RITSUMEIKAN ASIA PACIFIC UNIVERSITY

A Systematic Quantitative Approach in Adoption of New Technology

By

David Emmanuel S. Ong

3/1/2014

Independent Final Report Presented to Professor Shayan Ebrahim of Ritsumeikan Asia Pacific University in Partial Fulfillment of the Requirements for the Degree of Master of Business Administration

ACKNOWLEDGEMENTS

My sincerest gratitude goes out to the following people, who have in one way or another made this report possible:

First and foremost I would like to thank the Lord almighty for guiding in accomplishing this task.

I would like to express my sincere thanks to my adviser Professor SHAYAN Ebrahim, for his patience and sharing with me his vast knowledge and experience in the field of engineering. Thank you for your unwavering help and guidance all throughout this gargantuan task.

I would like to thank my parents and grandparents for providing me the never ending support and love allowing me to fulfill my dreams and continuously reach out for them.

To my sister and Matteo for helping me figure out and continuously improve myself.

To the entire staff of PCC, Pinky, Raquel, Engineer Capuno, Frank, Rene, Leni, and especially Ronald without your support this report wouldn't have been possible.

To my love Monica for giving me all the love, inspiration and support and for always pushing me to be the best I can be!

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Certification Page

I hereby confirm that the content of this report, "A Systematic Quantitative Approach in Adoption of New Technology", is my own work and that it has been cited properly in accordance with the APA citation style.

David Emmanuel S. Ong

Abstract

The industrial gas industry is a continuous and versatile market such that various sources and gas utilization emerge due to the exponential growth in technology. In this study we consider manufacturing for food grade liquid carbon dioxide (CO_2). Pacific Carbonic Corporation (PCC) is a company based in the Philippines and has continuously progressed with the carbon dioxide manufacturing process. In particular, the quality sector of production provides a critical control point for manufacturing food grade CO_2. Most CO_2 quality systems provide gas analysis through quantitative methods. Manufacturing systems for CO_2 are configured such that gas is often tested as final product prior to customer delivery. This research aims at developing a systematic quantitative analysis leading to making objective decisions on feasibility and superiority of adoption of gas testing technology in CO_2 manufacturing state providing real time results and eliminating subjective testing due to human error.

The study conducted utilized various theories including reliability, Markov analysis, decision analysis, and simulation. The data utilized in order to obtain reasonable results were collected and compiled from primary data within the plant. A data set of three years from 2010 – 2012 was used as a reference for characterizing the behavior of the plant's system and its modules.

The results from the study assessed the performance of the plants current operation system, its production status and capability through modeling. The technology which

may be incorporated with the system was assessed with the aid of decision analysis method's and through basic mapping of a simulation of the plant's production system. It revealed that the return on investment for the quality results achieved are well justified.

Title: A Systematic Quantitative Approach in Adoption of New Technology

Chapter 1: Introduction

1.1. Introduction

A carbon dioxide capture plant situated in the Philippines Pacific Carbonic Corporation (PCC) is involved in producing bulk liquefied carbon dioxide (CO_2). The CO_2 plant is situated beside an alcohol fermentation plant. Raw CO_2 gas is emitted by alcohol fermenter units at a theoretical rate of 1,800m^3/hr. This amount of CO_2 emissions are then translated for industrial utilization instead of becoming toxic hazardous chemicals accumulating as greenhouse gases to the atmosphere. Carbon dioxide emissions have been a widely disputed topic with respect to climate change and environment sustainability. A large amount of carbon dioxide emissions may come from sources such as power plants, cement production factories, iron and steel industries, petrochemical, bioethanol, bioenergy, oil and gas processing plants and other sources (Metz, Ogunlade, de ConincK, Loos, & Meyer, 2005). In order to solve the problem of the exponential increase of CO_2 emissions, there have been various alternative solutions such as pumping CO_2 into oil and gas fields, coal beds, and deep saline aquifers (CO2CRC, 2011). An amendment to the international treaty by the United Nations Framework Convention on Climate Change titled, the Kyoto protocol was also a proposed solution. Industrialized nations which ratified to the Kyoto protocol agree to reduce emissions of greenhouse gases contributing to global warming, gases emitted would include: carbon dioxide, methane, nitrous oxide, sulfur hexafluoride, HFC's and PFC's (West, 2013). PCC is capable of reducing CO_2 emissions and translating it for industrial purposes. Utilization for CO_2 may be seen in the following industries: food and beverage, electronics, metal fabrication and fire-fighting equipment.CO_2consumption continues to grow as new markets emerge for the capture and utilization of the product. Alongside the growth of its market base, PCC's introduction of strict quality assurance methods was implemented on August 2004. This was in partial compliance to strict vendor-supplier agreement to Coca-Cola quality assurance measures. Liquefied CO_2 manufactured under sub-par quality parameters may cause problems over the supply chain. As a result of these off-quality CO_2 specifications unfortunate events may occur such as product-recalls, delays, diverted orders and in extreme cases disposal of CO_2 product into the atmosphere. It is therefore imperative that CO_2 production be closely monitored in order to satisfy customers and provide consistent deliveries on time to reduce negative impacts on the company's reputability.

Raw CO_2 gas enters the plant with around 1460 – 8400 (ppm) parts per million of Total Hydrocarbon Content (THC).The activated carbon bed serves as a critical control point in removing the THC in the purification process. As of today during operation plant operators, supervisors, and analysts subjectively quantify the quality of manufactured gas through experienced olfactory senses. The process of simply “sniffing” the gas for trace of impurities in the activated carbon vessels may lead to errors and customer problems. These cause delays in deliveries prompting customers to avail the product through other sources. Quality is a paramount requirement in food grade liquid CO_2 specifications. If impurities are not detected immediately product recalls may occur over the supply chain. The main problem addressed by this study is to identify what types of technology and/or equipment can be introduced in the production of liquid carbon dioxide to prevent quality issues brought about by impurities in the gas purification process with the best cost/benefit given the performance of the production. This requires developing an analytical model to properly describe the behavior of the plant’s system.

A solution to determine the carbon vessels breakthrough limits was initially performed on May 13, 2013. PCC’s quality team sought to determine the actual amount of total hydrocarbons in a specified activated carbon vessel. This was done through an experimental set-up by connecting the plant’s existing GOW-Mac total hydrocarbon analyzer model: 23-550-1 into the outlet line of operational activated carbon vessels. The output value of total hydrocarbons (THC) in parts per million (ppm) served as a reference to the activated carbon vessel’s serviceability and a quantitative measure in contrast to olfactory sensory measuring techniques of operators and supervisors.

1.2. Research Proposal

This research aims to investigate the feasibility of determining the level of CO_2gas impurities in a more accurate and quantitative approach utilizing state of the art gas quality assurance technology. We will use an assortment of analytical methods to establish cost and performance of the production under the new technologies as compared to the existing scenario.

1.3. The research objectives for the Study

The study has (3) objectives. The first is to investigate and identify which kind of technology may be integrated to the liquid CO_2 production system. This will be done through an objective comparison of the available technology and their cost, performance characteristics.

The second objective of this study aims to determine a comparative cost estimate analysis on the current regime and with the prospected technology to be acquired.

The last objective of this study is to relate the invested technology on the value chain and determine its impacts on the customer.

1.4. Scope and Limitations

In this case the study is limited to the carbon dioxide plant purification process from the raw gas supply of alcohol fermentation. The study will not cover other raw gas sources for carbon dioxide sequestration.

This study will primarily deal with a particular sector of the CO2 gas refining process, namely the deodorization. Although there may be discussions on other process sections of refining liquid CO_2 it should be understood that these sections are not the primary focus of this study.

1.5. Research Methodology

The production system consists of a number of modules. Some of which are working in parallel or more complicated configurations. In particular activated carbon vessels can take 4 different states each of a random duration. This provides us a fairly complicated configuration of the production system. To understand the behavior of the system, reliability modeling is required.

In order to justify the technology to be used for this case characterizing the random behavior of the system will primarily need to be achieved. This will be done initially by collecting historical data of the carbon vessel in its different states. These records may be accessed through handwritten daily charts which are continuously carried out by plant operators and supervisors. Some characteristics in the data may not be immediately comprehensible due to random occurring events such as breakdown, power interruptions, low raw gas supply, and off-specification quality parameters. For these instances plant operators and supervisors must be questioned in order to clarify these variations.

It is important to consider estimating costs of the system under the current regime. These costs are specified as production, maintenance breakdown, and lost opportunity costs from customers. These financial components are considered as a significant constituent of understanding plant operating costs. As a proposed solution we aim to develop a comprehensive model of the behavior of the system. This would require a study on reliability modeling by looking into parameters such as the percentage of the operation when the plant is running and when it is offline. These metrics are to be broken down into each of the deodorization processes and the plants process components to get a detailed view of the data in order to achieve a feasible solution and analysis.

A literature search on reliability modeling and what other companies have been able to accomplish will be methodically incorporated as references to our development of a model. Other analysis techniques such as the distribution method, minimization function, and suitable statistical probability methods using the data collected on-site are to be utilized. Once the data is objectively reformed to our desired requirements we may be able to employ these figures into a respective reliability model. By using a model we ensure that the study we are performing is done through a systematic process which has been proven through theoretical and objective methods. With the model created we aim to obtain an objective analysis on the requested technology aimed to improve performance of the plant's production system. If the data collected does not fit into the parameters we aim to perceive, our study may resort to alternative techniques such as simulation and a comprehensive study for the estimation of relevant costs.

With these relevant factors brought into consideration a conclusive decision is deemed to be accomplished. The analysis through reliability engineering, detailed modeling or simulation may eliminate guess work and improve the accuracy of operating plant procedures. As a result of this a comparison of invested costs and current costs will further be investigated and presented. Finally a re-analysis of performance measures of the system under the new technology will be re-assessed. We will also consider the impacts this decision has brought into the company such as cost savings and the strategic fit that the plant may employ towards a customer oriented approach. If the outcome of this study proves to be a practical business solution then the company may opt to invest on the new technology.

1.7 Structure of the report

Chapter 1 explains a brief summary of the report. A description of carbon dioxide its sequestration and an introduction to the company is provided. The objectives of the report, which involve a comparative cost analysis of the technology its purpose and how the study would be performed, may be reviewed in this section.

Chapter 2 contains the literature review which provides a summary of techniques and what other researchers and companies have accomplished. The approaches used in the literature review played an integral role in the data collection and analysis of this report.

Chapter 3 provides an overall background on the company, its customers, and the manufacturing process. A brief explanation in regard to quality assurance of CO_2 is provided to further expand the relevance of this study.

Chapter 4 presents theoretical background on the approaches used in this study. These theories may be referred to as a background for the analysis of data.

Chapter 5 presents the data and development. This chapter addresses the issues with respect to the data used for the empirical analysis.

Chapter 6 contains the analysis and results. The information provided in this section was analyzed through the foundation of its theoretical background in chapter 4.

Chapter 7 provides a discussion on the study's findings and a conclusion for technological assessment.

Chapter 2: Literature

2.1 Gas Analysis History

Gas analysis traces its roots back to the industrial revolution. Coal was mined underground prompting young boys and old men into manual labor. Methane gas was one of the most dangerous causes of deaths inside a coal mine. Methane gas is dangerous because it cannot be seen or smelled, and appears naturally from the ground. Miners started to device ways to detect the gas which could cause their instant deaths by simply collapsing inside the cave. The first method of detecting methane was by using human detectors. Wrapping a wet blanket around a person's head and holding a long wick with a lit fire inside, this brave man would try to hit the walls of the coal mine. If a pocket of methane gas was present it would ignite a fire and depending on its quantity would either kill him or keep him alive. It was believed that the death of one man is better than sacrificing the entire team (Davalle, 2011). The second method was bringing in canaries into the mine. Canary birds had the most resemblance to the human central nervous system thus providing a good sensor from methane and other toxic gases such as carbon monoxide (Kaur, 2012). The canary bird would shake its cage if it was about to die which signaled miners to start evacuating. Worse if miners find the bird dead it would mean a more immediate evacuation. Canaries were very reliable and often used in coal mining. It was only during 1987 that using canaries as detectors were abolished from mining pits in Britain (Wilson, 2012).

2.2 CO2 gas testing equipment

The activated carbon region as a critical control point is consistently measured for gas impurities. Breakthrough control systems are available to detect if a vessel is rendered to be fit for operation or must be regenerated. The following paragraph describes the sensors which are available in the market for breakthrough control and quality systems. A total of 3 technologies from 6 companies were evaluated for this study. Each of these technologies, have positive and negative drawbacks toward incorporating them into the configuration of CO_2 capture system.

A gas chromatograph is an analytical instrument which measures the content of various components in a mixture. The principle of gas chromatography works as such: a sample of a gas solution to be tested is injected into the instrument. A separation tube known as the column separates various components of the gas. A detector then measures the amount of quantity of components that exit the column. In order to find out an unknown concentration, a standard sample with a known concentration is injected into the instrument. The standards sample retention time is then measured and compared to the test sample in order to calculate the amount of concentration (Shimadzu, 2013). Gas chromatographs may use different detectors. During 1955-1956 the first commercial gas chromatographs introduced to the United States utilized thermal conductivity sensors (TCD). These types of detectors were rugged, reliable, and easy to use although TCD's had limitations. The first reason was that helium was used as a carrier gas for the equipment which was prohibitive in price due to the lack of supply in America. The second limitation was that TCD's had poor sensitivity despite helium being its carrier gas (Ettre, 2002). This prompted scientists and researchers to explore the opportunities for gas detector systems.

The Flame Ionization Detector (FID) is able to detect the amount different gas components in a sample gas container. An FID works such that a sample gas enters a chamber where it is mixed by hydrogen and is ignited by flame. The ions emitted by this reaction are then detected by electrodes. The potential differences of these electrodes are then sent to a computer analyzing the quantity of components in the stream. Due to the equipment’s high sensitivity, it has been known to be well suited for hydrocarbons such as methane, ethane, acetylene, hydrocarbons, and for volatile organic compounds (VOCs) (AGA HIQ, n.d.)

The gas colorimetric method is a quick, easy and cost effective way to determining gas concentrations in a sample. A detector tube is formulated with high purity reagents that react with the target gas or vapor being measured (Kitagawa, 2005). Detector tubes require a sampling pump to push the gas being tested inside the detector tube. If a target chemical is present in the sample, the color of the reagent in the tube will change its color (Draeger, 2013). A corresponding amount of the chemical in the sample can be immediately read through its color range on the detector tube. There are different kinds of gas detector tubes and brands for various gases.

TIGG Corporation provides an activated carbon vessel breakthrough detector for their NITINOX disposable activated carbon units. The design of this technology provides a visual signal that the activated carbon vessel is free of organic or oxidizable material on specific levels. A color change from violet to brown/black may be observed when the activated carbon vessel is in operation. These color signals may be used as indications to adjust operating parameters, or replace the adsorbent. This activated carbon breakthrough detector is said to offer operational advantages. The following of which are: continuous sampling while the vessel is in operation, early warning breakthrough, and the elimination of constant chemical analysis by trained professionals (TIGG, 2013).

2.3 A study on beer and contaminants

In a study by (Wu, Lin, Fan, Dong, & Chen, 2006) commercial beers brewed in China were surveyed for the presence of potential contaminants. The contaminants cited were benzene, trihalomethanes and formaldehyde. Aromatic hydrocarbons which include benzene in foods arise from the various activities such as transferring food from packaging materials, food preservation and cooking processes, among others (Fabietti, Bocca, & A.P., 2001). Benzene was also classified as a Group 1 carcinogen by the International Agency for Research on Cancer (IARC) (Lyons, 1987). In this study, a formaldehyde analysis was done with a Clarus 500 gas chromatograph and a headspace autosampler. A total of eighty four (84) beers were tested. Out of these samples, six (6) beers that were brewed in China were detected to contain benzene in an amount ranging from 1.9 to 7.1μg/L. According to the (World Health Organization , 2001), benzene content should not be ingested at 10μg/L. At this amount of ingestion benzene could act as a cancer risk for human consumption (World Health Organization , 2001). The factories that brewed "contaminated" beers were then investigated to trace the source of benzene that was detected in the beers. As a result, it was determined that these factories had quality systems for water, although they did not have quality systems for carbon dioxide. In short, they had no way of measuring impurities that may be present in their carbon dioxide supplies. The investigation therefore suggested a root cause analysis on the carbon dioxide purification process was a source of benzene contamination for these beverages.

According to a paper done by (Yunhua, Wang, Hu, & Lei, 2004)a purification process for foodgrade CO_2 was detailed. Since 1991 (Yunhua, Wang, Hu, & Lei, 2004) alongside with Hangzhou Kuaikai Company have developed various ambient temperature sulfur removing catalysts. This study was mainly focused on CO2 systems from ammonia producing plants. The process involves a number of steps in fine sulfur removal. A final step with the (total hydrocarbon) THC-1 hydrocarbon removal catalyst was applied successfully to this system. THC-1 catalyst can remove hydrocarbons, CO, H_2, VOx and VOC's by catalytic oxidation. A total of 6 food grade CO_2 manufacturing plants have said to be successful in the use of THC-1 catalyst in China.

2.4 Activated carbon

The activated carbon bed is pivotal to different kinds of industries. Most plants use activated carbon bed systems to remove pollutants in their production process. San Jose Graphics (SJG), a printing company, utilizes four (4) carbon adsorption units in order to collect specific solvents such as toluene, heptanes and hexane(Payne & Toy, 1985). SJG's plant opted to regenerate their beds more frequently than necessary to prevent the risk of solvent breakthrough. The regeneration of SJG's carbon bed is similar to a CO_2 plant's procedure whereby steam is infused to remove trace contaminants through a boiler. In addition, SJG employed a dual carbon bed monitor so as to reduce the cycle time of steaming while providing for an accurate method of detecting carbon bed saturation. This technology then eliminated guesswork from regeneration procedures and cycle time was reduced from 21 to 17 cycles daily. Overall costs dropped and lightened the load on steam boilers (Payne & Toy, 1985). The company claims that carbon bed efficiency is now at 96-98% performance (Payne & Toy, 1985). San Jose's Graphics issue brought about savings to the company through reducing cycles of regeneration.

In a study by (Hwang, Dae, Sung, & Sung, 1997), an experimental and theoretical study was made on the adsorption and regeneration of methylene chloride vapor in a fixed bed of activated carbon using nitrogen carrier gas. The procedure employed was the use of a linear driving force mass transfer model. This model was found to be acceptable and suitable to the experimental data. For the adsorption of methylene chloride on activated carbon, the method validation showed that as the purge gas temperature increases, the desorption process progresses. This signifies that in a cyclic adsorption or desorption process an incomplete regeneration cycle is more favorable than a complete regeneration cycle. The cooling step which is followed by a hot purge of air in the regeneration cycle was then omitted for the adsorption of methylene chloride. In the course of reduction of steps in the regeneration cycle, energy savings on cooling were attained.

2.5 Data collection

The process of data collection is often difficult and messy. Data collected is not always characterized in its perfect shape and ready for analysis. This leads that at some point somebody must work with organizing, and “cleaning” the data for analysis. Data collected should be approached such that assumptions should not be immediately made. Some data may be out of range, or the file accepted itself may not be the actual file to be analyzed. A large part of data management is in correcting mistakes and thinking of other ways to work around them. Every person involved in the project must know who is authorized to make decisions when problems arise. For instance a data clerk may notice that a number of variables are missing therefore this problem must be reported to the correct personnel while the project is still in the data collection phase. A codebook is known to be a classic tool for research this would apply to any project involving analysis of data. Codebooks may be as simple as a notebook or electronic files in a computer what is important is that the data set is reliably recorded and may be stored for future reference. Some categories a codebook must include are: data collection procedures, data entry procedures, timeline, decisions about the data, who collected the data, and coding procedures. Having a codebook of necessary information may serve as a time saver to explain a project and its results to a new analyst. There are numerous ways to store data electronically, programs such as Microsoft Excel, ACCESS, SPSS, SAS can be read through many formats. Spreadsheets are fairly easy to use due to its accessibility with other programs and beginners find this format easy to use. Missing data is a common problem in data analysis. A variety of procedures may be employed to deal with this problem. The data collector may follow up with the source which immediately solves the problem for missing data, an analytical design such as generating a distribution for missing values is another solution and finally use simple dummy variables for the analysis(Boslaugh, 2012).

2.6 Reliability

Science and engineering use mathematical models for prediction. For instance, power consumed for a new electronic component may be predicted with theoretical equations such as the Ohm's law. A mathematical model may be accepted as a basis of scientific prediction given that the theory explains the relationship. If the model does not predict the outcome under certain circumstances, the theory may need to be revised. Scientists and engineers expect that these prediction models must be repeatable. Failure or its absence is highly dependent on human actions and perceptions. This presents a fundamental limitation for reliability prediction using these mathematical models. Predictions based on past data may not be sensible unless the fundamental conditions which may affect the future behavior of a system will not change (O'Connor, 2002).

Reliability allocation is used as an optimization process reducing total plant costs subject to plant safety goal constraints. In a study by (Yang, Hwang, Sung, & Jin, 1999) reliability allocation was applied to determine reliability characteristics of nuclear reactor subsystems, major components and plant procedures consistent with top level performance goals. The genetic algorithm is a tool used for most optimization problems. In this case it was applied to a pressurized water reactor. Costs for improving and degrading the system were included in the reliability allocation process. Reliability allocation emphasized several aspects in this study such as minimizing the risk of nuclear power plants under various constraints, allocating resources effectively and reduction of over design. Investment risks and health risks of a nuclear power plant were quantified with the following costs and their corresponding possible damages: minimum (US$ 1-6 million) primary system water loss, no spill into containment, no core equipment damage, maximum (1167 – US$ 3186 million) severe core damage or core melt, significant radioisotope release to the containment. The main goal of reliability allocation was to determine the reliability target in the system level with developed fault trees that consisted of system failures. A capital cost for each of the nuclear plants system was determine as a basis for investment risks in monetary terms. Results of this case showed system reliabilities for three typical cases. Varying the model by considering direct costs and indirect costs changed the systems availability. These results showed an optimal solution for operating costs which may be reduced greatly by optimizing the systems reliability at the same time maintaining the nuclear power plants safety. The genetic algorithm and reliability allocation process provided a good model developed for the pressurized water reactor. Other than achieving an optimum value in addition to this, insights on the reliabilities of the other systems components are also accomplished (Yang, Hwang, Sung, & Jin, 1999).

In designing an industrial plant one must take into consideration objectives of safe operation and economic service. An engineering analysis on reliability, availability and safety must be done together with economic analysis. In this study, a Monte Carlo simulation method and a genetic algorithm determining the plants optimal system design was considered (Cantoni, Marseguerra, & Zio, 2000). Safety and economics of procurement of plant equipment have a direct relationship with reliability of the system. Choosing reliable components allow the plant to run on the safe side and provide higher system availability although may be non-economic due to excessive component purchase costs. Components in redundant configurations may provide a higher system reliability and availability although purchase and repair costs may be significantly high. Therefore the designer of a system must define an objective function which would account for all these aspects for optimized plant operations. Optimization of the design of a shale oil plant was considered (Kumamoto, 1992). Five different modules were presented with a possible 153,664 configurations. This vast amount of configurations prompted a genetic algorithm analysis which subjected the modules to degrading repairs. Failure rates, repair rates, purchase costs, and repair costs were collated to serve as an objective function to net profit of the system. An efficient amount of Monte Carlo simulation runs was then performed as a feasible approach to fit the model.

A study done by (Shayan, 1986) on a coal burning power plant is considered. The aim of this study was to present a model which generates the reliability of components, and the average amount of power generated at any given period of time. The plants components were grouped into appropriate modules such that the whole unit is a series of 7 modules. Components of the power plant and their mean time between failure (MTBF) & mean time to repair (MTTR) rates were extracted from the data gathered over several years of production. Each mill has three states namely: operating, standby, failed (repair) with each containing different life distributions. However transitions exist between states such that a semi-Markov process is identified. Results have shown that this model is a representative of the actual system. A steady state was defined to a specified number of running modules. This presented that electricity generation was at its maximum output despite running more boiler modules. This model was programmed in Fortran the results generated were close to actual production output of the power plant. This study provides useful tools in providing planning resources, maintenance and design for new systems. Other production systems may be developed into the framework of this study given that the necessary data is available.

2.7 Decision Analysis

An expansion of a business involves an element of risk. A decision tree may provide a solution in categorizing how much expansion must be made, when an expansion must be done and if it is either feasible or not. These uncertainties must be primarily identified as a fundamental step to arriving at proper decisions. To illustrate how the decision tree works we consider an actual situation of a privately owned power plant. The future demand in this study presented that an additional 2,200 megawatts (MW) of electricity was needed within 15 years. The plant faces a number of options to either develop a new plant through means of nuclear generation at $775Million or follow a conservative approach of installing a coal fire plant at $350Million. Probabilities for each decision are associated with each uncertain event. In this case a reward cost of taking the action is presented after each branch in an attempt to find an optimal solution as a best action towards uncertainty. Again in this decision making process assumptions must be made to represent the model. It is shown that in this study investing on a nuclear power plant would involve higher initial costs from safety and environmental precautions. The management may then also decide whether to build a plant in stages. Cash flow summary branches in the decision tree are then analyzed from which alternative to be chosen. Other unanticipated considerations may be placed as additional factors such as timing of cash flows, changes in interest rates, cost and revenue estimates, and the probabilities of uncertain events. With these estimates a resulting decision for the company's strategy may be made (Sullivan & Claycombe, 1975).

Decision making involves various conditions of uncertainty. In this study an investment decision for infrastructure and development related to climate change was modeled. In designing climate sensitive investments historical weather and climate data are often used. Engineers use these to design the infrastructure of buildings, farmers for crop scheduling, insurance industry for calculating premiums and assessments on energy security requirements. Unfortunately climate decision models may not perfectly describe future climates due to the inherent uncertainty of the earth's climate system. As an example of a decision analysis case, a Ghanian hydraulic engineer requested the assistance of a climate modeler for the next 100 years. This was to demonstrate if constructing, water infrastructure on a specified location was a valuable investment. Climate models can be dangerously misleading. Different software may show conflicting results thereby adding confusion to the decision maker (Hallegate, Shah, Lempert, Brown, & Gill, 2012). No simulation modeling software can give perfect answers to real life situations however these tools may be considered in planning, forecasting in a safe deterministic environment.

2.8 Markov Chain

A reliability model is presented for use in scheduling and optimization of maintenance and renewal. A deterioration process of technical equipment is modeled by a Markov chain. Parameters with this Markov process may be estimated on the conditions and components of a system. The Norwegian Electricity Industry Association presents a model which can be used to compute performance measures and operational costs over a finite time horizon for hydro power components. Technical conditions indicated main states of the following 1: no degradation, 2: some degradation 3: serious degradation 4: worse that critical. The deterioration process of power plant components accelerates towards the end of life. Modeling these main states required fitting a gamma distribution into the values of preventive maintenance. This study mainly focused on using the Markov State model on periods when the system was to be inspected and when the next inspection will be carried out. These calculations provided a set of performance measures and expected number of inspection and maintenance action per year. Overall costs on inspection or renewal strategies were obtained to find an optimized calculation for future costs. After modeling the Markov process and performing simulations, the total estimated value of costs for corrective maintenance(costs for failure consequences, unscheduled plant down time and costs for replacement) were assessed at 2 500 000 Euro. Costs per preventive maintenance which included: (scheduled costs per replacement including production loss due to scheduled plant downtime) resulted to 800 000 Euro. The study proved to be an appropriate approach with this model according to expert opinion and was verified by Monte Carlo simulation (Welte, Vatn, & Heggset, 2006).

PSA Peugeot Citroën one of the largest carmakers of the world made a decision to introduce 25 new car models during 2001 – 2004. The PSA management decided to redesign their body manufacturing shops. This was to enable different car models to be assembled in each shop. In order to accomplish the task an Operations Research team was formed to develop efficiency of production lines. It was then determined that machines would require repair to retrofit new body designs. A continuous Markov chain was used as a representation of each machine going into an operational and a repair state. The team was able to conclude that the transition rate of a machine was regardless whether the machine was being operated or into the idle state. This application brought about substantial improvements on investment and no compromise to quality. A total of $130 million (6.5% of total profit) was credited to PSA as profits with the help of this study (Patchong, Lemoine, & Kern, 2003).

2.9 Simulation

A simulation software package or program provides a process designer or engineer to design and analyze manufacturing systems. Topics which are involved in developing a model through simulation include: manufacturing issues, techniques for building credible models, statistical consideration and the pitfalls of simulation (Law & McComas, 1986). A greater emphasis for automation to improve productivity has been evident today. Manufacturing systems tend to portray considerable complex scenarios where a powerful tool such as simulation would be substantial to comparing quality, and optimizing costs. In order for us to learn about a dynamic system a model is generally required to study its performance. For instance a decision must be made with regard to plant expansion by adding production lines. An additional line does not ensure a potential gain in productivity and may instead be an economic burden for the company. It would not be cost effective to install the system and remove it later if operations do not run as expected. However with the aid of simulation software, the current operation with the expansion may be analyzed. If the relationships between the systems are simple enough to analyze analytical solutions such as calculus, algebra, and probability theories may be used. Most manufacturing systems are too complex to be evaluated by mathematical concepts therefore simulation model is used. Discrete time model simulations are used in this process such that random probability samples are used in predicting the nature of a systems performance through a specified unit of time.

Simulation languages such as Fortran, Basic, GPSS, SEE, Why, Siman, Simscript, SLAM, Tess, Simul8 etc. allow the analyst to develop a simulation model of a manufacturing system (Law & McComas, 1986). Modelers use varied techniques for approximating a working model of the system some of the following fundamental steps before modeling are: a list of definitions must be primarily investigated as measures of performance; important people associated with the system must be interviewed to characterize obscure information. Lean manufacturing has been a current industry trend. A case based approach was used in this study to help a steel mill in eliminating waste, maintaining better inventory control, improve product quality and obtain overall financial and operational control. Value stream mapping (VSM) is used to map the current operating state of the ABS Steel company (Abdulmalek & Rajgopal, 2006). A simulation model for the managers was used to quantify benefits gained using lean tools and techniques. Value streams are collections of actions which are required to bring a product from its raw material state ending with the customer (Rother & Shook, 1999). ABS produces a variety of steel grades which are used primarily in appliance manufacturing. The plant works on a continuous process of 24 hours a day with 3 shifts, all year long, with exceptions of major shutdowns. The focus in this study is on the following steel grades: hydrogen batch annealed, continuous annealed and open coil annealed. Customer demands average at 76,500 tons monthly. Data collection began with production level at the blast furnace process down to inventory levels at the shipping department. Machine reliability, process cycle times, amount of workers and changeovers were considered as the plants historical data. In modeling this system several things stood out such as: large inventories, total production lead time were particularly long at a total of 56 days, and that each process produced to its own schedule. Direct shipping or warehousing system was also another issue which this case addressed. The push system represented the current situation at ABS and a hybrid push-pull system was used for comparison in the simulation process. The model was developed with System Modeling Corporation's Arena 5 software. The proposed system was run with the software to a later future state and results showed that in order to prevent producing more that market demand production lines may be switched to manufacture other product types to avoid inventory overruns and avoiding shutdowns over the production lines. Detailed animation of the system was sufficiently verified until shipment of the product, these were done through comparing outputs from the simulation to the actual system. The information provided by simulation aided in implementing lean manufacturing systems and motivated the organization in implementing these results (Abdulmalek & Rajgopal, 2006).

2.10 Summary

The literature in this chapter presents the quality assurance technology which may be adopted by PCC. Studies on manufacturing Carbon dioxide were also taken into consideration to gauge PCC's plant capabilities with current market trends and emerging available technology. The activated carbon's studies on other industries were also taken into consideration as a parallel investigation these studies may serve as suggestions to the current procedure of PCC. Data collection plays a fundamental role as a primary step of any research study. For this study data collection was done through manual process. The quality team consisting of three personnel aided in sifting through notebooks, process charts, and handwritten log-books were a primary technique in acquiring information. Variations in the data were present such that outliers were present and had to be addressed immediately. For these instances, the quality members addressed plant operators and supervisors why such behavior of data was present. Most problems with regard to missing data were resolved with approximate assumptions resulting in a fairly reasonable amount of data to represent the systems behavior. As a proposal PCC may opt to automate data collection on critical information. Reliability, Decision analysis, Markov chains, and simulation will serve as tools in constructing a representative of the system's production. These subjects are held together by the production of liquid CO_2. Reliability modeling has the advantage such that it can be used to predict the plants performance. Initially the plants random behavior must be established. One of the reasons that random distributions of the data are collected is so that even without reliability modeling, simulation may be performed. These random distributions will serve as data which may be input into a model system. The model would then represent a version of the plant in operation. Running the model would be as if you are actually operating the plant. This model can give us data collected from 1-3 years rather than waiting for a year of actual data. Modeling if done properly can represent the behavior of a system such that we can change parts of the system when we introduce new technology. We may be able to forecast the plants performance and see that if another technology is in place the behavior of the system may change. Comparing these results will give us a cost estimate of for example within a month what levels of production may incur, what components are in breakdown and which are in maintenance procedures, quality of produced gas and so forth. An approximate by a Markov chain may be done depending on the nature of the distributions.

Chapter 3: The Company Pacific Carbonic Corporation

3.1 PCC History

Pacific Carbonic Corporation (PCC) has been in the gas industry for 51 yearsand is a privately owned manufacturing enterprise. The company began in 1962 and was known as FO Manufacturing Corporation with a 10 metric ton capacity fuel burning plant in Marikina City Philippines. By 1971 the company changed its name to Liquid Carbonic Philippines Incorporated (LCPI). In 1972 Pacific Carbonic Corporation was established and incorporated with LCPI. PCC was hauling bulk liquefied CO2 from a fertilizer plant in Limay Bataan, while LCPI handled the retail business of CO2 cylinders. By 1992 PCC was able to expand and set-up their own operation of a 20-ton capacity CO_2manufacturing facility in Nasugbu, Batangas an approximate 3 hour drive from Metro Manila. Through continuous improvement, PCC has expanded its production in 2003 bringing the total rated capacity of the plant to 40 metric tons per day. The following year on August 2004, PCC's Nasugbu plant was able to incorporate in their practices ISO 9001:2000 Quality Management Systems(QMS). The ISO QMS was routinely audited with a three year accreditation period and is still continued as of today. Other highlights of the company included that in 2008 a third operational line of 20 metric tons in the Nasugbu plant was installed. Today PCC's Nasugbu plant operates 3 lines with a total capacity of 60 metric tons daily. On January 2009, Pacific Carbonic Corporation merged with Liquid Carbonic Philippines Incorporated with the surviving company known as Pacific Carbonic Corporation. The plant supplies manufactured liquefied bulk and retail CO_2cylinders for various sectors of the industry. Some of the major clients which PCC caters to are companies such as Coca-Cola, Pepsi Cola, Philip Morris, and Futaba. These companies utilize $CO_2$for their processes. Customers routinely audit plant safety, production and maintenance biennially ensuring that the company complies with manufacturing regulations. On February, 2013 PCC recently attained the Food Safety System Certification 22000 (FSSC 22000) recognized by the Global Food Safety Initiative (GFSI).PCC's Marikina and Batangas plant work hand in hand to provide continuous customer satisfaction.

3.2 PCC's Customers

CO_2 is prominently used by the beverage industry. Carbon Dioxide is mixed with water and a variety of syrup flavors giving a distinct taste of soda beverage (Carbon Dioxide In Beverages, 2013).PCC provides Coca-Cola, Pepsi-Cola and other small medium enterprises which utilize CO2 for their beverage production process. The Philippine fast food retail sector receives PCC's CO2 cylinders as their supply for their respective soda fountain machines.

The food industry make use of two types of gases to keep food fresh and in cold storage conditions, liquefied nitrogen and liquefied carbon dioxide. Liquefied

CO_2 is injected to create a layer of snow directly on the food. The snow gradually sublimes and acts as additional refrigeration and retains freshness (INGASCO, INC., 2008). Both of these gases are non-toxic, non-flammable leaving no residue on the food product, hence, the determining factors for their purchase lie on price and availability. In the case of PCC a direct customer which utilizes CO_2 is Mc Donald's. The fast food retail store utilizes CO_2 as an effective refrigerant for their chicken nuggets and burger patties.

