SYSTEM IDENTIFICATION MODELING FOR GASEOUS PILOT PLANT

AHMAD FIRDAUS BIN AB LAH

ELECTRICAL & ELECTRONICS ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
JUNE 2010

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by

Ahmad Firdaus bin Ab Lah

Project dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

JUNE 2010

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

(Ir. Dr. Idris bin Ismail)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

JUNE 2010

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.

(AHMAD FIRDAUS BIN AB LAH)

ACKNOWLEDGEMENT

First of all, I want to extend my gratitude to my supervisor, Ir. Dr. Idris bin Ismail for guiding me and giving full support throughout this project. Also, to Mr. Tri Chandra S. Wibowo for his support in training me on the operation of the plant using MATLAB. Not to forget, appreciation to Mr. Azhar bin Zainal Abidin for always be there when I need to use the lab and for supervising me during the experiments. Also for my family who are always giving me full support in doing this project and giving moral support I order to survive FYP. I also want to extend my appreciation to my friends who are always guiding me on this project and reports.

ABSTRACT

This project is about choosing the best system identification modeling for the gaseous pilot plant in Universiti Teknologi PETRONAS (UTP). The main activity for this project is developing suitable model for process using various techniques. System identification modeling is done by conducting experiments in the pilot plant laboratory to collect all input-output data of parameters of interest. Using these input and output data, model estimation can be done by selecting appropriate range and models. Parametric model estimation will be used in this project. Several techniques have been chosen to be investigated. They are Auto-Regressive with Exogenous Input (ARX), Auto-Regressive Moving Average with Exogenous Input (ARMAX), Box-Jenkins and state-space. These modeling techniques are conduct based on the procedures that already designed for those techniques. Using available modeling techniques in the MATLAB, it will be easier to carry out the experiment. After all the experiments are done, the best technique is chosen based on best fit criterion and Akaike's Final Prediction Error (FPE).

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

System identification for a plant can be achieved by using several modeling techniques. System identification is used to model the behavior of a process. These modeling techniques are separated into two categories which are linear and non-linear method.

Linear system identification is easier to implement compared to non-linear system identification but a lot of system nowadays are non-linear system. Linear system identification is not as flexible as non-linear system identification. It also cannot always ensure robustness [1]. Non-linear system can be described as a system that is not directly proportional to its input [3]. There are a lot of non-linear system identification techniques such as ARX, ARMAX, Box-Jenkins and State-Space modeling.

This project is carried on the gaseous pilot plant in UTP. Experiment is carried for data acquisition of input and output data. The data gathered from the plant is pressure of the main tank as output and valve opening as input. Selection of suitable parameter is important since the desired output must have big enough gain.

1.2 Problem Statement

Gaseous pilot plant located in Block 23 is one of the plants that available for student to learn about process control system in UTP. This plant consists of one main tank (VL-212), one buffer tank (VL-202), three control valve (PCV-202, FCV-211 and PCV-212). It has continuous air feed at 7 barg from a centralized compressor [10]. Figure 1 shows the overview of the plant. This plant can be multiple input single output (MISO) system, but for this project, single input and single output system (SISO) will be considered. From this plant, input data in form of valve opening and output in form of pressure will be gathered. From the data, model of the plant will be constructed using several techniques. However, not all techniques are suitable and precise for all type of plant. So, a study must be carried to investigate which technique is the best system identification modeling technique for the modeling pressure behavior of gaseous pilot plant in UTP.

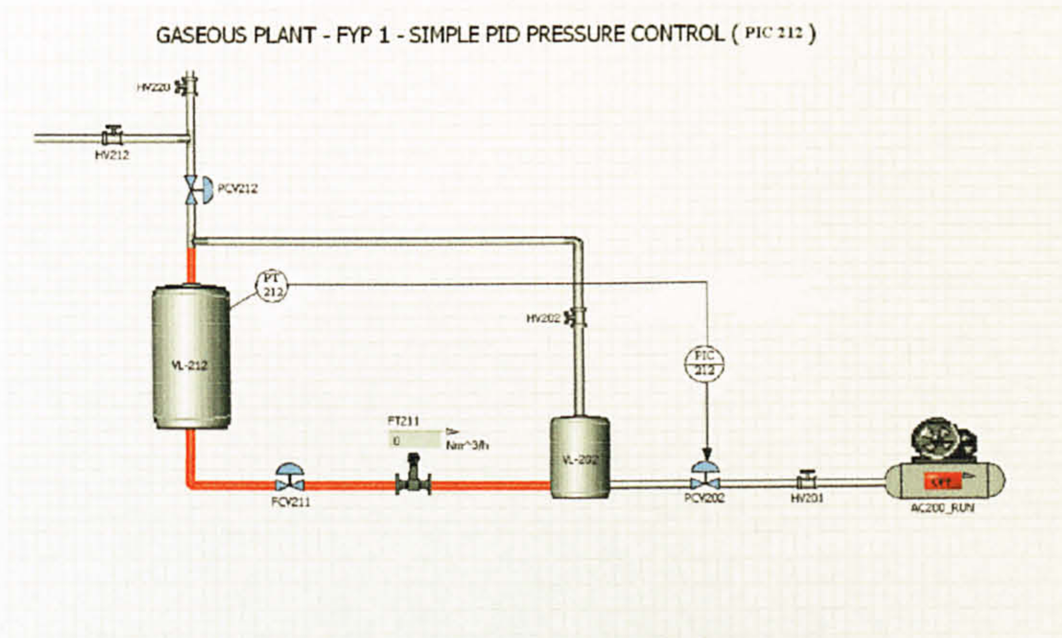


Figure 1: Gaseous Pilot Plant Overview

1.3 Objective

The main objective of this study is to investigate and implement system identification technique and propose solution for pressure behavior of gaseous pilot plant.

System identification technique is a method to represent the behavior of a process. This technique will generate a model of the process in various forms such as transfer function. System identification technique is very important in industrial process control since people can control and predict the output of the process based on the existing model. A good model should be able to represent the output of the process accurately if input data is given.

1.4 Scope of Study

A study on the gaseous pilot plant is essential for this project. This includes study on the process flow and important parameters. A study on how to use MATLAB XPC is very important since XPC is used to control the process flow and gather data from the plant. Basic MATLAB knowledge on how to gather data must be studied for data acquisition.

Various technique of system identification modeling will be studied such as ARX, ARMAX, Box-Jenkins and State-Space modeling. The study includes theories, implementation method, advantages and disadvantages.

After the required data is acquired, modeling process will be carried out in MATLAB. A good knowledge on MATLAB is essential for this project.

CHAPTER 2
LITERATURE REVIEW

2.1 ARX Modeling

ARX model is one of the parametric model structures that can represent the plant system [6]. The estimation of the ARX model is the most efficient of the polynomial estimation methods [8]. However, in ARX model, disturbance is part of the system dynamics [8]. This disadvantage can be reduced if the signal-to-noise ratio is good [8]. ARX model is a basic model in for several other models in parametric modeling [6]. The ARX model is represented by the equation [6]:

$$A(z^{-1})y(k) = B(z^{-1})u(k-d) + e(k) \tag{2.1}$$

Where,

$$A(z^{-1}) = 1 + a_1 z^{-1} + \cdots + a_{na} z^{-na}$$

$$B(z^{-1}) = b_1 + b_2 z^{-1} + \cdots + b_{nb} z^{-nb+1}$$

d = time delay

na = number of poles

nb = number of zeroes

$u(k)$ = input

$y(k)$ = output

$e(k)$ = noise

2.2 ARMAX Modeling

ARMAX model structure includes disturbance dynamics [8]. ARMAX model is useful when a lot of disturbance enter early in the system process, such as at the input [8]. The ARMAX model is represented by the equation [6]:

$$A(z^{-1})y(k) = B(z^{-1})u(k-d) + C(z^{-1})e(k) \qquad (2.2)$$

Where,

$$C(z^{-1}) = 1 + c_1 z^{-1} + \cdots + c_{nc} z^{-nc}$$

Based on investigation done by A. Florakis et. al (1998), it is proven that ARMAX can achieve better fit than ARX modeling [12]. In addition, a lower order model of ARMAX is required to get same result as ARX model [12]. J. C Yiu and S. Wang also mention about the advantages of ARMAX against ARX includes ability to deal with noise, high accuracy, accurate model parameter estimation and guaranteed algorithmic and model stability [13]. This doesn't mean that ARX is unreliable. ARX is effective, only ARMAX offer better accuracy and stability [13].

Although ARMAX seems to be better than ARX in results, it still have weaknesses. This includes difficulty of extrapolation beyond the range of training data and required a lot of training data [13].

2.3 State-Space Modeling

In state space modeling, state variables are used to describe a system by a set of first order differential or difference equations [9]. State space representation provides a convenient and compact way to model and analyze systems with multiple inputs and outputs [11]. It is the most suitable model for describing multiple inputs and multiple output system.

