USE OF A TEXTILE WASTEWATER SLUDGE AS A SUPPLEMENTAL SOLID FUEL

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Thesis submitted to the Faculty of the

Virginia Polytechnic Institute and State University

in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Mechanical Engineering

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February, 1996
Blacksburg, Virginia

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(ABSTRACT)

The dried sludge by-product generated by the wastewater treatment system at a textile dyeing and finishing facility in southwestern Virginia is currently disposed of in a conventional landfill. This method represents not only a substantial annual cost, but also a potentially serious environmental risk. An investigation was conducted at this facility with the goal of finding an alternative use or market for this by-product of textile manufacturing. After an extensive literature search and initial analyses, the feasibility of using the by-product as a supplemental fuel in the facility's coal boilers was investigated.

Proximate analyses showed that the by-product, with a relatively high heating value and low sulfur content, was fairly well suited for use a supplemental fuel. A brief test-burn of the by-product in one boiler resulted in no observable change in boiler operation or efficiency. Following a conversation with representatives of the Virginia Department of Environmental Quality, a list was formed of the potential air pollutants which are of particular concern when considering combustion processes. Subsequent chemical analyses and mass balances showed that burning the proposed fuel mixture would release

acceptably small amounts of a majority of these pollutants. The only pollutants which represent a potential problem are two heavy metals -- chromium and nickel. Additional laboratory testing helped to locate major sources of these elements within the plant. The concentrations of these metals in the final by-product are expected to be reduced to some extent by future source-reduction efforts.

It is recommended that the information contained in this report be used to complete an application for an air permit which would allow the facility to use the by-product as a supplemental fuel in the plant's coal boilers. If this permit application is approved, significant cost savings will be realized not only from the reduction in landfilling costs, but also from a reduction in coal usage. It is further recommended that these cost savings be used to investigate further waste reduction and process optimization measures.

ACKNOWLEDGEMENTS

I would like to thank Dr. Bill Thomas, who helped to keep me on track through the many twists and turns of this project. Many thanks also to Prof. Bill Mashburn and Dr. Greg Boardman for their support, and to John Risi, my "unofficial advisor", for his invaluable guidance.

Special thanks to Kevin and Earlie and the other plant personnel for their infinite patience during my many visits. Without their help, my research could never have progressed as far as it did.

Thanks also to Marilyn Grender, Angela Goodwin, and Olver Labs for the information and services they provided.

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INTRODUCTION

Solid waste production in the United States increases steadily from year to year. However, with the ever-growing population and increasingly stricter environmental regulations, the capacity to assimilate this waste is decreasing. For this reason, the disposal of solid waste, both municipal and industrial, has become a costly process. Successful industrial waste management can often make the difference between a competitive company and one that falls into bankruptcy. The textile industry is no exception to this rule. Because of the high volume and wide variety of chemicals and processes used in this industry, textile wastes are particularly difficult to deal with.

A study was initiated at a textile dyeing and finishing plant in southwestern Virginia with the goal of reducing the energy cost and environmental impact associated with the waste produced by the plant. Liquid effluent from the various processes within the facility are channeled outside for treatment. Following some chemical treatment of the printing and dyeing effluents, all waste streams are consolidated and biologically treated in an aeration lagoon. The waste is digested to a thick sludge before continuing to a belt press. The sludge is then dried in a gas-fired rotary kiln dryer to a moisture content of less than 10 per cent.

The final dried by-product is sent to a conventional landfill for ultimate disposal at a cost of $45 per ton. The facility currently produces approximately 30 tons per week of the dried by-product. This is equivalent to a total annual landfilling cost of nearly $75,000 per year. Additional operating costs associated with the waste treatment facility, including electricity, natural gas, chemicals, labor, and maintenance costs, total approximately $775,000 per year. Due to the high cost of landfill disposal, as well as the uncertainty of its continued availability, it is hoped that some alternative use can be found for this manufacturing by-product.

Extensive research has been performed at this plant by a number of organizations in the past. Most of these studies have been concerned primarily with waste reduction within the plant and optimization of the waste treatment facility. These studies provided valuable information. However, as a result of its present financial situation, the company does not have the resources necessary to pursue such avenues. The current investigation will focus on the more modest goal of finding a less costly end-use solution to the waste disposal problem. It is hoped that the cost savings which result from this investigation will provide the facility with part of the capital required to undertake the recommendations made by previous researchers.

The goals of this investigation are as follows:

1. To identify feasible alternative uses or disposal methods for the dried by-product produced by the plant. This goal will be accomplished primarily

through an extensive search of the literature.

2. To identify, based on these alternatives, those components of the by-product which represent the greatest environmental, economic, or regulatory concerns. Government regulatory agencies will most likely be contacted for assistance in this area.
3. To locate, through mass balances and chemical analyses, the sources of the problem components within the plant. It may then be possible to reduce or eliminate these components at their origin.
4. To provide facility management with information which will assist them in implementing the alternatives identified by this investigation. Whenever information cannot be supplied directly, procedures will be outlined by which plant personnel may obtain the necessary data.

LITERATURE REVIEW

TEXTILE WET PROCESSES

Textile wet processes may be essentially divided into three categories: preparation, coloring and finishing [1].

Preparation

The fabric which enters the wet processing plant typically contains many impurities. These may be natural impurities inherent in the fibers, they may be fungicides or pesticides applied to natural fibers during growth, or they may be chemicals added during weaving operations. In any case, these impurities must be removed before the fabric can be further processed. It is estimated that this set of pretreatment processes can account for as much as 50 per cent of the total water used in a textile plant [2].

Desizing. In the textile industry, chemicals which are applied to yarns prior to the production of woven fabric are called "sizes". These chemicals enhance the tensile strength and smoothness of the yarn so that it can withstand the harsh mechanical forces it will be subjected to during weaving [1]. Starch is traditionally used as sizing for natural fibers. However, with the increasing popularity of man-made fibers, the use of synthetic sizes such as polyvinyl alcohol (PVA) and carboxymethylcellulose (CMC) has become more common. Sizes represent the largest single group of chemicals used in the textile industry today [3].

Sizing materials form a protective coating on the surface of the fabric. This coating will interfere with subsequent processing steps, giving the finished fabric a splotchy or uneven appearance. Thus, these materials must be removed early in the finishing process [4]. Starches can generally be removed by dilute acid or enzyme solutions. Synthetic sizes, however, are more difficult to remove and specialized washing processes and chemicals must be used [5].

Scouring. The scouring process is essentially an intensive washing process which removes natural oils and waxes as well as man-made contaminants such as spinning oils. This operation is usually carried out in an alkaline solution at high temperature [1]. A number of other chemicals may also be added to the scouring bath to further improve the quality of the fabric. Caustic soda (sodium hydroxide, $NaOH$) may be added to neutralize acidic materials and dissolve silicates. Surface active agents ("Surfactants") reduce the surface tension of the water, ensuring its quick and even penetration into the fabric. Detergents emulsify oils, fats and waxes and hold these materials in suspension after removing them from the fabric [4].

Bleaching. Most fabrics entering the wet processing plant, especially those containing natural fibers, have a yellowish color. These fabrics must be bleached and whitened before colors are applied. Three types of bleaching processes are available: sodium hypochlorite (NaOCl), hydrogen peroxide (H_2O_2) and sodium chlorite ($NaClO_2$). Selection of the proper material, or combination of materials, is generally a function of the fabric type and the desired end product. Because bleaching is an oxidation process, some degradation of the fabric is inevitable [4].

Mercerization. Pure cotton fibers are often subjected to a strong caustic soda solution. This process increases the tensile strength, smoothness and luster of the fabric. Water and dye absorption properties are also increased, which effectively reduces the cost of dyeing the fabric. All mercerized fabrics must be neutralized and thoroughly washed prior to dyeing in order to remove the residual caustic [4].

Coloring

Dyeing involves the addition of chemicals to change the light-reflective properties of the fabric. Color addition may be accomplished in a number of ways and at a number of different points in the textile production process. There are also many different types of dyes, each having its own set of properties. Some examples of dye types and application methods are as follows:

Acid Dyes. The molecular structure of these dyes contain anionic functional groups of sulfonic or carboxylic acid salts. They are generally dyed onto fabrics from an acid solution and are most commonly used on wool, silk, nylon and other synthetics [5].

Direct Dyes. These dyes have a long, narrow molecular structure which makes them ideally suited for use on cellulosic fibers, such as cotton, hemp and rayon. Direct dyes are generally applied from a basic solution [5].

Reactive Dyes. These dyes are similar to acid or direct dyes except that they also contain a reactive group which is capable of forming covalent bonds with the fibers. These dyes are limited to use on cellulosic or nylon fibers [5].

Vat Dyes. Initially insoluble in water, these dyes are reduced in a basic solution prior to being applied to cellulosic or synthetic fibers. After application, the dyes must be reoxidized on the fabric either by the oxygen in the air or by a mild oxidizing agent, such as hydrogen peroxide [5].

Sulfur Dyes. These dyes consist of complex reaction mixtures of selected aromatic compounds with sodium polysulfide. Like vat dyes, they must be reduced in a base prior to application and later reoxidized on the fabric [5].

Disperse Dyes. Because of the small polar structure of the molecules, these dyes allow for the dyeing of hydrophobic thermoplastic fibers such as nylon, polyester, acrylic and other synthetics. The dyes are only slightly soluble in water and must be applied using surfactants [5].

Pigment Dyes. These dyes must be set to the fabric by use of a polymeric adhesive binder. The adhesive encapsulates the pigment and locks it to the fiber surface [5].

Continuous Dyeing. In this dyeing method, the fabric is continuously passed through a dye solution of sufficient length to achieve initial dye penetration. The dye is then fixed by steam heating of the fabric [5].

Fiber (Stock) Dyeing. In this dyeing method, colors are applied to the loose fibers before they are formed into yarns [5].

Thermosol Dyeing. Polyester is often dyed by sublimation of disperse dyes into the fabric under heat and partial vacuum. When the polyester is heated to approximately 200°C, molecular motion within the fabric increases enough to allow the dye vapor to penetrate the fibers. Upon subsequent cooling, the dye is permanently trapped within the fiber [5].

Printing. Printing can be considered a specialized dyeing process in which the application medium is thick and viscous. This consistency limits dye migration and permits the retention of a pattern on the fabric. The print paste is generally applied to the fabric by means of direct transfer using a block or engraved roller or by means of a partially marked flat or rotary screen and squeegee system [5].

Finishing

Finishing changes the properties of the fabric. This change may be functional or it may simply be aesthetic. Examples of physical (dry) finishing include flattening and rolling of the cloth. Heated presses or "calendaring" rolls can also be used to improve the reflectance and luster of the fabric. Examples of chemical (wet) finishing techniques include optical finishes, softeners, anti-static agents, water repellants and fire retardants. If the fabric is to be dyed, chemicals may be added to improve dye absorption [5].

EFFLUENT CONCERNS

Heavy Metals

One of the greatest pollution problems inherent in the textile finishing industry is the presence of heavy metals in the effluent stream. Some of the metals which are of highest concern are listed in Table I along with the associated Maximum Contaminant Level (MCL) applied by the Environmental Protection Agency (EPA) to all public drinking water supplies in the United States.

The potential health hazards associated with each of these metals vary. Many of the metals listed in Table I are thought to be human carcinogens [6]. A few, such as copper and selenium, are essential nutrients but become toxic at higher concentrations. The concentration limits listed for silver and zinc are actually *Secondary* Maximum Contaminant Levels, aesthetic limits which are related to the odor, taste or color of the water rather than the potential health risks [6].

Table I - Drinking Water Standards for Various Heavy Metals [6]

Contaminant	MCL (ppm in solution or mg/l)	Contaminant	MCL (ppm in solution or mg/l)
Antimony	0.005	Lead	0.005
Arsenic	0.050	Mercury	0.002
Beryllium	0.001	Nickel	0.100
Cadmium	0.005	Selenium	0.050
Chromium	0.100	Silver	0.090
Copper	1.300	Zinc	5.000

There is also concern with metals contaminating agricultural land. Some metals -- especially copper, nickel and zinc -- can adversely affect the growth of crops. Lead does not accumulate in vegetation; however, it is possible that this metal may be accumulated in farm animals as a result of grazing on contaminated land. The metal of highest concern in agriculture is cadmium. This element is toxic to humans at lower concentrations than is necessary to affect crops. Thus, cadmium can accumulate in plants without having any adverse affects on their growth, and be passed along to humans at toxic levels [7].

The most commonly indicted source of heavy metals in the textile industry is the dyeing process. Metals are often used in the production of dyes and colorants. Table II lists eight metals and their average concentrations, on an "as used" basis, in six types of dyes.

Table II - Average Metal Concentration of Selected Dyes [8]						
Element	Acid Dyes (ppm)	Basic Dyes (ppm)	Direct Dyes (ppm)	Disperse Dyes (ppm)	Fiber Reactive Dyes (ppm)	Vat Dyes (ppm)
Arsenic	<1	<1	<1	<1	1.4	<1
Cadmium	<1	<1	<1	<1	<1	<1
Chromium	9.0	2.5	3.0	3.0	24	83
Cobalt	3.2	<1	<1	<1	<1	<1
Copper	79	33	35	45	71	110
Lead	37	6.0	28	37	52	6.0
Mercury	<1	0.5	0.5	<1	0.5	1.0
Zinc	13	32	8.0	3.0	4.0	4.0

Metals are also sometimes found in the auxiliary chemicals used during dyeing. Oxidation of vat and sulfur dye compounds, for example, is often accomplished using dichromates, which contain chromium [8].

