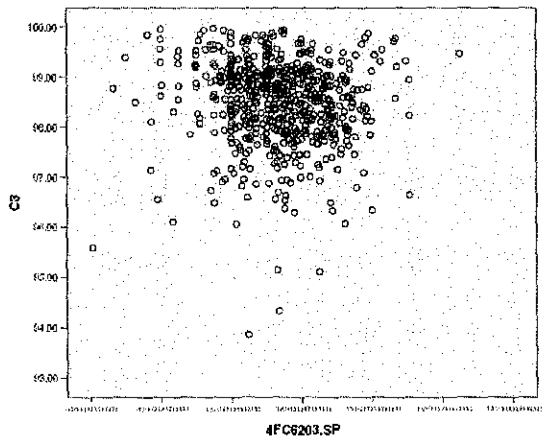

Frequency
200
150
100
50
0
Mean = 69.64890110141478
Std. Dev. = 4.462489997795214
N = 577
4TI6202.PV

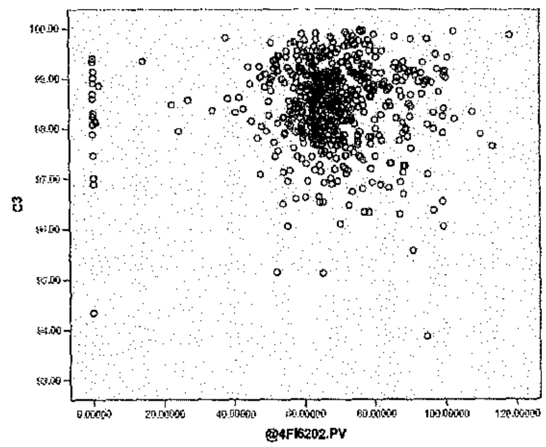

Frequency
500
400
300
200
100
0
Mean = 101.09722976800554
Std. Dev. = 6.039976876699605
N = 577
4TI6203.PV

