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\* U.S. DEPARTMENT OF ENERGY \*  
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\* INNOVATIVE CLEAN COAL TECHNOLOGY \*  
\* DEMONSTRATION PROJECT \*  
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\* PASSAMAQUODDY TECHNOLOGY RECOVERY SCRUBBER™ \*  
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\* PUBLIC DESIGN REPORT \*  
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## ABSTRACT

This Public Design Report provides available nonproprietary design information on the Passamaquoddy Technology Recovery Scrubber™ Demonstration Project at Dragon Products Company's cement plant at Thomaston, Maine. The Recovery Scrubber was developed to address simultaneously the emission of acidic gas pollutants and the disposal of alkaline solid waste at a cement plant. The process, however, has general application to other combustion processes.

The origins of the project, the present lack of alternatives to address the same problems, a description of the technology, and the design, construction and preliminary operation of the demonstration unit are presented.

## ACKNOWLEDGMENTS

The project was originated during the 1980s by Dragon Cement Company while under the ownership of the Passamaquoddy Indian Tribe. During the planning of the installation, the Company was sold to CDN(USA). After detailed review of the technology, the board of CDN(USA) decided to proceed with the project and grateful acknowledgment is made of their adoption of the project and their funding of half the total cost. The constructive assistance of the management and staff of Dragon Products Company during the course of the project have also been of invaluable assistance.

The Innovative Clean Coal Technology Program of the U.S. Department of Energy was critical in assisting Passamaquoddy Technology in meeting its share of project cost. The provision of \$5,980,000 by the Department of Energy is acknowledged, and the support and encouragement of the staff of the Department have been particularly appreciated.

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## TABLE OF CONTENTS

	<u>Page</u>
EXECUTIVE SUMMARY	10
1.0 INTRODUCTION	14
1.1 Purpose of Public Design Report	15
1.2 Brief Description of the Project	16
1.3 Objectives of the Project	21
1.4 Significance of the Project	21
1.5 DOE's Role in the Project	22
1.6 Project Management	23
2.0 TECHNOLOGY DESCRIPTION	25
2.1 Brief Description of the Technology Being Used	32
2.2 Proprietary Information	34
3.0 DESIGN BASIS	35
3.1 Feed Streams	35
3.2 Product Streams	36
3.3 Process Conditions	37
4.0 DETAILED PROJECT INFORMATION	38
4.1 Overall Design Description	38
4.2 Materials Balance and Heat Balance	40
4.3 Crystallizer Sub-system	43
4.4 Process & Instrumentation Drawings	44
4.5 Equipment List	50
4.6 Utility Requirements	53
4.7 Consumable Requirements	53
4.8 Waste Streams	53
5.0 TECHNICAL PERFORMANCE	54
5.1 System Modifications	54
5.2 Operating Performance	56
6.0 COSTS	57
6.1 Project Capital Costs	57
6.2 Operating & Maintenance Costs	59
6.3 Cost/Benefit Analysis	62
6.4 Scaling Considerations	63

## LIST OF TABLES

		<u>Page</u>
Table 1	Project Organization	24
Table 2	Maintenance cost estimates	60

## LIST OF FIGURES

Figure 1	Recovery Scrubber Schematic Process Flow	11
Figure 2	Dragon Cement Plant Layout	19
Figure 3	Dragon Cement Plant Process Flow	20
Figure 4	Recovery Scrubber Detailed Process Flow	26
Figure 5	Recovery Scrubber Layout	28
Figure 6	Recovery Scrubber Equipment Sub-systems	65

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Please note that, as some drawings have been reduced from 24"x36" originals, not all details may be legible. If full size drawings are required, please contact Passamaquoddy Technology L.P.

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LIST OF ABBREVIATIONS

CDN (USA)	Wholly owned subsidiary of Cementos del Norte, a consortium of Spanish cement companies which owns Dragon Products Company, Inc.
CKD	Cement kiln dust
DOE	U.S. Department of Energy
Dragon	The Dragon Products Company's cement plant located at Thomaston, Maine.
HPD	HPD, Inc., designers and suppliers of the crystallizer sub-system
PTech	Passamaquoddy Technology, L.P.
Recovery Scrubber	Passamaquoddy Technology Recovery Scrubber <sup>TM</sup>

