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Utilization of statistical tools to identify assignable causes of variability and model performance of a wet electrostatic precipitator

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Utilization of Statistical Tools to Identify Assignable Causes of Variability and Model Performance of a Wet Electrostatic Precipitator

A Thesis Project Prepared by

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Abstract

The King's Landing Wastewater Treatment Plant treats industrial sewer wastewater from nearly 200 manufacturing buildings for Eastman Kodak Company located at Kodak Park in Rochester, NY. The average throughput for the facility is 28 million gallons of wastewater per day (MGD) and discharges the resulting effluent into the Genesee River. Through a series of physical, chemical, and biological treatment processes, materials are removed from the wastewater and sludge is produced. The sludge is conveyed through a belt press for dewatering prior to incineration. The dewatered sludge is sent to a multiple hearth incinerator with a secondary combustion chamber/afterburner for thermal treatment. From the combustion and incineration process, off-gases are produced. Therefore, air pollution control equipment is needed to treat the gas stream. At King's Landing, an induced draft fan creates negative pressure through the hearth along with a series of air pollution control equipment (APCE) consisting of a quench chamber, condenser/scrubber, venturi, entrainment separator, and a wet electrostatic precipitator (WESP). This equipment captures the components in the air stream through processes such as gas saturation, caustic neutralization, and electron particle collection.

The WESP is a device that is used for fine particle collection in the range of 1 micron or less. Upon entereing the unit, the particles in the gas stream are given a charge. The particles accumulate on the surface of the WESP and are periodically flushed out and collected in the wash water. The efficiency of particles removed from the WESP can be indirectly correlated by the power value measured in KVA (kilovolt amps). As the power decreases, the particulate collection efficiency is lowered. This is due to the increased resistance in the system. Although there is system variability, the King's Landing multiple hearth incinerator and associated air pollution control equipment operates in accordance with all relevant environmental standards.

The purpose of this thesis is to use statistical analysis tools to determine the significant variables that affect the performance and efficiency of the WESP. The WESP is the last unit in the air pollution control equipment (APCE) system at King's Landing. Since the WESP is the final air-polishing device in the system, its optimal performance is critical.

The WESP is subject to the most variability from the upstream APCE as well as the combustion process because it is the final unit in the system. This paper will analyze multiple predictor variables, which are inputs into the WESP, and determine their significance on the power reading that will serve as the response variable.

Key Words: Wet electrostatic precipitator, variability, air pollution control equipment, multiple hearth incinerator, statistics

Problem Statement/Definition

Prior to January 2002, the WESP power, measured in kilovolt amps (KVA), averaged consistently above 1.3 KVA for a rolling hour average (RHA). After this time, the KVA readings have occasionally been observed to be in the range of 0.8-1.2 KVA for the rolling hour average. The exact root cause of this variation in the power reading is unknown. Because WESP power is an indirect measure of WESP performance and collection efficiency, it is important to obtain an understanding of the causes for variation and fluctuations.

Hypothesis statement: The variability observed in the KVA levels of the WESP is a direct result of an assignable cause due to an upstream process variable.

The hypothesis will be tested by analyzing the following process variables, which are presumed predictor variables: wet sludge feed rate, quench water flow, condenser water flow, venturi flow, venturi differential pressure, WESP secondary voltage, stack exhaust gas temperature, gas air flow rate, exhaust stack carbon monoxide level, exhaust stack oxygen level, and "3" hearth temperature. The WESP secondary power measured in KVA will be the only response variable.

Literature Review

Introduction

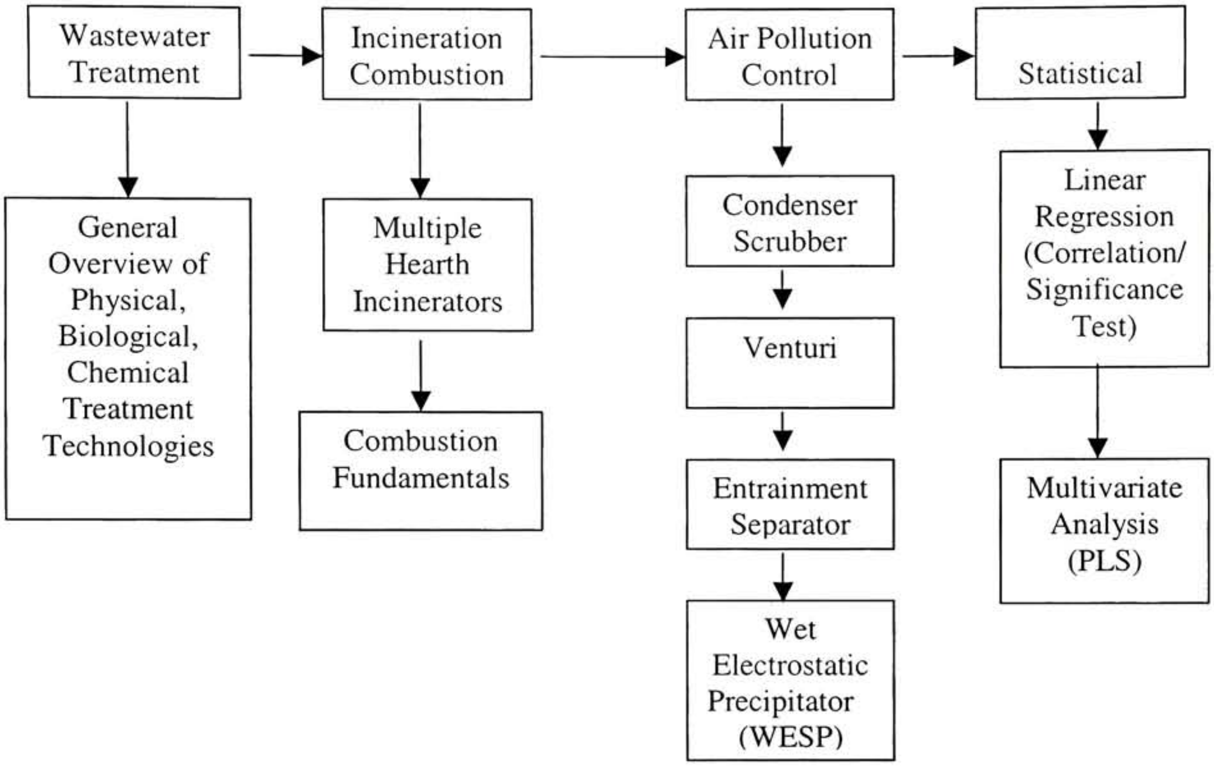
Four topics for this thesis were reviewed in the literature. These areas were wastewater treatment, incineration and combustion, air pollution control equipment, and statistical analysis tools. These searches included literature summaries of related areas of research and published technical papers.

A literature search was performed to gather information to provide a general overview of the wastewater treatment process, including aspects of the physical, chemical, and biological treatment technologies.

Another search was performed to investigate the incineration and combustion processes, as well as to gather detailed information regarding the construction and operation of a multiple hearth incinerator (MHI).

The analysis of the air pollution control equipment included information regarding condenser/scrubbers, venturi operations, and the basic principles of an entrainment separator. An additional search was performed on the fundamentals of a wet electrostatic precipitator (WESP).

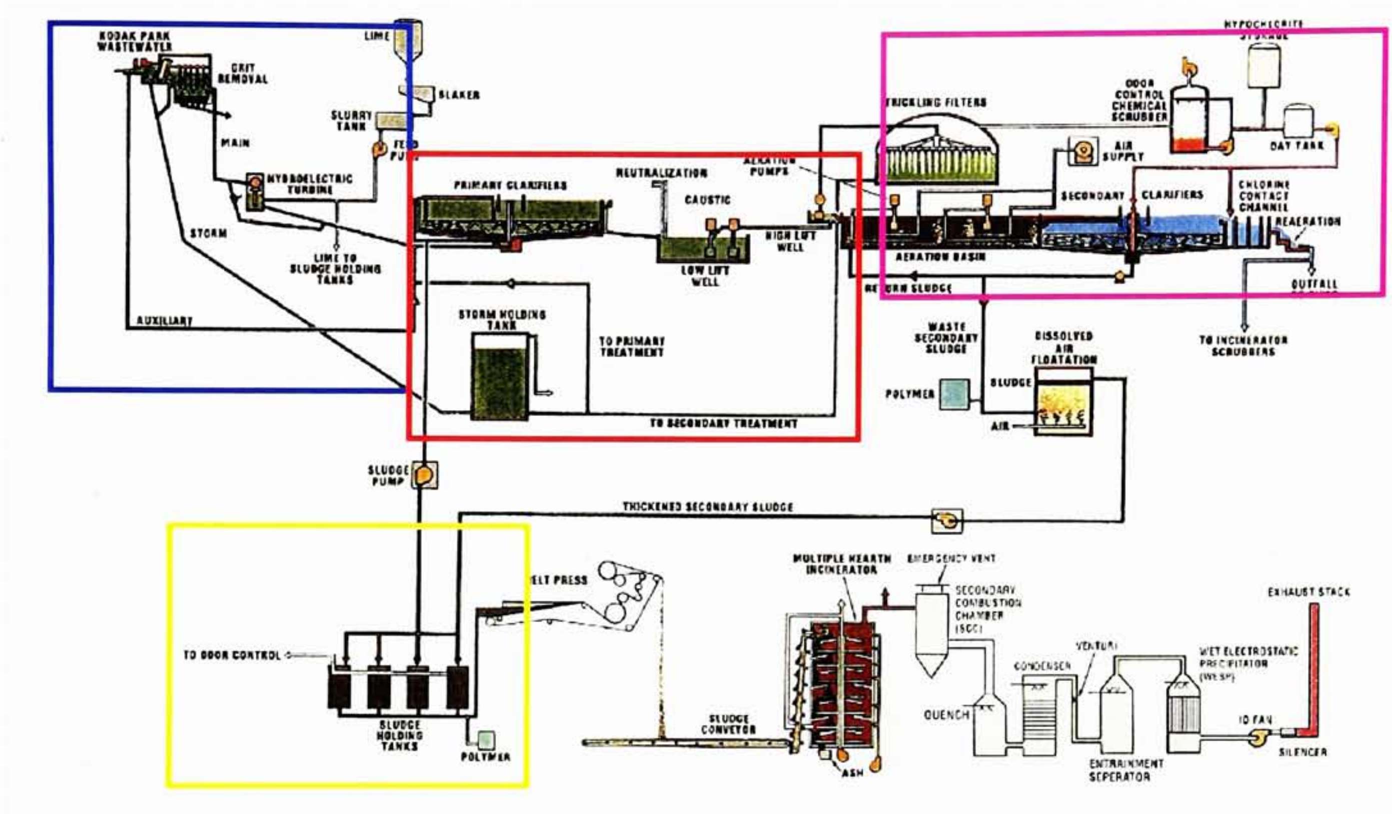
The statistical analysis tools that were researched included descriptive statistics, exploratory data analysis, plots, any applicable transformations, linear regression, correlation, hypothesis tests, and multivariate regression analysis (Partial Least Squares method). A flowchart for the searches is shown below.


Wastewater Treatment
Incineration Combustion
Air Pollution Control
Statistical
General Overview of Physical, Biological, Chemical Treatment Technologies
Multiple Hearth Incinerators
Combustion Fundamentals
Condenser Scrubber
Venturi
Entrainment Separator
Wet Electrostatic Precipitator (WESP)
Linear Regression (Correlation/ Significance Test)
Multivariate Analysis (PLS)

Wastewater Treatment Process Literature Review

The wastewater treatment process at the King's Landing Wastewater Treatment Plant (KLWWTP) represents a typical layout and process flow found throughout most industrial wastewater treatment systems. The processes can be divided into four categories of pretreatment, primary processing, secondary processing, and sludge management. The following paragraphs will discuss a general overview of the physical, chemical, and biological treatment technologies used to treat the industrial wastewater at Kodak Park. Most of the information represented in this literature review was derived from internal Kodak procedures and wastewater treatment textbooks. A flow chart of the entire process is shown below. The blue outlined area represents pretreatment, the red area is primary treatment, the purple area represents secondary treatment, and the yellow area represents sludge management.

KINGS LANDING INDUSTRIAL WASTE WATER PURIFICATION PLANT

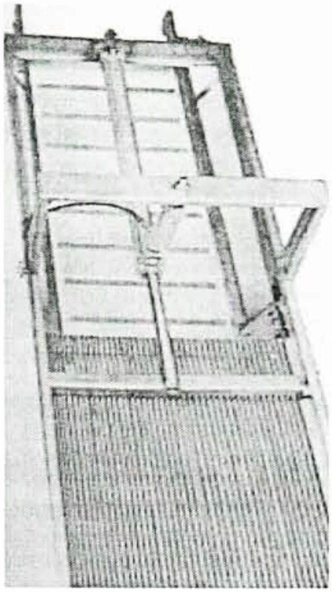


Kodak Diagram

Pretreatment Process

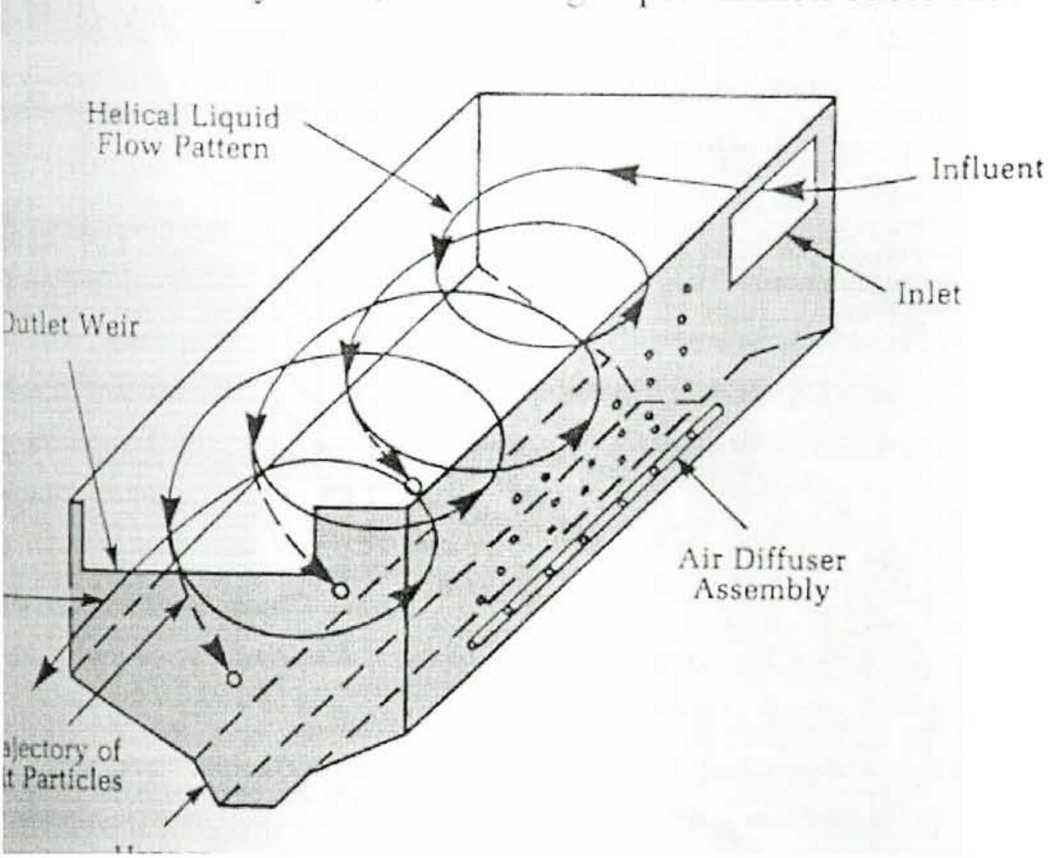
The average daily flow for the King's Landing Wastewater Treatment plant is 28 million gallons per day (MGD). The industrial wastewater is conveyed to the treatment plant through a 42″ main trunk line referred to as the "penstock." The flow enters a bar screen and goes into an aerated grit chamber. The purpose of pretreatment is to remove course material and large debris from the wastewater.

Bar Screen: The wastewater flows through the bars while a mechanical rake device is used to remove the debris from the bars as shown in the figure below.



Davis and Cornwell, p. 365

Aerated Grit Chamber: The wastewater flows from the bar screen and into the grit chamber. Air is supplied to the bottom of the chamber to agitate the water and helps to settle out heavy particulate matter. The velocity through the chamber is controlled by aeration rather than flow rate (Kodak procedures). Dense material such as sand, glass, silt, and pebbles are considered "grit" (Davis and Cornwell, p. 365). The grit is settled out prior to entering the primary treatment plant to protect mechanical equipment (pumps) from damage due to wear from pumping solid material in the wastewater. The physical dimensions of the aerated grit chamber at King's Landing are 60 ft long x 13 ft wide x 12 ft deep. An example of an aerated grit chamber is shown below.



Davis and Cornwell, p. 367

The settled grit is collected into 5 V-shaped hoppers and sent to a hydro-gritter where the grit is dewatered. The grit is collected and sent to the multiple hearth incinerator (MHI) for treatment. From the aerated grit chamber, the wastewater flows to a hydroelectric turbine where the velocity head of the flow is reduced as it descends along a vertical drop of 125 feet. In the process of reducing the velocity, the energy is absorbed and electric power is produced and used on-site. From the turbine, the flow enters a chamber where liquid lime is added for pH adjustment. From this chamber the flow enters the primary distribution chamber, which is the beginning of the primary treatment process.

Primary Treatment

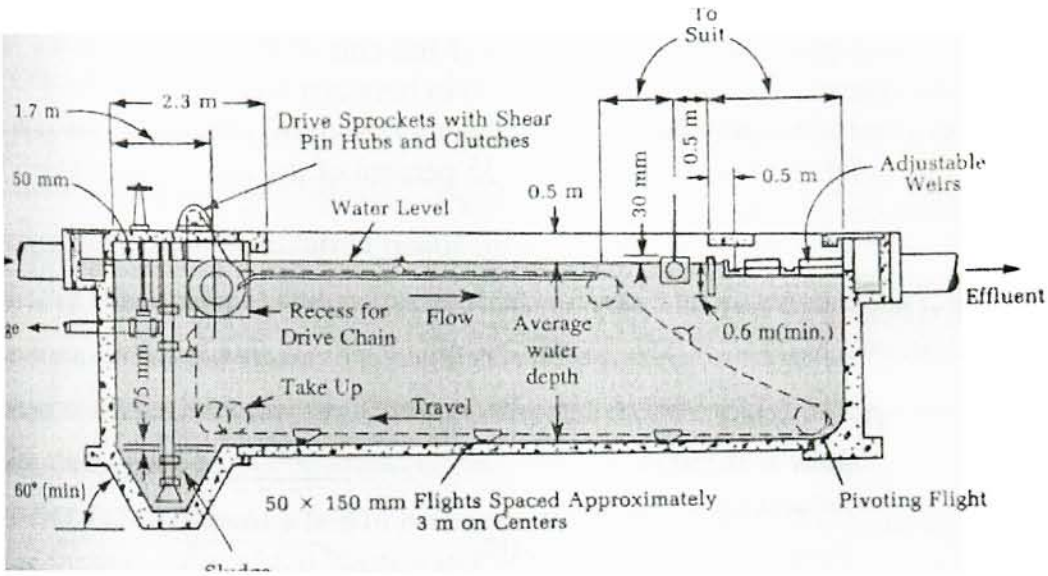
The primary treatment process consists of the equalization basin, three primary clarifiers, and the neutralization system.

Equalization Basin

The flow from the turbine enters a distribution chamber that contains a flow-equalization baffle. The equalization of flow is necessary to minimize variations in the wastewater velocity and concentration and to make the treatment process occur at a constant rate (Davis and Cornwell, p. 369). In addition, there are three sluice gates used to regulate the flow into the primary clarifiers.

Primary Clarifiers

The wastewater entering the primary clarifiers is screened for large debris but light organic suspended solids still remain (Davis and Cornwell, p. 372). Some of these suspended solids can be removed by gravity, given the proper retention time for settling. The flow into the primary clarifiers enters from the bottom through the center well where is it evenly distributed throughout the basin. Settled sludge is collected on the bottom of the basin and swept with a sweeper arm to a sludge pit. Floating solids are collected with an upper sweeper arm (skimmer) and deposited into a unit called the "scum trough." The sludge collected from the primary clarifiers is sent to the sludge holding tanks, which will be discussed in detail in the sludge management section. The King's Landing Treatment Plant contains three primary clarifiers. Two of the three are 130 ft in diameter and have a capacity of 1.5 MG. The third unit is 140 ft in diameter and has a capacity of 1.9 MG. A diagram of a primary clarifier is shown below.



Davis and Cornwell, p. 373

Neutralization System

The neutralization system consists of a covered chamber and tunnel with associated piping. The neutralization chamber accepts primary effluent from the clarifiers where caustic addition takes place to neutralize the pH. The neutralization channel conveys the wastewater from the neutralization chamber to the low lift well. The channel is 230 ft long and contains baffles for chemical mixing and flow control (Kodak procedures). The low lift well contains 5 low lift pumps each rated at 10,000 gallons per minute (GPM). The low lift well sends the flow to the high lift well where the secondary treatment process begins (Kodak procedures).

Secondary Treatment

The secondary treatment process consists of a trickling filter and activated sludge process (aeration basin and secondary clarifier) operating in series. The purpose or design basis for secondary treatment is to increase the removal of biochemical oxygen demand (BOD) and provide further removal of the suspended solids in the wastewater (Davis and Cornwell, pg. 374). The measurement of BOD in the plant influent and plant effluent provides the most common measurement of overall plant efficiency.

Trickling Filters

The wastewater is pumped into the top of the trickling filters from the high lift pumps and distributed throughout the unit. The trickling filters are used to stabilize the wastewater feed to the aeration basins by minimizing the variations in BOD loading. The trickling filters consist of a 68 ft diameter structure covered with a fiberglass dome to minimize odors. The structure is filled with PVC packing media to a depth of 21 ft (Kodak procedures). Bacteriological growth is formed on the surfaces of the media, which feed on the organic matter contained in the secondary plant influent stream and thus reduce the BOD. The effluent from the filters enters the aeration basins. Two diagrams of a trickling filter are shown below.

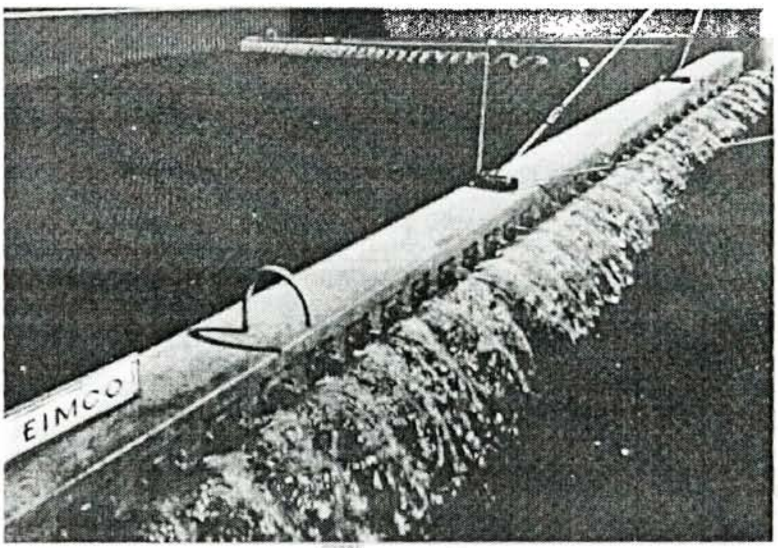
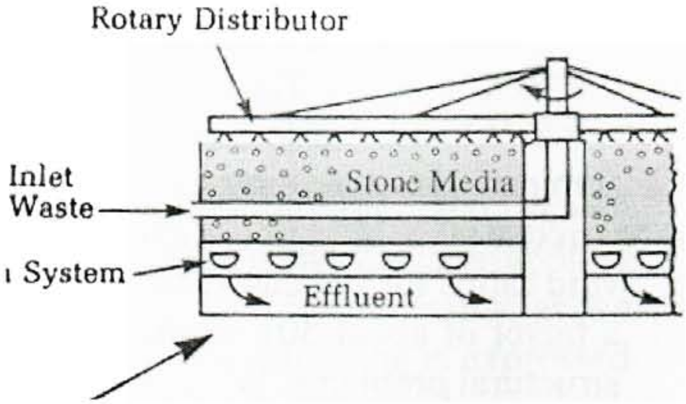


FIGURE 5-16

[illegible]

Davis and Cornwell, p. 376



Davis and Cornwell, p. 375

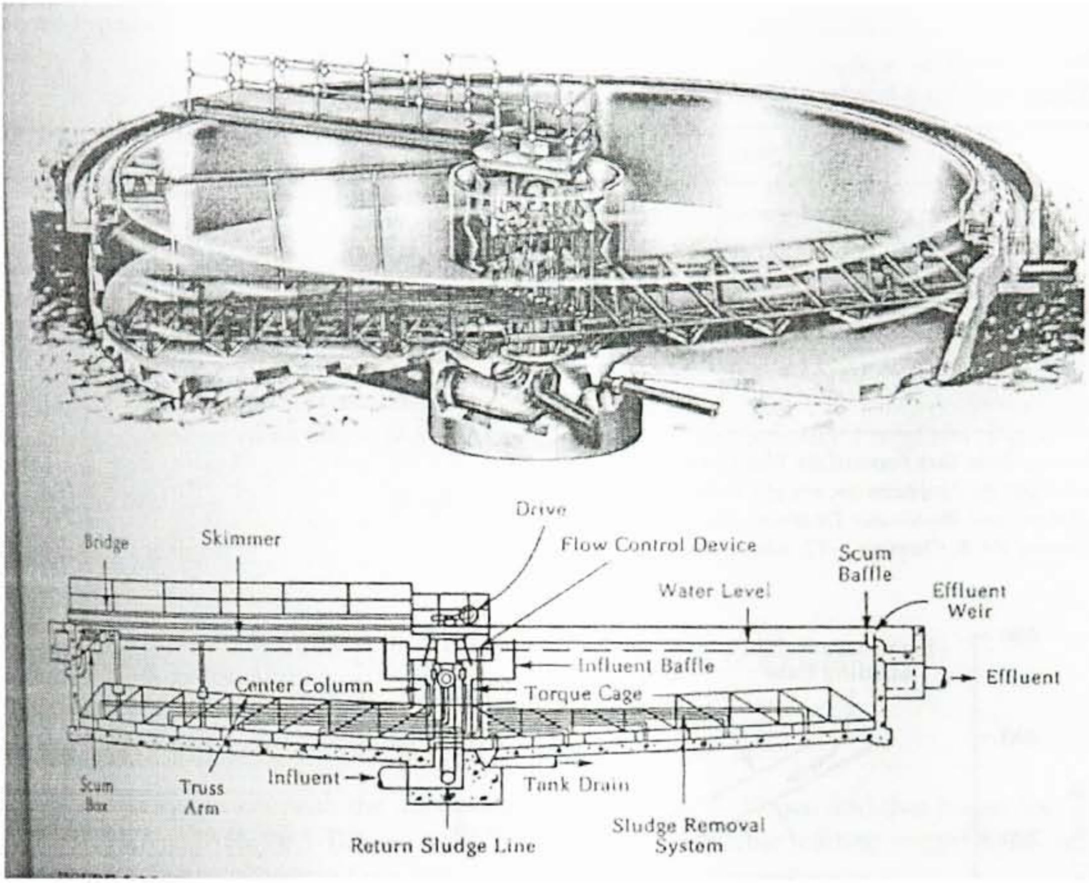
Activated Sludge Process

The activated sludge process consists of aeration basins and secondary clarifiers. The term "activated sludge" refers to a process where the wastewater is mixed with biological sludge containing microorganisms and is agitated and aerated (Davis and Cornwell, p. 382). The process of injecting air into the wastewater in the aeration basins supplies the necessary oxygen for the microorganisms to digest the organic material as food. As the size of the microorganisms increases, they flocculate together to form a mass called "activated sludge" (Davis and Cornwell, p. 382). The activated sludge mixture is sent to the secondary clarifier to be settled out and returned for reuse to the aeration basin. More activated sludge is generally produced than is required for this process. The secondary sludge processing will be discussed further in the Sludge Management Section. The KLWWTP contains 3 aeration basins each 130 ft square and 25 ft deep. With an operating level of 20 ft, the volume of wastewater and sludge is nearly 2,530,000 gallons (Kodak procedures). An aeration basin is shown below.

Davis and Cornwell, p. 382

Secondary Clarifiers

The clarifiers receive the flow from the aeration basins and distribute it from the center well. The velocity of the flow is limited by the clarifier and baffle design such that the biological floc will settle out of suspension to the bottom of the clarifier. The settled sludge is collected, and a portion of it is returned to the aeration basin. The remaining excess sludge is sent to the dissolved air floatation (DAF) chamber before being sent to the sludge holding tanks. The secondary clarifiers are shown below.



Davis and Cornwell, p. 403

Sludge Management

The sludge from the primary and secondary treatment processes is stored in the sludge holding tank area. King's Landing uses 4 sludge holding tanks for storage and sludge blending. Three of the tanks are 50,000-gallon capacity and the fourth tank has a 100,000-gallon capacity (Kodak procedures). Each holding tank also contains a mixer to keep the sludge agitated. The sludge removed from the primary clarifiers is called "primary sludge." It is removed from the clarifiers and sent to the holding tanks directly. The secondary sludge (referred to as "activated sludge") is taken from the secondary clarifiers but must first be thickened. Prior to storage in the holding tanks, the secondary sludge enters the DAF unit. The DAF unit is where a polymer is added to thicken the sludge, and air is forced through the bottom of the unit to push the sludge to the top. The polymer is added because large sludge floc aids in optimization of sludge dewatering.

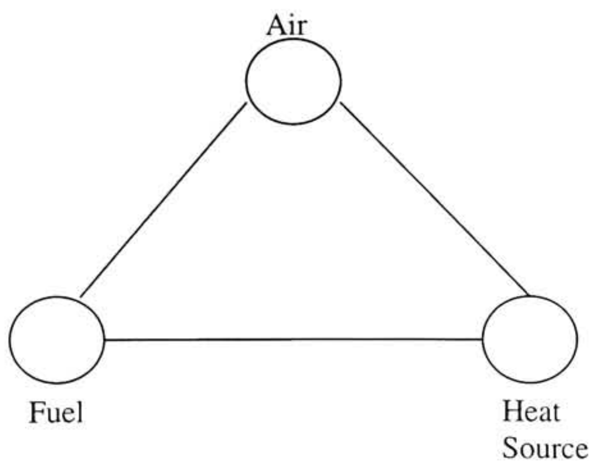
Both types of sludge are blended in the holding tanks to obtain an ideal percentage of solids by weight. Prior to incineration, the sludge is sent to a mechanical belt press for dewatering. The dewatered sludge exits the belt press and drops into the hearth incinerator bunker conveyor for treatment.

Incineration and Combustion Literature Review

The dewatered sludge and grit from the wastewater treatment process at King's Landing is managed by incineration. The process of incineration is a viable treatment option for hazardous waste because it reduces the total volume and also detoxifies the waste (Theodore and Reynolds, p. 15). This section will first outline the fundamentals of combustion and incineration and will provide an overview of the construction and operation of a multiple hearth incinerator (MHI).

Combustion and Incineration

Combustion, as defined by the North American Combustion Handbook, is "a rapid combination of oxygen with a fuel, resulting in the release of heat" (p. 1). Perfect theoretical combustion would imply that exactly the right amount of air and fuel are combined such that no excess products remain. Lean combustion means that too much oxygen or excess air is applied resulting in a shorter flame and an oxidizing condition (Reed, p. 4). Rich combustion is the opposite condition where too much fuel and not enough oxygen is combined producing a longer flame, otherwise known as "incomplete combustion" (Reed, p. 4). A product of incomplete combustion is carbon monoxide, which is monitored continuously in the incineration process to determine and ensure that complete combustion has occurred. The combustion triangle is shown below. All three factors in the triangle are important for complete combustion (Kodak procedures).