<u>**Appendix E.2 : Scatter Plots**</u>

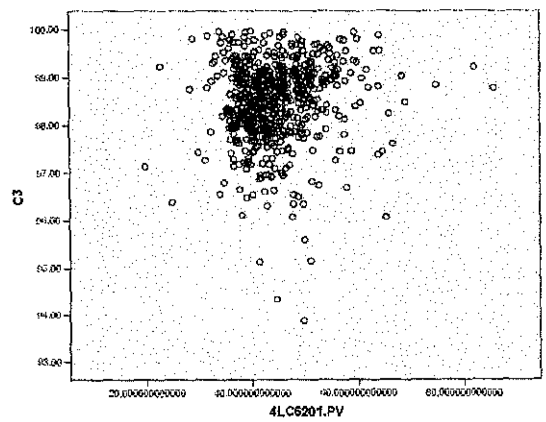
**Flow Variables**

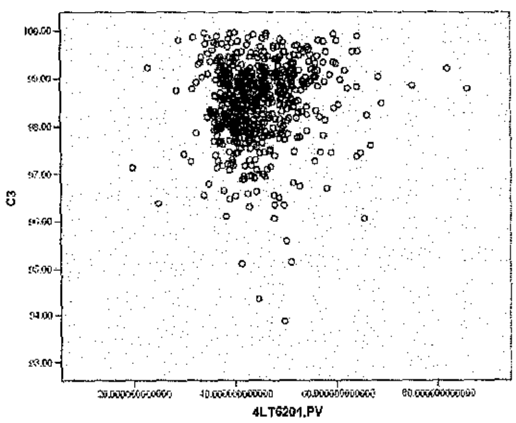


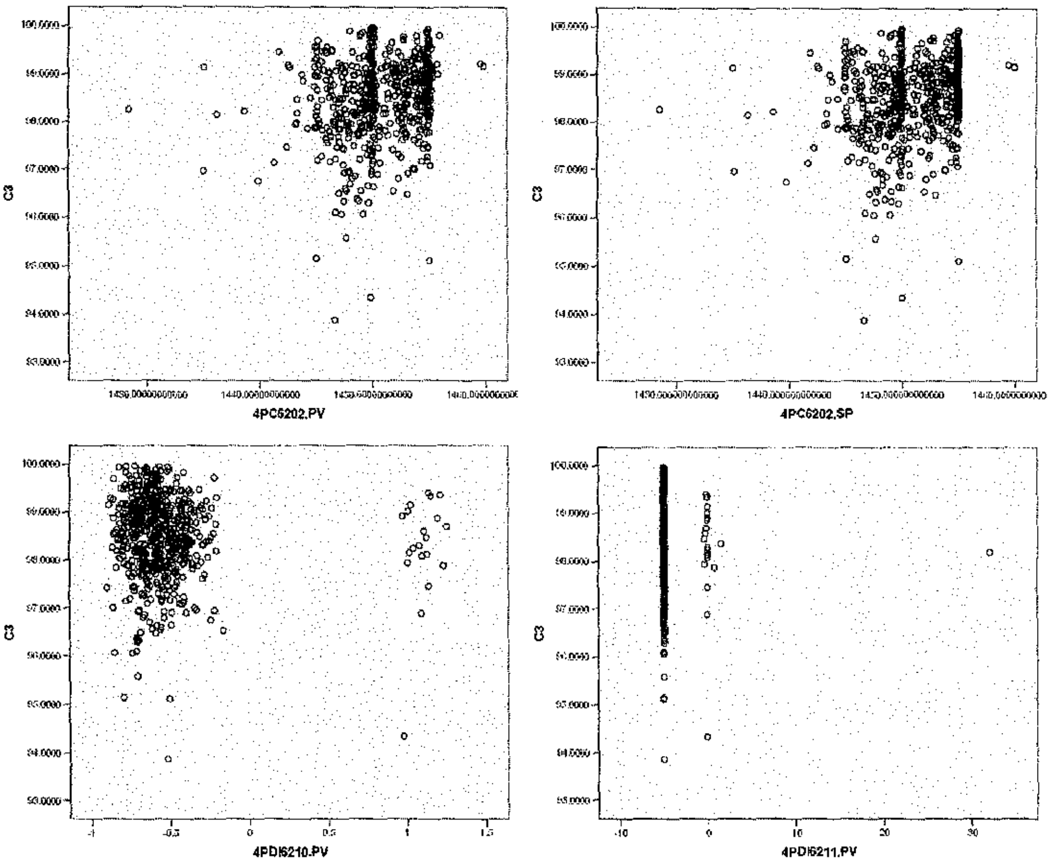




**Level Variables**

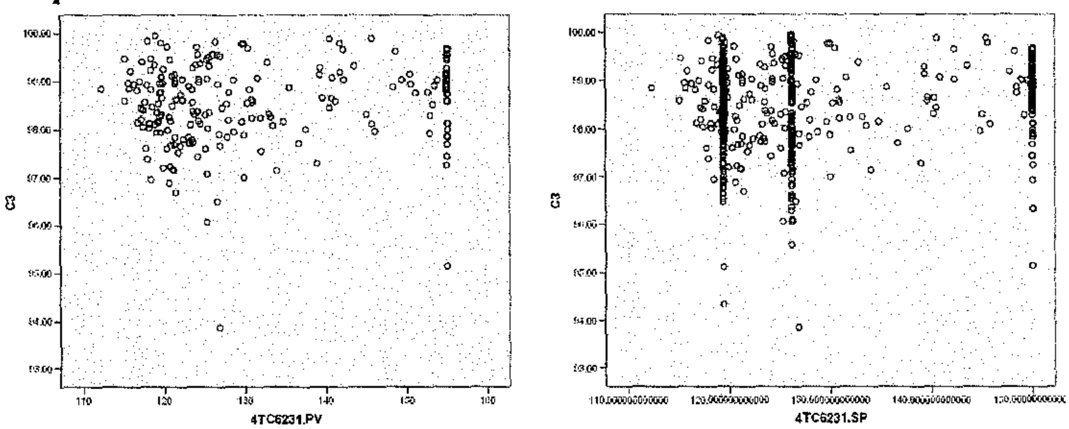


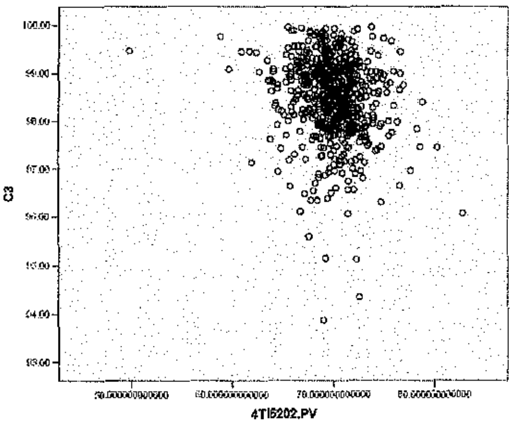



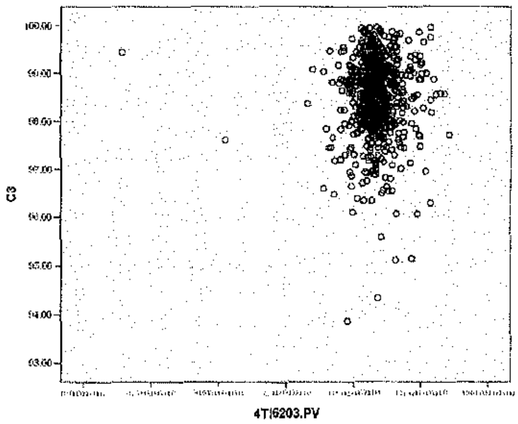
## Pressure Variables

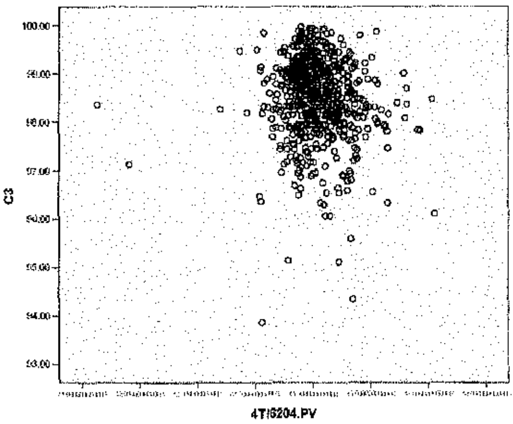


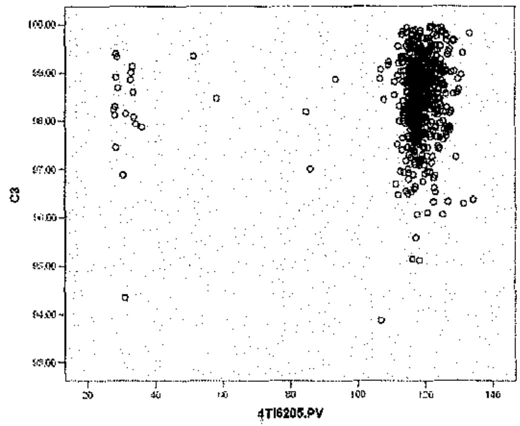

## Temperature Variables

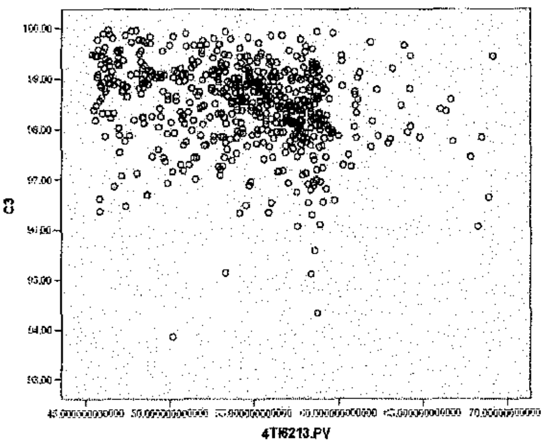


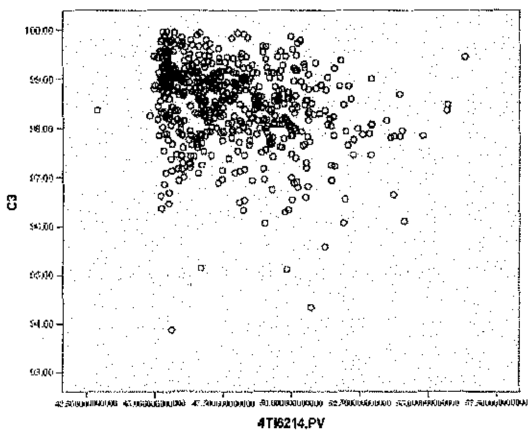

C3
4TI6202.PV


C3
4TI6203.PV


C3
4TI6204.PV


C3
20
40
60
80
100
120
140
4TI6205.PV


C3
4TI6213.PV


C3
4TI6214.PV

## Appendix E.3 : One Sample T-test

## Flow Variables

One-Sample Test

| | Test Value = 0 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| **C1** | 10.921 | 569 | .000 | .07909 | .0649 | .0933 |
| **C2** | 27.047 | 569 | .000 | .54989 | .5100 | .5898 |
| **C3** | 2650.851 | 569 | .000 | 98.47649 | 98.4035 | 98.5495 |
| **iC4** | 27.896 | 569 | .000 | .87795 | .8161 | .9398 |
| **nC4** | 4.743 | 568 | .000 | .025 | .01 | .04 |
| **4FY62022.PV** | 178.706 | 576 | .000 | 143.358957155118600 | 141.78335414816610 | 144.93456016207100 |
| **4FC6002.PV** | 169.989 | 576 | .000 | 124.854363667902900 | 123.41176412203690 | 126.29696321376900 |
| **@4FI6202.PV** | 90.061 | 571 | .000 | 67.01677809 | 65.5552160 | 68.4783402 |
| **4FC6203.SP** | 174.099 | 576 | .000 | 112.757000531439500 | 111.48493706199840 | 114.02906400088060 |
| **4FC6203.PV** | 167.243 | 572 | .000 | 112.956 | 111.63 | 114.28 |

## Level Variables

One-Sample Test

| | Test Value = 0 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| **C1** | 10.921 | 569 | .000 | .07909 | .0649 | .0933 |
| **C2** | 27.047 | 569 | .000 | .54989 | .5100 | .5898 |
| **C3** | 2650.851 | 569 | .000 | 98.47649 | 98.4035 | 98.5495 |
| **iC4** | 27.896 | 569 | .000 | .87795 | .8161 | .9398 |
| **nC4** | 4.743 | 568 | .000 | .025 | .01 | .04 |
| **4LC6201.PV** | 130.230 | 576 | .000 | 44.510405441297400 | 43.83911361998286 | 45.18169726261190 |
| **4LT6201.PV** | 130.241 | 576 | .000 | 44.508605252932010 | 43.83739716677656 | 45.17981333908740 |

## Pressure Variables

One-Sample Test

| | Test Value = 0 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| **C1** | 10.921 | 569 | .000 | .0790939 | .064869 | .093319 |
| **C2** | 27.047 | 569 | .000 | .5498927 | .509959 | .589826 |
| **C3** | 2650.851 | 569 | .000 | 98.4764907 | 98.403525 | 98.549457 |
| **iC4** | 27.896 | 569 | .000 | .87795 | .8161 | .9398 |
| **nC4** | 4.743 | 568 | .000 | .02483 | .0145 | .0351 |
| **4PC6202.SP** | 9503.635 | 576 | .000 | 1450.620236507528000 | 1450.32044065813200 | 1450.92003235692300 |
| **4PC6202.PV** | 2809.627 | 576 | .000 | 1450.15737634721600 | 1449.1436330057070 | 1451.1711196887240 |
| **4PDI6210.PV** | -36.445 | 563 | .000 | -.526 | -.55 | -.50 |
| **4PDI6211.PV** | -62.613 | 563 | .000 | -4.801 | -4.95 | -4.65 |