The advantage of state space modeling are only one structural decision to make, no iterative optimization involved, and less computational complexity [4]. The general representation for state-space models are [9]:

$$\begin{aligned} \dot{x}(t) &= Ax(t) + Bu(t) \\ y(t) &= Cx(t) + Du(t) \end{aligned} \tag{2.3}$$

2.4 Box-Jenkins Modeling

This method is also known as Autoregressive Integrated Moving Average (ARIMA) models. It was introduced by G. Box and G. Jenkins in 1970. It is used mainly for forecasting purpose. The modeling involves find the suitable process, fit it to the data and use that fitted data for forecasting [15].

The Box-Jenkins can be used to model stationary or nonstationary processes. A stationary process is a process that its properties are the same over time such as variation of data that fluctuate around the same mean value. A nonstationary process is a process that its properties changes over time such as changes in trends [14].

The interesting feature Box-Jenkins model is their ability to efficiently represent general nonstationary processes. For a process with trends that often change, like slope that changes every time in case of a pressure plant, Box-Jenkins model can represent that behavior accurately [14].

CHAPTER 3
METHODOLOGY

3.1 Procedure Identification

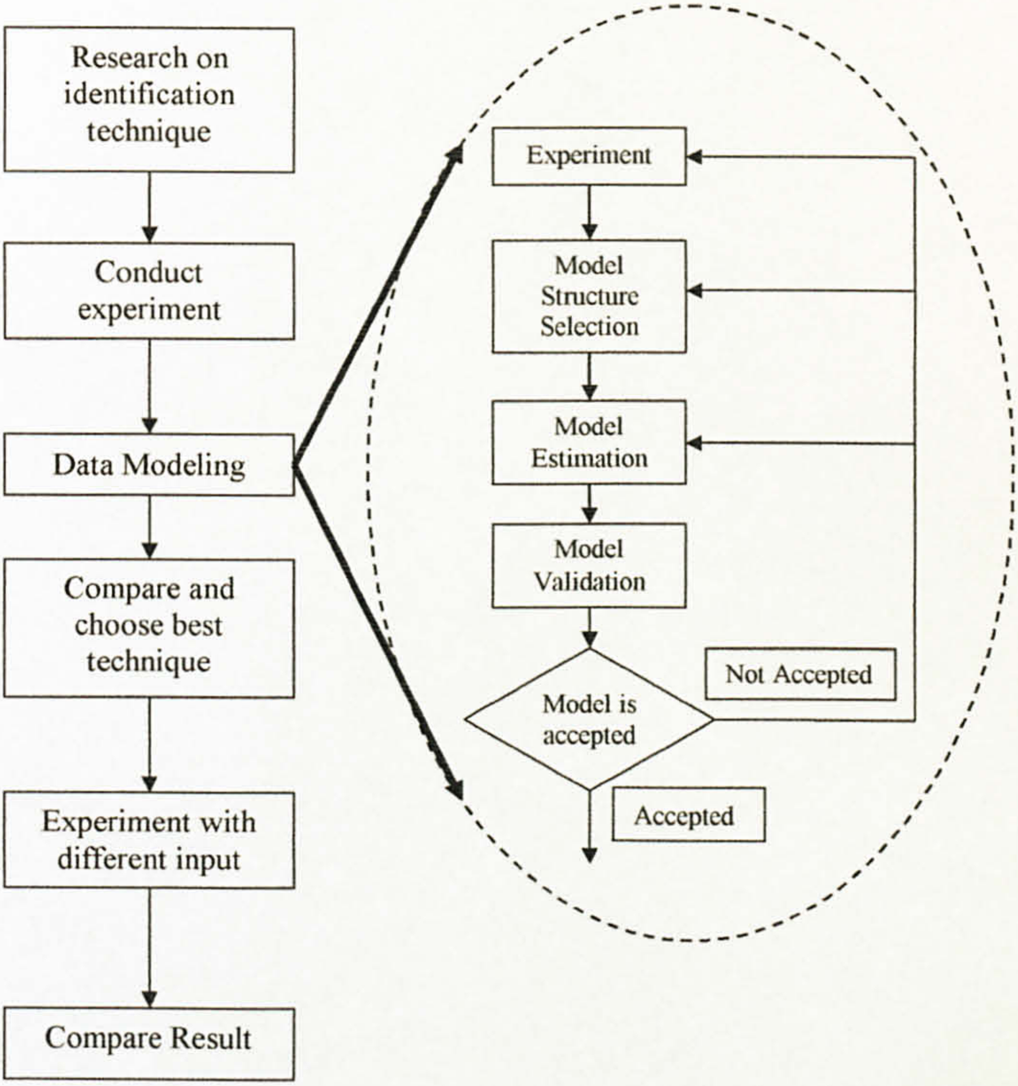


Figure 2: Project Flow Chart

In this project, flow chart in Figure 2 will be used as guideline to complete this project. Start with research on identification technique, various techniques will be evaluated and researched. Here, the advantages and disadvantages will be investigated. Research is done using available books obtained from UTP Information Resource Centre (IRC), research papers and guidance by supervisor, technician and a PhD student. This research also includes training on how to operate the plant using XPC tools.

Then, an experiment in gaseous pilot plant in UTP is conducted using by controlling the control valve and monitoring the pressure in the main tank. The system chosen here is single input and single output (SISO). The experiment is done in open loop environment. To start the experiment for data gathering, first all equipment must be powered on. The plant control mode must be in DCS mode because the there is no model yet in the XPC Target hardware. Then, MATLAB must be connected to the XPC Target hardware. Once connected, the Simulink model must be downloaded to the XPC Target hardware. Then, the sampling time is set to 1 second and sampling data is set to 10. Sampling time of 1 second is chosen because the process respond is not too fast, taking data every 1 second can still show accurate output. Besides, MATLAB cannot store the large number input/output in one time. If total data exceeds the maximum amount, the older data will be lost. Sampling data is set to 10 so the scope in MATLAB will update the reading on the screen for every 10 output data. This speed is sufficient to monitor changes in the output. Then, the process is started. The operating mode of the plant must be changed to XPC once the process is started.

The experiment is done by manipulating control valve PCV 212 in 20% to 40% of valve opening operating range and the pressure in main tank VL 212 is monitored using pressure transmitter PT 212. First experiment is done to get data for estimation. This experiment is done in linear mode where the controlled valve is changed from 40% to 20% and the pressure is monitored until it reaches steady state. The second experiment is done to get the data for validation. This experiment is done by waiting the pressure to achieve steady state at 40%

opening, and then it is varied in small opening changes from 20% to 40% and from 40% to 20% for every 3 minutes approximately. Then, the process is stopped and the data obtained is exported into .xls format for data analysis.

For data modeling, the data obtained is exported into a MATLAB with System Identification Toolbox available. Here, the data is analyzed and model is generated using ident function. For experiment part in data modeling, it is to obtain the input and output data. This experiment is done as stated before. Then structure selection is done. For this project, only one structure is chosen because we want to compare the performance of the techniques themselves, not finding the best structure for them to fit. Then, the models of the pressure behavior of them plant is generated for all techniques involved. These models are then validated using the data from second experiment. At this point, the data is evaluated based on error analysis methods. Here, the performance of the data can be seen.

For comparing and choosing best techniques, best fit criterion and FPE is used to evaluate the models. Based on performance criteria of each method, the best technique is chosen.

Then, a new experiment is done to check whether the model can represent the model if random and nonlinear changes are made. The second experiment consists of varying the input in small opening changes linearly up and down for a few cycles and random changes in nonlinear manner later on.

After evaluated the model with the new data, their performance is analyze. The result is then compared with previous result to check whether the model perform well or not and whether the same model come out as the best model.

Lastly, another data modeling is done using best model structure for each model. This modeling is very important since from here, best model for each identification technique can be investigated. The performance of each model is also expected to improve in this experiment. The parameter of each model structure in this experiment is chosen uniquely for each identification technique. The method chosen in order to find the best structure is trial and error method. This method is not an analytical as it is more into comparison. By testing each structure and modify a good structure, the best model structure can be found.