The Dry Ice Expanded Tobacco (DIET) process improves the quality of cigarettes and is an effective tool for tar and nicotine reduction. Dried and cut tobacco is submerged under high pressure liquid CO_2 conditions in a vessel called the impregnator. After a brief soak, the Carbon dioxide is drained to a process tank which is used again. Once the pressure of the impregnator is reduced, residual carbon dioxide in the tobacco cells turn into dry ice. When the tobacco is heated, the frozen CO_2 sublimes and increases the volume of the tobacco leaf to more than 100,000 times (AIRCODIET, n.d.). The tobacco expansion thereby increases the cigarette filling power and reduces unit production costs in cigarettes.

In the electronics industry CO_2 is used in manufacturing applications such as semiconductor device manufacturing, surface cleaning and circuit board assembly. Quality parameters in this sector require CO_2's moisture at its lowest possible value (AirProducts, 2009).

CO2 can be used for the metals industry in welding ships, construction sites and other manufacturing operations. CO2 may be used alone or with a combination of other gases as a shielding gas(argo-shield), protecting welding zones from the detrimental effects of corrosion (Bernard, 2012). CO2 users in this industry would include furniture assembly plants, ship welding industries, and welding propane tank assemblies.

Sand moulds and cores for casting iron utilize CO2 which is combined with other additives as a binding agent for the silica sand grains. This in turn reduces production time, fuel costs and reduces mould boxes required providing a great deal of accuracy in production (VEE J PEE, n.d.).

Finally CO2 is used as a fire retardant in cylinder form of fire extinguishers. Usually it is used when water is not effective or unfavorable in terminating a fire (Wormald, 2010).

CO2's other uses

CO2 can be altered from gas to its solid state, creates dry ice in the process hence the term deposition. Dry ice is commonly used in the airline industry for keeping food and drinks chilled and fresh prior to serving them to the passengers (Polarice , 2013). Airline evacuation slides also utilize a mix of Nitrogen and Carbon dioxide for immediate inflation (Huber, 2007).

Furthermore, the use of CO2 in slaughtering livestock produces less animal stress, injuries and better meat quality. As an insecticide, the gaseous phase of CO2 is injected in grain silos where CO2 gas displaces the existing air. The benefits of using CO2 as fumigation include deprivation of insects to develop insecticide immunity and an atmosphere of 60% carbon dioxide is fatal for insects (Aresta, 2003). CO2 can add nutrient absorbent to plants when injected to irrigation water because it changes the pH of soil which is an adherent to nutrient absorption.

A new technology called Porocrit is used for liquid foods and medicines. Food and medicine are sterilized, preserved by their contact with compressed CO2 at room temperature. Microbes and other infectious bacteria such as spores and viruses (e.g. E. Ecoli, salmonella and polio viruses) are killed effectively (Balaban & Ferrentino, 2012). CO2 is growing in the medical market industry in small volumes for laser surgery.

CO_2 from geothermal well's may be recycled by bringing hot CO_2 from the well onto the surface, thus capturing it and condensing it. The liquefied CO_2 is usually pumped back down into the well. Liquefied CO_2's density is naturally heavy which allows it to settle at the bottom of the well, pushing heat up to the surface of the earth. Heat is brought to the surface extracted and used to power turbines thus converting it to energy (Sandru, 2009).The demand for CO2 is continuously rising and its market expanding to diverse utilizations. There is difficulty though on carbon dioxide's production, often the price of CO2 recovery is costly.

The consequences of low quality CO_2 could be dire as the following event demonstrates.

On 16 June 1999 The Coca-Cola Company (CCC) reportedly recalled an estimate of 15 million bottles and cans of products in Belgian stores. The Belgian Health Ministry decided to place a ban on CCC products until the issue was resolved. According to CCC's then Chairman and CEO Doug Ivester, CCC withdrew products as a result of "unrelated" matters. Consumers complained that Coca-Cola products consisted of irregular taste and odor in their bottled products. More than 100 consumers were said to be affected by the incident. Reported symptoms were headaches, stomach-aches, shivering and nausea and in fact some consumers were even hospitalized. At this time the company identified two specific production and distribution problems. These were the following:

1.) "Off-quality" carbon dioxide which affected taste and odor of some bottled drinks.
2.) An offensive odor on the outside of some canned drinks. This odor seemed to intensify when cans were stored into the vending machines.

As a result of this event, CCC decreed a resolution of thoroughly cleansing their plants thereby recovering and destroying all affected products. After eight (8) days of product recall, the Belgian Health Ministry finally lifted their ban on CCC's trademark products(Johnson & Peppas, 2003).

The aforementioned incident demonstrates the hazardous effect of low-quality manufactured CO_2. If such defects (i.e. impurities) are found to be present in food products, it would not only affect the health and well-being of consumers but also the reputation and credibility of the business. The European Industrial Gases Association (EIGA)(AISBL, 2008) determined that industrial and food-grade CO_2 gas must be free from toxic components such as those enumerated in Table 1. It was emphasized that these toxic components must be removed from the manufactured CO_2 even before it is used for food products. The presence of such impurities may result into detrimental and long-term health issues.

Table 1 CO2 Impurities from manufacturing sources (AISBL, 2008)

Component	Combustion	Wells/ Geothermal	**<u>Fermentation</u>**	Hydrogen or Ammonia	Phosphate Rock	Coal Gasification	Ethylene Oxide	Acid Neutralization
Aldehyde	√	√	√			√	√	
Amines	√							
Benzene	√	√	√			√	√	√
Carbon Monoxide	√	√	√	√	√	√	√	√
CarbonylSulphide	√	√	√	√	√	√		√
Cyclic Aliphatic Hydrocarbons	√	√	√			√	√	
Dimethyl Sulphide		√		√	√	√		√
Ethanol	√	√	√			√	√	
Ethers		√	√			√	√	
Ethyl Acetate		√				√	√	
Ethyl Benzene		√	√			√	√	
Ethylene Oxide						√	√	

Halocarbons	√					√	√	
Hydrogen Cyanide	√					√		
Hydrogen Sulphide	√	√	√	√	√	√	√	√
Ketones	√	√	√			√	√	
Mercaptans	√	√	√	√	√	√	√	
Mercury	√	√				√	√	
Methanol	√	√	√			√	√	
Nitrogen Oxides	√		√			√	√	√
Phosphine				√	√			
Radon		√		√	√			√
Sulphur Dioxide	√	√	√	√	√	√		√
Toluene		√	√			√	√	
Vinyl Chloride	√					√	√	
Volatile Hydrocarbons	√	√	√			√	√	
Xylene		√	√			√	√	

PCC's raw gas supply is specifically obtained via the fermentation process. Therefore, it is likewise imperative that in this process, the manufactured CO_2 gas must be free from the aforementioned toxic/harmful substances. In fact, as per current practice in the industry, food and beverage companies have closely monitored the manufacturing practices of suppliers to ensure that such practices comply with the required standards and produce high-quality food-grade CO_2. To further expand on the nature and content of PCC'sCO$_2$ recovery system please refer to Figure 1.

3.3 PCC's plant operations

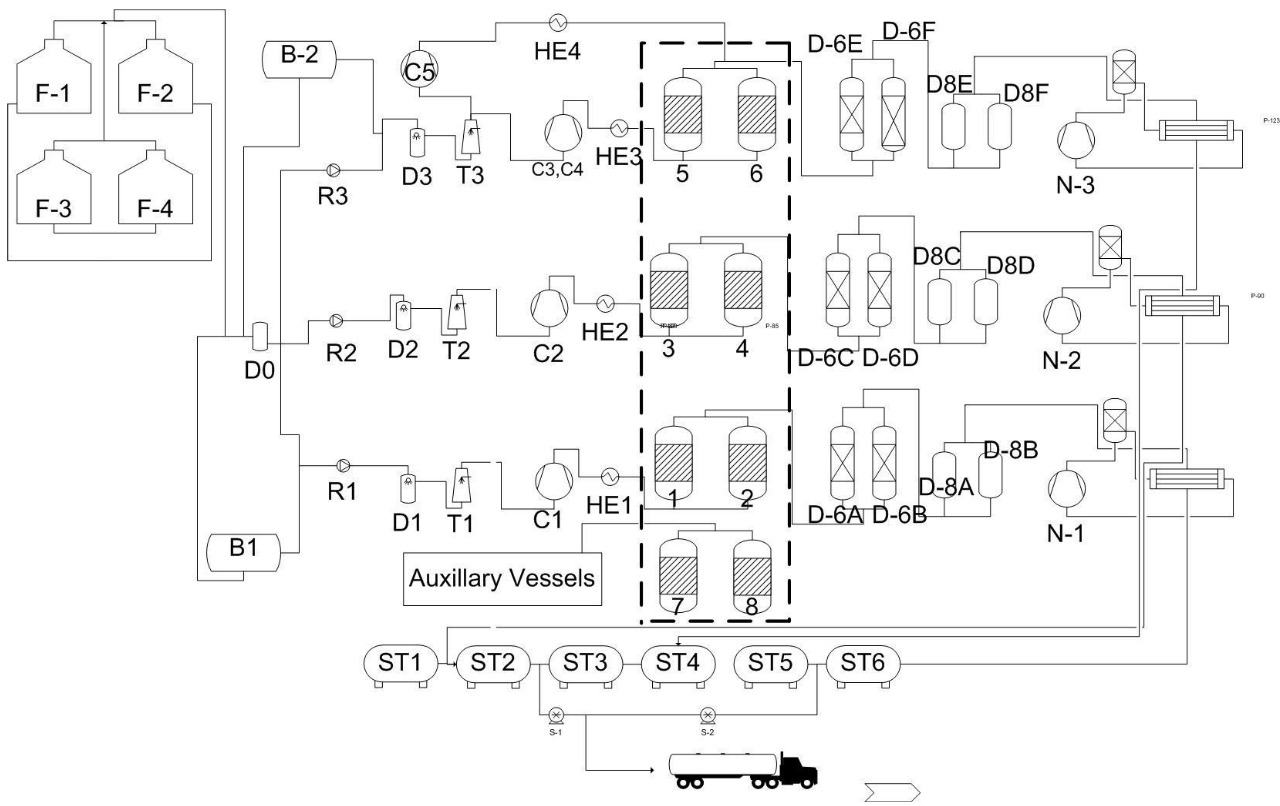


Figure 1 PCC's Current production System

Table 2 Plant Equipment and Symbols

Equipment List			
Displayed Text	**Description**	**Manufacturer**	**Figure**
F1 , F2 , F3 , F4	Fermentor	-	
B1, B2	Balloon	Germany	
D0, D1, D2, D3	Knockout Drum	PCC	
R1, R2, R3	Root Blower pump	China	
T1 , T2 , T3	Shower 1, 2, 3	Gases Industriales	
C1	Compressor 1	Germany	
C2	Compressor 2	England	
C3 C4	Compressor 3, 4	USA	
C5	Compressor 5	Germany	
HE 1,HE 2, HE 3, HE 4	Heat Exchanger 1	Gases Industriales & PCC	
1, 2,3,4,5,6,7,8	Deodorizer	Gases Industriales &PCC	
D6-(A,B,C,D,E,F)	Permanganate scrubber	Gases Industriales&PCC	
D8-(A,B,C,D,E,F)	Dryers	Gases Industriales&PCC	
N1, N2, N3	Ammonia Compressor	Japan	
ST1 , ST2,ST3,ST4,ST5,ST6	Storage tank	Gases Industriales	

The Carbon dioxide plant of PCC consists of 3 operational lines which continuously run 24 hours a day 7 days a week. Due to unexpected events such as power interruptions, low raw gas supply, and machine breakdowns, plant operations may come to a halt. Operators closely monitor equipment parameters through control charts to facilitate smooth operations. The process of CO_2capturebegins with raw gas excreted from the alcohol fermentation units(F-1, F-2, F-3, and F-4). A knockout drum initially removes the existing vapor in the gas stream at (D-0). Root gas blowers which act like fans push raw CO_2 gas into the respective operating lines(R1,R2, and R3). The gas balloon collecting unit (B1,B2) serves as a visual basis of how much raw gas is entering the plant. The balloon also controls the amount of energy the compressor must operate. If the balloon is seen to be completely inflated then its sensors would trigger the plants compressor to run at 100% capacity otherwise the plant may be run at 50% capacity. A second knockout drum and shower then removes the remaining alcohol and beers in the gas stream (D1,D2,and D3). The CO_2gas then goes up through a 30foot water shower were residual alcohols, sulfur and other contaminants are removed (T1, T2, T3). Compressors(C1, C2, C3, and C4)subject the gas pushing it to higher pressures to approximately 300psig.In partial commitment to continuous plant improvement and quality maintenance procedures PCC recently acquired a new compressor (C-5) in order to reduce plant stoppages due to compressor breakdowns. After compression the CO_2 gas rises in temperatures which could reach up to 220° C. Shell and tubing H_2O heat exchangers are then used as a medium to reduce gas temperatures to ambient working temperatures at 30°C(HE1,HE2,HE3, and HE4).Pressurized CO_2gas with pollutant molecules then enter the activated carbon vessel (1,2,3,4,5,6,7and 8, this process is further explained in the next paragraph). CO_2 Gas then passes through the potassium permanganate scrubber(D-6A, D-6B, D-6C,D-6D,D-6E,D-6F) to remove remaining contaminants such as sulfur contaminants, nitrogen oxide, benzene, formaldehyde etc. Excess water is then removed in the drying stage through activated alumina pellets (D-8A, D-8B, D8C, D8D, D8E and D8F). Finally liquefaction occurs by condensing the gas to -20°C with the help of an ammonia compressor and condenser (N_1, N_2, and N3). Liquid CO_2 is then placed in storage tanks (ST1, ST2, ST3, ST4, ST5 and ST6).Once a storage tank is full, PCC's quality assurance team performs a complete gas analysis based on the International Society of Beverage Technologists (ISBT) standards. Liquefied CO_2 is now ready for dispatch for PCC's customers. To ensure the quality of gas being received by PCC is fit for beverage manufacturing specifications, a sample of raw CO_2 gas and the final product is sent and tested by a reputable gas analysis laboratory in the USA on a yearly basis. Table 3 presents a total gas analysis of parameters in order to comply with food grade liquid CO_2 parameters.

Table 3 ISBT Food Grade Specifications

Component	Concentration
Assay	99.9% v/v min.
Moisture	50 ppm v/v max (20 ppm w/w max)
Ammonia	2.5 ppm v/v max
Oxygen	30 ppm v/v max
Oxides of Nitrogen (NO/NO2)	2.5 ppm v/v max each
Non-volatile residue (particulates)	10 ppm w/w max
Non-volatile organic residue (oil and grease)	5 ppm w/w max
Phosphine	0.3 ppm v/v max
Total volatile hydrocarbons (calculated as methane)	50 ppm v/v max of which 20 ppm v/v max non-methane hydrocarbons
Acetaldehyde	0.2 ppm v/v max
Benzene	0.02 ppm v/v max
Carbon Monoxide	10 ppm v/v max
Methanol	10 ppm v/v max
Hydrogen Cyanide	0.5 ppm v/v max
Total Sulphur	0.1 ppm v/v max
Taste and Odour in Water	No foreign taste or odour

3.4 The activated carbon vessels of PCC:

Activated carbon is known to be an effective adsorbent to remove impurities such as total hydrocarbon, and organic vapors from an effluent gas stream(United States Environmental Protection Agency, 1992). An activated carbon vessel contains activated carbon particles that are highly porous and possess fine capillaries known as the adsorbent. Pollutant molecules which are being removed are referred to as adsorbate. Through the aid of capillary and physical bonding, activated carbon adsorbs a large amount of these pollutants. These contaminant molecules are then stored on the surface or pores of the adsorbent. Eventually the adsorbent becomes saturated with pollutants and must be regenerated or in worst case scenarios disposed of and replaced. The term regeneration is described as desorption of these organic pollutants from the carbon vessels(United States Environmental Protection Agency, 1992). In order to regenerate a carbon vessel, hot steam is passed through it. The carbon particles must be subjected to a higher temperature since the vapors were absorbed. Saturated steam is used as a desorbing medium. A hot air purge is then blown into the vessel followed by atmospheric air as cooling. When a vessel starts the regeneration, an idling vessel needs to start its operation.

3.5 PCC Repair and Maintenance

PCC provides its own in-house repair and maintenance duties. Most equipment breakdowns involve machine troubleshooting such as motors, pumps, bearings, belts, pipes, heat exchangers, condensers, welding cryogenic vessels etc. On particular circumstances PCC may not be able to repair machine parts. During these situations faulty parts are sent to local fabrication shops that have equipments such as lathe and milling machines. As a final solution if parts are not repairable locally, replacement parts are procured through original equipment manufacturers (OEM) from abroad. Repair costs may vary depending on the machine breakdown. Often an approximate of US$500 is set on bi-weekly basis as cash allocation for repair and maintenance with the plant. Costs in this region may reach up to a maximum of US$7,000 for a single part in extreme cases when gross negligence on operation procedures occurs.

3.6 PCC Human Resources & Logistics

The Batangas CO_2 manufacturing plant maintains a total of 15 working personnel. With three lines in operation a plant supervisor and 2 operators continuously start-up the plant, check operation parameters, switch vessels, provide the plant with good manufacturing practices (GMP) and aid in repair and maintenance activities. PCC's head office is stated in Marikina City, it is approximately 100km's apart from the PCC Batangas manufacturing plant. A total of 8 bulk liquid CO2 transportable trailer tanks each at 10,000 metric tons are continuously utilized in transferring the final product to its customer's respective plants. The Marikina office/plant employs a total of 50 working personnel. This is because the Marikina plant serves as the administrative office which is involved in purchasing, logistics, human resource, accounting, marketing, and refilling CO_2 cylinders. Various CO_2 cylinders of different capacities ranging from 5lbs – 100lbs may be of use for the Coca-Cola, Pepsi Cola soft drink fountain dispenser, fire extinguishers, and metal foundry welding utilization.

Chapter 4: Theoretical background

This chapter offers an overview of the theories used in this study. Readers who are familiar with these topics may wish to bypass this chapter.

4.1 Markov Chain

There are various applications for Markov chains these include finance, market research genetics, medicine etc. Probability models for processes that evolve over time in a probabilistic manner are known to be stochastic processes. Markov chains exhibit a special property that how the process will evolve on the future depends only on the present state of the process. Markov chains are independent of the events happening in the past. The probability distribution of the remaining time until the process transits out of a given state is the same. This is regardless of how much the process has already spent in that state. This portrays that the random variable is memory-less and the process forgets its history. A probability distribution that possesses this property is the exponential distribution (Hillier & Lieberman, 2008). The basic properties of Markov chains follow: *S* denotes a set of states let $S = \{ S_1, S_2, \dots S_n\}$. A move from one state to another ($S_1 \rightarrow S_2$) is defined as a step, with a transition probability of P_{12} (Hillier & Lieberman, 2008). Matrix multiplication can be used to compute various state matrices of a Markov chain.

4.2 Reliability

The objective of reliability engineering is to determine if a product will perform its intended function for a specified time interval under stated conditions. Often an individual or a department is usually found in industries to perform the following tasks: analysis of optimization, failure mode effects, and criticality analysis, reliability prediction, supplier selection, reliability testing, and failure reporting and corrective actions (Stamatis, 2002). A systems reliability function depends on how the parts are arranged. If all parts must function for the system to operate then the systems reliability is a product of the components parts (Taylor, 2011).

Equation 1 System under a series of components

R_s = (R1) x (R2) . . . (Rn) , where Rn is the reliability of the nth component

Individual parts or a system's reliability as a whole may be increased. To increase reliability, redundant parts must be built as a back up to failure. Components in this configuration are said to be in parallel. Therefore a back-up component will automatically take place of a failed component (Taylor, 2011).

Equation 2 Reliability of the system in parallel

R_s = 1 –[(1-R1)(1-R2) . . . (1-Rn)]

Maintainability is referred to the ease with a product maintained or repaired. The distribution of failures over time is determined as the failure rate (Taylor, 2011).

Equation 3Failure rate

F(r) = w / t , where w = number of failures , t = total time in operation prior to failure

The mean time between failures may be expressed as the length before a product fails (MTBF).

Equation 4Mean time between failures (MTBF)

MTBF = 1 / F(r)

Equation 5 Mean time to Repair (MTTR)

MTTR = $\frac{\sum_{i=0}^{n} x1,x2,x3 \ldots xn}{r}$, x = hours of repair, r = total number of repairs

The average availability or "uptime" of a system may be calculated as the systems availability.

Equation 6 System Availability (SA)

SA = $\frac{MTBF}{MTBF+MTTR}$

4.3 Economic Order Quantity Model

The basic economic order quantity model shows a formula for determining an optimal size for inventory. It minimizes the sum of carrying costs and ordering costs. This model is limited to certain conditions such that demand is known and it is certain with time, no shortages of the product are allowed, lead time of these orders are constant, and that the order is received all at once (Taylor, 2011). For this study this model was used as an optimum quantity in ordering activated carbon pellets.

Equation 7Total Cost (TC)

$Total\ Cost = \frac{CoD}{Q} + \frac{CcQ}{2}$, Co = ordering cost

D = demand

Qopt = optimum quantity

Cc = carrying cost

Equation 8Optimum Quantity (Q_{opt})

$$Qopt = \sqrt{\frac{2(Co)(D)}{Cc}}$$

Equation 9Number of Orders per year (d)

$$d = \frac{D}{Qopt}$$

Equation 10Order Cycle time (O_c)

$Oc = \frac{Wd}{d}$, Wd = number of working days

Equation 11Re-order Level (R)

$R = dL, L$ = lead time

4.3 Cost Analysis

To contribute to the company’s achievement of a strategic goal, a decision analysis is often made. Outcomes are often not measured directly by profit instead some are measured in terms of quality, and cost-effectiveness, ease of use, maintenance cost, productivity etc. These factors may be interrelated which must be integrated with company objectives and goals. Decision making process is an important tool for an operations manager. The advantage of a systematic approach to decision making is beneficial to the user such that a structured, systematic approach to a decision is completed.

Payoff tables organize and illustrate payoffs with different decisions. Given the various states of nature a decision must take into effect. Under economic periods of uncertainty a decision maker may partake in a number of decisions.

Table 4Example of a Payoff table

Decision	A optimistic scenario	B pessimistic scenario
1x	P1	P3
2y	P2	P4

The minimax criterion engages the decision maker to assume the most optimistic competitive condition in the future resulting in a maximum payoff decision (Taylor, 2011).

The maximin criterion is a pessimistic approach such that the decision maker assumes that a minimum payoff will occur (Taylor, 2011).

The minimax regret criterion attempts to avoid regret. This is done by the decision maker in minimizing the maximum regret payoff under each state of the nature (Taylor, 2011).

A Hurwicz criterion represents decision payoffs weighted by a coefficient of optimism. This co-efficient may be between 0 and 1 such that ($0 < x < 1.0$). 1-x is the coefficient of pessimism. Equal likelihood assumes that the states of nature are likely to occur (Taylor, 2011).

Chapter 5: Data Collection

Data collection was performed through interviewing several departments of the company. A top to bottom management data collection approach was conducted. This method involved production supervisors and operators in characterizing ambiguous or missing entries. The plant maintains handwritten control charts, maintenance schedules, and operation log books. Most of the data characterized were quantitative and variable on a continuous running production system. Data collected had to be properly categorized electronic format. Microsoft Excel spreadsheets were used. Product recalls, manufacturing cost, and available technology was characterized with the aid of the marketing, finance, and procurement departments. For each of the activated carbon vessels the four states are described in the following paragraphs.

5.1 Operation Time $\alpha_n(t)$

Definition: Operation time is characterized by the symbol $\alpha_n(t)$, it is the length of time in hours between the point in which a vessel starts to produce CO_2 until it halts for any reason. The operating time of carbon vessels are constantly monitored by plant supervisors through sniffing the produced CO_2gas every 2 hours. Appendix A represents a histogram of the 8 vessels as a translated electronic copy of handwritten operation hours as data $\alpha_n(t)$.

5.2 Regeneration Time $\beta_n(t)$

Definition: The symbol for regeneration $\beta_n(t)$ represents the length of time in hours between a vessels regeneration state until it stops due to any reason. Regeneration may be attributed to a “cleaning” process within an activated carbon vessel. Plant operators then record data in a regeneration control sheet of an activated carbon vessel. Total hours in the regeneration state $\beta_n(t)$of a vessel may be viewed in Appendix B. A complete cycle of regeneration would require three steps which is always done in a sequential in the following order: 1)steaming, 2)hot air, and 3)cooling. Appendix B.1, B.2, and B.3 represent duration of the vessels steaming, hot air, and cooling states.

5.3 Idle Time $\delta_n(t)$

Definition: Idle hours$\delta_n(t)$represents the length of time in hours a vessel does no activity. A log book of operations was reviewed in order to categorize power interruptions, low raw gas supply, and repairs of other functional modules as the activated carbon vessel being idle. Often after a vessel's complete a regeneration cycle it would transit into a "waiting" idle state. Appendix C represents the idle time of the vessels.

5.4 Repair Time $\theta_n(t)$

Definition: Repair hours $\theta_n(t)$, represents the length of hours that a vessel is under repair prior to transitioning into any of the other three states. The repair hours within a vessel were obtained through the production department's breakdown and maintenance charts. It was determined that the repair data for a vessel was difficult to collect. These were due to factors wherein supervisors and operators would not log quick repairs which constituted for5 – 30 minutes of repair time on the vessel. With these circumstances at hand a reasonable statistical assumption was computed as a basis of a unit under the repair state. Appendix D represents repair data of the 8 activated carbon vessels.

5.5 Production Of CO2 in Metric Tons$\pi_n(t)$

Definition: The production of CO2 in metric tons after every service hour of an activated carbon vessel was recorded. The production level provides the amount of liquid CO2 a specific vessel would manufacture. For instance the activated carbon vessel 1 operates at 60 hours. At the 60th hour of operation plant operators record the amount of CO2 manufactured at the storage tank. With the data collected it shows that around, 30- 40 metric tons would be present after 60 hours of production. The production output of a vessel may be seen in Appendix E.

5.6 Markov Chain

A probabilistic model of the systems behavior was formed with states (operation, regeneration, idle, and repair within each of the activated carbon vessels. This model was formed with a matrix consisting of 32 x 32 states. The random distributions of the aforementioned states were modeled into their respective frequencies. If a Markov Chain were to be considered to be modeled for this system, a continuous Markov chain would be suitable for the evolution of the process. Deriving conditional probabilities for the states in this report has proven to be a difficult process. The exponential distribution is the only probability distribution which possesses a property wherein the probability distribution of the remaining time until a process transits out of a given state is always the same regardless of how long the process has spent in that state (Hillier & Lieberman, 2008). Upon collection of data for this report not all probability distributions displayed characteristics of exponential distributions. However some states displayed characteristics of exponential distributions such as the idle state of an activated carbon vessel. Due to the complex configuration of the system an exhaustive data collection must be taken into consideration. A deeper understanding of the Markov process and its characteristics will have to be studied further. Therefore Markov modeling in this study has been limited to considerable number of steps nevertheless to demonstrate the data collected, a transition matrix for the system was developed and may be viewed in the analysis chapter 6.2.

5.7 Product Recalls

Product recalls were collated through the purchasing department. These returns were due to the following issues: bulk liquid CO_2 was out of specifications with respect to moisture, receiving plants were at full capacity thereby diverting the order to other plants/customers, off-odor quality specifications, and other unspecified reasons.

Table 5Product Recalls

	Number of deliveries	Percentage out of total recalled deliveries
Due to moisture	9	30%
Due to receiving plants at full capacity storage	17	57%
Due to off odor	1	3%
Due to other reasons	3	10%
Total recalled deliveries	30	
Product recalls as a percentage of PCC's total deliveries in 3 years	1%	

The data in the table 5 shows that a total of 30 deliveries in the past three years from 2010 – 2012, have been diverted due to stated reasons. Most problems occur with logistics planning such that receiving plants are at full capacity 57% of the time. Moisture is a strict quality parameter for the electronics industry. At 30% of product rejects, PCC had to address the root cause of the issue. Quality analysts and production supervisors at first blamed electronic sensors of the customer were not properly calibrated causing these rejections. It was then determined that the alumina catalyst had not been replaced for 20 years. As a solution, the activated alumina whose content is in vessel (D8-A, B, C, D, E, F, Figure 1)was immediately replaced. As of 2013 there were no longer any rejection issues due to moisture. Within three years of production 1 account of off-odor specifications in CO_2 production occurred. A total of 1% of total deliveries within the span of 2010 – 2012 was diverted due to product recalls.

5.8 Available Technology

Five companies were contacted to provide PCC with product quotations for gas testing equipment. These companies were helpful enough to respond to the inquiries on the equipment suitability for CO_2 gas analysis. The following companies were contacted: Gow-Mac, Buck Scientific, VIG, Teledyne- Platinum Industries, Baseline – Mocon Inc, and Atlantic Analytical Laboratory.

Table 6 Available Technology

Company	Product (model number)	Price (US$)	Operating Costs in(US$)		Compatibility of use with this report
			Manpower	Equipment	
1.Gow-Mac (Monitoring Beverage Grade CO2 , 2012)	THC23-550-BG-1	$ 12, 600	US$ 10/test	$ 118.15/ test	✔
2. (Buck Scientific ,	Model 110 GC FID	$ 6, 495	US$ 10/test	$ 118.15/ test	✔

2013)					
3. (VIG Industries Inc., 2006)	Model 20 FID	$ 10, 950	US$ 10/test	$ 118.15/ test	✔
4. Teledyne (Platinum)	Model 4020	$ 13, 700	US$ 10/test	$ 118.15/test	✔
5. Baseline-Mocon Inc. (Baseline Mocon, 2013)	Series 9000 THA with FID	$ 10, 995	US$ 20/test	$ 118.15 / test	✔
	Model 8900 GC Acetaldehyde, Methanol, Benzene	$ 25, 075	US$ 50/test	$250 / test	✕
	Model 8900 GC Total Sulphurs	$ 30, 105	US$ 50/test	$ 250 / test	✕
6. AAL Atlantic Analytic Laboratory	DTM-4	$ 12, 000	US$ 10/test	$105.052 / test	✕

A representation of the current technology available is presented in Table6. The company, model name of the equipment, the products price, and an estimated value of operation costs per test are shown. Five technologies which contain the (✔)symbol may be purchased as a solution for the problem in this report.

5.9 Repair and Maintenance of Plant Modules

Each of the plants modules operate with various parts. The repair and maintenance of these plant modules were obtained through the PCC Batangas plant's production department. Data in the repair and maintenance chart contained the date, hours a module was under repair. The total reliability of the system with respect to Lines 1, 2, and 3 may be viewed in the analysis chapter 6.3. Appendix F presents the data collected from each of the plants modules in repair as terms of hours.

5.10 Production Costs of Manufacturing CO2

Operation costs of the manufacturing liquid CO_2 was obtained through the plant manager. Key process indicators of production (KPI) were carefully analyzed and placed into consideration for CO_2 costing. The data collected for manufacturing CO_2 was determined to be highly confidential therefore a representation in percentages as a total of cost per kg is shown in Table 7.

Table 7 Production Cost CO2

Raw gas	Rent	Manpower	Diesel	Water	Electricity	Quality Testing	Transportation	Transport losses
41.56%	0.91%	1.78%	6.54%	2.33%	21.49%	7.79%	13.85%	3.73%

About half of production expenses (41.56%) is paid to the alcohol plant for incoming raw material (CO_2 gas). Other expenses such as electricity (21.5%), transportation (13.85%), water (2.33%), and diesel consumption(6.54%)are significant expenses of manufacturing food grade liquid CO_2. Quality at present is at 7.8% of production costs. If PCC decides to incorporate new technology as a solution to breakthrough control in the deodorization region, the cost of quality in production will certainly increase. A model scenario of the equipment employed as production is presented in the analysis chapter 6.6.

5.11 Experimental Set-up

Figure 2 represents an experimental set-up of the activated carbon vessel. The first step occurs when raw CO_2 Gas would enter the carbon vessel trapping impurities such as total hydrocarbon. A pipeline on the exit of a vessel is tapped into the Gow-Mac Total Hydrocarbon (THC) testing apparatus. The THC analyzer then displays a quantitative amount of THC’s as parts per million (ppm). The activated carbon vessel is not a final CO_2 gas purification process therefore gas is purified further when it reacts with the next process.

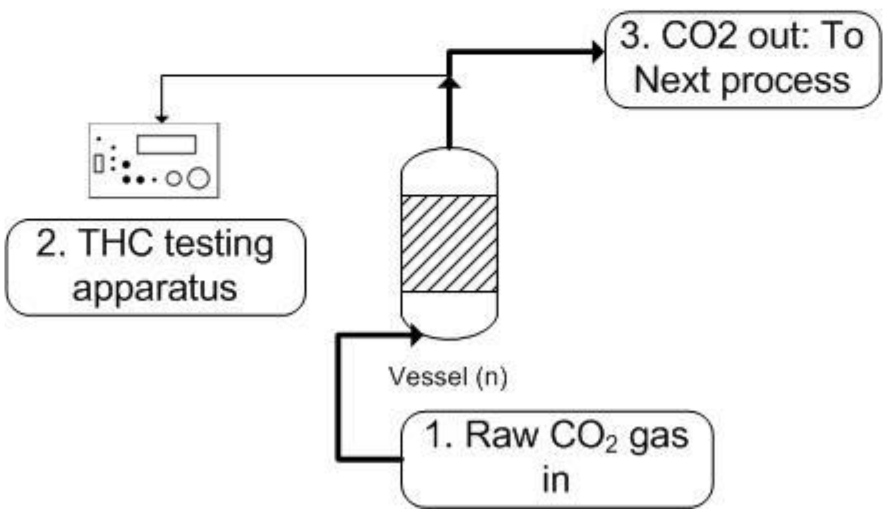


Figure 2 activated carbon vessel experimental set-up

Table 8 Comparison of D-5 states with and without technology

	Start-up	At 30 hours operation	End of service	service (hours)	steaming(hours)	hot air (hours)	Cooling (hours)
vessel 1	90.42ppm	9.92ppm	32.04ppm	$\alpha_{1.1}(t)=57.13$	$\phi_{1.1}(t)=11.42$	$\lambda_{1.1}(t)=13.93$	$\mu_{1.1}(t)=9.34$
vessel 2	83.82ppm	8.73ppm	31.56ppm	$\alpha_{2.1}(t)=57.01$	$\phi_{2.1}(t)11.27$	$\lambda_{2.1}(t)=14.79$	$\mu_{2.1}(t)=11.86$
Without analyzer/ “sniffing process”							
vessel 1	“good”	“good”	“bad”	$\alpha_1(t)=47.47$	$\phi_1(t)=13.84$	$\lambda_1(t)=18.09$	$\mu_1(t)=14.61$
vessel 2	“good”	“good”	“bad”	$\alpha_2(t)=48.62$	$\phi_2(t)=13.93$	$\lambda_2(t)=17.89$	$\mu_2(t)=14.79$

The experiment conducted showed an initial of 24 test trials for vessel 1 and 23 trials for vessel 2. Table 8 presents the average amount of contaminants when the vessel initially begins to operate values indicated for vessel 1 = 90.42ppm and vessel 2 = 83.82ppm. After 30 hours of operating exiting total hydrocarbons from the carbon bed drop to an average value of 9.92ppm and 8.73ppm for vessel 1 and 2 respectively. This signifies that the carbon vessel removes 99.4% of Total Hydrocarbon as contaminants during its operation phase. At 57 hours of operation around 32ppmof THC content was quantified prior to shifting the vessel. With the equipment installed, a breakthrough control limit 32ppm of THC content may be used as a benchmark instead of simply sniffing out CO_2 contaminants and subjectively determining if the quality of manufactured gas is “good” or “bad”. Other information the data on Table 8 present that the time a vessel in service was extended to an approximate of 10 hours. Steaming on the other hand was reduced by an approximate of 2 hours, hot air reduced by 4 hours, and cooling reduced by 3 hours. These significant changes have contributed to reduced costs on consumptions of diesel, electricity, and water. The actual data from this experimental testing may be seen at Appendix B.1.1 , and B.2.1.