At the multiple hearth incinerator, the fuel source is the wastewater sludge and grit, the heat is supplied by natural gas burners, and the air is supplied with the use of a fresh air fan. Other important principles of combustion include mixing, ignition, and flame stabilization. Proper mixing of the air and fuel is critical to ensure uniformity in the combustion chamber. Ignition of the fuel occurs when the supply of air and heat create an oxidation reaction and the fuel begins to release heat faster than the heat is lost to the surroundings in the chamber (Reed, p. 7). When the fuel source is able to maintain the combustion chamber temperature without the additional heat source, it has reached a state of autogenous burning (Kodak procedures). Flame stabilization is especially critical in the combustion process because it can make the difference between efficient or incomplete combustion. When burning sludge, this is an especially complicated process because the residence time (time it takes to completely treat the sludge) is between 1-2 hours. Many factors affect the stability of the flame including the feed rate of the sludge and the amount of available excess air and heat (Kodak procedures).

Incineration is defined as "a combustion process that uses rapid oxidation, excess air, and high temperatures to produce conditions to destroy hazardous waste and its constituents" (Gill and Quiel, p. 1). The construction and operation of a multiple hearth incinerator is discussed below.

Multiple Hearth Incinerators

The multiple hearth incinerator (MHI) is the most common type used for the incineration of sludge from both municipal and industrial treatment plants (Brunner, p. 95). The MHI at King's Landing was installed in 1975. It consists of an insulated steel shell and eight compartments or "hearths" each lined with brick refractory (Kodak procedures). The unit is 22 ft in diameter and spans 4 floors at the King's Landing facility. The figure below shows the construction of a typical MHI.

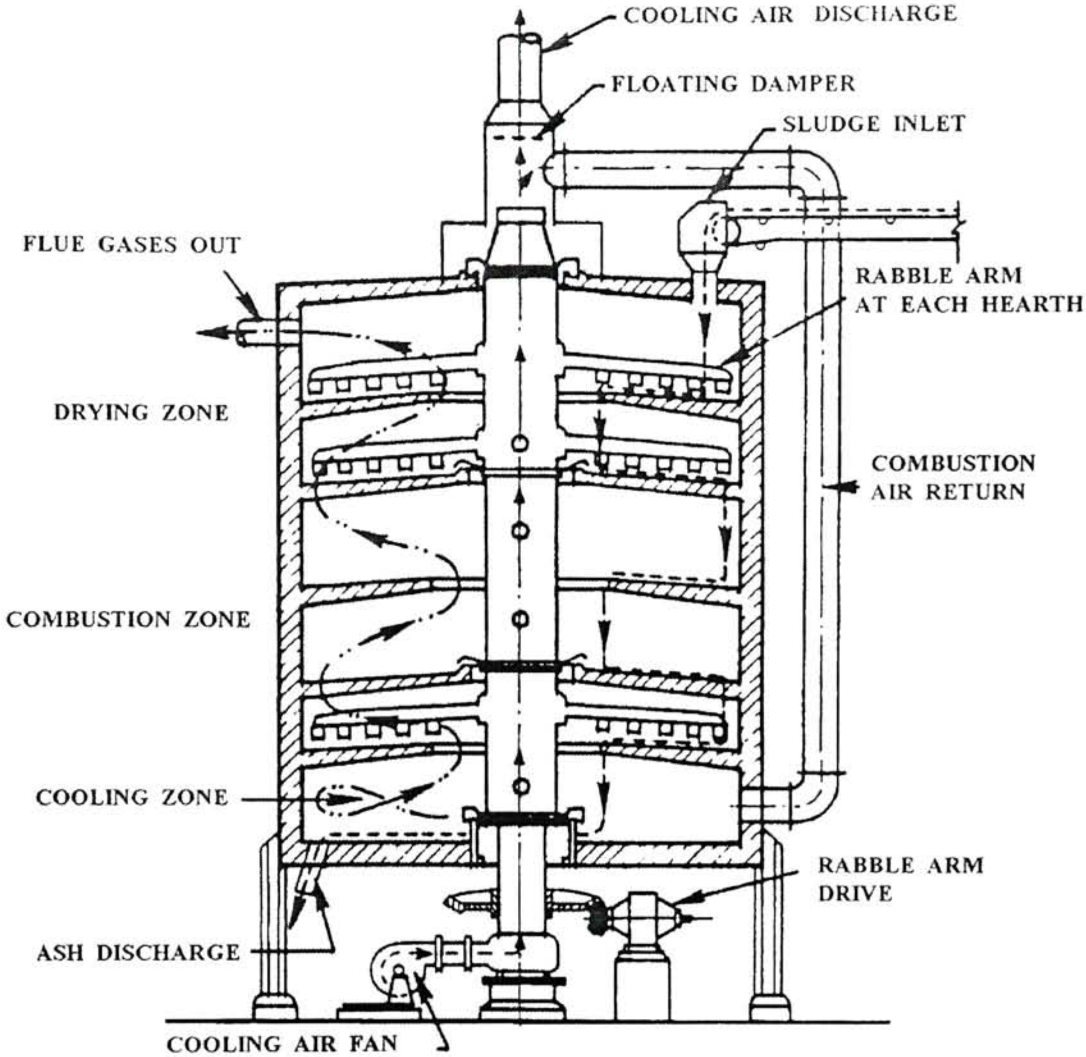


Figure 2.2-1. Cross Section of a Multiple Hearth Furnace

The MHI is comprised of 6 main components, which include the hearth outer shell, rabble system, sludge feed system, air systems, ash system, and burner systems (Kodak procedures).

Outer Shell

The outer shell is comprised of steel and contains an interior insulation material along with the 8 refractory-lined hearths. The shell maintains the structural integrity of the incinerator. Each hearth is given a number and serves a distinct purpose. The "0" hearth is highest, located at the top of the unit and is the last hearth in the process where the secondary combustion chamber is connected. The "1" and "2" hearths are known as the "drying zone" and the dewatered sludge enters the incinerator at the "1" hearth. The drying zone releases approximately 10 pounds of moisture per square foot of hearth area per hour (Brunner, p. 99). Hearths "3," "4," and "5" are referred to as the "burning zone." The sludge becomes ignitable when the moisture content reaches a level less than 30% (Brunner, p. 99). The dried sludge or "cake" drops down to the "3" hearth and may ignite and fall to the "4" hearth to burn. Hearths "6" and "7" are the ash cooling zones and the ash is discharged at the bottom of the "7" hearth (Kodak procedures). Each hearth contains a number of rabble arms to move the sludge, cake, or ash throughout the chamber.

Rabble System

The rabble system is comprised of a center shaft connected with the rabble arms located in each hearth and rotates at a given speed. The shaft speed is a critical parameter that either maintains or changes the burning conditions within the hearth. Each rabble arm contains a set of teeth directed inward or outward to facilitate the movement of material from one hearth to the next (Kodak procedures).

Sludge Feed System

The dewatered sludge travels from the belt press to the sludge bunker conveyor. The sludge bunker conveyor contains flights that aid in movement of the sludge to the elevating conveyor that feeds into the "1" hearth. The grit from the aerated grit chamber

is fed directly into the elevating conveyor and into the hearth (Kodak procedures). The sludge feed rate is a critical component in maintaining the burning conditions within the hearth. If too little sludge is fed, the ideal mixture of fuel and air will be compromised.

Ash System

The "7" hearth drops the ash into the ash conveyor where it is conveyed to a collection trailer. The ash conveyance system is pneumatic to minimize handling issues and sanitation concerns (Kodak procedures).

Air Handling System

The air handling system is comprised of several fans used for combustion air and cooling effects within the hearth. The combustion air fan supplies air to each natural gas burner located in the hearths. The fresh air fan supplies air in the "3", "5" and "7" hearths for cooling or to aid the combustion process (Kodak procedures). This fan also provides cooling air to assist during periods of shut down. The over-fire air system supplies air into the "3" and "4" hearths to provide turbulence for proper mixing of the fuel and combustion air.

Burner System

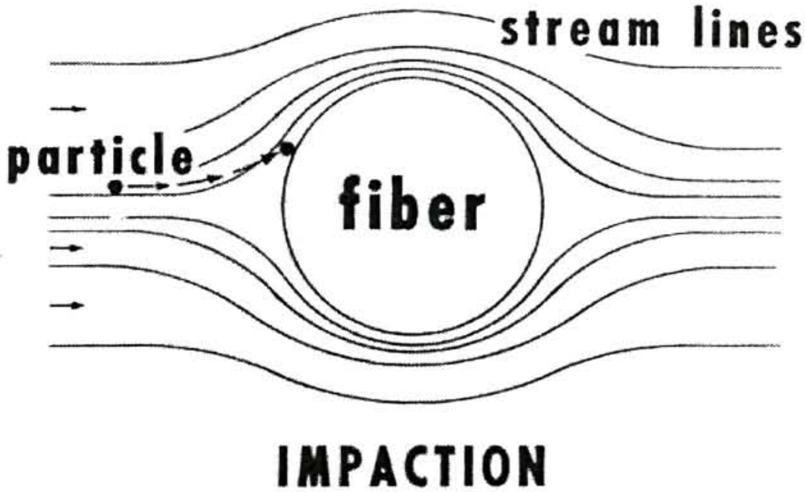
The hearth contains 12, North-American style fuel atomization burners (Kodak procedures). There are 4 burners in the "0" hearth, 2 burners in the "2," "3," "5," and "6" hearths. Natural gas is used to fuel to the burners to act as the heat source in the MHI. The burners are used to preheat the incinerator and obtain proper temperature during start up. They also provide additional heat to dry the incoming sludge and to initiate the ignition of the sludge cake. The burners also assist in providing a consistent source of heat to maintain level temperature control within the unit (Kodak procedures).

Secondary Combustion Chamber

The secondary combustion chamber is also referred to as the "afterburner." The purpose of an afterburner is to enhance the destruction efficiency by increasing the residence time of the gas. The afterburner is a secondary form of control where high temperatures are maintained outside of the hearth (Brunner, p. 80). The afterburner also contains natural gas burners to maintain a set-point temperature in the chamber and to ensure complete combustion. Once the gas exits the secondary combustion chamber, it enters the top the quench chamber and the air pollution control equipment (APCE) train.

Air Pollution Control Equipment Literature Review

Upon incineration of the wastewater sludge, the off gas produced from the multiple hearth and secondary combustion chamber is directed through a series of air pollution control equipment (APCE). The purpose of the APCE is to clean the gas by removing particulate matter, acid compounds, and metals. The removal of the particles is accomplished through particle conditioning. Particle conditioning includes methods that increase particle accumulation and promote condensation, which include impaction and adhesion of the particles (Bethea, p. 100). Impaction involves the collision of the particles with a media (typically water droplets). Once the particle collision occurs, adhesion of the two compounds must take place. In the figure below, fiber would be substituted for water droplet in this case.

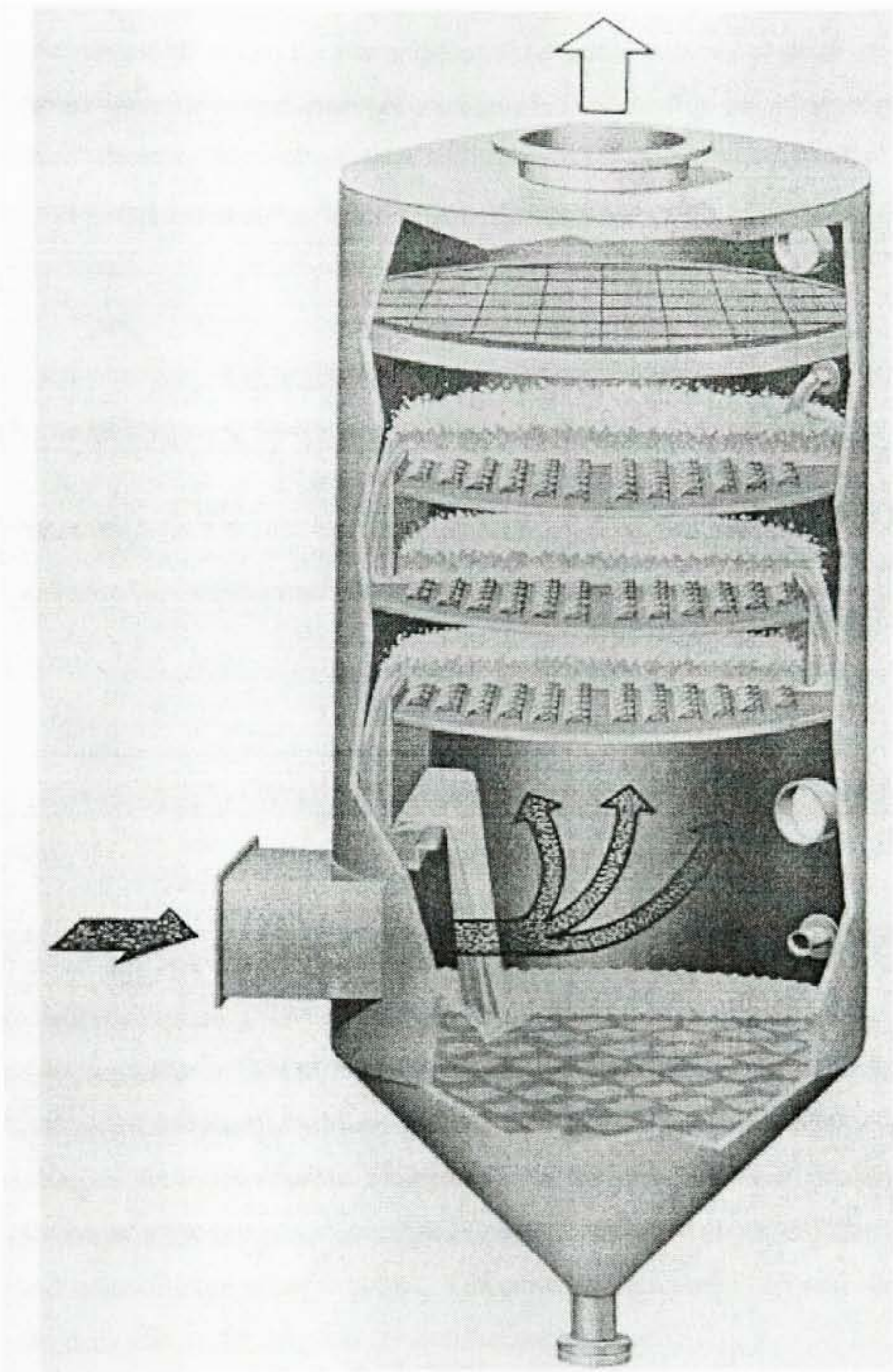


Bethea, p. 146

The equipment in the King's Landing process, listed in sequential order, includes the quench chamber, condenser/scrubber, venturi, entrainment separator, and wet electrostatic precipitator (WESP). Upon exiting the WESP, the clean air stream is pulled through an induced draft (ID) fan and directed out to the atmosphere through an exhaust stack. In this section, a general overview of the APCE will be given with more specific emphasis directed around the operation and functionality of the WESP.

Quench Chamber. The purpose of the quench chamber is to cool the gas that exits the combustion unit. The cooling is accomplished by using a series of water spray nozzles directed in the stream of hot gas flow within the chamber. The gas flow enters the chamber from the top and passes through the water spray. Cooling of the gas is necessary to protect the downstream equipment, as well as increase particle accumulation by increasing the humidity of the gas stream to the adiabatic saturation point (www.epa.gov, p. 97). When air containing a specific humidity and temperature passes over a stream of water, the water evaporates and mixes with the air stream. The moisture content of the air increases while the temperature decreases, which is due to the latent heat of vaporization of the evaporated water (Cengel and Boles, p. 697). A typical exhaust gas temperature from the secondary combustion chamber could be in the range of 1650°F-1700 °F. The quench reduces that temperature to a value less than 200 °F.

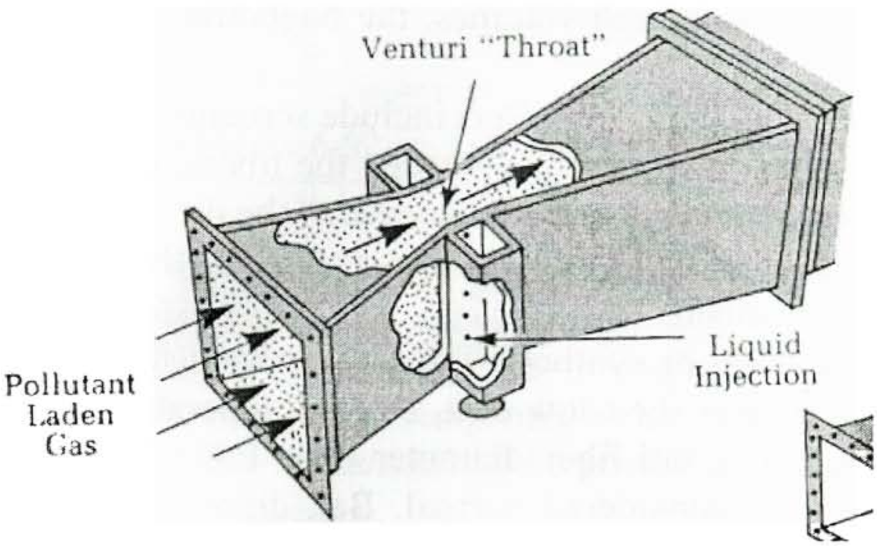
Condenser/Scrubber. The cooled gas stream exits the quench and enters the condenser/scrubber unit. The flow into the condenser enters at the bottom and travels upward through a plastic corrugated packing media. The packing media is used to increase the liquid-to-gas contact by creating a surface for the particles and water droplets to contact each other and collect. Above the packing media, is a series of water nozzles that spray downward into the gas stream and packing. The water vapor is condensed containing fine particles in the gas stream and is removed from the condenser overflow line (Kodak procedures). The remaining gas stream experiences additional cooling and exits the condenser/scrubber at the top of the unit and into the venturi. See figure below.



Bethea, p. 281

Venturi: The venturi is a mechanical device that removes particulate matter through the use of a mechanical damper. By restricting the diameter of the venturi throat through the use of a damper control, the velocity of the gas is increased. Water is added at this point

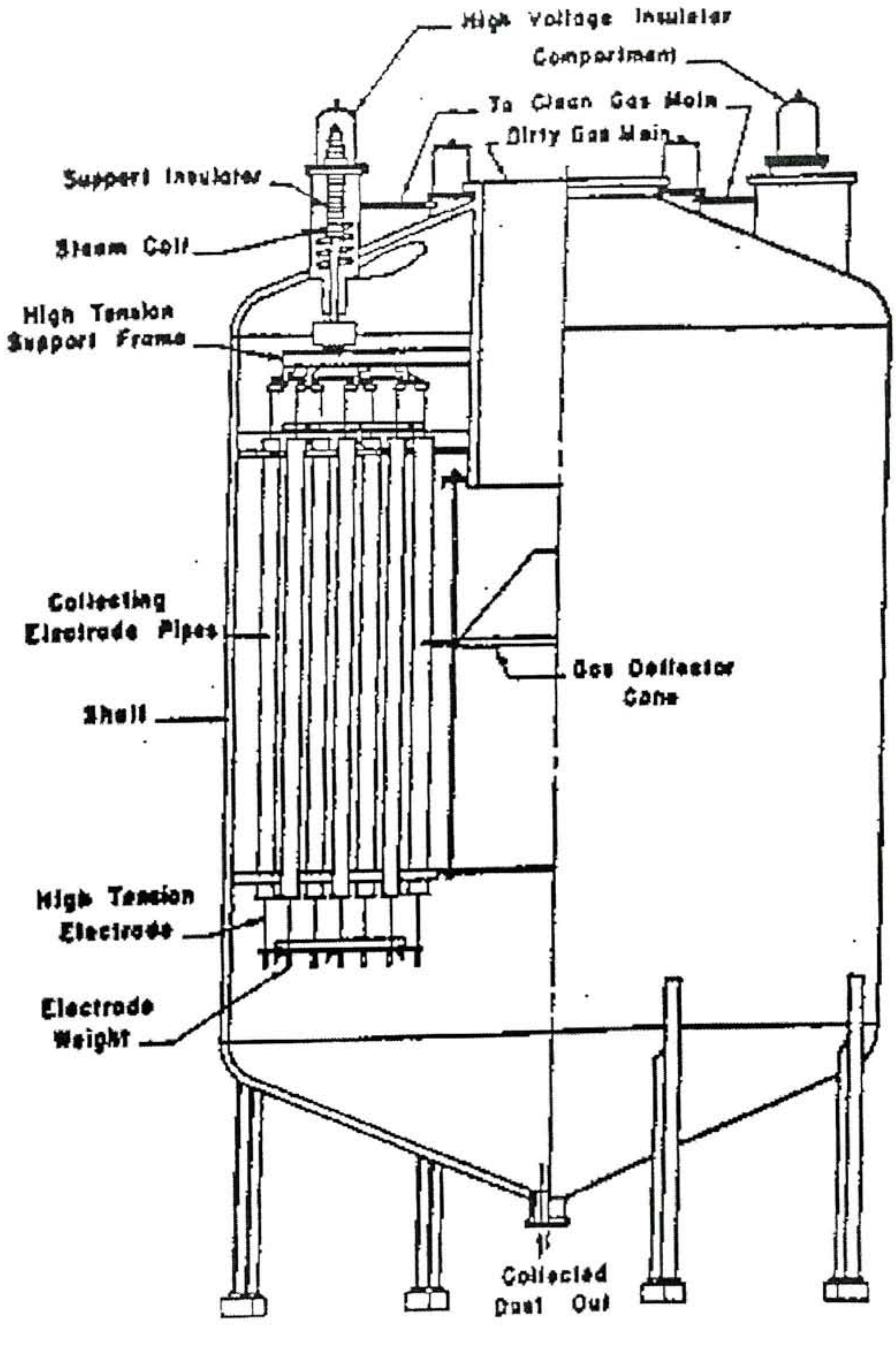
and is atomized as a result of the high-velocity condition (Bethea, p. 305). The high differential velocity between the gas and atomized water droplets in the diverging section of the venturi encourages impaction of the contaminants within the droplets (Kodak procedures). Because the contaminates are contained within a water droplet, collection and removal is enhanced at the WESP. See figure below.



Davis and Cornwell, p. 530

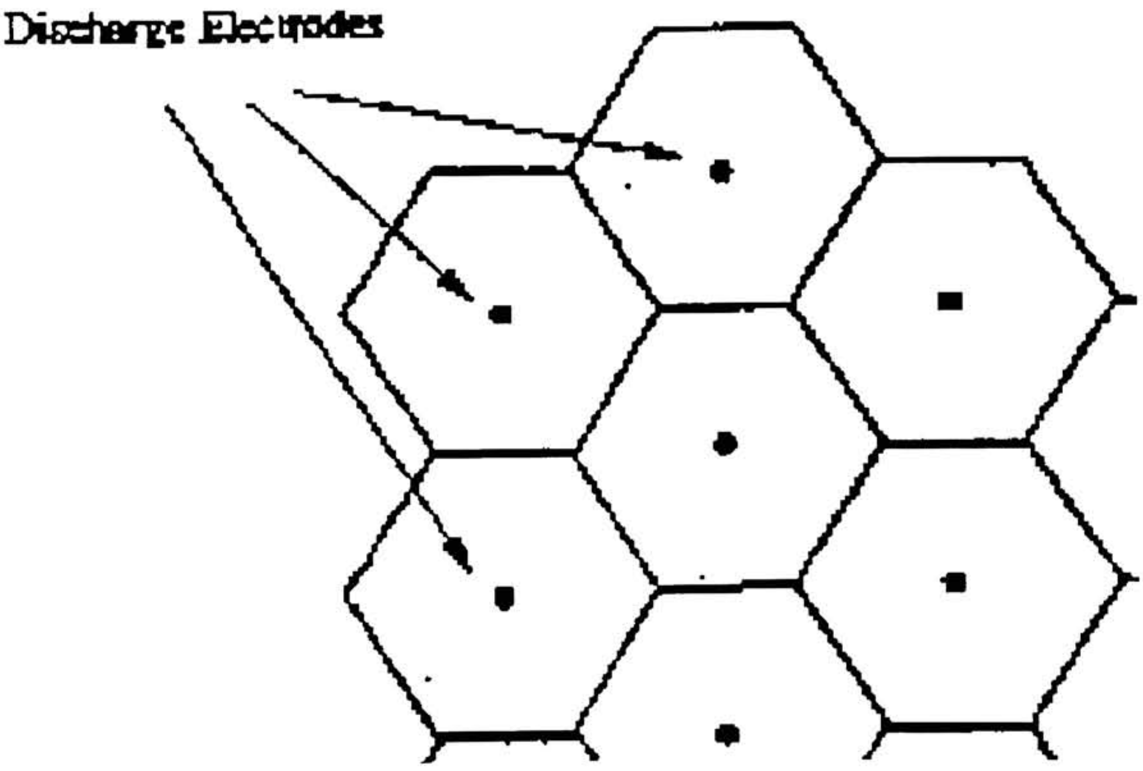
Entrainment Separator: The gas flow exits the bottom of the venturi and enters the entrainment separator at the bottom. The purpose of the entrainment separator is to remove entrained metals, particulate, and water from the contaminated air stream and also to decrease the velocity of the air stream from the venturi (Kodak procedures). The top of the entrainment separator contains 1-2 layers of plastic demister packing, used to collect and remove large water droplets. The entire gas stream is still saturated, but the WESP requires fine water droplets for optimal performance.

Wet Electrostatic Precipitator: The gas flow exits from the top of the entrainment separator and into the top of the WESP. A diagram of the WESP is shown below.



www.epa.gov, p. 5.2-1

The basic principle of the WESP is that fine particles are removed from the gas stream by charging the gas with an electronic field that promotes collection of the particles onto the collection tubes. Next the particles are flushed from the tubes and drained out of the WESP and back into the wastewater treatment plant (Kodak procedures). The water wash also maintains the saturation of the gas, which provides further cooling and conditioning (www.epa.gov, p. 5.2-8). The basic construction of a WESP consists of the outer shell, discharge electrodes, collecting electrodes, and insulators (Bethea, p. 209). The King's Landing WESP design is a wire pipe, meaning that a wire suspended from the top of the unit and is contained within the axis of a long, hexagonal pipe and acts as the discharge electrode (www.epa.com, p. 5.2-9). See figure shown below.



www.epa.com, p. 5.2-14

Principles of WESP Operation

The WESP uses electrical principles and concepts as the basis for particle collection. The gas stream enters the WESP as a collection of finely saturated gas particles traveling at a relatively low velocity. The water droplets within the gas stream contain the contaminant particles, which were impacted at the venturi. The main sequence involved in WESP particle removal includes electric field generation, particulate charging, particle migration to the collection electrode, and final flushing (www.epa.gov, p. 5.2-1). A diagram of the total system is shown below.

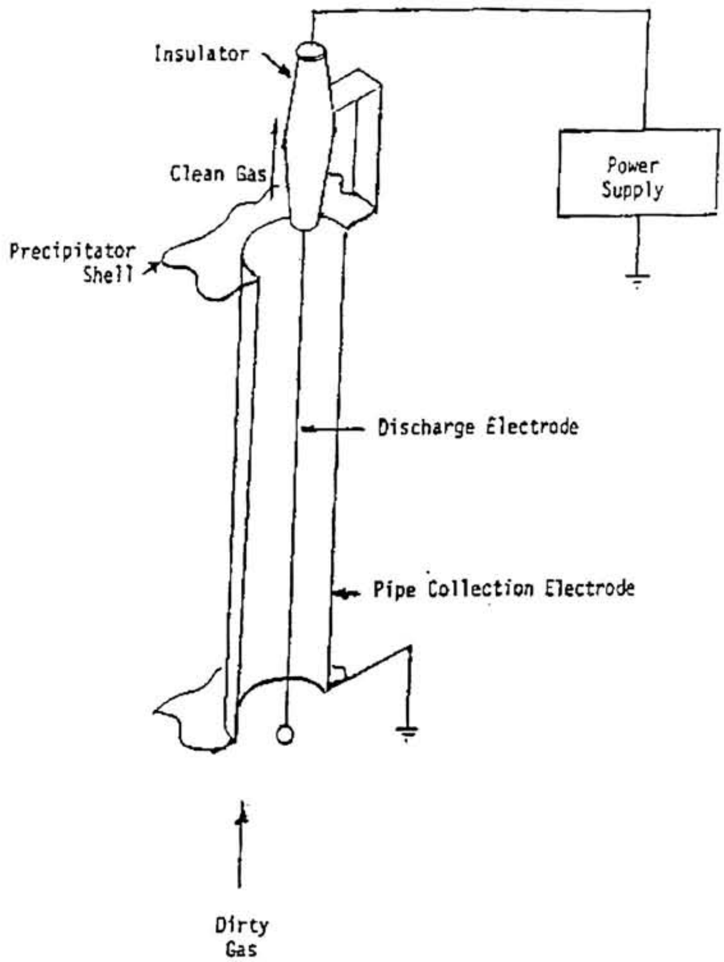


Figure 5.2-1. Cutaway view of Wire-Pipe Electrostatic Precipitator (Reference 2).

5.2-2 www.epa.gov, p. 5.2-2

Electric Field Generation

The electric field is generated through the use of the corona-discharge electrodes and a high-voltage power supply to the WESP The strength of the electric field is a major contributor to the performance of the WESP (www.epa.gov, p. 5.2-1). The electric field is generated between the discharge electrode and collection electrode.

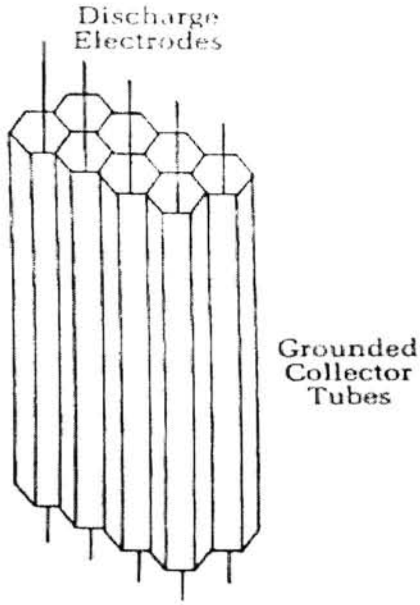
Corona Generation

The corona is formed by the electric field and represents the electrically active region of the gas stream (www.epa.gov, p. 5.2-4). The corona itself is a glow that may be white, bluish, or reddish in color and extends into the space between the discharge and collection electrode (Strauss, p.234). Here, the electrons are stripped and travel in one direction, leaving the remaining positive ions to travel in another direction. The corona generates a large amount of ions that possess the same charge as the discharge electrode. The ions are therefore attracted to the collection electrode located across the hexagonal space. While traveling across the space, the ions become attached to the incoming particles in the gas stream and migrate toward the collection electrode (Strauss, p. 229).

Particle Charging

The particles pass through the electric field located between the discharge and collection electrode. The quantity of ions located in this region must be adequate enough to surround the entire region of gas flow. The more ions the area contains, the higher the probability that any individual particle will collide with several ions and become charged (Bethea, p. 222). Once the particle is charged, it migrates towards the collection electrode.