## LIST OF UNITS

A	amps
BTU	British thermal unit
°F	degrees Fahrenheit
ft	foot
gpm	gallons per minute
gr/scf	grains per dry standard cubic foot
HP	horse power
inch H <sub>2</sub> O	pressure in inches water gauge
KCal/H	kilocalories per hour
KVA	kilovolt-amp
KW	kilowatt
KWH	kilowatt hour
Lb	pound weight
LbEq	pound equivalent
mg/NM <sup>3</sup>	milligrams per normal cubic meter
ppm	parts per million
rpm	revolutions per minute
T/H	(short) tons per hour
V	volts
∅	diameter

## GLOSSARY OF TERMS

$\text{Al}_2\text{O}_3$	Aluminum oxide
$\text{CO}_2$	Carbon dioxide
Ca	Calcium
$\text{CaCO}_3$	Calcium carbonate
CaO	Calcium oxide
$\text{Ca}(\text{OH})_2$	Calcium hydroxide
$\text{CaSO}_4$	Calcium sulfate
Cl	Chloride
$\text{Fe}_2\text{O}_3$	Ferric oxide
$\text{H}_2\text{O}$	Water
K	Potassium
KOH	Potassium hydroxide
$\text{K}_2\text{O}$	Potassium oxide
$\text{K}_2\text{SO}_4$	Potassium sulfate
KF	Kiln feed
LoI	Loss on ignition
MgO	Magnesium oxide
$(\text{NH}_4)_2\text{SO}_4$	Ammonium sulfate
Na	Sodium
$\text{Na}_2\text{O}$	Sodium oxide
NOx	Nitrogen oxides
O	Oxygen
S	Sulfur
$\text{SO}_2$	Sulfur dioxide
$\text{SO}_3$	Sulfur trioxide
$\text{SO}_4$	Sulfate
$\text{SiO}_2$	Silicon dioxide

## EXECUTIVE SUMMARY

The Passamaquoddy Technology Recovery Scrubber<sup>TM</sup> was conceived and developed specifically to address two problems experienced by the Dragon cement plant; meeting increasingly stringent gas emission limits for sulfur dioxide, and disposing of kiln dust, containing alkali oxides, which had to be wasted in order to avoid kiln operating and product quality problems.

The idea involved making the kiln dust into a slurry in order to leach out the species (primarily potassium and sulfur) which rendered it unacceptable for return to kiln feed. This slurry, the liquid part of which is an alkaline solution, acts as a scrubbing reagent for SO<sub>2</sub> in the flue gas while CO<sub>2</sub> in the gas serves to precipitate soluble calcium and release sulfate for combination with the potassium. The effect of the process is to scrub SO<sub>2</sub> from kiln flue gas, extract the volatile species from the dust allowing it to be returned to the kiln, and yield a leachate comprising potassium sulfate which can be crystallized (using heat recovered from the flue gas) and sold as fertilizer.