Chapter 6: Analysis

6.1 Activated Carbon Vessels Configuration

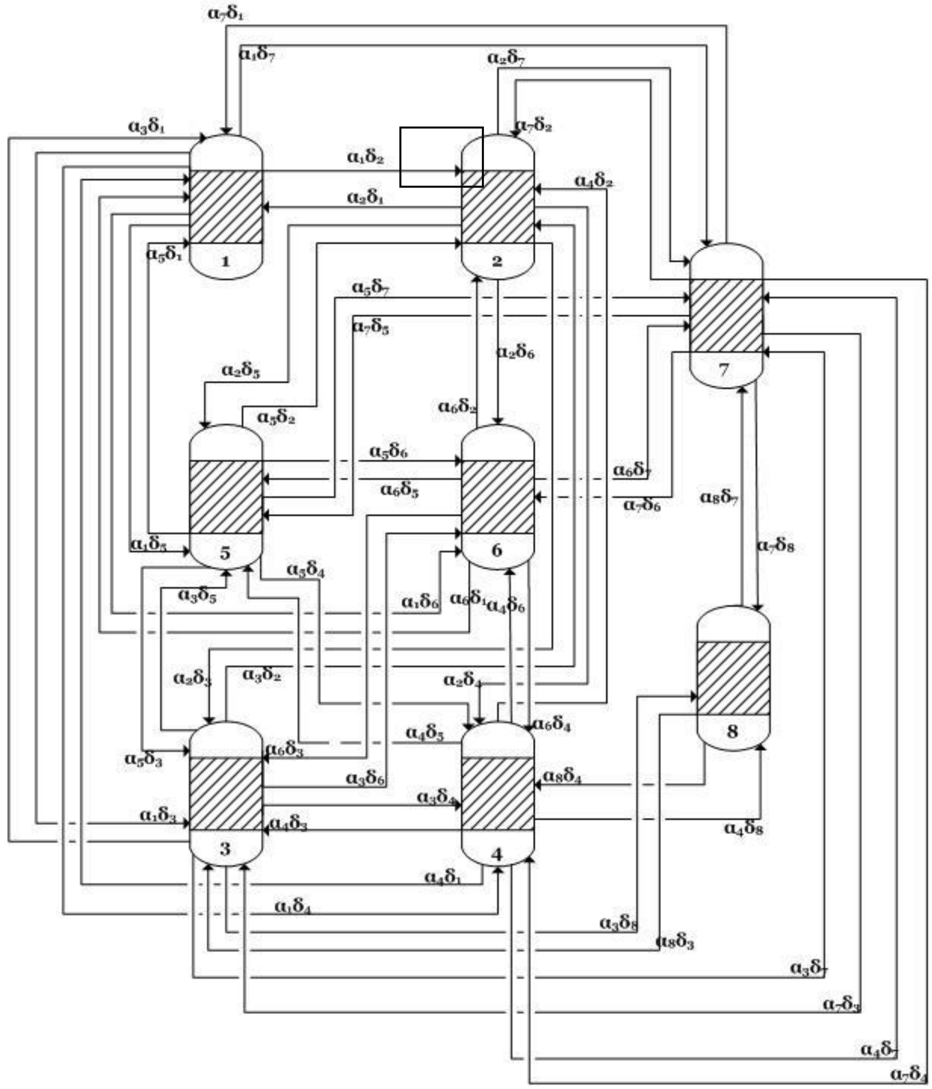


Figure 3Activated Carbon Vessel Configurations

The plant maintains a total of 8 activated carbon vessels. Once a vessel is rendered to be saturated of gas contaminants a properly regenerated idle bed goes online. As an example given in Figure 3: $\alpha_1\delta_2$ refers to an (operatingα_n) vessel moving to a ready (idleδ_n) vessel. Illustrated in Figure 3 are the possibilities of how the vessels are interconnected and may be serviceable to each other.

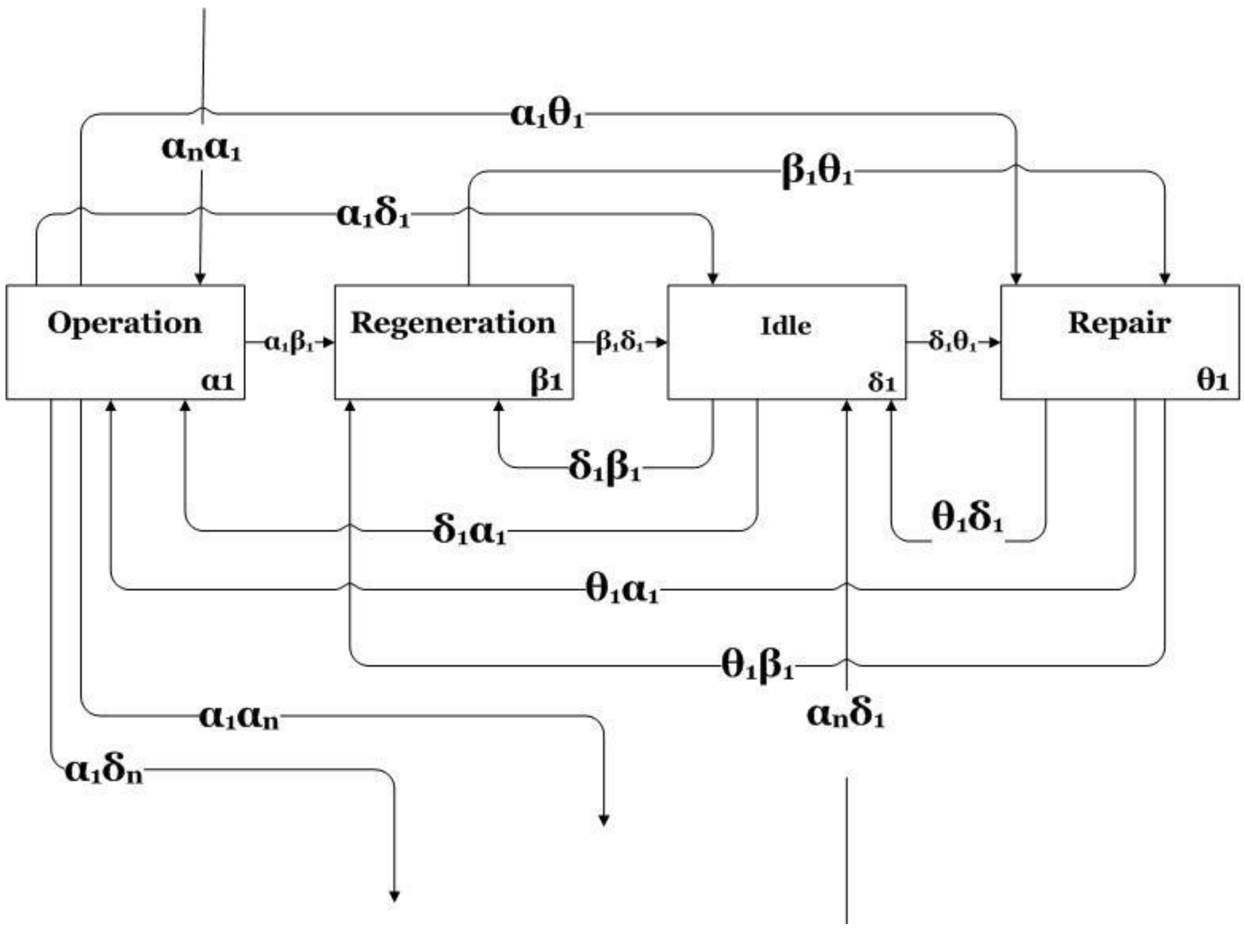


Figure 4Vessel 1 Transitioning to its different states

<u>The following states are given:</u>

α_n – Operating time of vessel *n*

β_n - Regenerating time of vessel *n*

δ_n - Idle time of vessel *n*

θ_n –Repair time of vessel *n*

n = vessel number { 1, 2, 3, 4, … 8}

There are 4 different states in a particular activated carbon vessel. These are represented by the symbols above (α, β,δ, and θ). A vessel in its specific state may transition randomly towards another state. There are 11 possibilities that a state may transition within a vessel, the following are identified as:($\alpha_1\beta_1$;operation-regeneration,$\alpha_1\delta_1$;operation-idle,$\alpha_1\theta_1$;operation-repair,$\beta_1\delta_1$;regeneration-idle,$\beta_1\theta_1$;regeneration-repair,$\delta_1\beta_1$;idle-regeneration,$\delta_1\alpha_1$;idle-operation,$\delta_1\theta_1$;idle-repair,$\theta_1\delta_1$;repair-idle,$\theta_1\alpha_1$;repair-operation,$\theta_1\beta_1$;repair-regeneration). Vessel 1 may transition to another vessel(n) with the following possibilities: ($\alpha_1\alpha_n$;operation-operation, $\alpha_1\delta_n$;operation-idle). Another vessel(n) may also transition into vessel 1 with the following states given: ($\alpha_n\alpha_1$;operation-operation,$\alpha_n\delta_1$operation-idle). These possibilities are all common for the 8 carbon vessels in the plant. The carbon vessel may incur corrosion and erosion due to wear and tear of operations. These circumstances may cause the unit to be repaired.

6.2 Markov Chain transition Matrix

A 32 x 32 matrix was configured in parallel to collecting data for reliability, and production analysis. The transition matrix presented attributed from the state distributions of (operation, regeneration, idle, and repair) collected from the activated carbon vessels. The state matrix presents a probability of what state the activated carbon vessels are in. To analyze the state matrix at Table 9, certain operating conditions must be initially set. PCC operates only with a maximum of 3 activated carbon vessels when incoming raw gas supply is at 100%. The amount of operating vessels may diminish due to low raw incoming gas to the plant. An initial state matrix may be multiplied to the transition state. Given in the following examples are:

A = [1 0 0 0 | 0 1 0 0 | 1 0 0 0| 0 1 0 0 | 1 0 0 0 | 0 0 0 1| 0 0 1 0 | 0 0 1 0], as the initial state

B = [32 x 32] , transition matrix (Table 9)

If matrix multiplication is done through A * B then, a probability of the vessels configurations may be seen with the output matrix. The average output of production for every vessel was calculated with its collected data from appendix E. Table 9 presents an estimated output per hour in kilograms of liquid CO_2 per activated carbon vessel.

Table 9 Average Production output per vessel

Activated Carbon Vessel	Manufactured Output in (kg/hr)
1	421.22
2	422.67
3	522.10
4	628.62
5	529.60
6	527.43

7	438.95
8	448.36

The transition matrix and these collected distributions may be utilized in a simulation software to show the amount of transitions between states of each vessel. The amount of production hour transitions from the simulation may then be multiplied with the corresponding vessels manufactured output of CO_2. However due to the complexity of the plants configuration of modules and its operating characteristics, a simple Markov on its initial state is presented for this case.

Table 10 Transition Matrix for Activated Carbon Vessels

		1				2				3				4				5				6				7				8			
		α_1	β_1	δ_1	Θ_1	α_2	β_2	δ_2	Θ_2	α3	β3	δ3	Θ3	α4	β4	δ4	Θ4	α5	β5	δ5	Θ5	α6	β6	δ6	Θ6	α7	β7	δ7	Θ7	α8	β8	δ8	Θ8
1	α_1	0%	28%	26%	11%	0%	0%	27%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	1%	0%	0%	0%	0%	0%	4%	0%	0%	0%	0%	0%
	β_1	0%	0%	91%	9%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	δ_1	85%	13%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Θ_1	27%	33%	40%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
2	α2	0%	0%	26%	0%	0%	26%	25%	11%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	1%	0%	1%	0%	0%	0%	0%	0%	8%	0%	0%	0%	0%	0%
	β2	0%	0%	0%	0%	0%	0%	96%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	δ2	0%	0%	0%	0%	82%	13%	0%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Θ2	0%	0%	0%	0%	52%	21%	27%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
3	α3	0%	0%	0%	0%	0%	0%	0%	0%	0%	26%	25%	15%	0%	0%	26%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	6%	0%
	β3	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	95%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	δ3	0%	0%	0%	0%	0%	0%	0%	0%	83%	14%	0%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Θ3	0%	0%	0%	0%	0%	0%	0%	0%	23%	21%	56%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
4	α4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	24%	0%	0%	24%	29%	10%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	10%	0%
	β4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	96%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	δ4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	90%	6%	0%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Θ4	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	15%	40%	45%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
5	α5	0%	0%	1%	0%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	30%	28%	12%	0%	0%	26%	0%	0%	0%	1%	0%	0%	0%	0%	0%
	β5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	95%	5%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	δ5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	93%	5%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
	Θ5	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	36%	31%	33%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
6	α6	0%	0%	1%	0%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	29%	0%	0%	32%	32%	2%	0%	0%	1%	0%	0%	0%	0%	0%
	β6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	94%	6%	0%	0%	0%	0%	0%	0%	0%	0%
	δ6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	95%	2%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%
	Θ6	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	38%	33%	30%	0%	0%	0%	0%	0%	0%	0%	0%	0%
7	α7	0%	0%	16%	0%	0%	0%	13%	0%	0%	0%	4%	0%	0%	0%	1%	0%	0%	0%	5%	0%	0%	0%	5%	0%	0%	44%	8%	3%	0%	0%	1%	0%
	β7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	94%	6%	0%	0%	0%	0%
	δ7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	92%	0%	0%	8%	0%	0%	0%	0%
	Θ7	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	43%	21%	36%	0%	0%	0%	0%	0%
8	α8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	9%	0%	0%	0%	15%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%	0%	0%	25%	46%	3%
	β8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	96%	4%
	δ8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	97%	0%	0%	3%
	Θ8	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	40%	30%	30%	0%

6.3 Reliability

An accurate reliability prediction of a product is highly desirable. Depending on the products market, and advance knowledge of reliability would allow forecasts to be made, support costs, spares requirements, warranty etc. Reliability could also be an integral part of the study of design processes, comparing options and critical reliability features of designs. In our study of the CO_2 plant, reliability was used to obtain measurements on repair and availability of specific modules of the plant. These reliability options provided a better perspective as a predictor of the systems behavior.

Nomenclature for activated carbon vessels :

n = vessel number {1,2,3, … 8}

$\alpha_n(t)$ = total hours of vessel n in operation

$\beta_n(t)$ = total hours of vessel n in regeneration

$\delta_n(t)$ = total hours of vessel n in idle

$\theta_n(t)$ = total hours of vessel n in repair

$\phi_n(t)$ = total hours of vessel n time in steaming

$\lambda_n(t)$ = total hours of vessel n time in hot air

$\mu_n(t)$ = total hours of vessel n time in cooling

$\pi_n(t)$= total hours of vessel n production

Nomenclature for Reliability:

T_{xr} = total operating time of a line "r" in 3 years, x = 1 (2010), x = 2 (2011), x =3 (2012),

andr = line 1, 2, or 3

Tt_r = Total Operating Time in hours for Lines 1, 2, 3, r = line

n = module number

Table 11 Total Operating Hours of a Line r, in 3 years

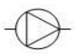
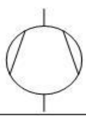
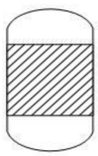
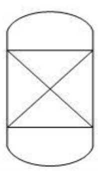
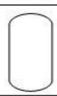
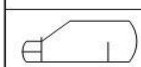
	2010	2011	2012	Total
Line 1	T_{11} = 7,384.80	T_{21} = 7,544.60	T_{31} = 7,576.71	Tt_1 = 22,506.11
Line 2	T_{12} = 7,130.22	T_{22} = 7,613.64	T_{32} = 6,501.32	Tt_2 = 21,245.18
Line 3	T_{13} = 5,913.51	T_{23} = 7,045.67	T_{33} = 6,450.56	Tt_3 = 19,409.74

Table 12Reliability Equations for PCC's System Modules

Equation			
Equipment	Displayed text	FR (Failure Rate)	MTTR (Mean time to repair)
Root Blower Pump	R1,R2,R3	$FR = \frac{\sum NF(Rx)}{Ttr}$	$MTTR = \frac{\sum Rn}{\sum NF}$
Knock Out Drum	D1,D2,D3	$FR = \frac{\sum NF(Dx)}{Ttr}$	$MTTR = \frac{\sum Dn}{\sum NF}$
Shower	T1,T2,T3	$FR = \frac{\sum NF(Tx)}{Ttr}$	$MTTR = \frac{\sum Tn}{\sum NF}$
Compressor	C1,C2,C3,C4	$FR = \frac{\sum NF(Cx)}{Ttr}$	$MTTR = \frac{\sum Cn}{\sum NF}$
Deodorizer	1,2,3,4,5,6,7,8	$FR = \frac{\sum NF(x)}{Ttr}$	$MTTR = \frac{\sum D5n}{\sum NF}$

Permanganate Scrubber	D6 [A,B,C,D,E,F]	FR = $\frac{\sum NF(D6x)}{Ttr}$	MTTR = $\frac{\sum D6n}{\sum NF}$
Alumina Dryer	D8 [A,B,C,D,E,F]	FR = $\frac{\sum NF(D8x)}{Ttr}$	MTTR = $\frac{\sum D8n}{\sum NF}$
Ammonia Compressor	N1,N2,N3	FR = $\frac{\sum NF(Nx)}{Ttr}$	MTTR = $\frac{\sum Nn}{\sum NF}$
Storage Tank	ST [1,2,3,4,5,6]	FR = $\frac{\sum NF(STx)}{Ttr}$	MTTR = $\frac{\sum Stn}{\sum NF}$
Boiler	BR[1,2]	FR = $\frac{\sum NF(BRx)}{Ttr}$	MTTR = $\frac{\sum BRn}{\sum NF}$
Cooling Tower	YCT[1,2,3,4]	FR = $\frac{\sum NF(YCTx)}{Ttr}$	MTTR = $\frac{\sum YCTn}{\sum NF}$
Blower	D5BL[1,2] D8BL[1,2]	FR = $\frac{\sum NF(D5BLx)}{Ttr}$	MTTR = $\frac{\sum D5Bln}{\sum NF}$
*NF = Number of failures *MTBF = $(FR)^{-1}$, for all modules in hours *SA= $\frac{MTBF}{MTBF+MTTR}$, for all modules hours/hours = % dimensionless			

Table 13 Equipment Reliability Table

Figure	Description	Displayed Text	Failure Rate	MTBF	MTTR	SERVICE AVAILABILITY	Number of Failures
Equipment Reliability List							
	Root Blower Pump	R1	0.000489	2046.01	1.909	0.999068	11
		R2	0.000567	1764.37	17.55	0.990148	8
		R3	0.00037047	2699.246	3.9	0.99855724	5
	Knock Out Drum	D1	0.000661	1512.131	3.15	0.997921	10
		D2	0.000496	2016.423	2.228571	0.998896	7
		D3	0.0005187	1928.033	2	0.9989637	7
	Shower	T1	0.000529	1890.164	11.53	0.9939331	8
		T2	0.000921	1085.766	15.26923	0.986132	13
		T3	0.0007409	1349.623	12.2	0.9910414	10
	Compressor	C1	0.00271	368.9526	11.05519	0.970908	61
		C2	0.002692	371.4463	14.52632	0.962364	38
		C3	0.000815	1226.93	66.0909	0.9488864	11
		C4	0.000593	1687.029	22.375	0.986911	8
	Deodorizer	1	0.00105	952.833	47.5	0.9525158	6
		2	0.000676	1479.5	40	0.9736756	4
		3	0.001222	1090.67	64	0.944573	3
		4	0.000791	1264.25	33.25	0.966183	4
		5	0.00079	1265.8	34.2	0.9736923	5
		6	0.000303214	3298	31	0.990687894	2
	Permanganate Scrubber	D6-A	0.0012019	832	6.66	0.9920509	9
		D6-B	0.0012019	832	7.44	0.9911317	9
		D6-C	0.001407658	710.4	5.72	0.9920125	10
		D6-D	0.001266892	789.33	4.9	0.993830528	9
		D6-E	0.002252252	444	4.625	0.989690722	8
		D6-F	0.001970721	507.428	4.85714	0.990518684	7
	Alumina Dryer	D8-A,B	0.0008886	1125.305	10.05	0.9911481	20
		D8-C,D	0.000921	1085.766	10.15385	0.990735	13
		D-8E,F	0.0006669	1499.581	7	0.9953537	9
	Ammonia Compressor	N-1	0.000933	1071.719	26.72619	0.9756691	21
		N-2	0.001063	940.9973	22.69	0.976455	15
		N-3	0.0007213	1386.41	37.14286	0.9739083	14
	Storage Tank	ST1	0.000265	3772.3	7	0.998148	2
		ST2	0.00265	3772.3	11.5	0.996961	2
		ST3	0.000141	7081.727	29.33	0.995875	7
		ST4	0.000188	5311.295	29	0.99457	4
		ST5*	0.000141	7081.727	29.33	0.995875	7
		ST6*	0.000188	5311.295	29	0.99457	4
	Boiler	BR1	0.001437833	695.49	13.1818	0.9813992	11
		BR2	0.001503	665.3889	63.888	0.912394	9
	Cooling Tower	YCT-1	0.00152103	657.44	3.282	0.9950319	23
		YCT-2	0.001521	657.4483	3.217391	0.9951301	23
		YCT-3	0.001587	630.0546	6.291667	0.9901128	24
		YCT-4	0.0012596	793.8959	7.20588	0.991005	17
	Blower	D5BL1	0.000926	1080.455	2.1818	0.997985	11
		D5BL2	0.001956064	511.2307	3.61363	0.99298111	13
		D8BL1	0.000489	2046.01	2	0.999023	11
		D8BL2	0.001137	879.833	7.341667	0.991725	12

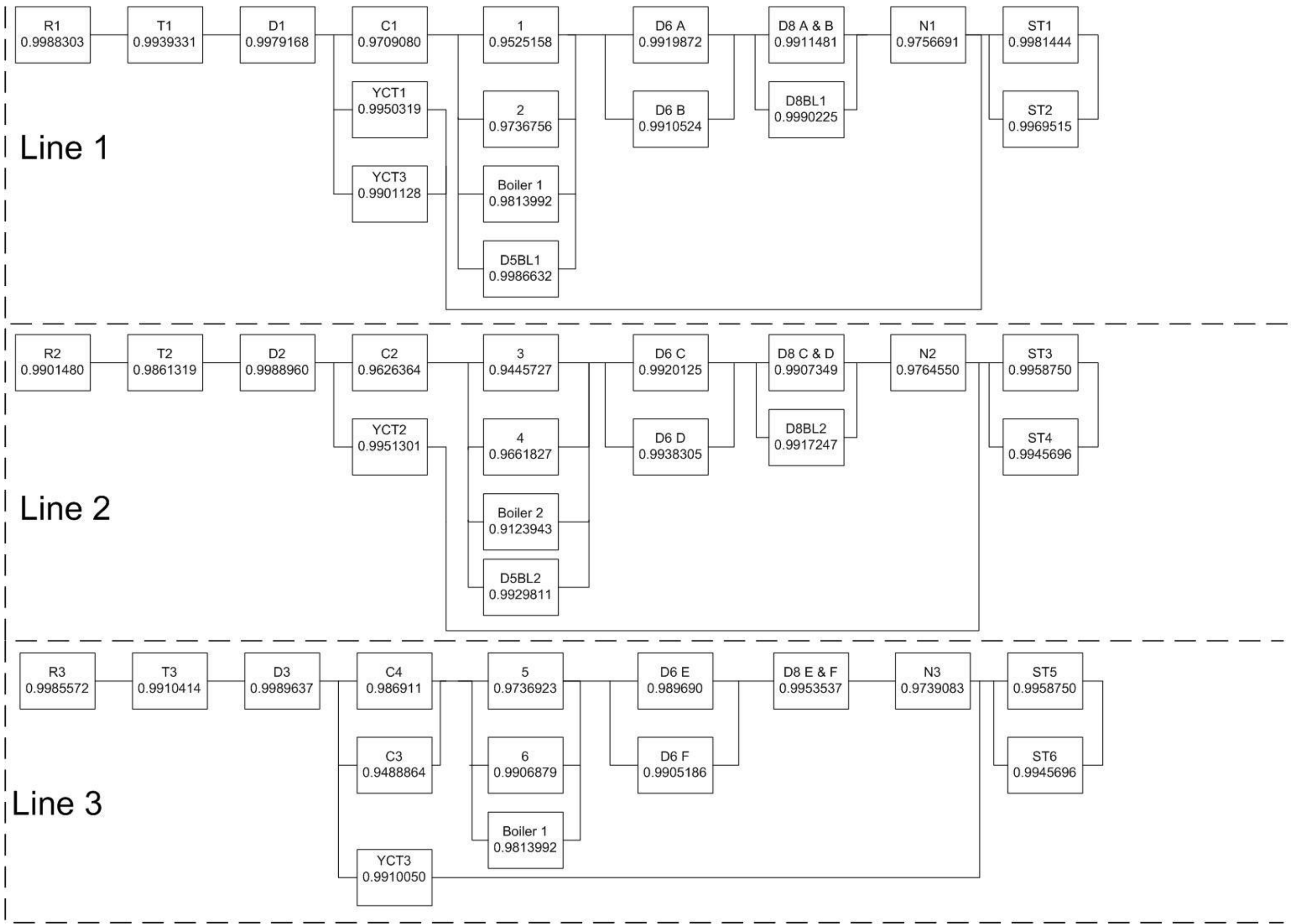


Figure 5PCC Reliability Block Diagram

PCC's modules were computed using theoretical equations which were presented in table 13. A summary of the equipment failure rate (FR), mean time between failures (MTBF), mean time to repair (MTTR), system availability (SA), and total number of failures (NF)may be accessed through Table 11. Value's within the boxed region of Figure 5present the modules system availability. Outlier values on the repair rate within the data set were properly categorized. One activated carbon vessel during 2011 was deemed to be unfit for operational conditions. Due the vessels cyclical operating life of around 40 years, an un-repairable crack was acquired lowering the factor of safety of the carbon vessel. Such an event like this would only occur after a specified number of years. Therefore including such a high value under the repair state would obstruct calculations on normal operating conditions. The System total availability for each of the plants lines are as follows:

Line 1 : 0.99069418 = 99.07%

Line 2 : 0.97489232 = 97.49%

Line 3 : 0.98828495 = 98.82%

These percentage values for system availability of the entire plant categorize line 1 as the most accessible line. According to the availability of modules a proper assessment can be achieved. Some modules attribute lower availability percentages. These low percentage modules may require additional maintenance operations. Critical components where repair and maintenance may be referenced to a function of time are the following:

Table 14 Critical Components Repair Hours

Module	Specific Part	Average hours under repair
T-2 / Shower	Cleaning internal shell section	15.5 hours
C-1 / Compressor 1	Replace piston rings, guide ring, valves	56 hours
C-2 / Compressor 2	Replace piston rings, guide ring, valves	70 hours

C-3 / Compressor 3	Replace piston rings, guide ring, valves	60 hours
C-4 / Compressor 4	Replace piston rings, guide ring, valves	60 hours
Deodorizer's (1,2,3,4,5,6)	Replacing perforated sheets, and activated carbon	50 hours
N(1,2,3) Ammonia Compressor's	Replacing needle bearing,piston rings, valves, micro switch	70 hours
Boiler 1	Replace inlet pipes, perform de-scaling	54 hours
Boiler 2	Re-expansion of tubes cleaning of external shell, replacing transformer	94 hours

Table 15 Economic Order Quantity for Activated Carbon

	Equipment Part	C_o	D	C_c	Q_{opt}	O_c	TC	d	R
Deodorizer	Activated Carbon	360	2400	0.75	1518	231	1138	2	441

C_o = per order cost, (US$)
D = demand per year of the unit, (kg)
C_c = carrying cost, (US$/kg)
Q_{opt} = optimum quantity to be ordered, (kg)
O_c = order cycle time, (days)
T_c = total cost, (US$)
d = number of orders per year,
R = reorder level , (kg)
*25kg per sack

The following paragraph explains in summary the impact of reliability in PCC's operations.

The system availability of the plants modules in this report were done as a summarized, simplified adaptation. From the computed availability, mean time between failure maintenance may be now properly categorized according to each of the systems modules. Operators and supervisors may opt to inspect the plants parts after a number of hours in operation with a proper MTBF value instead of a random estimate time categorizing maintenance scheduling procedures. PCC may opt to consider a proper in depth analysis for each part within the plants modules as a more accurate calculation of each component's wear and MTBF.

An average repair time in each module was accomplished. A significant reduction in hours under repair of these modules may provide better production benefits and longer operational hours. A categorization of repair and maintenance on critical components were also determined. In part of this specific reasons for failure and their repair were also recognized with the repair data collected.

The activated carbon bed serves as the quality control point. The amount of activated carbon in a deodorizer vessel must be continuously replaced on a yearly basis. Every three months about 5-10% of the activated carbon pellets are worn out due to continuous operations. Table 13 presents an economic ordering cost which may aid PCC in reducing inventory costs and achieving savings through ordering an optimum quantity. A reorder level and cycle time in this study was also attained to ensure that the plant does not run out of the product. Data at Table 15 present an optimum quantity order of 1,518 kg of activated carbon. This order may be replenished after stocks have reached a quantity of 441kg and this amount of carbon may be finished at an approximate of 231 days.

6.4 Technology Analysis

Table 16 presents a scenario if the technology were to be purchased. An increase in production cost of CO2 would be incurred if the company decides to operate with the technology acquired. Chapter 5.8 provided a number of quotations for Flame Ionization Detectors (FID). These technologies are all capable of sensing total hydrocarbon content (THC). It is known that FID sensors have same characteristics and operational capabilities. Some differences in the FID equipment may be through design, brand, and range of sensitivity, electronic components, software, and pipe columns however the equipment basic operating requirements are the same. Carrier gas as compressed air, Helium or Nitrogen may be used, Hydrogen is used to maintain a small amount of combustion and calibration gases such as zero and span gas (70ppm THC) must be available to operate the unit. With these working conditions the operating price with the equipment installed may be structured.

Table 16 Cost if technology is acquired

	Total additional Production Cost /year	Cost per kgof CO2	Increase in total manufacturing cost of CO2 as percentage (%)	Machine Repair cost for a part	Average price of a THC machine
Costs	US$ 300,000	US$ .08 - 0.09	19- 22%	US$ 2,000	US$ 11,000

If the technology is acquired and placed into PCC's operations, the cost on CO_2 quality testing would increase to a total of US$300,000 per year. These costs were calculated with the aid of the decision tree in Figure 6. The amount of CO_2

produced in metric tons was considered as the quantity to be tested in attaining a value of US$300,000. Economic conditions were also included to attain an approximate amount of CO_2 to be tested. Under these conditions the company may opt to invest on the technology, depending on the customer's acceptance of such price adjustments. At the current regime quality testing parameters as of manufacturing costs comprise of 7.79% (shown in chapter 5.10). If PCC opts acquire the equipment quality costs could rise to about 19-22% of manufacturing costs. A careful study on price adjustment, efficiency, and level of competitiveness must be considered by the company in this decision. With PCC's customer oriented approach, the company has been continuously complying with requirements such as the Quality Management Systems QMS ISO 9001:2008 and FSSC manufacturing procedures. PCC continued to lead in price competitiveness against its multinational competitors. In 2004 aside from Coca-Cola Bottlers Philippines, PCC was the first carbon dioxide plant in the Philippines to be ISO 9001:2008 certified. This milestone achievement was in parallel to PCC's CO_2 testing laboratory which was the first supplier accredited lab by Coca-Cola Philippines and in 2013 the Global Food Safety System Certification was acquired. It won't be long that PCC's food and beverage customers would require even more stringent manufacturing procedures such as placing the equipment reviewed in this study yet due to the changing market conditions, and economic stature of the country PCC may opt to value on other options. PCC's production may be diverted for other industrial purposes.

6.5 Technology Decision Tree Analysis

In this section we consider equipment for gas analysis. Results provided are expected expenses upon acquiring and operating the technology acquired. The analysis implied a one year approach on applying these technological advancements for technology acquisition. The figure provides an approximate cost on expenses for CO_2 production. This decision analysis may serve as a tool in comparing PCC's competitor's price with respect to quality. This also provides a benchmark tool on how the market is coping with technological advances considering the scarcity of CO_2 manufacturers in the Philippines.

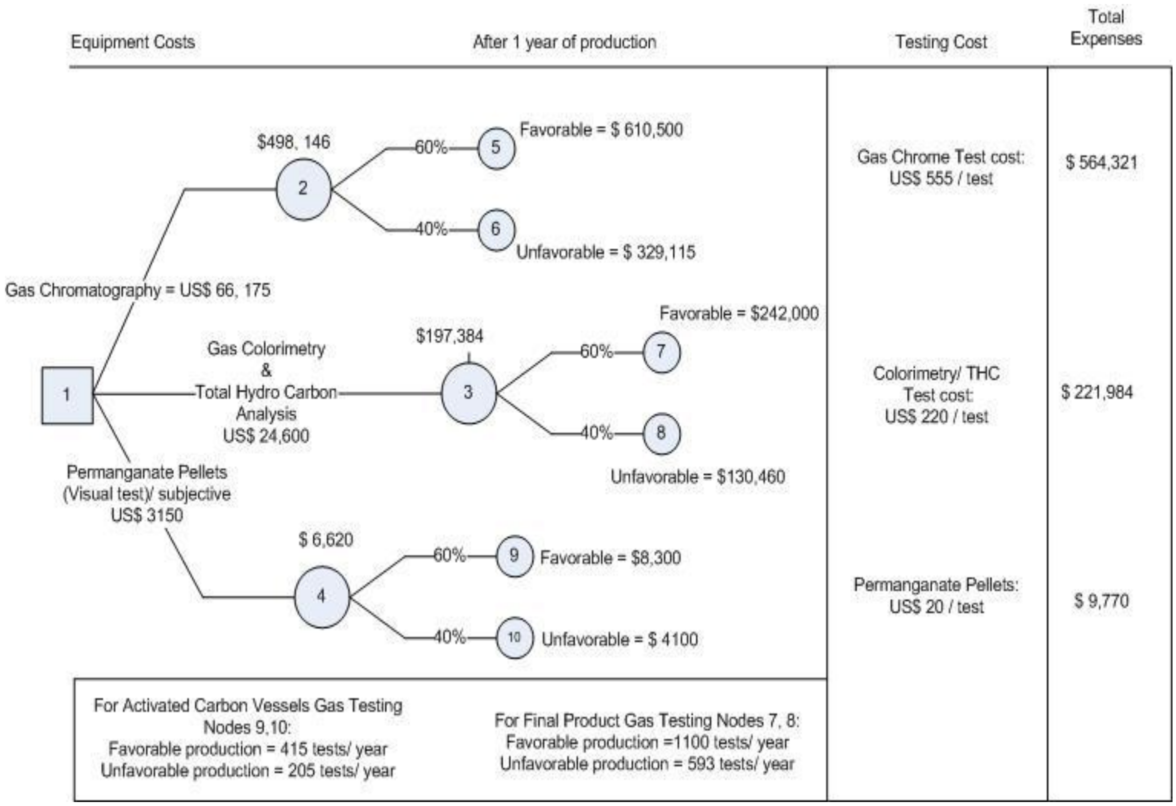


Figure 6 Comparison of Equipment Costs

A comparison of costs with respect to CO2 gas analyzers in their operation states and initial investments are seen in Figure 6. The Gas chromatograph (GC) can test a vast amount of gases. However in PCC's case only CO2 and its contaminant gases would only need to be tested. Some restrictions for the Gas chromatograph is its ease of use. Most gas chromatographs require certified chemists to operate this technology. In order to use the GC a sample amount of gas must be collected and for this case PCC's final product. This limitation of sample gas testing hinders this technology to be used for its lack of real time results.

The gas colorimetry and total hydrocarbon analysis is a much economic method of testing gas for specified parameters. A vacuum pump and detector tubes are required for gas colorimetry testing. Gas colorimetry testing requires final samples of the product which again hinder this device for this case although a simple aspirating apparatus with detector tubes may be used for gas detection, however accuracy would be limited for the device. The total hydrocarbon analysis test (THC) is often bundled with gas colorimetry. Limitations of the device would be that only hydrocarbons are tested however considering the problem of this case, most hydrocarbons exhibit these off-odor specifications such as acetaldehyde, benzene etc. Nitrogen, carbon monoxide and other contaminants which are not hydrocarbons may not be read by the device. The main advantage of using a THC tester is that it may be used in online gas testing. This would mean that the technology would give us a sense of how much contaminants are being removed in the activated carbon region, at the very moment inspected.

A third suggestion for testing equipment was a visual test using Potassium Permanganate pellets. As shown in figure 10 this is the most cost efficient way of testing the gas' online parameters. However one must take into consideration again the subjectivity of a visual test. The Potassium Permanganate pellets should be visually inspected and a color indication will deteriorate from violet to black. Depending on the sensitivity of operators and supervisors this simple sensory equipment would have to be reviewed on its compatibility as well with the activated carbon vessels under liquid carbon dioxide manufacturing conditions.

6.5 Production

For the three operational lines, the plant was placed into a halt due to machine breakdown, power interruptions and low raw gas supply. These hours of downtime were collated and calculated by summing the operation hours $\sum\alpha_n(t)$ data for every vessel and categorizing them with respect to each line. Table17 shows a summary and on an average how many days each line would be down in a year.