3.2 Tools and Equipments

- MATLAB 2007
- Gaseous Pilot Plant (pressure)
- Microsoft Excel 2007
- XPC Target
- Operator Workstation
- System Identification Toolbox

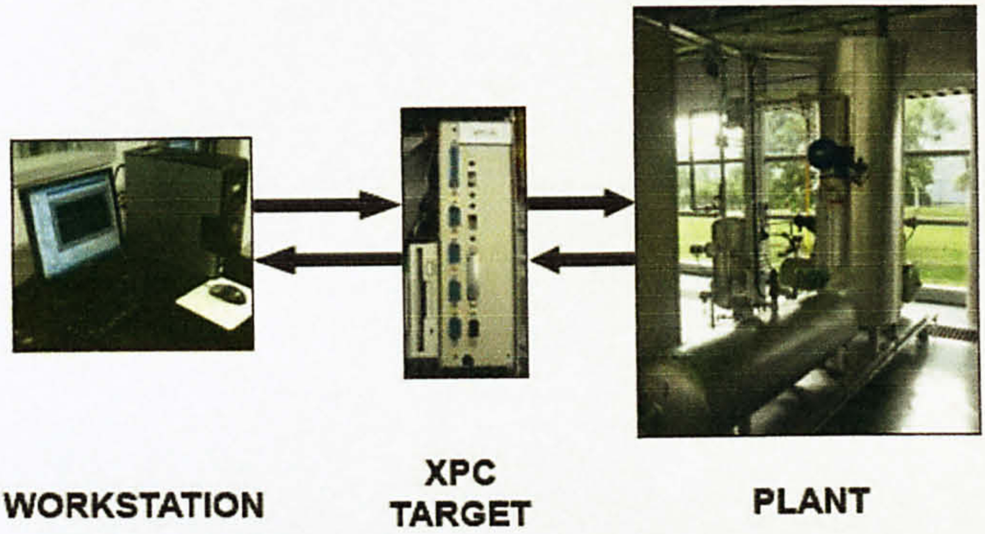


Figure 3: Plant Hardware Architecture

Figure 3 shows the architecture of plant control system. The plant is operated using Air Flow Process model that is created in Simulink MATLAB. The input that is given into the Simulink model will go to the desired control valve in the plant through the XPC Target since the input must be converted into suitable signal required by the valve. Then the output data from the transmitter in the plant will go to XPC Target to be processed into readable signal by the computer before it is displayed in the operator workstation.

The data gathered from this point must be exported because MATLAB will only keep the data for one experiment. If second experiment is done, MATLAB will reset all data. So, the data gathered must be converted into Microsoft Excel format using xlswrite command in the form xlswrite('filename', tg.out;1). The number '1' in the command is depending on the number of the output assigned in the Simulink model. Then the data must be imported back into the MATLAB for analysis. Using ident command, System Identification Toolbox is called. This tool is used to analyze the data gathered.

CHAPTER 4
RESULT AND DISCUSSION

4.1 Result

This experiment was done in open loop environment. The manipulated variable (MV) is opening of control valve PCV 212 and the controlled variable is the pressure of Tank 212 with the measurement taken from PT 212. The purpose of this experiment is to compare the model of ARX, ARMAX, Box-Jenkins and state-space. The operating range chosen for this experiment is 20% to 40% valve opening.

4.1.1 Experiment I

The data interpretation is done using MATLAB ident toolbox. Figure 4 shows experimental data that is used for estimation. This set of data is obtained by varying valve opening of PCV 212 from 20% to 40% in linear manner. This method is used to get a good model.

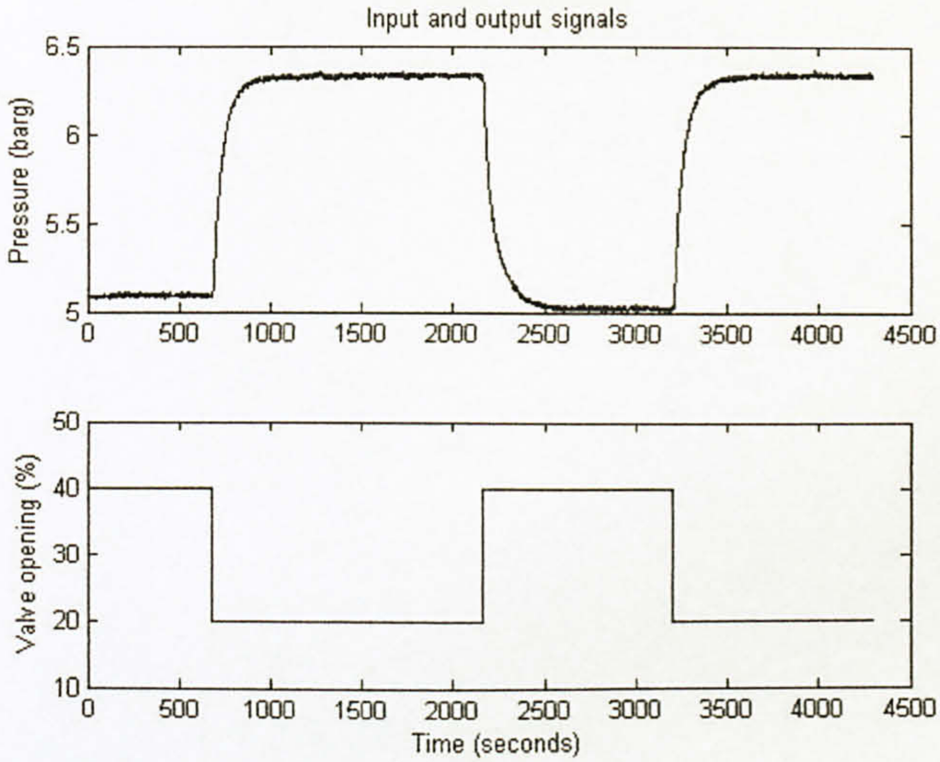


Figure 4: Input and Output Data for Estimation

Figure 5 shows data used for validation purpose. This input and output set is done by varying valve opening from 20% to 40% in small opening changes from 20%, 30%, 35%, 40% step change and reverse the values. This data is generated through short period with short changing period. Data from 150 second onward is taken into consideration because the previous data operate in 30% to 50% step change.

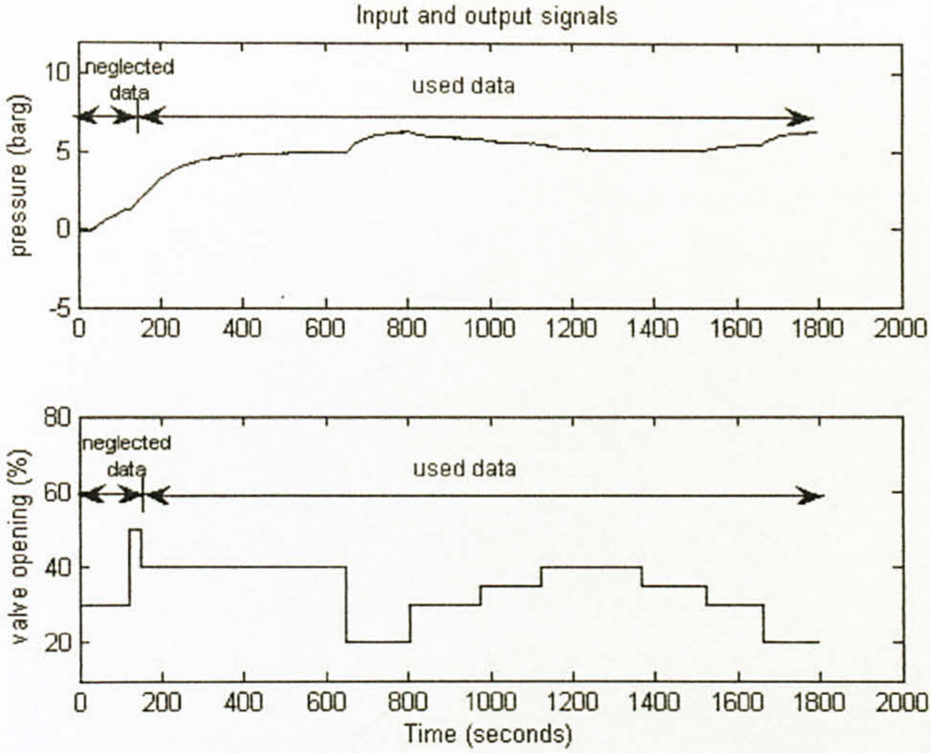


Figure 5: Input and Output Data for Validation Experiment I

Using parametric estimation, ARX, ARMAX, Box-Jenkins and state-space model are chosen to be evaluated.

After all models are estimated, the result is obtained as per Figure 6. The model structure used to find the model for each identification technique in this experiment is standardized. The value for each parameter is configured as follows:

$$na = 2 \tag{4.1}$$
$$nb = 2$$
$$nc = 2$$
$$nd = 2$$
$$nf = 2$$
$$nk = 2$$

Figure 6 shows the actual and simulated model output for parametric model estimation of second order system of the gaseous pressure plant.