There are other significant sources of heavy metals besides the dyeing operation. Metals may enter the effluent stream of a textile plant from a number of sources. Nickel-copper alloys, because of their exceptional strength and resistance to corrosion, are frequently used as pipes, nozzles and machine parts in the chemical and textile industries. Mercury is often used as a cathode in the electrolysis of sodium chloride to produce caustic soda, a substance which is used in high volume by textile finishing plants [9]. Water repellants, flame retardants, antifungal and anti-odor finishes may contain antimony and zinc. Incoming fabrics may be contaminated, since natural fibers can absorb heavy metals from the environment during growth. Raw water entering the plant from streams and wells may also contain metals in concentrations above effluent limits [10].

Toxicity

Along with metals limits, toxicity limits are also imposed on textile mill effluents. As the name implies, toxicity is a measure of the capability of a substance to kill living organisms. Toxicity is divided into two categories: acute and chronic. Acute toxicity is tested by exposing aquatic test organisms to some specific concentration of mill effluent. The organisms are then observed for a specified short time period, usually 48 hours. The goal of the test is to determine the "LC50", the concentration of effluent which is required to kill 50 per cent of the organisms. Chronic toxicity testing lasts much longer, using repeated dosing with renewed samples. Observations are made concerning not only the survival of the organisms, but also growth and reproduction. The goal of these observations is to determine the No Observed Effect Concentration (NOEC) of the effluent [11].

It is important to realize that toxicity and metals concentration are not equivalent. Many factors other than metals concentration can affect the toxicity of a textile plant's effluent, including surfactants, chlorinated organic compounds, oils and finishes. A plant can be in compliance with metals limits and be in violation of toxicity standards. The biodegradability of chemicals is often an important factor. A mildly toxic chemical which does not biodegrade, for example, could be much more detrimental than a highly toxic chemical which degrades quickly [10].

WASTE TREATMENT OPTIONS

"The objective of wastewater treatment is to reduce the amount of pollutants in the water to such a level that the water can be returned to the environment without causing stress on aquatic life and be of sufficient quality for subsequent (downstream) users" [12]. The design of a waste treatment system is highly dependent on such factors as the nature of the waste, the size of the facility, and the characteristics of the environment. Often, a treatment which is designed for one waste stream will not be suitable for others [2]. In general, however, a wastewater treatment scheme consists of a four-step process: (1) preliminary treatment, (2) primary sedimentation, (3) secondary treatment, and (4) sludge disposal.

Preliminary Treatment

Preliminary treatment modifies the effluent in order to improve the performance of subsequent treatment measures. One simple example of such an operation would be straining of the effluent. The waste stream is passed through screens or bar racks to remove foreign objects, such as sticks, leaves or lint, which may interfere with pumping operations [12].

Equalization is another simple preliminary treatment technique in which the effluent is allowed to collect in a large holding tank before continuing to further treatment. This helps to lessen large variations in flowrate and pollutant concentrations. Equalization can greatly improve the efficiencies of subsequent biological treatment systems, as these systems are sensitive to variations in organics and nutrients [2].

Primary Sedimentation

Sedimentation is the process by which materials are removed from a suspending fluid by means of gravity settling. Dense solid particles are easily removed from the effluent. Smaller particles, however, can remain suspended in water indefinitely. Most naturally occurring particles in water possess a negative charge. Because negative charges repel each other, these small particles generally do not agglomerate to form larger solids. The adverse affects of negative surface charges of these particles can be reduced by adding chemical coagulants [12].

A widely used coagulant is aluminum sulfate ($Al_2(SO_4)_3$), commonly known as alum. In simple terms, when this chemical is added to wastewater, positively charged ions (Al^{+3}) are released. These positively charged ions bond with suspended particles in the water, reducing their negative surface charge, as shown in Fig. 1. With their negative charges reduced, the particles are drawn together by intermolecular forces, forming larger precipitates which can be more easily removed. Gentle mixing, or flocculation, of the water can speed the agglomeration process [12].

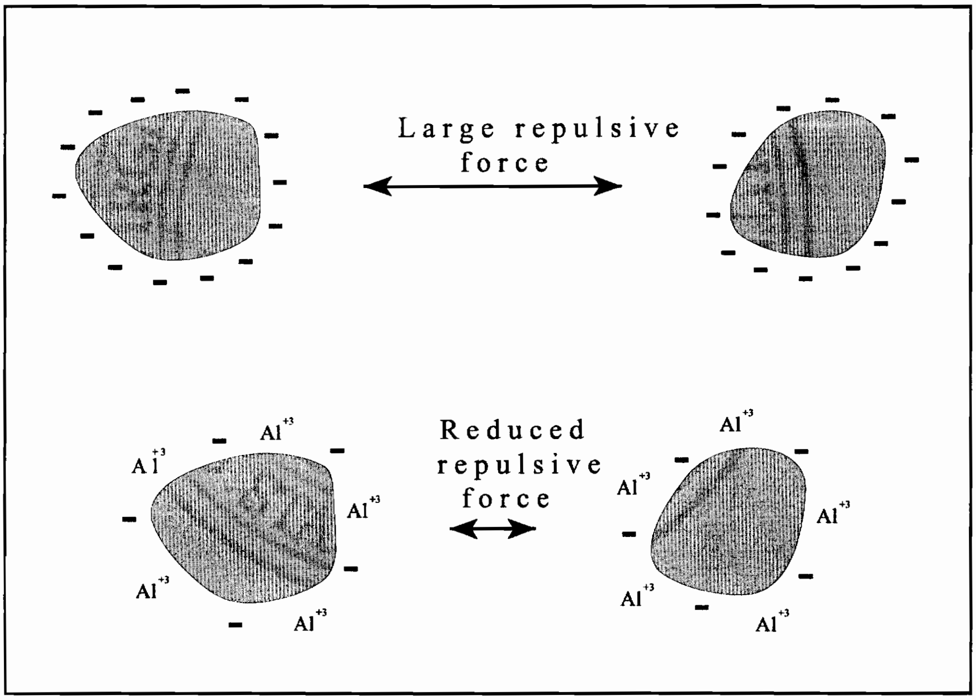

Figure 1 - Chemical Coagulation

Secondary (Biological) Treatment

Biological treatment is used to convert any soluble organic pollutants remaining in the wastewater into microbial solids which can be removed by settling. In simple terms, the microorganisms in the water feed on the organics, giving them the energy to grow and reproduce. The increasing microbial population forms a sludge which can be settled out [12]. Biological treatment typically provides better reduction of organic matter than chemical coagulation. Other pollution problems, such as biochemical oxygen demand (BOD), are also readily reduced [2].

The most common biological treatment scheme in use today is known as the activated sludge process. This process involves the use of an active population of microbes in the wastewater. Air is bubbled through the solution (aeration) in order to mix the water and provide oxygen to the organisms. As the microorganisms grow and reproduce, they not only consume most of the remaining soluble organics, but they also oxidize much of the waste material into carbon dioxide, nitrate (NO_3^-) and water. The resulting microbial mass can then be removed by settling, leaving a final effluent which is relatively free of organics [12].

An end product of wastewater treatment is a dense mixture of organic and inorganic solids in water commonly called "sludge". Sludge frequently has an offensive odor and appearance, and often contains low levels of various toxic substances. The disposal of wastewater sludge can account for as much as 50 per cent of the operating costs of a waste treatment facility [12].

SLUDGE DISPOSAL OPTIONS

Some sludge production is inevitable, and this material can be disposed of in a variety of ways. Often, especially in larger treatment plants (>10 MGD), the sludge is thickened by reducing the water content by gravity-draining or other methods before final disposal. The sludge may also be dewatered mechanically and dried in order to reduce its mass and simplify handling. Gravity-based dewatering includes spreading the sludge across sand beds and allowing the water to drain out. Alternatively, the sludge may be mechanically dewatered by use of a filter press. Due to high capital and operating costs, these dewatering processes are generally only used in medium to large treatment facilities.

Landfilling

Landfilling is the legal and controlled disposal of wastes into the ground. Although it is probably the least favorable disposal method from an environmental perspective, landfilling of industrial sludge is still a necessity and is widely practiced. Approximately 12 percent of the sludge produced by large wastewater treatment plants (>10 MGD) and 33 per cent of the sludge from small plants is disposed of in landfills [12].

The greatest concern with landfills is the production of "leachates". Waste entering a landfill invariably contains some moisture. Additional liquid can enter the landfill through precipitation (rain, etc.) and runoff from nearby surfaces. As this water flows into the landfill, it collects soluble contaminants from the surrounding waste and transports these elements downward. This contaminated liquid is known as leachate. If the leachate is allowed to escape a landfill containment system and reach the groundwater table, pollution of the drinking water supply may result. For this reason, stringent regulations are placed on all landfills operating in the United States [12].

The Solid Waste Disposal Facility Criteria, initiated by the EPA in 1991, control the location, operation and design of landfills. These regulations prevent the placement of landfills in highly populated areas or in areas with unstable land. They also require the control of all leachate produced by the landfill. In order to prevent contamination of the groundwater, certain types of waste are not allowed in landfills. All waste must pass a rigorous test procedure known as a Toxicity Characteristic Leachate Procedure (TCLP) before it is allowed to enter the landfill. This test is meant to simulate the leaching of waste in a landfill situation and detect which wastes pose a threat to the environment. Table III lists some of the contaminants which are regulated by the EPA. The center column of this table lists the maximum allowable contaminant levels for groundwater at landfill boundaries. The right-hand column lists the maximum toxicity concentration limits for the TCLP. If the leachate of a waste material is shown to contain any of the listed compounds in higher concentrations than the listed values, that waste material will be classified as "TCLP Toxic" [12].

Table III - Limits on Landfill Wastes [12]

Contaminant	Maximum Groundwater Contamination Limit (ppm in solution or mg/l)	Toxicity Concentration Limit (ppm in solution or mg/l)
Arsenic	0.05	5.0
Barium	1.0	100.0
Benzene	0.005	0.5
Cadmium	0.01	0.1
Carbon Tetrachloride	0.005	0.5
Chromium	0.05	5.0
Lead	0.05	5.0
Mercury	0.002	0.2
Selenium	0.01	1.0
Silver	0.05	5.0

Land Application

Solid waste can also be applied to land areas in order to perform some specific function. These functions may include agricultural benefits, such as fertilizing or soil conditioning, or it may involve site reclamation, such as the reclamation of strip-mined land [7]. Approximately 21 percent of the sludge produced by large wastewater treatment plants (>10 MGD) and 39 per cent of the sludge from small plants is ultimately disposed of by land application [12].

Municipal and industrial sludges often contain many of the nutrients which are essential to the growth of crops. Among the most important of these are nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), and magnesium (Mg). In general, every crop has a specific ratio of N:P:K which it requires for growth. If one of the nutrients is low, the other two will not be absorbed by the plants as efficiently. Thus, the fertilizer value of a sludge depends primarily on the N, P, and K content ratio. Industrial sludges usually contain insufficient potassium for plant growth. Supplemental fertilizers will most likely be required in order to achieve the proper N:P:K ratio [13].

The main limiting factor in the land application of industrial sludges, however, is metals content. As was previously mentioned, some heavy metals can adversely affect the growth of crops. Other metals, such as cadmium, can accumulate in crops and pose a serious health risk to humans. The cadmium content of industrial sludges often limits it application to agricultural lands [7].

Other contaminants can also preclude the use of industrial sludge as a fertilizer or soil conditioner. BOD and COD (chemical oxygen demand) of industrial wastes are generally much higher than those of municipal wastes. Industrial wastewaters often contain machine oils. Oil in agricultural soils can hinder the removal by plants of nitrogen. Textile effluents have also been known to contain pesticides, acids, solvents and other undesirable chemicals which can be toxic to plants [7].

Incineration

Incineration involves the combustion of waste materials to reduce their mass and organic content. Approximately 32 percent of the sludge produced by large wastewater treatment plants (>10 MGD) and 1 per cent of the sludge from small plants is disposed of by incineration [12]. Compared to landfilling, the incineration of solid wastes can be highly preferable. Contaminants which would remain in a landfill for generations are destroyed quickly by incineration. This disposal method not only avoids groundwater contamination, but also protects the company that produces the waste from long-term liability. Incineration produces ash, which may eventually go to landfill. Also, the concentrations of some contaminants may be higher in the ash than they were in the original waste. However, the volume of waste which goes to landfill, and therefore the cost of landfilling, is greatly reduced. In addition, by using an incinerator to produce a useful product such as steam, energy can be recovered from what would otherwise be more costly to dispose of [12].

The most important characteristic of all solid wastes relative to incineration, however, whether they be municipal, industrial or hazardous, is the fact that they do not behave as a single fuel material. The characteristics of an industrial waste are dependent upon the specific processes and technologies used at the industrial facility. Solid wastes are essentially heterogeneous mixtures of a number of different fuels [14].

Table IV represents the ultimate analysis of the blended wastes fed to a typical hazardous waste incinerator. The ash and moisture contents of waste sludges are generally much higher than those of a typical hydrocarbon fuel such as coal. Industrial wastes also typically have much higher concentrations of heavy metals and other pollutants than more conventional fuels. The greatest challenge to the combustion of solid wastes today, however, is the significant public opposition based upon perceived risks associated with airborne emissions and ash management [14].

Table IV - Ultimate Analysis of Fuel Feed to a Hazardous Waste Incinerator [14]

Component	Per Cent by Weight	
	Average	Range
Carbon	25.33	19.35 - 38.94
Hydrogen	4.52	3.07 - 6.81
Oxygen	5.34	3.87 - 10.97
Nitrogen	0.16	0.01 - 0.36
Sulfur	0.02	0.01 - 3.00
Chlorine	7.50	7.31 - 12.24
Moisture	12.78	7.52 - 26.43
Ash	44.36	11.77 - 45.22
Higher Heating Value (Btu/lb)	5,500	4,049 - 8,559

Reuse and Recycling

Municipal and industrial wastes, particularly the ash from combustion or incineration processes, have been used in the production of construction materials for many years. This practice is most common in Europe, where land for conventional waste disposal is scarce and municipal waste incineration is widespread. Bottom ash, from the combustion of coal, has been used as road base materials, as an embankment material, and as an aggregate in concrete and concrete products. Fly ash is also commonly used in composite cement and as a binder in concrete. Because of its composition (mostly silicon and aluminum oxides) and its spherical shape, fly ash has been shown to improve the strength and decrease the water demand of cement and concrete [15].