Table 17 Operating Hours per year in a Line

Line	Year	Hours Operation $(HO)_{ny}$	Hours idle	in Days	Average	Percentage Line is down
1	2010	7385	1375	57	52 days	14%
	2011	7545	1215	51		
	2012	7577	1183	49		
2	2010	7130	1630	68	70 days	19%
	2011	7614	1146	48		
	2012	6501	2259	94		
3	2010	5914	2846	119	96 days	26%
	2011	7046	1714	71		
	2012	6451	2309	96		
considerations: 8760 hours per year *to calculate for Hours idle in a year = 8760 - HO_n, where n = line, y = year						

Power interruptions cause around 150 hours / year this constitutes to 9.2% of plant stoppages. By analyzing the characteristics of the plants idle time [$\delta_3(t)$, $\delta_4(t)$] with respect to power interruptions, a theoretical amount of 100 metric tons in production of liquid CO2 is considered as lost opportunity.

The data to collect this information was based on Line 2 production:

Total hours per year = 8,760

Idle time 1 year= 8,760 – [$\sum\alpha_3(t) + \sum\alpha_4(t) + \sum\alpha_3\alpha_5(t) + \sum\alpha_3\alpha_6(t) + \sum\alpha_4\alpha_5(t) + \sum\alpha_4\alpha_6(t)$]

Idle time 1 year = 8,760 – 7,130

Total idle time 1 year = 1629

Power interruptions of $\sum\delta_3(t) + \sum\delta_4(t)$ = 150 hours

Percentage of Power Interruptions = 150/1629 = 9.2%

A low amount of incoming raw gas from the alcohol plant causes operating lines to shutdown forcing the plant to run at 50% capacity. During this scenario at least, one line operates to ensure continuous production. Low raw gas caused 80% of plant stoppages and 1307 hours were due to these issues. A theoretical amount of 862.62 metric tons of CO2 could have been realized if raw gas supply was sufficient for production.

6.6PCC's CO2 Production Analysis

As a total manufacturing overview, this chapter represents top management information. Most information on this region is considered to be classified. The company was considerate enough to review this section with respect to decision making processes.

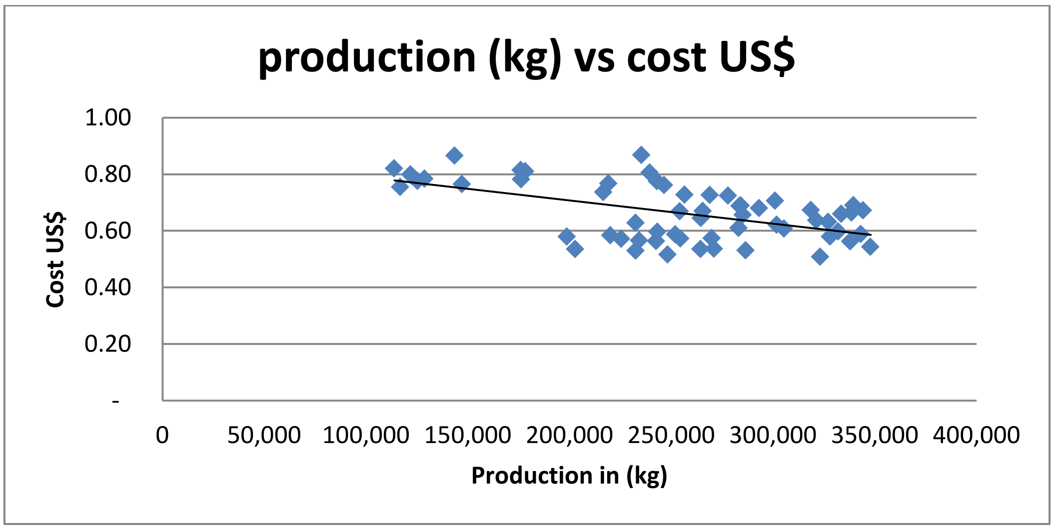


Figure 7 Production vs. Cost chart

The graph on Figure 7 represents the production of CO_2 against its cost per kilogram. A fairly linear relationship may be derived from the data collected. The data for establishing this chart was collected through a 5 year period of CO_2 manufacturing costs. Chapter 5.10's data parameters were utilized as a reference. The equation observed in the graph may serve as a tool to forecast production costs. The graph shows the function of cost per kilogram decreasing as production of CO_2 increases. The fairly linear relationship may represent the status of plant operations under manufacturing conditions of economies of scale. The equationof the line was calculated through regression analysis through SPSS. Table 18 presents the coefficients calculated from Figure 7's production per kilogram of liquid carbon dioxide. Equation 12 presents the equation of the line production vs costs.

Equation 12 Production vs Costs linear equation

$f(x) = 0.872 - 8.21*10^{-7}(x)$, where production amount in (kg) may be input with x

Table 18 Coefficients of production

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.872	.043		20.521	.000
	amount of production	-8.215E-7	.000	-.551	-5.024	.000

a. Dependent Variable: COSTS

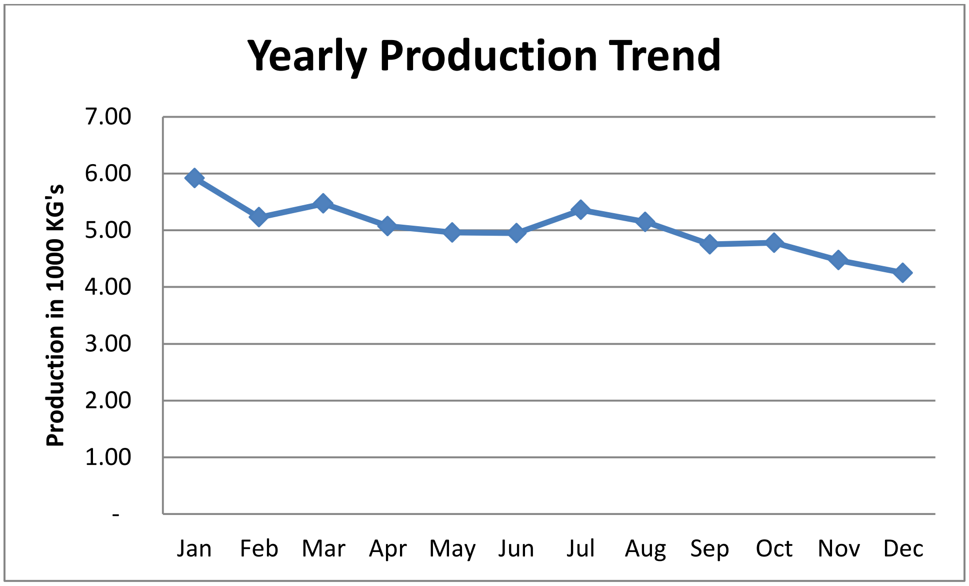


Figure 8 Yearly Production Trend

Production of CO_2 may be difficult at certain periods of the year. The data presented in Figure 8 may support order processing. During lean months of production the company may opt to purchase final product of CO_2 from other sources. Importation of liquid CO_2 may be another viable option however a study of costs must be done in order to achieve optimal expenses.

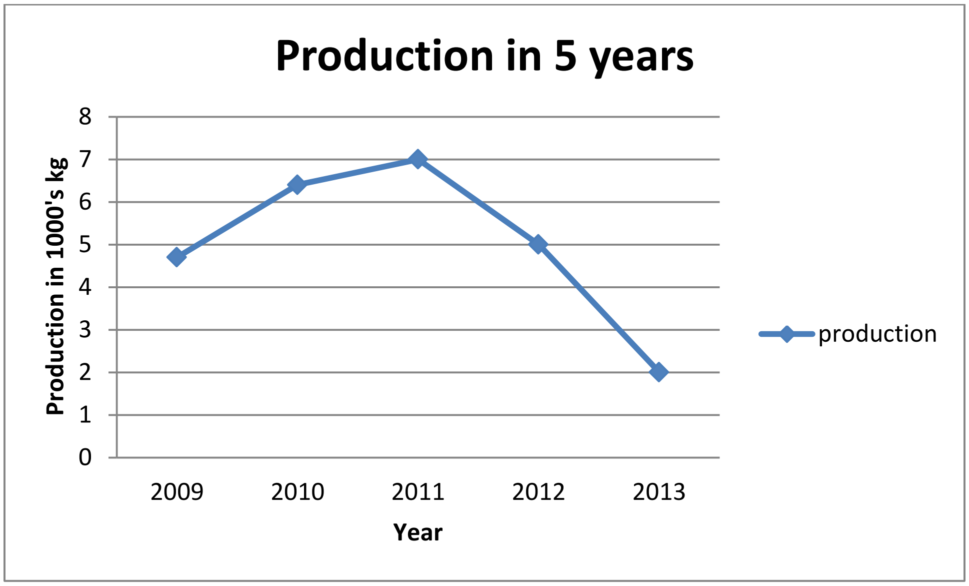


Figure 9 PCC's production of CO2 in the past 5 years

CO_2 production is at its lowest as of 2013. Economic factors which have caused a decline in CO_2 manufacturing are due to issues of raw gas supply. Sugar Cane is raw material for the production of alcohol and CO_2 as a byproduct is emitted. The price of locally produced sugar cane has been continuously rising in the Philippines. This continuous price increase has caused a direct impact on alcohol manufacturing plants. Most alcohol manufacturing companies opt to purchase final product as alcohol from other countries instead as a solution.

6.7 Decision Analysis for Production

CO_2 Production is clearly seen in Figure 9 of the previous chapter. With these economic situations PCC may continue to face intense adversity against its multinational competitors. The industrial use for CO_2 has expanded however problems due to raw material continue to arise. Thereby multinational companies have been considering on importation of liquid carbon dioxide however due to CO_2 liquid's volatility, this has been somewhat prohibitive in acquiring liquid CO_2 from abroad. Another issue to consider is that some industries have altered their manufacturing processes such that they use other gases besides CO_2 as a better alternative. In the gas industry today price alone does not insure instant procurement. Continuity and quality of supply must be considered as top managers and executives require these characteristics as a major indicator for a company's reputability.

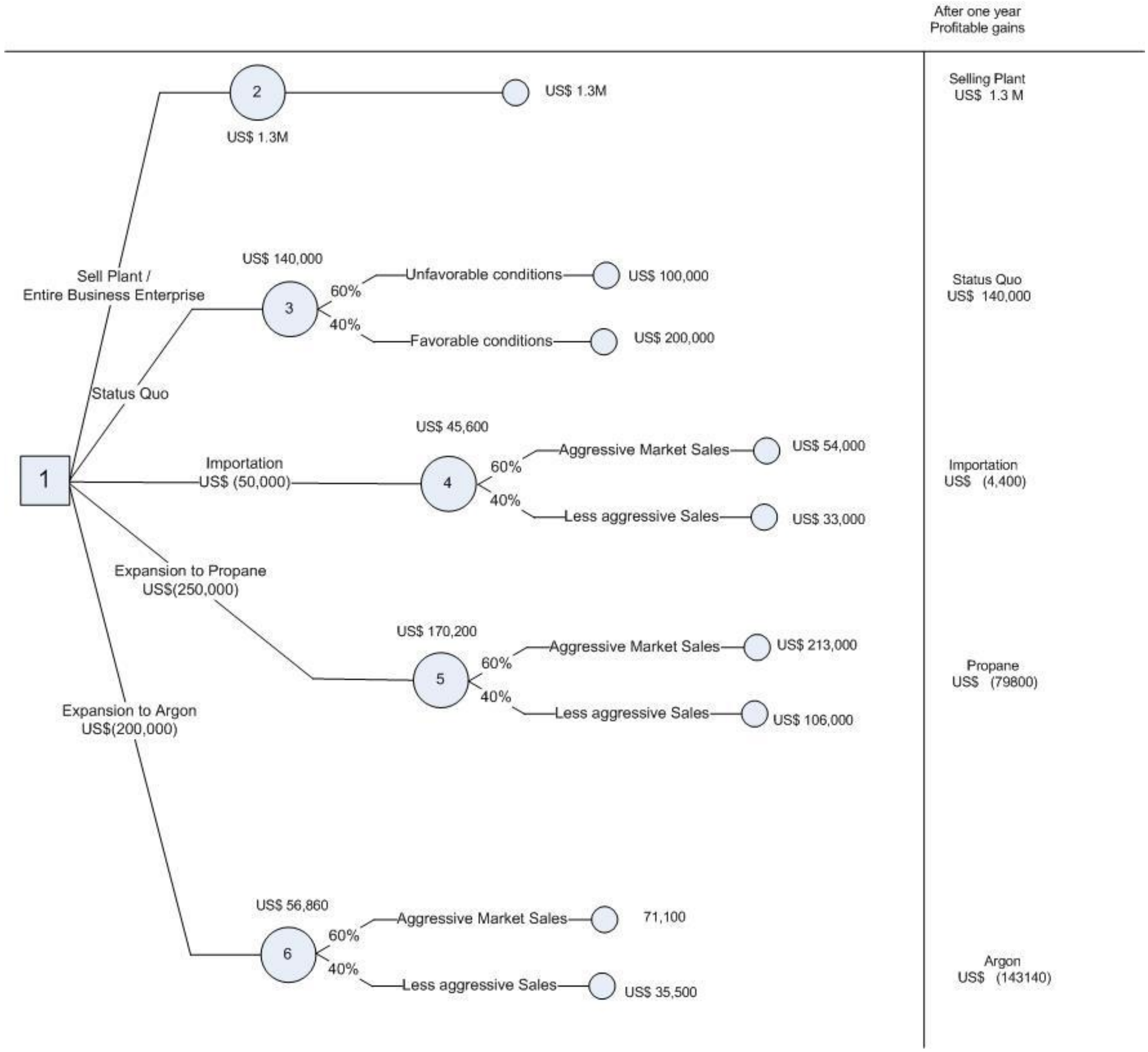


Figure 10 PCC's Expansion / New Market Options

The decision tree in Figure 10 presents actual viable solutions for PCC. A one year analysis was factored in between the given scenarios. Initial conditions were placed as capital expenditures after each modeled scenario presented after node 1. Selling the plant would be the most profitable out of all these decisions however other profitable investments in the future may be forfeited. PCC may opt to build either propane or, argon plant to gain on the market however a good marketing strategy must be acquired in order to gain customer loyalty. Argon and propane expansions may have a slightly expensive capital investment nonetheless under reasonable conditions return on investments may be realized in about a year. These options have only been assessed with a 1 year working scenario. These options may be further expanded to portray profitability gains in the future. The Probabilities of each decision in the analysis may be altered with actual data in order to provide a more accurate scenario.

6.8 Simulation

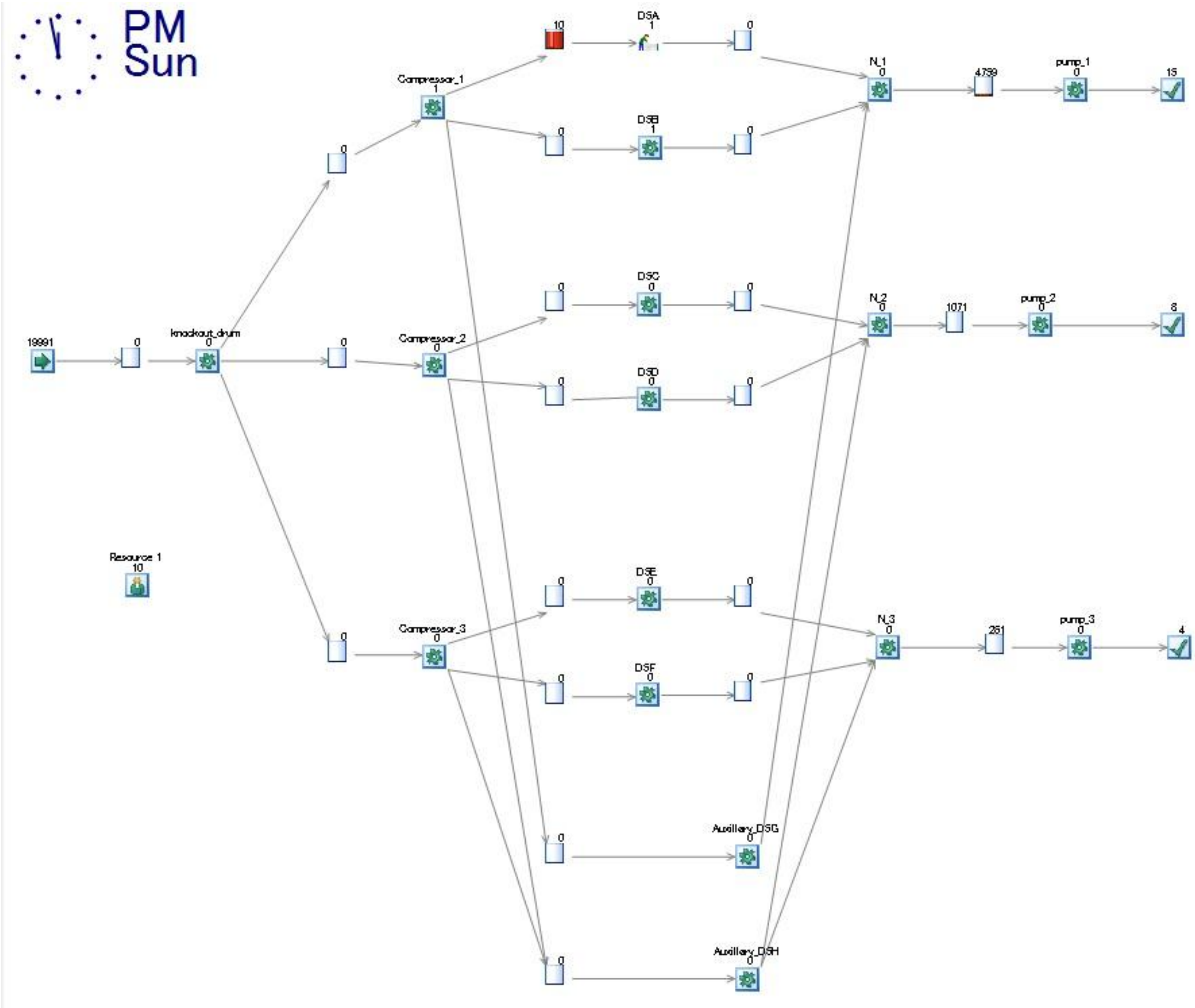


Figure 11 Simulation of PCC's process in Simul8 Software

Simul8 software was used in characterizing the behavior of how the plant operates. Each box depicted in Figure 11 represents the various modules of the plant's system. These modules were then given their respective characteristics of efficiency through the reliability data collected in chapter 5.9. The model could therefore give an estimate prediction as to when these modules may be under repair and maintenance. The regeneration hours of each activated carbon vessel were input as the probability distributions for the system. Each vessel performed under the characteristics of their regeneration states of operation, regeneration, idle, and repair. The user of this software must specify prior to running the model the incoming raw gas and its distribution. The model portrays a discrete process the characterized CO_2 plant system runs as a continuous process. Adjustments were performed on every workstation in order that characteristics and throughput may be verifiable to the actual data collected from the plant.

Table 19 PCC's Results from Simulation Software

SIMUL8 CORPORATION **Results Manager**

KPIs | KPI History | Scenarios | All Object Results | Custom Reports

		Low 95% Range	Average Result	High 95% Range
Work Complete 1	Average Time in System	1494.76	1522.28	1549.79
Compressor_1	Working %	59.87	60.01	60.16
	Stopped %	2.79	2.96	3.14
Compressor_2	Working %	19.96	20.03	20.10
	Stopped %	3.73	3.94	4.15
Compressor_3_4	Working %	19.91	20.02	20.12
	Stopped %	5.68	6.03	6.39
D5A	Working %	19.61	19.72	19.84
	Change Over %	62.63	62.69	62.76
	Stopped %	4.78	5.10	5.42
D5B	Working %	23.39	23.87	24.35
	Change Over %	38.09	38.76	39.44
	Stopped %	2.71	2.89	3.07
D5C	Working %	12.32	12.35	12.39
	Stopped %	5.03	5.51	5.98
D5D	Working %	6.15	6.32	6.49
	Stopped %	3.71	3.91	4.11
D5E	Working %	15.96	15.99	16.03
	Stopped %	2.81	2.99	3.17
D5F	Working %	3.74	3.84	3.94
	Stopped %	0.86	0.91	0.96
Auxillary_D5G	Working %	16.03	16.33	16.64
	Stopped %	0.82	0.98	1.14
Auxillary_D5H	Working %	1.37	1.54	1.70
	Stopped %	0.89	1.01	1.12
Work Complete 1	Number Completed	408.12	409.00	409.88
Work Complete 2	Number Completed	202.49	203.60	204.71
Work Complete 3	Number Completed	107.24	107.80	108.36
Auxillary_D5H	Blocked %	0.01	0.01	0.02
Auxillary_D5G	Blocked %	0.60	0.69	0.78
D5D	Change Over %	9.03	9.35	9.67
D5C	Change Over %	35.02	35.27	35.51
D5E	Change Over %	19.41	19.51	19.62
D5F	Change Over %	1.87	2.01	2.15

The data was primarily specified by the user and after 1 year the collected results may be seen in Table 19.Incoming raw gas was distributed based on percentages. In this scenario the user set parameters such that line 1 received most of incoming raw material at 60%. This setting would allow an accurate prediction of the plants behavior. Modules portrayed working, stopped, blocked, and changeover states. Stopped percentages represent the amount of repair with respect to these modules. The model mainly features on the activated carbon region due to its significance in this study. The “change over” state would represent the amount of regeneration a vessel would undergo in a manner of percentages. Blocked routes also show the amount of percentage that the system would have to shut down due to both activated carbon vessels in a line under regeneration. These are exemplified by the auxiliary vessels D5Gand D5H at 0.68% and 0.01% respectively. The amount of throughput as deliveries in a year may showed that an approximate of 720 deliveries constituting to 720 metric tons may be realized under these running conditions. Actual plant records show that about 800 deliveries are done by the company yearly. With these information approximate of costs with respect to the technology may therefore be specified. Table 20 presents a summary of costs at the plant’s current condition and the cost it would incur if the equipment was to be installed and operated with the aid of the simulation software. Testing costs were calculated by the amount of test gas needed and the required personnel.

Table 20 Comparison of Costs using the Simulation Software

Throughput	Testing At the current regime cost		Regime with New Technology Cost for a year of operation
720 metric tons	US$ 180,000		US$ 120,000
*Testing cost at = US$ 250 per test for THC + Gas Colorimetry *Testing cost at = US$ 150 per test for THC only *Cost per liter of fuel = US$ 1.16/liter			
Savings in costs			
Vessel	Number of Cycles of regeneration in a year	Cost savings in Fuel	Cost savings in Operation
1	60	US$ 5,568	US$ 31,200
2	59	US$ 5,475	
3	49	US$ 4,547	US$ 49,400
4	46	US$ 4,269	
5	56	US$ 5,197	US$ 58,240
6	56	US$ 5,197	
7	32	US$ 2,970	US$ 34,840
8	35	US$ 3,248	
		Total : 36, 471	Total: 173,680
Total savings cost at US$ 210,151			

Total Savings – Cost = US$ 210,151 – 120,000 = US$ 90,151

The study proves that a total of US$ 90,151 may be realized. The total net profitability would be at US$ 90,151 which would translate that investment on the technology is worthwhile provided that continuous raw material of CO2 is maintained.

7.0 Conclusions and discussions

This study has presented that in order to acquire technology for plant improvement processes a complete study must be performed. Theories in this study used such as the Markov chain, reliability engineering, decision analysis, aided in conforming to an accurate result. Other learning’s which have attributed to the betterment of the study is on the importance of data collection. Prior to 2010 the plant performed a 7 year retention period with respect to operation, and maintenance information. These documents were somewhat disposed of by plant managers. It was now realized that the plant’s data is an essential tool and may serve as references to future studies other than simulation.

The following paragraph represents a summary of the theories applied and its recommendations. Reliability was proven to be an accurate tool in determining maintenance and repair in the plants modules. However in this study each module was characterized as a total summary of its breakdowns. A Characterization on each of the parts in the plants modules such as bearings, belts, valves, and piston rings may provide an even more accurate reliability regime for further reference of the plant maintenance. Other recommendations on plant reliability would be on determining the distributions of each repair. Applying a Markov chain with respect to this study would require a deeper understanding of the topic thereby a basic understanding of how transition states and the vessels characteristics were specified to aid in performing simulation analysis.

Simulation was performed due to its versatility to fit the data into working software. The data collected and behavior of the system would be difficult and tedious to describe simply by using mathematical analysis. With the simulation software, data collected and distributions may be instantaneously utilized with the computing power of a computer. In the case of this study, the data had to be characterized to its proper format prior to feeding it into the software. The simulation model in this study also simply represented the important core modules of the plant. These were mainly the compressor, activated carbon vessels, refrigeration compressor, and its storage facilities. Collecting this amount of data would require more time and resources, if performed a complete model with all the modules of the plant may be properly characterized.

Other applications which may be used with the simulation software are on inputting the manufacturing costs on each of the plants modules. The discrete process of simulation may be properly utilized in PCC's retail sector of filling cylinder tanks. Finally using a continuous process in characterizing the plants behavior may also provide a more accurate approach to modeling the system as its flow of materials.

This report has provided a complete overview and study of the entire company from the manufacturing sector to the plants business decision options. The final decision in incorporating the technology may be reviewed by the board of trustees and its final impact on price to PCC's customers in valuing quality supply of liquid carbon dioxide.

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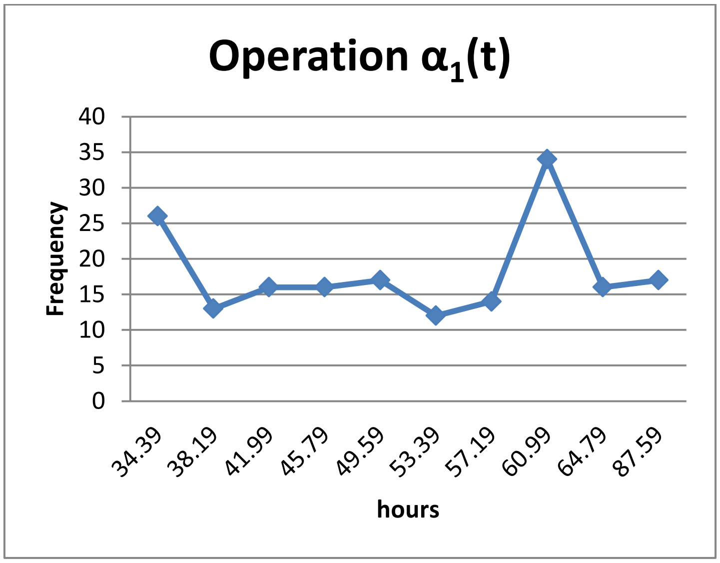
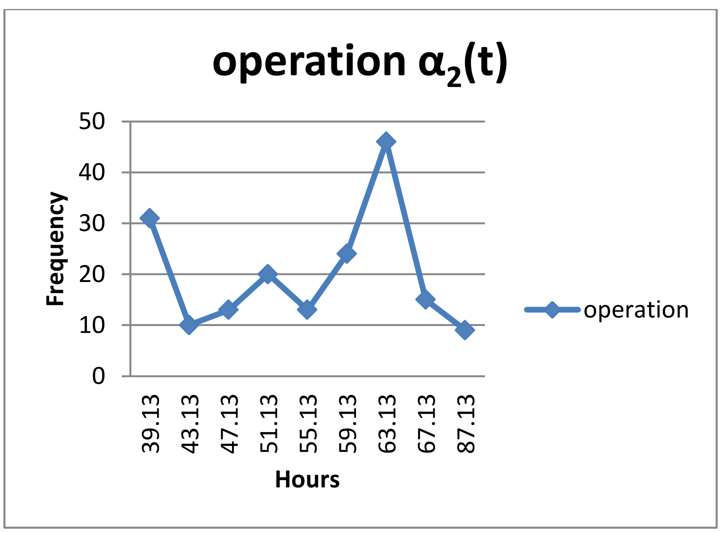
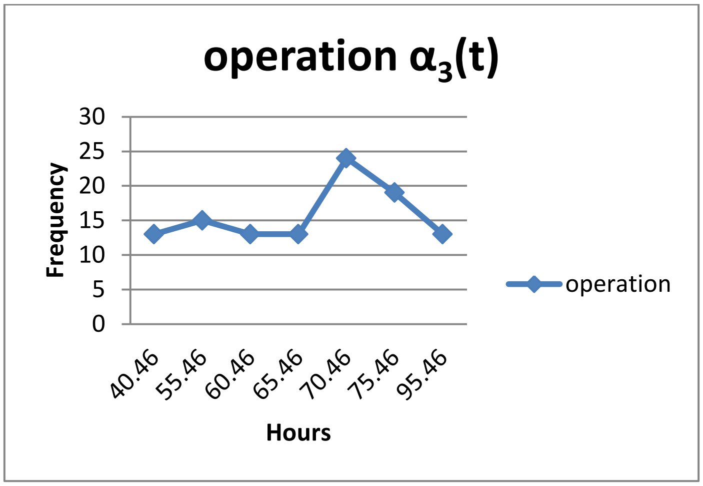
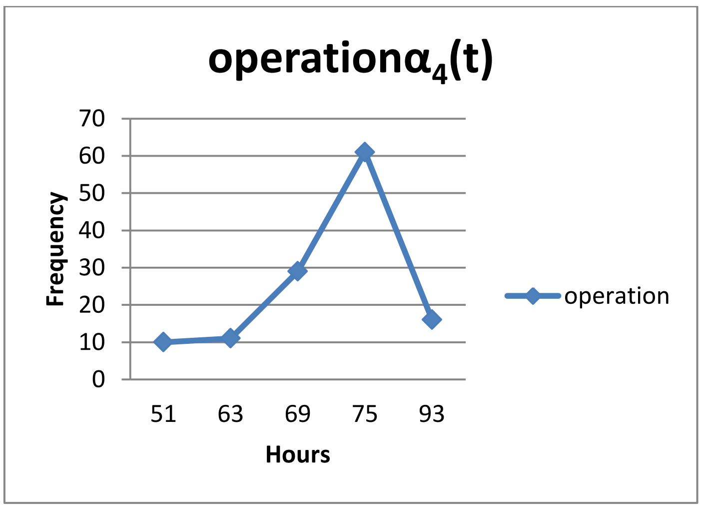
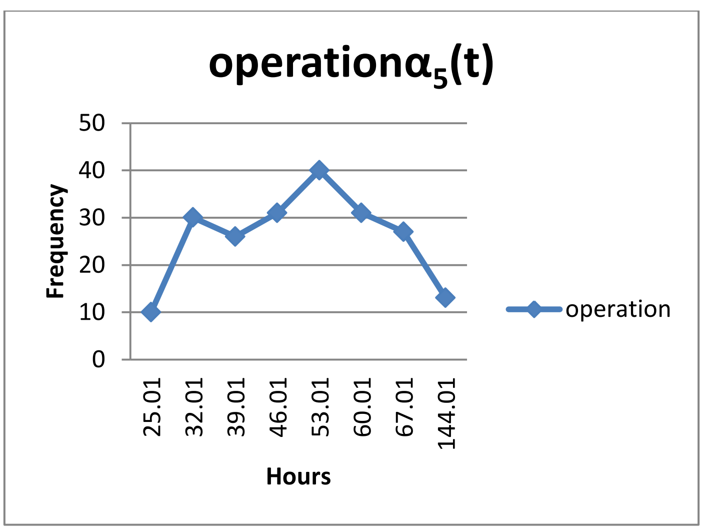
Appendix AOperation state in hours (2010 – 2012)

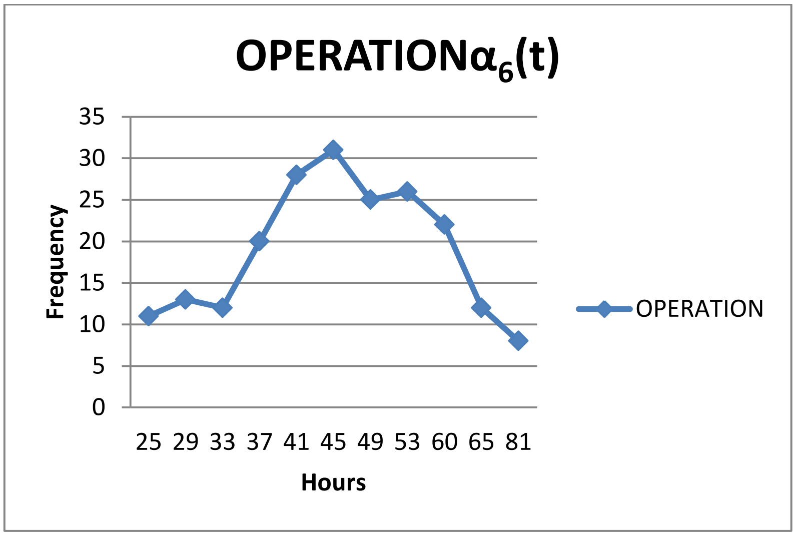


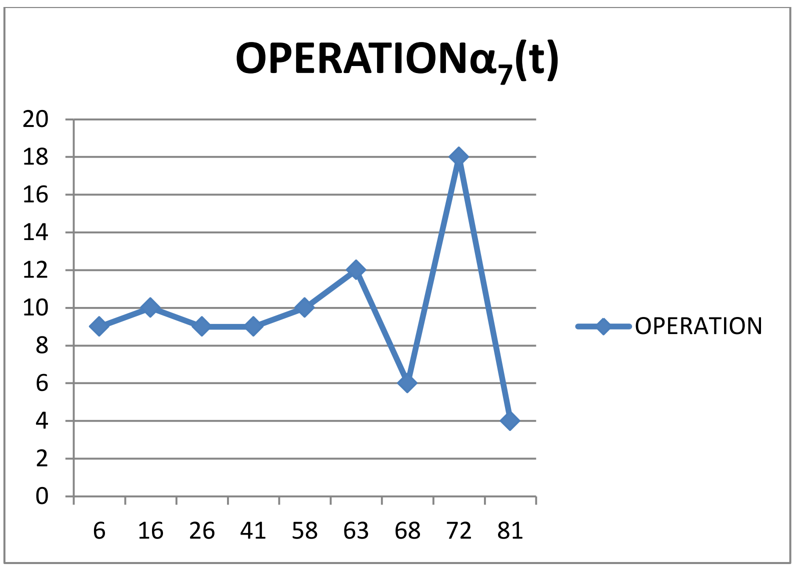


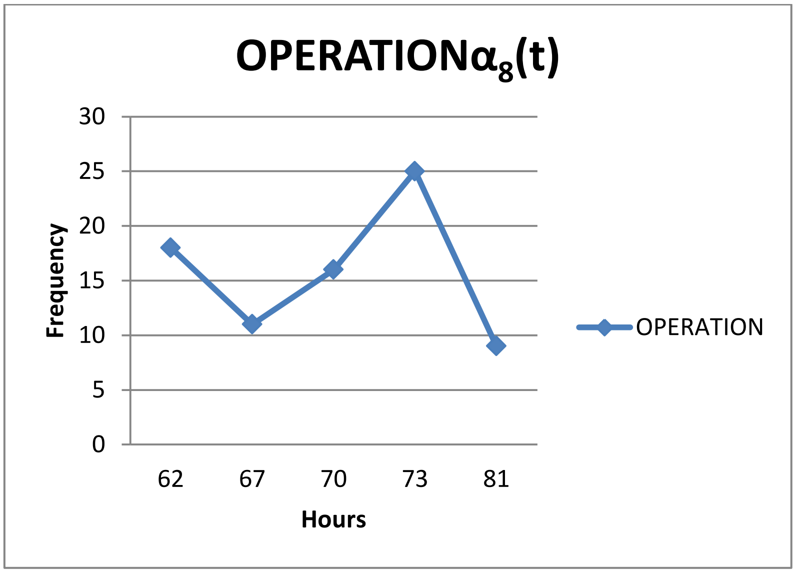

operation α3(t)
Frequency
30
25
20
15
10
5
0
40.46
55.46
60.46
65.46
70.46
75.46
95.46
Hours
operation


operationα4(t)
Frequency
70
60
50
40
30
20
10
0
51
63
69
75
93
Hours
operation


operationα5(t)
Frequency
50
40
30
20
10
0
25.01
32.01
39.01
46.01
53.01
60.01
67.01
144.01
Hours
operation


OPERATIONα6(t)
35
30
25
20
15
10
5
0
Frequency
25 29 33 37 41 45 49 53 60 65 81
Hours
OPERATION