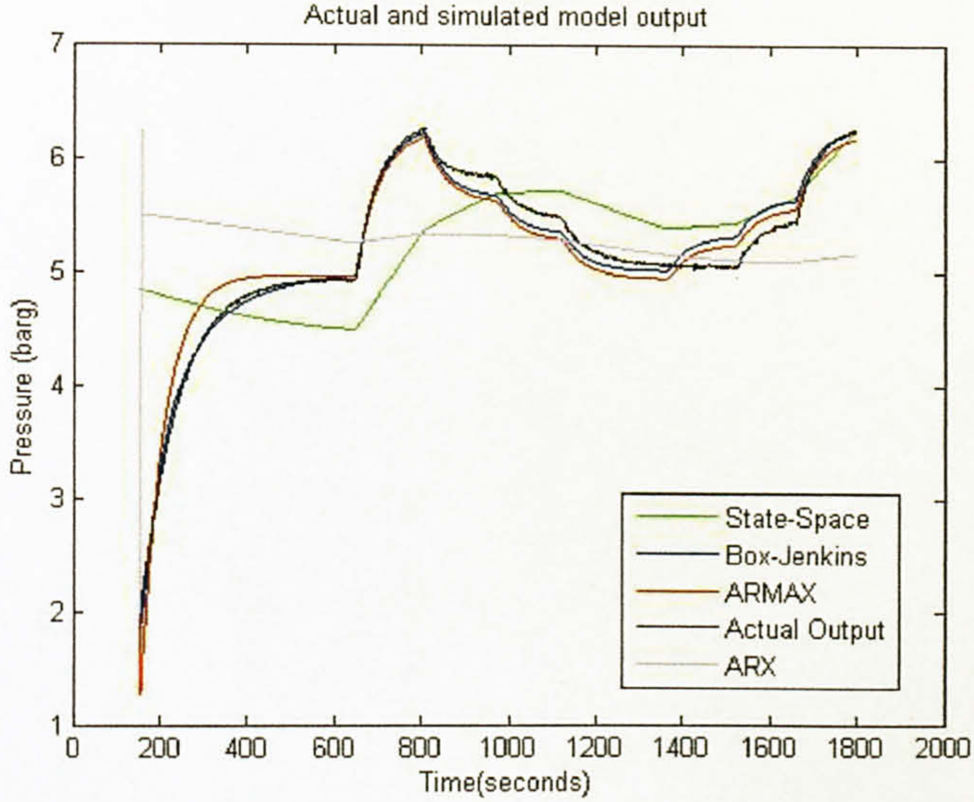


Figure 6: Model Output for Experiment I

In Figure 6 above, the green line represent ARX model, the blue line represent state-space model, the red line represent ARMAX model and the yellow line represent Box-Jenkins model.

The ARX model is obtained through equation:

$$A(q)y(t) = B(q)u(t) + e(t) \tag{4.2}$$

Where,

$$A(q) = 1 - 0.6938q^{-1} - 0.3066q^{-2}$$
$$B(q) = -0.0005368q^{-2} + 0.0004725q^{-3}$$

The ARMAX model is obtained from equation:

$$A(q)y(t) = B(q)u(t) + C(q)e(t) \tag{4.3}$$

Where,

$$A(q) = 1 - 1.981q^{-1} + 0.9812q^{-2}$$
$$B(q) = -0.001209q^{-2} + 0.001209q^{-3}$$
$$C(q) = 1 - 1.713q^{-1} + 0.7156q^{-2}$$

The Box-Jenkins model is obtained from equation:

$$y(t) = \left[\frac{B(q)}{F(q)}\right]u(t) + \left[\frac{C(q)}{D(q)}\right]e(t) \tag{4.4}$$

Where,

$$B(q) = -0.001225q^{-2} + 0.001225q^{-3}$$
$$C(q) = 1 - 0.9642q^{-1} + 0.1787q^{-2}$$
$$D(q) = 1 - 1.224q^{-1} + 0.2283q^{-2}$$
$$F(q) = 1 - 1.981q^{-1} + 0.9809q^{-2}$$

4.1.2 Experiment II

Second experiment uses the same input/output estimation data as in Experiment I which can be viewed in Figure 4. For validation data, different set of data is taken from different experiment with the same setting and operating range. Figure 7 shows input and output data used for validation in this experiment. The second set of validation data is generated through a long period by varying the input step change from 20% to 40% linearly for every 5 minutes approximately for 1 hour and then random generation of step change is done. The reason of using two validation data is to verify the result of first validation data and to see the performance of the model if random step input changes are made.

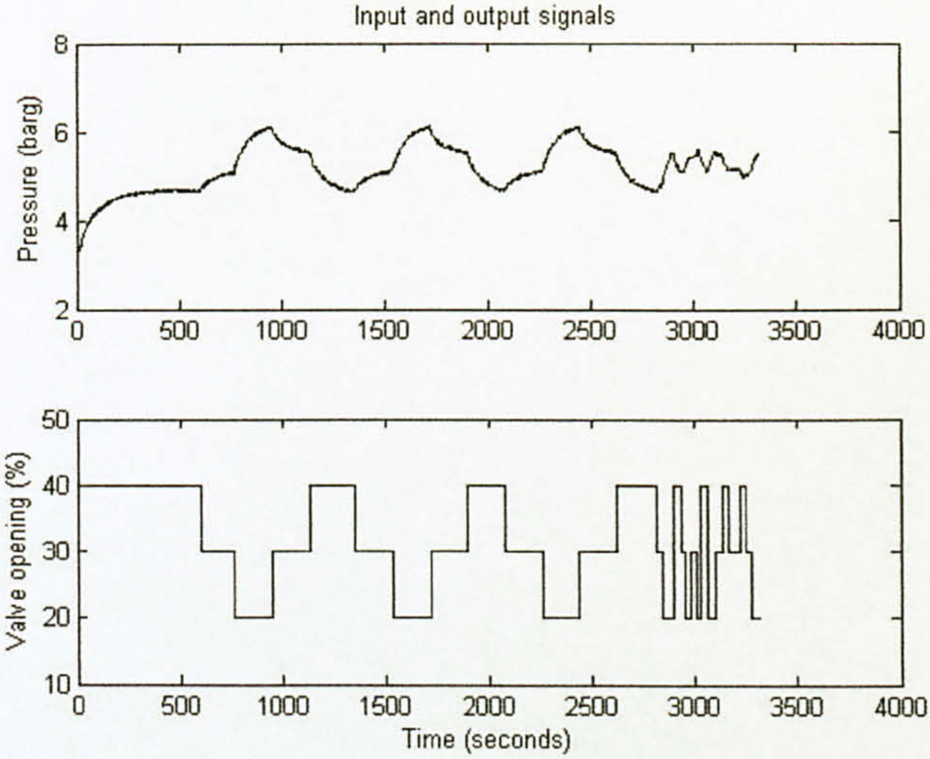


Figure 7: Input and Output Data for Validation for Experiment II

The same parametric estimations are used in this experiment as Experiment I. They are ARX, ARMAX, Box-Jenkins and state-space modeling. The same model structure as experiment I is used in this experiment.

After all models are estimated, the result as Figure 8 is obtained. Figure 8 shows Box-Jenkins, ARX, ARMAX and State-Space simulated models as compared to actual model where the green line represent ARX model, the blue line represent state-space model, the red line represent ARMAX model and the yellow line represent Box-Jenkins model.

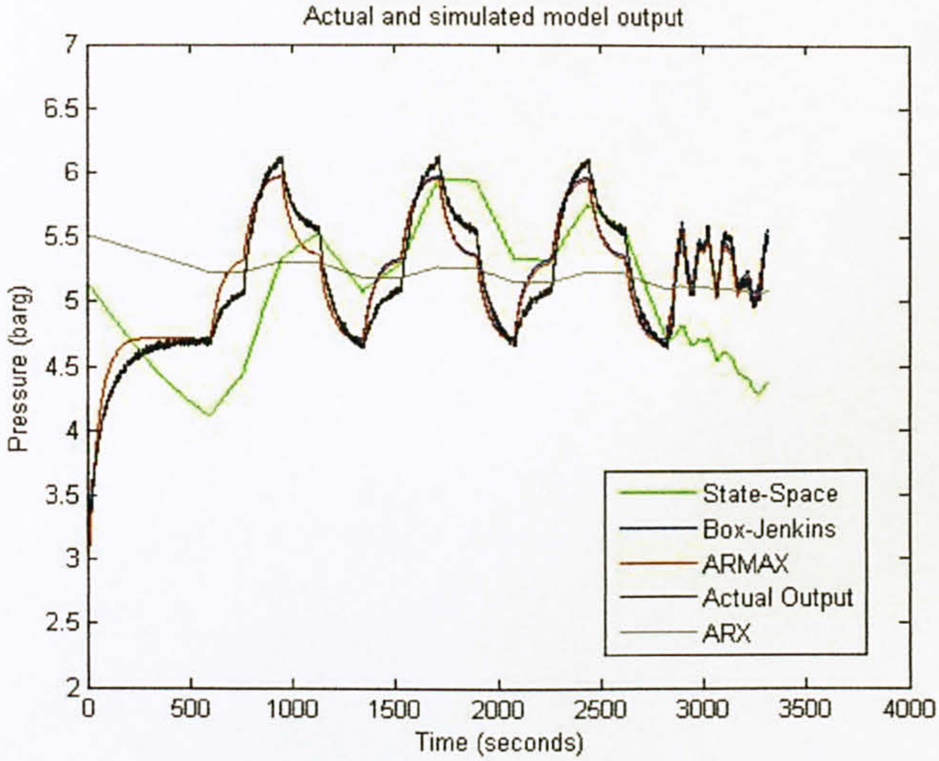


Figure 8: Model Output for Experiment II

Since same models are used for estimation as Experiment I, so all models' equations for Experiment II are the same as equation 4.2, 4.3 and 4.4 in Experiment I.