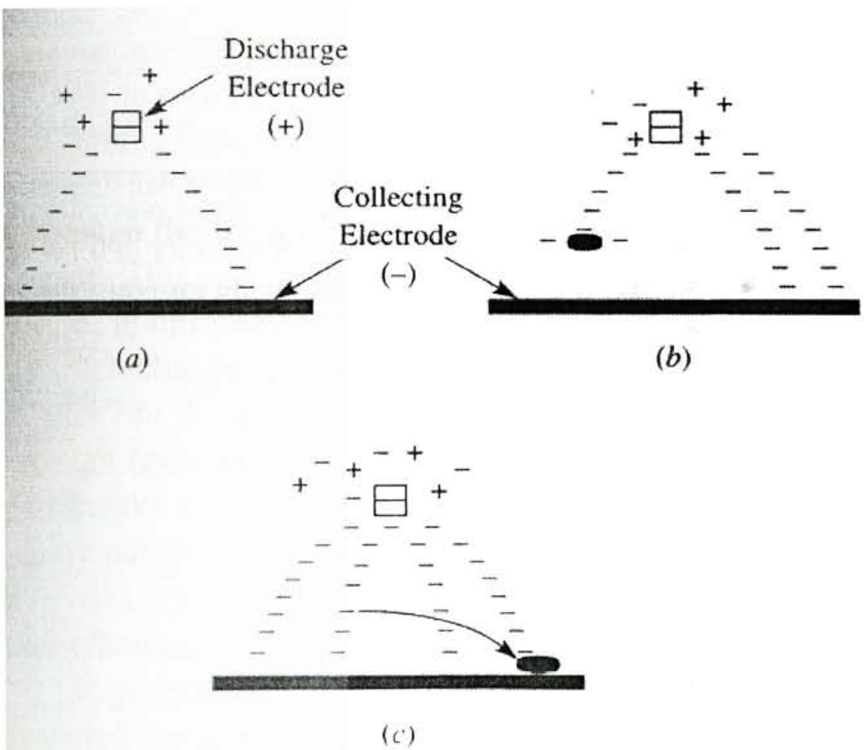
Particle Collection: Once the particles are charged and migrate to the collection tubes, particle collection is achieved. A diagram of the collection tubes, along with the electron behavior, is shown below.



(a)

FIGURE 6-35

Davis and Cornwell p. 532



GURE 6-36

Davis and Cornwell, p. 533

Particle Flushing:

Periodically the WESP initiates a flushing cycle with a duration of several minutes. The unit is flushed with water to remove the collected particles on the collection walls. The water is collected and drained form the WESP and returned back to the influent side of the wastewater treatment process.

WESP Parameters:

The performance of the WESP is controlled by applying a certain level of voltage. The efficiency of the WESP can indirectly be observed by the power level measured in kilovolt amps (KVA). As the load of particulates increase to the unit, the resistance increases within the unit; thus, the power and efficiency are lowered (Rose and Wood, p. 177). As a rule of thumb, increased voltage and increased power yield increased collection efficiency. Although higher power and voltage generally leads to increased efficiency, if too much voltage is applied, excessive sparking and arcing will occur. When arcing occurs, damage to the unit is inevitable, along with an associated decrease in efficiency (Rose and Wood, p. 186). The voltage level can be monitored along with the power and current readings. The King's Landing WESP monitored parameters directly measure the secondary voltage (in kilovolts KV) and display the calculated secondary power (in kilovolt amps KVA). Power is calculated using the equation:

$$\text{Power} = \text{volts X amps}$$

http://www.dbugman.com/handbook/tscmh3.html.

Case Studies:

A few case studies have been performed analyzing the operation and efficiency of a WESP. One such study was published in 1997 in the journal *Environmental International* entitled "White Smoke Emission from a Semiconductor Manufacturing Plant." This paper studied the combined removal efficiency of a wet scrubber in series with a WESP. The authors collected and measured inlet and outlet gas samples at various

voltage loadings. The results showed that the number of particles remaining in the outlet gas samples reduced as the operating voltages increased. The "white smoke" virtually disappeared from the plant stack once the WESP voltage was above 40 KV and was almost 100% efficient at 50 KV. The chart is attached below.

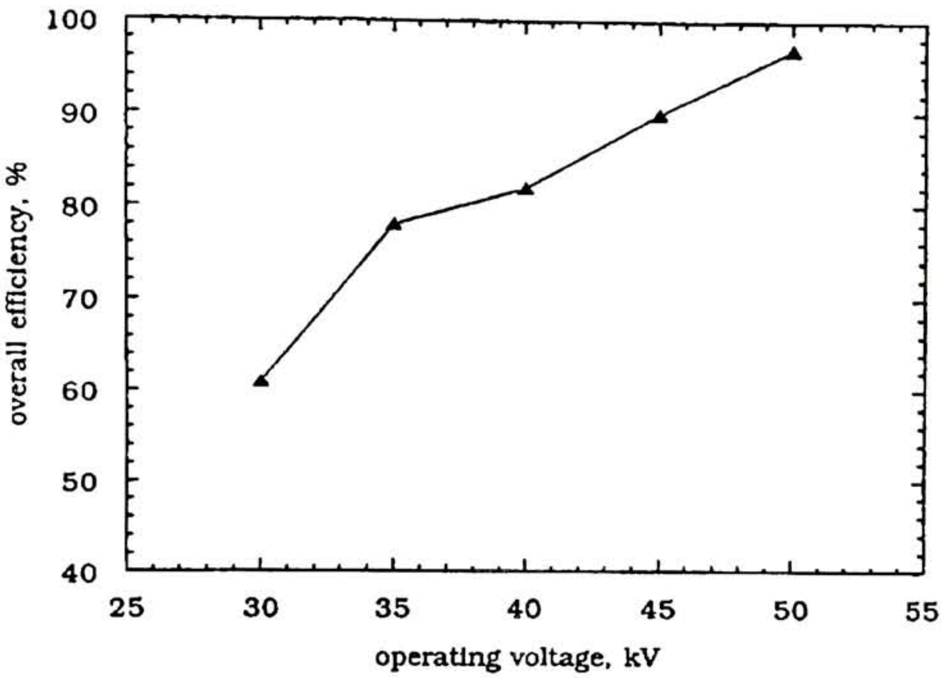


Fig. 7. Overall collection efficiency of the wet ESP vs operating voltage.

Tsai,Miao,Lu p. 496

Another case study published in the *Journal of Environmental Engineering* in March, 2000, entitled "Electrostatic Precipitator For Metal and Particulate Emission Control" discusses the use of a venturi scrubber and WESP used in series. This study dealt with municipal sludge waste, unlike King's Landing's industrial sewer sludge. Stack gas sampling was used to measure the performance of the unit for metals and particulate emissions. The WESP removal efficiencies are shown in the table below.

TABLE 5. Emission Rates of SRVSA Municipal Sewage Sludge Incinerator #2

Parameters (1)	WESP inlet (lbs/h) (2)	Stack (lbs/h) (3)	Removal (%) (4)	New Jersey DEPE permit limit (lbs/h) (5)
Particulate matter	0.18	0.0663	63.2	0.7
Arsenic	0.0 (7.5 E-5)	0.0 (7.4 E-5)	—	0.0014
Cadmium	8.45 E-6	2.11 E-7	97.5	0.0057
Chromium	1.02 E-5	8.52 E-6	16.5	0.066
Lead	0 0 (7.72 E-5)	0.0 (7.25 E-5)	—	0.058
Mercury	9.83 E-3	6.93 E-3	29.5	0.011
Nickel	1.18 E-5	4.03 E-6	65.8	0.045
Hydrogen chloride	0.43	0.020	95.3	1.52
Carbon monoxide	0.314	0.205	34.7	2.3
Nitrogen oxides	0.679	0.661	2.7	7.4
Sulfur dioxide	1.869	1.15	38.5	2.6

Note: Values in parentheses represent detection limits. Average flue gas components mass flow rates in lbs/h.

Yang and Beltran p. 236

Although this study did not relate voltage or power to efficiency, it did outline the main concepts surrounding suitable WESP applications and overall performance for lead and particulate removal.

Summary:

The background for all APCE upstream of the WESP is important to gain an understanding of the number of variables in this process. This thesis will go beyond the case studies that prove that voltage and power levels are performance indicators by analyzing the upstream APCE and other variables in the incineration process to see what parameters have an effect on the voltage and power.

Statistical Analysis Tools Literature Review

Materials and Methods:

Based upon the information that was desired, statistical analysis tools and applications were carefully chosen. Proper analysis required the identification of predictor and response variables. This thesis will analyze 10 predictor process variables as they relate to one response variable, in an effort to understand and optimize the process with respect to its output.

Exploratory data analysis will first be used to examine the variables. Descriptive statistics include mean, standard deviation, variance, sample size, quartiles, and other summary statistics, as well as histograms, scatter plot matrices, correlation matrices, and trend charts (Mendenhall eds., pg 4). This thesis will use the basic features of exploratory data analysis to start the analysis. The descriptive statistics through linear regression tools will be applied using the Minitab Statistical Software package and the PLS model will be developed, using PLSPC, a software package proprietary to Kodak. Many plots will be generated to target and focus upon time periods of unusual or predictive behaviors. These areas will be correlated with certain key process variables and analyzed with process knowledge to derive solutions or explanations with respect to the performance of the WESP. Using as few dimensions as possible, PLS modeling will be applied to the process and output data. The results of the model will focus further efforts on key parameters for continued analysis for process optimization for Kodak.

Discussion:

Response and Predictor Variables:

The response variable measures the effects of the process variables on its output and is also known as the "dependent variable." The predictor variables are the independent process variables that are presumed to affect the response variable (Mendenhall eds, p. 516).

Exploratory Data Analysis:

A scatter plot shows the relationship between two variables. Along with the existence of potential outliers, histograms show the shapes of each variable's data so that distributional assumptions can be checked. Correlations determine the amount of linear relationships between pairs of variables. Trend charts show how variables change over time.

Linear Regression:

Standard linear regression techniques require assumptions to be made about the data. One assumption is that there is a linear relationship between the predictor variable and the response variable. Another assumption is that the values of the random errors are independent, have a mean of zero and a common variance, and are normally distributed (Mendenhall eds, p. 540). A third assumption is that linear regression assumes that the measurements themselves (the predictor variables) contain no errors (Heckler, p. 6). The second and third assumptions are not true for the MHI and WESP variable data, which are highly correlated and definitely contain variability.

Partial Least-Squares Regression:

The correlation in the MHI and WESP data is why the partial least-squares (PLS) model was used. Further, PLS models the X variance as well as the Y variance and tries to fit a model that adequately explains both sources of variability.

The background for the basis of PLS can be traced back to Herman Wold. Wold needed a tool to analyze complex multivariate models derived from Psychological and Economic data (Heckler, p. 6). The data were highly correlated with a large number of variables. . PLS classifies the X (predictor variables) and Y (response variables) as the observed data. The unobserved data are the latent phenomena. A latent variable is not directly observable and tends to vary in the population and sample (Heckler, p. 7). Latent variables can be considered concepts where the outputs supporting the concepts are measured directly. An example of a latent variable is the concept of health. People are

considered healthy if they are of ideal weight for their height and have a normal blood pressure. Health cannot be directly measured, but is indirectly measured by the observed variables of weight and blood pressure.

The fundamental operation of PLS is to compute reasonably good estimates of latent variables, and base all future computations on those variables to optimize the model. PLS is basically a two-step process. The first step involves a statistical analysis using partial least squares regression. The second step of the process is the optimization part where cross validation is used along with orthogonal matrices (Hoskuldsson, p. 211). PLS can be viewed as a stepwise procedure where a pair of components in the X and Y space are selected, based on relative closeness to one another (Hoskuldsson, p. 217). This is also referred to as maximum covariance between the X variables and the Y space (Kourti, p. 13). The process continues until there are no more significant components remaining. The main goal of PLS is to reduce the number of variables down to a manageable number that adequately explains the X and Y relationship. In-depth process knowledge is required to analyze and evaluate the model and its applicability to the process.

Cross validation is the method used to determine the necessary number of dimensions in the model. Too few dimensions will under-fit the data and explain too little of its variability. Too many dimensions will over-fit the data and explain random noise, as well as process variability. One-dimensional data gives the same information as a pair-wise correlation (Heckler, p. 7). As a rule of thumb, less than 10 dimensions are considered a small number.

The process of cross validation consists of dividing the dataset into groups. A model is developed for the dataset by omitting one group at a time and modeling the remaining groups together. This model predicts the responses of the group that was excluded and measures the prediction error for this group (Heckler, p. 7). The process is repeated until all of the groups have been omitted once, and the corresponding prediction errors have been summarized. A result of zero is perfect and a result close to one is not favorable.

Each dimension in the final model has a cross-validation value. The number of optimal dimensions can be observed when the cross validation value does not differ much from one dimension to the next.

The PLS model uses a standard equation with matrix notation. X is considered to represent the predictor variables while Y is the response variable. T represents the latent variable predictions associated with the X-block data. T is also referred to as a "score" (Heckler, p. 6). U is the latent variable prediction associated with the Y-block data. P represents the X-block loadings. The loadings show how the latent variables are related to the original X and Y variables (Kourti, p. 13). Except with respect to the Y-block loadings, Q is the same concept as P. The standard equation for the PLS model is shown below:

$$X = T P^t + E$$

$$Y = T Q^t + F \qquad \text{where E and F are error terms.}$$

Once the PLS model is created, many plots may be analyzed to gain insight into the relationships in the data.

Case Studies:

A case study outlining the utilization of PLS modeling was written in the article "Process Analysis and Abnormal Situation Detection: From Theory to Practice," by Theodora Kourti. The article reviews the application of latent variable models based on historical data and examines the pros and cons for improving both batch and continuous processes. The article also provides insight into why univariate control charts are not good indicators of equipment performance or final product quality.

Univariate control charts use historical process data from historical runs of good performance or good product. The upper and lower limits are established by plus and minus 3-sigma levels from the target value (Kourti, p. 11). The univariate control charts do not consider the interactions of all the process variables. These charts do not consider that most variables are not independent. Usually, no one variable is important enough to

affect a large change to the response variable. In most cases, the simultaneous combined effect of all the variables is what produces the outcome on the response variable. This is another reason why PLS is a better application for identifying the significant variables and their effect on the response variable, for the MHI and WESP processes.

> The case study discussed in Kourti's article dealt with an actual problem encountered in industry that was rectified using PLS. The process contained a feed stream that had a known concentration of component A at 20%. The stream passed through a series of 12 separators until a stream with a high purity of component A was produced. The objective was to maintain a concentration of A greater than 99.5%, while recovering 92% of A in the stream. The problem occurred in the last three months where the recovery dropped below 92%. The company analyzed 447 process variables for 498 days. A set of 442 variables was projected to 7 principle components that could explain 93% of the variation and 93% in the recovery. The process behavior changed at points 400 to 490. It also showed an abnormal event manifested itself along the first principle component. In other words, a combination of variables from the first principle component seemed to be related to the event. Contribution plots were constructed using information from the loadings and weights of each measured variable to identify the process variables that numerically contributed to decrease noticed along t1 (Kourti p. 14). It was identified in the study that only four variables had the highest contribution to the overall observed change. Three of the four were controllable parameters while the fourth was codependent upon the others. This case study shows how 447 process variables were reduced to 4 that required additional analysis and process knowledge to fix the problem.

Conclusions:

Using the tools described above, the WESP functionality and output pollution control performance will be characterized for the 10 predictor and one response variable.

The development of a PLS model will attempt to indicate and describe which predictor variables are significant and ultimately optimize the effects on the WESP.

Scope of Work

The scope of work for this thesis included a comprehensive literature review and research of the principles involved with wastewater treatment, combustion and incineration, air pollution control equipment, and the application of various statistical tools as they relate to this analysis.

Statistical tools were used to analyze historical data and develop a predictive model based on the input variables for the performance of the WESP (measured by power level). The controllable variables that were analyzed for the unit were: venturi pressure drop, wet sludge feed rate, gas flow through the system, quench water flow, condenser water flow, and WESP voltage. Uncontrollable variables examined were: oxygen level (exiting stack), CO level (exiting stack), and #3 hearth temperature (which is a function of the combustibility of the sludge). The response variable observed was the power measure shown in the WESP.

Descriptive statistics, including a correlation matrix, were developed as the first step in this analysis. This matrix identified the interactions between the variables and the amount of noise in the data. Once the correlations were developed, a partial least-squares (PLS) regression analysis was performed. This demonstrated which variables were significant and also created models, or predictive equations. The models were evaluated using process knowledge and verified by running actual experimental process tests. The evolutionary operations (EVOP) process was implemented to gather small data trials within acceptable operating ranges.

The methodology, results, and conclusions are discussed in the next portion of this thesis.

Methodology

The chronological steps used in this analysis included: data collection and organization, development of an original model, evaluation of the model, development of a control chart and identification of outliers, development of new models, evaluation of new models, determination of an optimum model(s), EVOP trials, evaluation of the test trial results in comparison to the optimum model, and identification of shortcomings and advantages of the optimum models.

The first step was to collect 6 months of historical process parameter data. The data span was from July 2002 through December 2002. The raw data are located in **Appendix A**. The original variables included 12 predictor variables and 1 response variable. The variables and the rationale behind the selection of these variables as predictors for WESP efficiency are shown in **Table 1**.

Table 1. Table of Original 12 Variables

Variable Name	Units	Function in Process	Rationale
Wet sludge feed rate	Pounds/hour	Combustion fuel	Dictates how fast or slow the incineration process occurs
Quench water flow rate	Gallons/minute	Gas conditioning	Indirect measure of combustion process conditions
Condenser water flow rate	Gallons/minute	Gas conditioning	Indirect measure of combustion process conditions
Venturi throat flow	Gallons/minute	Particle Impaction w/water	Major gas cleaning device (particle collection/control efficiency)
Venturi total flow	Gallons/minute	Particle Impaction w/water	Major gas cleaning device (particle collection/control efficiency)
Venturi differential pressure	Inches wc	Particle Impaction w/water and particle collection	Major gas cleaning device (particle collection/control efficiency)
WESP Secondary Voltage	Kilovolts	Indirect measure of WESP efficiency	Power = volts*amps
WESP Secondary Power	Kilovolt-amps	Indirect measure of WESP efficiency	This is the response variable
Stack Exhaust Gas Temperature	Degrees F	Gas is cooled for equipment protection	Outlet temperature demonstrates cooling efficiency in system
Stack Carbon Monoxide concentration	ppm	Measure of combustion process efficiency	Indication of good versus bad combustion in system
Stack oxygen concentration	ppm	Measure of combustion process efficiency	Indication of good versus bad combustion in system
System airflow	ACFM	System is under negative pressure driven by an induced draft fan	Dictates process residence time
Multiple Hearth (#3 hearth) temperature	Degrees F	Hearth sludge burning zone	Indication of combustion conditions (wet versus dry sludge)

Some of the variables were directly controllable, while others were not controllable and were a result of the process conditions. All data points collected were on a rolling hourly average basis. The rolling hour averages are based on 60 rolling minute averages. The averaging algorithm as documented in Kodak operating procedures is shown below:

The 1-minute average is the arithmetic average of the 4 most recent 15-second observations and is calculated using the following equation where:

$$OMA = \frac{\sum_{i=1}^{4} Ci}{4}$$

OMA = one minute average
Ci = a fifteen-second observation

The hourly rolling average calculation is calculated by the following equation:

$$OHRA = \frac{\sum_{n=1}^{60} OMA}{60}$$

where:

OHRA = one-hour rolling average
OMA = one-minute average of a process parameter.

Each rolling hour average for each process parameter was averaged into one daily average to provide for data reduction. In addition, the data are more stable and robust because of the smoothing of any minor process or statistical fluctuations. Since the process required a large amount of time to reach steady state, any periods of start up, shut down, maintenance, or upset conditions were removed and not considered in this analysis.

Several predictive models were created and evaluated until the best-fit model was developed. Models were evaluated with and without outliers. The raw data were examined to see if there were reasons to exclude the outliers.

A control chart was developed to show the periods of time that the process was in statistical process control. The control chart was calculated in conjunction with a moving range chart. The methodology behind using the moving range chart is based on the use of a population (n) equal to 1. Each daily average is comprised of 1,440 data points (60 min/hr * 24 hrs/day). This average is updated every minute for the 24 hrs in the day. A value of $n = 1{,}440$ or $n = 24$ creates a very sensitive and narrow range for upper and lower control limits, which is not representative of the actual process. The KVA reading for the WESP does not change much throughout the day but, over time, the range may shift based on other process factors. The use of $n = 1$ represents the daily average of the rolling hour averages more consistently. The formula used to calculate the X-bar and moving range chart was:

Upper Control Limit (UCL) = $x + 3\ MR / d2$

Center Line (CL) = $\overline{x}$

Lower Control Limit (LCL) = $\overline{x} - 3\ \overline{MR} / d2$

Where:

$\overline{x}$ = the mean of the daily average KVA levels

$\overline{MR}$ = the average of the moving range

$MR_i = | x_i = x_{i-1} |$

$d2 = 1.128$ based on the standard factors chart for control charts

Models were created for the steady-state conditions and non-steady state conditions and compared against one another. Four additional variables, as well as interactions of variables, were included into the models to see what contributions improved the model fit. The four additional process parameters considered are shown in **Table 2**.

Table 2. Additional Variables

Variable Name	Units	Function in Process	Rationale
WESP wash water flow	Gallons/minute	Periodic self cleaning function of the WESP	See if correlation exists between low power and wash cycles
#2 Bunker conveyor speed	Feet/minute	One part of the sludge feed system	Dictates speed of the incineration process
Center shaft speed	rpm	Turns the rabble system to distribute the sludge in the hearth	Rabble speed is an element of hearth retention time
#0 Hearth draft pressure	Inches wc	Hearth is under negative pressure to prevent fugitive emissions into the building	Hearth draft pressure is an indirect indicator of combustion process conditions

Once the best-fit model was generated, an evolutionary operations (EVOP) experiment was designed and performed. The results of the experiment were analyzed and compared to the predictive model developed by the PLS software. Two levels of each variable were used. The designed experiment is known as a 2 x 2 matrix, shown in **Table 3**.

Table 3. Designed Experiment

	Sludge Feed	Airflow
test1	+	+
test2	+	
test3	-	
test4	·	+

Test condition 1:

Both sludge feed and airflow are maximized

Test condition 2:

Sludge feed is maximized and airflow is minimized

Test condition 3:

Both sludge feed and airflow are minimized

Test condition 4:

Sludge feed is minimized and airflow is maximized

The operating range for the sludge feed is from 5,000 lb/hr up to the maximum limit of 16,223 lb/hr. The airflow rate can vary from 10,000 acfm up to the maximum limit of 17,585 acfm. The sludge feed rates and airflow rates are not typically run to the permitted maximum. Therefore, to establish the ranges for maximum levels of these 2 variables, a range of +/- 10% from the permitted maximum was considered acceptable. The minimum value was established to be in the range of 20-60% of the maximum value.

Results

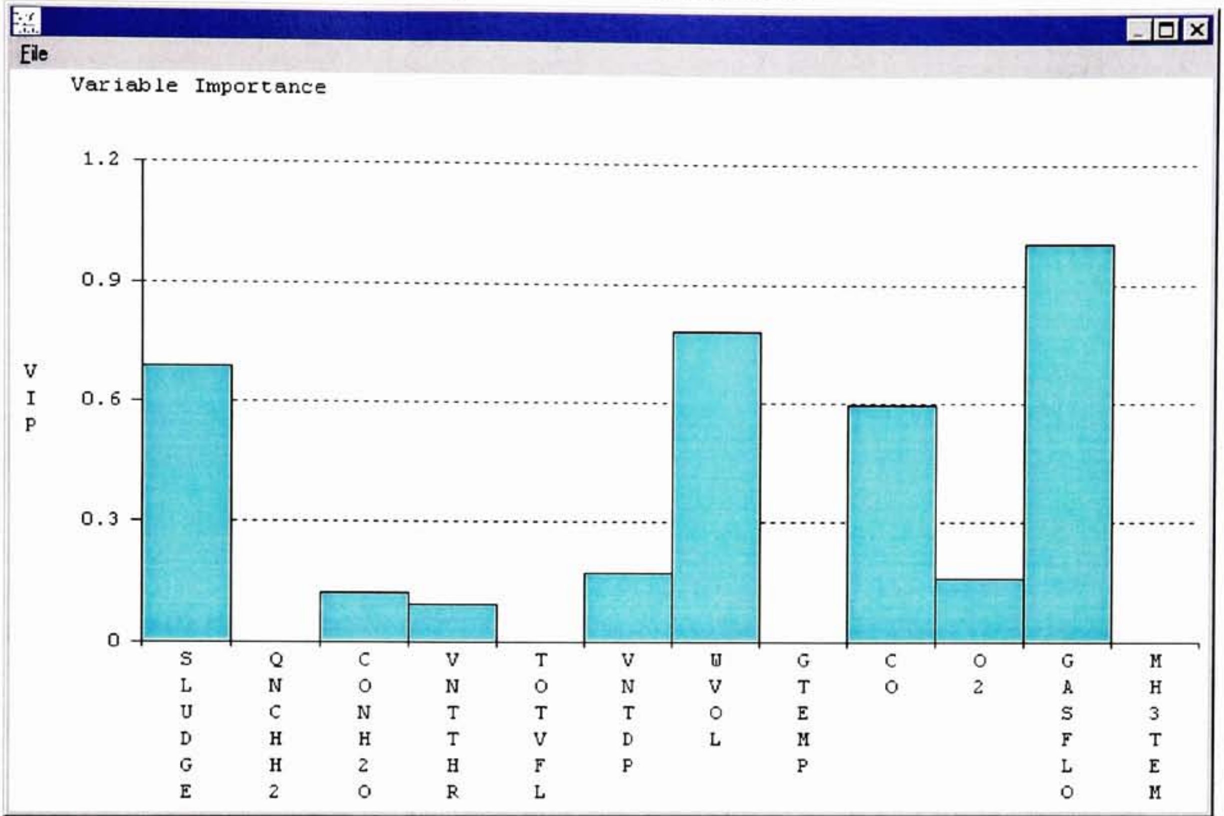
The final optimum models generated consisted of a 4-predictor variable model with an R-squared value of **0.544 and 1 dimension**, and a 5-variable model that considered the interactions among variables with an R-squared value of **0.571 and 1** dimension. Although the R-squared value is not overwhelmingly high to ensure complete confidence in the predictive model, the model did accurately predict most trends in the process and did account for some of the variability observed in the WESP power. There were other factors affecting and influencing the process beyond those demonstrated in this model. Extensive further research and work in this area would be required to fully explain the variability in WESP power.

After acquiring and reducing the data, an initial model was developed and a control chart drawn for the six-month period of data collected. Additional models were developed and analyzed as a result of findings from the initial model.

Each model is outlined below.

Model 1:
The first predictive model considered the original list of 12 predictor variables on the WESP power. The data contained 122 cases, which also included process outliers. The R-squared obtained from this model was 0.508 and the model identified 3 of the 12 predictor variables to be significant. The variable importance plot from the initial model is shown as **Graph 1**. A variable importance level of 0.6 was used as the significance level.

Graph 1. VIP Plot Model 1



As shown in **Graph 1,** the variables: sludge feed rate, WESP voltage, and gas flow rate were significant. The CO level was borderline for disregarding or not, based on the 0.6 significance level criteria.

The next step with Model 1 was to create a correlation matrix to look for relationships among the variables. The correlations of +/-0.5 and greater were considered to be strong correlations indicative of a relationship that should be examined further. The correlation matrix is shown as **Table 4.**

Table 4. Correlation Matrix Model 1

Correlation Matrix

File

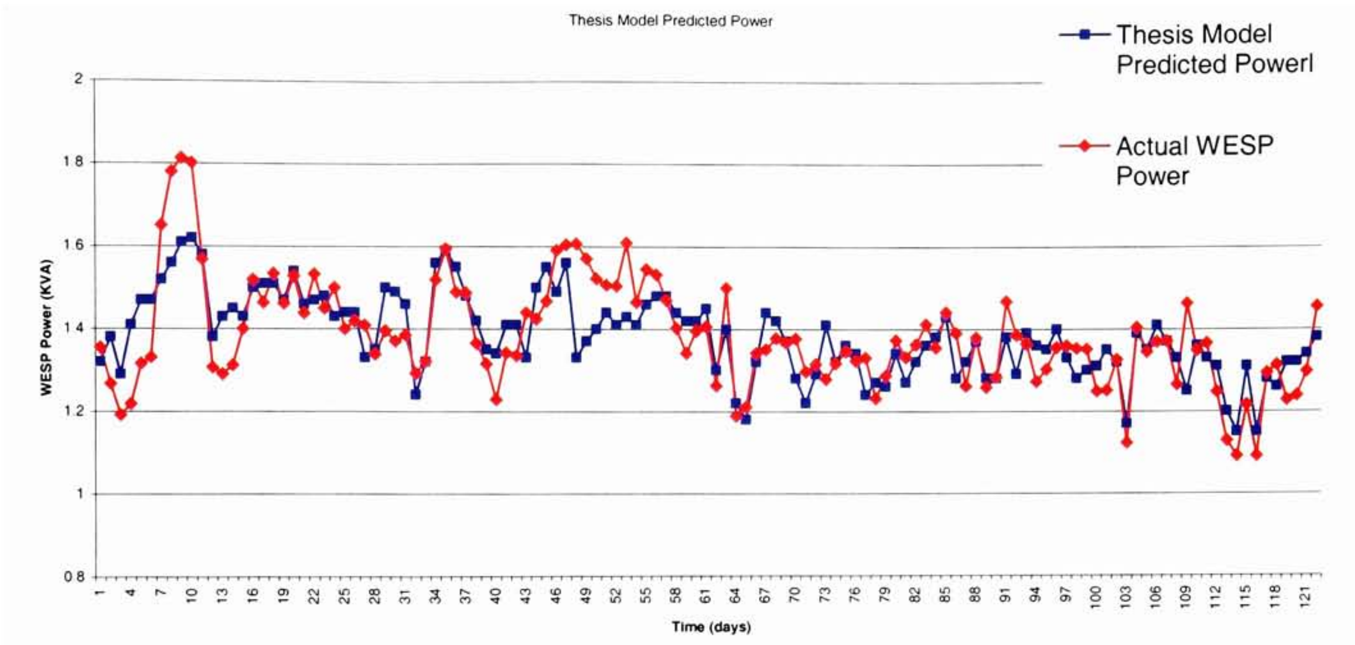
	SL...	QN...	CO...	VN...	TO...	VN...	WV...	WK...	GT...	CO	O2	GA...	MH...
SLUDGE	1	.306	ı814	.281	ı471	3E-4	.287	.505	ı429	ı552	.822	.355	.282
QNCHH2O	.306	1	.145	.382	ı278	.153	ı216	ı236	ı347	ı902	.234	ı315	.142
CONH2O	ı814	.145	1	.192	.139	ı782	.301	.212	ı536	ı753	ı853	.218	ı606
VNTTHR	.281	.382	.192	1	ı379	.115	0.19	.179	ı136	0.05	ı305	.235	ı903
TOTVFLOWS	ı471	ı278	.139	ı379	1	ı834	ı978	ı225	.128	ı981	ı369	ı674	ı745
VNTDP	3E-4	.153	ı782	.115	ı834	1	.575	.266	ı811	.531	.116	.274	.269
WVOL	.287	ı216	.301	0.19	ı978	.575	1	.532	ı364	.625	ı722	.552	.207
WKVA	.505	ı236	.212	.179	ı225	.266	.532	1	ı152	.507	.246	.604	ı904
GTEMP	ı429	ı347	ı536	ı136	.128	ı811	ı364	ı152	1	.114	ı968	ı798	.147
CO	ı552	ı902	ı753	0.05	ı981	.531	.625	.507	.114	1	.269	.512	ı347
O2	.822	.234	ı853	ı305	ı369	.116	ı722	.246	ı968	.269	1	ı316	.397
GASFLOW	.355	ı315	.218	.235	ı674	.274	.552	.604	ı798	.512	ı316	1	ı171
MH3TEMP	.282	.142	ı606	ı903	ı745	.269	.207	ı904	.147	ı347	.397	ı171	1

The darker colored boxes in the table show that a stronger correlation exists. Highlights from the table include strong correlations between WESP power (WKVA) and WESP voltage (WVOL) (0.532), sludge feed rate (sludge) (-0.505), CO (-0.507), and gas flow (-0.604). The correlation plots, a graph of the predicted KVA values versus the actual KVA values, along with the PLS software printout of the model, are in **Appendix B**.