OPERATIONα7(t)
20
18
16
14
12
10
8
6
4
2
0
6 16 26 41 58 63 68 72 81
OPERATION



α1(t) -operation hour				α1(t)	α2(t) -operation hour			
32.74	71.29	42.37	41.78	60.49	55.71	37.6	34.47	61.16
31.21	67.68	31.06	43.39	61.67	21.87	57.96	34.15	71.26
33.11	66.32	34.48	42.11	60	47.72	66.26	52.13	62.98
50.53	41.84	45.36	43.24	60	44.41	77.59	2.1	56.13
32.99	62.81	22.21	41.53	60	45.48	71.2	46.64	58.4
32.37	61.17	32.68	25.81	41.11	59.11	57.06	48.9	64.57
43.71	55.72	45.1	27.35	48.86	66.62	62.1	48.49	63.62
29.94	64.72	29.55	23.52	15.39	47.28	61.28	21.62	42.15
41.14	11.6	49.98	43.31	59.71	55.81	56.8	41.94	60
53.32	48.92	57.36	36.99	35.37	46.25	64.1	11.45	60.6
46.09	61.37	42.49	49.32	34.74	49.64	58.99	27.15	45.36
50.9	21.35	26.5	31.68	35.77	38.96	33.3	48.07	60.22
41.98	5.03	32.99	39.61	45	44.53	26.35	37.99	45.26
38.17	27.02	36.78	39.92	38.25	58.49	60.17	11.13	55.56
56.31	71.35	40.12	51.3	27.68	55.88	65.27	13.79	60.44
63.58	60	23.16	45.06	60.41	42.83	51.43	34.43	24.92
68.13	57.48	34.39	53.17	60.13	36.51	56.71	22.78	47.18
34.25	60.01	64.25	52.34	61.06	42.13	47.86	15.29	43.3
46.39	43.22	1.66	0.28	α2(t)	66.72		14.91	56.3
53.53	53.82	38.91	47.98	61.33	57.59	53.69	18.46	58.57
54.22	50.59	49.56	58.01	60.11	47.47	57.94	38.12	61.49

43.96	67.42	47.91	60.24	61.09	55.21	47.48	2.9	60.06
83.8	54.83	43.55	60	7.88	49.92	4.68	23.48	47.74
60.78	62.64	3.6	60.71	52.12	40.49	46.3	14.58	60.66
60.56	63.79	42.68	47.1	60.00	44.5	53.3	16.11	47.01
41.63	49.65	34.56	41.99	56.46	57.59	57.22	49	60.09
52.11	46.99	40.33	37.3	60.00	47.49	52.29	40.24	61.97
47.6	63.15	23.31	49.1	62.28	60	20.44	22.74	60.82
70.11	48.34	51.95	24.71	60.00	52	25.4	21.7	60.64
60.92	45.18	47.9	57.15	60.39	49.52	66.85	33.45	60
58.89	36.24	46.39	60.92	60.40	66.96	51.5	37.18	22.96
58.6	57.57	53.74	60	67.684	41.32	46.12	46.81	29.54
51	53.95		60	65.97	51.67	40.21	29.36	56.31
60.2	73.19	34.96	60.82	38.64	48.53	61.13	65.25	53.48
63.81	54.13	70.19	60	14.84	53.73	42.01	60.5	28.62
72.57	59.42	53.85	17.48	18.39	49.25	50.43	63.58	60.11
72.8	55.06	57.02	41.92	28.67	50.2	52.1	80.76	60
60.36	47.58	0.76	60.18	64.42	61.33	57		62.06
65.3	14.24	61.16	60.27	62.27	62.28	57.69	64.79	60.18
79.04	23.23	44.08	61	70	66.55	55.49	48.32	60
63	40.19	47.11	60	60.31	67.94	47.31	45.31	60.4
72.656	28.9	39.41	60	60.57	51.58	7.91	24.86	60.34
72.77	24.33	41.29	60.21	60.17	64.92	27.11	72.52	60.07
α3(t)			α4(t)			α5(t)		
59.18	26.58	37.66	63.53	69.22	68.87	52.61	53.47	3.23
55.24	_______	40.67	70.11	21.55	34.08	38.59	49.57	45.41
49	70.4	69.11	48.85	45.72	69.79	50.43	52.76	47.69
31.62	10.46	44.86	53.18		70.05	49.58	50.27	35.39
55.56	71.91	30.97	91.83	61.08	70.91	53.88	48.52	4.13
41.73	55.76	49.48	67.62	55.46	71.93	62.33	50.27	41.45
64.55	71.1	64.40	68.99	64.71	73.03	4.46	14.39	14.08
81.75		19.53	73.17	67.68	70.17	62.97	49.01	9.24
69.78	60.30	20.59	70.1	71.52	65.00	47.96	60.48	31.33
71.59	61.00	56.77	70.5	73.45	70.26	70.83	60.51	19.21
66.88	70.22	70.03	72.18	68.01	70.00	46.81	61.84	6.26
67.36	60.07	48.54	75.37	71.90	70.00	17.12	60.00	23.21
64.18	70.69	70.03	69.13	68.04	71.55	82.59	64.67	40.08

63.97	70.39	70.55	74.79	70.71	57.26	70.66	60.07	40.78
61.94	70.82	67.18	76.16	70.55	70.82	77.34	60.05	48.60
84.95	69.17	65.63	66.06	87.94	73.48	69.08	35.87	42.69
66.6	70.62	70.00	68.63	81.92	17.36	44.79	52.66	47.32
61.2	63.26	48.49	75.84	70.36	64.35	15.02	59.27	48.80
80.26	71.26	41.52	71.71	3.00	67.77	59.91		26.73
67.32	70.30	61.74	72.11	70.96	68.13	140.09	20.75	49.34
72.19	68.12	61.88	72.51	71.10	42.24	84.68	61.38	50.21
78.74	73.40	30.27	65.3	71.39	51.74	71.77	41.99	36.23
79.44	10.80		70.8	70.98	60.02	67.84	5.22	39.20
75.82	59.34		72.4	73.99	60.60	67.34	55.75	40.19
69.91	72.48		70.13	76.70	64.56	97.35	55.70	40.61
78.61	63.99		76.75	70.00	68.19	55.44	61.56	44.29
73.93	57.71		73.76	65.74	70.38	60.94	52.95	45.09
66.62	61.00		70.82	69.92	70.00	62.77	51.12	26.54
71.49	66.08		82.1	70.63	71.18	42.82	52.54	33.28
70.55	56.05		71.87	66.64	69.62	9.16	42.67	34.37
44.49	52.67		62.75	60.04	67.87	2.46	7.17	47.02
72.91	72.86		76.36	64.91	70.00	62.58	41.66	32.26
77.98	70.00		82.21	61.70	70.00	74.10	10.18	40.39
90.75	60.00		77.45	64.78	70.04	1.47	56.38	25.84
81.59	60.38		88.89	64.86	66.27	1.96	41.57	25.73
77	55.87		72.34	42.59	70.00	42.24	4.99	25.92
69.65	50.65		85.54	64.11	70.52	58.21	23.17	26.34
79.85	30.56		73.64	65.10		61.68	11.98	35.44
88.7	50.55		85.14	65.30		55.13	54.16	27.90
72.06	60.00		71.76	53.16		48.23	37.12	41.40
70.22	24.00		70	70.38		56.35	43.54	31.86
70.21	64.68		76.16	70.00		46.42	38.55	63.61
71.58	41.43		72.02	38.23		50.91	2.62	28.49
11.35	34.25		70.76	28.49		58.97	46.71	34.53
51.77	32.30		49.43	70.69		50.50	68.46	29.57
72.68	51.06		63.03	70.31		53.93	45.08	43.43
α5(t)		α6(t)						
49.28	18.01	22.81	43.71	47.35	29.19	53.79	50.31	
30.39	22.96	48.80	50.06	39.32	1.26	45.56	34.61	

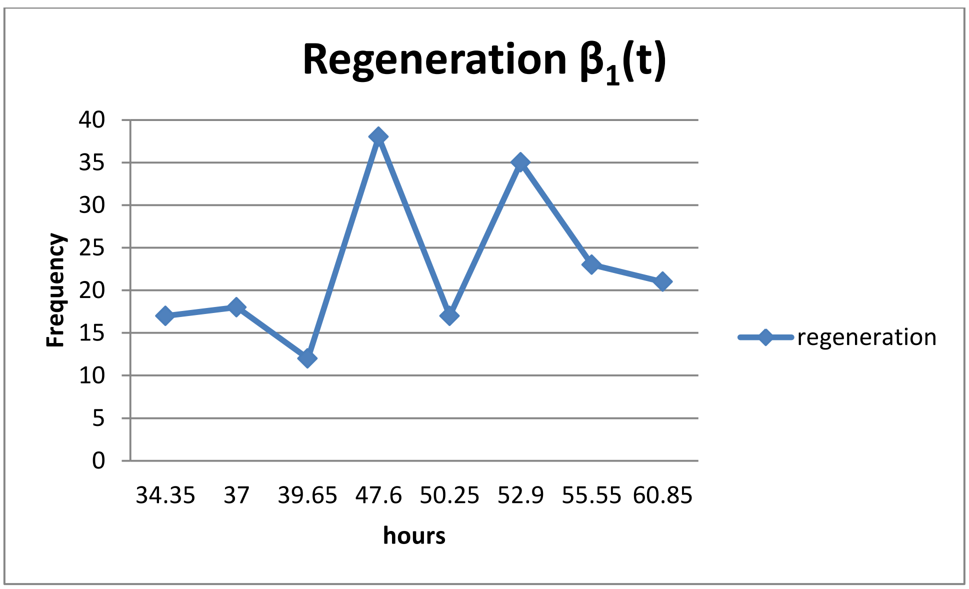
32.01	23.29	51.24	45.70	34.86	45.88	47.68	59.85	
28.06	32.74	11.96	4.50	37.11	32.69	44.23	60.67	
31.28	41.55	1.40	43.25	21.92	33.03	41.69	60.00	
35.77	27.35	21.72	46.12	6.16	27.38	30.89		
28.81	40.85	50.33	44.88	15.48	28.32	25.47		
38.50	43.70	10.70	50.09	7.77	31.33	27.17		
26.37	41.28	61.05	8.66	17.26	40.65	23.47		
45.46	48.71	53.84	40.18	28.67	30.77	49.28		
27.07	48.93	23.73	51.55	8.79	28.36	50.71		
43.28	39.67	48.99	1.68	7.24	26.72	57.48		
40.30	60.00	8.65	46.40	13.65	41.18	31.63		
38.89	10.94	13.13	42.56	7.27	39.53	52.63		
27.51	23.07	41.11	56.37	6.96	45.30	40.87		
28.33	59.60	55.46	51.28	40.39	25.97	49.25		
28.47	53.17	37.70	60.02	38.97	27.26	17.36		
34.12	63.71	23.31	52.97	38.09	25.57	28.22		
50.49	56.50	51.35	39.88	35.86	45.70	46.98		
40.12	53.06	66.92	43.27	41.66	37.50	55.90		
57.04	40.59	49.90	4.87	47.46	19.77	35.12		
60.01	31.29	44.40	35.33	39.44	23.31	42.15		
32.74	8.20	42.91		35.60	80.00	51.83		
34.31	44.93	42.34	35.03	39.11	57.04	52.99		
31.03	60.19	45.59	45.35	39.19		42.38		
34.00	50.19	45.09	45.28	43.95	49.25	31.89		
36.16	57.29	46.51	47.04	40.33	58.89	65.70		
34.08	54.89	41.24	4.65	46.29	69.09	59.59		
33.03	50.00	42.56	33.66	46.95	52.65	60.73		
32.07	58.77	40.26	38.04	41.89	13.67	35.64		
25.72	60.00	30.46	31.87	40.64	33.77	42.04		
35.93	60.63	1.79	35.59	41.49	63.51	51.52		
23.40	60.36	1.77	46.37	39.20	58.62	60.18		
30.18	47.68	51.15	40.47	9.68	65.37	44.09		
28.61	60.24	33.33	18.79	32.43	62.12	52.96		
26.89	42.25	2.14	17.16	32.43	56.51	49.10		
32.32	50.44	36.49	13.60	41.46	45.26	60.14		
29.64	60.00	45.77	24.24	34.29	55.72	59.65		

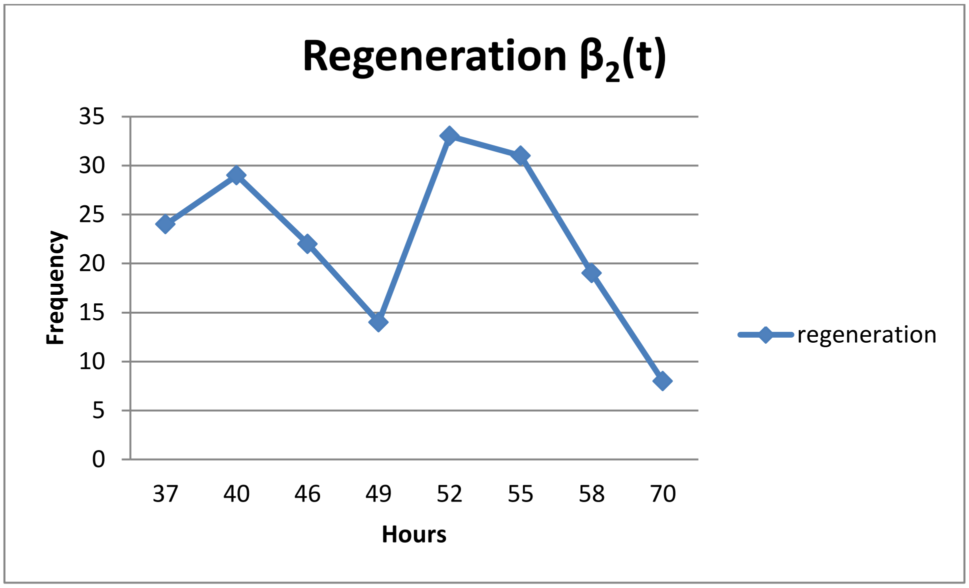
19.20	60.79	26.27	37.46	39.08	76.54	50.30		
24.38	60.16	12.79	3.72	33.57	61.26	52.62		
31.89	60.00	41.06	40.12	35.44	50.32	60.00		
19.54	49.50	41.55	52.30	39.38	55.35	57.71		
38.31	56.67	37.96	42.29	41.97	57.52	47.85		
47.81	60.00	42.97	32.24	28.42	31.04	49.87		
41.11	60.24	51.52	34.78	39.78	44.70	60.78		
60.35	55.19	42.18	47.12	15.80	62.35	60.00		
α7(t)			α8(t)					
56.13	8.26	4.93	6.00	65.63	71.07			
4.24	18.69	4.51	7.40	70.00	50.22			
71.42	39.84	10.06	66.80	72.80	58.84			
68.83	7.18	8.24	72.16	74.79	65.39			
29.93	39.76	33.80	74.30	80.55				
17.51	14.03	65.51	70.00	70.00				
6.41	77.76	29.38	73.12	69.34				
21.22	71.21	13.88	44.83	60.05				
70.42	71.74	70.04	74.35	68.16				
46.75	64.44	20.07	75.70	71.30				
2.10	10.31	5.23	70.14	71.06				
22.35	72.05	4.38	75.20	52.24				
0.25	33.96	69.99	60.00	68.04				
69.61	47.36	73.14	65.00	69.19				
70.83	69.50	39.06	69.41	68.47				
71.38	23.17	12.69	61.80	65.98				
70.00	59.79	16.43	60.41	64.27				
71.37	56.35	19.67	60.00	66.94				
59.47	45.55	4.24	61.49	70.19				
60.86	66.44	66.22	65.90	74.79				
59.00	46.73		63.79	70.91				
60.08	67.99		61.83	70.00				
70.56	49.72		69.18	70.08				
61.70	69.79		61.63	71.42				
60.34	4.80		30.10	70.40				
72.43	6.41		37.78	68.01				
61.40	2.20		71.11	70.09				

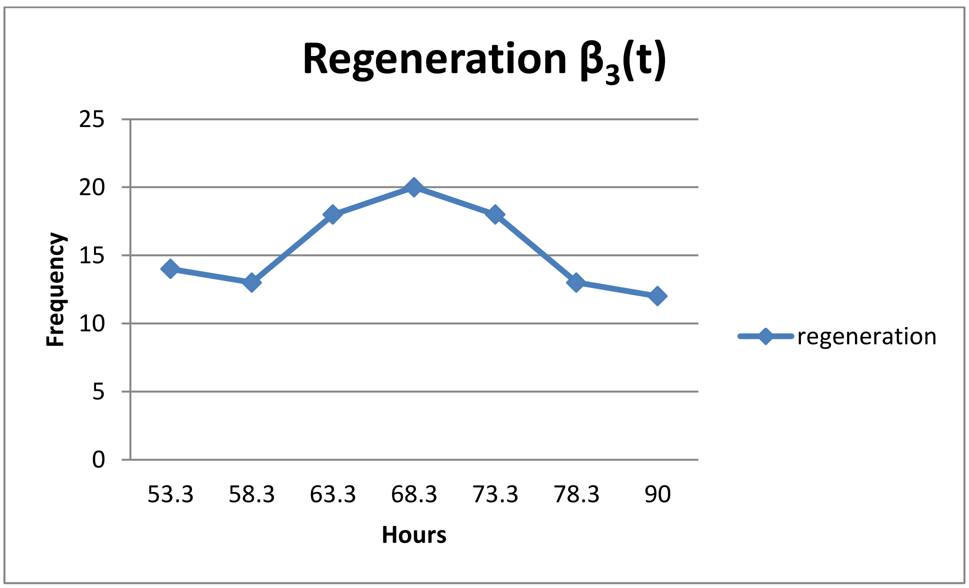
60.00	68.33
62.84	21.71
70.50	70.00
60.12	64.34
44.17	59.47
29.52	56.45
34.28	50.85

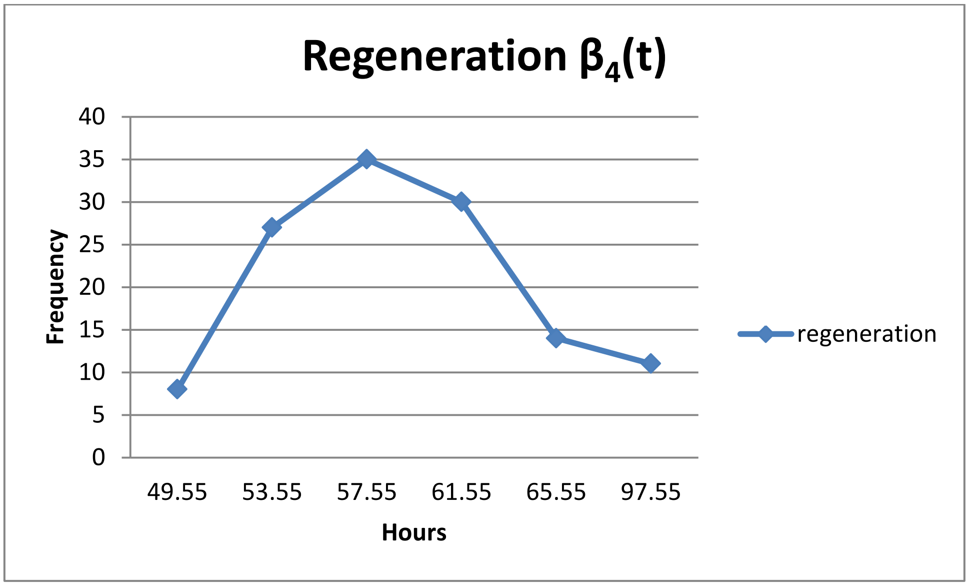
70.70	70.62
70.50	78.49
65.85	64.12
70.00	70.09
70.20	70.00
71.52	70.93
72.45	72.53
72.29	70.06
70.00	69.84
70.56	56.02

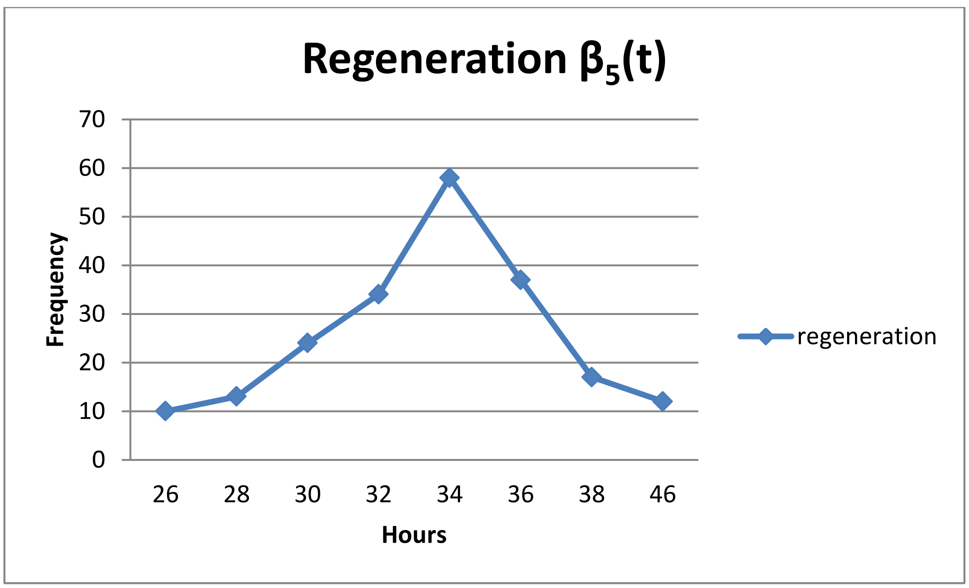
Appendix BRegenerationβ_n

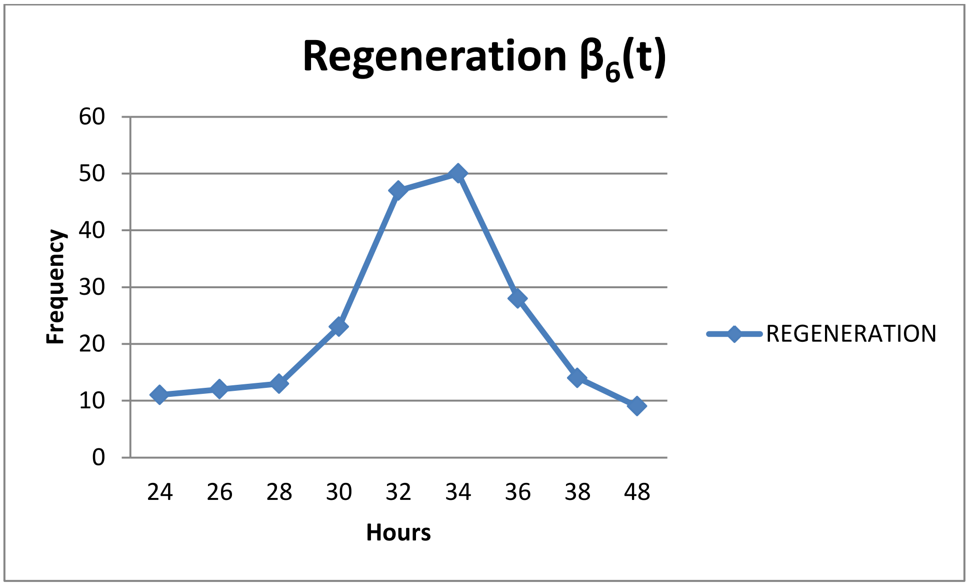


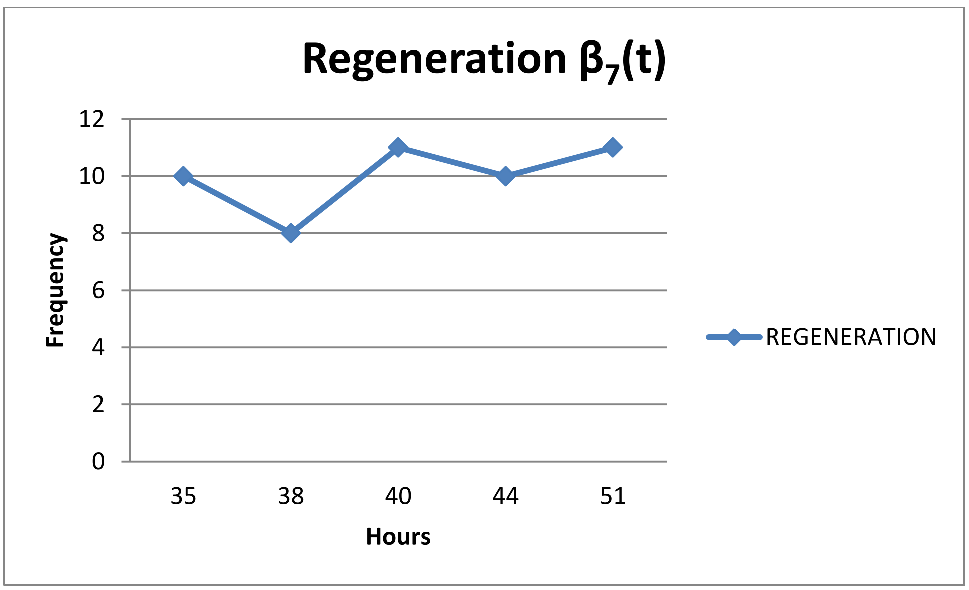

Regeneration β2(t)
35
30
25
20
15
10
5
0
Frequency
37
40
46
49
52
55
58
70
Hours
regeneration

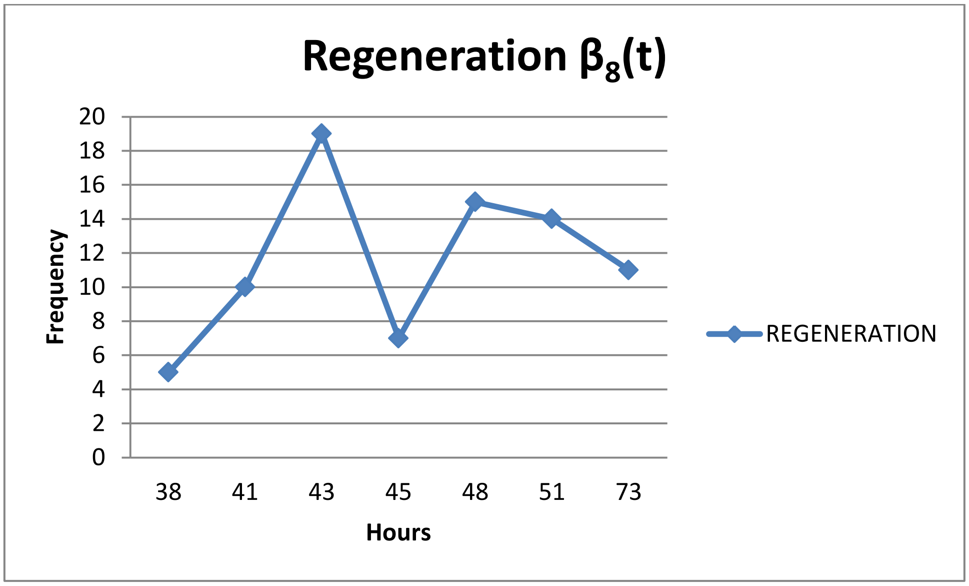

Regeneration β3(t)
25
20
15
10
5
0
Frequency
53.3
58.3
63.3
68.3
73.3
78.3
90
Hours
regeneration


Regeneration β4(t)
40
35
30
25
20
15
10
5
0
Frequency
49.55
53.55
57.55
61.55
65.55
97.55
Hours
regeneration

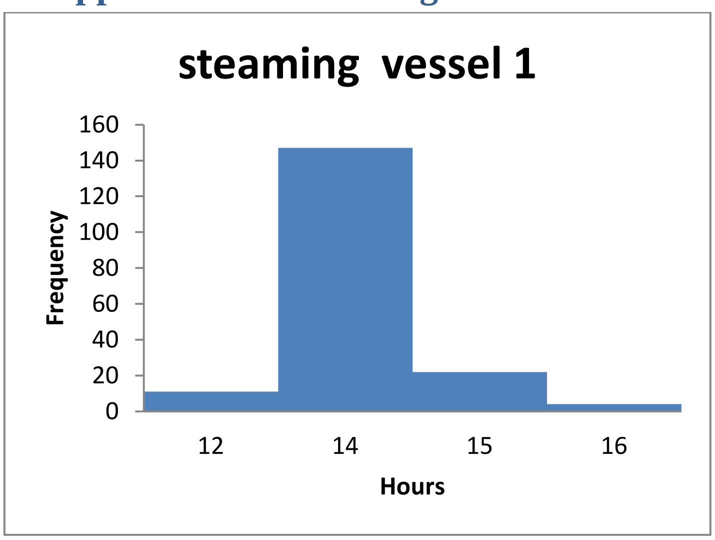

Regeneration β5(t)
70
60
50
40
30
20
10
0
Frequency
26
28
30
32
34
36
38
46
Hours
regeneration

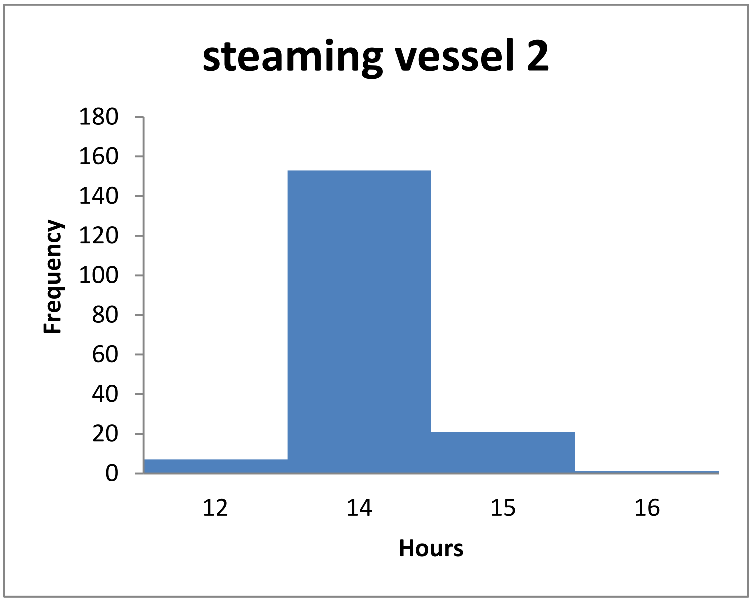

Regeneration β6(t)
60
50
40
30
20
10
0
Frequency
24
26
28
30
32
34
36
38
48
Hours
REGENERATION

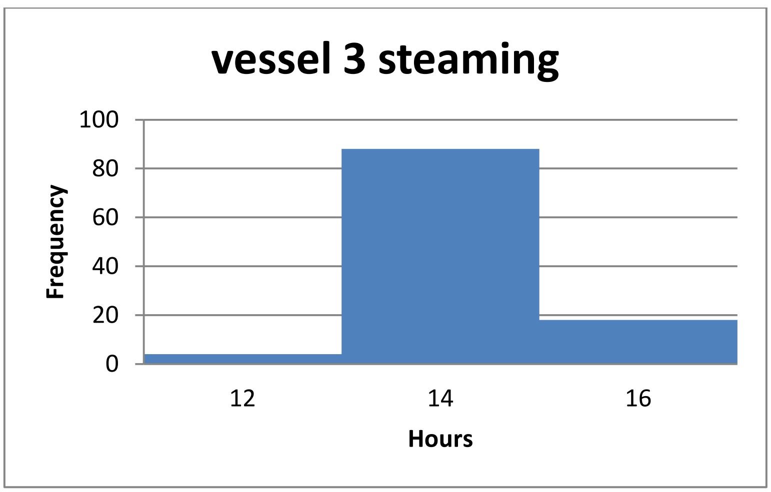

Regeneration β7(t)
12
10
8
6
4
2
0
Frequency
35
38
40
44
51
Hours
REGENERATION

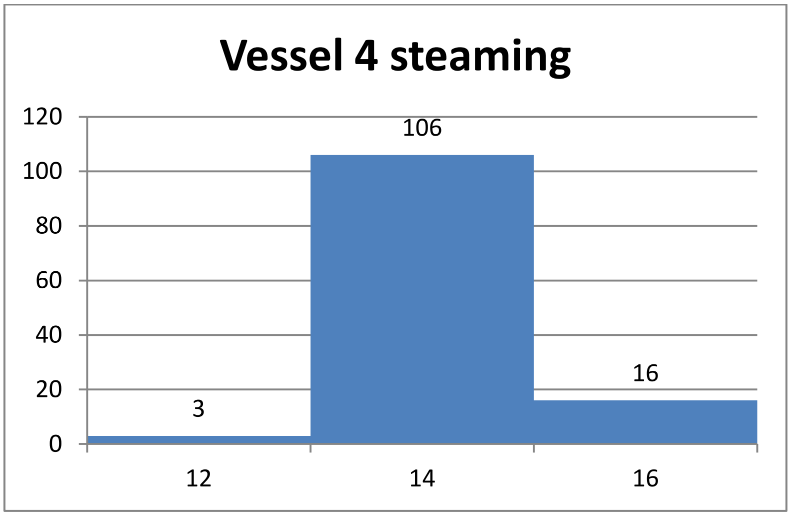


Appendix B.1 Steaming

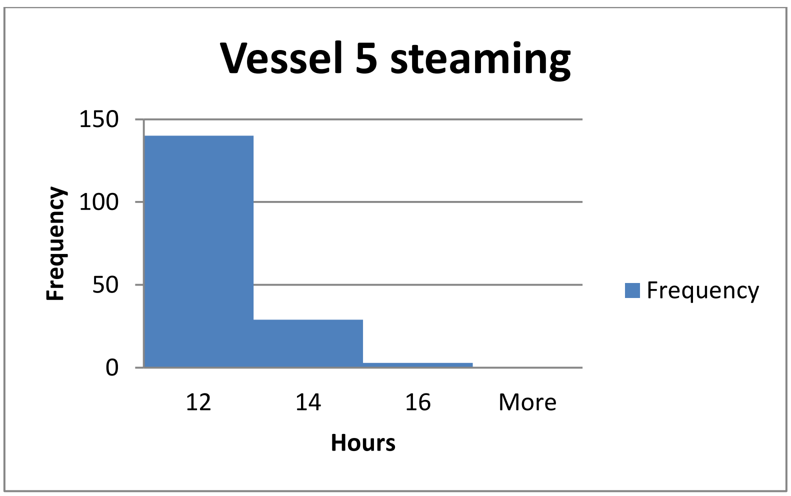



steaming vessel 2
Frequency
180
160
140
120
100
80
60
40
20
0
12
14
15
16
Hours

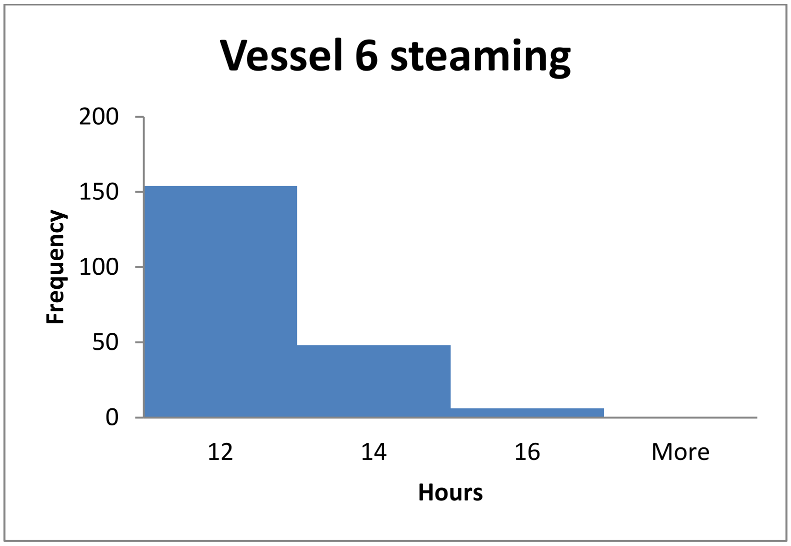

vessel 3 steaming
Frequency
100
80
60
40
20
0
12
14
16
Hours

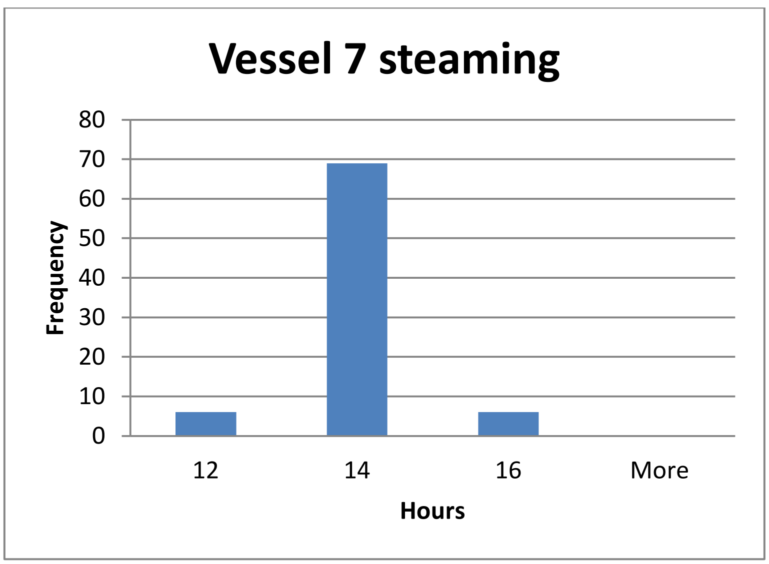


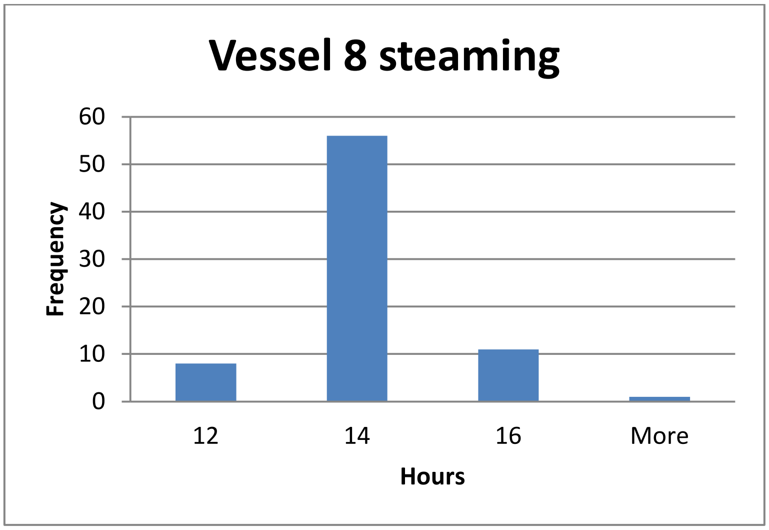
Vessel 4 steaming
120
100
80
60
40
20
0
106
3
16
12
14
16