## Temperature Variables

One-Sample Test

| | Test Value = 0 | | | | | |
|---|---|---|---|---|---|---|
| | t | df | Sig. (2-tailed) | Mean Difference | 95% Confidence Interval of the Difference | |
| | | | | | Lower | Upper |
| **C1** | 10.921 | 569 | .000 | .07909 | .0649 | .0933 |
| **C2** | 27.047 | 569 | .000 | .54989 | .5100 | .5898 |
| **C3** | 2650.851 | 569 | .000 | 98.47649 | 98.4035 | 98.5495 |
| **iC4** | 27.896 | 569 | .000 | .87795 | .8161 | .9398 |
| **nC4** | 4.743 | 568 | .000 | .025 | .01 | .04 |
| **4TI6009.PV** | 365.022 | 576 | .000 | 95.807434445650500 | 95.29191934560670 | 96.32294954569430 |
| **4TI6204.PV** | 796.530 | 576 | .000 | 45.001147255327300 | 44.89018298582693 | 45.11211152482760 |
| **4TI6205.PV** | 168.315 | 571 | .000 | 115.761 | 114.41 | 117.11 |
| **4TC6231.SP** | 272.097 | 576 | .000 | 127.418266560837100 | 126.49851786033170 | 128.33801526134250 |
| **4TC6231.PV** | 138.313 | 214 | .000 | 132.166 | 130.28 | 134.05 |
| **4TI6231.PV** | 371.478 | 576 | .000 | 116.033458947722100 | 115.41996308379800 | 116.64695481164620 |
| **4TI6214.PV** | 458.915 | 576 | .000 | 47.800861854487100 | 47.59628114181720 | 48.00544256715700 |
| **4TI6213.PV** | 258.191 | 576 | .000 | 54.278143395171000 | 53.86524297284570 | 54.69104381749620 |
| **4TI6202.PV** | 374.908 | 576 | .000 | 69.648901101414800 | 69.28402034319220 | 70.01378185963740 |
| **4TI6203.PV** | 402.061 | 576 | .000 | 101.097229708005400 | 100.60336387430370 | 101.59109554170720 |

## Appendix E.4 : Factorial Anova

### 4FC6203.PV

Tests of Between-Subjects Effects
Dependent Variable: C3

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 422.602(a) | 564 | .749 | .985 | .637 |
| Intercept | 5486488.752 | 1 | 5486488.752 | 7210209.505 | .000 |
| @4FC6203.PV | 422.602 | 564 | .749 | .985 | .637 |
| Error | 1.522 | 2 | .761 | | |
| Total | 5499586.274 | 567 | | | |
| Corrected Total | 424.124 | 566 | | | |

a R Squared = .996 (Adjusted R Squared = -.015)

### 4FY62022.PV

Tests of Between-Subjects Effects
Dependent Variable: C3

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 422.602(a) | 564 | .749 | .985 | .637 |
| Intercept | 5486488.752 | 1 | 5486488.752 | 7210209.505 | .000 |
| @4FY62022.PV | 422.602 | 564 | .749 | .985 | .637 |
| Error | 1.522 | 2 | .761 | | |
| Total | 5499586.274 | 567 | | | |
| Corrected Total | 424.124 | 566 | | | |

a R Squared = .996 (Adjusted R Squared = -.015)

### 4TI6009.PV

Tests of Between-Subjects Effects
Dependent Variable: C3

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| Corrected Model | 422.602(a) | 564 | .749 | .985 | .637 |
| Intercept | 5486488.752 | 1 | 5486488.752 | 7210209.505 | .000 |
| @4TI6009.PV | 422.602 | 564 | .749 | .985 | .637 |
| Error | 1.522 | 2 | .761 | | |
| Total | 5499586.274 | 567 | | | |
| Corrected Total | 424.124 | 566 | | | |

a R Squared = .996 (Adjusted R Squared = -.015)

**4TI6231.PV**

Tests of Between-Subjects Effects
Dependent Variable: C3

| Source | Type III Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|
| **Corrected Model** | 422.602(a) | 564 | .749 | .985 | .637 |
| **Intercept** | 5486488.752 | 1 | 5486488.752 | 7210209.505 | .000 |
| **@4TI6231.PV** | 422.602 | 564 | .749 | .985 | .637 |
| **Error** | 1.522 | 2 | .761 | | |
| **Total** | 5499586.274 | 567 | | | |
| **Corrected Total** | 424.124 | 566 | | | |

a R Squared = .996 (Adjusted R Squared = -.015)

## Appendix E.5 : Compare Means

### 4FC6203.PV

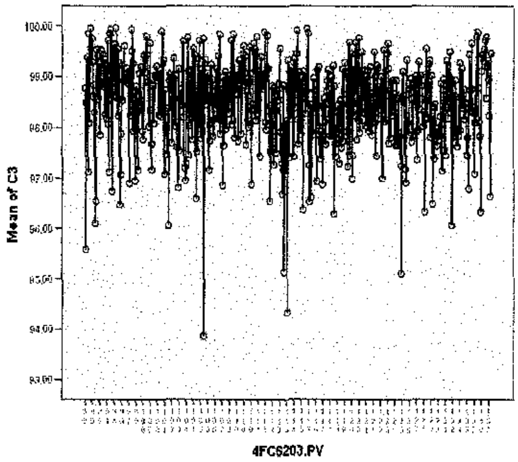
ANOVA Table

| | | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|
| C1 * 4FC6203.PV | Between Groups | (Combined) | 15.095 | 564 | .027 | 802.944 | .001 |
| | | Linearity | .027 | 1 | .027 | 821.753 | .001 |
| | | Deviation from Linearity | 15.068 | 563 | .027 | 802.911 | .001 |
| | Within Groups | | .000 | 2 | .000 | | |
| | Total | | 15.095 | 566 | | | |
| C2 * 4FC6203.PV | Between Groups | (Combined) | 125.242 | 564 | .222 | 1.625 | .459 |
| | | Linearity | .008 | 1 | .008 | .056 | .835 |
| | | Deviation from Linearity | 125.235 | 563 | .222 | 1.628 | .459 |
| | Within Groups | | .273 | 2 | .137 | | |
| | Total | | 125.516 | 566 | | | |
| C3 * 4FC6203.PV | Between Groups | (Combined) | 422.602 | 564 | .749 | .985 | .637 |
| | | Linearity | 2.056 | 1 | 2.056 | 2.703 | .242 |
| | | Deviation from Linearity | 420.546 | 563 | .747 | .982 | .638 |
| | Within Groups | | 1.522 | 2 | .761 | | |
| | Total | | 424.124 | 566 | | | |
| iC4 * 4FC6203.PV | Between Groups | (Combined) | 297.376 | 564 | .527 | 1.757 | .434 |
| | | Linearity | 3.043 | 1 | 3.043 | 10.139 | .086 |
| | | Deviation from Linearity | 294.333 | 563 | .523 | 1.742 | .436 |
| | Within Groups | | .600 | 2 | .300 | | |
| | Total | | 297.976 | 566 | | | |
| nC4 * 4FC6203.PV | Between Groups | (Combined) | 6.994 | 563 | .012 | 41.410 | .024 |
| | | Linearity | .003 | 1 | .003 | 11.207 | .079 |
| | | Deviation from Linearity | 6.991 | 562 | .012 | 41.463 | .024 |
| | Within Groups | | .001 | 2 | .000 | | |
| | Total | | 6.995 | 565 | | | |

Measures of Association

| | R | R Squared | Eta | Eta Squared |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| **C1 * 4FC6203.PV** | -.043 | .002 | 1.000 | 1.000 |
| **C2 * 4FC6203.PV** | -.008 | .000 | .999 | .998 |
| **C3 * 4FC6203.PV** | -.070 | .005 | .998 | .996 |
| **iC4 * 4FC6203.PV** | .101 | .010 | .999 | .998 |
| **nC4 * 4FC6203.PV** | -.022 | .000 | 1.000 | 1.000 |