Other strong correlations between the predictor variables include: sludge feed rate and oxygen level (-0.822), WESP voltage and venturi dp (-0.575), and venturi dp and CO (0.531).

The model produced the following graph of predicted versus actual values referred to as **Graph 3**.

Graph 3



Graph 3 considers all data including outliers. As shown in the beginning of the data (days 1-15), the periods of extreme high and low values are not accurately predicted by the model.

Control Chart:

The entire six-month data period was used to create a histogram to verify that the population was normally distributed. This histogram can be found in **Appendix C** as **Graph 2**. A control chart was created shortly after Model 1 was developed to identify whether or not the process was in statistical control. This would indicate whether or not there are assignable causes to the variation observed in the WESP power. The X-bar and MR charts are shown as **Charts 1 and 2**. The data for the calculation of the UCL, CL, and LCL for both the X-bar and MR charts can be found in **Appendix C**, along with larger versions of **Charts 1 and 2**.

As seen in the control charts, there are a few instances where the process is not within statistical process control. These outliers were examined on an individual basis. The graphs of each predictor variable over time can be found in **Appendix C**. The software also flagged these values as suspect and suggested deletion. Once they were identified as outliers from the

control chart, in addition to the analysis from the run charts of each variable, these data points were removed from the final data set.

Chart 1. X-Bar Chart

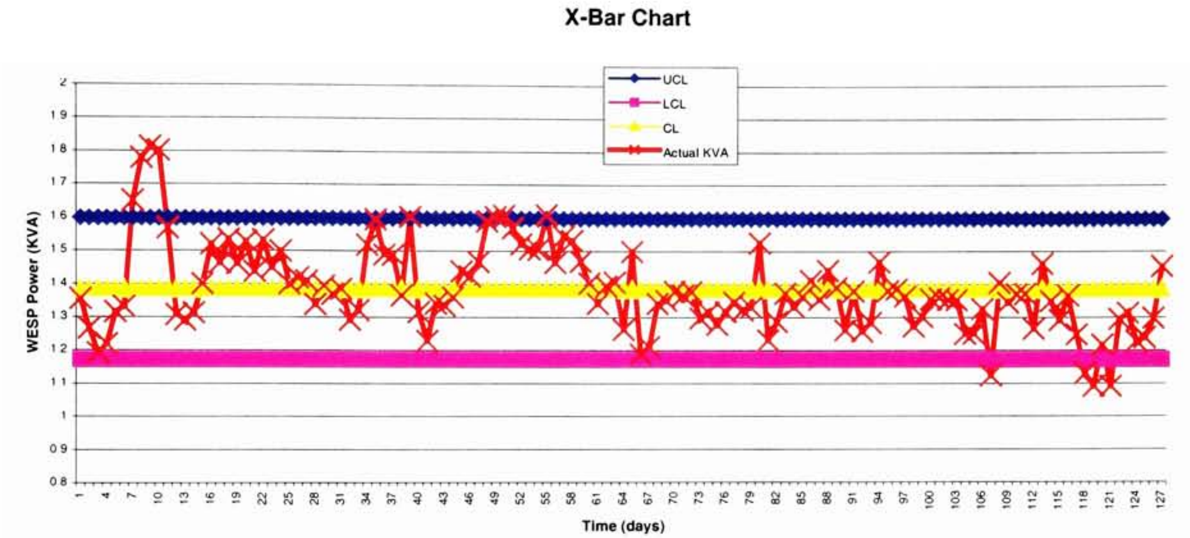
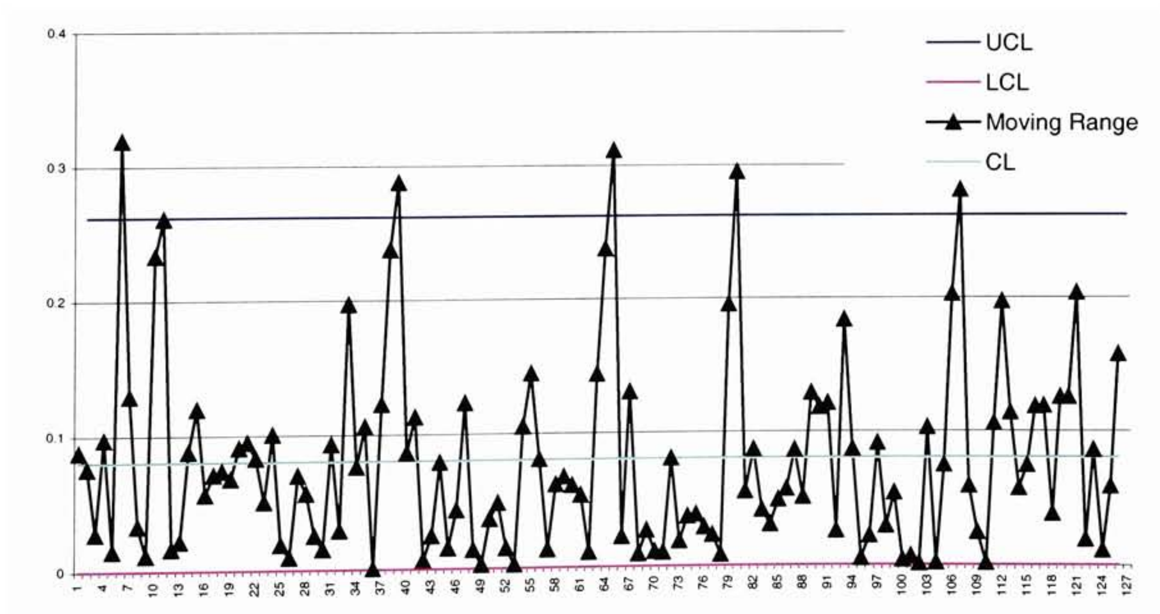


Chart 2. Moving Range Chart



Model 2:

From the control chart, there was a period of time from November 6 through December 12 where the process was more stable than the rest of the time period. Model 2 was created using the data from this time period and was referenced as a steady-state condition. The raw data and the PLS software printout are attached in **Appendix D**. This model used the original twelve-predictor variables and, thus, did not produce any new insights.

Model 3:

The control chart indicated a non-steady state condition from July through October. The raw data and PLS software printout can be obtained in **Appendix E**. Again, the original list of twelve predictor variables was used for this model, and no new information was obtained at this stage.

Model 4:

Because the R-squared value from Model 1 was indicating that only some of the variability was being explained and accounted for by the twelve selected predictor variables, additional process variables were selected in an attempt to increase the R-squared value of the model. If some variability was not accounted for, other variables in the process might have been contributing and therefore, needed to be included. Four additional process variables were added as predictors, and a new model with 118 cases resulted in a R-squared value of **0.499**. The details of this model can be found in **Appendix F**. This result was somewhat conflicting because the addition of more variables, in general, inflates the R-squared value. Further examination of outliers and data points ultimately led to the optimum model.

Model 5:

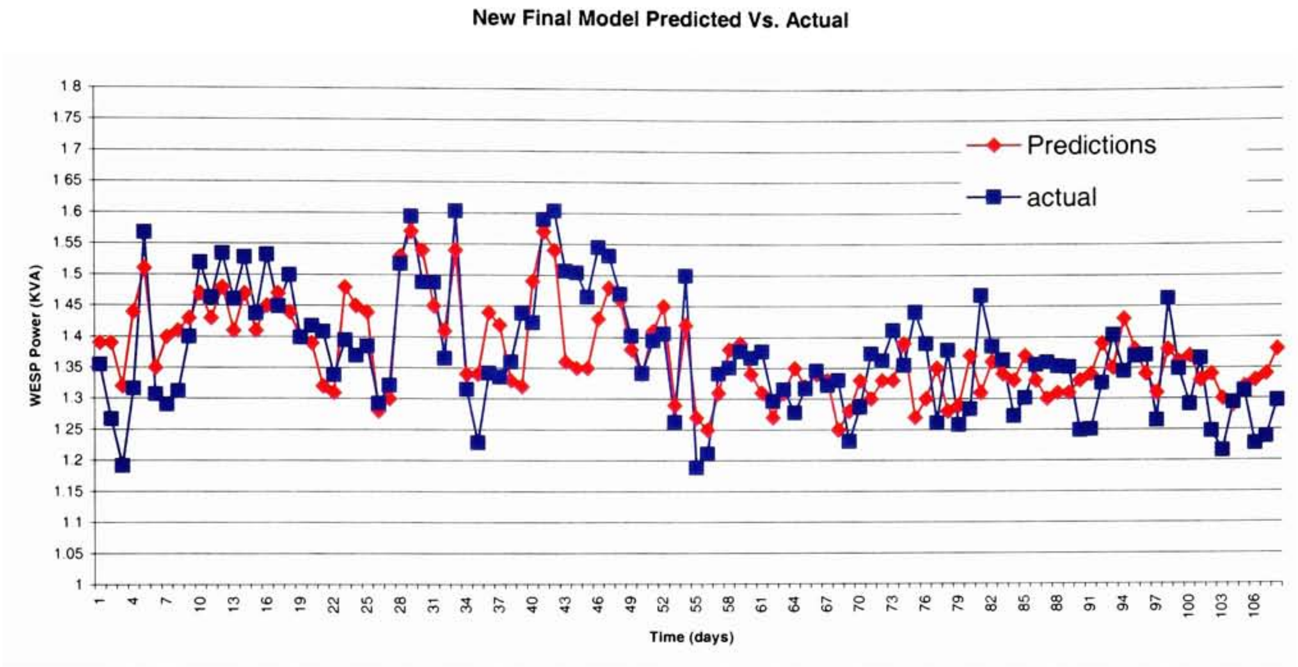
After several iterations of variable selections, de-selections, and combinations, the optimum model was created. Any outliers and periods where the process was above or below the control limits on the control chart were excluded. The 16-predictor model with 122 cases was examined and narrowed down to an 8-predictor model with 108 cases. Each variable was selectively removed until the final model produced the best R-squared value. The model

consisted of 108 cases, 4 predictor variables, 1 dimension, and a R-squared value of 0.544. The details of Model 5, along with associated graphs are located in **Appendix G**.

The predictions from the model were graphed versus the actual KVA readings for the 108 cases used to develop the model. The predicted versus actual graph is shown below as **Graph 4**. The final predictor variables were sludge feed rate, gas flow rate, hearth draft pressure, and WESP voltage. The resultant predictive equation is

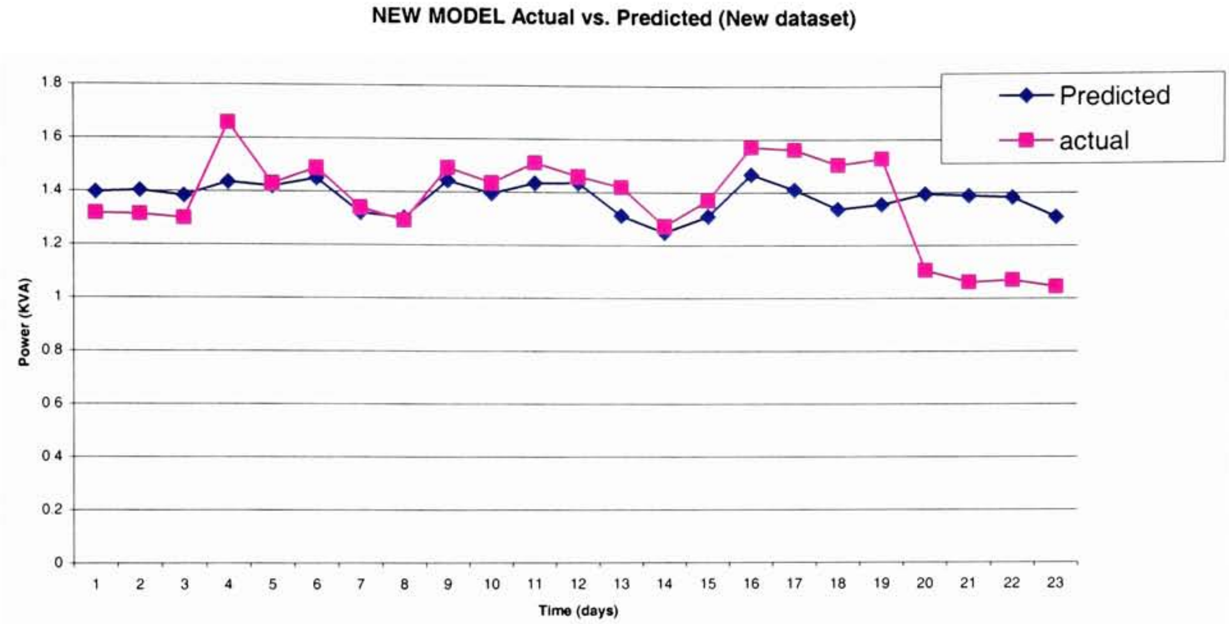
WESP KVA Predicted = 0.79 – (0.0000102 * sludge feed rate) + (0.0201 * WESP Voltage) – (0.0000368 * air flow rate) – (0.765 * Hearth Draft Pressure)

Graph 4



As shown in **Graph 4,** the predicted values correlate with the actual data for most cases. Periods of extreme highs and lows are not well predicted by the model, but the upward or downward trend in the data is predicted consistently. An additional graph of predicted versus actual data was created containing a data set of values from January 29 -Feburary 25, 2003. This graph was created to verify the accuracy of the predictions of the model with independent data. The graph is shown below as **Graph 5**.

Graph 5



The trends of the actual WESP power appear to be predicted by the model. The model does not accurately predict the extreme high and low values. This indicates that not all of the variability shown in the WESP power can be attributed to the sludge feed rate and gas flow rate, but that a portion of this variability is due to these two variables. The correlation matrix generated with these four variables was also consistent with the initial model and conveyed the same relationships. The table is shown below as **Table 5**.

Table 5. Correlation Matrix Model 5

	SLUDGE	WVOL	WKVA	GASFL...	DFTPR...
SLUDGE	1	-0.153	-0.474	0.291	0.406
WVOL	-0.153	1	0.49	-0.516	-0.392
WKVA	-0.474	0.49	1	-0.606	-0.61
GASFLOW	0.291	-0.516	-0.606	1	0.51
DFTPRES	0.406	-0.392	-0.61	0.51	1

As detected in earlier correlation matrices, the strong correlations with WESP power include: WESP voltage (0.49), gas flow (-0.606), sludge feed rate (-0.474), and hearth draft pressure (dftpres)(-0.61).

Model 6:

Once the optimum 4-variable model was created, a new model was developed to look at the interactions between the four variables. The resultant model can be found in **Appendix H**. The interaction model created and considered second-order terms (the square of each variable) and also considered all cross products of the four variables as new variables. Through a process of variable selection and de-selection with the interaction terms, a second optimum model was produced. The final model contained five variables, one dimension, and produced an R-squared value of 0.571. A listing of the final variables and their correlations is shown in **Table 6**.

Table 6. Correlation Matrix Model 6

Correlation Matrix

File

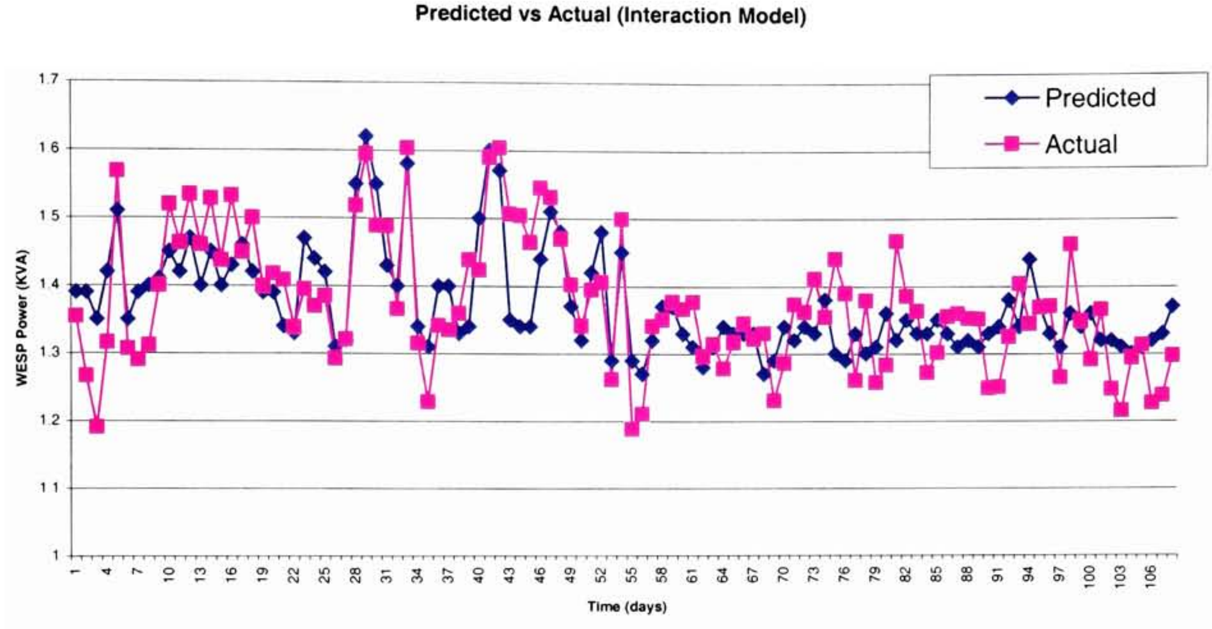
	SLUD...	WVOL	WKVA	GASF...	DFTP...	SLUD...
SLUDGE	1	-0.153	-0.474	0.291	0.406	-0.0736
WVOL	-0.153	1	0.49	-0.516	-0.392	0.219
WKVA	-0.474	0.49	1	-0.606	-0.61	0.454
GASFLOW	0.291	-0.516	-0.606	1	0.51	-0.191
DFTPRES	0.406	-0.392	-0.61	0.51	1	-0.635
SLUDGE*DFTP...	-0.0736	0.219	0.454	-0.191	-0.635	1

The only interaction that resulted in a significant contribution was the interaction between the sludge feed rate and the hearth draft pressure. The predictive equation that was generated as a result of this model is

WESP power = 0.843 – (0.00000916 * sludge feed rate) + (0.018 * WESP Vol) – (0.000033 * gas flow) – (0.686 * hearth draft pressure) – (0.000231 * (sludge*draft pressure))

A graph using this equation of the predicted versus actual is shown as **Graph 6**.

Graph 6



Graph 6 is very similar to the Model 5 graph. The graph shows how the predictive model is inadequate for predicting the more extreme values but does accurately represent the majority of the data.

EVOP trials:

In order to validate the models' results, an experiment was designed using the variables of sludge feed rate and gas flow rate. The gas flow and sludge feed rate controls are readily available by the control room operator and are, therefore, easy to adjust. WESP voltage and hearth draft pressure were excluded because the operator does not directly control the WESP voltage level. There is a controller that limits the voltage and current input into the WESP that historically has not been adjusted since the original installation of the equipment. The hearth draft pressure operates at an optimum set point, so any deviations from that set point could result in process upsets such as high CO levels in the combustion chamber.

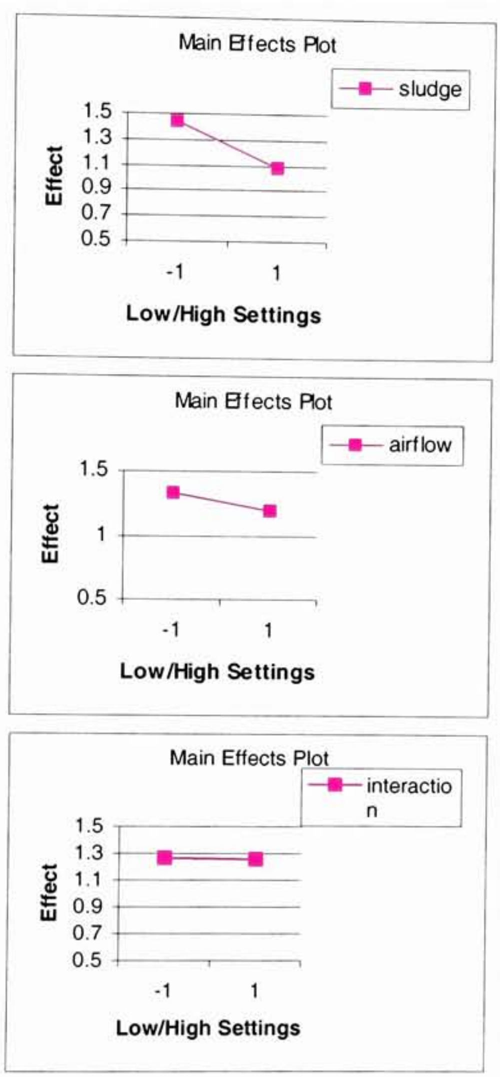
The raw test data are located in **Appendix I**. The average test run duration for each condition was approximately 40 minutes. The results are shown in **Table 7**.

Table 7. EVOP Results

	Sludge Feed	Airflow	Sludge*airflow	average Kva
test1	+	+	+	1.014764039
test2	+		-	1.153993094
test3			+	1.492279143
test4		+		1.374994891

Table 7 shows mean WESP outputs of the four trials. A graph of the main effects of both variables and the interaction effect is shown in **Graph 7,** and the graphs are also located in **Appendix I.**

Graph 7. Main Effects Plots



As shown above, the graph with the largest slope (-0.349) is the sludge graph. The next largest slope is the airflow graph (-0.128), and the smallest slope is due to the interaction of the two variables (-0.011).

Discussion

Model 1:

The positive correlation between WESP power and WESP voltage is intuitive based on Ohm's law where:

Power = Volts * Amps

The negative correlation between sludge feed rate and airflow provided interesting insights into the process. The larger the sludge load into the incinerator, the more load there is to the entire system. There is more off-gas to treat, thus more load is placed on the WESP. One could argue that more loading to the WESP would show a decrease in power.

The airflow correlation has a less direct explanation and could be based on several assumptions. As more air is pulled through the system at a fast rate, the water from the upstream air pollution control equipment may also be carried over into the next downstream process. For example, the water flow from the venturi could be carried in the gas stream through the entrainment separator and into the inlet of the WESP, thus suppressing the voltage due to excess moisture in the air stream. This theory is more difficult to demonstrate with process knowledge because no correlations exist between any of the water flow rates in any of the upstream equipment. Another explanation would correlate higher airflows with higher loading conditions; therefore, the WESP power would decrease as more load is placed on the unit. This relationship was evaluated in the EVOP trials when airflow and sludge feed rate were maximized and minimized and the results of those trials are discussed in the EVOP section.

The correlation between carbon monoxide (CO) and WESP power is not intuitive. One possible explanation is that higher levels of CO indicate varying combustion conditions within the process. Therefore, the loading to the WESP and the overall power may be negatively affected when more CO is generated or during upset conditions.

The correlation showing that the higher the sludge feed rate, the lower the air stream oxygen level is an intuitive, expected result. Because the three required elements for combustion include heat, oxygen, and fuel, there is no question that a surplus or increase in the fuel feed rate will consume the available oxygen. The negative correlation with WESP voltage and venturi differential pressure cannot be explained with certainty. Possibly, as airflow increases, the dp across the venturi would increase. This could be compounded by the negative correlation between airflow and WESP power. The problem with that line of reasoning is that no strong correlation exists between airflow and venturi dp, or venturi dp and WESP power, the correlation is only with WESP voltage. More investigation into this relationship is required.

Control Chart:

The results of the control chart show that there are periods when the process is not in statistical process control. These time periods were examined for each variable and no assignable cause could be directly related to the effect observed in the WESP power. These values were however, discarded from the final model.

Model 2:

The steady-state time period identified from the control chart was modeled to see if any new insights could be gained assuming less noise in the data. The steady-state model did not identify any new insights into the data.

Model 3:

The non-steady state time period identified from the control chart was modeled to look for new insights as well. This model did not identify any new insights into the data.

Model 4:

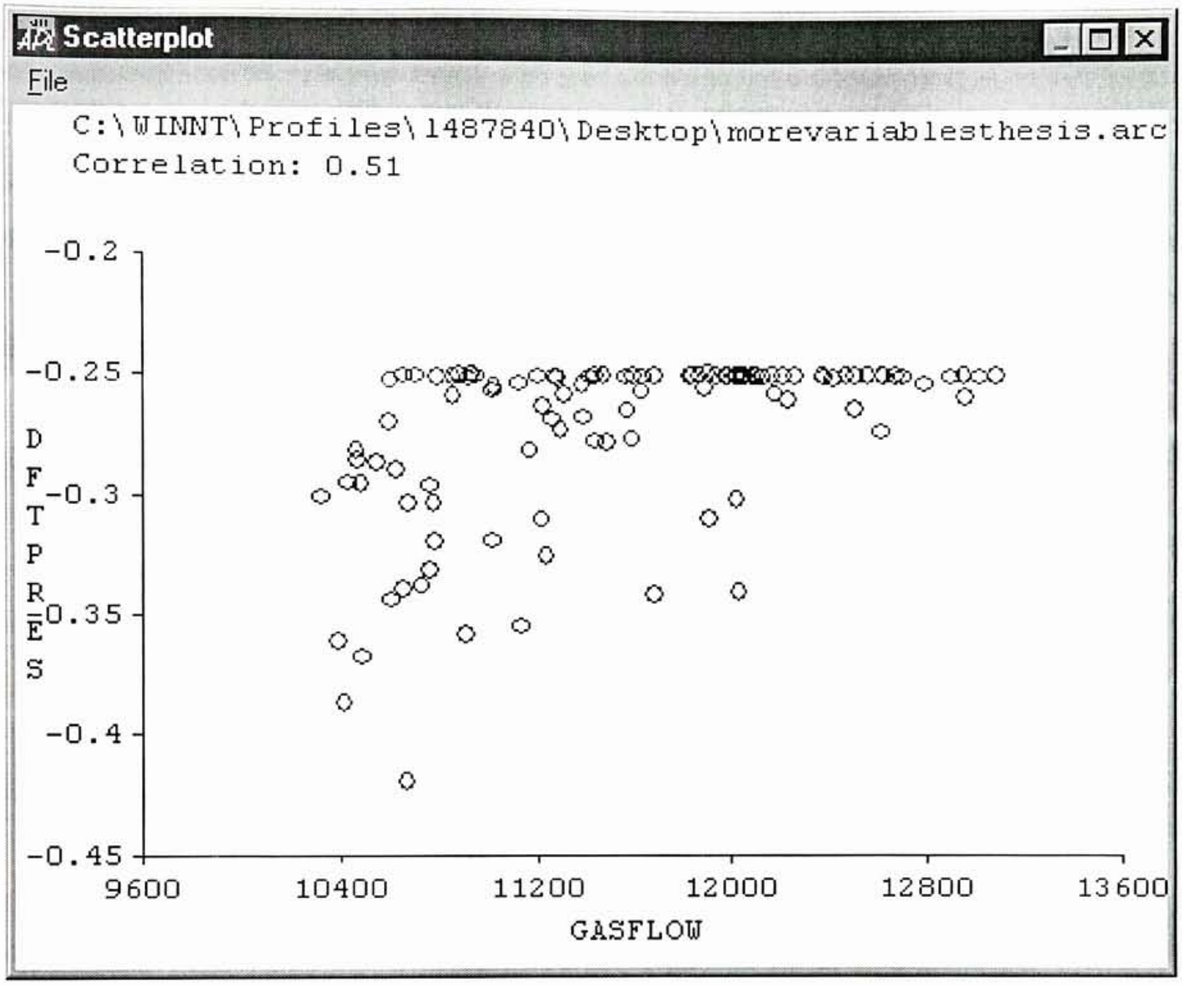
Model 4 was created to add more variables to the modeling analysis. This was in an attempt to find more assignable causes of variability that may have been overlooked with the original 12 variables used in Model 1. This model, although not the optimum model, provided the key insight that led to the optimum model. Typically, the addition of more

variables will inflate the R-squared value. In this case, the R-squared value actually decreased, indicating that the most significant variables were already identified. This led to the de-selection of non-significant variables, which produced Model 5.

Model 5:

Model 5 was the result of variable de-selection from Model 4 and resulted in the optimum model. The new variable of hearth draft pressure was added as a significant variable. The negative correlation with hearth draft pressure is not directly intuitive, but may be explained by fact that as the hearth draft becomes more positive, it is an indication that the process is becoming unstable. Therefore, as the draft pressure goes up, the resultant WESP power decreases because of the varying conditions within the hearth. The relationship between the draft pressure and gas flow rate shows a positive correlation of 0.51. This is graphically displayed in **Graph 8**. The set-point for the hearth draft is –0.25 in. water column.

Graph 8. Gas Flow Versus Draft Pressure



Graph 6 shows that the hearth draft pressure is typically run at or near the set point value. The correlation that the model has produced is based on the few data points that are more negative than the set point. These points seem to occur at lower airflow values. From a process standpoint, there is no direct theory to explain this correlation and, upon examination of the graph, the correlation is not considered to be extremely important.

Model 6:

Model 6 resulted in a similar output like Model 5, but considered one variable interaction. After all of the cross products and squares of each variable were modeled and determined to be insignificant, the only remaining interaction was that between sludge feed rate and hearth draft pressure. Intuitively, these two variables are correlated to the extent that the

feed rate of the sludge has a large impact on the hearth combustion conditions. The draft pressure is continuously affected by the rate at which materials are fed into the combustion chamber. The resultant model was shown to have a better fit than Model 5, but the interaction variable makes this model much more difficult to use in real practice. The amount of fit gained from this model is not statistically significant enough to warrant discounting Model 5 as the optimum model.

EVOP:

As expected based on the PLS model, the worst-case condition (or lowest KVA) was Test Condition 1 where gas flow and sludge feed rates were maximized. This result is not surprising, given that the highest loading to the unit would be under these conditions. Test Condition 2 indicates that sludge feed has a more negative impact on WESP power than airflow. This is not exactly in line with the PLS model that showed that airflow had a higher correlation factor than sludge. That being said, the model did indicate the same trends as seen here by the trials. This is also a small data set containing only 40 minutes of test data. A longer, more robust testing schedule would need to be implemented before distinguishing with certainty that airflow or sludge feed rate is more dominant over the other with regard to the impact on WESP power. Test Condition 3 yielded the highest WESP power, which was in line with the model trends and also with process knowledge that the lightest load to the WESP would correlate with the highest KVA readings.

The largest slope indicates the largest impact or effect on the response variable. This EVOP trial confirmed that the interaction between sludge and airflow rate is not significant. This conclusion was also a result that was obtained during the optimization of Model 6, the interaction model.

Conclusions

The primary goal of this thesis was to gain a better understanding of the sources and causes for the variability in the WESP power through historic process data. A hypothesis was formed around the idea that this variability is due to an assignable cause within the process. The goal was to identify certain input variables as factors that affect the WESP power reading and WESP performance. Sixteen process variables' data for a period of 6 months were analyzed. The modeling analysis eliminated 12 variables, leaving 4 as prime process effectors. Although the final model did not accurately predict all of the actual data, the model did accurately represent the general behavior of the data.

The EVOP trials and the final model both confirmed that the sludge feed rate and gas flow rates, when maximized, produce a negative effect on the WESP power. In order to draw further conclusions, a more robust model would need to be developed that could accurately predict the extreme values in the data, since they do exist and are a part of the normal operating process. More extensive experimental design is needed to verify the current work for repeatability and reproducibility.

The predictive equations developed by this analysis will be useful for concentrating process analysis efforts in new areas. The focus for optimizing WESP power and performance should consider sludge feed rate and airflow rates but could discount variables such as #3 hearth temperature and condenser flow rate.

Another consideration for further research would be to analyze the interior components of the WESP. This study assumed that WESP power is an indicator of performance. That assumption could be tested and verified to be true. There are many parameters within the WESP itself that could be modified to see if power is a true indicator of performance.