In the United States, investigations into alternative uses of waste materials has increased. At this time, the Departments of Transportation in 41 of the 50 states have performed some form of research into the use of waste materials in hot-mix asphalt. The most common waste material investigated has been rubber from scrap tires, although coal ash and blast furnace slag have also been investigated in 21 states [16]. Research has shown that the use of these waste materials in highway construction can be economically as well as technologically feasible. Bottom ashes can be safely used in embankments, subgrades, and bases. However, because some bottom ashes are highly corrosive, they should not be used near metal structures or components [17].

The primary shortcoming of recycling technology is the leaching potential of the waste materials. It is well known that the leaching characteristics of these materials are much less favorable than those of more conventional construction materials. However, it has not been proven one way or the other whether or not the widespread use of these materials would be environmentally detrimental. In general, each material will have its own unique properties. For now, the consensus opinion for the use of waste materials in construction should continue to evaluate on a case-by-case basis [15].

FACILITY PROCESSES DESCRIPTIONS

WATER TREATMENT

The facility currently pumps approximately 8 million gallons of water per week from a nearby river and treats it to drinking-water standards before it enters the plant. The estimated cost of pumping and treating the water is approximately $1.40 per 1,000 gallons of water.

TEXTILE PROCESSING

The facility is dedicated to the printing and dyeing of fabric for use as bed linens and draperies. The plant produces approximately 2 million yards of treated fabric each week. The printed fabric produced by the facility is used to make linen products for the high-end market. The company also produces some sheets and pillow cases for industrial, commercial and institutional purposes (hospitals, hotels, prisons, etc.). The raw fabric arrives from worldwide sources in the form of large rolls and is sent either to storage or directly to processing.

Bleach Range

All incoming fabric, called "greige goods", passes through one of two Bleach Ranges. The Bleach Range, as shown in Fig. 2, is essentially a preparation process for subsequent dyeing and printing operations. The fabric is first pulled through a singeing operation to remove excess fuzz. Next, the fabric is immersed in a soapy hot-water solution in the "wetout" operation and then exposed to saturated steam in a J-box. After being washed, the fabric is saturated with a bleach solution and passed through a second J-box. From here, the fabric passes through two wash cycles and is placed in a wet bin before progressing to the Finishing Range.

Finishing Range

Once again, all incoming fabric passes through one of two identical Finishing Ranges. A Finishing Range, as shown in Fig. 3, applies chemical treatments to change the appearance or properties of the fabric. The fabric is first flattened and stretched open to its full width in the sutton opener. In a process similar to ironing wrinkled clothing, moisture is applied to the material in the wetout pad and the fabric is subjected to a series of steam cans to help the fabric remain flat. Finishing resins are then added to the fabric in the application dye pad. Common finishes include waterproofing, anti-static and brightening treatments. Light pigment dyes may also be applied at this time. The finished fabric is dried and straightened before being wound onto a roll. From here the fabric is sent to storage, fabrication, one of three Print Ranges, or to the Thermosol Range.

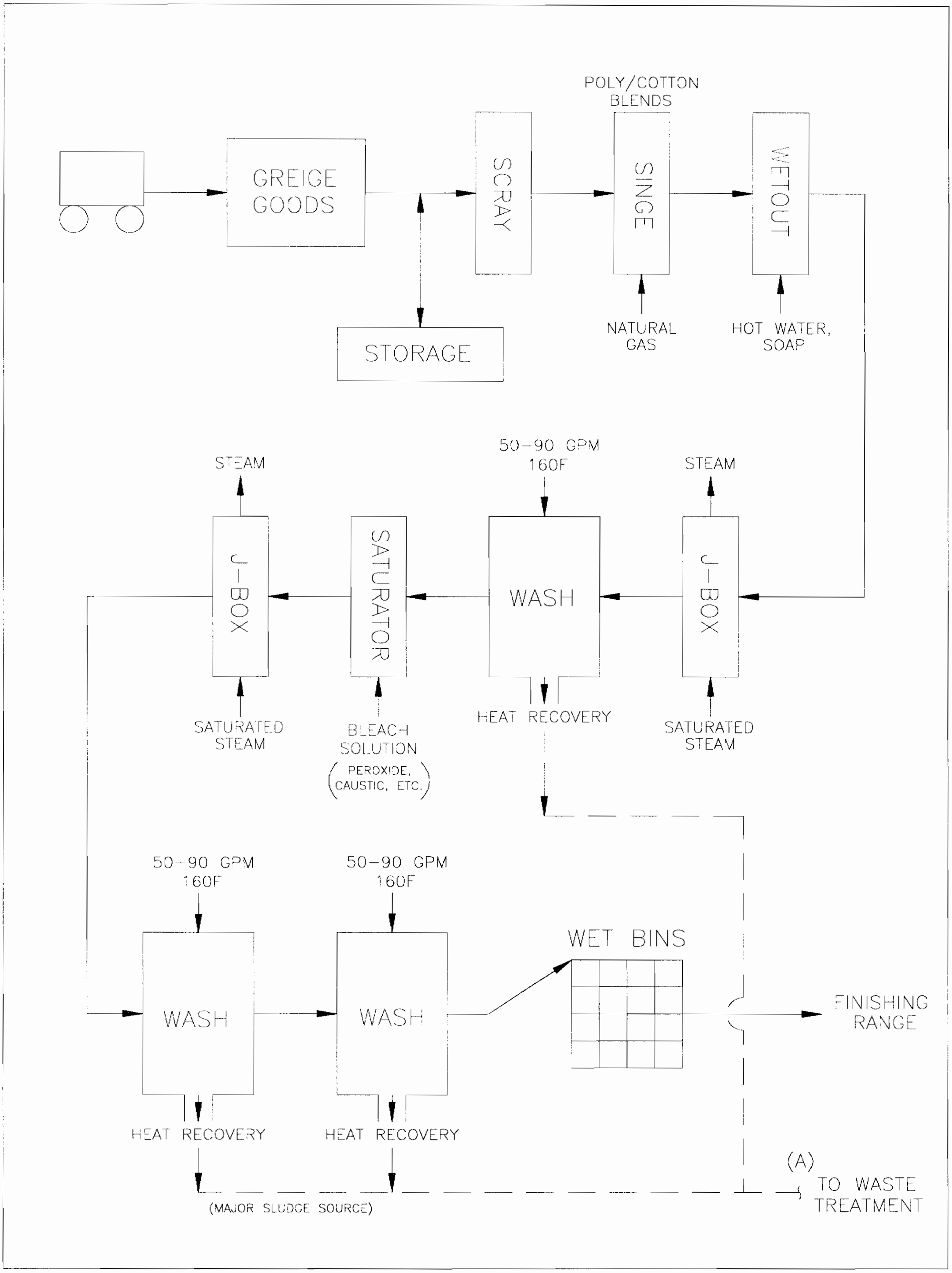

Figure 2 - Bleach Range

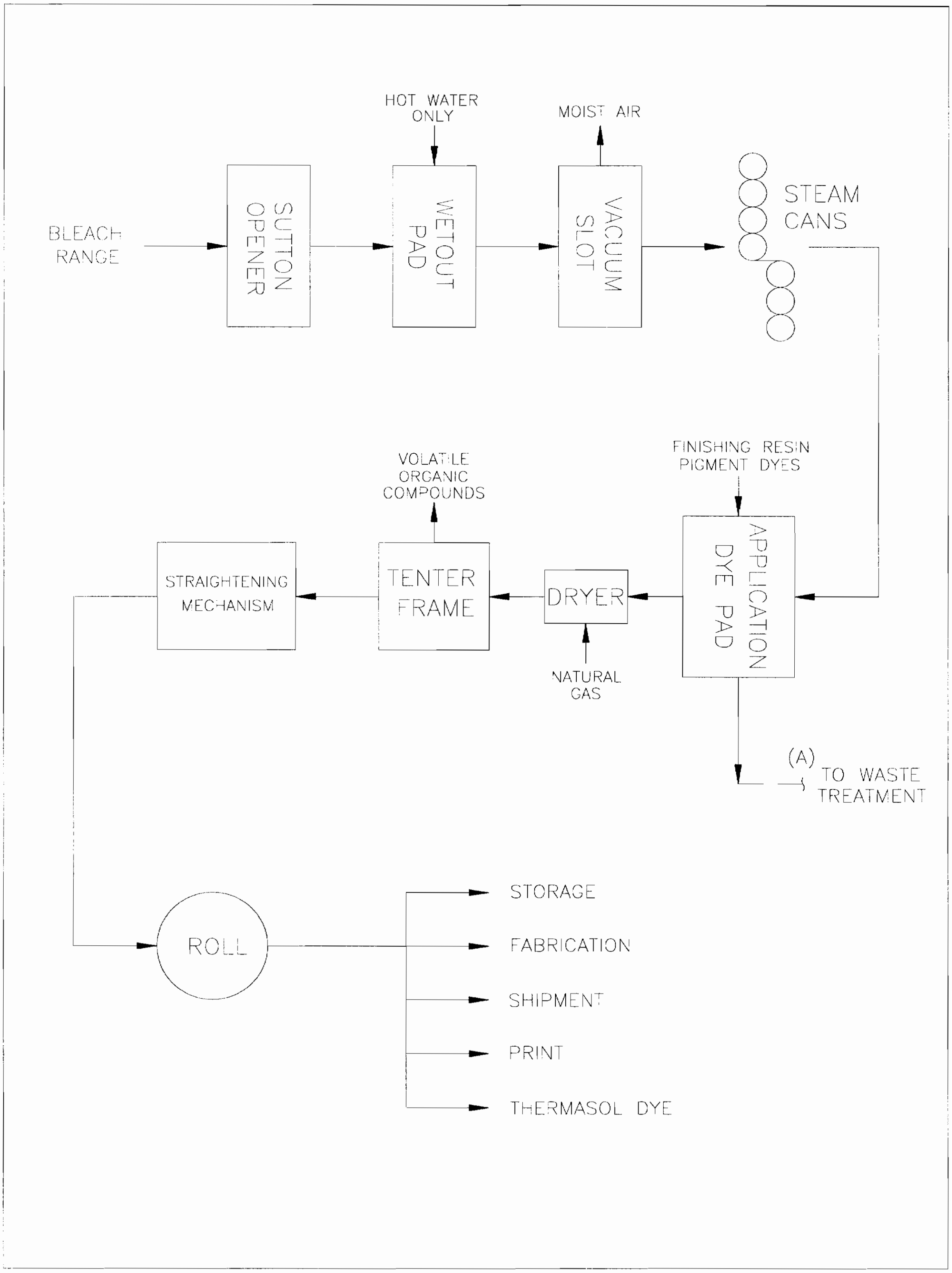

Figure 3 - Finishing Range

Thermosol Dye Range

The Thermosol dye line, shown in Fig. 4, applies solid colors to the fabric. Fabric from the Finishing Range is immersed in pigment, reactive or vat disperse dyes. The fabric is then dried slowly by means of a predryer, steam cans and a curing oven. This slow drying process helps to prevent dye migration. If reactive or vat disperse dyes are used, the fabric needs to pass through the chemical pad and the reduction box in order to set the dyes. Subsequent washing processes remove excess chemicals and dyes before the fabric is dried and rolled. All fabric dyed on the Thermosol Range must make a second pass through the Finishing Range.

Printing Range

Three Printing Lines apply multi-color patterns to the fabric. A typical Printing Line is shown in Fig. 5. These patterns range from solid colors to highly complicated designs. Glue is applied to the fabric so that the fabric will adhere to a magnetic belt. The belt then runs under a number of rotating cylindrical nickel screens. A metal rod, riding along the inside surface of each cylinder, is pulled toward the belt by magnetic forces. This has a "squeegee" effect, forcing print paste through tiny holes in the screen onto the fabric, as shown in Fig. 6. A number of these print screens in series, each applying a single color, creates a pattern on the fabric. After washing, drying and curing, the fabric is straightened and rolled. From here, the fabric will be sent to fabrication or shipping.