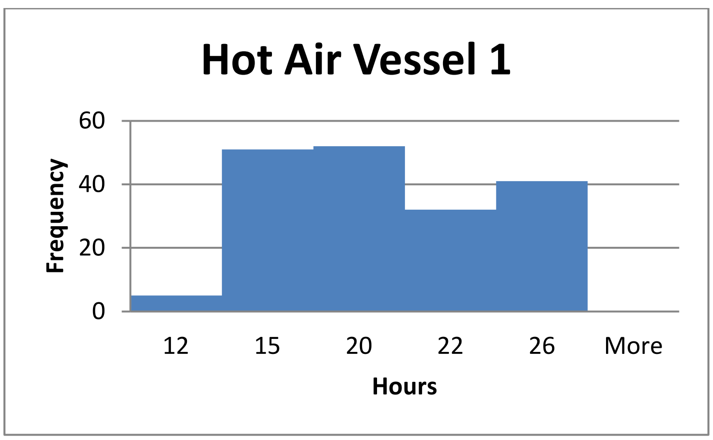
Vessel 5 steaming
Frequency
150
100
50
0
12
14
16
More
Hours
Frequency


Vessel 6 steaming
200
150
100
50
0
Frequency
12
14
16
More
Hours


Vessel 7 steaming
80
70
60
50
40
30
20
10
0
Frequency
12
14
16
More
Hours



Appendix B.2 Hot Air



Hot air							
1	2	3	4	5	6	7	8
22.30	21.00	23.40	23.30	14.20	13.00	12.30	33.30
18.00	24.15	24.40	24.50	14.30	13.20		41.55
17.40		23.45	33.00	15.55	13.15	12.45	
18.40	21.00	30.30	26.00		12.10	19.00	35.00
17.25	21.35	-	30.55	14.25	12.10	22.30	23.30
20.30	21.30	30.40	30.55	16.00			32.00
19.00	21.45	24.50	29.25		13.05		40.40

24.20	20.30	24.25	28.15	13.00			29.00
22.45	24.00	25.20	30.10	12.50	12.25	14.40	26.30
25.15	22.30	26.50	28.35	12.50	12.00	14.50	22.25
23.45	26.40	26.50	28.00	12.25	11.25	19.10	31.45
22.20	25.50	27.50	27.00				30.00
21.30	20.40	30.00	25.30	13.10	12.10	22.00	17.00
25.25	24.15	25.00	26.30	11.50		22.00	29.15
22.20	22.00	28.38	28.40	16.15	13.00	25.00	20.25
20.00	23.30	28.50	26.00	12.50	11.45	16.50	17.30
21.40	23.30	27.20	24.35	13.35	11.15	22.40	26.20
25.00	22.20	36.00	25.30		11.00	17.50	33.30
22.30	23.10	31.45	27.35	14.00	10.30	16.00	22.00
23.05	22.15	29.30	25.30	13.15	12.48	17.55	19.00
20.50	21.35	26.50	27.45	13.00	11.20	20.20	18.30
21.40	20.50	27.50	25.40	11.40	10.30	13.30	18.30
22.10	23.15	27.00	26.25	13.25	10.00	11.30	19.00
24.00	22.20	31.25	25.30	15.00	14.55	14.55	16.50
22.15	21.40	37.30	25.30	12.25	12.30	16.20	30.00
22.00	23.20	30.30	32.00	11.45	10.50	17.05	17.00
22.00	23.10	31.05	30.55	17.40	11.25	23.40	13.45
21.00	21.30	30.20	30.15	12.40	11.20	17.30	7.00
24.45	22.00	36.30	30.15	11.30	9.45	13.15	16.00
21.30	22.00	17.00	26.55		10.00	14.25	16.55
21.00	20.30	18.00	29.30		9.45	18.05	15.25
13.00	22.05	31.30	27.45	10.30		14.30	18.05
21.00	22.25	31.15	27.00	10.30		27.50	17.30
21.00	20.20	31.40	27.00		9.40	15.40	18.20
20.45	23.50	29.40	33.35		11.00	12.30	19.55
22.26	20.20	34.00	28.20	11.25			18.25
22.15	19.40	33.15	29.30	13.00	12.05	12.15	17.00
21.15	19.15	32.13	28.45	13.00	11.20	14.30	20.15
20.15	20.35	32.45	28.45	15.30	13.50	12.30	17.30
20.00	30.05	31.40	29.50	15.25		13.20	17.55
22.40	20.10	38.25	32.45	14.20		16.30	18.40
20.25	19.25	39.00	53.40	14.00	13.00	13.35	21.55
21.00	20.35	37.40	31.20	14.20	14.45	13.45	19.50

22.05	21.00		32.30	14.00	13.15	18.40	17.30
22.50	18.35	32.50	24.00	14.15	13.50	15.05	15.50
20.45	20.45	40.00	23.00	17.27	11.30	12.35	27.50
24.00	20.40		26.55	15.15	15.15	14.55	16.10
20.55	20.15	35.30	33.35	17.00	13.35	12.00	19.10
20.25	20.00			16.00	15.20	16.15	17.45
24.55	21.20	33.00		15.50		15.35	18.00
21.20	21.00	37.50	23.00	16.40	13.45	13.25	18.40
22.35	21.35	36.10	28.00	16.00	14.40	16.10	19.40
23.15	22.15		21.15	20.15	15.45	13.00	17.45
	21.50		25.20		16.40	14.40	19.30
21.55	21.55	33.35	21.30	18.40		15.45	18.55
20.45	21.30	33.35	21.40	13.00	31.00	14.30	18.30
	20.15	37.35	30.15	15.00	14.10	14.00	17.35
		32.06	29.55	14.00		15.15	21.30
22.15	22.20	35.30	27.55	17.30	13.10	17.00	21.25
23.00	21.25	33.00	29.45	15.00	14.00	14.45	20.45
21.20	23.55	37.00	28.30	14.55	17.00	18.20	19.00
24.00	22.15	39.55	30.45	14.15	13.40	12.30	19.20
	21.00	37.00	27.00	17.55	14.50	12.30	20.00
22.30		37.00	33.20	17.25	15.25	20.00	20.10
23.49	19.55	41.30			15.20	14.30	18.10
23.25	18.00	37.30	36.00	17.50	13.50	12.15	22.00
21.40	19.25	42.20	25.20	18.10	15.20	16.20	22.25
22.00		40.15	23.55	21.30	16.10	17.40	20.25
24.30	20.50	41.00	24.10			18.15	20.30
23.30	18.30	38.50	33.45	17.02	16.42	16.35	17.45
22.00	18.05	42.10	37.30	13.50	18.25	20.00	20.15
22.55	18.15	40.30	45.10	18.10	15.50	13.15	29.00
21.31	14.35	34.15	30.00	17.20	15.45		16.55
22.30	15.04	38.35	27.00	17.10		27.50	19.45
22.20	12.15	35.30	29.35	16.10	11.35	15.40	23.25
24.40	17.35	37.35	33.00	14.35	8.00	12.30	19.15
21.30	19.00	38.25	28.30		16.50	12.15	22.00
22.45	16.10	35.40	28.00	16.30	17.00	14.30	20.25

1	2	3	4	5	6	7
23.50	15.45	35.00	25.40		15.15	14.30
22.35	18.30	30.30	28.45	16.30	14.10	13.20
22.05	18.15	31.15	22.40	16.30	15.20	16.30
21.45	19.35	30.30	27.10			13.35
18.30	19.00	18.30	26.40	17.15	13.20	15.05
18.10	19.10	28.30	24.35			14.50
	22.00	28.00	25.05	16.25	16.00	24.30
19.55	18.00	31.45	27.05	14.00		14.55
18.00		6.50	26.35	17.00	14.15	16.15
17.40	18.30	43.10	44.45	14.55	14.20	16.10
18.30	18.25	31.30	33.00		14.30	
18.00		32.55	28.25	14.35	13.50	
18.45	18.30	56.40	30.30	16.00	13.45	
18.50	19.20	28.30	22.40	14.50	13.22	
19.40	16.20	32.55	23.30		15.50	
18.30	19.00	25.25	25.25	13.50	14.00	
19.05	17.35	24.30	23.25	14.00	15.00	
21.00	19.10	26.15	25.30	13.00	14.00	
19.40	19.10	29.45			14.10	
21.40	18.50	27.30	27.45	17.55	13.10	
17.00	18.35		24.30	17.05		
19.00	18.35	26.00	28.00		13.50	
14.30	17.45	28.40	29.20	13.20	13.50	
16.25	24.15	35.15	26.10	11.20		
16.15	22.15	32.30	28.10		13.35	
16.50	19.00	29.45	29.30	14.00		
17.40	20.15	22.55	30.15	13.50		
15.50		25.20	36.30	11.55	14.05	
17.00	21.45	23.20	26.10	12.20		
18.45	19.20	25.40	27.45	13.00		
14.00	17.15	27.30	27.15	12.20	11.50	
	21.45	25.00	26.00	12.10	12.40	
14.55	21.00	25.30	26.20	13.50	13.30	
14.30	21.45	34.20	28.00	13.55	11.15	
14.25	20.00	26.00	32.25	11.20	11.30	

13.45		26.50	27.45	13.55	11.40	
	19.00	11.20	23.55	13.00	13.50	
15.15			29.20	14.25	11.50	
14.20			31.10	11.30	12.55	
14.40	19.00		29.25	9.35	11.45	
8.45	19.20		26.15	13.50	14.20	
15.45	22.40		30.00	15.15	11.00	
20.00	19.25		28.00	15.50	10.25	
23.55			33.30	13.40	12.25	
16.40	20.45		40.20	13.15	11.30	
	20.05		27.25	13.00	13.50	
16.40	13.35		26.35	11.00	14.25	
18.10	18.10		29.30	11.45	13.35	
18.15	14.55		26.55	10.15	13.45	
14.12	17.00		29.00	12.05	12.55	
	12.45		33.15	12.10	14.15	
16.20			40.30		13.55	
15.30	14.25				14.30	

1	2	5	6	5	6
14.55	14.55	10.20	12.15	12.00	13.00
16.30	16.00	9.50	11.25	13.30	14.30
16.20		17.05	11.45	11.35	14.40
15.00	13.00		11.45	12.15	13.55
14.20	10.35	10.45	11.45	12.45	12.05
19.05	11.55	10.22	12.15	14.50	11.45
14.30	13.30	10.15	12.00	15.10	12.40
17.40	15.50	14.05	12.00	15.15	11.50
15.00	15.55	12.40		14.15	12.35
14.45	10.10	11.30	12.25	12.35	9.50
14.45	11.50	14.00	10.40	13.55	13.10
14.00	11.25		12.00	14.50	
13.55	11.30	12.35	13.35	16.30	13.30
17.00	10.50	11.10	13.55	13.40	13.50
14.20	12.55	12.15	14.50	14.45	12.05

10.50	12.50	12.10	12.50	12.10	14.00
12.25	12.30	14.50	11.50	13.55	13.00
10.40	13.25	10.15	12.15	16.00	14.40
11.40	12.55	10.55	12.20	14.15	13.00
13.30	12.30	10.50	12.10	13.40	14.00
15.05	14.50	9.45	11.15	15.30	14.05
13.05	12.15	10.15	12.30	17.05	12.20
12.20	14.15	10.30	12.20	12.05	12.20
16.25	13.30	13.10	12.40	13.35	14.05
16.00	13.25	11.35	12.30	16.10	16.35
13.55	13.40	11.00	11.30	16.10	16.40
13.55	12.35	10.50	14.30	13.30	16.20
13.35	14.00	10.55	13.00		14.35
13.20	14.40	10.25	12.45	15.00	14.45
13.20	14.30	11.45	11.50		15.10
14.15	12.20	10.50	12.00	14.10	13.25
14.55	13.30	11.10	14.00	11.50	7.30
18.10	15.15	10.35	13.05	13.40	15.00
16.10	13.05	10.25	11.30	13.00	
13.30	14.15	11.05	12.15	14.40	12.50
16.15	14.15	13.00	12.25	15.45	12.10
13.25	15.15	12.30	13.45	15.50	12.50
14.00	14.20	8.45	10.20	10.00	11.05
13.05	16.30	12.30	12.30	12.30	
12.35	17.50	12.00			
15.20	13.55	10.55	11.15		
13.45	14.25	10.45	20.30		
16.10	12.40	9.50	13.10		
	14.15	10.10	11.50		
13.30	14.55	10.20	11.15		
13.20	13.20	12.00	12.45		
18.30	14.55	10.00	10.10		
14.05	16.20	11.15	10.45		
12.10	16.15	10.55	10.50		
13.45	14.40	10.50	12.00		
13.35	15.00	10.30	11.30		

12.45	13.40	12.05	11.30
13.30	13.35	7.40	11.20
13.50	15.00	10.10	10.40
12.10	16.35	10.50	12.35
10.20	12.45	2.00	11.45
13.30	15.25	8.10	11.50
13.10	12.30	9.15	13.20
12.50	12.05	8.05	13.15
13.35	16.00	10.30	10.20
	13.50	11.20	11.05
	16.40	11.20	11.30
	13.40		12.00
	15.55		11.30
	13.55		11.40
			11.15

Appendix B.3 Cooling

<table>
<tr><th>1</th><th>2</th><th>3</th><th>4</th><th>5</th><th>6</th><th>7</th><th>8</th></tr>
<tr><td>17.00</td><td>16.30</td><td>10.30</td><td>10.00</td><td>7.25</td><td>6.30</td><td rowspan="2">8.00</td><td>6.00</td></tr>
<tr><td>15.15</td><td rowspan="2">16.15</td><td>8.00</td><td>12.00</td><td>5.00</td><td>6.15</td><td>4.45</td></tr>
<tr><td>12.50</td><td>7.15</td><td>9.45</td><td rowspan="2">5.45</td><td>5.15</td><td>6.00</td><td></td></tr>
<tr><td>12.00</td><td>17.00</td><td>5.30</td><td>9.30</td><td>3.00</td><td>5.15</td><td>5.00</td></tr>
<tr><td>20.45</td><td>15.30</td><td>-</td><td>9.50</td><td>4.00</td><td rowspan="2">4.35</td><td rowspan="4">8.30</td><td>4.30</td></tr>
<tr><td>13.00</td><td>8.30</td><td>10.50</td><td>8.50</td><td rowspan="2">5.05</td><td>6.30</td></tr>
<tr><td>14.45</td><td>16.30</td><td>10.30</td><td>10.00</td><td rowspan="2">8.25</td><td>6.00</td></tr>
<tr><td>18.00</td><td>18.00</td><td>10.20</td><td>15.00</td><td>5.30</td><td>8.00</td></tr>
<tr><td>20.30</td><td>20.00</td><td>14.15</td><td>11.40</td><td>6.35</td><td>5.00</td><td>6.00</td><td>9.00</td></tr>
<tr><td>15.00</td><td>19.35</td><td>16.00</td><td>12.50</td><td>5.10</td><td>2.00</td><td>7.00</td><td>9.00</td></tr>
<tr><td>11.55</td><td>20.00</td><td>11.45</td><td>14.30</td><td rowspan="2">6.35</td><td rowspan="2">6.00</td><td>17.45</td><td>6.15</td></tr>
<tr><td>18.00</td><td>17.10</td><td>12.00</td><td>14.00</td><td></td><td>8.00</td></tr>
<tr><td>16.30</td><td>15.30</td><td>17.00</td><td>13.30</td><td>6.00</td><td rowspan="2">7.00</td><td>8.00</td><td>11.00</td></tr>
<tr><td>13.30</td><td>17.00</td><td>11.00</td><td>12.00</td><td>5.00</td><td>14.20</td><td>8.40</td></tr>
<tr><td>14.45</td><td>16.30</td><td>14.30</td><td>13.30</td><td>9.30</td><td>4.00</td><td>6.45</td><td>7.30</td></tr>
</table>

16.30	18.50	10.40	11.00	7.40	6.00	8.45	7.00
16.30	15.25	19.30	13.35	8.30	5.30	8.00	11.30
13.00	16.00	15.30	13.00		5.00	7.55	31.20
14.00	17.00	12.35	17.30	7.00	6.30	10.25	6.30
16.15	15.00	18.45	14.00	8.05	5.42	6.30	11.00
14.10	14.10	19.30	17.10	9.00	4.00	6.15	7.00
16.20	13.30	20.00	11.50	6.20	6.00	6.30	7.00
10.35	13.45	20.00	17.00	6.20	6.30	8.15	7.05
18.25	17.20	19.15	16.00	7.00	4.45	7.00	7.10
17.00	13.00	11.30	20.00	10.15	6.30	7.20	5.00
16.40	15.10	21.30	13.00	5.15	9.50	7.55	8.00
15.15	19.30	23.30	14.00	8.00	8.15	6.15	8.30
18.00	14.30	18.30	17.45	6.00	6.00	9.30	7.30
18.30	15.00	19.45	21.00	11.30	8.00	11.00	9.00
11.00	16.00	13.00	21.20		9.00	10.00	9.30
17.30	18.15	8.00	10.00		11.00	8.30	9.00
17.00	19.45	24.00	16.00	16.00		10.30	8.20
16.00	19.35	20.15	19.00	16.00		7.15	9.30
16.30	20.40	22.00	20.00		7.00	6.50	9.40
14.30	16.15	15.00	19.00		5.00	8.00	8.35
14.00	16.25	21.35	16.30	11.40			8.50
17.00	14.50	22.20	20.00	12.00	5.55	8.00	7.30
17.10	18.00	19.30	15.30	11.00	9.00	8.00	9.00
19.15	22.10	23.00	14.15	9.00	8.00	7.30	10.30
16.00	24.45	18.50	19.20	12.15		10.00	11.30
20.30	18.00	22.50	20.00	8.15		8.30	9.00
18.45	23.30	23.30	27.45	12.20	11.00	8.30	8.30
16.20	16.35	29.00	21.00	8.00	11.00	8.55	8.20
18.30	20.40		22.30	11.30	8.50	8.50	9.00
20.20	20.15	23.00	10.00	12.15	6.20	3.00	11.30
18.00	22.00	28.30	10.50	12.30	5.00	8.00	9.50
12.00	17.00		12.30	10.40	5.00	10.00	10.00
19.30	24.00	26.40	21.35	13.45	7.00	6.30	11.15
19.00	16.25			11.00	6.00	9.25	12.00
19.00	17.30	24.20		13.40		10.40	10.40
20.00	18.40	18.10	10.15	12.40	7.00	6.35	14.45

19.40	22.15	14.20	11.40	11.00	8.00	14.40	13.00
17.30	23.45		8.50	8.20	6.00	13.30	10.00
	14.00		13.30		12.00	47.45	12.00
21.30	20.00	21.35	10.30	10.00		13.00	14.00
18.45	20.00	14.30	10.30	9.00	7.00	7.40	11.00
	19.15	15.00	11.30	8.50	6.10	12.15	10.40
		30.54	10.10	6.50		15.40	12.55
20.00	18.05	15.00	14.05	8.30	7.00	16.00	14.00
19.15	22.00	22.08	13.30	7.45	8.00	13.00	11.50
15.15	20.30	17.00	10.00	8.00	8.00	14.00	13.00
17.45	17.40	13.00	12.00	8.40	4.00	6.30	12.30
	18.15	20.05	14.00	8.00	7.30	8.00	10.40
15.20		16.30	10.30	6.25	7.00	4.30	13.00
19.25	16.30	18.00			6.25	10.30	14.15
19.20	18.25	28.00	13.00	8.20	4.50	8.00	12.45
17.30	16.25	19.40	13.50	8.30	6.30	15.00	13.35
16.00		20.30	14.00	13.00	7.20	10.00	16.00
13.30	16.10	18.30	15.15			13.45	12.00
17.30	16.30	18.30	13.30	11.00	6.00	12.00	9.30
15.40	15.15	31.30	13.05	8.00	6.00	4.30	13.25
18.40	14.05	30.00	13.40	8.05	8.45	11.00	14.00
14.59	16.30	30.30	12.00	6.00	4.19		15.20
19.30	15.10	27.00	16.00	8.00		7.15	15.30
17.00	16.02	20.30	13.00	8.10	0.00	6.50	13.45
15.00	22.15	27.00	15.00	9.35	5.00	8.00	16.00
15.30	13.45	26.15	13.45		5.37	8.00	14.30
13.00	16.15	28.25	15.30	8.00	9.00	8.00	13.45
16.30	16.30	26.15	13.35		9.00	11.30	

1	2	3	4	5	6	7
14.45	18.50	32.00	16.00	9.30	7.30	10.00
14.25	21.15	25.35	14.35	10.30	10.40	8.30
17.00	16.35	13.45	18.30			8.30
16.00	17.00	43.20	18.00	8.25	8.55	3.00
20.15	16.00	31.20	14.15			9.15
	16.00	22.30	17.00	8.00	8.45	12.00

18.05	16.00	30.30	17.05	9.00		10.00
18.00		8.00	17.00	7.35	7.45	9.25
21.25	18.40	30.50	18.00	8.45	8.40	14.40
18.15	17.00	20.10	13.30		7.00	
18.50		22.00	18.00	10.00	8.00	
20.00	18.40	9.50	12.30	9.00	9.10	
19.00	18.05	26.30	5.15	8.00	7.00	
	19.05	30.45	15.30		8.30	
23.30	17.00	26.00	14.30	9.45	8.40	
16.20	19.20	22.30	14.30	8.30	7.40	
19.40	17.45	24.30	14.40	9.30	6.00	
23.30	17.45	29.30			8.00	
14.40	14.00	23.10	11.00	9.00	8.20	
19.30	14.20		14.30	10.40		
20.00	19.00	28.25	14.30		8.05	
18.30	14.30	27.00	13.00	10.00	8.05	
13.50	21.00	20.15	14.10	9.55		
15.40	21.30	18.30	15.30		9.30	
17.40	21.00	20.00	16.00	9.30		
17.20	11.50	21.40	15.00	10.10		
16.30		20.00	16.00	9.10	16.25	
14.50	18.15	24.30	18.10	10.30		
17.45	20.00	22.15	12.50	12.00		
17.30	20.00	20.00	17.40	10.30	11.15	
	19.55	19.00	17.30	10.00	13.45	
17.05	22.30	20.30	17.00	10.00	12.30	
19.00	19.00	16.00	11.30	11.00	16.00	
16.45	20.00	18.10	17.20	11.35	8.50	
16.45		19.50	17.50	10.20	11.50	
	20.00	12.00	15.00	10.30	8.00	
15.45			18.00	13.50	9.00	
15.10			19.20	16.30	12.00	
18.20	21.00		23.00	12.00	12.00	
9.00	20.30		19.00	10.40	13.30	
21.15	20.50		14.20	9.00	10.00	
20.00	18.15		22.00	9.35	11.30	
17.20			17.30	12.00	13.00	
17.35	17.30		11.50	11.00	12.30	

	18.15		19.00	8.10	12.10
17.35	6.45		17.30	0.00	6.00
16.00	17.50		22.00	9.30	8.00
24.20	8.25		18.30	8.45	9.00
14.05	6.00		20.30	8.40	9.00
	7.30		18.30	8.20	10.15
12.10			14.00		9.30

1	2	5	6	5	6
17.30	7.25	8.00	8.45		12.35
14.25	10.30	5.05	9.35	10.45	9.20
17.15	9.00	4.25	6.20	7.30	9.50
18.00			5.45	9.00	9.20
17.00	10.00	9.00	4.30	6.30	7.30
18.45	6.45	6.30	4.30	8.00	7.45
14.00	6.00	6.40	5.00	8.00	10.00
17.00	8.15	5.00	9.00	8.00	6.20
14.30	8.30	5.20		8.10	11.50
15.00	7.45	6.30	5.35	10.15	9.10
17.50	8.20	5.00	9.00	8.00	11.10
17.50	9.05		8.30	9.30	10.00
17.00	9.00	5.30	7.25	7.00	
19.05	8.30	7.00	7.15	6.05	11.00
17.30	6.50	6.25	5.00	6.00	7.50
15.00	8.45	5.30	6.25	8.30	7.25
6.00	8.40	5.30	7.10	9.10	8.00
7.55	8.30	7.25	5.15	9.00	9.30
7.45	10.35	6.05	8.10	8.35	8.00
8.45	9.35	4.30	11.00	9.45	8.00
8.00	9.00	14.15	8.00	8.20	6.30
6.25	11.40	5.15	5.35	6.00	7.05
9.35	11.45	6.00	8.00	7.15	8.20
8.00	13.10	6.30	7.00	10.50	9.15
6.30	12.30	7.45	6.30	9.55	7.45
9.40	10.45	3.45	11.00	7.20	10.00
6.50	9.15	5.00	5.50	7.20	11.30
6.50	9.30	4.40	5.30	6.10	8.30

6.15	10.30	5.25	7.00		10.45
8.30	8.20	6.15	7.40	5.00	13.00
8.50	9.00	7.40	7.15		14.20
6.30	8.30	6.20	7.15	6.20	9.00
4.35	10.25	9.05	9.10	4.10	4.35
9.20	10.00	7.15	8.15	5.00	5.00
8.30	14.40	8.00	10.00	4.50	
5.35	13.15	7.05	9.00	9.00	5.30
7.30	11.00		11.20	7.00	4.00
10.30	9.15		8.00	6.30	3.40
8.00	9.10		6.15		
9.40	8.30	4.30	3.10		
8.15	8.30	6.00			
9.00	11.00	7.05	5.40		
9.50	12.35	8.00	4.00		
6.50	10.30	6.00	4.30		
	9.10	6.30	4.25		
9.00	9.00	8.00	3.00		
9.55	13.00	10.00	3.50		
7.30	13.40	6.40	4.35		
7.30	12.00	10.00	7.20		
7.20	11.00	9.00	3.30		
6.40	12.10	6.30	4.20		
7.00	11.00	10.00	3.30		
10.30	11.00	8.00	3.35		
8.00	10.00	6.55	7.00		
12.00	17.00	9.10	4.20		
7.20	12.00	12.30	6.30		
7.20	9.30	12.20	3.45		
8.45	12.00	8.30	6.30		
8.00	10.00	10.10	6.00		
7.15	12.35	6.00	6.15		
7.00	9.00	7.30	5.40		
	11.30	5.50	5.45		
	12.00	5.00	7.00		
	11.30	4.30	7.00		
	9.30	5.15	8.00		
	13.30	7.20	5.30		

		10.00	7.45

Appendix B 1.1 Total Hydrocarbon Analysis experiment Line 1

D-5 THC Analysis Report

			THC Analysis Results						
Date on-line	**Line #**	**Vessel ID**	**Newly Shifted**	**Result Half-time Opn. Hour**	**Remarks**	**Actual OpnHrs**	**Result**	**Remarks**	**REG'N**
5/13/2013 4:47	**1**	A	**90**	**13**	Good	60.04	**31**	Slight	**38.1**
5/16/2013 7:22	**1**	B	**87**	**9**	Good	60.63	**29**	Slight	**46.5**
5/18/2013 20:05	**1**	A	**80**	**11**	Good	60.23	**30**	Slight	**39.5**
5/21/2013 8:30	**1**	B	**84**	**6**	Good	60	**29**	Slight	**40.55**
5/23/2013 20:30	**1**	A	**88**	**12**	Good	60.43	**32**	Slight	**38.35**
5/26/2013 9:00	**1**	B	**79**	**8**	Good	60.37	**31**	Slight	**40.1**
5/28/2013 22:00	**1**	A	**89**	**11**	Good	60.11	**34**	Slight	**38.1**
5/31/2013 10:05	**1**	B	**83**	**8**	Good	60.43	**29**	Slight	**40.3**
6/3/2013 13:30	**1**	A	**86**	**15**	Good	59.86	**38**	Slight	**37.1**
6/6/2013 3:16	**1**	B	**72**	**12**	Good	54.87	**27**	Slight	**44.4**
6/8/2013 14:35	**1**	A	**85**	**9**	Good	60.41	**24**	Slight	**41.3**
6/11/2013 6:15	**1**	B	**68**	**10**	Good	55.72	**30**	Slight	**37.4**
6/13/2013 14:00	**1**	A	**64**	**14**	Good	60.13	**26**	Slight	**37.3**
6/16/2013 3:50	**1**	B	**42**	**7**	Good	62.78	**29**	Slight	**43.25**
6/18/2013 19:35	**1**	A	**54**	**6**	Good	60	**27**	Slight	**42.2**
6/21/2013 19:15	**1**	B	**38**	**8**	Good	60.06	**32**	Slight	**40**
6/24/2013 7:30	**1**	A	**46**	**10**	Good	60.01	**27**	Slight	**32.2**
6/26/2013 19:30	**1**	B	**89**	**9**	Good	60	**29**	Slight	**40.05**
7/1/2013 20:10	**1**	B	**102**	**11**	Good	60.66	**32**	Slight	**40.2**
7/4/2013 16:00	**1**	A	**108**	**8**	Good	59.28	**39**	Slight	**38.05**
7/9/2013 18:55	**1**	A	**99**	**9**	Good	60.32	**41**	Slight	**32.25**
7/12/2013 12:45	**1**	B	**103**	**6**	Good	60	**42**	Slight	**34.3**
7/15/2013 6:55	**1**	A	**107**	**11**	Good	38.6	**38**	Slight	

									33.45
7/17/2013 18:30	**1**	A	**99**	**15**	Good	20.29	**34**	Slight	**40.3**
7/21/2013 23:00	**1**	C	**96**	**9**	Good	60.03	**21**	Slight	**42.35**
7/24/2013 15:20	**1**	B	**89**	**6**	Good	60	**28**	Slight	**33.05**
7/28/2013 16:05	**1**	A	**94**	**12**	Good	60.13	**32**	Slight	**32.1**
8/5/2013 21:00	**1**	B	**88**	**10**	Good	60.33	**30**	Slight	**34**
8/8/2013 10:55	**1**	A	**105**	**8**	Good	60.77	**32**	Slight	**30.05**
8/11/2013 6:30	**1**	B	**113**	**9**	Good	60.08	**31**	Slight	**34.15**
8/13/2013 18:30	**1**	A	**138**	**9**	Good	52.09	**34**	Slight	**30.3**
8/18/2013 15:00	**1**	A	**117**	**7**	Good	58.59	**40**	Slight	**35**
8/26/2013 10:20	**1**	A	**96**	**10**	Good	60	**30**	Slight	**33**
8/29/2013 2:00	**1**	B	**92**	**14**	Good	60.05	**41**	Slight	**37.15**
8/31/2013 22:45	**1**	A	**84**	**12**	Good	48.32	**28**	Slight	**34**
9/3/2013 0:02						14.41			
9/3/2013 19:30	**1**	B	**84**	**9**	Good	59.9	**30**	Slight	**37.45**
9/6/2013 12:45	**1**	A	**88**	**8**	Good	55.8	**25**	Slight	**32**
9/8/2013 23:15	**1**	B	**91**	**6**	Good	52.56	**34**	Slight	**35.3**
9/12/2013 14:00	**1**	A	**81**	**11**	Good	40.02	**27**	Slight	**31.2**
9/14/2013 21:27	**1**	B	**83**	**9**	Good	57.09	**41**	Slight	**37**
9/18/2013 10:10	**1**	A	**84**	**10**	Good	43.05	**28**	Slight	**31**
9/20/2013 14:25	**1**	B	**79**	**9**	Good	58.88	**36**	Slight	**34.4**
9/24/2013 13:00	**1**	A	**116**	**7**	Good	60.21	**41**	Slight	**31.35**
9/27/2013 17:20	**1**	B	**116**	**5**	Good	52.51	**32**	Slight	**39**
9/30/2013 17:10	**1**	A	**92**	**8**	Good	58.47	**34**	Slight	**34.4**
10/3/2013 21:20	**1**	B	**73**	**6**	Good	54.03	**27**	Slight	**36**
10/7/2013 18:00	**1**	A	**79**	**7**	Good	59.92	**31**	Slight	**33.15**
10/11/2013 18:30	**1**	B	**74**	**9**	Good	60.06	**23**	Slight	**36.3**

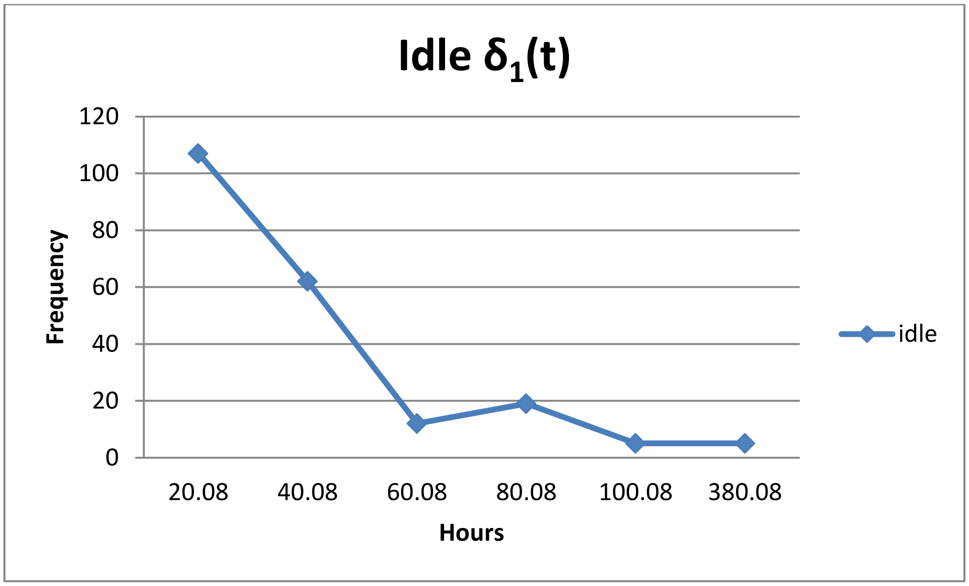
Appendix B 2.1 Total Hydrocarbon Analysis Experiment Line 3