4.1.3 Best Model Structure

In this part, best model structure for each identification technique is searched and used to get the best model for each identification technique. The validation data used for this part is the same as validation data in Experiment I and Experiment II. The output plots for each identification technique is expected to improve and can closely match the actual output plot. Figure 9 and 10 shows the actual and simulated model output using the best model structure.

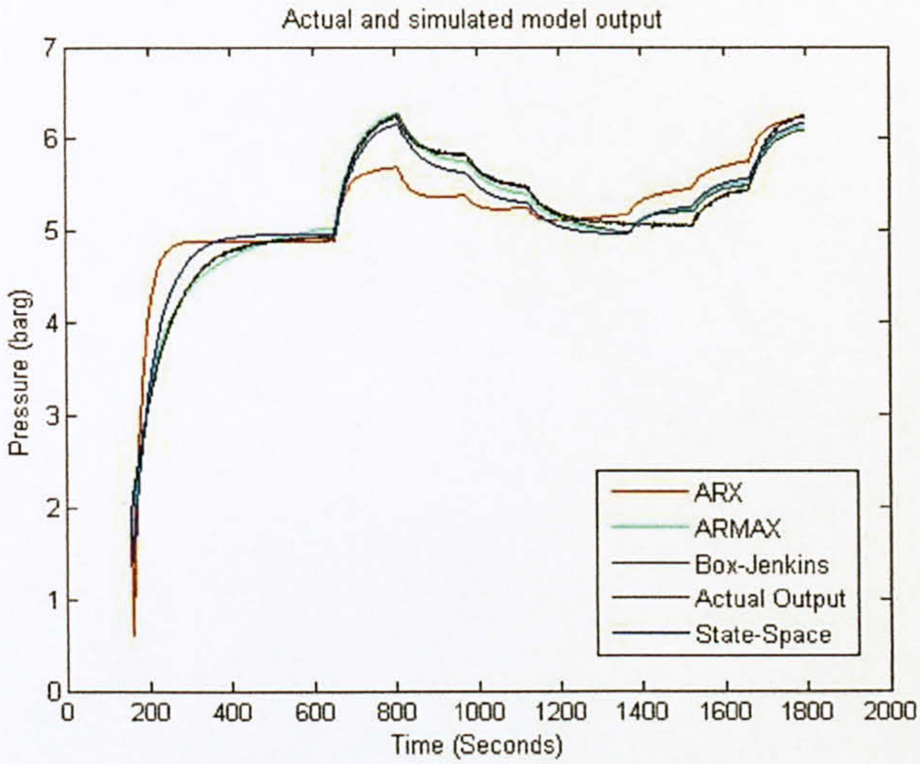


Figure 9: First Model Output Using Best Structure

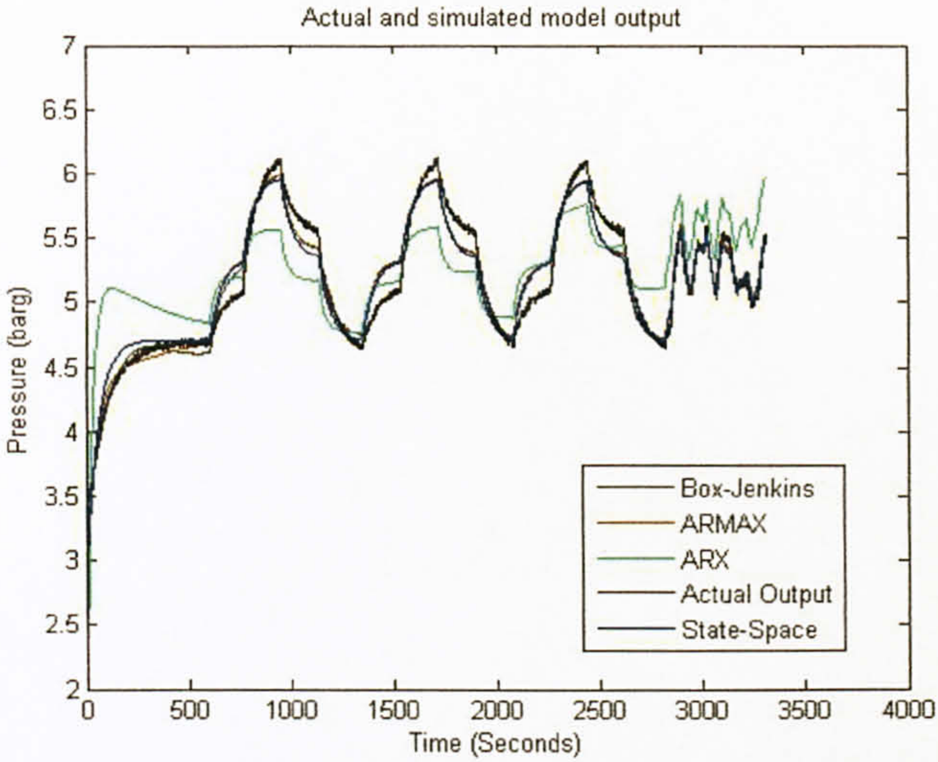


Figure 10: Second Model Output Using Best Structure

The values for each parameter in the model structure for each model in this part are different between each model. For ARX, the values are:

$$na = 10 \tag{4.5}$$
$$nb = 10$$
$$nk = 1$$

For ARMAX, the values for the parameters are:

$$na = 5 \tag{4.6}$$
$$nb = 10$$
$$nc = 10$$
$$nk = 5$$

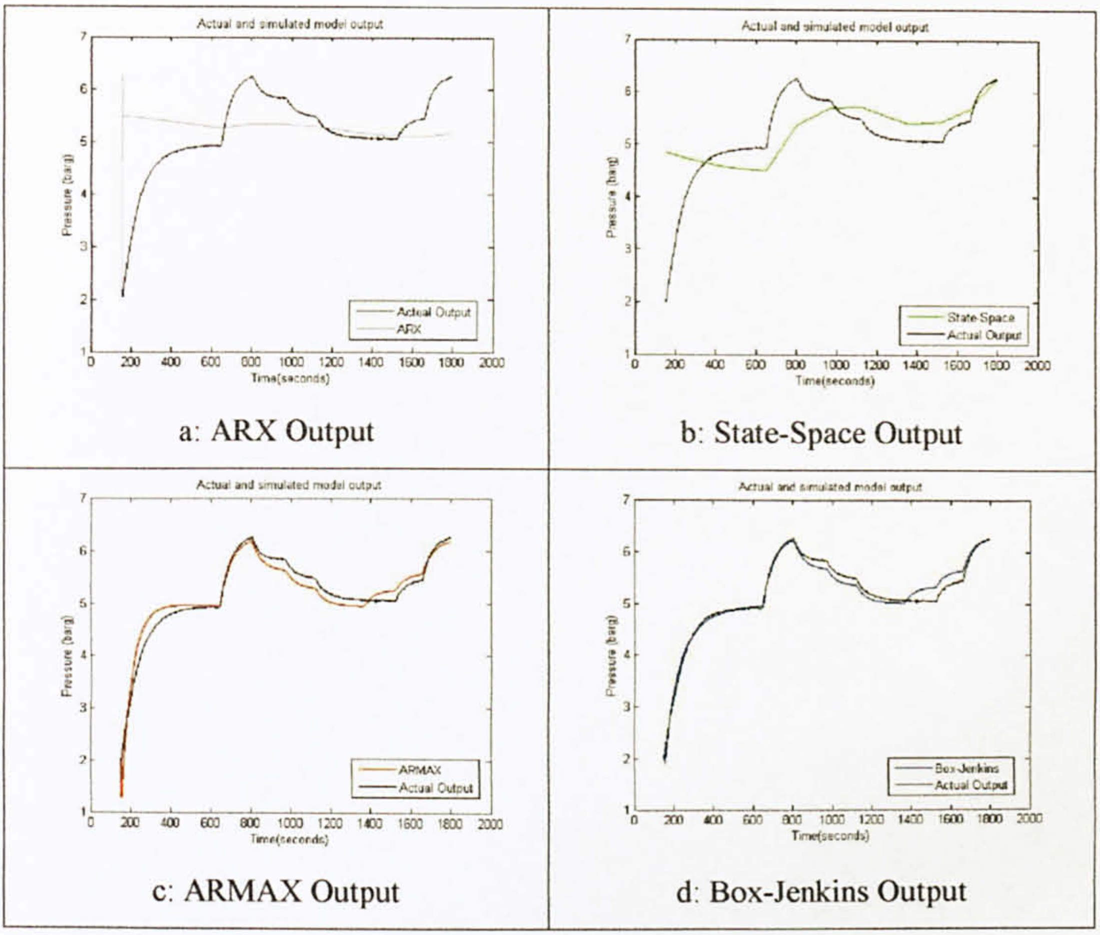
For state-space, the values used for each parameter are:

$$
\begin{aligned}
n &= 2 \\
nk &= 3
\end{aligned}
\tag{4.7}
$$

For Box-Jenkins method, the parameters are:

$$
\begin{aligned}
nb &= 10 \\
nc &= 10 \\
nd &= 10 \\
nf &= 10 \\
nk &= 7
\end{aligned}
\tag{4.8}
$$