**Mean of $C_3$ vs. 4FC6203.PV**

## 4FY62022.PV

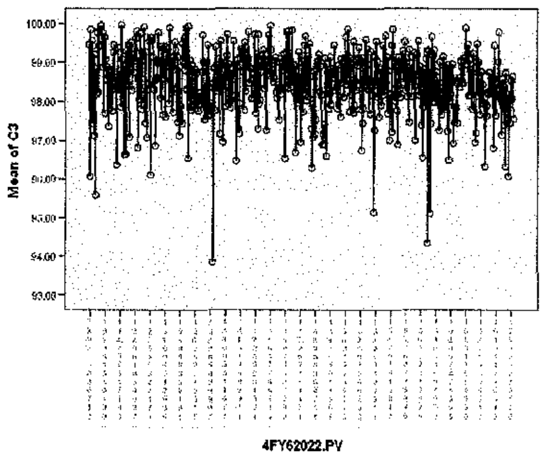
ANOVA Table

| | | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|
| **C1 * 4FY62022.PV** | **Between Groups** | **(Combined)** | 15.095 | 564 | .027 | 802.944 | .001 |
| | | **Linearity** | .034 | 1 | .034 | 1024.898 | .001 |
| | | **Deviation from Linearity** | 15.061 | 563 | .027 | 802.550 | .001 |
| | **Within Groups** | | .000 | 2 | .000 | | |
| | **Total** | | 15.095 | 566 | | | |
| **C2 * 4FY62022.PV** | **Between Groups** | **(Combined)** | 125.242 | 564 | .222 | 1.625 | .459 |
| | | **Linearity** | .467 | 1 | .467 | 3.417 | .206 |
| | | **Deviation from Linearity** | 124.776 | 563 | .222 | 1.622 | .460 |
| | **Within Groups** | | .273 | 2 | .137 | | |
| | **Total** | | 125.516 | 566 | | | |
| **C3 * 4FY62022.PV** | **Between Groups** | **(Combined)** | 422.602 | 564 | .749 | .985 | .637 |
| | | **Linearity** | 7.918 | 1 | 7.918 | 10.406 | .084 |
| | | **Deviation from Linearity** | 414.684 | 563 | .737 | .968 | .643 |
| | **Within Groups** | | 1.522 | 2 | .761 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total | | 424.124 | 566 | | | |
| iC4 * 4FY62022.PV | Between Groups | (Combined) | 297.376 | 564 | .527 | 1.757 | .434 |
| | | Linearity | 5.400 | 1 | 5.400 | 17.993 | .051 |
| | | Deviation from Linearity | 291.976 | 563 | .519 | 1.728 | .439 |
| | Within Groups | | .600 | 2 | .300 | | |
| | Total | | 297.976 | 566 | | | |
| nC4 * 4FY62022.PV | Between Groups | (Combined) | 6.994 | 563 | .012 | 41.410 | .024 |
| | | Linearity | .000 | 1 | .000 | .025 | .889 |
| | | Deviation from Linearity | 6.994 | 562 | .012 | 41.483 | .024 |
| | Within Groups | | .001 | 2 | .000 | | |
| | Total | | 6.995 | 565 | | | |

Measures of Association

| | R | R Squared | Eta | Eta Squared |
|---|---|---|---|---|
| C1 * 4FY62022.PV | -.048 | .002 | 1.000 | 1.000 |
| C2 * 4FY62022.PV | .061 | .004 | .999 | .998 |
| C3 * 4FY62022.PV | -.137 | .019 | .998 | .996 |
| iC4 * 4FY62022.PV | .135 | .018 | .999 | .998 |
| nC4 * 4FY62022.PV | .001 | .000 | 1.000 | 1.000 |




**Mean of $C_3$ vs. 4FY62022.PV**

## 4TI6009.PV

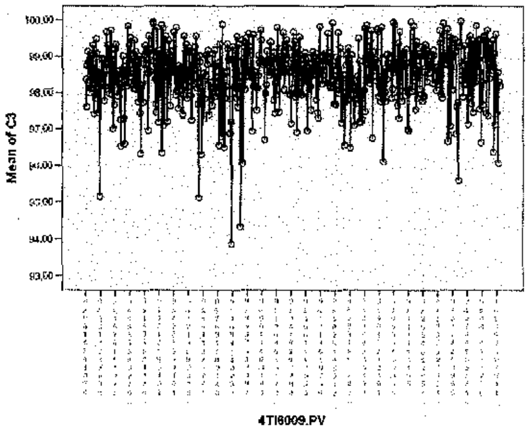
ANOVA Table

| | | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|
| C1 * 4TI6009.PV | Between Groups | (Combined) | 15.095 | 564 | .027 | 802.944 | .001 |
| | | Linearity | .083 | 1 | .083 | 2501.899 | .000 |
| | | Deviation from Linearity | 15.012 | 563 | .027 | 799.927 | .001 |
| | Within Groups | | .000 | 2 | .000 | | |
| | Total | | 15.095 | 566 | | | |
| C2 * 4TI6009.PV | Between Groups | (Combined) | 125.242 | 564 | .222 | 1.625 | .459 |
| | | Linearity | 1.934 | 1 | 1.934 | 14.154 | .064 |
| | | Deviation from Linearity | 123.308 | 563 | .219 | 1.603 | .464 |
| | Within Groups | | .273 | 2 | .137 | | |
| | Total | | 125.516 | 566 | | | |
| C3 * 4TI6009.PV | Between Groups | (Combined) | 422.602 | 564 | .749 | .985 | .637 |
| | | Linearity | .119 | 1 | .119 | .157 | .731 |
| | | Deviation from Linearity | 422.483 | 563 | .750 | .986 | .637 |
| | Within Groups | | 1.522 | 2 | .761 | | |
| | Total | | 424.124 | 566 | | | |
| iC4 * 4TI6009.PV | Between Groups | (Combined) | 297.376 | 564 | .527 | 1.757 | .434 |
| | | Linearity | 4.354 | 1 | 4.354 | 14.509 | .063 |
| | | Deviation from Linearity | 293.022 | 563 | .520 | 1.734 | .438 |
| | Within Groups | | .600 | 2 | .300 | | |
| | Total | | 297.976 | 566 | | | |
| nC4 * 4TI6009.PV | Between Groups | (Combined) | 6.994 | 563 | .012 | 41.410 | .024 |
| | | Linearity | .004 | 1 | .004 | 13.222 | .068 |
| | | Deviation from Linearity | 6.990 | 562 | .012 | 41.460 | .024 |
| | Within Groups | | .001 | 2 | .000 | | |
| | Total | | 6.995 | 565 | | | |

Measures of Association

| | R | R Squared | Eta | Eta Squared |
|---|---|---|---|---|
| C1 * 4TI6009.PV | .074 | .006 | 1.000 | 1.000 |
| C2 * 4TI6009.PV | .124 | .015 | .999 | .998 |

| | | | | |
|---|---|---|---|---|
| **C3 * 4TI6009.PV** | .017 | .000 | .998 | .996 |
| **iC4 * 4TI6009.PV** | -.121 | .015 | .999 | .998 |
| **nC4 * 4TI6009.PV** | .024 | .001 | 1.000 | 1.000 |




**Mean of $C_3$ vs. 4TI6009.PV**

## 4TI6231.PV

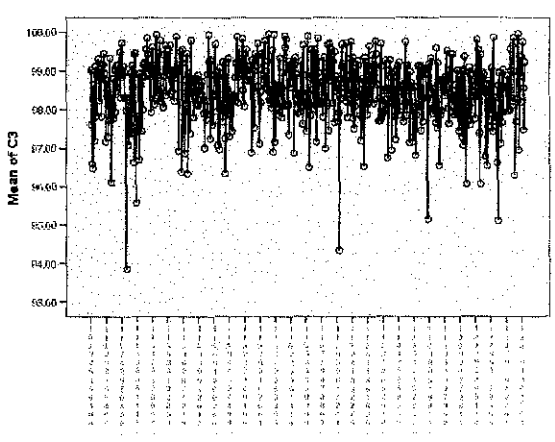
ANOVA Table

| | | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|
| **C1 * 4TI6231.PV** | **Between Groups** | **(Combined)** | 15.095 | 564 | .027 | 802.944 | .001 |
| | | **Linearity** | .051 | 1 | .051 | 1541.128 | .001 |
| | | **Deviation from Linearity** | 15.044 | 563 | .027 | 801.633 | .001 |
| | **Within Groups** | | .000 | 2 | .000 | | |
| | **Total** | | 15.095 | 566 | | | |
| **C2 * 4TI6231.PV** | **Between Groups** | **(Combined)** | 125.242 | 564 | .222 | 1.625 | .459 |
| | | **Linearity** | .940 | 1 | .940 | 6.882 | .120 |
| | | **Deviation from Linearity** | 124.302 | 563 | .221 | 1.616 | .461 |
| | **Within Groups** | | .273 | 2 | .137 | | |
| | **Total** | | 125.516 | 566 | | | |
| **C3 * 4TI6231.PV** | **Between Groups** | **(Combined)** | 422.602 | 564 | .749 | .985 | .637 |
| | | **Linearity** | .383 | 1 | .383 | .504 | .551 |
| | | **Deviation from Linearity** | 422.219 | 563 | .750 | .986 | .637 |
| | **Within Groups** | | 1.522 | 2 | .761 | | |
| | **Total** | | 424.124 | 566 | | | |
| **iC4 *** | **Between** | **(Combined)** | 297.376 | 564 | .527 | 1.757 | .434 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **4TI6231.PV** | **Groups** | **Linearity** | .452 | 1 | .452 | 1.506 | .345 |
| | | **Deviation from Linearity** | 296.924 | 563 | .527 | 1.757 | .434 |
| | **Within Groups** | | .600 | 2 | .300 | | |
| | **Total** | | 297.976 | 566 | | | |
| **nC4 * 4TI6231.PV** | **Between Groups** | **(Combined)** | 6.994 | 563 | .012 | 41.410 | .024 |
| | | **Linearity** | .011 | 1 | .011 | 35.338 | .027 |
| | | **Deviation from Linearity** | 6.984 | 562 | .012 | 41.421 | .024 |
| | **Within Groups** | | .001 | 2 | .000 | | |
| | **Total** | | 6.995 | 565 | | | |