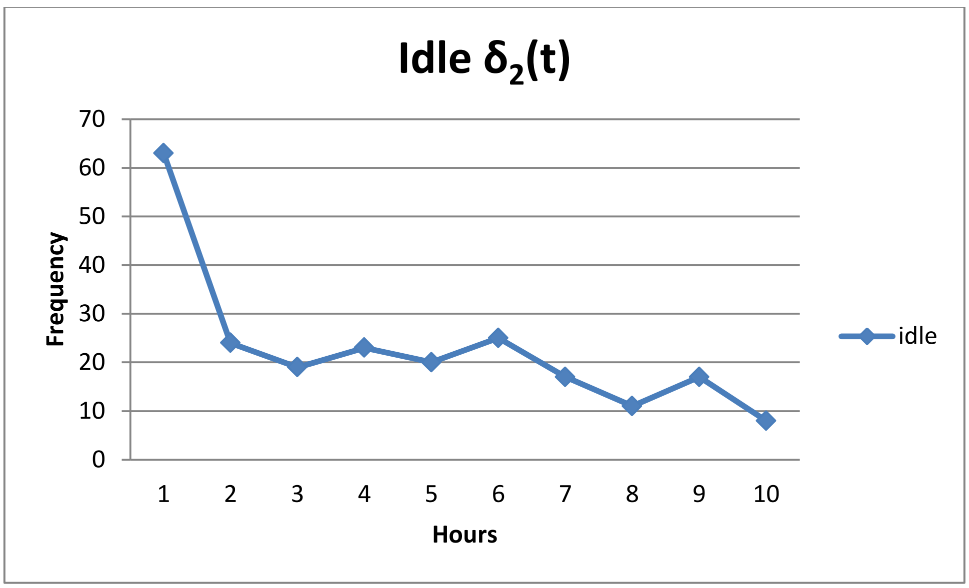
D-5 THC Analysis Report

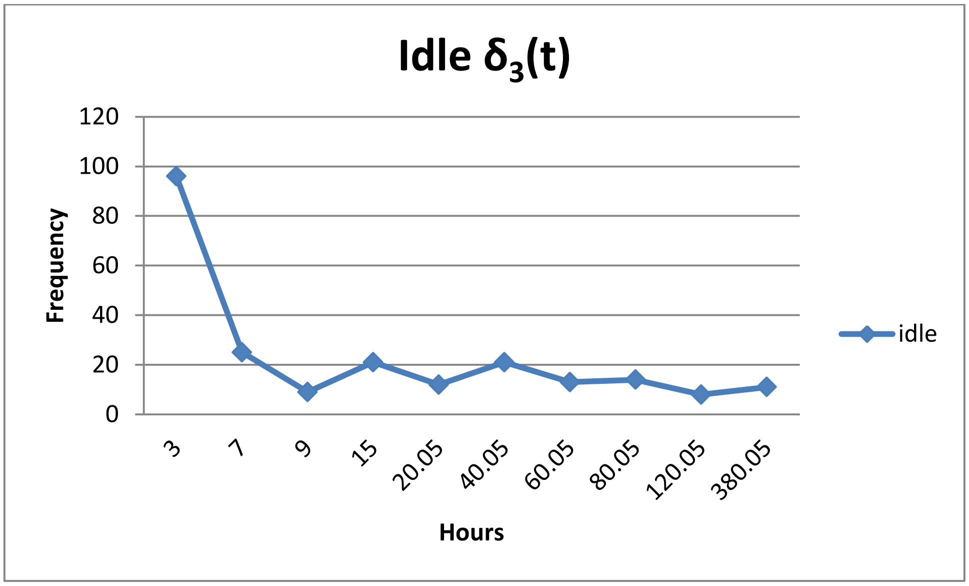
THC Analysis Results

Date on-line	Line #	Vessel ID	Newly Shifted	Result Half-time Opn. Hour	Remarks	Actual OpnHrs	Result	Remarks	REG'N
8/12/2013 4:20	**3**	A	**90**	**78**	Good	57.89	**27**	Slight	**24.5**
8/15/2013 13:50	**3**	B	**87**	**76**	Good	60	**24**	Slight	**30.45**
8/19/2013 11:12	**3**	A	**79**	**81**	Good	54.87	**32**	Slight	**27.4**
8/22/2013 0:50	**3**	B	**84**	**85**	Good	59.62	**26**	Slight	**30.1**
8/25/2013 17:30	**3**	A	**88**	**91**	Good	55.95	**29**	Slight	**29.1**
8/30/2013 15:45	**3**	B	**89**	**94**	Good	60.17	**42**	Slight	**26**
9/13/2013 10:25	**3**	A	**76**	**78**	Good	41.02	**38**	Slight	**27**
9/15/2013 11:38	**3**	B	**96**	**89**	Good	59.11	**34**	Slight	**30**
9/19/2013 2:15	**3**	A	**92**	**79**	Good	50.63	**23**	Slight	**25.1**
9/21/2013 9:20	**3**	B	**84**	**83**	Good	60	**30**	Slight	**23**
9/24/2013 17:25	**3**	A	**83**	**77**	Good	53	**32**	Slight	**25.45**
9/29/2013 9:30	**3**	B	**84**	**96**	Good	57.75	**31**	Slight	**28**
10/3/2013 1:45	**3**	A	**79**	**93**	Good	51.92	**48**	Slight	**26.4**
10/5/2013 17:01	**3**	B	**86**	**76**	Good	60	**27**	Slight	**28.45**
10/9/2013 1:00	**3**	A	**89**	**75**	Good	59.62	**41**	Slight	**28.05**
10/12/2013 5:10	**3**	B	**78**	**81**	Good	60	**28**	Slight	**25.3**

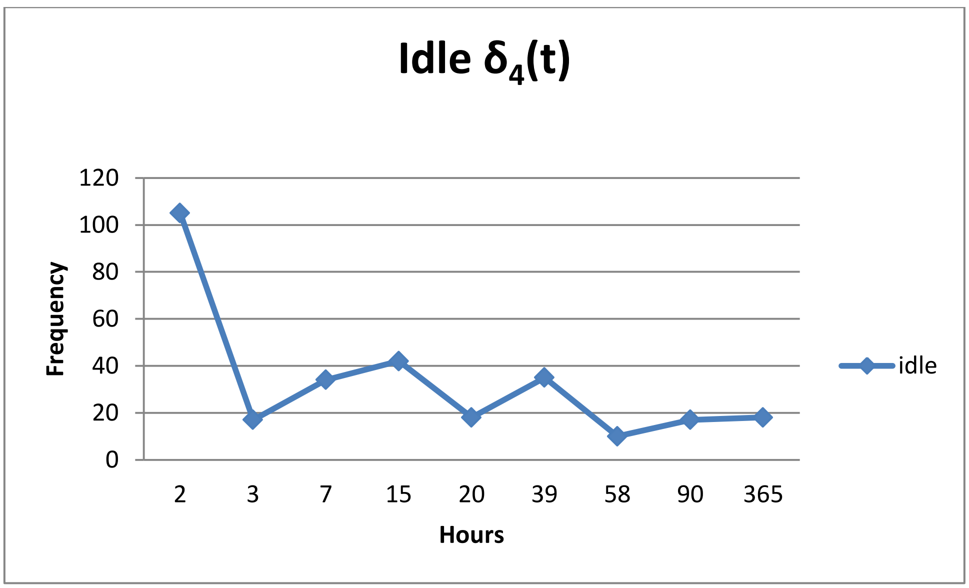
Appendix CIdle



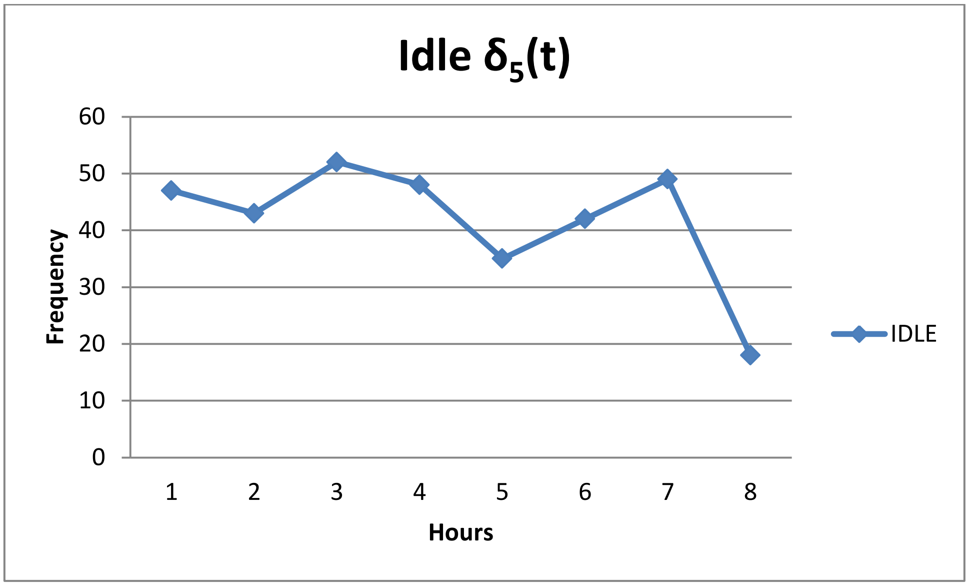




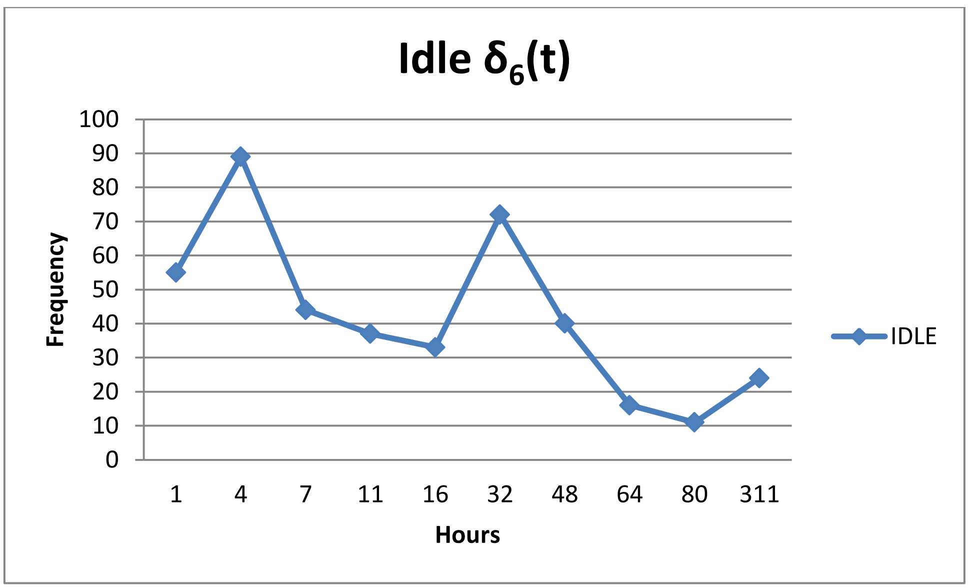
Idle δ3(t)
120
100
80
60
40
20
0
Frequency
3
7
9
15
20.05
40.05
60.05
80.05
120.05
380.05
Hours
idle



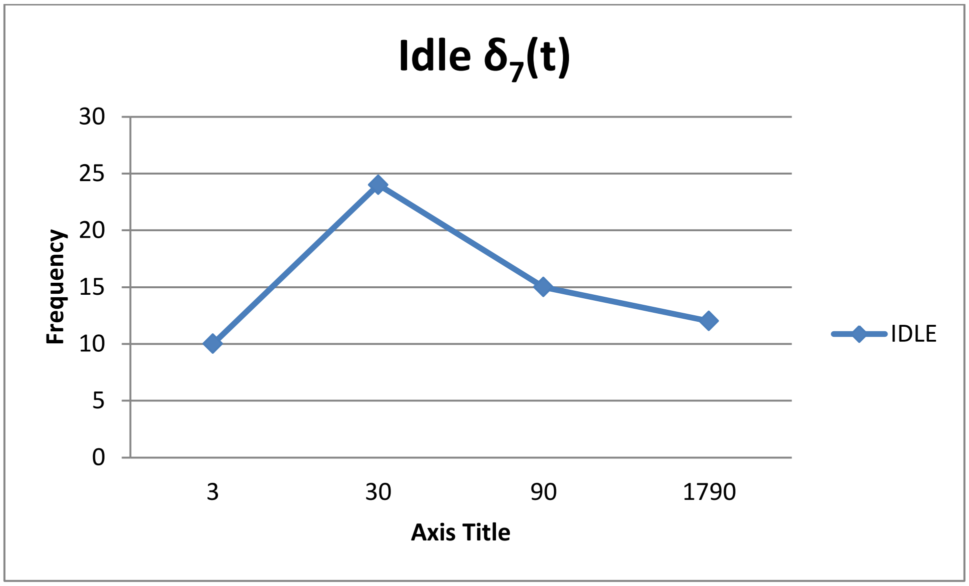
Idle δ4(t)
120
100
80
60
40
20
0
Frequency
2
3
7
15
20
39
58
90
365
Hours
idle

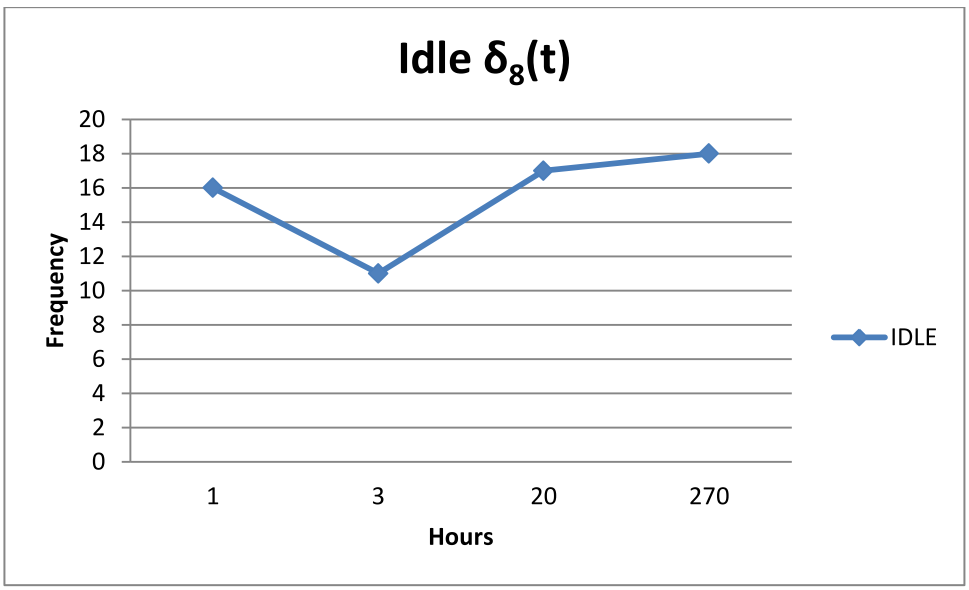


Idle $\delta_5(t)$
60
50
40
30
20
10
0
Frequency
1
2
3
4
5
6
7
8
Hours
IDLE



Idle $\delta_6(t)$
100
90
80
70
60
50
40
30
20
10
0
Frequency
1
4
7
11
16
32
48
64
80
311
Hours
IDLE





Appendix DRepair

Vessel 1, 2 , where D5-A = vessel 1 and D5-B = vessel 2

2011

Date	Total Hrs.	Vessel	Wok Performed
2/21/2011	38	D5- B	Replaced the mesh wire, replaced 10 sacks of act carbon

4/7/2011	80	D5- A	Replaced SS perforated sheet/mesh wire, added filtered act carbon
7/7/2011	32	D5- A	Replaced SS perforated sheet/mesh wire, repaired carbon bed
7/30/2011	72	D5- B	Replaced SS perforated sheet/mesh wire, replaced 3" ball valve
9/4/2011	35	D5- A	Replaced SS perforated sheet/mesh wire, replaced carbon bed support
11/9/2011	15	D5- B	Replaced new act carbon (Norit), replaced mesh wire
11/12/2011	54	D5- A	Replaced SS perforated sheet/mesh wire, repaired carbon bed support
12/26/2011	50	D5- A	Replaced SS perforated sheet/mesh wire, repaired carbon bed support

2012

Date	Total Hrs.	Vessel	Wok Performed
3/27/2012	35	D5-B	Checked SS perforated sheet, mesh wire and carbon bed support
5/4/2012	34	D5- A	Replaced SS perforated sheet/mesh wire, repaired carbon bed support, replaced
			new act carbon (Norit)

D-5 VESSEL 3,4 Line 2, where a =3, b =4

Line 2

Date Start	Time	Date Finished	Time	Total	D5	WORK DONE
1/15/2011	0800H	1/16/2011	1600H	32	D5B	**Replaced the mesh wire, replaced 20 sacks of act. Carbon**
4/21/2011	0900H	4/22/2011	1000H	23	Heat exchanger	Cleaning of H.E.
6/20/2011	0800H	6/23/2011	1600H	80	D5A	**Replaced perforated S.S. & mesh wire**
7/24/2011	0800H	7/25/2011	2000H	38	D5B	Checking of S.S. perforated, carbon bed & mesh wire
9/13/2011	1000H	9/13/2011	1800H	8	Heat exchanger	Clean inner tubes
9/18/2011	0800H	9/21/2011	1700H	80	D5A	**Replaced SS perforated sheet, mesh wire, repair the vessel**
#######	0800H	10/27/2011	1600H	32	D5A	**Replaced perforated S.S. & mesh wire**
#######	0900H	11/2/2011	1200H	51	D5B	**Replaced perforated S.S. & mesh wire**
1/26/2012	0900H	1/28/2011	1700H	56	D5B	**Replaced perforated S.S. & mesh wire**
4/14/2012	1600H	4/14/2012	1800H	2	Blower	**Replaced v-belts**
4/15/2012	0800H	8/31/2011	1430H	3318	D5A	**Fabricated new vessel**
2/1/2013	1800H	2/2/2013	0200H	8	Heat exchanger	Cleaning of tubes (water side)
4/25/2013	0900H	4/25/2013	1410H	5.1	Heat	Cleaning of tubes (water side)

					exchanger	

Activated Carbon, where D5 A = vessel 5 D5 B = vessel 6
Line 3

2011

Date	Total Hrs.	Vessel	Wok Performed
1/23/2011	56	D5-A	Replaced mesh wire, carbon bed support, temp gauge housing
8/16/2011	13	D5-A	Replaced SS perforated sheet/mesh wire
8/31/2011	33	D5-B	Replaced perforated SS carbon bed/mesh wire, carbon bed support
11/29/2011	14	D5-A	Replaced perforated SS carbon bed/mesh wire, carbon bed support
12/23/2011	29	D5-B	Replaced act carbon with Norit (20 bags)

2012

Date	Total Hrs.	Vesse l	Wok Performed
1/17/2012	56	D5-A	Replaced perforated SS/mesh wire#14, temp gauge casing, carbon bed support
5/5/2012	32	D5-A	Replaced mesh wire, act carbon (Norit), carbon bed support

Appendix EProduction

Production							
1	2	3	4	5	6	7	8
15	26	24	22	31.00	11.00	30	6
12	10	25	22	22.50	27.00	29	6
16	20	17	22	30.00	30.50	27	33
26	18	26	46	26.00	7.00	32	28
12	23	28	32	32.00	1.00	34	42
14	24	36	39	37.50	11.50	22	42
19	32	32	41	2.50	30.00	9	31
14	21	43	36	37.00	6.00	33	24
19	24	45	39	27.50	36.00	35	33

22	23	36	42	38.00	31.50	31	34
16	22	31	39	37.00	41.00	33	31
23	18	41	36			25	39
17	20	38	39	40.00	12.50	25	27
17	25	31	45	37.50		26	30
26	24	54	39	37.50	24.00	24	33
27	18	38	32	36.00	32.50	26	28
32	16	28	43	33.00	22.00	33	27
14	19	42	41		12.00	27	28
21	28	36	48	35.00	8.50	32	31
23	24	44	41	50.00	36.00	31	33
25	22	43	33	45.00	29.00	24	42
18	23	43	33	38.00	25.50	24	25
37	21	44	39	36.50	24.00	28	39
27	18	39	39	35.00	24.50	32	29
26	19	53	51	48.00	25.00	24	23
18	26	33	40	32.50	24.00	21	31
25	19	36	44	36.00	26.00	12	33
20	25	39	44	37.00	24.00	14	36
31	25	34	41	31.00	24.50	9	30
21	20	28	41		23.50	11	30
22	26	40	38		19.50	4	27
23	18	41	43	37.00		11	35
21	24	40	48	39.50		17	34
24	20	42	40		30.50	3.5	46
25	23	44	33		20.00	19	26
33	20	34	37	24.50		6	46
33	21	50	44	33.00	18.50	32	42
23	24	49	48	36.00	25.00	33	28
27	26	36	39	33.00	22.00	33	37
34	27	44	35	29.00		32	33
23	28	30	39	33.00	24.00	6	33
31	24	34	33	27.50	23.50	34	41
28	25	21	41	30.50	20.50	12	31
20	30		28	32.00	24.50	18	32
31	23	49	42	30.00	31.00	23	27

23	16	13	28	30.00	23.50	10	31
26	24		16	31.00	24.00	23	28
21	24	42	28	29.00	28.00	25	32
25	32			32.00	27.50	19	27
24	32	47		29.00		28	26
23	23	37	33	27.00	24.00	17	27
25	24	52	34	29.00	26.00	25	29
4	22		33	34.50	24.50	20	28
19	23		42		32.50	28	28
24	27	32	39	35.50		2	23
9	23	34	39	35.50	23.00	3	24
2	13	39	38	36.50	30.50	2	23
10	10	39	40	35.00	1.00	45	34
30	25	32	38	38.00	25.50	12	23
23	24	38	41	35.00	24.00	24	32
24	22	39	41	34.00	33.00	26	29
24	23	36	47	19.00	30.00	23	23
	20	36	48	31.00	34.50	20	21
18		39	36	33.50	30.00	21	26
26	27	40	2		22.00	2.00	26
21	18	38	40	7.00	24.00	32.50	28
32	23	32	43	28.00	2.50	2.50	21
32		38	41	14.00	18.50	5.00	23
35	23	7	44	3.50		4.00	23
25	18	33	44	20.00	12.00	19.50	25
21	20	32	50	20.00	17.00	28.00	32
23	24	30	40	28.50	18.00	17.00	25
30	10	36	40	20.00	19.00	7.00	26
21	13	36	37	19.50	2.00	20.00	20
20	21	36	34	21.00	16.00	10.50	33
13	21	32	31	24.00	17.50	2.00	25
25	30	40	29		15.00	2.00	27
22	17	31	28	19.00	16.50	33.00	24
30	27	31	32		18.00	38.00	
Production							
1	2	3	4	5	6	7	

24	19	30	39	23.00	19.00	24.50
27	24	42	35	20.00	18.00	8.00
26	24	33	22			
16	18	39	30	16.50	17.00	
23	24	17	33			
	26	25	32	22.00	18.00	
12	23	28	28	16.50		
14		15	41	18.00	19.00	
12	14	35	39	18.00	19.50	
17	11	21	11		17.00	
14		9	20	19.00	13.50	
16	16	26	35	26.50	14.00	
19	17	32	33	20.00	19.50	
14	14	25	38		20.50	
16	16	15	28	19.00	19.50	
21	25	20	21	20.00	16.00	
11	1.5	35	32	16.00	14.00	
16	17	18			18.50	
23	20	18	55.00	20.00	14.00	
12	21		53.00	13.00		
22	11	25	56.30		7.50	
24	21	13	55.20	18.00	11.00	
19	33	6	54.20	13.50		
14	12	23	57.40		24.50	
14	19	23	59.30	14.00		
16	17	21	59.15	21.50		
19	5	23	66.30	21.00	14.50	
11	6	40	58.20	21.50		
13	16	30	54.35	21.50		
20	10	30	59.00	20.00	21.50	
1	8	26	58.00	21.00	18.00	
19	6	23	57.50	13.00	18.00	
19	8	16	53.30	32.50	17.00	
17	16	23	63.45	36.00	22.00	
17		26	59.35	15.00	20.50	
2	11	10	52.55	17.00	17.00	

Production								
1	2	5	6	5	6	4	1	2
20	8	23.00	31.00	23.50	16.00	61.20	19	23
16	9	36.50	32.00	23.50	16.50	64.30	9	24
17	21	23.50	35.00	20.50	16.50	66.25	24	28
13	16		19.00	20.50	26.00	59.15	26	10
21	9	35.00	33.50	17.00	23.00	58.20	21	14
22	9	32.00	23.50	17.50	24.50	64.00	25	23
19	14	32.00	30.50	18.00	24.00	65.00	25	24
22	16	30.00	30.50	26.00	22.00	66.10	25	13
	22	30.50		13.50	19.00	60.25	8	25
16	13	24.00	28.50	19.00	22.00	58.05	18	27
27	31	27.00	33.00	12.00	20.00	65.30	23	25
24	30		24.00	12.00	5.00	59.25	27	22
26	25	27.50	25.00	12.00	14.00	63.30	22	21
.5	33	34.00	28.00	12.50	14.00	65.45	24	28
26		28.00	30.00	19.00	22.00	68.30	25	24
17	33	32.00	26.50	22.00	16.50		28	25
21	25	29.50	22.50	13.00	20.00		27	26
19	15	28.00	36.50	27.00	15.00		18	32
16	11	32.00	34.00	16.00	18.00		24	28
14	32	34.00	34.00	18.00	21.00		18	24
19	32	34.50	23.00	16.50	20.50		21	21
11	29	34.00	26.00	21.50	15.50		27	23
5	28	27.00	28.50	10.50	20.00		25	2
16	25	34.00	34.00	24.00	8.50		21	20
18	25	25.00	27.00	17.50	18.00		29	21
19	21	28.00	29.00	19.00	16.00		17	13
12	27	33.50	28.00	17.00	23.00			24
19	26	30.50	34.00	18.50				19
12	30	30.00	33.50	21.00	19.00			22
12	34	30.00	28.00	17.50	19.50			23
11	18	28.00	28.50	21.50	17.00			21
16	24	29.00	30.00	12.00	17.50			

14	24	30.00	28.00	24.00	18.50
20	21	30.00	27.00	12.50	22.50
13	16	27.50	28.00	22.00	20.00
17	19	30.00	31.50	20.00	17.00
16	23	21.50	29.50	19.50	12.00
21	27	20.00	30.50	15.00	21.00
18	10	19.00	30.00	15.50	20.00
20	18	18.50	25.00	15.00	24.00
21	17	14.00	28.00	17.00	11.50
-	24	21.00	32.50	28.00	18.50
22	20	12.50	31.00	20.00	12.00
24	22	17.00		19.00	26.50
25	27	16.50	20.00		18.00
28	18	15.00	31.00		10.00
28	25	18.50	27.00	16.00	12.00
20	21	17.00	31.50	20.00	38.00
21	24	10.50	29.50	15.50	32.00
12	27	13.50	26.00	20.00	
		18.00	23.00		
		10.50	26.00		
		23.00	35.00		
		25.00	29.00		
		24.00	25.00		
		31.00	27.50		
		16.00	29.00		
		12.00	18.00		
		13.00	22.00		
		19.00	31.00		
		24.50	30.00		
		17.00	28.00		
		24.00	25.50		
		25.50	27.00		
		24.00	25.00		
		30.00	24.50		
		30.00	18.00		
			15.00		

17.00
14.00

Appendix F Repair of modules

Appendix F.1 Repair for Line 1

RAW GAS BLOWER 1-2-3

YEAR 2010

Date	Total Hrs.	Blower	Work Done
14-Jul-10	2	D8	Changed oil/adjust v-belts
11-Jul-10	2	RGB	Changed oil/adjust v-belts
11-Jul-10	2	D5	Changed oil/adjust v-belts
22-Aug-10	1	RGB	Checked suction filter/adjust v-belts
22-Aug-10	1	D5	Checked suction filter/adjust v-belts
22-Aug-10	1	D8	Checked suction filter/adjust v-belts
8-Sep-10	8	D5	Cleaned suction filter, belt adjustment
7-Oct-10	2	D5	Changed oil, bearing lubrication, adjust v-belts
27-Oct-10	1.5	RGB	Changed oil, bearing lubrication, adjust v-belts, motor checking
27-Oct-10	1.5	D8	Changed oil, bearing lubrication, adjust v-belts
18-Nov-10	8	D8	Changed oil, checked/adjust v-belts, bearing lubrication, motor checking
16-Dec-10	7	RGB	Changed oil, checked/adjust v-belts, bearing lubrication, motor checking

YEAR 2011

Date	Total Hrs.	Blower	Work Done
13-Feb	1.5	D8	Changed oil/adjust v-belts, bearing lubrication
13-Feb	1.5	RGB	Changed oil/adjust v-belts, bearing lubrication
12-Mar	2	D5-Blower	Changed oil/adjust v-belts, bearing lubrication, motor checking, cleaned suction filter
4-Sep	2	RGB	Changed oil/adjust v-belts, bearing lubrication, motor checking, cleaned suction filter
4-Sep	2	D5- Blower	Changed oil/adjust v-belts, bearing lubrication, motor checking, cleaned suction filter
4-Sep	1	D-8 Blower	Changed oil/adjust v-belts, bearing lubrication, motor checking, cleaned suction filter

YEAR 2012

Date	Total Hrs.	Blower	Work Done
2-Feb	1	D8-Blower	Replaced v-belts 2 pcs
5-Apr	1	D8-Blower	Check/adjust v-belts, cleaned/checked suction filters
5-Apr	1	D5-Blower	Check/adjust v-belts, cleaned/checked suction filters
5-Apr	1	RGB	Check/adjust v-belts, cleaned/checked suction filters
7-Apr	2	D5-Blower	Check/adjust v-belts, cleaned/checked suction filters, changed oil
7-Apr	2	D8-Blower	Check/adjust v-belts, cleaned/checked suction filters, changed oil
10-Apr	1.5	RGB	Changed oil
28-Aug	1.5	D5-Blower	Check/adjust v-belts, cleaned/checked suction filters, bearing lubrication
28-Aug	1.5	D8-Blower	Check/adjust v-belts, cleaned/checked suction filters, bearing lubrication
28-Aug	1	RGB	Check/adjust v-belts, cleaned/checked suction filters, bearing lubrication
21-Oct	1	RGB	Checked v-belts
10-Nov	1.5	D5-Blower	Check/adjust v-belts, cleaned/checked suction filters, bearing lubrication
14-Nov	1.5	D8-Blower	Check/adjust v-belts, cleaned/checked suction filters, bearing lubrication
14-Nov	1.5	RGB	Check/adjust v-belts, cleaned/checked suction filters, bearing lubrication
16-Nov	1	D5-Blower	Changed oil, cleaned suction filter, check v-belts

Water Scrubber (T-1)

2011

Date	**Total Hrs.**	**Work Done**
2/11/2011	24	Cleaning of internal shell section/rascheg rings
5/12/2011	4	Cleaning of internal shell section/rascheg rings
9/8/2011	10	Cleaning of internal shell section/rascheg rings
12/9/2011	12	Re-circulated the vessel with chlorine to clean the rascheg rings and internal section
2/15/2012	2	Replaced the goulds pump
3/21/2012	12.3	Re-circulated the vessel with chlorine to clean the rascheg rings and internal section

9/30/2012	14	Cleaning of internal shell section/rascheg rings
12/19/2012	14	Cleaning of internal shell section/rascheg rings
2/19/2013	15	Re-circulated the vessel with chlorine to clean the rascheg rings and internal section

Foam Trap D-0

2011

Date	Total Hrs.	Work Done
2/12/2011	4	Cleaning of internal shell section/replaced water content
5/2/2011	4	Cleaning of internal shell section/replaced water content
6/13/2011	4	Cleaning of internal shell section/replaced water content
7/7/2011	3	Cleaning of internal shell section/replaced water content
8/1/2011	1	Cleaning of internal shell section/replaced water content
11/11/2011	3	Cleaning of internal shell section/replaced water content

2012

Date	Total Hrs.	Work Done
3/21/2012	2	Cleaning of internal shell section/replaced water content
6/12/2012	3	Cleaning of internal shell section/replaced water content
8/5/2012	3	Cleaning of internal shell section/replaced water content
10/2/2012	4.5	Cleaning of internal shell section/replaced water content

Cooling Tower's

2010

Date	Start	Stop	Total Hrs.	Work Performed
5/16/10	1400H	2100H	7	Cleaning of pvc fillers & sprinklers.
6/2/10	1600H	2400H	8	Cleaning of pvc fillers & sprinklers.
7/11/10	0800H	1800H	10	Cleaning of pvc fillers & sprinklers, checking/cleaning of fan blade.
07/21/10	0900H	1600H	7	Cleaning of pvc fillers & sprinklers.
08/10/10	0900H	1400H	5	Cleaning of pvc fillers & sprinklers.
9/8/2010	0800H	1700H	8	Cleaning of pvc fillers & sprinklers motor lubrication.

10/11/2010	0800H	1900H	11	Cleaning of pvc fillers & sprinklers.
11/27/2010	0800H	0800H	24	Cleaning of pvc fillers & sprinklers.