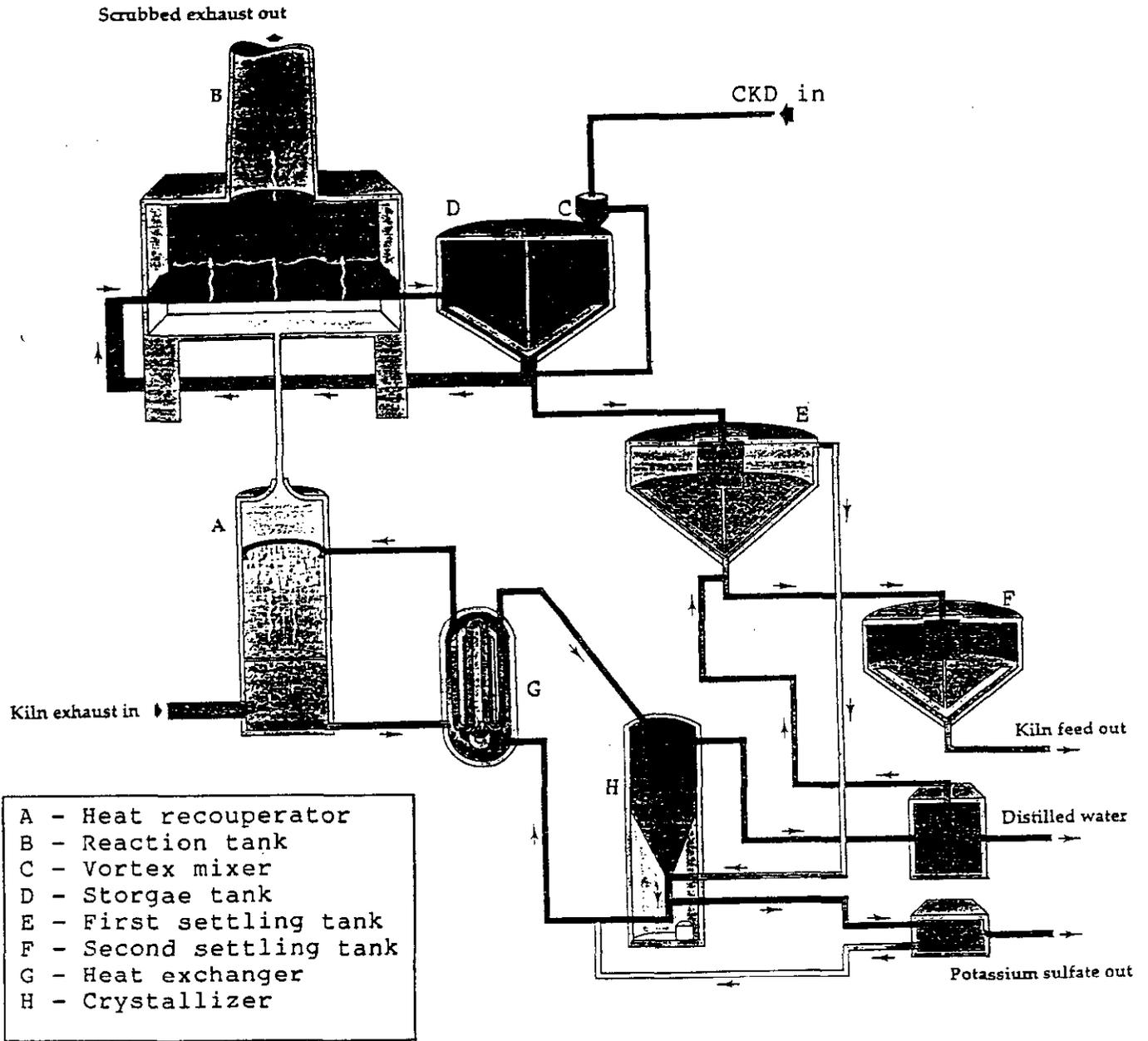
Apart from widespread application in the cement industry, it was evident that, if the process could be demonstrated, its potential would extend to any plant burning fossil fuel where an alkaline waste either occurs intrinsically or can be juxtaposed. Obvious candidates appeared to include the pulp & paper industry and waste incineration.

The chemistry was proved in a 1/100th scale pilot plant using actual kiln dust and a slip stream of kiln gas. A full scale demonstration installation was commissioned in 1989 by CDN (USA), the owners of the Dragon plant with the financial support of the U.S. Department of Energy under its Innovative Clean Coal Technology Program. Construction was commenced in April 1990 and the system was first started up on December 20, 1990.

A schematic process flow is shown in Figure 1.

Flue gas is taken from the kiln ID fan discharge and passes through a forced draft system fan which is controlled to maintain the kiln fan outlet pressure unchanged. The gas is quenched to 140°F in the heat recuperator (A) before passing to the reaction tank (B). This is a sieve tray reactor which is a large perforated plate. The gas passes up through the plate and contacts the slurried kiln dust before being

Figure 1 - Schematic Process Flow



demisted and discharged through the Scrubber stack. Kiln dust is conveyed to a vortex mixer (C) at the storage tank (D) and mixed into the slurry. The slurry is circulated over the reaction tank sieve-tray to contact the flue gas. The reactions which take place can be summarized:



After a predetermined retention time, the slurry is transferred to a settling tank (E) where solids are concentrated before being pumped to a second settling tank (F). During this transfer, the slurry is diluted with clean water. The concentrated slurry from the second settling tank is returned to the cement plant kiln feed system.

The leachate from the first settling tank contains potassium sulfate in solution which is fed to the crystallizer (H). A combination of heat recovered from the flue gas and vacuum is used to evaporate water and crystallize the potassium sulfate. Crystallized salt is removed by centrifugation, is pelletized, dried and conveyed to storage.

The water evaporated from the leachate is condensed and can either be reused in the Scrubber system or made available for other use.

Control of the Recovery Scrubber is from the cement plant central control room and no dedicated staff are required either for operation or maintenance.