Measures of Association

| | R | R Squared | Eta | Eta Squared |
|---|---|---|---|---|
| **C1 * 4TI6231.PV** | .058 | .003 | 1.000 | 1.000 |
| **C2 * 4TI6231.PV** | .087 | .007 | .999 | .998 |
| **C3 * 4TI6231.PV** | -.030 | .001 | .998 | .996 |
| **iC4 * 4TI6231.PV** | -.039 | .002 | .999 | .998 |
| **nC4 * 4TI6231.PV** | .039 | .002 | 1.000 | 1.000 |




**Mean of $C_3$ vs. 4TI6231.PV**

## Appendix E6 : Reliability Analysis

## Flow Variables

Case Processing Summary

| | | N | % |
|---|---|---|---|
| Cases | Valid | 565 | 97.4 |
| | Excluded(a) | 15 | 2.6 |
| | Total | 580 | 100.0 |

a Listwise deletion based on all variables in the procedure.

Reliability Statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | N of Items |
|---|---|---|
| .669 | .351 | 10 |

Item Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| C1 | .07691452035399 | .163566965507099 | 565 |
| C2 | .54499649911505 | .471480549904397 | 565 |
| C3 | 98.48033228849560 | .866657272953024 | 565 |
| iC4 | .87338219292036 | .725855715994939 | 565 |
| nC4 | .02251028495575 | .111360065267466 | 565 |
| 4FY62022.PV | 144.45997756012770 | 16.778372856275400 | 565 |
| 4FC6002.PV | 125.85432057338470 | 15.522987539406000 | 565 |
| @4FI6202.PV | 67.09559999469030 | 17.739073493510310 | 565 |
| 4FC6203.SP | 113.49274405420350 | 14.431698606362370 | 565 |
| 4FC6203.PV | 113.49217039823000 | 14.530803908865030 | 565 |

Inter-Item Correlation Matrix

| | C1 | C2 | C3 | iC4 | nC4 | 4FY62022. PV | 4FC6002. PV | @4FI6202. PV | 4FC6203. SP | 4FC6203. PV |
|---|---|---|---|---|---|---|---|---|---|---|
| C1 | 1.000 | .121 | -.239 | -.030 | .074 | -.047 | -.068 | -.021 | -.040 | -.043 |
| C2 | .121 | 1.000 | -.484 | -.091 | -.044 | .060 | .048 | -.045 | -.008 | -.007 |
| C3 | -.239 | -.484 | 1.000 | -.795 | -.203 | -.138 | -.077 | .030 | -.069 | -.070 |
| iC4 | -.030 | -.091 | -.795 | 1.000 | .100 | .136 | .078 | -.002 | .100 | .102 |
| nC4 | .074 | -.044 | -.203 | .100 | 1.000 | .001 | -.009 | -.007 | -.022 | -.022 |
| 4FY62022. | - | .060 | - | .136 | .001 | 1.000 | .938 | -.001 | .445 | .443 |

| | C1 | C2 | C3 | iC4 | nC4 | 4FY62022.PV | 4FC6002.PV | @4FI6202.PV | 4FC6203.SP | 4FC6203.PV |
|---|---|---|---|---|---|---|---|---|---|---|
| PV | .047 | | .138 | | | | | | | |
| **4FC6002.PV** | -.068 | .048 | -.077 | .078 | -.009 | .938 | 1.000 | .026 | .481 | .478 |
| **@4FI6202.PV** | -.021 | -.045 | .030 | -.002 | -.007 | -.001 | .026 | 1.000 | .115 | .117 |
| **4FC6203.SP** | -.040 | -.008 | -.069 | .100 | -.022 | .445 | .481 | .115 | 1.000 | .999 |
| **4FC6203.PV** | -.043 | -.007 | -.070 | .102 | -.022 | .443 | .478 | .117 | .999 | 1.000 |

The covariance matrix is calculated and used in the analysis.

Inter-Item Covariance Matrix

| | **C1** | **C2** | **C3** | **iC4** | **nC4** | **4FY62022.PV** | **4FC6002.PV** | **@4FI6202.PV** | **4FC6203.SP** | **4FC6203.PV** |
|---|---|---|---|---|---|---|---|---|---|---|
| **C1** | .027 | .009 | -.034 | -.004 | .001 | -.130 | -.172 | -.060 | -.095 | -.102 |
| **C2** | .009 | .222 | -.198 | -.031 | -.002 | .478 | .352 | -.374 | -.051 | -.050 |
| **C3** | -.034 | -.198 | .751 | -.500 | -.020 | -2.000 | -1.034 | .466 | -.868 | -.883 |
| **iC4** | -.004 | -.031 | -.500 | .527 | .008 | 1.658 | .874 | -.022 | 1.051 | 1.071 |
| **nC4** | .001 | -.002 | -.020 | .008 | .012 | .002 | -.016 | -.014 | -.036 | -.036 |
| **4FY62022.PV** | -.130 | .478 | -2.000 | 1.658 | .002 | 281.514 | 244.237 | -.307 | 107.861 | 107.968 |
| **4FC6002.PV** | -.172 | .352 | -1.034 | .874 | -.016 | 244.237 | 240.963 | 7.080 | 107.654 | 107.806 |
| **@4FI6202.PV** | -.060 | -.374 | .466 | -.022 | -.014 | -.307 | 7.080 | 314.675 | 29.567 | 30.069 |
| **4FC6203.SP** | -.095 | -.051 | -.868 | 1.051 | -.036 | 107.861 | 107.654 | 29.567 | 208.274 | 209.502 |
| **4FC6203.PV** | -.102 | -.050 | -.883 | 1.071 | -.036 | 107.968 | 107.806 | 30.069 | 209.502 | 211.144 |

The covariance matrix is calculated and used in the analysis.

Summary Item Statistics

| | **Mean** | **Minimum** | **Maximum** | **Range** | **Maximum /** | **Variance** | **N of** |
|---|---|---|---|---|---|---|---|

| | | | | | Minimum | | Items |
|---|---|---|---|---|---|---|---|
| **Item Means** | 66.439 | .023 | 144.460 | 144.437 | 6417.510 | 3614.281 | 10 |
| **Item Variances** | 125.811 | .012 | 314.675 | 314.662 | 25374.817 | 18445.596 | 10 |
| **Inter-Item Covariances** | 21.126 | -2.000 | 244.237 | 246.238 | -122.093 | 2961.872 | 10 |
| **Inter-Item Correlations** | .051 | -.795 | .999 | 1.794 | -1.257 | .084 | 10 |

The covariance matrix is calculated and used in the analysis.

Item-Total Statistics

| | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Squared Multiple Correlation | Cronbach's Alpha if Item Deleted |
|---|---|---|---|---|---|
| **C1** | 664.31603384612300 | 3160.602 | -.064 | .998 | .677 |
| **C2** | 663.84795186736200 | 3158.969 | .005 | 1.000 | .677 |
| **C3** | 565.91261607798100 | 3168.846 | -.104 | 1.000 | .679 |
| **iC4** | 663.51956617355600 | 3150.720 | .101 | 1.000 | .676 |
| **nC4** | 664.37043808152100 | 3159.668 | -.018 | .996 | .677 |
| **4FY62022.PV** | 519.93297080634900 | 1958.411 | .619 | .885 | .564 |
| **4FC6002.PV** | 538.53862779309200 | 1984.930 | .675 | .888 | .549 |
| **@4FI6202.PV** | 597.29734837178600 | 2711.972 | .072 | .022 | .734 |
| **4FC6203.SP** | 550.90020431227300 | 2042.015 | .697 | .998 | .547 |
| **4FC6203.PV** | 550.90077796824700 | 2037.625 | .694 | .998 | .547 |

Scale Statistics

| Mean | Variance | Std. Deviation | N of Items |
|---|---|---|---|
| 664.39294836647700 | 3159.456 | 56.209040554667600 | 10 |

ANOVA(a)

| | | Sum of Squares | df | Mean Square | F | Sig |
|---|---|---|---|---|---|---|
| **Between People** | | 178193.332 | 564 | 315.946 | | |
| **Within People** | **Between Items** | 18378621.405 | 9 | 2042069.045 | 19506.825 | .000 |
| | **Residual** | 531380.293 | 5076 | 104.685 | | |
| | **Total** | 18910001.698 | 5085 | 3718.781 | | |
| **Total** | | 19088195.030 | 5649 | 3379.040 | | |

Grand Mean = 66.43929483664770

a The covariance matrix is calculated and used in the analysis.