This study showed how the integration of statistical tools and historical data has the potential to reach leaps and bounds for process optimization. Often times the answers to many questions are buried beneath data that have been collected for years but never

analyzed. This study showed how much can be gained from sorting through that data with a specific process, methodology, and goal. This knowledge is invaluable when optimizing a very complex process. The use of statistical tools to predict and model process behavior is a powerful key that can unlock many unknowns.

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Appendix A

Raw Process Data

DATE	DATE	SLUDGE	QNCHH2O	CONH2O	VNTTHR	TOTVFLOWS	VNTDP	WVOL	WKVA	GTEMP	CO	O2	GASFLOW	MH3TEMP	WESPWSH	BUNSPD	SFTRPM	DFTPRES
02-Jul	72	11936.328	189.723	1100.035	104.999	209.999	43.621	46.170	1.354	174.965	1.666	9.226	10949.644	1543.276	0.252	32.267	1.365	-0.250
03-Jul	73	12379.940	197.723	1100.017	105.000	210.002	46.824	46.129	1.267	174.986	0.850	6.115	10856.525	1582.667	0.233	37.318	1.637	-0.259
04-Jul	74	13988.604	198.407	1100.013	104.999	209.997	46.329	45.956	1.191	174.963	0.624	5.722	11987.009	1578.351	0.229	34.119	1.464	-0.250
05-Jul	75	9759.873	198.639	1099.989	104.999	210.001	47.110	46.839	1.219	175.029	0.999	8.273	11678.713	1576.143	0.224	28.758	1.435	-0.250
06-Jul	76	8902.619	197.980	1100.005	105.000	209.999	47.514	47.084	1.316	175.033	0.908	7.905	10791.507	1574.886	0.214	25.200	1.434	-0.250
07-Jul	77	7299.985	197.969	1100.008	105.000	209.999	40.062	47.022	1.331	175.035	1.192	9.128	11479.823	1574.994	0.186	25.191	1.434	-0.250
13-Jul	713	8292.241	194.917	1100.020	105.001	209.999	45.275	47.360	1.650	167.443	0.006	8.260	10863.194	1566.012	0.217	23.877	1.517	-0.251
14-Jul	714	7684.123	194.697	1100.000	105.001	210.000	47.110	47.656	1.779	175.031	0.003	8.840	10638.499	1575.003	0.211	22.538	1.596	-0.287
15-Jul	715	6402.813	193.700	1100.005	104.999	209.999	46.995	47.624	1.813	174.992	0.004	9.633	10294.489	1574.983	0.224	22.188	1.595	-0.330
16-Jul	716	5862.895	193.903	1100.005	105.001	210.000	47.057	47.688	1.801	175.031	0.012	9.891	10305.989	1570.853	0.233	22.131	1.596	-0.378
18-Jul	718	6345.926	190.858	1099.999	105.001	210.000	47.305	46.656	1.568	174.990	0.014	9.774	10321.527	1566.425	0.225	24.383	1.684	-0.301
19-Jul	719	11085.180	186.655	1100.032	105.000	209.999	47.659	45.169	1.307	174.938	0.010	7.310	11681.619	1574.679	0.224	37.070	1.669	-0.250
20-Jul	720	8669.796	183.691	1100.023	104.999	209.999	47.922	45.818	1.290	175.048	0.006	8.242	11206.162	1555.980	0.233	29.250	1.480	-0.250
21-Jul	721	8881.677	180.515	1099.977	105.000	210.000	48.137	46.048	1.312	175.001	0.003	8.254	10935.489	1559.989	0.227	31.524	1.490	-0.250
22-Jul	722	10382.619	182.722	1099.975	105.000	209.998	48.143	45.335	1.400	175.009	0.005	6.796	10550.097	1572.278	0.220	36.430	1.499	-0.286
24-Jul	724	8818.710	191.010	1099.970	105.001	210.000	46.301	46.560	1.519	175.040	0.005	8.180	10630.096	1570.752	0.223	34.584	1.593	-0.289
25-Jul	725	8542.523	191.141	1100.004	105.001	209.999	45.570	46.719	1.463	175.010	0.039	8.746	10855.372	1574.565	0.210	32.782	1.600	-0.251
26-Jul	726	8259.123	191.382	1100.006	105.000	209.999	46.862	46.552	1.534	174.971	0.007	8.890	10431.493	1557.392	0.220	23.387	1.573	-0.295
27-Jul	727	9227.549	191.778	1099.986	105.001	210.000	48.396	45.658	1.460	174.995	0.006	7.726	10703.246	1574.897	0.230	25.373	1.612	-0.250
28-Jul	728	7527.567	192.057	1099.985	105.001	210.000	48.095	45.981	1.528	174.960	0.003	8.742	10464.179	1575.027	0.222	21.375	1.613	-0.281
29-Jul	729	9948.880	191.755	1100.007	105.000	209.999	47.931	45.796	1.437	175.000	0.006	7.433	10657.866	1574.573	0.231	23.605	1.616	-0.250
31-Jul	731	9977.579	191.793	1100.001	105.000	210.002	47.409	46.070	1.532	175.031	0.020	7.277	10467.135	1572.662	0.262	30.573	1.454	-0.286
01-Aug	81	9611.426	191.554	1100.018	105.001	209.999	47.599	46.425	1.449	175.001	0.062	7.974	10786.613	1576.109	0.216	34.918	1.461	-0.319
02-Aug	82	11065.903	192.150	1100.001	105.000	210.001	47.586	45.976	1.499	175.022	0.075	6.839	10674.581	1576.273	0.210	34.900	1.617	-0.303
03-Aug	83	10646.677	191.548	1100.006	104.999	210.002	48.169	46.081	1.399	174.964	0.019	8.073	11486.591	1582.214	0.212	35.170	1.645	-0.278
04-Aug	84	11545.259	189.695	1100.014	105.001	209.998	48.169	45.946	1.418	174.998	0.044	6.933	10881.563	1588.297	0.211	41.226	1.634	-0.250
05-Aug	85	13725.707	188.809	1099.968	104.999	210.001	47.130	45.880	1.408	174.928	0.055	6.422	12101.790	1585.550	0.198	45.257	1.700	-0.250
06-Aug	86	12449.483	190.312	1100.024	105.000	210.002	47.615	45.595	1.338	174.978	0.015	7.144	12469.428	1588.279	0.203	41.911	1.690	-0.250
07-Aug	87	9069.604	196.325	1100.012	105.000	210.000	48.265	46.062	1.395	175.073	0.061	8.267	10765.435	1579.938	0.195	30.983	1.612	-0.331
08-Aug	88	9798.951	200.389	1100.009	105.001	210.002	48.474	45.919	1.370	175.031	0.114	7.467	10485.676	1585.019	0.198	31.269	1.622	-0.295
09-Aug	89	10723.056	201.073	1099.992	105.002	209.999	48.482	46.028	1.385	174.992	0.221	7.274	10766.621	1585.548	0.208	35.724	1.622	-0.296

13-Aug	813	14190.958	192.176	1100.067	104.999	210.001	45.117	45.889	1.292	175.151	0.536	6.144	13016.297	1579.304	0.200	41.450	1.773	-0.250
14-Aug	814	12342.514	187.772	1099.993	104.999	210.000	47.362	46.042	1.321	175.014	0.029	7.499	12948.309	1579.894	0.217	36.762	1.782	-0.250
15-Aug	815	6896.365	185.687	1099.982	104.998	210.000	48.548	46.491	1.518	175.028	0.538	10.446	10608.559	1579.997	0.209	22.848	1.774	-0.344
19-Aug	819	6684.916	179.976	1099.983	104.999	210.000	48.323	46.472	1.594	174.992	0.018	9.565	10416.739	1587.511	0.200	20.576	1.733	-0.387
20-Aug	820	7564.971	182.603	1099.981	105.001	210.002	48.026	46.210	1.488	175.019	0.095	9.225	10389.467	1582.042	0.203	23.380	1.721	-0.361
21-Aug	821	8926.215	179.096	1100.016	105.001	210.000	48.202	46.506	1.488	174.990	0.400	8.660	10600.812	1571.552	0.202	22.787	1.692	-0.270
22-Aug	822	9701.478	177.371	1099.997	105.003	210.004	48.073	45.650	1.365	175.071	0.148	7.826	10603.837	1557.241	0.229	22.964	1.622	-0.252
23-Aug	823	6225.129	180.896	1099.986	104.999	209.998	44.832	45.473	1.603	174.959	0.097	9.551	10489.273	1512.367	0.181	25.643	1.615	-0.367
24-Aug	824	12869.971	192.124	1100.001	105.000	209.999	49.100	44.223	1.315	174.997	0.145	5.790	11260.817	1589.684	0.212	41.499	1.802	-0.268
25-Aug	825	12940.312	195.690	1100.003	105.000	210.000	48.948	44.389	1.229	175.024	0.266	6.384	12020.163	1600.014	0.222	40.943	1.807	-0.301
26-Aug	826	11373.671	192.405	1100.004	105.000	209.999	49.624	44.974	1.342	175.031	0.500	6.857	10728.196	1583.503	0.224	37.273	1.806	-0.338
27-Aug	827	10759.519	190.717	1100.026	104.999	210.001	49.754	45.030	1.335	174.838	0.311	6.958	10779.801	1574.547	0.218	34.270	1.708	-0.304
30-Aug	830	8721.638	188.798	1099.993	105.000	210.000	46.832	41.645	1.360	164.919	6.443	7.603	11438.821	1513.277	0.168	29.878	1.500	-0.277
31-Aug	831	13018.173	188.016	1100.009	105.000	210.000	49.487	44.040	1.439	174.987	0.594	5.337	11273.492	1600.075	0.217	43.854	1.695	-0.250
01-Sep	91	8188.108	187.234	1099.991	105.001	210.001	48.954	45.286	1.423	175.066	0.335	8.558	10909.494	1589.466	0.199	29.458	1.682	-0.358
02-Sep	**92**	6604.344	186.787	1100.015	105.001	209.999	48.534	45.292	1.467	174.987	0.448	9.043	10572.923	1589.981	0.235	23.029	1.536	-0.418
05-Sep	95	7829.848	184.154	1099.991	104.999	210.000	49.691	46.144	1.590	175.004	0.513	7.951	10672.190	1575.397	0.195	31.965	1.781	-0.420
06-Sep	96	5440.961	185.313	1100.015	105.000	210.002	49.667	46.502	1.604	175.024	0.505	9.534	10657.455	1572.807	0.196	22.982	1.777	-0.339
12-Sep	**912**	9107.122	191.698	1099.978	105.000	210.001	47.811	43.209	1.606	173.173	0.567	8.029	12089.230	1561.724	0.181	28.066	1.743	-0.252
13-Sep	**913**	9861.372	189.262	1100.002	104.999	210.001	48.826	44.708	1.570	175.009	0.547	8.313	12391.379	1583.539	0.215	34.158	1.750	-0.250
14-Sep	**914**	8668.368	187.348	1099.986	105.001	210.000	48.651	45.122	1.521	174.994	0.579	9.163	12506.288	1581.352	0.193	32.133	1.700	-0.250
15-Sep	915	7314.798	185.550	1099.999	104.999	209.998	48.810	45.089	1.506	174.989	0.648	9.703	12213.381	1580.111	0.198	27.957	1.530	-0.250
16-Sep	916	8899.733	184.060	1099.999	105.001	209.999	49.158	44.811	1.504	174.960	0.704	9.060	12230.713	1588.221	0.191	31.181	1.778	-0.259
17-Sep	**917**	8013.069	183.140	1100.002	105.000	210.000	47.779	45.047	1.609	175.028	0.820	9.822	12037.482	1580.117	0.211	20.037	1.268	-0.356
18-Sep	918	7719.357	182.389	1099.986	105.000	210.001	48.651	44.564	1.464	175.025	0.546	9.740	12505.872	1581.603	0.204	28.206	1.577	-0.264
19-Sep	919	7436.016	181.986	1099.980	104.998	209.998	48.874	44.578	1.545	175.029	0.611	9.457	11218.153	1577.222	0.203	29.296	1.519	-0.310
20-Sep	920	6772.279	181.178	1099.989	105.001	210.000	48.520	44.623	1.531	174.979	0.573	9.714	11136.765	1574.979	0.204	26.722	1.517	-0.354
21-Sep	921	6034.184	184.217	1100.008	104.999	210.000	48.736	44.514	1.469	174.994	0.826	10.036	11238.641	1574.702	0.218	24.839	1.506	-0.325
22-Sep	922	7571.735	183.227	1100.018	104.999	209.999	49.033	44.377	1.402	175.000	0.517	9.291	11569.972	1575.973	0.216	31.586	1.556	-0.264
23-Sep	923	6618.230	181.728	1099.972	105.000	209.999	49.175	44.421	1.341	174.945	0.561	10.296	12618.641	1575.015	0.206	27.181	1.549	-0.250
24-Sep	924	7327.671	181.410	1100.018	105.000	209.999	48.811	44.579	1.395	175.033	0.782	9.668	11910.250	1575.014	0.201	29.213	1.548	-0.309
25-Sep	925	6895.830	180.911	1100.026	105.001	210.000	48.745	44.892	1.406	174.993	0.909	10.008	11681.841	1577.501	0.208	26.714	1.882	-0.341
26-	926	10318.	179.27	1099.9	105.00	210.0	48.3	43.679	1.262	175.03	0.553	8.280	12790.43	1577.791	0.206	41.20	2.014	-0.253

Sep		507	6	91	0	00	77			7			1			2		
27-Sep	927	6792.258	176.024	1099.987	105.001	210.000	47.294	44.007	1.499	174.922	1.112	10.614	12030.180	1567.829	0.235	38.007	1.913	-0.340
08-Oct	108	13585.157	190.214	1057.832	105.012	209.994	48.070	44.544	1.188	174.976	0.675	7.047	12956.880	1575.379	0.212	31.433	1.460	-0.258
09-Oct	109	13375.671	189.328	1055.961	105.016	210.007	48.626	43.550	1.211	175.028	0.976	6.859	12895.443	1576.265	0.217	38.581	1.590	-0.250
10-Oct	1010	11914.056	188.069	1054.340	105.017	209.984	49.142	43.564	1.341	175.048	1.001	7.081	11563.962	1594.707	0.207	36.240	1.823	-0.250
11-Oct	1011	8663.859	187.945	1056.802	105.003	209.981	49.256	44.090	1.350	175.010	1.071	8.734	11015.062	1594.179	0.197	28.960	1.840	-0.256
12-Oct	1012	8296.937	187.329	1056.116	105.000	210.026	49.057	44.292	1.377	175.034	1.026	8.669	10922.738	1591.526	0.202	26.112	1.836	-0.251
14-Oct	1014	7876.570	185.453	1049.791	104.999	209.992	51.139	43.817	1.366	174.980	1.096	9.278	11977.445	1577.771	0.181	23.908	1.803	-0.250
16-Oct	1016	9646.964	184.474	1046.685	105.003	210.003	48.559	43.558	1.377	174.913	1.138	8.079	12089.360	1568.474	0.199	31.767	1.425	-0.250
17-Oct	1017	11921.526	182.873	1044.637	104.999	209.992	48.578	43.166	1.296	175.043	0.904	6.685	12557.806	1574.982	0.182	34.379	1.561	-0.250
18-Oct	1018	9895.738	181.943	1042.683	105.003	210.004	49.515	44.037	1.315	174.979	1.111	8.093	12417.288	1580.419	0.188	31.933	1.621	-0.251
19-Oct	1019	6684.327	181.818	1040.715	105.000	209.973	49.568	43.832	1.278	175.201	1.179	9.767	12176.669	1585.077	0.196	22.628	1.644	-0.257
21-Oct	1021	10477.417	183.331	1059.197	105.002	209.998	49.693	44.401	1.316	175.163	0.919	7.600	12090.449	1585.011	0.203	35.749	1.719	-0.250
22-Oct	1022	9186.076	182.961	1058.480	105.003	209.991	48.580	44.769	1.345	174.953	1.025	8.621	12166.778	1585.500	0.190	29.733	1.721	-0.250
23-Oct	1023	9231.715	181.317	1058.088	105.000	210.005	48.955	44.894	1.322	175.022	1.098	8.689	12371.743	1585.625	0.188	32.079	1.725	-0.250
26-Oct	1026	10067.503	180.410	1050.778	105.003	210.005	46.668	43.350	1.330	174.898	1.182	7.959	11671.802	1547.881	0.188	32.079	1.725	-0.250
28-Oct	**1028**	10418.106	192.204	1066.602	104.930	209.847	50.617	44.784	1.525	174.767	1.537	10.492	12493.531	1586.762	0.232	33.337	1.688	-0.241
29-Oct	1029	12332.150	231.024	1100.016	105.035	209.996	50.437	43.480	1.231	174.993	1.079	7.731	13078.362	1587.307	0.194	37.916	1.699	-0.250
30-Oct	1030	13244.091	230.225	1100.014	105.039	210.002	50.283	43.836	1.286	174.978	1.603	10.087	12611.063	1566.727	0.186	38.252	1.752	-0.273
06-Nov	1106	11981.667	207.889	1090.238	105.001	209.993	49.315	43.896	1.373	174.987	1.158	7.482	11385.524	1585.286	0.209	37.847	1.748	-0.254
07-Nov	**1107**	14000.628	206.954	1090.518	105.000	209.995	49.772	43.828	1.331	174.989	1.353	6.444	12294.961	1602.089	0.203	43.153	1.820	-0.250
08-Nov	1108	12945.874	214.279	1095.094	105.001	209.999	48.998	43.477	1.362	175.030	1.371	6.900	11636.801	1599.973	0.186	43.145	1.823	-0.250
09-Nov	1109	11891.752	223.397	1099.999	105.000	210.015	49.048	43.512	1.411	175.027	1.367	7.332	11123.269	1596.503	0.199	39.602	1.825	-0.253
10-Nov	1110	10617.005	222.471	1099.995	105.000	210.002	48.147	43.496	1.354	174.965	1.159	7.809	11439.893	1589.869	0.195	31.837	1.831	-0.250
11-Nov	1111	6634.440	222.177	1099.947	105.001	209.993	48.446	43.954	1.441	175.008	1.606	9.909	11226.332	1558.241	0.213	20.288	1.401	-0.262
12-Nov	1112	13298.222	222.004	1099.906	105.001	210.000	49.534	43.311	1.389	174.957	1.137	6.405	12047.541	1593.849	0.217	34.034	1.710	-0.250
13-Nov	1113	9048.959	221.770	1100.015	104.999	210.005	49.787	43.439	1.261	174.953	1.410	9.134	12669.940	1574.082	0.208	23.873	1.576	-0.250
16-Nov	1116	8061.892	192.158	1100.020	105.001	209.991	48.168	44.646	1.379	149.271	2.178	10.086	12262.004	1564.183	0.222	28.237	1.797	-0.250
17-Nov	1117	11818.310	191.447	1100.002	104.999	209.988	49.418	43.634	1.257	167.406	1.643	7.717	12379.638	1581.382	0.188	35.770	1.860	-0.250
18-Nov	1118	12043.382	191.015	1100.016	104.999	209.999	50.118	43.763	1.283	172.264	1.588	7.425	12129.304	1587.926	0.178	36.595	1.860	-0.250
19-Nov	1119	9675.330	190.738	1100.011	105.000	209.995	50.320	44.663	1.467	180.005	1.808	8.418	11309.929	1591.292	0.179	33.759	1.767	-0.257
20-Nov	**1120**	10793.477	190.200	1099.988	105.003	209.991	44.259	42.721	1.380	172.333	88.198	9.901	11118.215	1546.471	0.184	27.490	1.490	-0.439
21-Nov	1121	11102.745	189.140	1099.990	105.002	210.009	49.293	43.546	1.385	175.017	1.516	7.901	11826.691	1580.027	0.193	37.585	1.619	-0.250

22-Nov	1122	8261.356	187.537	1099.975	104.999	209.999	49.424	43.570	1.363	175.003	1.694	9.256	11274.969	1580.355	0.191	26.946	1.625	-0.250
23-Nov	1123	8600.159	181.951	1099.993	105.001	209.991	50.212	43.668	1.272	175.060	1.580	9.182	11835.123	1579.996	0.225	22.319	1.615	-0.250
24-Nov	1124	9398.959	179.233	1100.007	104.999	209.992	49.908	43.747	1.301	174.958	1.390	8.624	11862.526	1579.996	0.213	24.403	1.610	-0.250
25-Nov	1125	7615.921	177.207	1100.022	105.000	209.998	50.256	43.992	1.355	175.035	1.757	9.620	11471.434	1580.048	0.207	22.553	1.606	-0.250
26-Nov	1126	9187.110	177.401	1100.024	104.999	210.003	50.528	44.057	1.359	174.934	1.763	9.170	12023.470	1579.840	0.205	24.174	1.598	-0.250
27-Nov	1127	11373.455	189.746	1100.043	105.000	209.981	50.250	43.775	1.353	175.025	1.814	7.407	12082.982	1579.158	0.213	28.752	1.730	-0.250
28-Nov	1128	11804.434	191.504	1100.010	105.001	210.000	50.037	43.692	1.351	174.987	1.713	7.105	11596.032	1592.513	0.198	38.429	1.843	-0.250
29-Nov	1129	10860.184	191.156	1099.992	105.000	210.006	48.551	43.308	1.249	175.021	1.616	7.742	11888.930	1590.064	0.211	39.265	1.854	-0.254
30-Nov	1130	10891.652	189.118	1100.016	104.999	209.998	48.674	42.850	1.251	174.971	1.270	7.238	11022.152	1590.010	0.200	39.414	1.854	-0.254
01-Dec	1201	10675.608	186.836	1100.037	104.999	209.993	49.804	44.105	1.325	174.933	1.805	7.761	11628.573	1581.587	0.189	42.537	1.848	-0.256
02-Dec	**1202**	11822.732	185.383	1100.002	105.001	209.984	48.268	43.911	1.123	174.983	1.879	8.807	14437.855	1575.700	0.188	42.414	1.804	-0.250
06-Dec	1206	8985.153	179.663	1099.258	105.001	209.993	51.113	44.680	1.403	175.085	1.735	9.655	11295.800	1577.202	0.181	30.464	1.793	-0.273
07-Dec	1207	8536.527	179.074	1099.272	104.999	209.993	51.033	44.755	1.344	174.883	1.728	9.177	11984.581	1571.075	0.222	32.536	1.745	-0.250
08-Dec	1208	7912.766	177.787	1099.049	105.000	210.008	50.555	44.100	1.369	175.039	1.684	8.519	11015.865	1590.584	0.212	33.533	1.747	-0.319
09-Dec	1209	9299.052	178.216	1099.593	105.002	210.005	52.753	44.726	1.371	175.084	1.754	8.563	11589.635	1590.120	0.194	35.411	1.740	-0.276
10-Dec	1210	8441.321	177.320	1099.489	105.000	210.003	51.354	44.269	1.265	174.948	1.739	8.966	12054.755	1572.983	0.196	29.090	1.689	-0.250
11-Dec	1211	10190.510	177.516	1099.450	104.999	209.999	50.782	44.837	1.462	175.068	2.472	8.630	12702.131	1574.299	0.200	35.580	1.790	-0.250
12-Dec	1212	7837.776	177.604	1098.899	104.996	209.997	51.024	44.327	1.348	174.962	2.690	9.648	11283.785	1577.309	0.210	28.546	1.797	-0.250
15-Dec	1215	7682.463	175.860	1097.865	105.000	209.993	50.145	43.644	1.291	134.852	2.213	8.836	11421.981	1576.426	0.187	27.769	1.697	-0.250
16-Dec	1216	10497.052	174.769	1097.547	105.001	209.990	51.118	44.000	1.366	174.923	2.436	8.496	11168.958	1584.953	0.187	34.417	1.695	-0.281
17-Dec	1217	7324.022	174.217	1097.152	104.999	210.007	51.094	45.053	1.247	175.030	2.929	10.101	13014.859	1586.482	0.212	28.581	1.693	-0.250
18-Dec	**1218**	10164.762	175.105	1096.639	105.004	209.995	51.611	44.405	1.129	174.896	2.362	8.581	13185.705	1561.651	0.205	42.286	1.701	-0.250
19-Dec	**1219**	11629.138	174.131	1096.126	105.000	210.020	49.798	43.991	1.090	175.057	2.217	9.141	13179.026	1555.051	0.210	41.924	1.689	-0.250
20-Dec	1220	7778.542	172.475	1093.600	105.001	209.999	48.797	43.452	1.216	174.708	1.764	9.554	11903.064	1555.338	0.266	32.842	1.407	-0.249
21-Dec	**1221**	11629.138	174.131	1096.126	105.000	210.020	49.798	43.991	1.090	175.057	2.217	9.141	13179.026	1555.051	0.210	41.924	1.689	-0.250
22-Dec	1222	10717.119	180.151	1096.558	105.000	209.995	49.836	43.274	1.294	174.981	1.752	7.476	11936.882	1580.518	0.211	38.045	1.837	-0.250
23-Dec	1223	11447.420	179.204	1095.743	105.000	210.001	49.742	43.274	1.313	174.967	1.752	7.476	12015.649	1585.090	0.200	39.751	1.840	-0.250
24-Dec	1224	8052.586	178.542	1094.376	104.999	209.999	50.462	43.600	1.227	174.817	2.094	9.652	12504.665	1582.023	0.221	29.446	1.796	-0.250
26-Dec	1226	7318.642	221.443	1100.015	105.000	209.994	50.004	44.335	1.238	174.996	2.167	10.374	12623.219	1549.301	0.195	25.912	1.796	-0.250
27-Dec	1227	8488.182	200.405	1099.015	105.000	209.983	50.214	44.332	1.297	175.009	2.216	9.463	12047.697	1566.805	0.198	29.684	1.766	-0.250
31-Dec	1231	8121.636	181.009	1098.778	105.002	209.999	49.183	44.120	1.454	174.972	1.871	8.974	11389.754	1580.486	0.154	28.794	1.582	-0.267

Appendix B

PLS Software Printout Model 1

Note:
some of the software data has been omitted to conserve space

Response variable(s)...
WKVA
Number of response variables: 1

Predictor variable(s)...
SLUDGE QNCHH2O CONH2O VNTTHR TOTVFLOWS VNTDP WVOL GTEMP CO O2 GASFLOW MH3TEMP
Number of predictor variables: 12

Cases...
72 73 74 75 76 77 713
714 715 716 718 719 720
721
722 724 725 726 727 728
729 731 81 82 83 84 85
86
87 88 89 813 814 815 819
820 821 822 824 825 826
827
831 91 92 95 96 912 913
914 915 916 917 918 919
920
921 922 923 924 925 926
927 108 109 1010 1011 1012
1014 1016
1017 1018 1019 1021 1022 1023
1026 1029 1030 1106 1107 1108
1109 1110
1111 1112 1113 1116 1117 1118
1119 1121 1122 1123 1124 1125
1126 1127
1128 1129 1130 1201 1202 1206
1207 1208 1209 1210 1211 1212
1216 1217
1218 1219 1220 1221 1222 1223
1224 1226 1227 1231

Number of cases: 122

Preprocessing options. Key:
[VarName Center Scale]

[WKVA Mean Std] [SLUDGE Mean Std] [QNCHH2O Mean Std]
[CONH2O Mean Std] [VNTTHR Mean Std] [TOTVFLOWS Mean Std]
[VNTDP Mean Std] [WVOL Mean Std] [GTEMP Mean Std]
[CO Mean Std] [O2 Mean Std] [GASFLOW Mean Std]
[MH3TEMP Mean Std]

Computation status: No errors encountered
Number of model dimensions: 2

Missing value code: -999
Number of missing values in X: 0
Number of missing values in Y: 0

X Block Model Information:
X Weights

Var	Dim1	Dim2
SLUDGE	-0.442	-0.268
QNCHH2O	0.00206	0.237
CONH2O	0.185	-0.147
VNTTHR	-0.156	0.287
TOTVFLOWS	0.0196	-0.192
VNTDP	-0.233	0.461
WVOL	0.466	-0.266
GTEMP	-0.0133	-0.0849
CO	-0.444	-0.109
O2	0.215	0.183
GASFLOW	-0.529	-0.178
MH3TEMP	0.00791	0.64

X Loadings

Var	Dim1	Dim2
SLUDGE	-0.365	-0.28
QNCHH2O	-0.0477	0.205
CONH2O	0.207	-0.124
VNTTHR	-0.209	0.246
TOTVFLOWS	0.0588	-0.291
VNTDP	-0.318	0.486
WVOL	0.5	-0.209
GTEMP	0.00506	0.0234
CO	-0.4	0.0101
O2	0.167	0.176
GASFLOW	-0.467	-0.218
MH3TEMP	-0.126	0.6

X R2 (Communalities)

Var	Dim1	Dim2
SLUDGE	0.373	0.457
QNCHH2O	0.00635	0.0516
CONH2O	0.12	0.137
VNTTHR	0.122	0.188
TOTVFLOWS	0.00966	0.101
VNTDP	0.283	0.537
WVOL	0.699	0.746
GTEMP	0.0000714	0.000662
CO	0.448	0.448
O2	0.078	0.111
GASFLOW	0.609	0.661
MH3TEMP	0.0445	0.433

Variable Importance

0 0.5

1

+----------------------+----------
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SLUDGE ***********************************

QNCHH2O *

CONH2O *******

VNTTHR *****

TOTVFLOWS*

VNTDP *********

WVOL **************************************
*

GTEMP *

CO ******************************

O2 *********

GASFLOW **************************************
****

MH3TEMP *

Y Block Model Information:

Y Weights

Var	Dim1	Dim2
WKVA	1	1

Y Loadings

Var	Dim1	Dim2
WKVA	1	1

Inner Relation Coefficients:

0.429 0.243

(Preprocessed) Regression Coefficients

Var	WKVA
SLUDGE	-0.278
QNCHH2O	0.0588
CONH2O	0.0534
VNTTHR	-0.00557
TOTVFLOWS	-0.0372
VNTDP	0.0000266
WVOL	0.16
GTEMP	-0.0271
CO	-0.24
O2	0.148
GASFLOW	-0.298
MH3TEMP	0.159

Regression Coefficients

Var	WKVA
Inter	164
SLUDGE	-0.0000172
QNCHH2O	0.000644
CONH2O	0.000455
VNTTHR	-0.138
TOTVFLOWS	-0.722
VNTDP	0.00000215
WVOL	0.0177
GTEMP	-0.00137
CO	-0.0418
O2	0.0165
GASFLOW	-0.0000472
MH3TEMP	0.00188

Score Matrix A: T=XA

Var	Dim1	Dim2
SLUDGE	-0.442	-0.365
QNCHH2O	0.00206	0.238
CONH2O	0.185	-0.107
VNTTHR	-0.156	0.253
TOTVFLOWS	0.0196	-0.187
VNTDP	-0.233	0.41
WVOL	0.466	-0.164
GTEMP	-0.0133	-0.0878
CO	-0.444	-0.206
O2	0.215	0.23
GASFLOW	-0.529	-0.294
MH3TEMP	0.00791	0.641