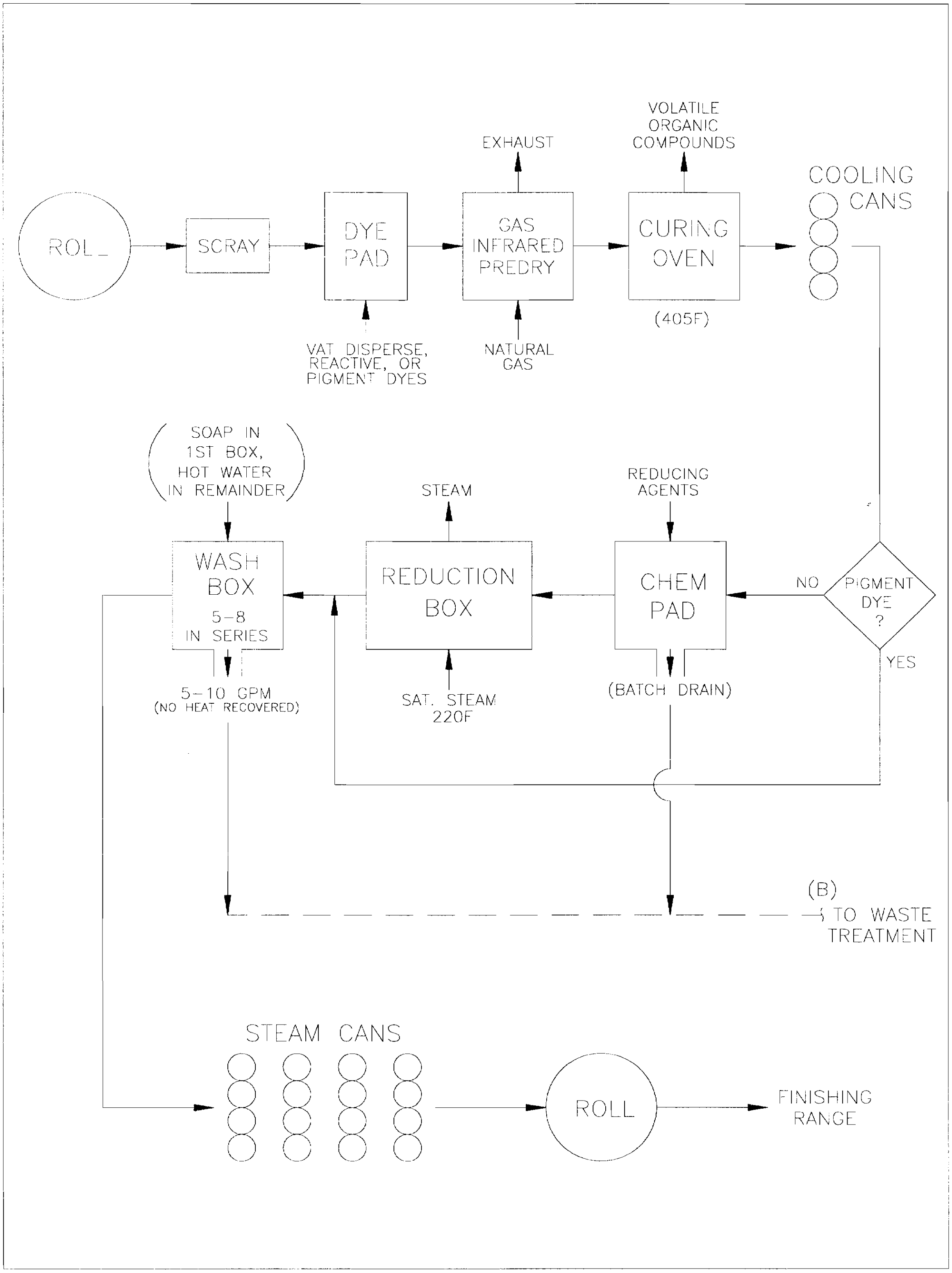

Figure 4 - Thermosol Range

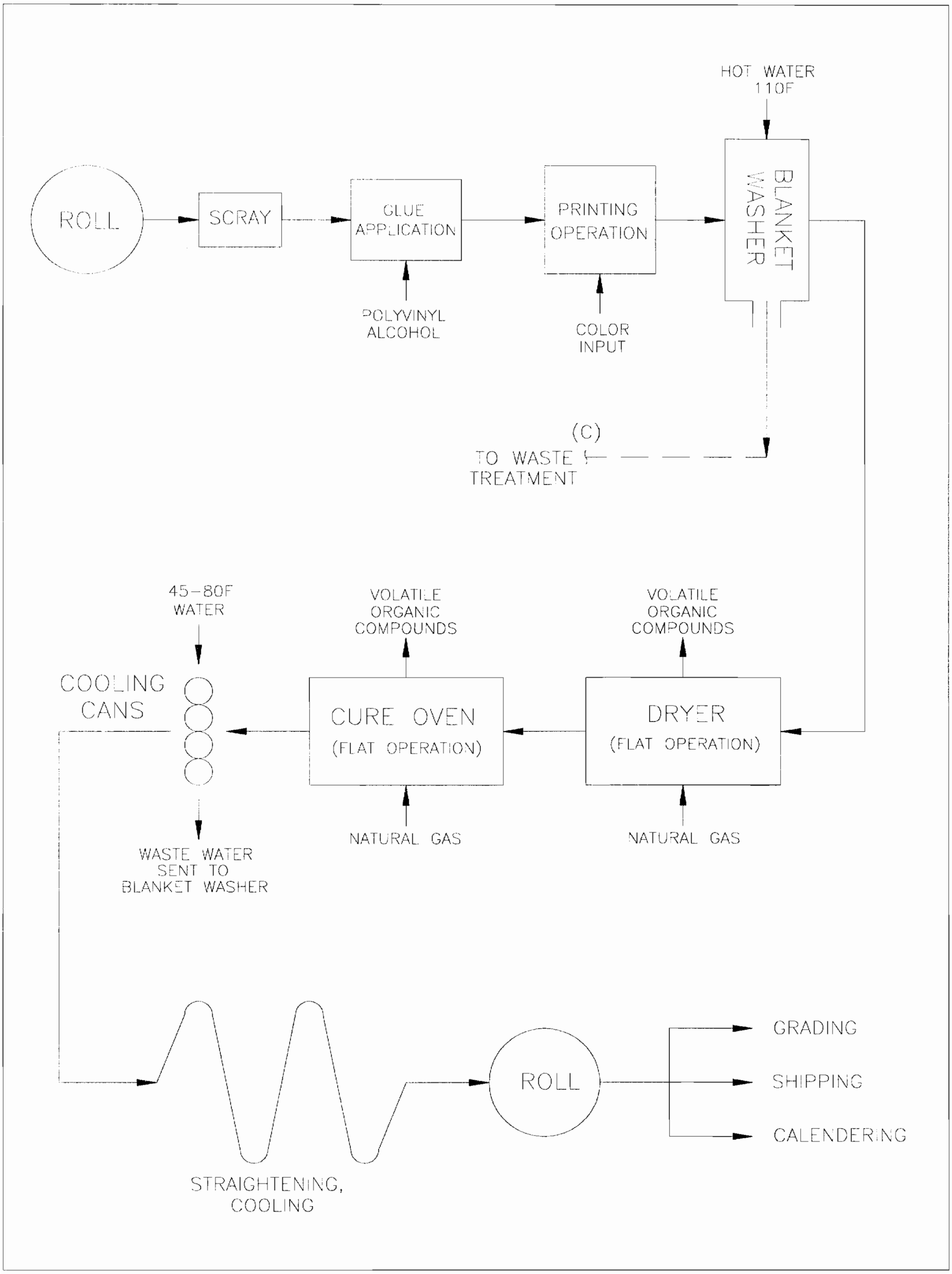

Figure 5 - Print Range

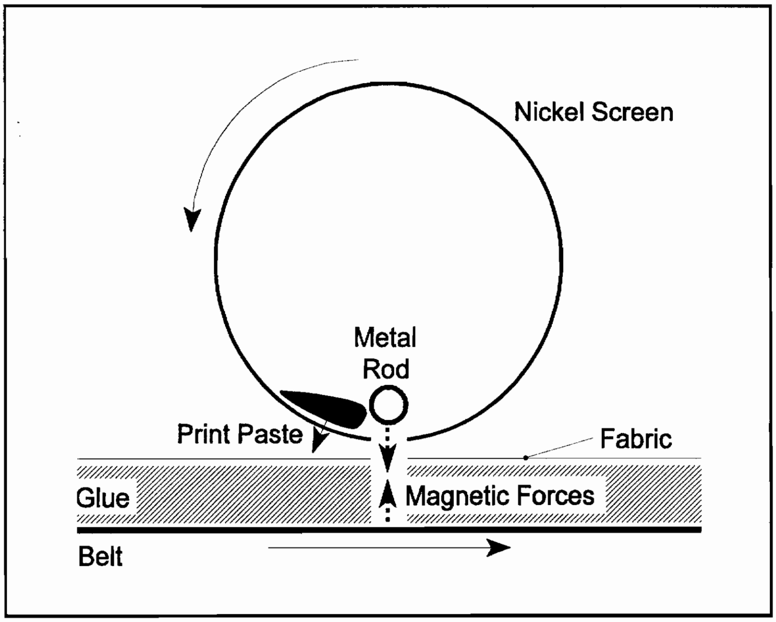

Figure 6 - Print Paste Application

WASTEWATER TREATMENT

A schematic of the entire waste-treatment facility is shown in Fig. 7.

Bleaching and Finishing Waste

Effluent from the Bleaching and Finishing lines are combined before leaving the plant. This effluent flows at a rate of approximately 0.48 MGD through a pair of Hycor™ screens, which remove lint from the water. The effluent then passes through a plume on its way to the aeration lagoon. Effluent leaving the lagoon passes through a clarifier. From here clean water is discharged to a nearby river. A portion of the remaining sludge is recirculated through the aeration lagoon while the rest is sent to the No. 2 digester, and later transferred to the No. 1 digester.

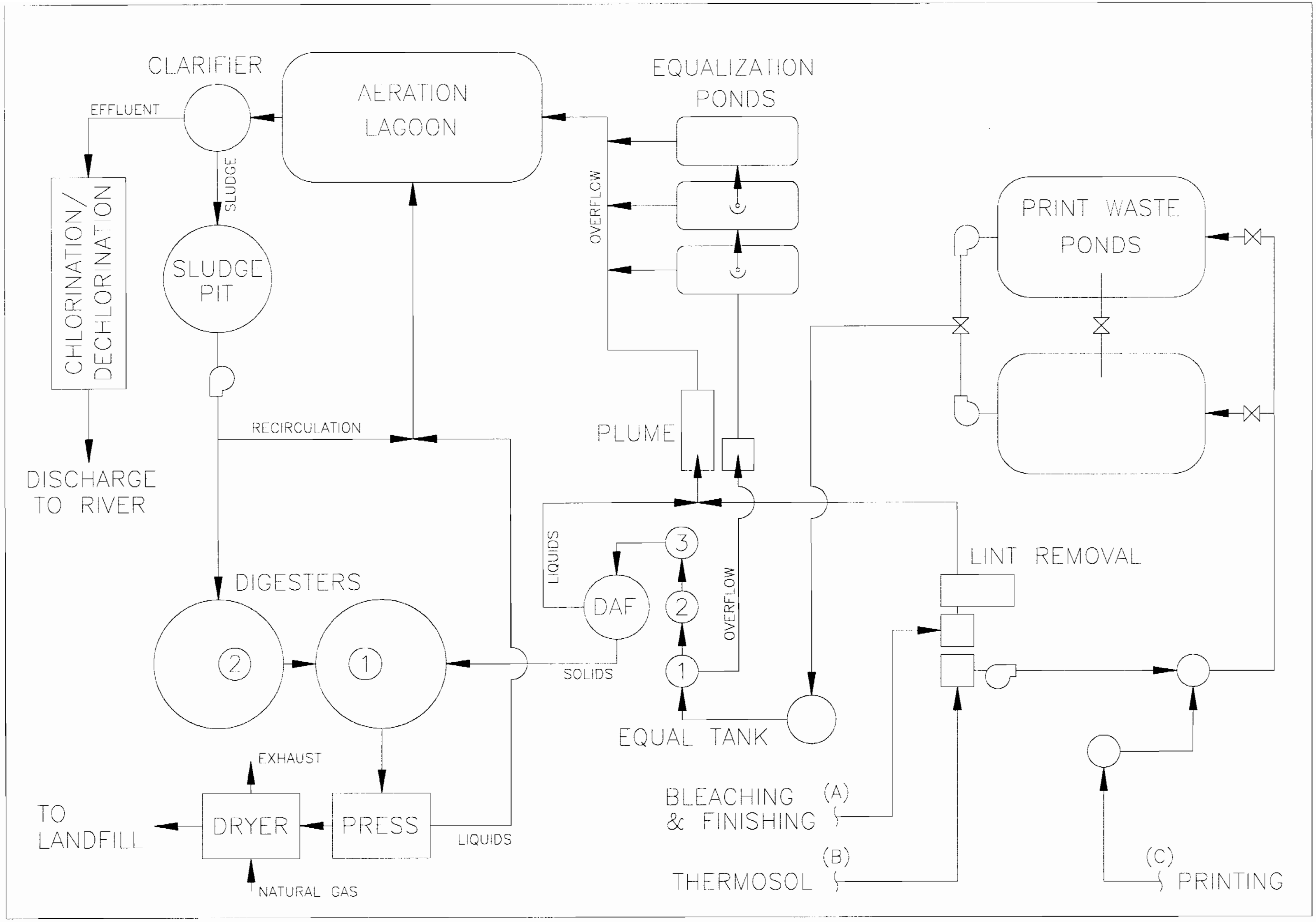

Figure 7 - Waste Stream

Print and Thermosol Waste

Effluent from the Thermosol dye line is pumped at a rate of approximately 0.22 MGD into a manhole junction outside the plant. Here it mixes with the effluent from the Print range, which is flowing at a rate of approximately 0.20 MGD. The combined Print and Thermosol effluent then continues to the print waste ponds, which provide some equalization. From here, the effluent is pumped to an equalization tank before entering the Dissolved Air Flotation (DAF) process.

Dissolved Air Flotation

After equalization, the effluent flows into tank 1. Here, sulfuric acid (H_2SO_4) is added to lower the pH of the effluent to approximately 4.5, while Polytec 150, an aluminum-based liquid coagulant similar to alum, is added to thicken the solids. Overflow from this tank is sent to a series of three equalization ponds before continuing to the aeration lagoon. In tank 2, caustic soda (sodium hydroxide, NaOH) is added to raise the pH to approximately 7.5. The alkalinity of the effluent helps to form larger flocculants. The effluent is then thoroughly mixed in tank 3 before continuing to the DAF tank. In this tank, air is bubbled up through the effluent to bring the coagulated solids to the surface. These solids are then skimmed off the top of the tank and removed from the effluent. The liquid, now with much lower solids, joins the Bleaching and Finishing effluent in the aeration lagoon. The removed solids are pumped directly to the No. 1 digester.