## Level Variables

Case Processing Summary

| | | N | % |
|---|---|---|---|
| Cases | **Valid** | 566 | 97.6 |
| | **Excluded(a)** | 14 | 2.4 |
| | **Total** | 580 | 100.0 |

a Listwise deletion based on all variables in the procedure.

Reliability Statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items(a) | N of Items |
|---|---|---|
| .575 | -.326 | 7 |

a The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Item Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| **C1** | .07677862897527 | .163454127337414 | 566 |
| **C2** | .54564138162545 | .471312903245088 | 566 |
| **C3** | 98.48080873321550 | .865964167354561 | 566 |
| **iC4** | .87245748939930 | .725546681257210 | 566 |
| **nC4** | .02247051413428 | .111265496012091 | 566 |
| **4LC6201.PV** | 44.71388119606584 | 7.442476392164560 | 566 |
| **4LT6201.PV** | 44.71223363101272 | 7.441440597134860 | 566 |

Inter-Item Correlation Matrix

| | C1 | C2 | C3 | iC4 | nC4 | 4LC6201.PV | 4LT6201.PV |
|---|---|---|---|---|---|---|---|
| **C1** | 1.000 | .120 | -.239 | -.029 | .074 | .000 | .000 |
| **C2** | .120 | 1.000 | -.484 | -.092 | -.044 | -.064 | -.065 |
| **C3** | -.239 | -.484 | 1.000 | -.795 | -.203 | .097 | .097 |
| **iC4** | -.029 | -.092 | -.795 | 1.000 | .101 | -.067 | -.066 |
| **nC4** | .074 | -.044 | -.203 | .101 | 1.000 | -.053 | -.053 |
| **4LC6201.PV** | .000 | -.064 | .097 | -.067 | -.053 | 1.000 | 1.000 |
| **4LT6201.PV** | .000 | -.065 | .097 | -.066 | -.053 | 1.000 | 1.000 |

The covariance matrix is calculated and used in the analysis.

Inter-Item Covariance Matrix

| | C1 | C2 | C3 | iC4 | nC4 | 4LC6201.PV | 4LT6201.PV |
|---|---|---|---|---|---|---|---|
| **C1** | .027 | .009 | -.034 | -.003 | .001 | .000 | .000 |
| **C2** | .009 | .222 | -.197 | -.032 | -.002 | -.226 | -.226 |
| **C3** | -.034 | -.197 | .750 | -.499 | -.020 | .628 | .628 |
| **iC4** | -.003 | -.032 | -.499 | .526 | .008 | -.359 | -.358 |
| **nC4** | .001 | -.002 | -.020 | .008 | .012 | -.044 | -.044 |
| **4LC6201.PV** | .000 | -.226 | .628 | -.359 | -.044 | 55.390 | 55.382 |
| **4LT6201.PV** | .000 | -.226 | .628 | -.358 | -.044 | 55.382 | 55.375 |

The covariance matrix is calculated and used in the analysis.

Summary Item Statistics

| | Mean | Minimum | Maximum | Range | Maximum / Minimum | Variance | N of Items |
|---|---|---|---|---|---|---|---|
| **Item Means** | 27.061 | .022 | 98.481 | 98.458 | 4382.668 | 1428.686 | 7 |
| **Item Variances** | 16.043 | .012 | 55.390 | 55.378 | 4474.185 | 722.279 | 7 |
| **Inter-Item Covariances** | 2.601 | -.499 | 55.382 | 55.881 | -110.918 | 142.761 | 7 |
| **Inter-Item Correlations** | -.036 | -.795 | 1.000 | 1.795 | -1.258 | .098 | 7 |

The covariance matrix is calculated and used in the analysis.

Item-Total Statistics

| | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Squared Multiple Correlation | Cronbach's Alpha if Item Deleted |
|---|---|---|---|---|---|
| **C1** | 189.34749294545310 | 221.554 | -.011 | .998 | .592 |
| **C2** | 188.87863019280290 | 222.654 | -.096 | 1.000 | .596 |
| **C3** | 90.94346284121280 | 219.766 | .039 | 1.000 | .591 |
| **iC4** | 188.55181408502900 | 223.488 | -.115 | 1.000 | .600 |
| **nC4** | 189.40180106029410 | 221.714 | -.060 | .996 | .592 |
| **4LC6201.PV** | 144.71039037836250 | 55.374 | 1.000 | 1.000 | -.033(a) |
| **4LT6201.PV** | 144.71203794341560 | 55.389 | 1.000 | 1.000 | -.033(a) |

a The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Scale Statistics

| Mean | Variance | Std. Deviation | N of Items |
|---|---|---|---|
| 189.42427157442840 | 221.527 | 14.883781888592170 | 7 |

ANOVA(a)

| | | Sum of Squares | df | Mean Square | F | Sig |
|---|---|---|---|---|---|---|
| **Between People** | | 17880.391 | 565 | 31.647 | | |
| **Within People** | **Between Items** | 4851816.311 | 6 | 808636.052 | 60154.192 | .000 |
| | **Residual** | 45570.826 | 3390 | 13.443 | | |
| | **Total** | 4897387.136 | 3396 | 1442.105 | | |
| **Total** | | 4915267.527 | 3961 | 1240.916 | | |

Grand Mean = 27.06061022491834

a The covariance matrix is calculated and used in the analysis.

## Pressure Variables

Case Processing Summary

| | | N | % |
|---|---|---|---|
| **Cases** | **Valid** | 557 | 96.0 |
| | **Excluded(a)** | 23 | 4.0 |
| | **Total** | 580 | 100.0 |

a Listwise deletion based on all variables in the procedure.

Reliability Statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items(a) | N of Items |
|---|---|---|
| .476 | -.133 | 9 |

a The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Item Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| **C1** | .07801921723519 | .164477236832011 | 557 |
| **C2** | .54557095511670 | .473351328660734 | 557 |
| **C3** | 98.48062431418310 | .871228489210761 | 557 |
| **iC4** | .87113274506284 | .728331672510184 | 557 |
| **nC4** | .02277973249551 | .112133950019201 | 557 |
| **4PC6202.SP** | 1450.63659646053000 | 3.618205011470361 | 557 |
| **4PC6202.PV** | 1450.61859689709100 | 3.643678580561583 | 557 |
| **4PDI6210.PV** | -.52484223339318 | .344210277898480 | 557 |
| **4PDI6211.PV** | -4.79796388330342 | 1.832241468839767 | 557 |

Inter-Item Correlation Matrix

| | C1 | C2 | C3 | iC4 | nC4 | 4PC6202.SP | 4PC6202.PV | 4PDI6210.PV | 4PDI6211.PV |
|---|---|---|---|---|---|---|---|---|---|
| **C1** | 1.000 | .121 | -.240 | -.029 | .073 | .023 | .025 | -.009 | -.034 |
| **C2** | .121 | 1.000 | -.486 | -.089 | -.044 | .005 | .003 | .003 | .070 |
| **C3** | -.240 | -.486 | 1.000 | -.795 | -.203 | .214 | .215 | -.063 | -.038 |
| **iC4** | -.029 | -.089 | -.795 | 1.000 | .101 | -.259 | -.260 | .078 | .011 |
| **nC4** | .073 | -.044 | -.203 | .101 | 1.000 | -.037 | -.036 | -.019 | -.022 |
| **4PC6202.SP** | .023 | .005 | .214 | -.259 | -.037 | 1.000 | .999 | -.003 | -.084 |
| **4PC6202.PV** | .025 | .003 | .215 | -.260 | -.036 | .999 | 1.000 | -.003 | -.085 |
| **4PDI6210.PV** | -.009 | .003 | -.063 | .078 | -.019 | -.003 | -.003 | 1.000 | .420 |
| **4PDI6211.PV** | -.034 | .070 | -.038 | .011 | -.022 | -.084 | -.085 | .420 | 1.000 |

The covariance matrix is calculated and used in the analysis.