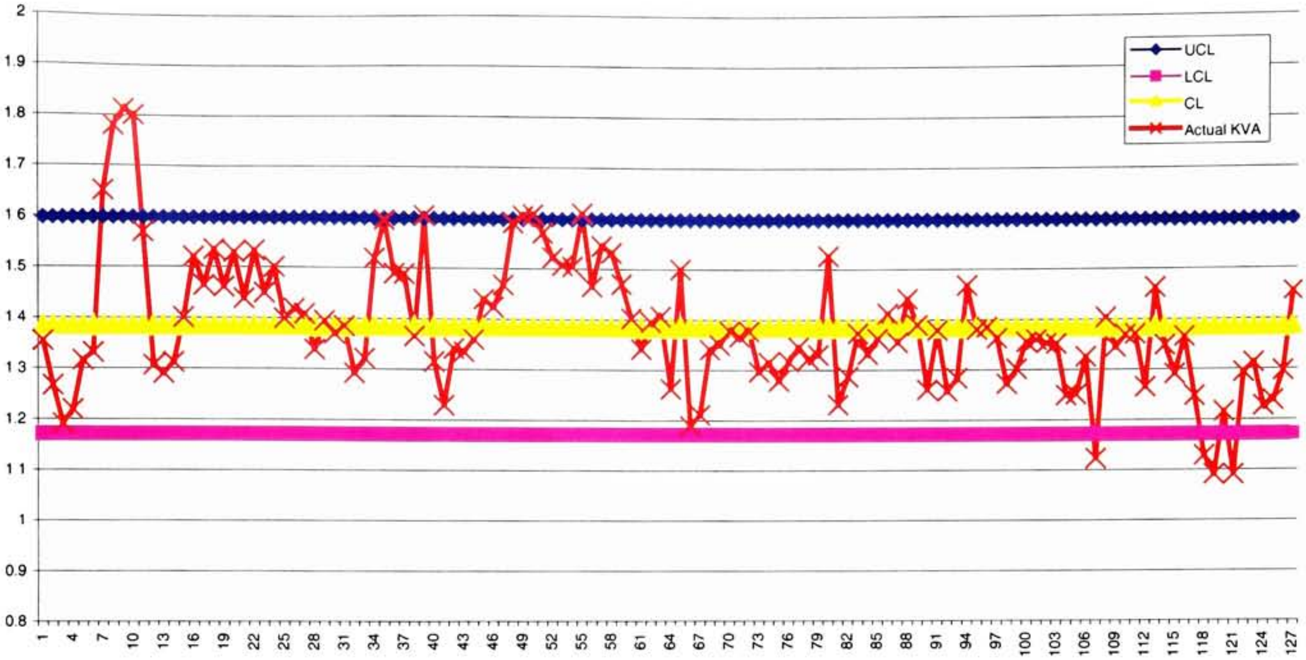
Predictions

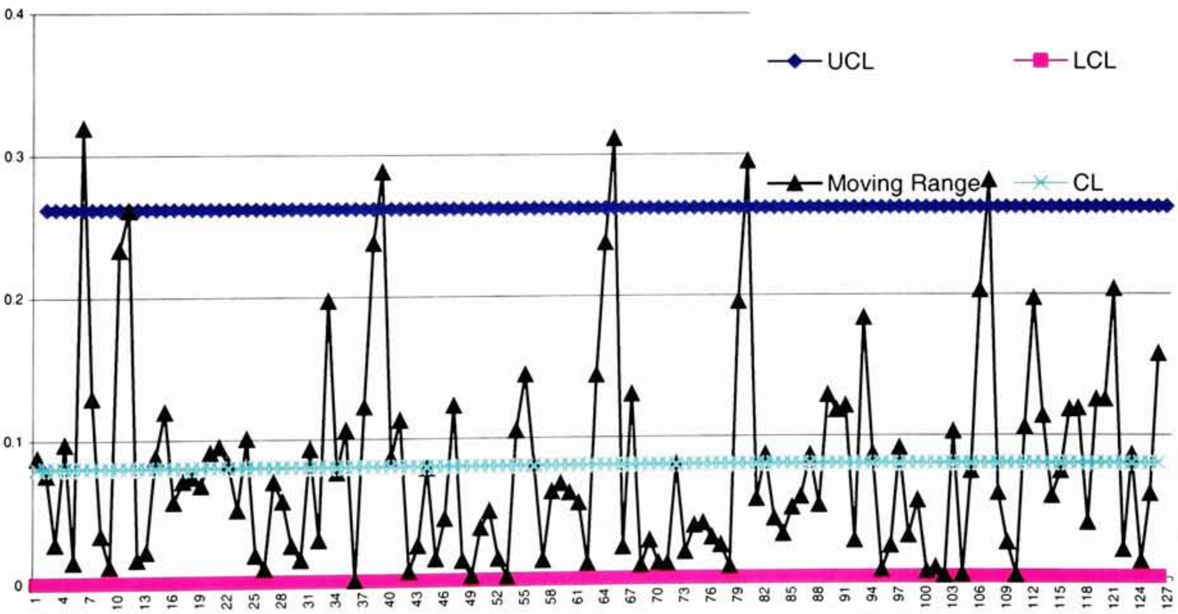
Case	WKVA
72	1.32
73	1.38
74	1.29
75	1.41
76	1.47
77	1.47
713	1.52
714	1.56
715	1.61
716	1.62
718	1.58
719	1.38
720	1.43
721	1.45
722	1.43
724	1.5
725	1.51
726	1.51
727	1.47
728	1.54
729	1.46
731	1.47
81	1.48
82	1.43
83	1.44
84	1.44
85	1.33
86	1.35
87	1.5
88	1.49
89	1.46
813	1.24
814	1.32
815	1.56
819	1.59
820	1.55
821	1.48
822	1.42
824	1.35
825	1.34
826	1.41
827	1.41
831	1.33

91	1.5
92	1.55
95	1.49
96	1.56
912	1.33
913	1.37
914	1.4
915	1.44
916	1.41
917	1.43
918	1.41
919	1.46
920	1.48
921	1.48
922	1.44
923	1.42
924	1.42
925	1.45
926	1.3
927	1.4
108	1.22
109	1.18
1010	1.32
1011	1.44
1012	1.42
1014	1.37
1016	1.28
1017	1.22
1018	1.29
1019	1.41
1021	1.32
1022	1.36
1023	1.34
1026	1.24
1029	1.27
1030	1.26
1106	1.34
1107	1.27
1108	1.32
1109	1.36
1110	1.38
1111	1.43
1112	1.28
1113	1.32
1116	1.37
1117	1.28
1118	1.28
1119	1.38
1121	1.29
1122	1.39
1123	1.36
1124	1.35
1125	1.4
1126	1.33
1127	1.28
1128	1.3
1129	1.31
1130	1.35
1201	1.32
1202	1.17
1206	1.39
1207	1.35
1208	1.41
1209	1.37
1210	1.33
1211	1.25
1212	1.36
1216	1.33
1217	1.31
1218	1.2
1219	1.15
1220	1.31
1221	1.15
1222	1.28
1223	1.26
1224	1.32
1226	1.32
1227	1.34
1231	1.38

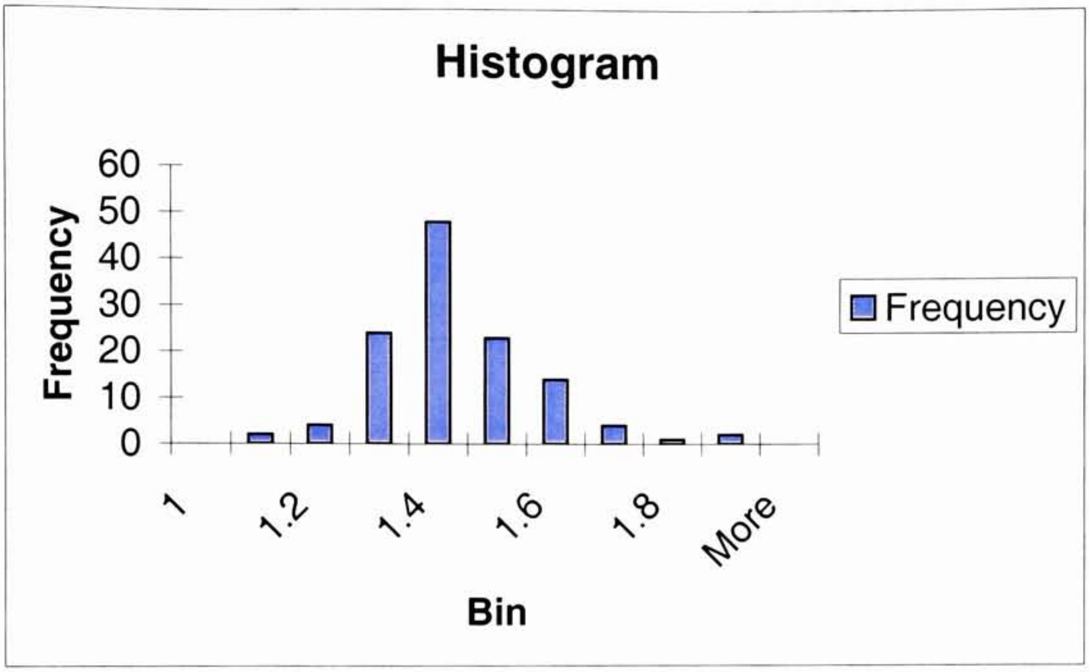
Appendix C

Control Chart Data


UCL
LCL
CL
Actual KVA


UCL
LCL
Moving Range
CL

Graph 2. Histogram of actual KVA data



CL	CL	LCL	MR	X-bar	Days	Highest-Lowest	KVA Min	KVA MAX	UCL (xbar)	LCL(xbar)	CL (xbar)
				1.35	1.00	1.65	0.89	2.53	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.27	2.00	0.27	1.14	1.41	1.60	1.17	1.38
0.26	0.08	0.00	0.08	1.19	3.00	0.22	1.07	1.29	1.60	1.17	1.38
0.26	0.08	0.00	0.03	1.22	4.00	0.29	1.07	1.36	1.60	1.17	1.38
0.26	0.08	0.00	0.10	1.32	5.00	0.33	1.14	1.48	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.33	6.00	0.31	1.20	1.51	1.60	1.17	1.38
0.26	0.08	0.00	0.32	1.65	7.00	0.36	1.49	1.85	1.60	1.17	1.38
0.26	0.08	0.00	0.13	1.78	8.00	0.22	1.66	1.88	1.60	1.17	1.38
0.26	0.08	0.00	0.03	1.81	9.00	0.19	1.71	1.90	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.80	10.00	0.15	1.73	1.88	1.60	1.17	1.38
0.26	0.08	0.00	0.23	1.57	11.00	0.54	1.51	2.05	1.60	1.17	1.38
0.26	0.08	0.00	0.26	1.31	12.00	0.33	1.39	1.72	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.29	13.00	0.31	1.14	1.45	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.31	14.00	0.18	1.20	1.37	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.40	15.00	0.15	1.23	1.38	1.60	1.17	1.38
0.26	0.08	0.00	0.12	1.52	16.00	0.26	1.26	1.52	1.60	1.17	1.38
0.26	0.08	0.00	0.06	1.46	17.00	0.50	1.41	1.91	1.60	1.17	1.38
0.26	0.08	0.00	0.07	1.53	18.00	0.67	1.30	1.98	1.60	1.17	1.38
0.26	0.08	0.00	0.07	1.46	19.00	0.32	1.37	1.69	1.60	1.17	1.38
0.26	0.08	0.00	0.07	1.53	20.00	0.25	1.34	1.59	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.44	21.00	0.30	1.34	1.64	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.53	22.00	0.20	1.35	1.55	1.60	1.17	1.38
0.26	0.08	0.00	0.08	1.45	23.00	0.51	1.42	1.92	1.60	1.17	1.38
0.26	0.08	0.00	0.05	1.50	24.00	0.36	1.24	1.60	1.60	1.17	1.38
0.26	0.08	0.00	0.10	1.40	25.00	0.37	1.28	1.65	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.42	26.00	0.32	1.26	1.57	1.60	1.17	1.38

CL	CL	LCL	MR	X-bar	Days	Highest-Lowest	KVA Min	KVA MAX	UCL (xbar)	LCL(xbar)	CL (xbar)
0.26	0.08	0.00	0.01	1.41	27.00	0.19	1.33	1.51	1.60	1.17	1.38
0.26	0.08	0.00	0.07	1.34	28.00	0.20	1.33	1.53	1.60	1.17	1.38
0.26	0.08	0.00	0.06	1.39	29.00	0.35	1.14	1.48	1.60	1.17	1.38
0.26	0.08	0.00	0.03	1.37	30.00	0.23	1.24	1.47	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.38	31.00	0.17	1.28	1.45	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.29	32.00	0.18	1.28	1.46	1.60	1.17	1.38
0.26	0.08	0.00	0.03	1.32	33.00	0.22	1.20	1.42	1.60	1.17	1.38
0.26	0.08	0.00	0.20	1.52	34.00	0.08	1.27	1.36	1.60	1.17	1.38
0.26	0.08	0.00	0.08	1.59	35.00	0.17	1.44	1.61	1.60	1.17	1.38
0.26	0.08	0.00	0.11	1.49	36.00	0.28	1.45	1.73	1.60	1.17	1.38
0.26	0.08	0.00	0.00	1.49	37.00	0.29	1.35	1.64	1.60	1.17	1.38
0.26	0.08	0.00	0.12	1.37	38.00	0.21	1.39	1.60	1.60	1.17	1.38
0.26	0.08	0.00	0.24	1.60	39.00	0.16	1.27	1.43	1.60	1.17	1.38
0.26	0.08	0.00	0.29	1.32	40.00	0.41	1.38	1.80	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.23	41.00	0.33	1.11	1.44	1.60	1.17	1.38
0.26	0.08	0.00	0.11	1.34	42.00	0.28	1.11	1.39	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.33	43.00	0.22	1.23	1.44	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.36	44.00	0.28	1.23	1.51	1.60	1.17	1.38
0.26	0.08	0.00	0.08	1.44	45.00	0.80	1.20	2.01	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.42	46.00	0.36	1.26	1.63	1.60	1.17	1.38
0.26	0.08	0.00	0.04	1.47	47.00	0.34	1.24	1.58	1.60	1.17	1.38
0.26	0.08	0.00	0.12	1.59	48.00	0.21	1.35	1.56	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.60	49.00	0.18	1.51	1.69	1.60	1.17	1.38
0.26	0.08	0.00	0.00	1.61	50.00	0.20	1.50	1.70	1.60	1.17	1.38
0.26	0.08	0.00	0.04	1.57	51.00	0.71	1.37	2.08	1.60	1.17	1.38
0.26	0.08	0.00	0.05	1.52	52.00	0.24	1.42	1.66	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.51	53.00	0.22	1.37	1.60	1.60	1.17	1.38
0.26	0.08	0.00	0.00	1.50	54.00	0.23	1.42	1.65	1.60	1.17	1.38
0.26	0.08	0.00	0.11	1.61	55.00	0.34	1.35	1.69	1.60	1.17	1.38
0.26	0.08	0.00	0.14	1.46	56.00	0.82	1.31	2.13	1.60	1.17	1.38
0.26	0.08	0.00	0.08	1.54	57.00	0.29	1.33	1.62	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.53	58.00	0.16	1.47	1.63	1.60	1.17	1.38
0.26	0.08	0.00	0.06	1.47	59.00	0.19	1.43	1.62	1.60	1.17	1.38
0.26	0.08	0.00	0.07	1.40	60.00	0.16	1.40	1.55	1.60	1.17	1.38
0.26	0.08	0.00	0.06	1.34	61.00	0.23	1.28	1.52	1.60	1.17	1.38
0.26	0.08	0.00	0.05	1.39	62.00	0.17	1.26	1.43	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.41	63.00	0.23	1.28	1.51	1.60	1.17	1.38
0.26	0.08	0.00	0.14	1.26	64.00	0.33	1.22	1.55	1.60	1.17	1.38
0.26	0.08	0.00	0.24	1.50	65.00	0.33	1.07	1.40	1.60	1.17	1.38
0.26	0.08	0.00	0.31	1.19	66.00	0.41	1.02	1.43	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.21	67.00	0.41	1.01	1.42	1.60	1.17	1.38
0.26	0.08	0.00	0.13	1.34	68.00	0.24	1.23	1.46	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.35	69.00	0.18	1.27	1.45	1.60	1.17	1.38
0.26	0.08	0.00	0.03	1.38	70.00	0.26	1.23	1.49	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.37	71.00	0.32	1.23	1.55	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.38	72.00	0.54	1.23	1.78	1.60	1.17	1.38
0.26	0.08	0.00	0.08	1.30	73.00	0.25	1.19	1.43	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.31	74.00	0.31	1.16	1.47	1.60	1.17	1.38
0.26	0.08	0.00	0.04	1.28	75.00	0.28	1.13	1.41	1.60	1.17	1.38
0.26	0.08	0.00	0.04	1.32	76.00	0.33	1.14	1.47	1.60	1.17	1.38

CL	CL	LCL	MR	X-bar	Days	Highest-Lowest	KVA Min	KVA MAX	UCL (xbar)	LCL(xbar)	CL (xbar)
0.26	0.08	0.00	0.03	1.35	77.00	0.16	1.27	1.43	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.32	78.00	0.17	1.24	1.41	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.33	79.00	0.40	1.16	1.56	1.60	1.17	1.38
0.26	0.08	0.00	0.20	1.53	80.00	0.97	1.29	2.27	1.60	1.17	1.38
0.26	0.08	0.00	0.29	1.23	81.00	0.23	1.12	1.35	1.60	1.17	1.38
0.26	0.08	0.00	0.06	1.29	82.00	0.59	1.10	1.69	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.37	83.00	0.21	1.28	1.49	1.60	1.17	1.38
0.26	0.08	0.00	0.04	1.33	84.00	0.25	1.19	1.44	1.60	1.17	1.38
0.26	0.08	0.00	0.03	1.36	85.00	0.24	1.24	1.48	1.60	1.17	1.38
0.26	0.08	0.00	0.05	1.41	86.00	0.13	1.35	1.48	1.60	1.17	1.38
0.26	0.08	0.00	0.06	1.35	87.00	0.15	1.28	1.43	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.44	88.00	0.50	1.25	1.75	1.60	1.17	1.38
0.26	0.08	0.00	0.05	1.39	89.00	0.24	1.24	1.48	1.60	1.17	1.38
0.26	0.08	0.00	0.13	1.26	90.00	0.27	1.08	1.35	1.60	1.17	1.38
0.26	0.08	0.00	0.12	1.38	91.00	0.66	1.24	1.90	1.60	1.17	1.38
0.26	0.08	0.00	0.12	1.26	92.00	0.25	1.14	1.39	1.60	1.17	1.38
0.26	0.08	0.00	0.03	1.28	93.00	0.40	1.16	1.56	1.60	1.17	1.38
0.26	0.08	0.00	0.18	1.47	94.00	0.46	1.30	1.76	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.38	95.00	1.16	0.49	1.66	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.39	96.00	0.22	1.27	1.49	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.36	97.00	0.22	1.26	1.47	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.27	98.00	0.19	1.20	1.39	1.60	1.17	1.38
0.26	0.08	0.00	0.03	1.30	99.00	0.16	1.22	1.37	1.60	1.17	1.38
0.26	0.08	0.00	0.05	1.36	100.00	0.14	1.28	1.42	1.60	1.17	1.38
0.26	0.08	0.00	0.00	1.36	101.00	0.15	1.28	1.43	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.35	102.00	0.16	1.27	1.44	1.60	1.17	1.38
0.26	0.08	0.00	0.00	1.35	103.00	0.22	1.29	1.50	1.60	1.17	1.38
0.26	0.08	0.00	0.10	1.25	104.00	0.22	1.14	1.36	1.60	1.17	1.38
0.26	0.08	0.00	0.00	1.25	105.00	0.13	1.19	1.32	1.60	1.17	1.38
0.26	0.08	0.00	0.07	1.33	106.00	0.44	1.12	1.56	1.60	1.17	1.38
0.26	0.08	0.00	0.20	1.12	107.00	0.45	0.94	1.39	1.60	1.17	1.38
0.26	0.08	0.00	0.28	1.40	108.00	0.13	1.36	1.50	1.60	1.17	1.38
0.26	0.08	0.00	0.06	1.34	109.00	0.20	1.23	1.43	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.37	110.00	0.11	1.31	1.42	1.60	1.17	1.38
0.26	0.08	0.00	0.00	1.37	111.00	0.10	1.32	1.42	1.60	1.17	1.38
0.26	0.08	0.00	0.11	1.26	112.00	0.30	1.06	1.36	1.60	1.17	1.38
0.26	0.08	0.00	0.20	1.46	113.00	0.32	1.23	1.55	1.60	1.17	1.38
0.26	0.08	0.00	0.11	1.35	114.00	0.07	1.32	1.39	1.60	1.17	1.38
0.26	0.08	0.00	0.06	1.29	115.00	0.58	1.08	1.67	1.60	1.17	1.38
0.26	0.08	0.00	0.07	1.37	116.00	0.13	1.29	1.43	1.60	1.17	1.38
0.26	0.08	0.00	0.12	1.25	117.00	0.14	1.16	1.31	1.60	1.17	1.38
0.26	0.08	0.00	0.12	1.13	118.00	0.12	1.07	1.19	1.60	1.17	1.38
0.26	0.08	0.00	0.04	1.09	119.00	0.09	1.05	1.13	1.60	1.17	1.38
0.26	0.08	0.00	0.13	1.22	120.00	0.30	1.07	1.37	1.60	1.17	1.38
0.26	0.08	0.00	0.13	1.09	121.00	0.09	1.05	1.13	1.60	1.17	1.38
0.26	0.08	0.00	0.20	1.29	122.00	0.11	1.24	1.35	1.60	1.17	1.38
0.26	0.08	0.00	0.02	1.31	123.00	0.15	1.24	1.39	1.60	1.17	1.38
0.26	0.08	0.00	0.09	1.23	124.00	0.61	0.76	1.37	1.60	1.17	1.38
0.26	0.08	0.00	0.01	1.24	125.00	0.26	1.15	1.42	1.60	1.17	1.38
0.26	0.08	0.00	0.06	1.30	126.00	0.25	1.17	1.42	1.60	1.17	1.38

Appendix D

PLS Model 2 Steady State

PLS Master Listing

Imported from
C:\WINNT\Profiles\I487840\Desktop\steadystate.txt
Date: 6th April 2003 [12:27]
Current file spec:
C:\WINNT\Profiles\I487840\Desktop\steadystate.arc
PLSPC/W Version 4.4.
Release 2 (14 March 2000)

Response variable(s)...
WKVA
Number of response variables:
1

Predictor variable(s)...
SLUDGE QFLOW COND
VTHROAT VTOTAL VDP
LNWVOL GTEMP
CO O2 GASFLOW
MH3TEMP
Number of predictor variables:
12

Cases...
CASE10 CASE11 CASE12
CASE14 CASE15 CASE16
CASE17 CASE18 CASE19
CASE20
CASE21 CASE22 CASE23
CASE24 CASE25 CASE26
CASE27 CASE28 CASE29
CASE30
CASE32

Number of cases: 21

Preprocessing options. Key:
[VarName Center Scale]

[WKVA Mean Std] [SLUDGE Mean Std] [QFLOW Mean Std]
[COND Mean Std]
[VTHROAT Mean Std]
[VTOTAL Mean Std]
[VDP Mean Std] [LNWVOL Mean Std] [GTEMP Mean Std]
[CO Mean Std] [O2 Mean Std] [GASFLOW Mean Std]
[MH3TEMP Mean Std]

Computation status: No errors encountered
Number of model dimensions:
1

Missing value code: -999
Number of missing values in X: 0
Number of missing values in Y: 0

X Block Model Information:
X Weights

Var	Dim1
SLUDGE	-0.342
QFLOW	-0.118
COND	-0.21
VTHROAT	0.000521
VTOTAL	0.269
VDP	0.459
LNWVOL	0.415
GTEMP	0.376
CO	0.139
O2	0.158
GASFLOW	-0.608
MH3TEMP	0.168

X Loadings

Var	Dim1
SLUDGE	-0.402
QFLOW	-0.329
COND	-0.34
VTHROAT	-0.0542
VTOTAL	0.232
VDP	0.395
LNWVOL	0.339
GTEMP	0.251
CO	0.19
O2	0.282
GASFLOW	-0.33
MH3TEMP	0.0146

X Scores

Case	Dim1
CASE10	-3.63
CASE11	-1.71
CASE12	2.03
CASE14	-1.03
CASE15	0.195
CASE16	-0.173
CASE17	-0.603
CASE18	1.16
CASE19	0.548
CASE20	-1.69
CASE21	-0.64
CASE22	-1.44
CASE23	-1.56
CASE24	-0.49
CASE25	-4.18
CASE26	2.07
CASE27	1.33
CASE28	2.63
CASE29	2.94
CASE30	1.35
CASE32	2.89

X R2 (Communalities)

Var Dim1
SLUDGE 0.652
QFLOW 0.435
COND 0.467
VTHROAT 0.0118
VTOTAL 0.216
VDP 0.628
LNWVOL 0.462
GTEMP 0.254
CO 0.145
O2 0.32
GASFLOW 0.438
MH3TEMP 0.000859

Variable Importance
0 0.5
1
+------------------------+-------
-----------------+
SLUDGE
****
****
QFLOW
****
COND
****
*
VTHROAT**
VTOTAL ******************
VDP
****
****
LNWVOL
****
*
GTEMP *********************
CO *************
O2 **************************
GASFLOW**********************
****
MH3TEMP*

Y Block Model Information:
Y Weights

Var Dim1
WKVA 1

Y Loadings

Var Dim1
WKVA 1

Y Scores

Case Dim1
CASE10 -0.911
CASE11 -0.554
CASE12 1.97
CASE14 0.848
CASE15 0.544
CASE16 -0.711
CASE17 -0.306
CASE18 0.437
CASE19 0.492
CASE20 0.399
CASE21 0.382
CASE22 -1.03
CASE23 -1.01
CASE24 0.023
CASE25 -2.77
CASE26 1.1
CASE27 0.287
CASE28 0.625
CASE29 0.647
CASE30 -0.809
CASE32 0.339

Y R2 (Communalities)

Var Dim1
WKVA 0.499

Inner Relation Coefficients:
0.352

(Preprocessed) Regression Coefficients

Var WKVA
SLUDGE -0.12
QFLOW -0.0416
COND -0.074
VTHROAT 0.000183
VTOTAL 0.0946
VDP 0.161
LNWVOL 0.146
GTEMP 0.132
CO 0.0488
O2 0.0555
GASFLOW -0.214
MH3TEMP 0.0589

Regression Coefficients

Var WKVA
Inter -183
SLUDGE -0.0000058
QFLOW -0.000517
COND -0.0145
VTHROAT 0.0104
VTOTAL 0.924
VDP 0.0113
LNWVOL 2.17
GTEMP 0.00455
CO 0.0134
O2 0.00478
GASFLOW -0.0000218
MH3TEMP 0.00067

Score Matrix A: T=XA

Var	Dim1
SLUDGE	-0.342
QFLOW	-0.118
COND	-0.21
VTHROAT	0.000521
VTOTAL	0.269
VDP	0.459
LNWVOL	0.415
GTEMP	0.376
CO	0.139
O2	0.158
GASFLOW	-0.608
MH3TEMP	0.168

Predictions

Case	WKVA
CASE10	1.23
CASE11	1.28
CASE12	1.38
CASE14	1.3
CASE15	1.33
CASE16	1.32
CASE17	1.31
CASE18	1.35
CASE19	1.34
CASE20	1.28
CASE21	1.31
CASE22	1.29
CASE23	1.28
CASE24	1.31
CASE25	1.22
CASE26	1.38
CASE27	1.36
CASE28	1.39
CASE29	1.4
CASE30	1.36
CASE32	1.4

Appendix E

PLS Model 3 Non-Steady State

PLS Master Listing

Imported from C:\WINNT\Profiles\I487840\Desktop\nonsteadystate.txt
Date: 6th April 2003 [12:34]
Current file spec: C:\WINNT\Profiles\I487840\Desktop\nonsteadystate.arc
PLSPC/W Version 4.4.
Release 2 (14 March 2000)

Response variable(s)...
WKVA
Number of response variables: 1

Predictor variable(s)...
SLUDGE QFLOW CONDFLOW VTHROAT VTOTAL VDP LNWVOL GTEMP CO O2 GFLOW MH3TEMP
Number of predictor variables: 12

Cases...
CASE1 CASE2 CASE3 CASE4 CASE5 CASE6 CASE7 CASE8 CASE9 CASE10
CASE11 CASE12 CASE13 CASE14 CASE15 CASE16 CASE17 CASE18 CASE19 CASE20
CASE21 CASE22 CASE23 CASE24 CASE25 CASE26 CASE27 CASE28 CASE29 CASE30
CASE31 CASE32 CASE33 CASE34 CASE35 CASE36 CASE37 CASE38 CASE39 CASE40
CASE41 CASE42 CASE43 CASE44 CASE45 CASE46 CASE47 CASE48 CASE49 CASE50
CASE51 CASE52 CASE53 CASE54 CASE55 CASE56 CASE57 CASE58 CASE59 CASE60
CASE61 CASE62 CASE63 CASE64 CASE65 CASE66 CASE67 CASE68 CASE69 CASE70
CASE71 CASE72 CASE73 CASE74 CASE75 CASE76 CASE77 CASE78 CASE79 CASE80
CASE81 CASE82

Number of cases: 82

Preprocessing options. Key: [VarName Center Scale]

[WKVA Mean Std]
[SLUDGE Mean Std]
[QFLOW Mean Std]
[CONDFLOW Mean Std]
[VTHROAT Mean Std]
[VTOTAL Mean Std]
[VDP Mean Std] [LNWVOL Mean Std] [GTEMP Mean Std]
[CO Mean Std] [O2 Mean Std] [GFLOW Mean Std]
[MH3TEMP Mean Std]

Computation status: No errors encountered

Number of model dimensions: 2

Missing value code: -999
Number of missing values in X: 0
Number of missing values in Y: 0

X Block Model Information:
X Weights

Var	Dim1	Dim2
SLUDGE	-0.541	-0.276
QFLOW	-0.14	0.269
CONDFLOW	0.294	-0.0972
VTHROAT	-0.215	0.0353
VTOTAL	-0.0463	-0.254
VDP	-0.0931	0.728
LNWVOL	0.38	-0.321
GTEMP	-0.0862	-0.633
CO	-0.224	-0.114
O2	0.413	0.251
GFLOW	-0.429	0.0973
MH3TEMP	-0.122	0.321

X Loadings

Var	Dim1	Dim2
SLUDGE	-0.489	-0.29
QFLOW	-0.173	0.0192
CONDFLOW	0.299	-0.175
VTHROAT	-0.214	-0.127
VTOTAL	-0.0108	-0.336
VDP	-0.189	0.592
LNWVOL	0.413	-0.336
GTEMP	0.00141	-0.227
CO	-0.203	0.245
O2	0.369	0.361
GFLOW	-0.431	0.127
MH3TEMP	-0.162	0.185

X Scores

Case	Dim1	Dim2
CASE1	0.62	-3.4
CASE2	-0.939	-1.7
CASE3	-1.96	-2.2
CASE4	0.185	-0.831
CASE5	0.828	-0.66
CASE6	1.6	-3.45
CASE7	2.1	1.92
CASE8	1.99	-0.422
CASE9	2.79	-0.0288
CASE10	3.02	0.0245
CASE11	2.62	0.0708
CASE12	-0.522	-0.821
CASE13	1.03	-0.701
CASE14	1.17	-0.692
CASE15	0.177	-0.84
CASE16	1.31	-1.14
CASE17	1.5	-1.19
CASE18	1.88	-0.82
CASE19	0.578	-0.0699
CASE20	1.56	0.31
CASE21	0.42	-0.511
CASE22	0.588	-0.942
CASE23	0.786	-0.56
CASE24	-0.0318	-1.05
CASE25	0.0478	-0.271
CASE26	-0.322	-0.592
CASE27	-1.55	-1.62
CASE28	-1.37	-0.865
CASE29	0.785	0.142
CASE30	0.281	0.129
CASE31	-0.172	-0.0218
CASE32	-2.26	-2.92
CASE33	-1.18	-1.19
CASE34	2.3	0.775
CASE35	2.33	0.593
CASE36	1.89	0.166
CASE37	1.4	-0.524
CASE38	0.852	-1.15
CASE39	2.9	-2.22
CASE40	-1.89	-0.285
CASE41	-2.22	0.0365
CASE42	-0.733	0.122
CASE43	-0.377	0.174
CASE44	-1.52	2.2
CASE45	-2.31	-0.201
CASE46	0.694	0.732
CASE47	1.42	0.966
CASE48	1.09	0.406
CASE49	2.3	1.11
CASE50	-0.67	0.741
CASE51	-0.745	0.382
CASE52	-0.0846	0.559
CASE53	0.62	0.961
CASE54	-0.203	0.835
CASE55	0.607	0.266
CASE56	0.263	0.832
CASE57	0.971	0.818
CASE58	1.29	0.756
CASE59	1.39	1.12
CASE60	0.628	0.899
CASE61	0.651	1.35
CASE62	0.664	0.756
CASE63	1.02	0.845
CASE64	-1.18	-0.0914
CASE65	0.977	0.221
CASE66	-3.26	-0.864
CASE67	-3.83	-0.704
CASE68	-2.86	0.502
CASE69	-0.76	1.46
CASE70	-0.59	0.64
CASE71	-0.956	2.11
CASE72	-1.86	0.0395
CASE73	-3.13	-0.374
CASE74	-2.1	0.478
CASE75	-0.67	1.98
CASE76	-1.86	0.38
CASE77	-1.1	0.481
CASE78	-1.14	0.349
CASE79	-1.44	-1.46
CASE80	0.714	4.13
CASE81	-3.97	1.98
CASE82	-3.1	1.65