Press and Dryer

When the solids content in the No. 1 digester reaches 2-3 per cent by total mass, the sludge is pumped to the press building. Through the addition of both anionic and cationic polymers and the use of a belt press, the solids content is raised to 15-25 per cent before the sludge continues to the rotary kiln dryer. Optimum dryer performance is achieved by mixing wet sludge with recycled dry sludge to maintain a solids content of approximately 30 per cent entering the dryer. The dryer has a rated capacity of 4.3 MMBtu per hour, which is equivalent to approximately 4,175 SCF per hour of natural gas. Sludge leaving the dryer generally has a final moisture content of 8-10 per cent of total mass and has a consistency similar to that of potting soil. The final dried product is then shipped to a conventional landfill for disposal.

PROCEDURES

APPROACH

Identify Alternatives to Disposal

A number of disposal alternatives for the dried by-product were investigated. The three most promising alternatives investigated were use as fertilizer on agricultural lands, use as an aggregate in construction materials, and use as a supplemental fuel in the facility's coal boilers. All efforts were made to determine which alternative could be implemented and would be most beneficial to the company.

When evaluating the disposal alternatives, the most important factor, with respect to the goal of the project, was the potential cost savings for each disposal method. Thus, priority was placed on finding marketable uses for the waste material. A second important consideration, however, was the overall environmental impact of the plant. It was necessary that the solution chosen would not adversely impact surrounding communities and wildlife.

Identify Problem Components of By-Product

After an extensive literature search into the above disposal alternatives, and with assistance from the Virginia Department of Environmental Quality (VDEQ), a list was developed of the potential problem components of the by-product. These problem components include any substances which could represent environmental, economic, or regulatory concerns. Examples of such concerns would be any substance which is not suitable for conventional landfill disposal, generates unacceptable emissions when incinerated, etc. Subsequent chemical analyses of the dried by-product showed which of these problematic components existed in unacceptably high concentrations, and thus were obstacles to successfully completing the project.

Identify Sources of Problem Components

Once the problematic components of the by-product had been identified, it was next necessary to determine the origins of these components within the plant. Using this information, the problematic components could possibly be eliminated or reduced at their sources. In order to accomplish this task, mass balances and additional chemical analyses were performed.

The mass balance began in the waste treatment facility outside the plant. The first batch of effluent samples were taken of the Bleaching and Finishing waste, the Thermosol waste, and the Print waste at points just prior to their eventual intermixing. A number of other waste streams, those suspected by plant personnel of contributing problematic components, were also sampled at this time.

After the greatest contributors of the problematic components were identified, a second batch of samples were collected inside the plant, upstream from the waste treatment facility. A number of chemicals which are used in high volume inside the plant, such as caustic soda and Polytec 150, were also sampled at this time.

ANALYTICAL PROCEDURES

Heavy Metals Detection

The presence of certain heavy metals in the by-product represented a potential problem for all three alternative solutions considered. Thus, extensive metals testing was performed by a number of laboratories.

In order to analyze solid samples, the materials had to be "digested" into an acid solution. All solid digestions were performed by Olver Laboratories, located in Blacksburg, Virginia. These digestions were accomplished using Method 3050 (Acid Digestion of Sediments, Sludges and Soils) described in reference 18.

Metals analyses of digested solids were performed by laboratories in the Crop, Soil and Environmental Systems Department of VPI&SU. A Jarrell-Ash Atomscan 2400 sequential inductively coupled plasma spectrometer was used. The analyses were accomplished using Method 3120 B (Inductively Coupled Plasma Method) described in reference 19.

Metals analyses of liquid effluents were performed by laboratories in the Environmental Engineering Department using a Perkin-Elmer Zeeman 5100 PC graphite furnace. These analyses were accomplished using Method 3113 B (Electrothermal Atomic Absorption Spectroscopic Method) described in reference 19.

Metals analyses of industrial chemicals was performed by Olver Laboratories. Total chromium was detected using EPA Method 218.2 while total nickel was detected using EPA Method 249.2 (Graphite Furnace Methods).

Proximate and Fusion Temperature Analyses

In order to evaluate the use of the by-product as a supplemental fuel, a number of proximate analyses were performed. A proximate analysis gives, on a mass basis, the relative amounts of moisture, volatile matter, fixed carbon, sulphur, and ash in a fuel. The heating value of the waste material was also determined.

Proximate analyses were performed by Virginia Power Laboratories using ASTM standard methods. The heating value of the by-product was determined using ASTM Method D 2015-77. Per cent moisture was determined using ASTM Method D 3173-73. Per cent volatiles was determined using ASTM Method D 3175-77. Per cent sulfur was determined using ASTM Method D 3177-76. Per cent ash was determined using ASTM Method D 3174-73.

A great concern of plant personnel relating to the combustion process was the fusion temperature of the by-product. The interior of the boiler furnace can exceed 2700°F. At this temperature, it is not unusual for fuel materials to liquify and then solidify as a slag on the furnace grates. This slagging effect decreases the boiler efficiency. Also, cleaning the grates is a costly and time consuming process.

Fusion temperature analyses were also performed by Virginia Power Laboratories using ASTM Method B 1875-74.

Mass Balances

Flowrates of the effluents at various points in the waste stream were estimated largely by primitive methods. Some flow velocities were evaluated by measuring the time required to transport a floating piece of material a specified distance. Other flowrates were determined by measuring the time required to fill a container of specified volume. When possible, a Controlotron Uniflow universal transit time flowmeter was used to measure the effluent flow. Usage rates of chemicals and fuels were based primarily on plant records for the past year.

EXPERIMENTATION

In order to evaluate the physical feasibility of using the by-product as a supplemental fuel in the facility's coal boilers, permission was requested from the VDEQ to perform a brief test-burn of the by-product in one of the three boilers. Permission was granted by the VDEQ and, on June 28, 1995, a mixture of approximately 15 per cent dried by-product and 85 per cent bituminous coal was burned for approximately four hours.

The coal was screw-fed across the roof of the boiler-house into a storage bunker immediately prior to combustion. The feed rate of the coal was measured to be approximately 13,920 lb/hr. The necessary feed rate of by-product into the storage bunker in order to achieve a mixture composition of 15 per cent by-product was calculated to be 2,456 lb/hr. The by-product was transported to the roof of the boiler house by means of a crane with a cement bucket.

During the test-burn, qualitative observations were made of the boiler flame, the stack emissions, and ash production. The efficiency of the boiler was also measured both during and after the experiment using an Enerac 2000E combustion analyzer.

RESULTS AND DISCUSSION

MOST FEASIBLE END-USE SOLUTION

Use of the dried by-product as a fertilizer or as an aggregate in construction materials was not pursued. The reasons included the concerns noted in the relevant literature, the numerous and ever-changing chemical content of the dried by-product, and the extensive modifications required in the plant's operations to limit heavy metals concentrations. The uncertainty of a market for the recycled by-product and the risks related to long-term liability are also serious deterrents for using the by-product as a fertilizer or an aggregate material. Practical limitations on time and funding for the present project admittedly precluded fully investigating every alternative use for the waste product. Instead, it was necessary to focus on the one alternative which seemed most feasible. Consequently, an investigation into the use of the by-product as a supplemental fuel in the facility's coal boilers was pursued.

As a first step in the investigation, a number of proximate analyses of the by-product, as well as the coal burned by the facility, were performed. Average results of these analyses are presented in Table V.

Table V - Proximate Analyses of By-Product and Coal (Dry Basis)

Component	Per Cent by Weight	
	By-Product	Bituminous Coal
Volatile	62.0	37.0
Carbon	13.0	56.0
Sulfur	0.41	0.83
Ash	25.0	7.50
Higher Heating Value (Btu/lb)	7,500	14,000

Relatively High Heating Value

As can be seen from Table V, the by-product has a heating value of 7,500 Btu/lb, more than half that of the coal. Referring back to Table IV, it can be seen that this heating value is near the upper end of the range of heating values typical of incinerator fuels, and over 35 per cent greater than the average. Taking advantage of this heating value by incinerating the by-product in the facility's boilers will allow the company to reduce its use of coal, thus reducing energy costs.

Relatively Low Sulfur Content

From Table V, it can also be seen that the by-product has a sulfur content which is less than half that of the coal. This feature is an added benefit to the company. As a result of the emissions from the facility's coal boilers, the facility has had some difficulty is the past complying with the National Ambient Air Quality Standard for Sulfur Dioxide (SO_2)

[20]. By reducing coal usage and supplementing the coal with the low-sulfur by-product, the facility will be able to reduce these SO_2 emissions.

CONCERNS

Stack Emissions

The plan to incinerate the dried by-product was discussed with local representatives of the Virginia Department of Environmental Quality [21]. The VDEQ representatives provided a list of pollutants which are of particular concern when considering emissions from combustion processes. These pollutants are listed in Table VI, along with their associated "exemption limits". Exemption limits are emissions values (lb/hr and ton/yr) below which a pollutant need not even be considered when applying for an air permit. If the emissions of a particular pollutant are above the associated exemption limit, the pollutant emissions will need to be modelled by a computer simulation program. This computer simulation considers the local weather patterns and surrounding terrain to determine if the air emissions are environmentally acceptable.

Table VI - Exemption Limits for Potential Pollutants		
Pollutant	Hourly Exemption Limit (lb/hr)	Annual Exemption Limit (ton/yr)
Antimony	0.003300	0.007250
Arsenic	0.013200	0.029000
Beryllium	0.000132	0.000290
Cadmium	0.003300	0.007250
Chromium	0.003300	0.007250
Cobalt	0.003300	0.007250
Lead	0.009900	0.021750
Manganese	0.330000	0.725000
Mercury	0.003300	0.007250
Nickel	0.006600	0.014500
Selenium	0.013200	0.029000

A number of metals analyses were performed on the dried by-product and on the bituminous coal. The results of these analyses are shown in Table VII. Samples of both the by-product and the coal were then burned to ash using a Leco TGA-500 multiple sample furnace. The resulting ash samples were also tested for metals content. These results are also presented in Table VII. Values for the by-product and its resulting ash, unless otherwise noted, are based on the average of three grab samples, collected over a four-month period. Values for the coal and its resulting ash are based on a single grab sample.

Table VII - Results of Metals Analyses

Element	Dried By-Product (ppm or mg/kg)	By-Product Ash (ppm or mg/kg)	Bituminous Coal (ppm or mg/kg)	Coal Ash (ppm or mg/kg)
Antimony	<5.0[1]	<5.0[1]	<5.0	<5.0
Arsenic	<5.0[1]	<5.0[1]	<5.0	<5.0
Beryllium	<0.500[1]	<0.500[1]	<0.500	<0.500
Cadmium	1.11	1.99	0.25	<0.25
Chromium	6.36	3.53	<2.5	<0.25
Cobalt	1.8	7.46	3.83	8.00
Lead	5.0[1]	<5.0[1]	<5.0	<5.0
Manganese	84.47	273.97	3.49	10.09
Mercury	0.35[1]	<0.10[1]	0.70	<0.10
Nickel	10.12	22.15	2.80	16.56
Selenium	<0.50[1]	<0.50[1]	<0.50	<0.50

Using these results, as well as the results of the proximate analyses described previously, the stack emissions from burning the dried by-product can be estimated.

Fuel Composition. Based on plant records, the facility currently burns approximately 8,700 lb/hr, or 14,400 ton/yr, of bituminous coal in three boilers. At the same time, the facility produces approximately 980 lb/hr, or 1,620 ton/yr, of the dried by-product. By using the by-product as a supplemental fuel, the company will be able to reduce its coal

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[1] Based on a single grab sample.

consumption. The reduced coal consumption rate, CC_P, can be estimated as follows:

$$CC_P = [\,(CC_C)(HVC) - (BP)(HVB)\,] / HVC$$

where

CC_C = current coal consumption rate, lb/hr or ton/yr

HVC = heating value of coal, Btu/lb

BP = by-product production rate, lb/hr or ton/yr

HVB = heating value of by-product, Btu/lb

Therefore, the proposed hourly consumption rate of coal is found by

$$CC_P = [\,(8{,}700)(14{,}000) - (980)(7{,}500)\,] / (14{,}000)$$

$$CC_P = 8{,}175 \text{ lb/hr}$$

Thus, in order to incinerate all of the by-product while maintaining the same steam production rate, it will be necessary for the facility to burn 8,175 lb/hr (13,530 ton/yr) of bituminous coal with 980 lb/hr (1,620 ton/yr) of dried by-product. This equates to a fuel composition of approximately 11 per cent by-product and 89 per cent coal.

<u>Metals Emissions</u>. Based on the proposed fuel composition, the emission rate, ER, for each metal from burning the fuel mixture can be estimated as follows:

$$ER = [\,C_B - (AC_B)(C_{BA})\,](CR_B)(K) + [\,C_C - (AC_C)(C_{CA})\,](CR_C)(K)$$

where

C_B = metal concentration in by-product, ppm

AC_B = ash content of by-product, no units

C_{BA} = metal concentration in by-product ash, ppm

CR_B = consumption rate of by-product, lb/hr or ton/yr

C_C = metal concentration in coal, ppm

AC_C = ash content of coal, no units

C_{CA} = metal concentration in coal ash, ppm

CR_C = consumption rate of coal, lb/hr or ton/yr

K = conversion constant, 10^{-6}

Therefore, the hourly emission rate for manganese is found by

$$ER_{Mn} = [\,84.47 - (0.25)(273.97)\,](980)(10^{-6}) + [\,3.49 - (0.075)(10.09)\,](8{,}175)(10^{-6})$$

$$ER_{Mn} = 0.038002 \text{ lb/hr}$$

Referring back to Table VI, it can be seen that this value is less than the hourly exemption limit for manganese. The same method was used to determine the hourly and annual emissions rates for all of the listed metals. These estimated emissions rates are shown in

Table VIII. Check marks adjacent to the values indicate that the emissions are below the associated exemption limits. It should be noted that, for all metals concentrations listed in Table VII as "<", a zero concentration is assumed.