2011

Date	Total Hrs.	Cooling Tower's	Work Performed
1/2/2011	3	C.Tower 1	Cleaned of pvc fillers, sprinklers
	3	C.Tower 2	Cleaned of pvc fillers, sprinklers
	3	C.Tower 3	Cleaned of pvc fillers, sprinklers
2/7/2011	4	C.Tower 1	Checked motor fan blades/cleaned pvc fillers
	4	C.Tower 2	Checked motor fan blades/cleaned pvc fillers
	3	C.Tower 3	Checked motor fan blades/cleaned pvc fillers
3/22/2011	2	C.Tower 1	Cleaned of pvc fillers, motor lubrication
	2	C.Tower 2	Cleaned of pvc fillers, motor lubrication
	3	C.Tower 3	Cleaned of pvc fillers, motor lubrication
3/24/2011	6	C.Tower 3	Replaced bearings on sprinkler
4/9/2011	3	C.Tower 1	Cleaned pvc fillers, sprinklers
	3	C.Tower 2	Cleaned pvc fillers, sprinklers
	3	C.Tower 3	Cleaned pvc fillers, sprinklers
5/16/2011	4	C.Tower 3	Cleaned pvc fillers/checked motor fan blades
5/18/2011	3.5	C.Tower 1	Cleaned pvc fillers/checked motor fan blades
	3.5	C.Tower 2	Cleaned pvc fillers/checked motor fan blades
5/26/2011	3	C.Tower 1	Cleaned pvc fillers, sprinklers
	3	C.Tower 2	Cleaned pvc fillers, sprinklers
	2	C.Tower 3	Cleaned pvc fillers, sprinklers
7/2/2011	2	C.Tower 1	Cleaned pvc fillers, motor greasing
	2	C.Tower 2	Cleaned pvc fillers, motor greasing
	3	C.Tower 3	Cleaned pvc fillers, motor greasing
8/15/2011	2	C.Tower 1	Cleaned pvc fillers, sprinklers
	2	C.Tower 2	Cleaned pvc fillers, sprinklers
	3	C.Tower 3	Cleaned pvc fillers, sprinklers
9/8/2011	3	C.Tower 1	Cleaned pvc fillers, lubrication/greasing of motor
10/21/2011	4	C.Tower 1	Cleaned pvc fillers, sprinklers
	4	C.Tower 2	Cleaned pvc fillers, sprinklers
	4	C.Tower 3	Cleaned pvc fillers, sprinklers

11/2/2011	2	C.Tower 1	Cleaned pvc fillers/checked motor fan blades
	2	C.Tower 2	Cleaned pvc fillers/checked motor fan blades
	2	C.Tower 3	Cleaned pvc fillers/checked motor fan blades
12/24/2011	5	C.Tower 1	Cleaned pvc fillers/lubrication motor bearing
	5	C.Tower 2	Cleaned pvc fillers/lubrication motor bearing
	5	C.Tower 3	Cleaned pvc fillers/lubrication motor bearing

2012

Date	Total Hrs.	Cooling Tower's	Work Performed
1/10/2012	3	C.Tower 1	Cleaning of pvc fillers, sprinklers
	3	C.Tower 2	Cleaning of pvc fillers, sprinklers
	2	C.Tower 3	Cleaning of pvc fillers, sprinklers
2/1/2012	2	C.Tower 1	Cleaning of pvc fillers, sprinklers
	2	C.Tower 2	Cleaning of pvc fillers, sprinklers
	2	C.Tower 3	Cleaning of pvc fillers, sprinklers
3/15/2012	2	C.Tower 1	Cleaning of pvc fillers, sprinklers
	2	C.Tower 2	Cleaning of pvc fillers, sprinklers
	2	C.Tower 3	Cleaning of pvc fillers, sprinklers
4/28/2012	2	C.Tower 1	Cleaning of pvc fillers, sprinklers
	2	C.Tower 2	Cleaning of pvc fillers, sprinklers
	3	C.Tower 3	Cleaning of pvc fillers, sprinklers
5/6/2012	2	C.Tower 1	Cleaning of pvc fillers, sprinklers
	2	C.Tower 2	Cleaning of pvc fillers, sprinklers
	2	C.Tower 3	Cleaning of pvc fillers, sprinklers
6/22/2012	3	C.Tower 1	Cleaning of pvc fillers, sprinklers, checking motor fan blades, motor lubrication
	2	C.Tower 2	Cleaning of pvc fillers, sprinklers, checking motor fan blades, motor lubrication
	3	C.Tower 3	Cleaning of pvc fillers, sprinklers, checking motor fan blades, motor lubrication
7/10/2012	3	C.Tower 1	Cleaning of pvc fillers, sprinklers
	2.5	C.Tower 2	Cleaning of pvc fillers, sprinklers
	3	C.Tower 3	Cleaning of pvc fillers, sprinklers
8/17/12	72	C.Tower 3	Replaced water sprinkler head, cleaned pvc pipe & filters
8/21/12	3	C.Tower 1	Cleaning of pvc fillers, sprinklers
	3	C.Tower 2	Cleaning of pvc fillers, sprinklers
	3	C.Tower 3	Cleaning of pvc fillers, sprinklers

9/10/12	4	C.Tower 1	Cleaning of pvc fillers, sprinklers
	3	C.Tower 2	Cleaning of pvc fillers, sprinklers
9/20/12	4	C.Tower 3	Cleaning of pvc fillers, checked motor fan blade
10/20/12	11	C.Tower 1	Cleaning pvc fillers, sprinkler
	11	C.Tower 2	Install ladder, cleaning pvc fillers, sprinkler
	10	C.Tower 3	Install ladder, cleaning pvc fillers, sprinkler
11/22/12	4	C.Tower 1	Cleaning pvc fillers, sprinkler
	4	C.Tower 2	Cleaning pvc fillers, sprinkler
	4	C.Tower 3	Cleaning pvc fillers, sprinkler

Compressor 1

YEAR 2010

Date	Total Hrs.	Work Done
5/28/2010	0.166666667	Welded the blow down pipe
6/3/2010	6	Replaced gasket 2nd stage
6/4/2010	5	Checked/inspected suction & discharge valve, oil ring
6/7/2010	2.2	Replaced gasket 2nd stage
6/11/2010	2	Replaced gasket 2nd stage, gate valve, cleaned suction filter
6/12/2010	11	Cleaning of inter/aftercooler, align v-belts
6/19/2010	1	Replaced and aligned v-belt
July 11-12	27	Cleaning of inter/aftercooler/Heat Exchanger
8/12/2010	7	Checked the knock out drum, repaired internal section due to vibration
8/22/2010	8	Cleaning of H.E., water head jacket, aligned v-belts
9/8/2010	6	Checked/inspected 2nd stage valves
9/9/2010	6	Cleaning of H.E., water head jacket, aligned v-belts
October 11-12	27	Cleaning of suction/disch valves, H.E., water jacket, cuno filter
November 22-23	32	Cleaning of H.E., water head jacket, aligned v-belts
December 2-4	56	Cleaning of suction/disch valves, H.E., water jacket, cuno filter, inter/aftercooler
		v-belts checking

YEAR 2011

Date	Total Hrs.	Work Done
1/15/2011	5	Replaced the gasket of 2nd stage head cover, changed oil, checked v-belts

1/30/2011	1.5	Replaced v-belts
2/8/2011	5	Cleaning of H.E.
2/11/2011	8	Replaced 1 pc guide ring, 4 pcs piston ring (2nd stage), checked suction/disch valve
3/8/2011	2	Replaced 1/2" B.I. nipple, checked v-belts
4/4/2011	13	Replaced Gasket, o-ring, cleaning/flushing of intercoolers, checked v-belts
4/7/2011	26	De-scaling of H.E.
4/18/2011	32	Replaced piston/guide ring (1st stage), checked piston rod packings/oil scraper ring
		replaced cylinder head gasket
4/26/2011	4.5	Checked the H.E. tubings
5/12/2011	5	Checked/cleaned suction/disch valves, checked v-belts, checked intercooler
5/22/2011	7	Replaced 4 pcs damper plates, 2 pcs valve plates (2nd stage)
5/24/2011	56	Replaced 6 pcs. Piston rod carbon packing/4 pcs piston rings/1 pc guide ring
		de-scaling on C1 water head jacket (2nd stage) with de-scaler concentration
5/30/2011	10	Changed oil, cleaned oil/cuno filters, cleaned internal section of crankcase
6/20/2011	1	Replaced v-belts
6/23/2011	6	Re-alligned pulley, installed lock nut
7/17/2011	4	Cleaned H.E./aftercooler, checking v-belts/water jacket, bearing lubrication
8/19/2011	0.5	checked v-belts
9/8/2011	4	Cleaned aftercooler
9/10/2011	24	Replaced 2nd stage cylinder head gasket, cleaned suction/disch valves,
		checked v-belts, lubricated unloaders
9/21/2011	1.5	Replaced 1 pc valve plate, 1 pc spring plate at disch valve
10/3/2011	8	Cleaned water head jacket/H.E., checked v-belts
10/5/2011	2	Replaced v-belts
11/21/2011	28	Replaced the intercooler
11/19/2011	24	Checked/cleaned suction/disch valves, checked v-belts, motor bearing greasi
12/9/2011	8	Replaced 2 pcs piston rings, 1 pc guide ring
12/31/2011	9	Replaced 1 pc damper plate, 1 pc o-ring, checked/cleaned unloaders
	295	

YEAR 2012

Date	Total Hrs.	Work Done
1/1/2012	12	Replaced 2 pcs valve plates, 1 pc damper plate
1/11/2012	3	Cleaned the H.E. (water side)
1/21/2012	5	Changed oil, cleaned oil cuno filters
2/8/2012	2	Replaced 2 pcs valve plates

2/5/2012	3	Replaced 2 pcs valve plate/2 pcs damper plates
2/28/2012	31	De-clogged CO2 line, installed purging line
3/20/2012	7	Cleaned tubes/flushing of water head jackets, checked v-belts
4/5/2012	4	Replaced 1 pc damper plate, checked/cleaned suction/disch valves
4/9/2012	9	Replaced 4 pcs piston rings/1 pc guide ring, checked/cleaned suction/disch valves
4/25/2012	6	Cleaned H.E.
6/9/2012	1	Checked/cleaned suction/disch valves, checked v-belts, flushing of water head jacke
6/12/2012	4	Replaced cylinder head gasket, checked suction/disch valve, damper plate
8/2/2012	35	Replaced 4 pcs piston ring/1 pc guide ring/4 pcs piston rod packing
8/5/2012	26	Replaced piston 1st stage, replaced 1 pair piston rod packing, replaced cylinder hea
		gasket, performed flushing on oil cooler, replaced piston ring 2 pcs
8/26/2012	9	Cleaned aftercooler
9/17/2012	1	Replaced v-belts, cleaned water head jacket
10/3/2012	7	Checked/cleaned suction/disch valves
10/20/2012	5	Changed oil, cleaned oil cuno filters, replaced head gasket 2nd stage
11/14/2012	5	Cleaned aftercooler water tube side
12/1/2012	8	Replaced gasket, valve plate, damper plate 2nd stage, lubricated the unloade

D-6 Line 1 vessels

2011

Date	Total Hrs.	Vessel	Work Performed
1/20/2011	24	B	Cleaning of internal shell section (water & kmno4 side)
3/10/2011	14	A	Installed steamline, cleaned internal section, introduce steam for cleaning
4/21/2011	7	B	Cleaning of internal shell section (water & kmno4 side)
5/12/2011	7	A	Cleaning of internal shell section (water & kmno4 side)
7/15/2011	7	B	Cleaning of internal shell section (water & kmno4 side)
8/20/2011	7	A	Cleaning of internal shell section (water & kmno4 side)
10/15/2011	7	B	Cleaning of internal shell section (water & kmno4 side)
11/19/2011	6	A	Cleaning of internal shell section (water & kmno4 side)

2012

Date	Total Hrs.	Vessel	Work Performed
1/16/2012	5	B	Cleaning of internal shell section (water & kmno4 side)
2/2/2012	4	A	Cleaning of internal shell section (water & kmno4 side)

2/14/2012	1	B	Replaced 1 pc 1/2" gate valve on sight glass, cleaned sight glass
4/12/2012	2	B	Cleaning of internal shell section (water & kmno4 side)
5/15/2012	3	A	Cleaning of internal shell section (water & kmno4 side)
7/4/2012	7	B	Cleaning of internal shell section (water & kmno4 side)
8/19/2012	6	A	Cleaning of internal shell section (water & kmno4 side)
10/9/2012	7	B	Cleaning of internal shell section (water & kmno4 side)
10/15/2012	11	A	Cleaning of internal shell section (water & kmno4 side)
10/28/2012	2	A	Replaced the B.I. nipple 1/2" and sight glass

Boiler 40 H.P

2010

Date	Total Hrs.	H.P	Work Performed
6/15/2010	7	40	Dismantled the old feed pump/replaced with a new one
9/27/2010	76	40	Replaced 1" B.I. nipple/gasket, de-scale/flush out internal shell section
12/15/2010	8	40	Descaling of tubes, clean nozzle, fuel filter & fuel pump/flush out internal section

2011

Date	Total Hrs.	H.P	Work Performed
5/18/2011	2	40	Replaced the relief valve
7/19/2011	2	40	Checked wiring/neon transformer
9/8/2011	2	40	Descaling of tubes, clean nozzle, fuel filter & fuel pump
9/21/2011	1	40	Replaced nozzle tip, cleaning of foil filter/strainer

2012

Date	Total Hrs.	H.P	Work Performed
1/12/2012	6	40	Replaced the feed pump
2/13/2012	32	40	Replaced 1" B.I. nipple/gasket, de-scale/flush out internal shell section
6/28/2012	7	40	Replaced handhole gasket
9/26/2012	2	40	Replaced spray nozzle, install diesel meter

Boiler 60 H.P

2010

Date	Total Hrs.	Work Performed
2/9/2011	80	Cleaned internal shell section from carbon deposits, cleaned boiler tubes, nozzle spray,
		filter, igniter, drain valve, oil filter, fuel pump, replaced 2 pcs nozzle
3/22/2011	336	Replaced 30 pcs 2"Ø of new tubes, de-scaling, cleaned internal section
6/7/2011	4	Cleaned fuel pump, fuel filter, oil pump, drain valve, diffuser
		Replaced 2 pcs nozzle igniter
10/16/2011	86	Replaced neon transformer, re-expand the tubings
5/28/2012	4	Replaced high limit press troll, modutrol, eye flame & control relay
6/7/2012	4	Re-expand the tube ends
6/25/2012	1	Replaced press limit control & press limit switch control
11/21/2012	54	Replaced 2 pcs nozzle, cleaned fuel filter/oil filter
6/24/2013	6	Replaced neon transformer, checked electrical wiring

Alumina Dryer

2010

Date	Total Hrs.	Work Done
5/25/2010	1.5	Cleaning of H.E.
6/1/2010	53	Performed cleaning of internal shell section/checking of heater
7/8/2010	4	Cleaning of H.E.
9/27/2010	56	Replaced CO2 filters/cleaning of H.E./checked heater
10/18/2010	4	Performed cleaning of internal shell section

2011

Date	Total Hrs.	Work Done
2/8/2011	1	Cleaning of H.E.
3/5/2011	6.5	Cleaning of CO2 filters (in/out)
4/18/2011	5	Replaced 6 pcs filter dryer (in)
5/22/2011	6	Cleaning of H.E.
6/18/2011	7	Performed cleaning of internal shell section
8/13/2011	2	Performed cleaning of internal shell section
9/3/2011	4	Pull out/replaced alumina

11/15/2011	2	Cleaning of H.E.
12/7/2011	4	Replaced activated alumina
12/9/2011	5	Cleaning of CO2 filters/checking of heater

2012

Date	**Total Hrs.**	**Work Done**
4/10/2012	3	Replaced inlet filter
5/6/2012	3	Checking of heater/terminal tightening
6/14/2012	1	Cleaning of H.E. (flushing)
9/30/2012	31	Checking of CO2 filters
11/12/2012	2	Checking of heater/terminal tightening

N-1

YEAR 2010

Date	Total Hrs.	Work Done
5/11/2010	2	Belt tensioning/alignment
June 1-4	78	Changed oil, checked/cleaned suction/disch valves, cleaned cuno filter,
		replaced piston #6, connecting rod, alum piston, lock spring
6/11/2010	2	Replaced compression ring/oil ring, belt tensioning/alignment
7/2/2010	1.5	Replaced solenoid valve at E3
7/11/2010	5	Cleaning of condensers, oil purging
9/9/2010	8	Cleaning of condensers, oil purging
Nov. 25 Dec. 1	144	Overhauled

YEAR 2011

Date	Total Hrs.	Work Done
2/13/2011	2	Oil purging on E3/oil seperator
3/8/2011	4	Cleaned/flushed the condensers
4/9/2011	32	Changed oil, oil purging of E3, cleaned crankcase, oil cuno filter, suction filter
5/10/2011	6	Replaced 2 1/2" B.I. pipe
5/19/2011	6	Cleaned condensers

7/2/2011	2	Oil purging of E3
7/19/2011	14	Performed purging, check valve checking
8/25/2011	0.75	Replaced temp control
9/6/2011	4	Checked/calibrated oil press gauge, oil purging E3 cleaned the condensers
9/23/2011	78	Replaced needle bearing of piston #3&6, replaced bearing halves of piston
		3&5, replaced suction valve of piston #3&6, replaced o-ring on shaft seal
10/3/2011	80	Replaced main shaft, replaced all set bearing halves, replaced o-ring of oil pump,
		Installed pilot light for heater indicator
11/20/2011	32	Cleaned condensers (big/small)

YEAR 2012

Date	Total Hrs.	Work Done
3/21/2012	8	Replaced bearing halves/needle bearing #3&6, replaced alum piston #6
9/30/2012	52	Checked/cleaned suction/disch valves, cleaned the condensers, oil purging E3

Tank

Date	Total Hrs.	Tank	Work Done
2/11/2011	14	2	Depresurrized/purged internal shell section section, rinsed w/ good CO2
2/25/2011	6	1	Depresurrized/purged internal shell section section, rinsed w/ good CO2
11/19/2011	9	2	Depresurrized/purged internal shell section section, rinsed w/ good CO2
11/23/2011	8	1	Depresurrized/purged internal shell section section, rinsed w/ good CO2
12/3/2012	7.3	1	Depresurrized/purged internal shell section section, rinsed w/ good CO3
12/10/2012	6	2	Depresurrized/purged internal shell section section, rinsed w/ good CO4

Appendix F.2 Line 2

COMPRESSOR C2

Line 2

Date Start	Time	Date Finished	Time	Total	WORK DONE

1/16/2011	0800H	1/16/2011	1700H	9	Cleaning of heat exchanger, motor greasing, checking v-b
3/8/2011	0900H	3/8/2011	1400H	5	Changed oil, cleaning oil cuno filter, suction/disch. Valve
3/8/2011	0900H	3/8/2011	1600H	7	Cleaned internal secti of crank case, clean c filter, replaced gaske
3/18/2011	0800H	3/19/2011	2200H	38	replaced piston ring (& 2nd stage), guide ri (1st & 2nd stage)
3/27/2011	0900H	3/27/2011	1500H	6	Replaced set screw aluminum cover 2nd st
4/22/2011	0900H	4/22/2011	1600H	7	Cleaning of heat exchanger, suction fil
5/18/2011	1000H	5/18/2011	1700H	7	Replaced garlock gask oil ring
5/19/2011	0300H	5/19/2011	1900H	16	Replaced valve plate piston ring, guide rin
5/19/2011	0900H	5/19/2011	1300H	4	Cleaning of oil cuno fi motor bearing greasin checked v-belts
7/27/2011	1000H	7/27/2011	1600H	5	Changed oil, replaced belts
8/2/2011	0900H	8/2/2011	2200H	13	Replaced piston ring pcs., gasket
8/31/2011	1800H	9/1/2011	0100H	7	Cleaning of intercooler/heat exchan
9/2/2011	1400H	9/2/2011	1530H	1.3	Replaced valve sprin valve seat
11/3/2011	2100H	11/4/2011	1700H	20	Replaced guide ring piston ring
12/14/2011	0800H	12/15/2011	1700H	32	Replaced piston ring guide ring piston ro carbon packing 2nd sta
1/21/2012	1100H	1/21/2012	0000H	13	Cleaning of H2O hea jacket, H.E., checked belts
2/13/2012	1000H	2/13/2012	1400H	4	Replaced 1 pc. Valv plate of disch. Valve
2/14/2012	1900H	2/15/2012	1600H	21	Replaced guide ring piston ring, oil ring
2/21/2012	0900H	2/21/2012	1600H	7	Replaced valve cover ring, checked/cleane suction, disch. Valve

3/6/2012	1100H	3/6/2012	1600H	5	Replaced o-ring, checl 1st stage suction &dis Valves
3/13/2012	1000H	3/20/2012	1400H	172	Replaced 1 pc. Guid ring, 2pcs. Piston rin changed oil
5/4/2012	1100H	5/5/2012	0200H	15	Cleaning of H.E., mo bearing greasing, checking v-belts
5/15/2012	1300H	5/15/2012	1800H	5	Replaced gasket
5/24/2012	0900H	5/24/2012	1200H	3	Changed oil
5/29/2012	0055H	5/29/2012	0700H	6.05	Replaced 2nd stage suction valve plate
6/14/2012	1000H	6/14/2012	1600H	6	Checked/cleaned sucti disch. Valves
7/13/2012	0900H	7/13/2012	1200H	3	Changed oil
8/16/2012	0800H	8/17/2012	1700H	32	Replaced piston ring guide ring, moisture tr cylinder head gaske
9/7/2012	0900H	9/7/2012	1400H	5	Cleaned intercooler
9/7/2012	1000H	9/7/2012	1600H	6	Replaced circuit breal 300 amp.
10/18/2012	2000H	10/19/2012	1700H	32	Change 3 pcs. Piston r (2nd stage), changed piston rod packing
10/23/2012	0800H	10/23/2012	1700H	9	Relaced guide ring 1 stage, replaced piston r
11/12/2012	0900H	11/12/2012	1600H	7	cleaning of intercooler stage

N2

Line 2

Date Start	Time	Date Finished	Time	Total	WORK DONE
2/6/2011	0900H	2/6/2011	1000H	1	Cleaning of condensers, purging
3/8/2011	0900H	3/8/2011	1900H	10	cleaning of condensers, purging E3/oil seperato
4/20/2011	0800H	4/22/2011	1600H	56	Replaced needle bearing piston #3 and 6
5/30/2011	0900H	5/30/2011	1600H	6	Cleaning of condensers
7/7/2011	0900H	7/711	1600H	6	Cleaning of condensers, purging of E3

10/1/2011	1400H	10/1/2011	1500H	1	Replaced v-belts (c-168
12/10/2011	0800H	12/12/2011	1600H	32	Replaced the condense (small) oil purging e3, cleaning condensers
1/26/2012	1600H	1/29/2012	1400H	70	Replaced valves, cleaning condensers, oil cuno filte suction filter
1/26/2012	0900H	1/26/2012	1700H	8	Cleaning of condensers, purging e3
2/13/2012	1550H	2/13/2012	1710H	1.2	Malfunction of SV #1,2, Replaced 10 amp. Protect fuse2 pcs.
4/24/2012	0900H	4/24/2012	1600H	6	Cleaning of condensers, purging
7/7/2012	0800H	7/10/2012	1900H	83	Replaced micro-switch low level float, e3 solenc valve coil,
					solenoid valve of sub-cooler, replaced wiring
10/17/2012	0800H	10/19/2012	1800H	58	Replaced needle bearing, ring, piston ring
11/20/2012	0930H	11/20/2012	1045H	1.15	Replaced v-belt (c-168
12/31/2012	1300h	12/31/2012	1400H	1	Replaced v-belts (c-168

WATER SCRUBBER

Line 2

Date Start	**Time**	**Date Finished**	**Time**	**Total**	**WORK DONE**
1/16/2011	1600H	1/17/2011	0600H	14	Cleaning of internal shell section, rascheg rings
3/18/2011	1600H	3/19/2011	0500H	13	Cleaning of internal shell section, rascheg rings
4/21/2011	0900H	4/22/2011	0800H	23	Chemical circulating, cleani of internal shell section
7/27/2011	0900H	7/28/2011	1600H	31	Cleaning of internal shell section, rascheg rings
9/24/2011	1500H	9/25/2011	0600H	15	Chlorine recirculation, cleaning of internal shell section
11/4/2011	0030H	11/4/2011	1400H	13.5	Cleaning of internal shell section, rascheg rings
1/25/2012	1600H	1/26/2011	0800H	16	Cleaning of internal shell section, rascheg rings
3/22/2012	1930H	3/23/2012	0730H	12	Cleaning of internal shell section, rascheg rings

5/13/2012	1600H	4/13/2012	0000H	8	Cleaning of internal shell section, rascheg rings
7/26/2012	0900H	7/26/2012	2100H	12	Cleaning of internal shell section, rascheg rings
10/17/2012	0200H	10/17/2012	1400H	12	Cleaning of internal shell section, rascheg rings
11/15/2012	0200H	11/15/2011	1100H	9	Cleaning of internal shell section, rascheg rings
2/25/2013	1000H	2/26/2011	0600H	20	Cleaning of internal shell section, rascheg rings

D6

Line 2

Date Start	Time	Date Finished	Time	Total	WORK DONE
1/21/2011	1600H	1/22/2011	0000H	8	Cleaning of CO2 filters, checking of heaters
4/21/2011	1000H	4/21/2011	1400H	5	**Replaced 10 pcs filter/dryer inlet**
4/22/2011	0900H	4/22/2011	1600H	6	Cleaning of H.E.
6/15/2011	0900H	6/15/2011	1600H	7	Cleaning of tubes water side
7/26/2013	0800H	7/26/2011	1700H	8	Cleaning of CO2 filters, checking of heaters
10/19/2011	0800H	10/19/2011	1600H	8	Cleaning of CO2 filters, checking of heaters
12/12/2011	1000H	12/12/2011	1600H	6	Cleaning of H.E.
2/21/2012	1000H	2/21/2012	1700H	7	**replaced filters inlet**
3/12/2012	0900H	3/12/2012	1500H	6	**Replaced roots blower**
4/14/2012	1000H	4/14/2012	1900H	9	Cleaning of CO2 filters, checking of heaters
6/26/2012	0800H	6/26/2012	1600H	8	**Replaced motor 7.5 HP 440V, 3 phase, 8 amp.**
7/17/2012	0800H	7/19/2012	1700H	49	**Replaced H.E.**
9/26/2012	1700H	9/26/2012	2200H	5	**Replaced filters**
5/3/2013	1300H	5/3/2013	1630H	3.5	**Replaced inlet filters**

RAW GAS BLOWER

Line 2

Date Start	Time	Date Finished	Time	Total	Blower	WORK DONE
1/16/2011	0100H	1/16/2011	0400H	3	Raw gas	**Replaced bearing, motor checking**
2/18/2011	0900H	2/18/2011	1400H	5	D5	Checked/adjust v-belts, checked/cleaned suct filter

3/10/2011	1400H	3/10/2011	1700H	3	D8	Changed oil, lubricate the bearing, motor checking, cleaned suction filter
4/19/2011	0900H	4/19/2011	1400H	5	D5	Changed oil, adjust v-belts, bearing lubricatio cleaned suction filter
4/19/2011	1300H	4/19/2011	1500H	2	Raw gas	Bearing lubrication, motor checking
5/3/2011	1000H	5/3/2011	1200H	2	D8	Checked v-belts, checked/cleaned suction filt
5/7/2011	0900H	5/7/2011	11.30H	2.5	D5	Bearing lubrication, motor checking
6/20/2011	0900H	6/20/2011	1400H	5	D8	Check/adjust v-belts, checked/cleaned suctio filter, bearing lubrication
7/26/2011	0900H	7/27/2011	2200H	37	Raw gas	**Replaced 2 pcs bearing, replaced steel coupling grid**
7/27/2011	1400H	7/27/2011	1600H	2	D8	**Replaced v-belts, cleaned suction filters**
8/17/2011	1300	8/17/2011	1900H	6	D5	Check/adjust v-belts, checked/cleaned suctio filter, bearing lubrication
9/17/2011	0900H	9/17/2011	1400H	5	D8	Check/adjust v-belts, checked/cleaned suctio filter, bearing lubrication
10/9/2011	1700H	10/9/2011	1900H	2	D5	Checked v-belts, checked/cleaned suction filt
#######	0900H	#######	1100H	2	Raw gas	Bearing lubrication, motor checking
#######	0900H	#######	1100H	2	D8	**Replaced v-belts 2pcs, lubricate bearings replaced gear oil**
#######	0900H	#######	1500H	6	RG,D5,D8	**Installed sight glass, changed oil, bearing lubrication, adjust v-belts**
#######	0900H	#######	1100H	2	D5	Check/adjust v-belts, checked/cleaned suctio filter, bearing lubrication
1/24/2012	0800H	1/26/2012	1100H	51	Raw gas	**Replaced bearing, replaced mechanical se**
2/6/2012	0900H	2/16/2012	1600H	7	D5	Check/adjust v-belts, checked/cleaned suctio filter, bearing lubrication
3/30/2012	0900H	3/30/2012	1700H	8	D8	Changed oil, check v-belts, bearing lubricatio motor checking
4/12/2012	0800H	4/12/2012	1400H	6	D5	Changed oil, check v-belts, check/clean sucti filter
4/18/2012	0900H	4/22/2012	1600H	104	D5	**Raw gas blower (impeller type) was replac with roots blower**
5/4/2012	0900H	5/4/2012	1200H	3	D8	check/adjust v-belts, cleaning of suction filt
5/12/2012	1000H	5/12/2012	1200H	2	D5	Check/adjust v-belts, motor checking
6/18/2012	1000H	6/18/2012	1200H	2	D5	Check/adjust v-belts, checked/cleaned suctio filter, bearing lubrication
7/13/2012	0400H	7/13/2012	2000H	16	D8	Overhaul, cleaned internal parts, shaft alignment, motor checking
7/21/2012	1100H	7/21/2012	1200H	1	Raw gas	Motor checking, bearing lubrication
8/8/2012	1130H	8/8/2012	1145H	0.3	D5	Changed oil

8/9/2012	0900H	8/9/2012	1100H	2	Raw gas	Changed oil, v-belts checking
8/15/2012	0900H	8/17/2012	0310H	54	Raw gas	**Replaced bearings, shafting re-machined**
8/16/2012	0800H	8/17/2012	1900H	35	D8	**Replaced 4 pcs bearing, 4 pcs oil seal**
11/8/2012	0930H	11/8/2012	1040H	1.1	D8	Adjust v-belts

CO2 STORAGE TANK

Line 2

Date Start	Time	Date Finished	Time	Total	Tank #	WORK DONE
12/12/2010	0900H	12/13/2010	1400H	29	4	Depressurized, inject good CO2 & purge, performed tests
12/22/2010	1400H	12/23/2010	1000H	20	3	Depressurized, inject good CO2 & purge, performed tests
7/3/2011	0200H	7/3/2011	1600H	14	3	Depressurized, inject good CO2 & purge, performed tests
12/11/2011	0900H	12/12/2011	0600H	21	4	Depressurized, inject good CO2 & purge, performed tests
7/19/2012	0900H	6/20/2012	2200H	31	3	Depressurized, inject good CO2 & purge, performed tests
12/31/2012	0800H	11/1/2011	2200H	38	4	Depressurized, inject good CO2 & purge, performed tests
12/6/2012	0800H	12/8/2012	1100H	51	3	Depressurized, inject good CO2 & purge, performed tests

Appendix F.3 Line 3 Modules

Line 3

2011

Date	Total Hrs.	Wok Performed
1/18/2011	8	**Replaced level float switch**
4/12/2011	6	Cleaning of condensers (small/big)
5/2/2011	76	**Replaced needle bearing/bearing halves, changed oil, cleaning suction/disch. Valves**
6/11/2011	7	Checked/cleaned condensers, clean cooling towers, oi purging E3
6/27/2011	37	**Replaced aluminum piston #3/6, needle bearing, pin (#3/6)**
7/3/2011	6	Cleaning of condensers (small/big)
9/15/2011	4	Cleaning of condensers (small/big)
12/14/2011	30	**Replaced o-ring, suction press. Gauge, double collar o-ring, cleaning of condensers**

2012

Date	Total Hrs.	Wok Performed
1/19/2012	152	Replaced alum. Piston #3, needle bearing#6, replaced also connecting rod,
		bearing halves #3, changed oil
4/24/2012	6	Cleaned condenser (small)
7/24/2012	96	Cleaned condensers, checked piston#3&6, changed oil, cleaned oil cuno/suction filter
8/19/2012	82	
9/16/2012	3	Checked/reconnect and tightened terminals
9/25/2012	7	Cleaning of condensers

Cooling Tower
Line 3

2011

Date	Total Hrs.	Wok Performed
1/6/2011	4	Clean pvc fillers and sprinklers
3/8/2011	5	Clean pvc fillers and sprinklers, checked/cleaned fan blades, lubricate motor bearing
4/5/2011	5	Cleaning of pvc fillers & sprinklers
5/12/2011	12	Cleaning of pvc fillers & sprinklers
6/18/2011	16	Cleaning of pvc fillers, fan blades, perform repainting
7/15/2011	5	Cleaning of pvc fillers & sprinklers
9/8/2011	6	Cleaning of pvc fillers & sprinklers
10/5/2011	4	Clean pvc fillers
10/20/2011	5	Cleaning of pvc fillers & sprinklers
10/29/2011	26	Clean pvc fillers and sprinklers, checked/cleaned fan blades, lubricate motor bearing

2012

Date	Total Hrs.	Wok Performed
1/7/2012	5	Cleaning of pvc fillers, checking motor fan blades, motor bearing lubrication
4/3/2012	4	Cleaning of pvc fillers, checking motor fan blades
6/9/2012	5	Cleaning of pvc fillers, checking motor fan blades
9/10/2012	6	Cleaning of pvc fillers, checking motor fan blades

11/9/2012	5	Cleaning of pvc fillers, checking motor fan blades
11/21/2012	4.5	Cleaned pvc fillers, sprinklers
12/5/2012	5	Cleaned pvc fillers, sprinklers

Water Scrubber T-3
Line 3

2011

Date	Total Hrs.	Wok Performed
1/19/2011	14	Cleaning of rascheg rings, internal shell section, re-circulate with chlorine
4/9/2011	17	Cleaning of rascheg rings, internal shell section, re-circulate with chlorine
7/31/2011	13	Cleaning of rascheg rings, internal shell section, re-circulate with chlorine
9/23/2011	13	Cleaning of rascheg rings, internal shell section, re-circulate with chlorine
12/9/2011	12	Cleaning of rascheg rings, internal shell section, re-circulate with chlorine

2012

Date	Total Hrs.	Wok Performed
6/10/2012	13	Cleaning of rascheg rings, internal shell section, re-circulate with chlorine
7/24/2012	12	Cleaning of rascheg rings, internal shell section, re-circulate with chlorine
9/26/2012	14	Cleaning of rascheg rings, internal shell section, re-circulate with chlorine
11/28/2012	1	Replaced v-belt (A-41)
12/19/2012	13	Cleaning of rascheg rings, internal shell section, re-circulate with chlorine

Raw Gas Blower
Line 3

2011

Date	Total Hrs.	Wok Performed
2/16/2011	14	Replaced 2 pcs bearing

2012

Date	Total Hrs.	Wok Performed
1/18/2012	0.5	Bearing lubrication, motor checking/cleaning
3/5/2012	2	Checking of v-belts, bearing lubrication, cleaning/checking of suction filter
4/10/2012	2	Checking of v-belts, bearing lubrication, cleaning/checking of suction filter
4/22/2012	1	Replaced & adjust v-belts

D6

2012

Date	Total Hrs.	Vessel	Wok Performed
2/7/2012	5	A	Cleaned internal shell section
2/26/2012	5	B	Cleaned internal shell section
3/10/2012	5	A	Cleaned internal shell section
3/25/2012	4	B	Cleaned internal shell section
5/28/2012	4	A	Cleaned internal shell section
6/7/2012	5	A	Cleaned internal shell section
6/19/2012	4	B	Cleaned internal shell section
7/3/2012	5	B	Cleaned internal shell section
7/28/2012	4	A	Cleaned internal shell section
6/22/2012	5	A	Cleaned internal shell section
8/28/2012	6	B	Cleaned internal shell section
9/18/2012	4	A	Cleaned internal shell section
9/19/2012	5	B	Cleaned internal shell section
9/10/2012	5	A	Cleaned internal shell section
10/14/2012	5	B	Cleaned internal shell section

Alumina Dryer A/B
Line 3

2011

Date	Total Hrs.	Vessel	Wok Performed
4/18/2011	26	A/B	Replaced filter inlet 5 pcs
8/8/2011	7	B	pulled out and fitered the alumina
8/14/2011	3	A/B	Replaced filter inlet 5 pcs
1/19/2012	7	A	Checked alumina's physical appearance, checking/cleaning of filters

5/22/2012	2	A/B	Checked/tightened the Heater terminal
6/8/2012	6	A/B	Cleaning of heat exchanger water tubes
9/28/2012	5	A/B	Replaced filters, check heater, performed flushing
11/16/2012	1	A/B	Replaced v-belt (a-59)
5/18/2013	6	A/B	Cleaning of heat exchanger

Foam Trap (D-O)			
Line 3			
2011			
Date	**Total Hrs.**	**Vessel**	**Wok Performed**
7/7/2011	2	A	Cleaning/replaced water content
9/12/2011	2	B	Cleaning of internal shell section/replaced water content
2/25/2012	2	A	Cleaning of internal shell section/replaced water content
4/9/2012	1	B	Cleaning of internal shell section/replaced water content
6/21/2012	1	A	Cleaning of internal shell section/replaced water content
11/28/2012	1	B	Cleaning of internal shell section/replaced water content
1/11/2013	5	A	Replaced 6" diameter sight glass, cleaned/replaced water

C3 Compressor
Line 3

Date	**Total Hrs.**	**Wok Performed**
1/24/2011	66	Replaced ryder ring, piston ring, carbon packing
3/10/2011	47	Replaced carbon packing, checked/cleaned suction/disch valves
3/24/2011	32	Cleaning of intercooler/aftercooler
8/9/2011	35	Replaced piston rod packing, piston ring, guide ring, oil seal
10/7/2011	98	Replaced piston rings, changed oil, checked v-belts, cleaned oil/cuno filter
2/17/2012	2	Flushing/cleaning of H.E., bearing lubrication
4/19/2012	54	Replaced piston/guide rings, checked piston rod packing

5/23/2012	343	Replaced motor 60 HP
7/25/2012	18	Replacement of 1 1/2" - 2"ǿ pipes and flanges
8/2/2012	1	Checked suction valve (2nd stage)
9/27/2012	31	Checked/cleaned suction/disch valves
1/15/2013	5	Cleaning of H.E.
2/6/2013	1,440	Replaced cylinder housing (brand new), replace piston/guide rings,
		cleaning of oil/cuno filters, replaced piston rod (new), cleaned cylinder housing
5/6/2013	3	Checked suction/disch valves
5/11/2013	16	Cleaned intercooler/H.E.
8/28/2013	29	Replaced piston ring, adjusted lock knot

C4 Compressor
Line 3

Date	Total Hrs.	Wok Performed
3/4/2011	4	Replaced v-belt
3/24/2011	16	Cleaned intercooler/aftercooler
9/12/2011	56	Checked v-belts, piston/guide ring, checke/cleaned suction/disch valves
4/13/2012	49	Replaced piston/guide rings
5/16/2012	2	Checked suction/disch valves
6/9/2012	3	Changed oil, cleaned oil filter
7/25/2012	16	Replaced 1 1/2" - 2"ǿpipings
9/25/2012	33	Replaced piston/guide rings, checked/cleaned suction/disch valves
5/11/2013	15	Cleaned intercooler/aftercooler
5/20/2013	119	Replaced ryder ring/piston rings, changed oil, checked/cleaned suction/disch valves
6/26/2013	8	Replaced piston rings, checked guide rings
8/9/2013	31	Repaired piston sleeves, replaced piston rings
9/2/2013	6	replaced H.E.
10/25/2013	54	Replaced piston rod packing, oil seal, piston/guide rings,
		checked suction/disch valves