X R2 (Communalities)

Var	Dim1	Dim2
SLUDGE	0.638	0.766
QFLOW	0.0794	0.0799
CONDFLOW	0.239	0.285
VTHROAT	0.122	0.147
VTOTAL	0.000312	0.171
VDP	0.095	0.626
LNWVOL	0.455	0.626
GTEMP	0.00000533	0.078
CO	0.11	0.2
O2	0.362	0.56
GFLOW	0.494	0.519
MH3TEMP	0.0703	0.122

Variable Importance

```
     0                    0.5
1
     +----------------------+------
----------------+
SLUDGE
***********************************
***************
QFLOW  ******
CONDFLOW*************
VTHROAT **********
VTOTAL  **
VDP   **
LNWVOL  ********************
GTEMP  *
CO    *****
O2
*********************************
GFLOW
****************************
MH3TEMP ****

---------------------------------------
----------------------------
```

Y Block Model Information:

Y Weights

Var	Dim1	Dim2
WKVA	1	1

Y Loadings

Var	Dim1	Dim2
WKVA	1	1

Y Scores

Case	Dim1	Dim2
CASE1	-0.504	-0.779
CASE2	-1.16	-0.746
CASE3	-1.73	-0.859
CASE4	-1.52	-1.6
CASE5	-0.793	-1.16
CASE6	-0.681	-1.39
CASE7	1.71	0.779
CASE8	2.68	1.8
CASE9	2.93	1.69
CASE10	2.84	1.5
CASE11	1.09	-0.0659
CASE12	-0.862	-0.631
CASE13	-0.985	-1.44
CASE14	-0.823	-1.34
CASE15	-0.165	-0.243
CASE16	0.731	0.149
CASE17	0.309	-0.358
CASE18	0.84	0.00576
CASE19	0.287	0.0314
CASE20	0.795	0.102
CASE21	0.114	-0.0719
CASE22	0.825	0.564
CASE23	0.203	-0.145
CASE24	0.582	0.596
CASE25	-0.171	-0.192
CASE26	-0.03	0.112
CASE27	-0.101	0.585
CASE28	-0.625	-0.0189
CASE29	-0.203	-0.55
CASE30	-0.392	-0.516
CASE31	-0.276	-0.2
CASE32	-0.973	0.029
CASE33	-0.755	-0.231
CASE34	0.72	-0.299
CASE35	1.29	0.259
CASE36	0.497	-0.34
CASE37	0.494	-0.127
CASE38	-0.423	-0.8
CASE39	1.36	0.0698
CASE40	-0.799	0.0388
CASE41	-1.45	-0.462
CASE42	-0.601	-0.277
CASE43	-0.651	-0.484
CASE44	-0.466	0.209
CASE45	0.125	1.15
CASE46	0.0109	-0.296
CASE47	0.337	-0.294
CASE48	1.26	0.773
CASE49	1.36	0.341
CASE50	1.38	1.68
CASE51	1.11	1.44
CASE52	0.744	0.781
CASE53	0.632	0.358
CASE54	0.613	0.703
CASE55	1.4	1.13
CASE56	0.318	0.202
CASE57	0.921	0.492
CASE58	0.82	0.249
CASE59	0.357	-0.256
CASE60	-0.148	-0.425
CASE61	-0.604	-0.893
CASE62	-0.203	-0.497
CASE63	-0.12	-0.573
CASE64	-1.2	-0.674
CASE65	0.58	0.148
CASE66	-1.75	-0.305
CASE67	-1.58	0.115
CASE68	-0.606	0.662
CASE69	-0.535	-0.199
CASE70	-0.334	-0.0724
CASE71	-0.416	0.00679
CASE72	-0.338	0.485
CASE73	-0.94	0.445
CASE74	-0.8	0.131
CASE75	-1.08	-0.782
CASE76	-0.789	0.0323
CASE77	-0.574	-0.0889
CASE78	-0.748	-0.245
CASE79	-0.686	-0.0482
CASE80	0.776	0.46
CASE81	-1.43	0.326
CASE82	-1.02	0.355

Y R2 (Communalities)

Var	Dim1	Dim2
WKVA	0.523	0.558

Inner Relation Coefficients:

0.443 0.152

(Preprocessed) Regression Coefficients

Var	WKVA
SLUDGE	-0.297
QFLOW	-0.0253
CONDFLOW	0.124
VTHROAT	-0.0963
VTOTAL	-0.0604
VDP	0.0665
LNWVOL	0.131
GTEMP	-0.137
CO	-0.123
O2	0.233
GFLOW	-0.188
MH3TEMP	-0.00904

Regression Coefficients

Var	WKVA
Inter	229
SLUDGE	-0.0000178
QFLOW	-0.000386
CONDFLOW	0.000899
VTHROAT	-1.27
VTOTAL	-0.456
VDP	0.00564
LNWVOL	1.5
GTEMP	-0.0131
CO	-0.0206
O2	0.025
GFLOW	-0.0000304
MH3TEMP	-0.0000847

Score Matrix A: T=XA

Var	Dim1	Dim2
SLUDGE	-0.541	-0.381
QFLOW	-0.14	0.241
CONDFLOW	0.294	-0.04
VTHROAT	-0.215	-0.00665
VTOTAL	-0.0463	-0.263
VDP	-0.0931	0.709
LNWVOL	0.38	-0.247
GTEMP	-0.0862	-0.65
CO	-0.224	-0.157
O2	0.413	0.331
GFLOW	-0.429	0.0138
MH3TEMP	-0.122	0.297

Predictions

Case	WKVA
CASE1	1.39
CASE2	1.33
CASE3	1.26
CASE4	1.42
CASE5	1.46
CASE6	1.45
CASE7	1.59
CASE8	1.53
CASE9	1.59
CASE10	1.6
CASE11	1.58
CASE12	1.37
CASE13	1.47
CASE14	1.48
CASE15	1.42
CASE16	1.48
CASE17	1.49
CASE18	1.52
CASE19	1.45
CASE20	1.52
CASE21	1.44
CASE22	1.44
CASE23	1.46
CASE24	1.4
CASE25	1.42
CASE26	1.39
CASE27	1.3
CASE28	1.32
CASE29	1.47
CASE30	1.44
CASE31	1.41
CASE32	1.23
CASE33	1.33
CASE34	1.57
CASE35	1.57
CASE36	1.54
CASE37	1.49
CASE38	1.45
CASE39	1.55
CASE40	1.3
CASE41	1.29
CASE42	1.38
CASE43	1.4
CASE44	1.38
CASE45	1.28
CASE46	1.48
CASE47	1.53
CASE48	1.49
CASE49	1.58
CASE50	1.4
CASE51	1.39
CASE52	1.43
CASE53	1.48
CASE54	1.43
CASE55	1.46
CASE56	1.45
CASE57	1.5
CASE58	1.51
CASE59	1.53
CASE60	1.48
CASE61	1.49
CASE62	1.48
CASE63	1.5
CASE64	1.35
CASE65	1.48
CASE66	1.21
CASE67	1.18
CASE68	1.26
CASE69	1.41
CASE70	1.4
CASE71	1.41
CASE72	1.31
CASE73	1.23
CASE74	1.31
CASE75	1.42
CASE76	1.32
CASE77	1.37
CASE78	1.36
CASE79	1.31
CASE80	1.55
CASE81	1.23
CASE82	1.27

Appendix F

Model 4 (16 Predictor Variables 118 Cases)

PLS Master Listing

Imported from C:\WINNT\Profiles\l487840\Desktop\morevariablesthesis.txt
Date: 6th April 2003 [12:37]
Current file spec:
C:\WINNT\Profiles\l487840\Desktop\morevariablesthesis.arc
PLSPC/W Version 4.4.
Release 2 (14 March 2000)

Response variable(s)...
WKVA
Number of response variables: 1

Predictor variable(s)...
SLUDGE
QNCHH2O
CONH2O VNTTHR
TOTVFLOWS
VNTDP
LNWVOL GTEMP
CO O2
GASFLOW
MH3TEMP
WESPWSH
BUNSPD
SFTRPM
DFTPRES

Number of predictor variables: 16

Cases...
CASE1 CASE2 CASE3
CASE4 CASE5 CASE6
CASE11 CASE12
CASE13 CASE14 CASE15
CASE16 CASE17 CASE18
CASE19 CASE20
CASE21 CASE22 CASE23
CASE24 CASE25 CASE26
CASE27 CASE28
CASE29 CASE30 CASE31
CASE32 CASE33 CASE34
CASE35 CASE36
CASE37 CASE38 CASE39
CASE40 CASE41 CASE42
CASE43 CASE44
CASE45 CASE46 CASE47
CASE48 CASE49 CASE52
CASE53 CASE54
CASE56 CASE57 CASE58
CASE59 CASE60 CASE61
CASE62 CASE63
CASE64 CASE65 CASE66
CASE67 CASE68 CASE69
CASE70 CASE71
CASE72 CASE73 CASE74
CASE75 CASE76 CASE77
CASE78 CASE79
CASE81 CASE82 CASE83
CASE84 CASE85 CASE86
CASE87 CASE88
CASE89 CASE90 CASE91
CASE92 CASE93 CASE94
CASE96 CASE97
CASE98 CASE99 CASE100
CASE101 CASE102
CASE103 CASE104
CASE105
CASE106 CASE107
CASE108 CASE109
CASE110 CASE111
CASE112 CASE113
CASE114 CASE115
CASE116 CASE117
CASE118 CASE119
CASE120 CASE121
CASE122 CASE123
CASE124 CASE125
CASE126 CASE127

Number of cases: 118

Preprocessing options. Key: [VarName Center Scale]

[WKVA Mean Std]
[SLUDGE Mean Std]
[QNCHH2O Mean Std]
[CONH2O Mean Std]
[VNTTHR Mean Std]
[TOTVFLOWS Mean Std]
[VNTDP Mean Std]
[LNWVOL Mean Std]
[GTEMP Mean Std]
[CO Mean Std] [O2 Mean Std] [GASFLOW Mean Std]
[MH3TEMP Mean Std]
[WESPWSH Mean Std]
[BUNSPD Mean Std]
[SFTRPM Mean Std]
[DFTPRES Mean Std]

Computation status: No errors encountered
Number of model dimensions: 2

Missing value code: -999
Number of missing values in X: 0
Number of missing values in Y: 0

X Block Model Information:
X Weights

Var	Dim1	Dim2
SLUDGE	-0.383	0.0448

QNCHH2O	-0.0384	0.219
CONH2O	0.157	-0.0299
VNTTHR	-0.153	0.147
TOTVFLOWS	0.00928	-0.109
VNTDP	-0.162	0.181
LNWVOL	0.349	-0.222
GTEMP	0.0593	0.0259
CO	-0.323	-0.0997
O2	0.17	-0.171
GASFLOW	-0.521	-0.304
MH3TEMP	-0.00907	0.374
WESPWSH	-0.0183	-0.609
BUNSPD	-0.325	0.189
SFTRPM	-0.0814	0.45
DFTPRES	-0.456	-0.193

X Loadings

Var	Dim1	Dim2
SLUDGE	-0.368	0.0934
QNCHH2O	-0.0905	0.212
CONH2O	0.154	-0.0222
VNTTHR	-0.18	0.118
TOTVFLOWS	0.0358	-0.0981
VNTDP	-0.196	0.252
LNWVOL	0.381	-0.102
GTEMP	0.0488	0.0638
CO	-0.276	-0.115
O2	0.201	-0.177
GASFLOW	-0.41	-0.188
MH3TEMP	-0.102	0.481
WESPWSH	0.135	-0.443
BUNSPD	-0.35	0.147
SFTRPM	-0.188	0.496
DFTPRES	-0.377	-0.261

X Scores

Case	Dim1	Dim2
CASE1	0.936	-4.26
CASE2	0.0458	-0.57
CASE3	-0.772	-1.76
CASE4	0.918	-1.96
CASE5	1.84	-1.08
CASE6	2.51	-1.23
CASE11	3.58	-0.258
CASE12	-0.229	-0.759
CASE13	1.38	-2.2
CASE14	1.43	-1.74
CASE15	1.15	-0.283
CASE16	2.16	-0.441
CASE17	1.89	-0.442
CASE18	3.12	-0.773
CASE19	1.47	-0.71
CASE20	2.8	-0.203
CASE21	1.52	-0.793
CASE22	1.9	-2.06
CASE23	2.12	-0.151
CASE24	1.36	0.576
CASE25	0.774	-0.0139
CASE26	0.103	0.512
CASE27	-1.25	0.328
CASE28	-1.13	0.00185
CASE29	2.4	1.35
CASE30	1.74	1.42
CASE31	1.09	1.05
CASE32	-1.79	-0.406
CASE33	-0.962	-0.901
CASE34	3.67	0.954
CASE35	4.58	1.88
CASE36	3.8	1.47
CASE37	2.25	0.154
CASE38	1.59	-1.41
CASE39	4.26	-0.101
CASE40	-1.11	1.36
CASE41	-1.08	1.06
CASE42	0.781	1.4
CASE43	0.799	0.658
CASE44	-2.19	-1.75
CASE45	-1.72	0.908
CASE46	2.44	1.75
CASE47	4.14	0.542
CASE48	3.34	2.43
CASE49	3.59	1.38
CASE52	-0.137	-0.0586
CASE53	0.692	-0.746
CASE54	-0.0957	0.706
CASE56	0.437	-0.882
CASE57	1.82	0.0249
CASE58	2.71	0.258
CASE59	2.44	-0.621
CASE60	0.767	-0.799
CASE61	0.442	-1.33
CASE62	1.33	-0.321
CASE63	1.92	0.846
CASE64	-1.74	0.445
CASE65	0.965	-0.495
CASE66	-2.25	-1.47
CASE67	-3.36	-1.12
CASE68	-2.36	1.59
CASE69	-0.194	1.84
CASE70	0.245	0.782
CASE71	-0.55	1.02
CASE72	-1.29	-1.24
CASE73	-2.36	0.0155
CASE74	-1.61	-0.0826
CASE75	-0.167	0.193
CASE76	-1.52	0.199
CASE77	-0.728	0.437
CASE78	-0.875	0.14
CASE79	-1.12	-0.415
CASE81	-3.66	1.61
CASE82	-3.09	1.49
CASE83	-1.38	0.996
CASE84	-2.96	1.44
CASE85	-2.31	2.4
CASE86	-1.42	1.96
CASE87	-0.822	1.78
CASE88	1.28	-1.17
CASE89	-2.18	0.68
CASE90	-0.803	-0.836
CASE91	-0.648	-1.57
CASE92	-2.11	1.02
CASE93	-2.01	1.63
CASE94	-0.345	1.8
CASE96	-1.47	0.145
CASE97	0.15	0.331
CASE98	-0.134	-1.15
CASE99	-0.28	-0.781
CASE100	0.454	-0.649
CASE101	-0.315	-0.936
CASE102	-1.5	-0.0978
CASE103	-1.85	1.4
CASE104	-1.7	0.58
CASE105	-1.23	1.67
CASE106	-1.52	1.41
CASE107	-3.4	-0.551
CASE108	0.172	1.34

CASE109 -0.549 -0.996
CASE110 0.727 0.9
CASE111 -0.58 1.03
CASE112 -0.555 -0.373
CASE113 -1.74 -0.601
CASE114 -0.106 -0.235
CASE115 -0.77 0.0753
CASE116 -0.691 1.16
CASE117 -0.933 -1.65
CASE118 -2.68 -1.32
CASE119 -2.61 -2.34
CASE120 -0.443 -4.29
CASE121 -2.61 -2.34
CASE122 -1.9 0.24
CASE123 -2.16 0.66
CASE124 -1.08 -0.957
CASE125 -0.532 -0.376
CASE126 -0.695 0.134
CASE127 0.299 1.47

X R2 (Communalities)

Var	Dim1	Dim2
SLUDGE	0.472	0.486
QNCHH2O	0.0285	0.0999
CONH2O	0.0828	0.0836
VNTTHR	0.113	0.135
TOTVFLOWS	0.00447	0.0197
VNTDP	0.134	0.235
LNWVOL	0.505	0.522
GTEMP	0.0083	0.0147
CO	0.266	0.287
O2	0.141	0.19
GASFLOW	0.584	0.64
MH3TEMP	0.0362	0.403
WESPWSH	0.0635	0.375
BUNSPD	0.427	0.462
SFTRPM	0.124	0.513
DFTPRES	0.494	0.601

Variable Importance

```
               0
0.5              1
               +-----------------
-----+-----------------------+
SLUDGE
***************************
QNCHH2O          *
CONH2O           ******
VNTTHR           ******
TOTVFLOWS        *
VNTDP            *****
LNWVOL
*****************************
GTEMP            **
CO
**********************
O2               ******
GASFLOW
**********************************
***************
MH3TEMP          *
WESPWSH          *
BUNSPD
**********************
SFTRPM           **
DFTPRES
**********************************
************

----------------------------------------
---------------------------
```

Y Block Model Information:

Y Weights

Var	Dim1	Dim2
WKVA	1	1

Y Loadings

Var	Dim1	Dim2
WKVA	1	1

Y Scores

Case	Dim1	Dim2
CASE1	-0.0959	-0.457
CASE2	-0.911	-0.929
CASE3	-1.61	-1.31
CASE4	-1.36	-1.71
CASE5	-0.453	-1.16
CASE6	-0.315	-1.28
CASE11	1.89	0.504
CASE12	-0.539	-0.451
CASE13	-0.692	-1.22
CASE14	-0.491	-1.04
CASE15	0.326	-0.12
CASE16	1.44	0.601
CASE17	0.913	0.183
CASE18	1.57	0.366
CASE19	0.886	0.319
CASE20	1.52	0.436
CASE21	0.672	0.0832
CASE22	1.55	0.82
CASE23	0.781	-0.0382
CASE24	1.25	0.726
CASE25	0.318	0.0188
CASE26	0.493	0.453
CASE27	0.405	0.889
CASE28	-0.246	0.19
CASE29	0.278	-0.648
CASE30	0.0441	-0.628
CASE31	0.187	-0.235
CASE32	-0.677	0.0136
CASE33	-0.406	-0.0349
CASE34	1.42	0.00554
CASE35	2.13	0.364
CASE36	1.15	-0.321
CASE37	1.14	0.274
CASE38	0.00474	-0.61
CASE39	2.21	0.569
CASE40	-0.461	-0.0345
CASE41	-1.26	-0.846
CASE42	-0.216	-0.517
CASE43	-0.277	-0.585
CASE44	-0.0486	0.797
CASE45	0.686	1.35
CASE46	0.543	-0.399
CASE47	0.947	-0.65
CASE48	2.09	0.801
CASE49	2.22	0.834
CASE52	1.45	1.51
CASE53	1.31	1.05
CASE54	1.29	1.33
CASE56	0.925	0.756
CASE57	1.67	0.972

CASE58 1.55 0.502
CASE59 0.972 0.0304
CASE60 0.347 0.0509
CASE61 -0.22 -0.39
CASE62 0.278 -0.233
CASE63 0.381 -0.359
CASE64 -0.954 -0.283
CASE65 1.25 0.878
CASE66 -1.64 -0.77
CASE67 -1.43 -0.135
CASE68 -0.222 0.688
CASE69 -0.134 -0.0594
CASE70 0.116 0.0215
CASE71 0.0135 0.226
CASE72 0.111 0.609
CASE73 -0.636 0.273
CASE74 -0.463 0.158
CASE75 -0.808 -0.743
CASE76 -0.449 0.136
CASE77 -0.182 0.0988
CASE78 -0.398 -0.0606
CASE79 -0.322 0.111
CASE81 -1.25 0.166
CASE82 -0.731 0.461
CASE83 0.0748 0.606
CASE84 -0.311 0.83
CASE85 -0.026 0.867
CASE86 0.431 0.98
CASE87 -0.0979 0.219
CASE88 0.704 0.211
CASE89 0.229 1.07
CASE90 -0.967 -0.657
CASE91 0.129 0.379
CASE92 -0.997 -0.181
CASE93 -0.756 0.0188
CASE94 0.947 1.08
CASE96 0.189 0.754
CASE97 -0.0164 -0.0742
CASE98 -0.862 -0.81
CASE99 -0.589 -0.481
CASE100 -0.0883 -0.264
CASE101 -0.051 0.0705
CASE102 -0.114 0.463
CASE103 -0.126 0.59
CASE104 -1.08 -0.424
CASE105 -1.06 -0.588
CASE106 -0.367 0.219
CASE107 -2.25 -0.935
CASE108 0.359 0.293
CASE109 -0.189 0.0229
CASE110 0.0384 -0.242
CASE111 0.0533 0.277
CASE112 -0.928 -0.714
CASE113 0.903 1.57
CASE114 -0.154 -0.113
CASE115 -0.685 -0.388
CASE116 0.00728 0.274
CASE117 -1.09 -0.731
CASE118 -2.19 -1.16
CASE119 -2.55 -1.54
CASE120 -1.39 -1.21
CASE121 -2.55 -1.54
CASE122 -0.661 0.0722
CASE123 -0.483 0.351
CASE124 -1.28 -0.864
CASE125 -1.18 -0.973
CASE126 -0.633 -0.365
CASE127 0.828 0.712

Y R2 (Communalities)

Var Dim1 Dim2
WKVA 0.519 0.603

Inner Relation Coefficients:
0.386 0.23

(Preprocessed) Regression Coefficients

Var WKVA
SLUDGE -0.161
QNCHH2O 0.0332
CONH2O 0.0637
VNTTHR -0.035
TOTVFLOWS -0.0209
VNTDP -0.0309
LNWVOL 0.105
GTEMP 0.0326
CO -0.168
O2 0.0367
GASFLOW -0.304
MH3TEMP 0.0821
WESPWSH -0.148
BUNSPD -0.102
SFTRPM 0.0672
DFTPRES -0.249

Regression Coefficients

Var WKVA
Inter 141
SLUDGE -0.00000821
QNCHH2O 0.000294
CONH2O 0.000442
VNTTHR -0.702
TOTVFLOWS -0.329
VNTDP -0.00203
LNWVOL 1.05
GTEMP 0.000772
CO -0.02
O2 0.00335
GASFLOW -0.0000401
MH3TEMP 0.000633
WESPWSH -0.927
BUNSPD -0.00175
SFTRPM 0.0551
DFTPRES -0.711

Score Matrix A: T=XA

Var Dim1 Dim2
SLUDGE -0.383 -0.059

QNCHH2O	-0.0384	0.209
CONH2O	0.157	0.0128
VNTTHR	-0.153	0.105
TOTVFLOWS	0.00928	-0.106
VNTDP	-0.162	0.137
LNWVOL	0.349	-0.128
GTEMP	0.0593	0.042
CO	-0.323	-0.187
O2	0.17	-0.125
GASFLOW	-0.521	-0.445
MH3TEMP	-0.00907	0.372
WESPWSH	-0.0183	-0.614
BUNSPD	-0.325	0.101
SFTRPM	-0.0814	0.428
DFTPRES	-0.456	-0.316

Predictions

Case	WKVA
CASE1	1.3
CASE2	1.35
CASE3	1.29
CASE4	1.35
CASE5	1.41
CASE6	1.44
CASE11	1.51
CASE12	1.34
CASE13	1.37
CASE14	1.38
CASE15	1.41
CASE16	1.44
CASE17	1.43
CASE18	1.48
CASE19	1.41
CASE20	1.48
CASE21	1.41
CASE22	1.39
CASE23	1.45
CASE24	1.44
CASE25	1.4
CASE26	1.38
CASE27	1.32
CASE28	1.32
CASE29	1.5
CASE30	1.47
CASE31	1.44
CASE32	1.28
CASE33	1.3
CASE34	1.54
CASE35	1.6
CASE36	1.56
CASE37	1.46
CASE38	1.4
CASE39	1.54
CASE40	1.35
CASE41	1.35
CASE42	1.43
CASE43	1.41
CASE44	1.23
CASE45	1.32
CASE46	1.51
CASE47	1.55
CASE48	1.56
CASE49	1.55
CASE52	1.36
CASE53	1.38
CASE54	1.38
CASE56	1.36
CASE57	1.44
CASE58	1.48
CASE59	1.45
CASE60	1.38
CASE61	1.35
CASE62	1.41
CASE63	1.47
CASE64	1.3
CASE65	1.39
CASE66	1.23
CASE67	1.2
CASE68	1.31
CASE69	1.4
CASE70	1.39
CASE71	1.37
CASE72	1.28
CASE73	1.27
CASE74	1.3
CASE75	1.36
CASE76	1.31
CASE77	1.35
CASE78	1.33
CASE79	1.31
CASE81	1.25
CASE82	1.27
CASE83	1.33
CASE84	1.28
CASE85	1.33
CASE86	1.35
CASE87	1.37
CASE88	1.39
CASE89	1.29
CASE90	1.31
CASE91	1.3
CASE92	1.3
CASE93	1.32
CASE94	1.4
CASE96	1.31
CASE97	1.38
CASE98	1.33
CASE99	1.33
CASE100	1.37
CASE101	1.33
CASE102	1.3
CASE103	1.32
CASE104	1.31
CASE105	1.36
CASE106	1.34
CASE107	1.21
CASE108	1.41
CASE109	1.32
CASE110	1.42
CASE111	1.37
CASE112	1.33
CASE113	1.28
CASE114	1.35
CASE115	1.33
CASE116	1.36
CASE117	1.29
CASE118	1.22
CASE119	1.2
CASE120	1.24
CASE121	1.2
CASE122	1.29
CASE123	1.29
CASE124	1.3
CASE125	1.33
CASE126	1.34
CASE127	1.41

Appendix G

Model 5 (First Optimum Model w/4 predictors)

PLS Master Listing

Imported from
C:\WINNT\Profiles\l487840\Desktop\morevariablesthesis.txt
Date: 6th April 2003 [12:49]
Current file spec:
C:\WINNT\Profiles\l487840\Desktop\morevariablesthesis.arc
PLSPC/W Version 4.4.
Release 2 (14 March 2000)

Response variable(s)...
WKVA
Number of response variables:
1

Predictor variable(s)...
SLUDGE WVOL
GASFLOW
DFTPRES

Number of predictor variables:
4

Cases...
CASE1 CASE2 CASE3
CASE5 CASE11 CASE12
CASE13 CASE14
CASE15 CASE16 CASE17
CASE18 CASE19 CASE20
CASE21 CASE22
CASE23 CASE24 CASE25
CASE26 CASE27 CASE28
CASE29 CASE30
CASE31 CASE32 CASE33
CASE34 CASE35 CASE36
CASE37 CASE38
CASE39 CASE40 CASE41
CASE42 CASE43 CASE44
CASE45 CASE46
CASE48 CASE49 CASE53
CASE54 CASE56 CASE57
CASE58 CASE59
CASE60 CASE61 CASE62
CASE63 CASE64 CASE65
CASE66 CASE67
CASE68 CASE69 CASE70
CASE71 CASE72 CASE73
CASE74 CASE75
CASE76 CASE77 CASE78
CASE81 CASE82 CASE83
CASE85 CASE86
CASE87 CASE88 CASE89
CASE90 CASE91 CASE92
CASE93 CASE94
CASE96 CASE97 CASE98
CASE99 CASE100 CASE101
CASE102 CASE103
CASE104 CASE105
CASE106 CASE108
CASE109 CASE110
CASE111 CASE112
CASE113 CASE114
CASE115 CASE116
CASE117 CASE120
CASE122 CASE123
CASE124 CASE125
CASE126 CASE127

Number of cases: 108

Preprocessing options. Key:
[VarName Center Scale]

[WKVA Mean Std] [SLUDGE Mean Std] [WVOL Mean Std]
[GASFLOW Mean Std]
[DFTPRES Mean Std]

Computation status: No errors encountered
Number of model dimensions:
1

Missing value code: -999
Number of missing values in X: 0
Number of missing values in Y: 0

X Block Model Information:
X Weights

Var	Dim1
SLUDGE	-0.432
WVOL	0.447
GASFLOW	-0.553
DFTPRES	-0.556

X Loadings

Var	Dim1
SLUDGE	-0.411
WVOL	0.471
GASFLOW	-0.553
DFTPRES	-0.551

X Scores

Case	Dim1
CASE1	0.224
CASE2	0.317
CASE3	-1.05
CASE5	1.34
CASE11	2.81
CASE12	-0.551
CASE13	0.561
CASE14	0.81
CASE15	1.06
CASE16	1.86
CASE17	1.22
CASE18	2.2

CASE19 0.753
CASE20 1.89
CASE21 0.696
CASE22 1.49
CASE23 1.99
CASE24 1.35
CASE25 0.48
CASE26 0.261
CASE27 -1.12
CASE28 -1.24
CASE29 2.15
CASE30 1.6
CASE31 1.25
CASE32 -1.88
CASE33 -1.39
CASE34 3.08
CASE35 3.92
CASE36 3.26
CASE37 1.54
CASE38 0.758
CASE39 3.26
CASE40 -0.71
CASE41 -0.705
CASE42 1.36
CASE43 0.951
CASE44 -0.896
CASE45 -1.1
CASE46 2.32
CASE48 3.87
CASE49 3.27
CASE53 -0.202
CASE54 -0.509
CASE56 -0.5
CASE57 1.22
CASE58 2.12
CASE59 1.71
CASE60 0.152
CASE61 -0.63
CASE62 0.725
CASE63 1.6
CASE64 -1.77
CASE65 0.993
CASE66 -2.13
CASE67 -2.57
CASE68 -1.28
CASE69 0.0994
CASE70 0.245
CASE71 -0.658
CASE72 -1.21
CASE73 -2.18
CASE74 -1.3
CASE75 -0.445
CASE76 -1.04
CASE77 -0.681
CASE78 -0.791
CASE81 -2.52
CASE82 -1.86
CASE83 -0.97
CASE85 -1.58
CASE86 -0.925
CASE87 -0.951
CASE88 0.398
CASE89 -2.03
CASE90 -1.57
CASE91 -0.571
CASE92 -1.84
CASE93 -1.64
CASE94 -0.0755
CASE96 -1.32
CASE97 -0.315
CASE98 -0.761
CASE99 -0.912
CASE100 -0.158
CASE101 -0.864
CASE102 -1.47
CASE103 -1.23
CASE104 -1.34
CASE105 -0.893
CASE106 -0.761
CASE108 0.316
CASE109 -0.422
CASE110 1.22
CASE111 0.107
CASE112 -0.65
CASE113 -1.25
CASE114 0.0767
CASE115 -0.276
CASE116 -0.0449
CASE117 -0.81
CASE120 -0.748
CASE122 -1.43
CASE123 -1.64
CASE124 -1.17
CASE125 -0.813
CASE126 -0.625
CASE127 0.113

X R2 (Communalities)