Table VIII - Estimated Emissions Rates

Element	Hourly Emissions (lb/hr)		Annual Emissions (ton/yr)	
Antimony	---	✓	---	✓
Arsenic	---	✓	---	✓
Beryllium	---	✓	---	✓
Cadmium	0.002644	✓	0.004374	✓
Chromium	0.005368		0.008874	
Cobalt	0.014960		0.024760	
Lead	0.004900	✓	0.008100	✓
Manganese	0.038002	✓	0.062865	✓
Mercury	0.006065		0.010038	
Nickel	0.017228		0.028504	
Selenium	---	✓	---	✓

As can be seen from Table VIII, four of the eleven listed metals exceed the exemption limits. However, in the cases of cobalt and mercury, the emissions from burning the by-product represent only a small fraction of the total metals emissions. Burning the by-product contributes less than 6 per cent of the total mercury emissions and none of the cobalt emissions. In fact, because the concentrations of these two metals are higher in the coal than in the by-product, using the by-product as a supplemental fuel actually reduces the plant's total cobalt and mercury emissions. Thus, the metals of primary concern are chromium and nickel.

Consistency of By-Product Composition

As fashions change, so must the textile industry. The colors and patterns produced by a textile dyeing and finishing plant will inevitably change with the demands of consumers over time. These changes can result in fluctuations in the composition of the plant's waste stream. There is concern that these fluctuations may cause short-term peaks in the concentrations of certain metals in the dried by-product. If a permit for the combustion of the proposed fuel mixture is approved based on the current by-product composition, the metals emissions may exceed permissible limits in the future.

Based on the metals analyses performed during this project, the by-product composition appears to be fairly consistent. Results of testing for cadmium in the by-product varied from the average value by a maximum of 16 per cent. Results for manganese varied from the average value by a maximum of 18 per cent. Results for all other metals tested varied from the average values by less than 7 per cent. These results, however, encompass only a four-month period. It cannot be assumed that the by-product composition will remain consistent over a span of years.

In the future, the composition of the dried by-product should be monitored for any short-term peaks in metals concentrations. If, at any time, the concentration of any metal increases to the point that the emissions from burning the by-product would exceed the permit limits, the rate of burning the by-product should be reduced. If and when the metal concentration drops back down to an acceptable level, the by-product incineration rate may be increased.

Fuel Handling/Stokering

Additional concerns pertain to the physical handling of the dried by-product. There was apprehension at the onset of the project that the stoker feeders would not be able to properly feed the granular by-product into the boilers. There was also some apprehension about the fusion temperature of the by-product. If the by-product liquifies at the extreme temperatures in the furnace, the boiler efficiency would be adversely affected.

The test-burn experiment performed on June 28, 1995, helped to alleviate these worries. Based on qualitative observations of the furnace flame and the stack emissions, the fuel mixture appeared to burn well. Combustion analyses were performed both during the experiment (burning the fuel mixture) and after the experiment (burning coal alone). The results of these analyses are shown in Table IX.

Table IX - Results of Combustion Analyses

	Fuel Mixture	Coal Alone
Gas Temperature	415°F	438°F
O_2	13.5%	13.6%
CO	49 ppm	35 ppm
CO_2	6.4%	6.4%
Efficiency	82.3%	81.4%

As can be seen from Table IX, there was no significant change in efficiency due to the burning of the fuel mixture. Ash fusion also presented no problem. When the boiler grates were dumped at the end of the experiment, the ash slid clean away, leaving no build up of slag. Subsequent analysis showed that the by-product has a fusion temperature of approximately 2,600°F, which is comparable to that of the coal. Additional data collected during the test-burn experiment is included in Appendix II.

This experiment provided invaluable information; a second, longer test-burn could provide even more. The second experiment should last between 24 and 48 hours. A number of combustion analyses should be performed before, during, and after the recommended second test-burn experiment. If an appropriate combustion analyzer is used, it will be possible to determine the sulfur dioxide (SO_2), nitrogen oxides (NO_X) and carbon monoxide (CO) emissions for the proposed fuel mixture. These values are required for a VDEQ air permit application. A stack gas analyzer should also be used during the test-burn to determine the emissions rates of total suspended particulates (TSP), 10μm or smaller particulates (PM_{10}), and volatile organic compounds (VOC). These values are also required for the permit application.

A physical requirement which remains is the transport of the dried by-product from the rotary dryer to the boiler house, a distance of approximately 375 ft.

Additional Energy Conservation Measures

The by-product is currently dried by a natural gas-fired rotary kiln dryer. However, when the waste product is used as a supplemental fuel in the facility's coal boilers, the use of more expensive gas fuel to dry it should be re-evaluated. Natural gas is purchased by the company at a rate of $3.50 per MMBtu, based on the facility's billing history. The current drying method results in a total annual cost of approximately $53,000. If the same amount of heat were provided by burning coal, the cost would be only $27,000. There are a number of possible ways in which this increment cost could be greatly reduced or eliminated.

It is likely that the by-product may be fed into the boiler furnace with a significantly higher moisture content. The drying energy would then be provided by the coal/by-product mixture. In the past, an investigation was performed into feeding the wet sludge from the digesters into the boiler furnace. This experiment had less than satisfactory results, and it was concluded that some dewatering would be necessary. It may, therefore, be possible to feed the sludge from the belt press directly into the furnace, bypassing the final drying step. Because of the relatively high moisture content of the sludge, this strategy may still prove to be impractical.

It may be possible to use the coal-fired boiler flue gases to dry the by-product before it enters the furnace. In this case, the drying energy is provided by "waste" heat.

It is apparent that further study is necessary to design a more economic system for handling and burning the waste by-product.

ANTICIPATED COST SAVINGS

If the plan to use the by-product as a supplemental fuel in the facility's coal boilers is implemented, the company will realize cost savings not only from the reduction in landfill costs, but also from the reduction in coal consumption. Some additional operating costs will result, however, due to an increase in ash production.

Reduced Landfill Costs

The current charge for landfill disposal is $45 per ton of waste. Thus, the cost savings, CS_1, due to the reduction in landfilling waste can be estimated as follows:

$$CS_1 = (BP)(LC)$$

where

BP = by-product production rate, ton/yr

LC = landfilling charges, \$/ton

Thus,

$$CS_1 = (1{,}620 \text{ ton/yr})(\$45/\text{ton})$$

$$CS_1 = \$72{,}900/\text{yr}$$

Reduced Coal Consumption

Coal is currently purchased and shipped to the company at a total cost of approximately \$50 per ton. Thus, the cost savings, CS_2, due to the reduction in coal demand can be estimated as follows:

$$CS_2 = (CC_C - CC_P)(CC)$$

where

CC_C = current coal consumption rate, ton/yr

CC_P = proposed coal consumption rate, ton/yr

CC = cost of coal, \$/ton

Thus,

$$CS_2 = (14{,}400 - 13{,}530 \text{ ton/yr})(\$50/\text{ton})$$

$$CS_2 = \$43{,}500/\text{yr}$$

Increased Ash Handling Costs

The facility currently ships boiler ash to a nearby cinder block manufacturer at a cost of $27.25 per ton of ash. Based on the results of proximate analyses described previously, the increase in ash handling charges, CS_3, can be estimated as follows:

$$CS_3 = [\,(BP)(AC_B) + (CC_P - CC_C)(AC_C)\,](AH)$$

where

AC_B = ash content of by-product, no units

AC_C = ash content of coal, no units

AH = ash handling charge, \$/ton

Thus,

$$CS_3 = [\,(1{,}620 \text{ ton/yr})(0.25) + (13{,}530 - 14{,}400 \text{ ton/yr})(0.075)\,](\$27.25/\text{ton})$$

$$CS_3 = \$9{,}260/\text{yr}$$

Total Cost Savings

The total estimated cost savings, CS_T, is then found by

$$CS_T = CS_1 + CS_2 - CS_3$$

$$CS_T = \$72{,}900/\text{yr} + \$43{,}500/\text{yr} - \$9{,}260/\text{yr}$$

$$CS_T = \$107{,}000/\text{yr}$$

It should be noted that this figure is based on the assumption that the cinder block manufacturer will continue to accept the boiler ash even after the by-product is mixed into the fuel. If this assumption is not valid, then the boiler ash will most likely be disposed of in conventional landfill. In this case, assuming a landfilling charge of $45 per ton of waste, the total estimated cost savings would be approximately $52,500 per year. It will be necessary to perform a TCLP test on the ash produced by burning the dried by-product in the near future. The results of this analysis will determine whether or not the new ash can be disposed of in conventional landfill. In addition, these results may also determine whether or not the boiler ash will continue to be accepted by the cinder block manufacturer. Referring to Table VII, it can be seen that five of the ten elements detected during the TCLP test -- arsenic, chromium, lead, mercury, and selenium -- exist in lower concentrations in the by-product ash than in the by-product itself. The dried by-product has passed the TCLP test in the past. For these reasons, it is expected that the by-product ash will meet the TCLP requirements for these metals. However, failure to meet any of the TCLP limits would result in the ash being classified as a hazardous waste.

SOURCES OF PROBLEM COMPONENTS

In the hopes that the chromium and nickel concentrations in the final by-product could be reduced or eliminated, an effort was made to quantify the sources of these metals within the plant. A number of samples were taken throughout the waste stream to be tested for chromium and nickel. Eight-hour composite samples were taken from the combined Bleaching and Finishing effluent, as well as the Thermosol effluent and the Print effluent, at the first available point outside the plant.

Samples were also taken from the effluent of the "screen remake" and "blanket washer" operations. Screen remake is the operation which prepares the long, cylindrical screens for the printing operation. The waste stream from this operation is separate from the Print effluent. The waste from the blanket washers are part of the Print effluent. This operation, which takes place immediately after the print paste is applied, rinses excess chemicals from the fabric and helps to remove the fabric from the magnetic belt.

Samples were also taken of a number of chemicals which are used in high volume in the plant. Caustic soda (sodium hydroxide, NaOH) is used in the Bleach Range and in the waste treatment facility to adjust the pH of the water. Polytec 150 is a polymer blend consisting of approximately 90 per cent alum (aluminum sulfate, $Al_2(SO_4)_3$) and 10 per cent of a polyamine. This chemical is used primarily in the waste treatment facility as a coagulant. Sodium silicate ($Na_2O \cdot SiO_2$) is used in the Bleach Range to slow the reaction of the hydrogen peroxide, thus protecting the fabric.

The results of the metals analyses, as well as estimates of the flow rates of the associated effluents and chemicals, are shown in Table X.

Table X - Results of Metals Testing Throughout Plant

Location	Chromium (ppb in solution or µg/l)	Nickel (ppb in solution or µg/l)	Flow Rate (gal/hr)
Bleach/Finish	0.088	9.7	30,000
Thermosol	1.550	3.1	13,750
Print	0.520	3.6	12,325
Screen Remake	1,320	8.9	28
Blanket Washers	0.350	9.5	3,600
Chemical	Chromium (ppm in solution or mg/l)	Nickel (ppm in solution or mg/l)	Consumption Rate (lb/hr)
Caustic Soda	0.35	3.15	87
Polytec 150	35.00	5.00	21
Sodium Silicate	1.00	<0.05	194

Based on these results, the contamination rate, CR, of chromium and nickel contributed by each operation can be estimated as follows:

$$CR = (Q)(C)(OS)(K_1)(K_2)(K_3)$$

where

Q = flow rate of effluent, gal/hr

C = metal concentration in effluent, µg/l

OS = annual operating schedule, hr/yr

K_1 = conversion constant, 3.7853 l/gal

K_2 = conversion constant, 2.2046×10^{-9} lb/µg

Thus, the contamination rate of chromium from the Thermosol effluent is

$$CR = (13{,}750)(1.55)(4{,}000)(3.7853)(2.2046 \times 10^{-9})$$

$$CR = 0.712 \text{ lb/yr}$$

The contamination rates for both metals due to each of the effluents and chemicals were calculated in a similar manner. These results are shown in Table XI. The contamination rates are compared to the total amounts of chromium and nickel discharged from the plant in the dried by-product itself. The by-product contributes 20.6 lb/yr of chromium and 32.8 lb/yr of nickel.

Table XI - Contamination Rates of Chromium and Nickel				
Source	Chromium (lb/yr)	Per Cent of Total Cr	Nickel (lb/yr)	Per Cent of Total Ni
Bleach/Finish	0.088	0.43	9.72	29.65
Thermosol	0.712	3.46	1.42	4.34
Print	0.214	1.04	1.48	4.52
Screen Remake	1.23	5.96	0.008	0.02
Blanket Washers	0.042	0.20	1.14	3.48
Caustic Soda	0.080	0.39	0.716	2.18
Polytec 150	2.17	10.55	0.310	0.95
Sodium Silicate	0.527	2.56	---	---

It should be possible to reduce the concentrations of these metals in the final by-product. This reduction can be accomplished in a number of ways. For example, it can be seen from Table XI that the greatest known source of chromium is the Polytec 150 coagulant. Thus, the concentration of chromium in the final by-product can be reduced by using a "cleaner" liquid alum product. In fact, all incoming raw materials, especially those chemicals used in high volume, should be periodically checked for contamination by heavy metals. One such chemical which should be investigated is the sulfuric acid (H_2SO_4) which is added during the DAF operation. The second greatest known contributor of chromium is the screen remake operation. The facility is currently in the process of phasing out the waste-producing screen preparation process with a more modern, waste-free laser engraving process. It is recommended that these efforts be continued and, if possible, accelerated.