Inter-Item Covariance Matrix

| | C1 | C2 | C3 | iC4 | nC4 | 4PC6202.SP | 4PC6202.PV | 4PDI6210.PV | 4PDI6211.PV |
|---|---|---|---|---|---|---|---|---|---|
| **C1** | .027 | .009 | -.034 | -.003 | .001 | .014 | .015 | .000 | -.010 |
| **C2** | .009 | .224 | -.200 | -.031 | -.002 | .008 | .005 | .001 | .061 |
| **C3** | -.034 | -.200 | .759 | -.505 | -.020 | .674 | .683 | -.019 | -.061 |
| **iC4** | -.003 | -.031 | -.505 | .530 | .008 | -.683 | -.690 | .020 | .015 |
| **nC4** | .001 | -.002 | -.020 | .008 | .013 | -.015 | -.015 | -.001 | -.005 |
| **4PC6202.SP** | .014 | .008 | .674 | -.683 | -.015 | 13.091 | 13.167 | -.003 | -.557 |
| **4PC6202.PV** | .015 | .005 | .683 | -.690 | -.015 | 13.167 | 13.276 | -.004 | -.565 |
| **4PDI6210.PV** | .000 | .001 | -.019 | .020 | -.001 | -.003 | -.004 | .118 | .265 |
| **4PDI6211.PV** | -.010 | .061 | -.061 | .015 | -.005 | -.557 | -.565 | .265 | 3.357 |

The covariance matrix is calculated and used in the analysis.

Summary Item Statistics

| | Mean | Minimum | Maximum | Range | Maximum / Minimum | Variance | N of Items |
|---|---|---|---|---|---|---|---|
| **Item Means** | 332.881 | -4.798 | 1450.637 | 1455.435 | -302.344 | 402634.349 | 9 |
| **Item Variances** | 3.489 | .013 | 13.276 | 13.264 | 1055.859 | 31.289 | 9 |
| **Inter-Item Covariances** | .320 | -.690 | 13.167 | 13.857 | -19.078 | 4.861 | 9 |
| **Inter-Item Correlations** | -.013 | -.795 | .999 | 1.794 | -1.256 | .069 | 9 |

The covariance matrix is calculated and used in the analysis.

Item-Total Statistics

| | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Squared Multiple Correlation | Cronbach's Alpha if Item Deleted |
|---|---|---|---|---|---|
| **C1** | 2995.85249498778300 | 54.432 | -.008 | .998 | .484 |
| **C2** | 2995.38494324990200 | 54.515 | -.043 | 1.000 | .489 |
| **C3** | 2897.44988989083600 | 52.646 | .082 | 1.000 | .478 |
| **iC4** | 2995.05938145995600 | 57.648 | -.338 | 1.000 | .531 |
| **nC4** | 2995.90773447252300 | 54.523 | -.057 | .996 | .485 |
| **4PC6202.SP** | 1545.29391774448800 | 16.140 | .867 | .997 | -.153(a) |
| **4PC6202.PV** | 1545.31191730792800 | 15.973 | .865 | .997 | -.154(a) |
| **4PDI6210.PV** | 2996.45535643841200 | 53.807 | .102 | .186 | .479 |
| **4PDI6211.PV** | 3000.72847808832200 | 52.798 | -.064 | .191 | .536 |

a The value is negative due to a negative average covariance among items. This violates reliability model assumptions. You may want to check item codings.

Scale Statistics

| Mean | Variance | Std. Deviation | N of Items |
|---|---|---|---|
| 2995.93051420501900 | 54.441 | 7.378417624831060 | 9 |

ANOVA(a)

| | | Sum of Squares | df | Mean Square | F | Sig |
|---|---|---|---|---|---|---|
| **Between People** | | 3363.247 | 556 | 6.049 | | |
| **Within People** | **Between Items** | 1794138658.873 | 8 | 224267332.359 | 70781458.135 | .000 |
| | **Residual** | 14093.254 | 4448 | 3.168 | | |
| | **Total** | 1794152752.127 | 4456 | 402637.512 | | |
| **Total** | | 1794156115.374 | 5012 | 357972.090 | | |

Grand Mean = 332.88116824500210

a The covariance matrix is calculated and used in the analysis.

## Temperature Variables

Case Processing Summary

| | | N | % |
|---|---|---|---|
| **Cases** | **Valid** | 213 | 36.7 |
| | **Excluded(a)** | 367 | 63.3 |
| | **Total** | 580 | 100.0 |

a Listwise deletion based on all variables in the procedure.

Reliability Statistics

| Cronbach's Alpha | Cronbach's Alpha Based on Standardized Items | N of Items |
|---|---|---|
| .537 | .444 | 15 |

Item Statistics

| | Mean | Std. Deviation | N |
|---|---|---|---|
| **C1** | .07417840375587 | .163620321266652 | 213 |
| **C2** | .58084507042254 | .498036938310142 | 213 |
| **C3** | 98.53981220657270 | .846964592631871 | 213 |
| **iC4** | .77366197183099 | .672579320081844 | 213 |
| **nC4** | .03046948356808 | .150980335025310 | 213 |
| **4TI6009.PV** | 96.02691270711830 | 1.151548180442863 | 213 |
| **4TI6204.PV** | 44.95142950138576 | .365807218375046 | 213 |
| **4TI6205.PV** | 118.04151321126750 | 5.499390060330370 | 213 |
| **4TC6231.SP** | 131.18470316425730 | 12.482085355795660 | 213 |
| **4TC6231.PV** | 132.16368480281680 | 14.061264055360200 | 213 |
| **4TI6231.PV** | 116.22683332559640 | 3.001368500299624 | 213 |
| **4TI6214.PV** | 47.15534339152590 | 1.466056847828780 | 213 |
| **4TI6213.PV** | 53.23452024504610 | 3.608632312624981 | 213 |
| **4TI6202.PV** | 69.20279315715660 | 2.608833031042179 | 213 |
| **4TI6203.PV** | 101.61748576276170 | 2.047075171117764 | 213 |

Inter-Item Correlation Matrix

| | C1 | C2 | C3 | iC4 | nC4 | 4TI6009.PV | 4TI6204.PV | 4TI6205.PV | 4TC6231.SP | 4TC6231.PV | 4TI6231.PV | 4TI6214.PV | 4TI6213.PV | 4TI6202.PV | 4TI6203.PV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **C1** | 1.000 | .189 | -.397 | .079 | .172 | -.040 | -.003 | -.090 | -.073 | -.075 | .042 | -.006 | .028 | .065 | .061 |
| **C2** | .189 | 1.000 | -.515 | -.128 | -.043 | .100 | -.253 | -.112 | -.103 | -.095 | .146 | -.023 | .061 | .182 | .036 |
| **C3** | -.397 | -.515 | 1.000 | -.737 | -.202 | .138 | .035 | .229 | .127 | .122 | -.115 | -.171 | -.206 | -.171 | -.030 |
| **iC4** | .079 | -.128 | -.737 | 1.000 | .020 | -.259 | .128 | -.184 | -.043 | -.043 | .006 | .211 | .194 | .046 | -.003 |
| **nC4** | .172 | -.043 | -.202 | .020 | 1.000 | .094 | .068 | -.004 | -.102 | -.098 | .089 | .099 | .055 | .083 | .002 |
| **4TI60** | - | .1 | .1 | - | .0 | 1.000 | -.152 | .080 | -.289 | -.283 | .364 | -.156 | -.084 | .216 | .215 |