Var Dim1
SLUDGE 0.365
WVOL 0.479
GASFLOW 0.659
DFTPRES 0.655

Variable Importance
0
0.5 1
+------------------
-----+----------------------+
SLUDGE
****
WVOL
****
**
GASFLOW
****
****
DFTPRES
****
****

Y Block Model Information:
Y Weights

Var Dim1
WKVA 1

Y Loadings

Var Dim1
WKVA 1

Y Scores

Case Dim1
CASE1 -0.202
CASE2 -1.1
CASE3 -1.87
CASE5 -0.596
CASE11 1.98
CASE12 -0.691
CASE13 -0.859
CASE14 -0.637
CASE15 0.262
CASE16 1.49
CASE17 0.909
CASE18 1.64
CASE19 0.88
CASE20 1.57
CASE21 0.643
CASE22 1.61
CASE23 0.765
CASE24 1.28
CASE25 0.254
CASE26 0.446
CASE27 0.349
CASE28 -0.367
CASE29 0.21
CASE30 -0.0477
CASE31 0.11
CASE32 -0.842
CASE33 -0.544
CASE34 1.47
CASE35 2.25
CASE36 1.17
CASE37 1.16
CASE38 -0.0911
CASE39 2.34
CASE40 -0.605
CASE41 -1.49
CASE42 -0.334
CASE43 -0.402
CASE44 -0.15
CASE45 0.659
CASE46 0.502
CASE48 2.2
CASE49 2.35
CASE53 1.35
CASE54 1.33
CASE56 0.922
CASE57 1.75
CASE58 1.61
CASE59 0.975
CASE60 0.286
CASE61 -0.338
CASE62 0.21
CASE63 0.323
CASE64 -1.15
CASE65 1.28
CASE66 -1.9
CASE67 -1.67
CASE68 -0.341
CASE69 -0.244
CASE70 0.0315
CASE71 -0.0815
CASE72 0.0255
CASE73 -0.797
CASE74 -0.606
CASE75 -0.986
CASE76 -0.591
CASE77 -0.297
CASE78 -0.535
CASE81 -1.47
CASE82 -0.901
CASE83 -0.0139
CASE85 -0.125
CASE86 0.378
CASE87 -0.204
CASE88 0.679
CASE89 0.156
CASE90 -1.16
CASE91 0.0452
CASE92 -1.19
CASE93 -0.93
CASE94 0.947
CASE96 0.111
CASE97 -0.114
CASE98 -1.05
CASE99 -0.746
CASE100 -0.194
CASE101 -0.153
CASE102 -0.222
CASE103 -0.235
CASE104 -1.28
CASE105 -1.26
CASE106 -0.501
CASE108 0.3
CASE109 -0.305
CASE110 -0.0541
CASE111 -0.0377
CASE112 -1.12
CASE113 0.898
CASE114 -0.266
CASE115 -0.851
CASE116 -0.0883
CASE117 -1.3
CASE120 -1.62
CASE122 -0.825
CASE123 -0.629
CASE124 -1.51
CASE125 -1.39
CASE126 -0.794
CASE127 0.815

Y R2 (Communalities)

Var Dim1
WKVA 0.559

Inner Relation Coefficients:
0.509

(Preprocessed) Regression Coefficients

Var WKVA
SLUDGE -0.22
WVOL 0.227
GASFLOW -0.281
DFTPRES -0.283

Regression Coefficients

Var	WKVA
Inter	0.79
SLUDGE	-0.0000102
WVOL	0.0201
GASFLOW	-0.0000368
DFTPRES	-0.765

Score Matrix A: T=XA

Var	Dim1
SLUDGE	-0.432
WVOL	0.447
GASFLOW	-0.553
DFTPRES	-0.556

Predictions

Case	WKVA
CASE1	1.39
CASE2	1.39
CASE3	1.32
CASE5	1.44
CASE11	1.51
CASE12	1.35
CASE13	1.4
CASE14	1.41
CASE15	1.43
CASE16	1.47
CASE17	1.43
CASE18	1.48
CASE19	1.41
CASE20	1.47
CASE21	1.41
CASE22	1.45
CASE23	1.47
CASE24	1.44
CASE25	1.4
CASE26	1.39
CASE27	1.32
CASE28	1.31
CASE29	1.48
CASE30	1.45
CASE31	1.44
CASE32	1.28
CASE33	1.3
CASE34	1.53
CASE35	1.57
CASE36	1.54
CASE37	1.45
CASE38	1.41
CASE39	1.54
CASE40	1.34
CASE41	1.34
CASE42	1.44
CASE43	1.42
CASE44	1.33
CASE45	1.32
CASE46	1.49
CASE48	1.57
CASE49	1.54
CASE53	1.36
CASE54	1.35
CASE56	1.35
CASE57	1.43
CASE58	1.48
CASE59	1.46
CASE60	1.38
CASE61	1.34
CASE62	1.41
CASE63	1.45
CASE64	1.29
CASE65	1.42
CASE66	1.27
CASE67	1.25
CASE68	1.31
CASE69	1.38
CASE70	1.39
CASE71	1.34
CASE72	1.31
CASE73	1.27
CASE74	1.31
CASE75	1.35
CASE76	1.32
CASE77	1.34
CASE78	1.33
CASE81	1.25
CASE82	1.28
CASE83	1.33
CASE85	1.3
CASE86	1.33
CASE87	1.33
CASE88	1.39
CASE89	1.27
CASE90	1.3
CASE91	1.35
CASE92	1.28
CASE93	1.29
CASE94	1.37
CASE96	1.31
CASE97	1.36
CASE98	1.34
CASE99	1.33
CASE100	1.37
CASE101	1.33
CASE102	1.3
CASE103	1.31
CASE104	1.31
CASE105	1.33
CASE106	1.34
CASE108	1.39
CASE109	1.35
CASE110	1.43
CASE111	1.38
CASE112	1.34
CASE113	1.31
CASE114	1.38
CASE115	1.36
CASE116	1.37
CASE117	1.33
CASE120	1.34
CASE122	1.3
CASE123	1.29
CASE124	1.32
CASE125	1.33
CASE126	1.34
CASE127	1.38

Appendix H

Model 6 (Second Optimum Model, considers interactions)

PLS Master Listing

Imported from
C:\WINNT\Profiles\I487840\Desktop\morevariablesthesis.txt
Date: 6th April 2003 [12:53]
Current file spec:
C:\WINNT\Profiles\I487840\Desktop\morevariablesthesis.arc
PLSPC/W Version 4.4.
Release 2 (14 March 2000)

Response variable(s)...
WKVA
Number of response variables:
1

Predictor variable(s)...
SLUDGE WVOL
GASFLOW
DFTPRES
SLUDGE*DFTPRES
Number of predictor variables:
5

Cases...
CASE1 CASE2 CASE3
CASE5 CASE11 CASE12
CASE13 CASE14
CASE15 CASE16 CASE17
CASE18 CASE19 CASE20
CASE21 CASE22
CASE23 CASE24 CASE25
CASE26 CASE27 CASE28
CASE29 CASE30
CASE31 CASE32 CASE33
CASE34 CASE35 CASE36
CASE37 CASE38
CASE39 CASE40 CASE41
CASE42 CASE43 CASE44
CASE45 CASE46
CASE48 CASE49 CASE53
CASE54 CASE56 CASE57
CASE58 CASE59
CASE60 CASE61 CASE62
CASE63 CASE64 CASE65
CASE66 CASE67
CASE68 CASE69 CASE70
CASE71 CASE72 CASE73
CASE74 CASE75
CASE76 CASE77 CASE78
CASE81 CASE82 CASE83
CASE85 CASE86
CASE87 CASE88 CASE89
CASE90 CASE91 CASE92
CASE93 CASE94
CASE96 CASE97 CASE98
CASE99 CASE100 CASE101
CASE102 CASE103
CASE104 CASE105
CASE106 CASE108
CASE109 CASE110
CASE111 CASE112
CASE113 CASE114
CASE115 CASE116
CASE117 CASE120
CASE122 CASE123
CASE124 CASE125
CASE126 CASE127

Number of cases: 108

Preprocessing options. Key:
[VarName Center Scale]

[WKVA Mean Std]
[SLUDGE Mean Std]
[WVOL Mean Std]
[GASFLOW Mean Std]
[DFTPRES Mean Std]
[SLUDGE*DFTPRES Mean Std]

Computation status: No errors encountered
Number of model dimensions:
1

Missing value code: -999
Number of missing values in X: 0
Number of missing values in Y: 0

X Block Model Information:
X Weights

Var	Dim1
SLUDGE	-0.4
WVOL	0.414
GASFLOW	-0.512
DFTPRES	-0.515
SLUDGE*DFTPRES	0.383

X Loadings

Var	Dim1
SLUDGE	-0.352
WVOL	0.425
GASFLOW	-0.488
DFTPRES	-0.557
SLUDGE*DFTPRES	0.384

X Scores

Case	Dim1
CASE1	0.336
CASE2	0.359
CASE3	-0.602
CASE5	1.01
CASE11	2.86
CASE12	-0.48

```
CASE13  0.264
CASE14  0.519
CASE15  0.787
CASE16  1.63
CASE17  0.859
CASE18  2.02
CASE19  0.507
CASE20  1.67
CASE21  0.54
CASE22  1.21
CASE23  1.69
CASE24  0.895
CASE25  0.281
CASE26  0.326
CASE27  -0.691
CASE28  -0.958
CASE29  1.98
CASE30  1.31
CASE31  0.897
CASE32  -1.35
CASE33  -1.11
CASE34  3.6
CASE35  5.04
CASE36  3.7
CASE37  1.26
CASE38  0.567
CASE39  4.37
CASE40  -0.701
CASE41  -1.23
CASE42  0.576
CASE43  0.571
CASE44  -0.968
CASE45  -0.762
CASE46  2.56
CASE48  4.66
CASE49  4.16
CASE53  -0.604
CASE54  -0.669
CASE56  -0.707
CASE57  1.34
CASE58  2.9
CASE59  2.3
CASE60  -0.107
CASE61  -1.08
CASE62  0.899
CASE63  2.2
CASE64  -1.71
CASE65  1.65
CASE66  -1.81
CASE67  -2.08
CASE68  -1.06
CASE69  -0.137
CASE70  -0.0667
CASE71  -0.96
CASE72  -1.26
CASE73  -1.89
CASE74  -1.31
CASE75  -0.804
CASE76  -1
CASE77  -0.826
CASE78  -0.922
CASE81  -2.16
CASE82  -1.85
CASE83  -0.807
CASE85  -1.22
CASE86  -0.766
CASE87  -0.907
CASE88  0.0452
CASE89  -1.58
CASE90  -1.66
CASE91  -0.857
CASE92  -1.58
CASE93  -1.38
CASE94  -0.21
CASE96  -1.19
CASE97  -0.596
CASE98  -0.969
CASE99  -1.01
CASE100 -0.527
CASE101 -0.995
CASE102 -1.3
CASE103 -1.03
CASE104 -1.27
CASE105 -0.847
CASE106 -0.756
CASE108  0.139
CASE109 -0.663
CASE110  1.33
CASE111 -0.046
CASE112 -0.886
CASE113 -1.24
CASE114 -0.28
CASE115 -0.628
CASE116 -0.217
CASE117 -1.16
CASE120 -1.06
CASE122 -1.34
CASE123 -1.44
CASE124 -1.42
CASE125 -1.17
CASE126 -0.856
CASE127 -0.0964

X R2 (Communalities)

Var         Dim1
SLUDGE        0.299
WVOL        0.435
GASFLOW       0.575
DFTPRES       0.748
SLUDGE*DFTPRES 0.356


Variable Importance
                 0
0.5                 1
                 +----------------
-----+--------------------+
SLUDGE
*********************
WVOL
******************************
GASFLOW
***********************************
****
DFTPRES
***********************************
***************
SLUDGE*DFTPRES
************************


-----------------------------------
-------------------------


Y Block Model Information:
Y Weights

Var  Dim1
```

WKVA 1

Y Loadings

Var Dim1
WKVA 1

Y Scores

Case Dim1
CASE1 -0.202
CASE2 -1.1
CASE3 -1.87
CASE5 -0.596
CASE11 1.98
CASE12 -0.691
CASE13 -0.859
CASE14 -0.637
CASE15 0.262
CASE16 1.49
CASE17 0.909
CASE18 1.64
CASE19 0.88
CASE20 1.57
CASE21 0.643
CASE22 1.61
CASE23 0.765
CASE24 1.28
CASE25 0.254
CASE26 0.446
CASE27 0.349
CASE28 -0.367
CASE29 0.21
CASE30 -0.0477
CASE31 0.11
CASE32 -0.842
CASE33 -0.544
CASE34 1.47
CASE35 2.25
CASE36 1.17
CASE37 1.16
CASE38 -0.0911
CASE39 2.34
CASE40 -0.605
CASE41 -1.49
CASE42 -0.334
CASE43 -0.402
CASE44 -0.15
CASE45 0.659
CASE46 0.502
CASE48 2.2
CASE49 2.35
CASE53 1.35
CASE54 1.33
CASE56 0.922
CASE57 1.75
CASE58 1.61
CASE59 0.975
CASE60 0.286
CASE61 -0.338
CASE62 0.21
CASE63 0.323
CASE64 -1.15
CASE65 1.28
CASE66 -1.9
CASE67 -1.67
CASE68 -0.341
CASE69 -0.244
CASE70 0.0315
CASE71 -0.0815
CASE72 0.0255
CASE73 -0.797
CASE74 -0.606
CASE75 -0.986
CASE76 -0.591
CASE77 -0.297
CASE78 -0.535
CASE81 -1.47
CASE82 -0.901
CASE83 -0.0139
CASE85 -0.125
CASE86 0.378
CASE87 -0.204
CASE88 0.679
CASE89 0.156
CASE90 -1.16
CASE91 0.0452
CASE92 -1.19
CASE93 -0.93
CASE94 0.947
CASE96 0.111
CASE97 -0.114
CASE98 -1.05
CASE99 -0.746
CASE100 -0.194
CASE101 -0.153
CASE102 -0.222
CASE103 -0.235
CASE104 -1.28
CASE105 -1.26
CASE106 -0.501
CASE108 0.3
CASE109 -0.305
CASE110 -0.0541
CASE111 -0.0377
CASE112 -1.12
CASE113 0.898
CASE114 -0.266
CASE115 -0.851
CASE116 -0.0883
CASE117 -1.3
CASE120 -1.62
CASE122 -0.825
CASE123 -0.629
CASE124 -1.51
CASE125 -1.39
CASE126 -0.794
CASE127 0.815

Y R2 (Communalities)

Var Dim1
WKVA 0.587

Inner Relation Coefficients:
0.493

(Preprocessed) Regression Coefficients

Var WKVA

SLUDGE -0.198
WVOL 0.204
GASFLOW -0.252
DFTPRES -0.254
SLUDGE*DFTPRES 0.189

Regression Coefficients

Var WKVA
Inter 0.843
SLUDGE -0.00000916
WVOL 0.018
GASFLOW -0.000033
DFTPRES -0.686
SLUDGE*DFTPRES
0.000231

Score Matrix A: T=XA

Var Dim1
SLUDGE -0.4
WVOL 0.414
GASFLOW -0.512
DFTPRES -0.515
SLUDGE*DFTPRES 0.383

Predictions

Case WKVA
CASE1 1.39
CASE2 1.39
CASE3 1.35
CASE5 1.42
CASE11 1.51
CASE12 1.35
CASE13 1.39
CASE14 1.4
CASE15 1.41
CASE16 1.45
CASE17 1.42
CASE18 1.47
CASE19 1.4
CASE20 1.45
CASE21 1.4
CASE22 1.43
CASE23 1.46
CASE24 1.42
CASE25 1.39
CASE26 1.39
CASE27 1.34
CASE28 1.33
CASE29 1.47
CASE30 1.44
CASE31 1.42
CASE32 1.31
CASE33 1.32
CASE34 1.55
CASE35 1.62
CASE36 1.55
CASE37 1.43
CASE38 1.4
CASE39 1.58
CASE40 1.34
CASE41 1.31
CASE42 1.4
CASE43 1.4
CASE44 1.33
CASE45 1.34
CASE46 1.5
CASE48 1.6
CASE49 1.57
CASE53 1.35
CASE54 1.34
CASE56 1.34
CASE57 1.44
CASE58 1.51
CASE59 1.48
CASE60 1.37
CASE61 1.32
CASE62 1.42
CASE63 1.48
CASE64 1.29
CASE65 1.45
CASE66 1.29
CASE67 1.27
CASE68 1.32
CASE69 1.37
CASE70 1.37
CASE71 1.33
CASE72 1.31
CASE73 1.28
CASE74 1.31
CASE75 1.34
CASE76 1.33
CASE77 1.33
CASE78 1.33
CASE81 1.27
CASE82 1.29
CASE83 1.34
CASE85 1.32
CASE86 1.34
CASE87 1.33
CASE88 1.38
CASE89 1.3
CASE90 1.29
CASE91 1.33
CASE92 1.3
CASE93 1.31
CASE94 1.36
CASE96 1.32
CASE97 1.35
CASE98 1.33
CASE99 1.33
CASE100 1.35
CASE101 1.33
CASE102 1.31
CASE103 1.32
CASE104 1.31
CASE105 1.33
CASE106 1.34
CASE108 1.38
CASE109 1.34
CASE110 1.44
CASE111 1.37
CASE112 1.33
CASE113 1.31
CASE114 1.36
CASE115 1.34
CASE116 1.36
CASE117 1.32
CASE120 1.32
CASE122 1.31
CASE123 1.3
CASE124 1.31
CASE125 1.32
CASE126 1.33
CASE127 1.37

Appendix I

EVOP Test Data

Test 1	sludge	airflow	KVA
03-23-03 00:01	14483.75	13035.94043	1.016978145
03-23-03 00:02	14487.96191	13026.95898	1.014658093
03-23-03 00:03	14479.55859	12983.43457	1.014698982
03-23-03 00:04	14467.78125	13027.79688	1.01243186
03-23-03 00:05	14436.75879	13044.47852	1.010556817
03-23-03 00:06	14405.82813	13110.40527	1.007711768
03-23-03 00:07	14415.58984	12928.14941	1.012019873
03-23-03 00:08	14391.98438	13023.28711	1.01085794
03-23-03 00:09	14354.23438	13026.26758	1.014541745
03-23-03 00:10	14324.95313	13031.09082	1.015072942
03-23-03 00:11	14313.70996	12995.36133	1.014327168
03-23-03 00:12	14296.4375	13101.26074	1.016691327
03-23-03 00:13	14280.04004	13042.70117	1.013509154
03-23-03 00:14	14271.96484	12985.99121	1.006390333
03-23-03 00:15	14292.81543	12916.0293	1.003790259
03-23-03 00:16	14293.70996	12971.99414	1.002991438
03-23-03 00:17	14292.13379	12984.53613	0.999472857
03-23-03 00:18	14279.70996	12989.20215	0.998089373
03-23-03 00:19	14259.25	12970.27637	1.000219226
03-23-03 00:20	14223.0625	13003.22461	1.003916025
03-23-03 00:21	14178.70313	12949.82324	1.008400083
03-23-03 00:22	14148.9873	12915.00879	1.006252527
03-23-03 00:23	14130.02734	12922.76855	1.008513093
03-23-03 00:24	14146.57422	12882.83398	1.013297677
03-23-03 00:25	14124.18359	12865.54297	1.019636273
03-23-03 00:26	14100.9248	13040.53418	1.022042632
03-23-03 00:27	14085.42188	12860.78027	1.022057056
03-23-03 00:28	14082.53809	12942.10449	1.020439625
03-23-03 00:29	14076.12793	12915.51465	1.022794247
03-23-03 00:30	14040.70313	12926.78516	1.022688627
03-23-03 00:31	14001.55566	12867.92969	1.017370939
03-23-03 00:32	13977.625	12778.06543	1.023202062
03-23-03 00:33	13946.44922	12817.60449	1.022072196
03-23-03 00:34	13886.54004	12846.95605	1.024793267
03-23-03 00:35	13846.35938	12940.23926	1.026869893
03-23-03 00:36	13849.10254	12826.62207	1.022594333
03-23-03 00:37	13832.19238	12774.73438	1.027116418
03-23-03 00:38	13819.02246	12739.56836	1.023735285
03-23-03 00:39	13784.80371	12713.14746	1.023127437
03-23-03 00:40	13787.3623	12740.43164	1.024632573
average	**14172.41096**	**12936.63455**	**1.014764039**

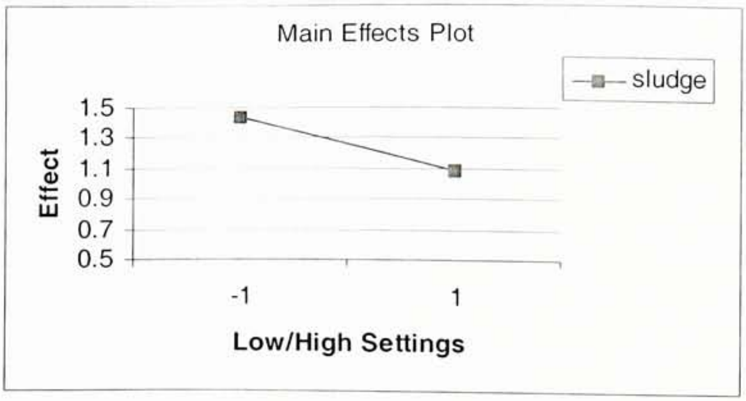
Test 2 data

	Sludge (16,223)	airflow (17,585 max)	KVA (0.97 min)
03-13-03 01:51	12256.77441	11483.40137	1.187356114
03-13-03 01:52	12259.58691	11397.72656	1.187210679
03-13-03 01:53	12276.66504	11433.48926	1.184314609
03-13-03 01:54	12320.77441	11594.64258	1.181380272
03-13-03 01:55	12337.25	11446.93945	1.174921632
03-13-03 01:56	12336.75879	11519.91992	1.174862385
03-13-03 01:57	12317.35254	11547.53516	1.175497651
03-13-03 01:58	12268.25879	11529.78418	1.173534274
03-13-03 01:59	12222.23047	11562.5957	1.171374321
03-13-03 02:00	12182.78418	11531.68652	1.168680787
03-13-03 02:01	12174.25	11476.27441	1.164955974
03-13-03 02:02	12165	11588.29102	1.164105296
03-13-03 02:03	12145.72754	11609.55371	1.163196445
03-13-03 02:04	12135.89355	11711.67871	1.161361814
03-13-03 02:05	12157.22754	11767.60254	1.15555644
03-13-03 02:06	12146.35547	11744.09473	1.155313134
03-13-03 02:07	12137.97754	11628.63672	1.158980131
03-13-03 02:08	12153.19043	11710.84668	1.159398198
03-13-03 02:09	12169.99316	11762.38281	1.158316016
03-13-03 02:10	12190.41309	11836.99512	1.155225873
03-13-03 02:11	12217.19629	11764.40332	1.154870152
03-13-03 02:12	12213.81738	11920.35156	1.152967334
03-13-03 02:13	12213.08691	12006.80566	1.144392848
03-13-03 02:14	12209.25488	11849.08008	1.134191394
03-13-03 02:15	12208.42676	11603.77441	1.132281184
03-13-03 02:16	12182.6748	11497.79785	1.12961185
03-13-03 02:17	12165.15918	11335.66504	1.130093694
03-13-03 02:18	12163.25	11310.9209	1.134723067
03-13-03 02:19	12159.35254	11244.02734	1.129710913
03-13-03 02:20	12135.16797	11188.66699	1.129925728
03-13-03 02:21	12127.29297	11036.65234	1.135183454
03-13-03 02:22	12108.71191	11069.9707	1.137101293
03-13-03 02:23	12111.1748	11143.2959	1.138360858
03-13-03 02:24	12089.84668	10981.0498	1.140356898
03-13-03 02:25	12069.10254	11132.36621	1.144702077
03-13-03 02:26	11908.41309	11177.74707	1.144119382
03-13-03 02:27	11705.59668	11515.71777	1.143506408
03-13-03 02:28	11497.54297	11613.6084	1.14021647
03-13-03 02:29	11294.09375	11567.80469	1.142320991
03-13-03 02:30	11098.58691	11666.62402	1.145545721
average	**12105.80532**	**11512.76018**	**1.153993094**

		airflow	sludge	KVA
test 3	02-02-03 20:43	10742.83	5118.587	1.46197
	02-02-03 20:44	10715.52	5085.903	1.46097
	02-02-03 20:45	10921.26	5090.603	1.459387
	02-02-03 20:46	10813.24	5062.575	1.458121
	02-02-03 20:47	10796.56	5070.303	1.452919
	02-02-03 20:48	10775.31	5047.325	1.455566
	02-02-03 20:49	10865.56	5055.84	1.454094
	02-02-03 20:50	10868.96	5040.006	1.458171
	02-02-03 20:51	10896.27	5052.759	1.462479
	02-02-03 20:52	10882.18	5033.603	1.464628
	02-02-03 20:53	10918.84	5042.447	1.471001
	02-02-03 20:54	10830.55	5018.672	1.470948
	02-02-03 20:55	10918.28	5039.394	1.476439
	02-02-03 20:56	10862.04	5021.881	1.479322
	02-02-03 20:57	10843.48	5040.334	1.484322
	02-02-03 20:58	10901.27	5019.131	1.482365
	02-02-03 20:59	10916.89	5035.987	1.483003
	02-02-03 21:00	10891.02	5009.84	1.484915
	02-02-03 21:01	10870.51	5022.147	1.483809
	02-02-03 21:02	10864.96	5010.131	1.489821
	02-02-03 21:03	10869.98	5023.256	1.496258
	02-02-03 21:04	10911.92	5008.347	1.492097
	02-02-03 21:05	10968.21	5020.994	1.492633
	02-02-03 21:06	10927.67	5000.125	1.490389
	02-02-03 21:07	10831.63	5015.628	1.486569
	02-02-03 21:08	10856.9	5009.484	1.483146
	02-02-03 21:09	10866.16	5027.366	1.490924
	02-02-03 21:10	10891.09	5009.922	1.493886
	02-02-03 21:11	10887.65	5026.166	1.497439
	02-02-03 21:12	10822.48	5008.069	1.499068
	02-02-03 21:13	10809.65	5019.15	1.523753
	02-02-03 21:14	10872.78	5000.853	1.532446
	02-02-03 21:15	10846.57	5018.631	1.534523
	02-02-03 21:16	10901.34	5000.194	1.53679
	02-02-03 21:17	10896.03	5021.375	1.539323
	02-02-03 21:18	10831.13	4998.609	1.542347
	02-02-03 21:19	10961.76	5005.547	1.541798
	02-02-03 21:20	10932.76	4989.019	1.535699
	02-02-03 21:21	10937.82	5004.847	1.533169
	02-02-03 21:22	10888.23	4990.969	1.528873
	02-02-03 21:23	10895.68	5005.634	1.518064
average		**10870.8**	**5027.357**	**1.492279**

Test 4

	sludge	airflow	kva
02-13-03 02:46	4148.175	12183.3	1.468378
02-13-03 02:47	4151.025	12163.69	1.466132
02-13-03 02:48	4084.137	12289.96	1.469544
02-13-03 02:49	4073.219	12299.46	1.469722
02-13-03 02:50	4007.403	12231.9	1.461471
02-13-03 02:51	3946.781	12351.66	1.459295
02-13-03 02:52	3857.944	12407.88	1.45338
02-13-03 02:53	3766.522	13724.86	1.449713
02-13-03 02:54	3693.865	14923.75	1.436825
02-13-03 02:55	3588.522	17377	1.424309
02-13-03 02:56	3518.453	17436.75	1.410357
02-13-03 02:57	3421.088	17284.86	1.397934
02-13-03 02:58	3346.397	17320.03	1.384952
02-13-03 02:59	3248.947	17237.52	1.370971
02-13-03 03:00	3175.622	16561.25	1.365683
02-13-03 03:01	3077.706	15362.91	1.366063
02-13-03 03:02	3007.166	13353.67	1.362922
02-13-03 03:03	2920.5	12766.86	1.36009
02-13-03 03:04	2845.972	12551.14	1.364701
02-13-03 03:05	2752.047	12505.62	1.361749
02-13-03 03:06	2677.713	12500.99	1.356931
02-13-03 03:07	2589.441	12471.67	1.353547
02-13-03 03:08	2522.128	12454.98	1.351942
02-13-03 03:09	2429.544	12316.16	1.345843
02-13-03 03:10	2364.659	12327.62	1.340587
02-13-03 03:11	2268.816	12240.15	1.336872
02-13-03 03:12	2211.503	12291.42	1.34641
02-13-03 03:13	2118.962	12276.95	1.358045
02-13-03 03:14	2056.188	12385.63	1.358726
02-13-03 03:15	1974.575	12348.08	1.351107
02-13-03 03:16	1894.397	12328.91	1.345208
02-13-03 03:17	1832.709	12472.65	1.344445
02-13-03 03:18	1740.462	12332.88	1.340751
02-13-03 03:19	1692.859	12279.72	1.34237
02-13-03 03:20	1630.472	12324.38	1.33895
02-13-03 03:21	1554.684	12384.99	1.336469
02-13-03 03:22	1518.347	12469.6	1.33359
02-13-03 03:23	1457.744	12434.58	1.330522
02-13-03 03:24	1371.734	12407.21	1.33188
02-13-03 03:25	1333.647	12345.65	1.323594
02-13-03 03:26	1281.041	12356.79	1.320159
02-13-03 03:27	1199.119	12392.79	1.31556
02-13-03 03:28	1159.047	12484.1	1.317083
average	**2639.797**	**13231.67**	**1.374995**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1.3
1.1
0.9
0.7
0.5
Effect
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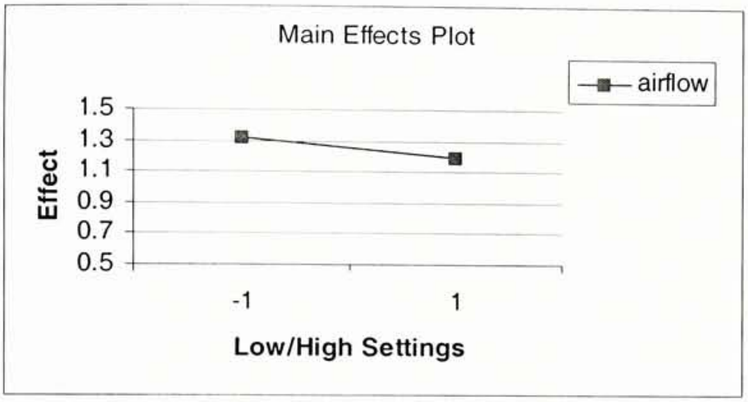
1
Low/High Settings


Main Effects Plot
airflow
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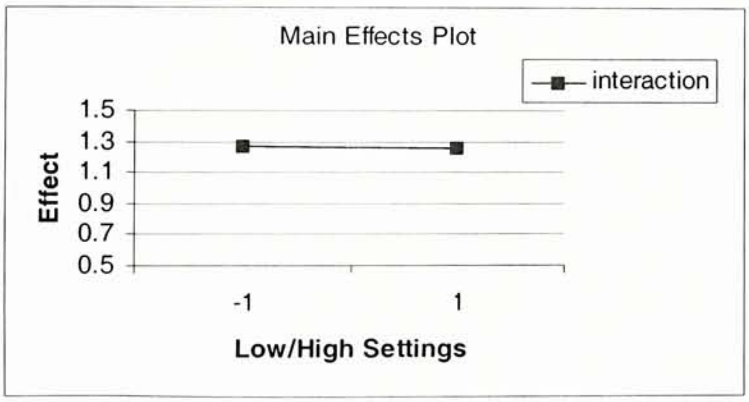
1.3
1.1
0.9
0.7
0.5
Effect
-1
1
Low/High Settings


Main Effects Plot
interaction
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1.3
1.1
0.9
0.7
0.5
Effect
-1
1
Low/High Settings