It can be seen from Table XI that the values listed account for a total of only 25 per cent of the chromium and 45 per cent of the nickel present in the final waste by-product. This discrepancy could be a result, to some extent, of the conservative estimates used for the flowrates of the effluent streams. It is also likely that some additional chromium and nickel are entering the waste stream during the treatment process. Metals could enter the effluent through runoff from nearby structures or as contaminants in polymers and other chemicals. Due to the limited time and resources available during this project, it was not possible to investigate every possible source of heavy metals. However, the procedures outlined in this report can be used by plant personnel to seek out further sources of chromium and nickel.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of this investigation, the use of the dried by-product as a supplemental fuel in the facility's coal boilers is a viable solution to reduce the associated disposal costs. Additional efforts will have to be made, however, before the plan can be fully implemented. The following recommendations are provided to assist facility management in completing the necessary work to implement the plan:

1. A second, longer test-burn experiment should be performed in one of the facility's boilers, as described in the previous chapter. It is expected that VDEQ representatives will be supportive of this experiment, as they were of the initial test-burn.

2. A combustion analyzer and a stack gas analyzer should be used during the recommended second test-burn experiment. It may be possible to obtain a stack gas analyzer either from the facility's electric power utility or from the VDEQ.

3. It is recommended that efforts be made to reduce the final concentrations of chromium and nickel in the waste by-product. Some sources of these metals within the plant, as well as strategies for reducing or eliminating them, are described. Using the procedures outlined in this report, it should also be possible

to locate additional sources of chromium and nickel.

4. It is next recommended that a VDEQ permit application for the necessary boiler modification be completed. Most of the information required for this application is included in this report. Some additional information can be obtained by following the recommendations previously described. The VDEQ should also be made aware of the source reduction efforts being pursued by the facility. It may be possible for the facility to obtain a "temporary" air permit, with provisions made for reductions in metals emissions in the future.

5. It is recommended that the composition of the dried by-product be monitored for any short-term peaks in metals concentrations. This safeguard will prevent the metals emissions from burning the proposed fuel mixture from exceeding permit limits. The VDEQ should also be notified of this plan.

6. Finally, it is recommended that the cost savings that result from the recommendations in this report be used to make further steps toward total optimization, including improvements to the waste treatment facility, as well as additional waste reduction and recycling efforts inside the plant.

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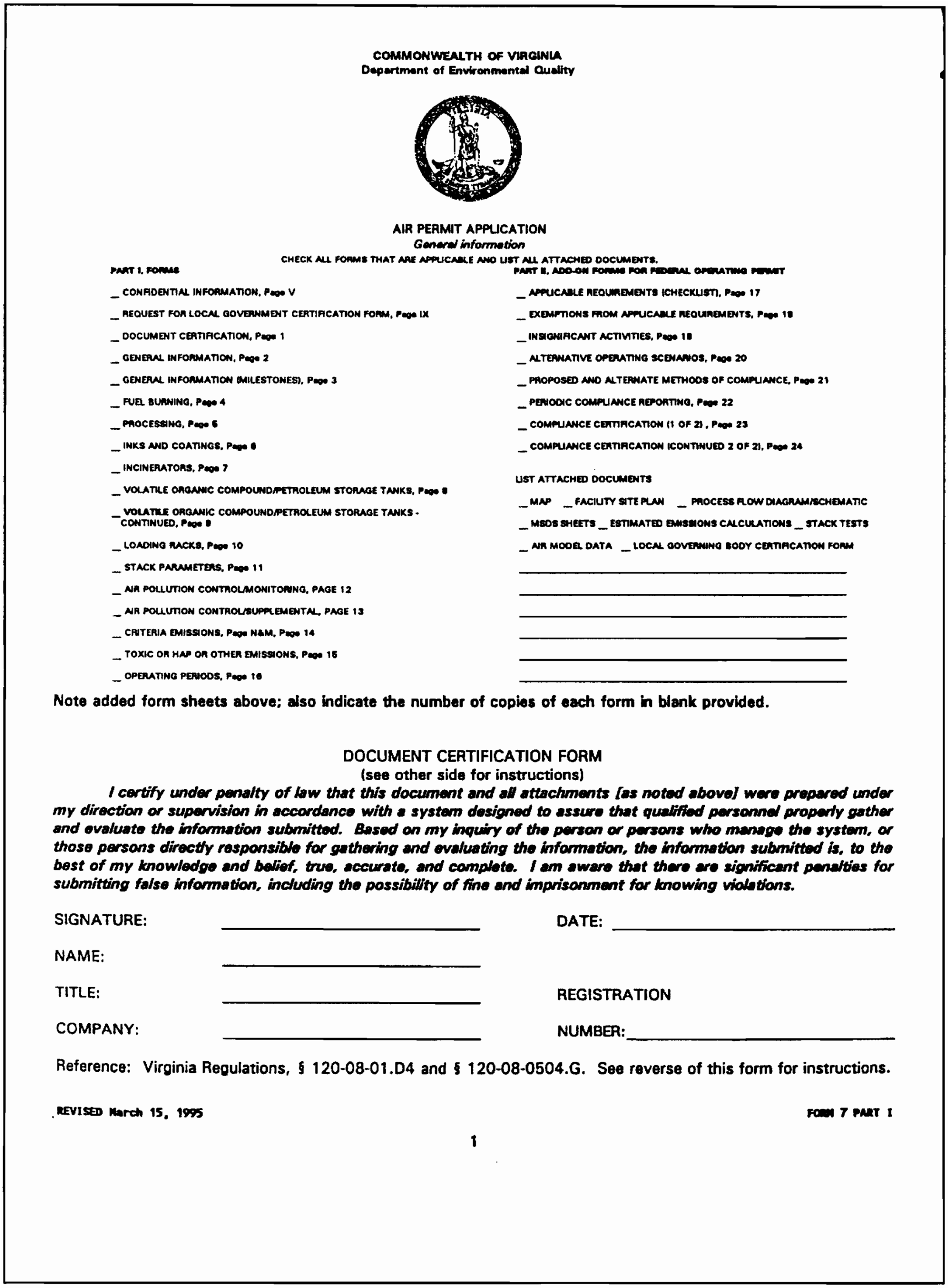
APPENDIX I

VDEQ Air Permit Application

Relevant pages of a Virginia Department of Environmental Quality Air Permit Application are included.



COMMONWEALTH OF VIRGINIA
Department of Environmental Quality

AIR PERMIT APPLICATION

General information

CHECK ALL FORMS THAT ARE APPLICABLE AND LIST ALL ATTACHED DOCUMENTS.

PART 1, FORMS

__ CONFIDENTIAL INFORMATION, Page V
__ REQUEST FOR LOCAL GOVERNMENT CERTIFICATION FORM, Page IX
__ DOCUMENT CERTIFICATION, Page 1
__ GENERAL INFORMATION, Page 2
__ GENERAL INFORMATION (MILESTONES), Page 3
__ FUEL BURNING, Page 4
__ PROCESSING, Page 5
__ INKS AND COATINGS, Page 6
__ INCINERATORS, Page 7
__ VOLATILE ORGANIC COMPOUND/PETROLEUM STORAGE TANKS, Page 8
__ VOLATILE ORGANIC COMPOUND/PETROLEUM STORAGE TANKS - CONTINUED, Page 9
__ LOADING RACKS, Page 10
__ STACK PARAMETERS, Page 11
__ AIR POLLUTION CONTROL/MONITORING, PAGE 12
__ AIR POLLUTION CONTROL/SUPPLEMENTAL, PAGE 13
__ CRITERIA EMISSIONS, Page N&M, Page 14
__ TOXIC OR HAP OR OTHER EMISSIONS, Page 15
__ OPERATING PERIODS, Page 16

PART II, ADD-ON FORMS FOR FEDERAL OPERATING PERMIT

__ APPLICABLE REQUIREMENTS (CHECKLIST), Page 17
__ EXEMPTIONS FROM APPLICABLE REQUIREMENTS, Page 18
__ INSIGNIFICANT ACTIVITIES, Page 19
__ ALTERNATIVE OPERATING SCENARIOS, Page 20
__ PROPOSED AND ALTERNATE METHODS OF COMPLIANCE, Page 21
__ PERIODIC COMPLIANCE REPORTING, Page 22
__ COMPLIANCE CERTIFICATION (1 OF 2) , Page 23
__ COMPLIANCE CERTIFICATION (CONTINUED 2 OF 2), Page 24

LIST ATTACHED DOCUMENTS

__ MAP __ FACILITY SITE PLAN __ PROCESS FLOW DIAGRAM/SCHEMATIC
__ MSDS SHEETS __ ESTIMATED EMISSIONS CALCULATIONS __ STACK TESTS
__ AIR MODEL DATA __ LOCAL GOVERNING BODY CERTIFICATION FORM
____
____
____
____
____
____

Note added form sheets above; also indicate the number of copies of each form in blank provided.

DOCUMENT CERTIFICATION FORM

(see other side for instructions)

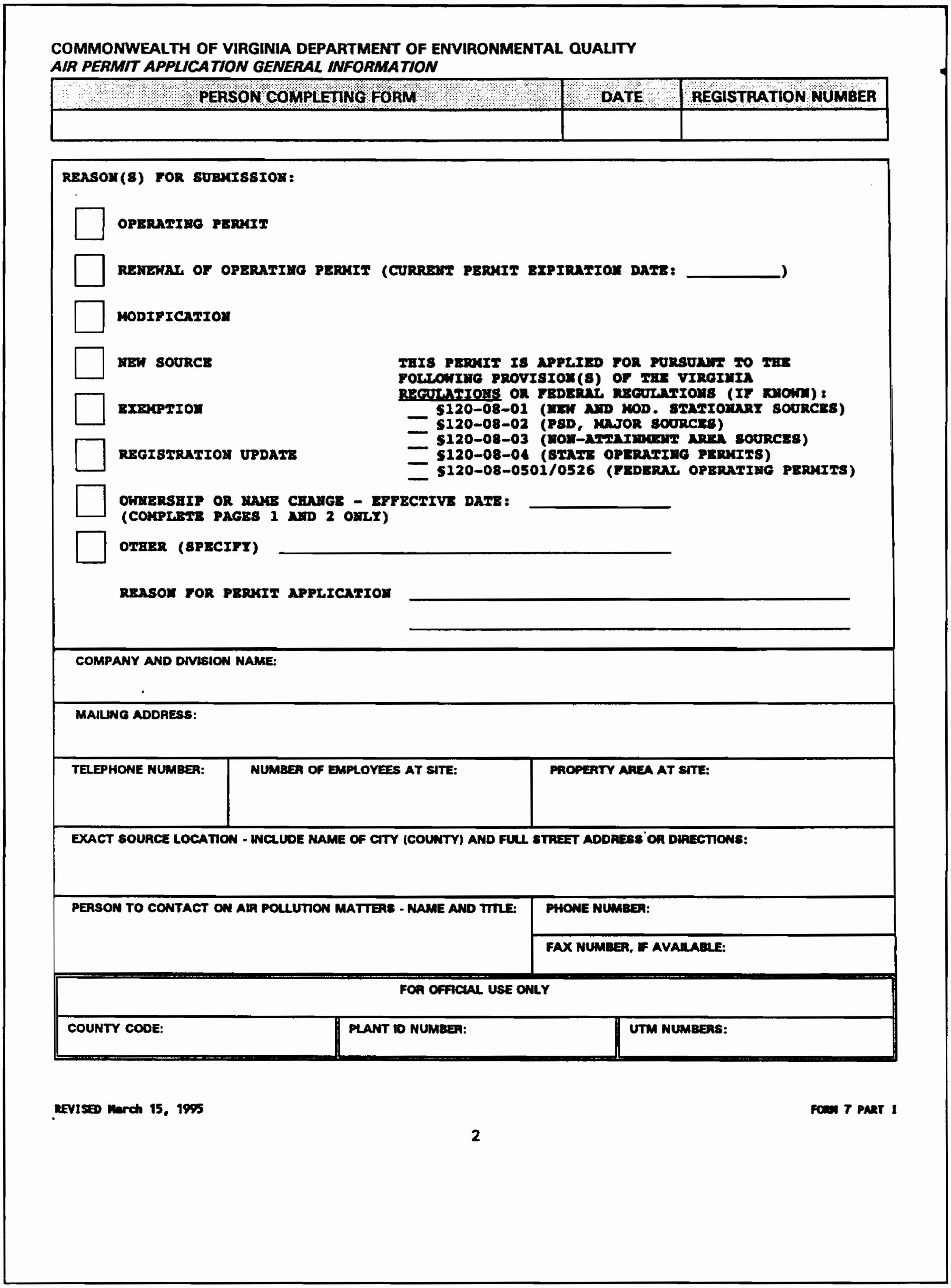
I certify under penalty of law that this document and all attachments [as noted above] were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering and evaluating the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

SIGNATURE: ______________________ DATE: ______________________
NAME: ______________________
TITLE: ______________________ REGISTRATION
COMPANY: ______________________ NUMBER: ______________________

Reference: Virginia Regulations, § 120-08-01.D4 and § 120-08-0504.G. See reverse of this form for instructions.