| | C1 | C2 | C3 | iC4 | nC4 | 4TI6009.PV | 4TI6204.PV | 4TI6205.PV | 4TC6231.SP | 4TC6231.PV | 4TI6231.PV | 4TI6214.PV | 4TI6213.PV | 4TI6202.PV | 4TI6203.PV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **09.PV** | .040 | 00 | 38 | .259 | 94 | | | | | | | | | | |
| **4TI6204.PV** | -.003 | -.253 | .035 | .128 | .068 | -.152 | 1.000 | .021 | -.014 | -.019 | .135 | .803 | .657 | .284 | .019 |
| **4TI6205.PV** | -.090 | -.112 | .229 | -.184 | -.004 | .080 | .021 | 1.000 | .163 | .179 | .170 | -.013 | .014 | -.006 | .095 |
| **4TC6231.SP** | -.073 | -.103 | .127 | -.043 | -.102 | -.289 | -.014 | .163 | 1.000 | .994 | -.022 | -.092 | -.030 | -.028 | .033 |
| **4TC6231.PV** | -.075 | -.095 | .122 | -.043 | -.098 | -.283 | -.019 | .179 | .994 | 1.000 | -.030 | -.095 | -.032 | -.025 | .020 |
| **4TI6231.PV** | .042 | .146 | -.115 | .006 | .089 | .364 | .135 | .170 | -.022 | -.030 | 1.000 | .183 | .177 | .387 | .559 |
| **4TI6214.PV** | -.006 | -.023 | -.171 | .211 | .099 | -.156 | .803 | -.013 | -.092 | -.095 | .183 | 1.000 | .888 | .388 | .054 |
| **4TI6213.PV** | .028 | .061 | -.206 | .194 | .055 | -.084 | .657 | .014 | -.030 | -.032 | .177 | .888 | 1.000 | .570 | .103 |
| **4TI6202.PV** | .065 | .182 | -.171 | .046 | .083 | .216 | .284 | -.006 | -.028 | -.025 | .387 | .388 | .570 | 1.000 | .318 |
| **4TI6203.PV** | .061 | .036 | -.030 | -.003 | .002 | .215 | .019 | .095 | .033 | .020 | .559 | .054 | .103 | .318 | 1.000 |

The covariance matrix is calculated and used in the analysis.

Inter-Item Covariance Matrix

| | C1 | C2 | C3 | iC4 | nC4 | 4TI6009.PV | 4TI6204.PV | 4TI6205.PV | 4TC6231.SP | 4TC6231.PV | 4TI6231.PV | 4TI6214.PV | 4TI6213.PV | 4TI6202.PV | 4TI6203.PV |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **C1** | .027 | .015 | -.055 | .009 | .004 | -.008 | .000 | -.081 | -.150 | -.172 | .021 | -.001 | .017 | .028 | .020 |
| **C2** | .015 | .248 | -.217 | -.043 | -.003 | .057 | -.046 | -.308 | -.642 | -.665 | .219 | -.017 | .110 | .237 | .037 |
| **C3** | -.055 | -.217 | .717 | -.420 | -.026 | .135 | .011 | 1.068 | 1.340 | 1.449 | -.291 | -.212 | -.629 | -.377 | -.053 |
| **iC4** | .009 | -.04 | -.420 | .452 | .002 | -.201 | .032 | -.680 | -.363 | -.411 | .012 | .209 | .472 | .081 | -.004 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 3 | | | | | | | | | | | | | |
| **nC4** | .004 | -.003 | -.026 | .002 | .023 | .016 | .004 | -.003 | -.192 | -.208 | .040 | .022 | .030 | .033 | .001 |
| **4TI6009.PV** | -.008 | .057 | .135 | -.201 | .016 | 1.326 | -.064 | .504 | -4.158 | -4.575 | 1.260 | -.264 | -.351 | .649 | .507 |
| **4TI6204.PV** | .000 | -.046 | .011 | .032 | .004 | -.064 | .134 | .042 | -.064 | -.097 | .148 | .431 | .868 | .271 | .014 |
| **4TI6205.PV** | -.081 | -.308 | 1.068 | -.680 | -.003 | .504 | .042 | 30.243 | 11.175 | 13.815 | 2.808 | -.105 | .268 | -.082 | 1.068 |
| **4TC6231.SP** | -.150 | -.642 | 1.340 | -.363 | -.192 | -4.158 | -.064 | 11.175 | 155.802 | 174.496 | -.836 | -1.690 | -1.358 | -.903 | .852 |
| **4TC6231.PV** | -.172 | -.665 | 1.449 | -.411 | -.208 | -4.575 | -.097 | 13.815 | 174.496 | 197.719 | -1.247 | -1.959 | -1.599 | -.922 | .590 |
| **4TI6231.PV** | .021 | .219 | -.291 | .012 | .040 | 1.260 | .148 | 2.808 | -.836 | -1.247 | 9.008 | .805 | 1.919 | 3.031 | 3.437 |
| **4TI6214.PV** | -.001 | -.017 | -.212 | .209 | .022 | -.264 | .431 | -.105 | -1.690 | -1.959 | .805 | 2.149 | 4.699 | 1.485 | .163 |
| **4TI6213.PV** | .017 | .110 | -.629 | .472 | .030 | -.351 | .868 | .268 | -1.358 | -1.599 | 1.919 | 4.699 | 13.022 | 5.364 | .759 |
| **4TI6202.PV** | .028 | .237 | -.377 | .081 | .033 | .649 | .271 | -.082 | -.903 | -.922 | 3.031 | 1.485 | 5.364 | 6.806 | 1.697 |
| **4TI6203.PV** | .020 | .037 | -.053 | -.004 | .001 | .507 | .014 | 1.068 | .852 | .590 | 3.437 | .163 | .759 | 1.697 | 4.191 |

The covariance matrix is calculated and used in the analysis.

Summary Item Statistics

| | Mean | Minimum | Maximum | Range | Maximum / Minimum | Variance | N of Items |
|---|---|---|---|---|---|---|---|
| **Item Means** | 67.320 | .030 | 132.164 | 132.133 | 4337.575 | 2518.883 | 15 |
| **Item Variances** | 28.125 | .023 | 197.719 | 197.696 | 8673.771 | 3767.061 | 15 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Inter-Item Covariances** | 2.020 | -4.575 | 174.496 | 179.070 | -38.143 | 291.802 | 15 |
| **Inter-Item Correlations** | .051 | -.737 | .994 | 1.731 | -1.349 | .059 | 15 |
| The covariance matrix is calculated and used in the analysis. | | | | | | | |

Item-Total Statistics

| | Scale Mean if Item Deleted | Scale Variance if Item Deleted | Corrected Item-Total Correlation | Squared Multiple Correlation | Cronbach's Alpha if Item Deleted |
|---|---|---|---|---|---|
| **C1** | 1009.73000800132700 | 846.754 | -.074 | .999 | .540 |
| **C2** | 1009.22334133466000 | 848.359 | -.087 | 1.000 | .542 |
| **C3** | 911.26437419851000 | 841.912 | .070 | 1.000 | .538 |
| **iC4** | 1009.03052443325200 | 848.234 | -.067 | 1.000 | .542 |
| **nC4** | 1009.77371692151500 | 846.613 | -.064 | .998 | .540 |
| **4TI6009.PV** | 913.77727369796400 | 857.732 | -.192 | .379 | .549 |
| **4TI6204.PV** | 964.85275690369700 | 842.844 | .146 | .725 | .538 |
| **4TI6205.PV** | 891.76267319381500 | 756.853 | .195 | .168 | .520 |
| **4TC6231.SP** | 878.61948324082500 | 335.259 | .777 | .989 | .222 |
| **4TC6231.PV** | 877.64050160226600 | 291.366 | .744 | .989 | .248 |
| **4TI6231.PV** | 893.57735307948600 | 814.416 | .132 | .492 | .531 |
| **4TI6214.PV** | 962.64884301355700 | 836.798 | .084 | .902 | .537 |
| **4TI6213.PV** | 956.56966616003600 | 811.916 | .103 | .870 | .535 |
| **4TI6202.PV** | 940.60139324792600 | 818.085 | .142 | .528 | .531 |
| **4TI6203.PV** | 908.18670064232100 | 823.707 | .155 | .359 | .531 |

Scale Statistics

| Mean | Variance | Std. Deviation | N of Items |
|---|---|---|---|
| 1009.80418640508300 | 846.075 | 29.087373552144740 | 15 |

ANOVA(a)

| | | Sum of Squares | df | Mean Square | F | Sig |
|---|---|---|---|---|---|---|
| **Between People** | | 11957.864 | 212 | 56.405 | | |
| **Within People** | **Between Items** | 7511308.334 | 14 | 536522.024 | 20552.836 | .000 |
| | **Residual** | 77478.232 | 2968 | 26.105 | | |
| | **Total** | 7588786.566 | 2982 | 2544.865 | | |
| **Total** | | 7600744.430 | 3194 | 2379.695 | | |
| Grand Mean = 67.32027909367220 | | | | | | |
| a The covariance matrix is calculated and used in the analysis. | | | | | | |