4.2 Discussion



a: ARX Output

b: State-Space Output

c: ARMAX Output

d: Box-Jenkins Output

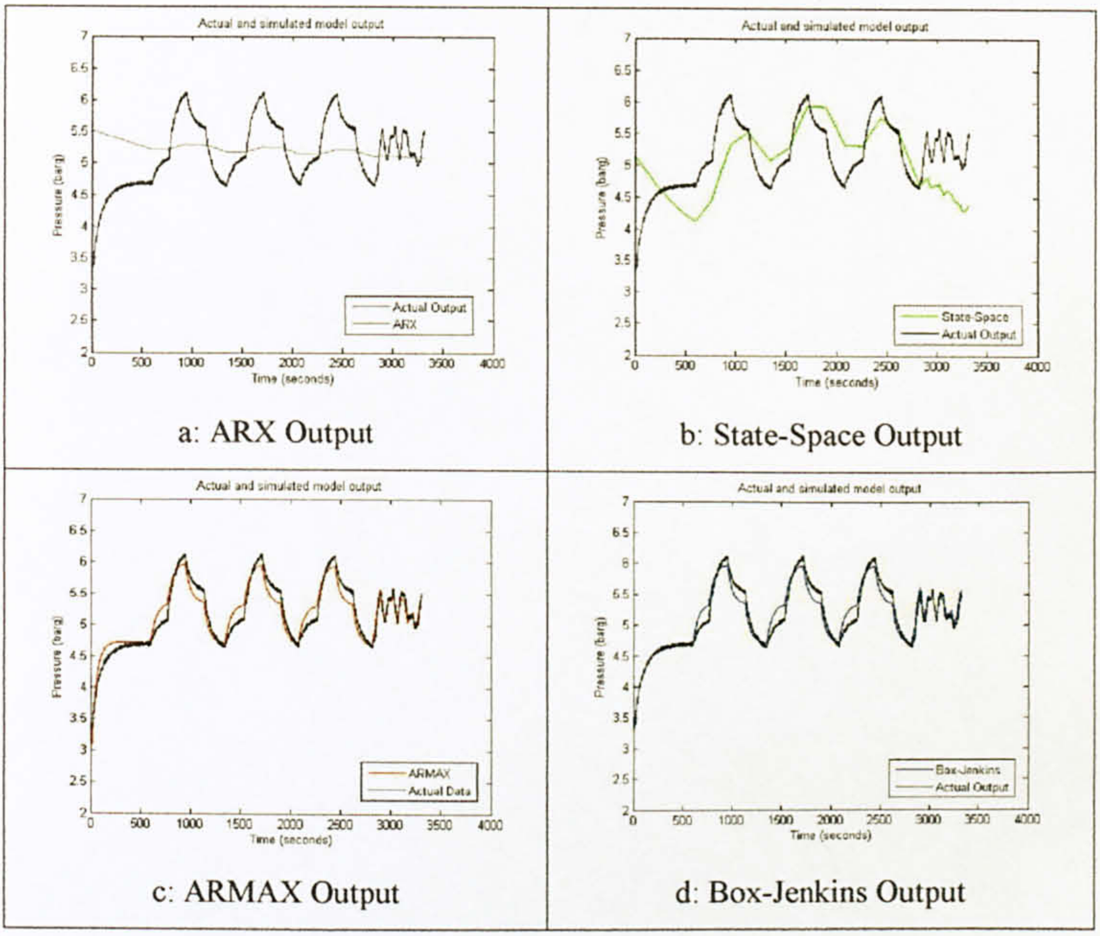
Figure 11: Simulated Output in Separate Graphs for Experiment I

Figure 11 shows the separate plot of each identification techniques. By looking at simulated output of each method, the only acceptable models to be chosen are ARMAX and Box-Jenkins because they are closely simulated the actual output. Next, analysis is done using best fit criterion.

Table 1: Best Fit Criterion for Experiment I

Model	Best Fit (%)
ARX	-7.277
ARMAX	77.23
State-space	17.45
Box-Jenkins	84.64

From best fit criterion result in Table 1, Box-Jenkins model shows the best model among all four models tested. As shown in Figure 12, the simulated Box-Jenkins model output is closely equal to the actual output of the plant.



a: ARX Output

b: State-Space Output

c: ARMAX Output

d: Box-Jenkins Output

Figure 12: Simulated Output in Separate Graphs for Experiment II

Figure 12 shows the separate plot for each modeling method used. In here also, only ARMAX and Box-Jenkins model which shows the simulation output closely represent the actual output. Best fit criterion is used next to evaluate the model based on error analysis.

Table 2: Best Fit Criterion for Experiment II

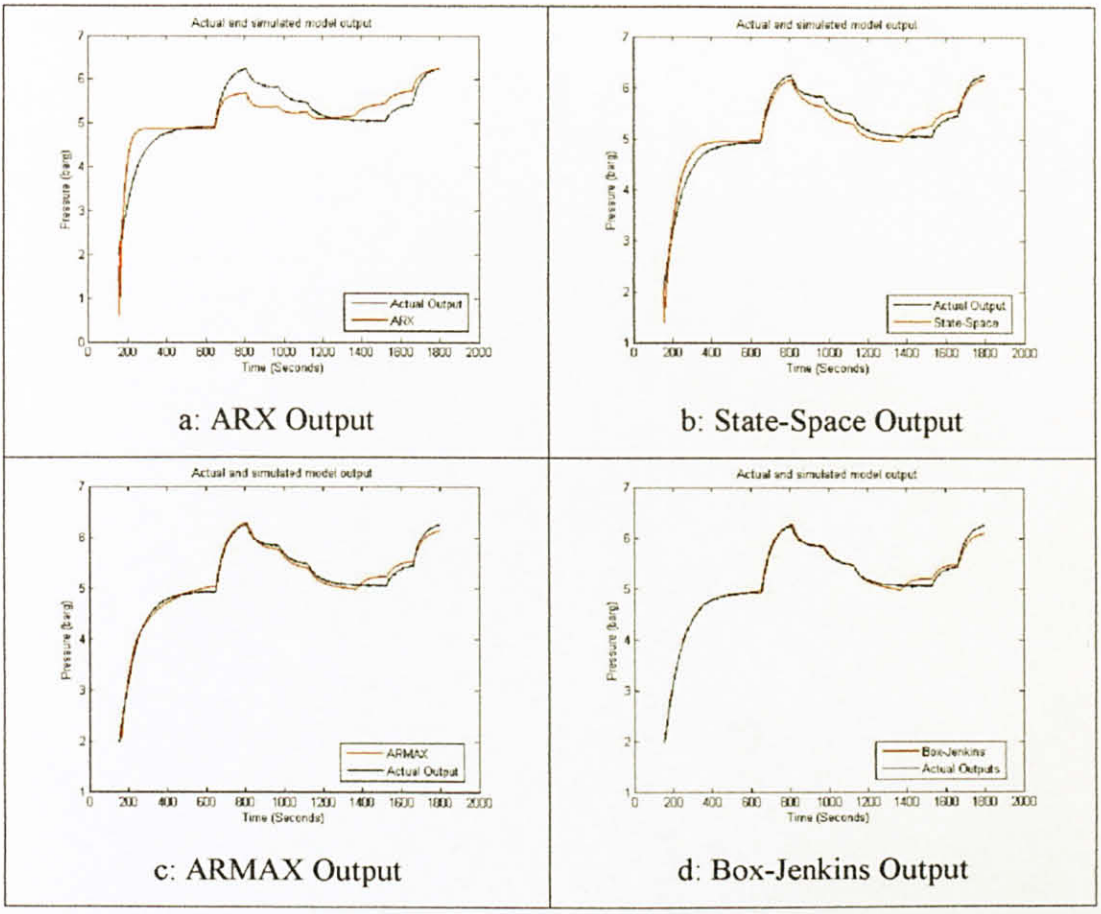
Model	Best Fit (%)
ARX	-7.69
ARMAX	73.61
State-space	-0.7301
Box-Jenkins	75.45

Based on best fit criterion shows in Table 2, Box-Jenkins shows the best model of all modeling techniques used. The higher the best fit value, the better the model. Figure 12 shows that the simulated output by Box-Jenkins and ARMAX model can closely represent the actual output of the plant. Since Box-Jenkins shows the highest best fit value, it is chosen to be the best modeling technique for this method.