REVISED March 15, 1995 FORM 7 PART I

1



COMMONWEALTH OF VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY

AIR PERMIT APPLICATION GENERAL INFORMATION

PERSON COMPLETING FORM	DATE	REGISTRATION NUMBER

REASON(S) FOR SUBMISSION:

☐ OPERATING PERMIT

☐ RENEWAL OF OPERATING PERMIT (CURRENT PERMIT EXPIRATION DATE: ___________)

☐ MODIFICATION

☐ NEW SOURCE

☐ EXEMPTION

☐ REGISTRATION UPDATE

THIS PERMIT IS APPLIED FOR PURSUANT TO THE FOLLOWING PROVISION(S) OF THE VIRGINIA <u>REGULATIONS</u> OR FEDERAL REGULATIONS (IF KNOWN):

- __ §120-08-01 (NEW AND MOD. STATIONARY SOURCES)
- __ §120-08-02 (PSD, MAJOR SOURCES)
- __ §120-08-03 (NON-ATTAINMENT AREA SOURCES)
- __ §120-08-04 (STATE OPERATING PERMITS)
- __ §120-08-0501/0526 (FEDERAL OPERATING PERMITS)

☐ OWNERSHIP OR NAME CHANGE - EFFECTIVE DATE: ______________
(COMPLETE PAGES 1 AND 2 ONLY)

☐ OTHER (SPECIFY) ______________________________

REASON FOR PERMIT APPLICATION ______________________________

____

COMPANY AND DIVISION NAME:		
MAILING ADDRESS:		
TELEPHONE NUMBER:	NUMBER OF EMPLOYEES AT SITE:	PROPERTY AREA AT SITE:
EXACT SOURCE LOCATION - INCLUDE NAME OF CITY (COUNTY) AND FULL STREET ADDRESS OR DIRECTIONS:		
PERSON TO CONTACT ON AIR POLLUTION MATTERS - NAME AND TITLE:	PHONE NUMBER: FAX NUMBER, IF AVAILABLE:	

FOR OFFICIAL USE ONLY		
COUNTY CODE:	PLANT ID NUMBER:	UTM NUMBERS:

REVISED March 15, 1995

FORM 7 PART I

2

COMMONWEALTH OF VIRGINIA DEPARTMENT OF ENVIRONMENTAL QUALITY
AIR PERMIT APPLICATION GENERAL INFORMATION (CONTINUED)

COMPANY NAME	DATE	REGISTRATION NUMBER

IS THE FACILITY TO BE PERMITTED AS A PORTABLE PLANT? YES __ NO __

DESCRIBE THE PRODUCTS MANUFACTURED AND/OR SERVICES PERFORMED AT THIS FACILITY:

LIST THE STANDARD INDUSTRIAL CLASSIFICATION (SIC) CODE(S) FOR THE FACILITY:

☐☐☐☐ ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ ☐☐☐☐ ☐☐☐☐

PRIMARY SIC

PLEASE LIST ALL THE FACILITIES IN VIRGINIA UNDER COMMON OWNERSHIP OR CONTROL BY THE OWNER OF THIS FACILITY:

MILESTONES. This section is to be completed if the permit application includes a new emissions unit or modification to existing operations.

MILESTONES*	STARTING DATE	ESTIMATED COMPLETION DATE
New equipment installation		
Modification of existing process or equipment		
Start-up dates		

* For new or modified installations to be constructed in phased schedule, give construction/installation starting and completion date for each phase.

FUEL-BURNING EQUIPMENT AND STATIONARY COMBUSTION ENGINES (EXCEPT INCINERATORS) (BOILERS, TURBINES, GAS/DIESEL ENGINES, KILNS, ETC.):

COMPANY NAME	DATE	REGISTRATION NUMBER

☐ Check box if this page shows alternative operating scenario(s).

UNIT REF. NO.	EQUIPMENT MANUFACTURER AND MODEL NUMBER, IF KNOWN; OTHERWISE, TYPE OF EQUIPMENT (DATE OF MANUFACTURE OR CONSTRUCTION)	MOD CODE*	MAXIMUM RATED INPUT HEAT CAPACITY FOR EACH FUEL (MILLION BTU/HR)	TYPE OF FUEL	TYPE OF EQUIPMENT (USE CODE A)	MAXIMUM RATED OUTPUT APPROPRIATE TO SOURCE TYPE			USAGE (USE CODE B)
						STEAM QUANTITY (lb/hr)	OUTPUT BRAKE HORSEPOWER (BHP)	ELECTRICAL POWER (KW)	

Code A - Equipment
BOILER TYPE:
1. Pulverized Coal - Wet Bottom
2. Pulverized Coal - Dry Bottom
3. Pulverized Coal - Cyclone Furnace
4. Spreader Stoker
5. Chain or Travelling Grate Stoker
6. Underfeed Stoker
7. Hand Fired Coal
8. Oil, Tangentially Fired
9. Oil, Horizontally Fired (except rotary cup)
10. Gas, Tangentially Fired
11. Gas, Horizontally Fired

Code A (continued)
12. Wood with Flyash Reinjection
13. Wood without Flyash Reinjection
14. Other Specify ____________
STATIONARY ENGINE TYPE:
15. Combustion Turbine
16. Internal Combustion Engine
17. Other Specify ____________
OTHER COMBUSTION UNITS:
18. Oven / Kiln
19. Rotary Kiln
18. Process Furnace
99. Other Specify ____________

Code B - Usage
1. Steam Production
2. Drying / Curing
3. Space Heating
4. Process Heat
5. Food Processing
6. Electrical Generation
7. Mechanical Work
99. Other ____________

* FOR MODIFICATION CODES SEE INSTRUCTIONS ON NEXT PAGE.

STACK PARAMETERS AND FUEL DATA:

COMPANY NAME	DATE	REGISTRATION NUMBER

☐ Check box if this page shows alternative operating scenario(s).

UNIT REF. NO.	VENT/ STACK NO.	VENT/STACK OR EXHAUST DATA						FUEL(S) DATA						
		VENT/ STACK CONFIG. (USE CODE K)	VENT STACK HEIGHT (feet)	EXIT DIA. (feet)	EXIT GAS VELOCITY (fpm)	EXIT GAS VOLUME (acfm)	EXIT GAS TEMP. (°F)	TYPE OF FUEL	MAX. RATED BURNED/ HOUR (SPECIFY UNITS)	MAX. EXPECTED BURNED/ DAY (SPECIFY UNITS)	MAX. EXPECTED BURNED/ YEAR (SPECIFY UNITS)	HIGHER HEATING VALUE (SPECIFY UNITS)	MAX. % SULFUR	MAX. % ASH

Code K - Vent/Stack Configuration

1. Unobstructed vertical discharge
2. Obstructed vertical discharge (e.g., raincap)
3. Horizontal or downward discharge (e.g., T-stack)
99. Other (specify) ____________

REVISED March 15, 1995

FORM 7 PART I

AIR POLLUTION CONTROL AND MONITORING EQUIPMENT:

COMPANY NAME	DATE	REGISTRATION NUMBER

☐ Check box if this page shows alternative operating scenario(s).

UNIT REF. NO.	MODE CODE	VENT/ STACK NO.	DEVICE REF. NO.	POLLUTANT/PARAMETER (See Instructions)	AIR POLLUTION CONTROL EQUIPMENT				MONITORING INSTRUMENTATION
					MANUFACTURER AND MODEL NUMBER	TYPE (USE CODE L)	% EFFICIENCY		SPECIFY TYPE, MEASURED POLLUTANT, AND RECORDER USED
							DESIGN	ACTUAL	

Code L - AIR POLLUTION CONTROL EQUIPMENT TYPE

1. Settling Chamber
2. Cyclone
3. Multicyclone
4. Cyclone scrubber
5. Orifice scrubber
6. Mechanical scrubber
7. Venturi scrubber
   - (a) fixed throat
   - (b) variable throat
8. Mist eliminator
9. Electrostatic Precipitator
   - (a) hot side
   - (b) cold side
   - (c) high voltage
   - (d) low voltage
   - (e) single stage
   - (f) two stage
   - (g) other (specify) ______________
10. Filter
    - (a) baghouse
    - (b) other (specify) ______________
11. Catalytic Afterburner
12. Direct Flame Afterburner
13. ABSORBER
    - (a) packed tower
    - (b) spray tower
    - (c) tray tower
    - (d) venturi
    - (e) other (specify) ______________
14. ADSORBER
    - (a) activated carbon
    - (b) molecular sieve
    - (c) activated alumina
    - (d)silica gel
    - (e) other (specify) ______________
15. Condenser (specify) ______________
99. Other (specify) ______________

CRITERIA POLLUTANT EMISSIONS:

COMPANY NAME	DATE	REGISTRATION NUMBER

☐ Check box at left if this page shows alternative operating scenario(s).

UNIT REF. NO.	MODE CODE	*MAXIMUM* EMISSION RATES TO ATMOSPHERE OF *CRITERIA* POLLUTANTS															BASIS OF ESTIMATE (USE CODE M)
		TOTAL SUSPENDED PARTICULATES (TSP) *		10 µM OR SMALLER PARTICULATES * (PM_{10})		SULFUR DIOXIDE (SO_2)		NITROGEN OXIDES (NO_x)		CARBON MONOXIDE (CO)		VOLATILE ORGANIC COMPOUNDS * (VOC)		LEAD (Pb)		STATE OPERATING PERMIT EMISSION CAP (Yes/No)	
		lb/hr	tons/yr	lb/hr	tons/yr	lb/hr	tons/yr	lb/hr	tons/yr	lb/hr	tons/yr	lb/hr	tons/yr	lb/hr	tons/yr		

<u>Code M - Emission Estimate Method (provide detailed calculations including assumed control efficiency of control equipment to support reported values.)</u>

1. Stack Test (include a copy of summary)
2. Material Balance (include calculations)
3. Emission Factor (identify source) and include calculations
99. Other (describe)

* TSP, PM_{10}, VOCs should also be split up by component and reported under TOXIC OR HAZARDOUS POLLUTANTS.

COMPANY NAME	DATE	REGISTRATION NUMBER

☐ Check box if this page shows alternative operating scenario(s).

TOXIC OR HAZARDOUS OR OTHER REGULATED POLLUTANT EMISSIONS FROM PROPOSED FACILITY:

UNIT REF. NO.	MOD CODE	VENT/ STACK NO	MAXIMUM EMISSION RATES TO ATMOSPHERE OF POLLUTANT (Specify pollutant)*					STATE OPERATING PERMITS EMISSION CAP (YES/NO)	BASIS OF ESTIMATES (USE CODE M)
			NAME CAS #	CONTROLLED		UNCONTROLLED			
				lb/hr	tons/yr	lb/hr	tons/yr		

Code M - Emission Estimate Method (provide detailed calculations including assumed control efficiency of control equipment, if applicable)

1. Stack Test (include a copy)
2. Material Balance (include calculations)
3. Emission Factor (identify)
99. Other (describe) ______________

* If you have other regulated pollutants, list as the first CAS number. Toxic Pollutant means on designated list. Particulate matter and volatile organic compounds are not toxic pollutants as generic classes of substances, but individual substances within these classes may be non-criteria toxic pollutants because their toxic properties or because a TLV (tm) has been established. See toxic pollutant listing in the front of this application. Specify which pollutants are also reported as TSP, PM10, or VOCs.

OPERATING PERIODS: (Optional use, to establish restriction on operating hours.)

COMPANY NAME	DATE	REGISTRATION NUMBER

☐ Check box if this page shows alternative operating scenario(s).

UNIT REF. NO.	PERCENT ANNUAL USE/THROUGHPUT BY SEASON				NORMAL PROCESS/EQUIPMENT OPERATING SCHEDULE			MAXIMUM EQUIPMENT/PROCESS OPERATING SCHEDULE		
	DECEMBER — FEBRUARY	MARCH — MAY	JUNE — AUGUST	SEPTEMBER — NOVEMBER	HOURS PER DAY	DAYS PER WEEK	WEEKS PER YEAR	HOURS PER DAY	DAYS PER WEEK	WEEKS PER YEAR

MAXIMUM FACILITY OPERATING SCHEDULE		
HOURS PER DAY	DAYS PER WEEK	WEEKS PER YEAR

APPENDIX II

Test-Burn Experimental Data

The following page contains additional information gathered during the test-burn experiment that was performed on June 28, 1995.

Note: Opacity is a measure of the quality of the stack emissions. Opacity measurements involve naked-eye comparisons to established standards. An opacity of 0-5 per cent indicates that virtually no visible emissions were present. Higher percentages indicate thicker, darker emissions. In general, an opacity less than 40 per cent is desired.

Table XII - Test-Burn Experimental Data			
Time	Approx. Opacity (%)	Steam Flowrate (lb/hr)	Steam Pressure (psig)
10:53 a[2]	20-30	20,000	150
11:00 a	5	55,000	125
11:15 a	0-5	48,000	125
11:30 a	0-5	43,000	125
11:50 a	0-5	40,000	125
12:00 p	10	50,000	125
12:05 p	5	50,000	125
12:07 p	40	55,000	124
12:10 p[3]	5	50,000	125
12:25 p	5	45,000	125
12:30 p	0-5	45,000	125
1:50 p[4]	60-80	45,000	120
2:00 p	60	40,000	120
2:15 p	0-5	46,000	125
2:45 p	0-5	45,000	125

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[2] Began feeding by-product into boiler at approximately 10:30 a.

[3] Gas boiler turned on to meet plant steam demand.

[4] Boiler grates dumped.

VITA

David Kaiser Mowery was born in Harrisburg, Pennsylvania on September 28, 1971. In the Fall of 1990, he began an undergraduate program in Mechanical Engineering at Virginia Polytechnic Institute and State University, located in Blacksburg, Virginia. During his senior year, David developed a great interest in the field of Energy Management. After graduating in May of 1994 with a Bachelor of Science in Mechanical Engineering, he began working for the Industrial Energy Center, an Energy Management consulting group based in the Mechanical Engineering Department of VPI&SU. David's work with the IEC eventually developed into a graduate-level research project. He completed the degree of Master of Science in Mechanical Engineering in the Spring of 1996.