Table 3:Akaike's Final Prediction Error

Model	Akaike's Final Prediction Error
ARX	7.56965×10^{-5}
ARMAX	5.46358×10^{-5}
State-space	6.06003×10^{-5}
Box-Jenkins	5.49819×10^{-5}

For FPE, the most accurate model must have the smallest value of FPE [20]. Based on this fact, ARMAX is chosen to be the most accurate model since it has the smallest number of FPE. For analysis using FPE, ARMAX is chosen to be the best modeling technique.



a: ARX Output

b: State-Space Output

c: ARMAX Output

d: Box-Jenkins Output

Figure 13: First Simulated Model Output for Best Model Structure

Figure 13 shows the output plots of first validation data for each identification technique using the best model structure. All of the models show improved performance in the plot. However, ARX performance is still far from good since the simulated output plot is not in the acceptable range although it can produce identical shape. Box-Jenkins shows the best simulated plot of all identification method used.

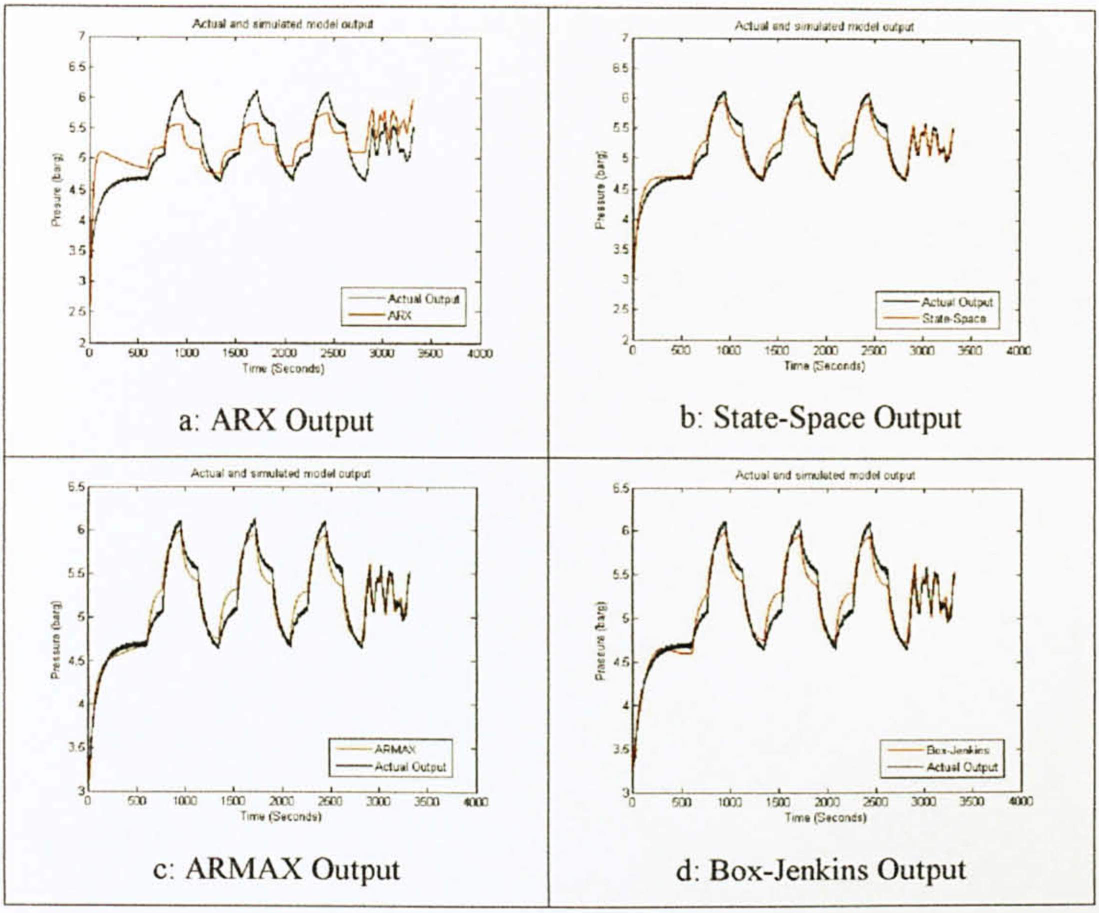


Figure 14: Second Simulated Model Output for Best Model Structure

Figure 14 shows the simulated output plot of second validation data using each model with best structure. Here, all models show improved performance too. All models' simulated outputs are close to actual output except for ARX. Although improved model structure is used, ARX still does not shows excellent result as other identification techniques.

Table 4: First Best Fit Criterion for Data Using Best Structure

Model	Best Fit (%)
ARX	49.66
ARMAX	89.02
State-space	79.24
Box-Jenkins	91.7

Table 5: Second Best Fit Criterion for Data Using Best Structure

Model	Best Fit (%)
ARX	33.50
ARMAX	77.23
State-space	75.62
Box-Jenkins	78.46

Table 4 and Table 5 shows the best fit criterion error analysis for first validation data and second validation data using best structure for each model. From both table, Box-Jenkins still appear to be the best model identification technique compared to other techniques used. This is expected because Box-Jenkins is the later improvement of ARX compared to ARMAX. So, it should show better performance than ARX and ARMAX. ARX however still is not performing well as other techniques. The factors that contribute to this problem may be insufficient data and existence of some undesirable (and unnoticeable) disturbance in the system.

So, there is two possible techniques can be chosen for best technique. If best fit criterion error analysis method is used, Box-Jenkins will be chosen and if FPE method is used, ARMAX will be chosen. Based on the analysis done, only ARMAX and Box-Jenkins are reliable model for the specific system in 20% to 40% operating range since they give good value of best fit criterion and show small values of FPE. ARX and state-space model shows the worst fit criterion for the system. However, this does not mean that the model is not suitable.

For this experiment, PCV 212 is controlled since it gives significant response to the system. Choosing PCV 202 is not suitable since the output gain is very small. Same model structure is used to estimate the model for each technique. The reason of using same model structure is to compare the performance of each modeling technique under the same condition.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In conclusion, for models those are evaluated using best fit criterion, Box-Jenkins technique appears to be the best technique with highest fit value followed by ARMAX, state-space and ARX respectively. For models evaluated using FPE, ARMAX come out to be the best technique to represent the pressure behavior of the plant at operating range of 20% to 40% with the lowest error value followed by Box-Jenkins, state-space and ARX respectively. The result has come out with two techniques for best technique because two different error analysis methods are used. So, basically the result depends on what method of error analysis is adopted to evaluate the models.

5.2 Recommendation

For further research, validation data taken should be in more random sequence. If the data is more random, the model may perform as good as in less random validation data. The error might be higher. Investigation also can be done to check whether the model is affected by more random data or not affected at all. More random data also may show the limitation of the modeling technique used because each technique handle the input and output data in different ways.

Best model structure of each model should be further investigated so each technique can show its best model of the plant. This model structure is not the same for every modeling technique. The model structures chosen may not be the best since the best fit results are not very close to 100%. In ARX case specifically, the model is still far from excellent. So, further investigation for the structure and configuration during modeling process should be carried on to find better model for ARX.

More error analysis methods should be adopted to evaluate to performance of the model. If more error analysis methods are used, the best technique can be chosen by selecting the most frequent technique that appear as the best technique for individual method.

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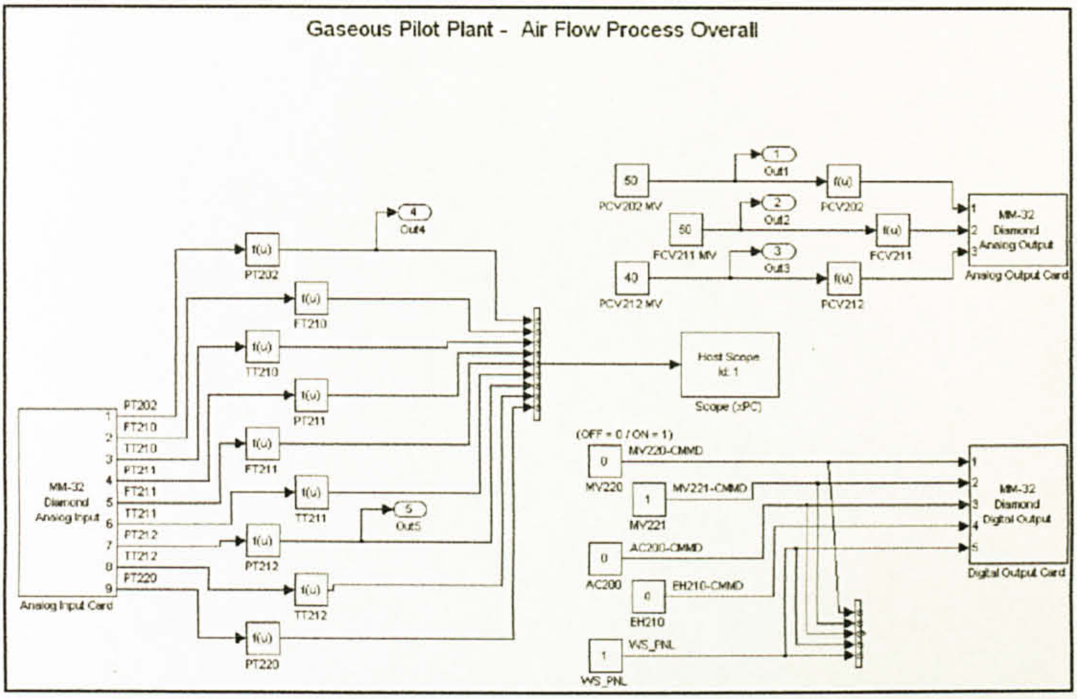
APPENDICES

APPENDIX A

SIMULINK DIAGRAM FOR AIR FLOW PROCESS



GANTT CHART FOR FYP 1

No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■													
2	Preliminary Research Work		■	■	■										
	-Data Gathering		■	■	■										
	-Research on the Topic		■	■	■										
3	Research on Identification Method		■	■	■										
4	Submission of Preliminary Report					■									
5	Project Work						■	■							
	-Experiment in Gaseous Pilot Plant and Modeling						■	■							
6	Submission of Progress Report								■						
7	Seminar													■	
8	Submission of Interim Report Final Draft													■	
9	Submission of Interim Report														■

■ Work Done

APPENDIX B

GANTT CHART FOR FYP 2

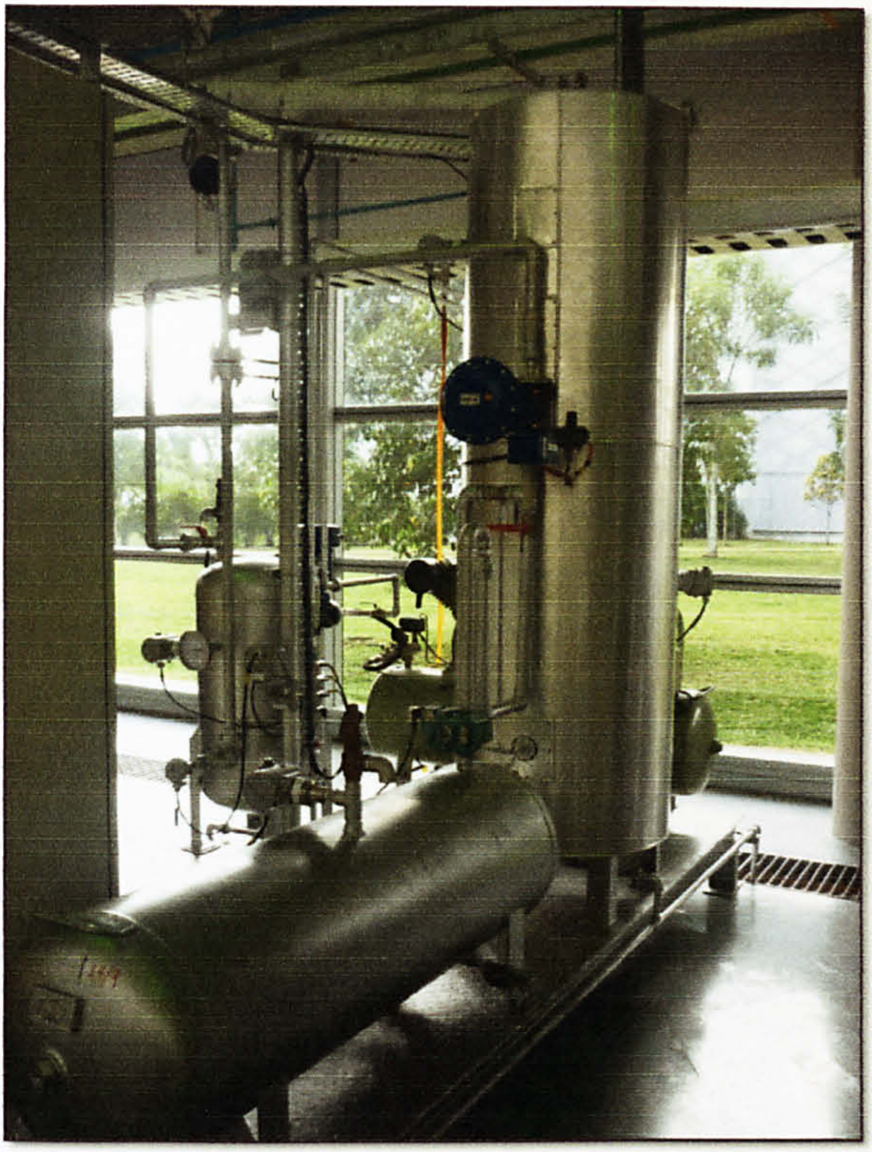
No.	Detail/ Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Literature Review														
2	Conduct Second Experiment														
	- Device failure for first time														
	- Experiment success for second time														
3	Data Modeling														
4	Data Analysis														
	- Best fit criterion														
	- Akaike's FPE														
5	Report Preparation														
6	Report Submission														

Work Done

APPENDIX C

APPENDIX D

GASEOUS PLANT SYSTEM

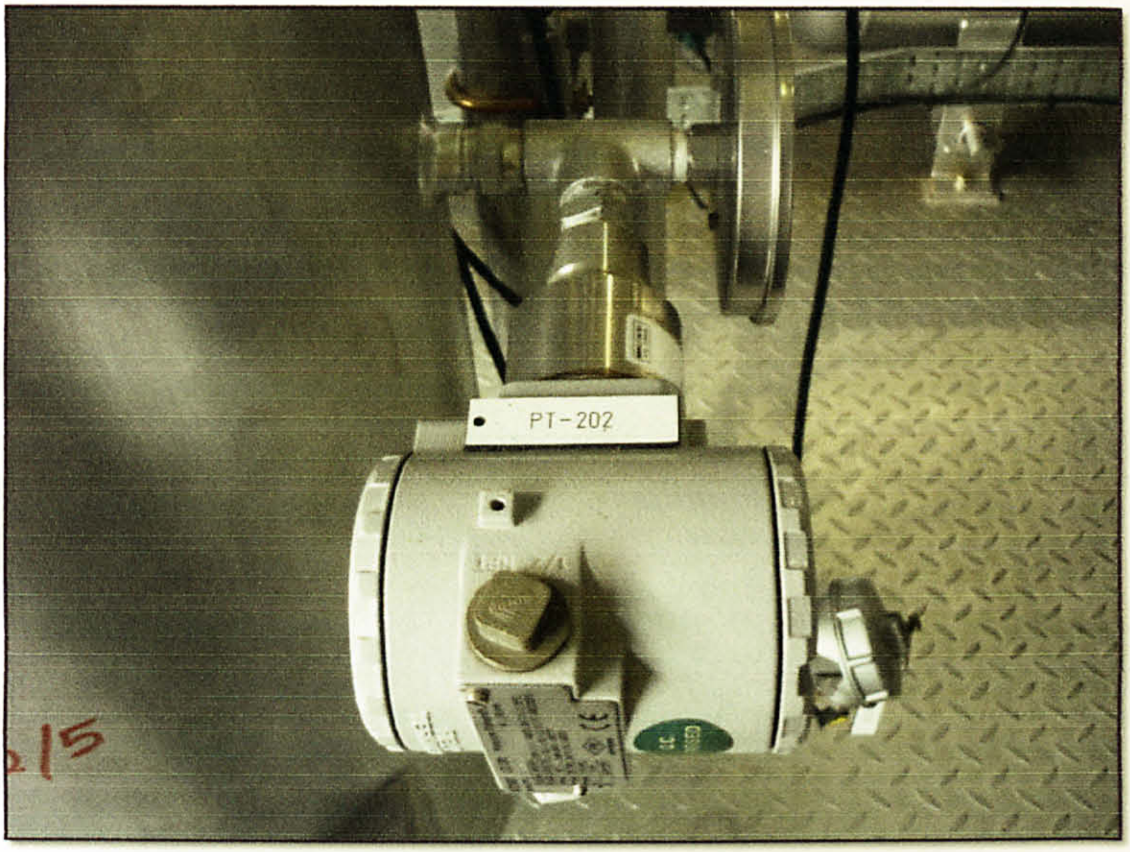


APPENDIX E

BUFFER TANK

APPENDIX F

TRANSMITTER



APPENDIX G
CONTROL VALVE