From the outset the basic concept and technology were confirmed. Apart from routine plumbing and electrical malfunctions, subsequent operation revealed a number of problems which have been addressed and corrected. Principal areas requiring modification were:

- Inadequate sieve tray flatness
- Inadequate gas distribution below the sieve-tray
- System for slurrying kiln dust
- Particulate accretion below sieve-tray
- Mist elimination
- Potassium sulfate pellet formation

Operation of the installation has been impacted by the depressed cement market in New England over the past three years which has given rise to extended shut downs of the cement plant. For this reason, the 13-month operating period

under DOE supervision has been extended to August 1993.

The Recovery Scrubber is now operating with an estimated availability of 95%. During 1993 operation, essentially all kiln dust fed to the Scrubber has been treated and returned to the cement kiln without problem, and all flue gas has been cleaned with an SO<sub>2</sub> removal efficiency of better than 90%.

It should be appreciated that, while the chemistry of the Recovery Scrubber is innovative, the equipment involved is largely standard. One of the major design considerations was material selection as the moist flue gas, prior to neutralization in the reaction tank, is seriously corrosive. This was handled by appropriate use of stainless steels, fiberglass, and vinyl ester resin linings.

Principal sub-systems employed include:

- Water spray tower heat recuperator
- Sieve-tray reactor
- Vortex mixer for hydrating kiln dust
- Settling tanks for separating slurry solids and leachate
- Evaporative crystallizer for extracting salt product

The total cost of the installation has been \$17,750,000. This, however, included considerable rework and modification. An independent estimate of the Recovery Scrubber "as built" gave \$10,090,000. Operating cost, including electric power and maintenance, is estimated to be \$500,000 per year.

Benefits from operating the Recovery Scrubber, depending upon the extent to which Dragon chooses to accept outside waste materials, are estimated at \$4,497,000 per year, but could be raised to approximately \$7,000,000 per year by judicious acceptance of outside waste materials for disposal. In addition, the plant has:

- Eliminated the landfilling of waste kiln dust
- Facilitated the recovery of the existing stockpile
- Ensured regulatory compliance of gaseous emissions and entrained particulates
- Enabled the kiln to burn high-sulfur fuels
- Made possible the acceptance for disposal fees of outside waste materials such as biomass ash and lime sludge which can be incorporated into kiln feed

## 1.0 INTRODUCTION

The reduction of sulfur dioxide and carbon dioxide emissions has become a key element of environmental policies world wide. The combustion of a low rank coal with 3% sulfur can give rise to more than 8Lb SO<sub>2</sub> per million BTU. This compares with a limit on utilities of 2.5Lb required under the 1990 Amendments to the Federal Clean Air Act for enforcement by 1995 and 1.2Lb by 2000. Note that in 1990, 65% of coal shipped to utilities exceeded the latter limit and it has been estimated that the cost of compliance will be \$15-20 billion.

Available means of compliance are switching to low sulfur fuel or scrubbing of exhaust gas. A price premium of \$2-4 per ton already applies to low sulfur coal and this difference is expected to increase. Scrubbing, usually with lime or limestone, eliminates SO<sub>2</sub> emission to the atmosphere but often substitutes for this a solid/liquid waste problem. There is, therefore, obvious need for a cost-effective, zero-discharge technology which would facilitate the use of high-sulfur fuels.

While emission of acidic gaseous pollutants is a ubiquitous problem concomitant to the combustion of fossil fuels, some industrial processes employing combustion also generate alkaline solid waste which is itself a disposal problem. It is the purpose of the Recovery Scrubber to use the one to neutralize the other, to clean exhaust gas, to separate salt product from the solid waste so that the waste can be recovered and reused, and to isolate and purify the salt product for sale.

The process was developed to solve the particular problems of a cement plant and the prototype installation is on a cement kiln. The technology, however, has potential application to other combustion processes where an approximate stoichiometric balance between acidic and alkaline pollutants exists naturally or can be arranged. An obvious example is the pulp & paper industry where fossil fueled power boilers often operate adjacent to wood fired boilers which produce an alkaline biomass ash.

## 1.1 PURPOSE OF THE PUBLIC DESIGN REPORT

This report is compiled to describe both the origins and the context of the project and the concept, design, construction, and initial operation of the installation.

The scope of the report is limited to non-proprietary information and includes, therefore, a description of the various design considerations but is not intended to provide sufficient information to facilitate the design of an installation.

## 1.2 BRIEF DESCRIPTION OF THE PROJECT

The Dragon Products Company cement plant in Thomaston, Maine is an integrated plant with one long wet-process kiln rated at 1450 tons per day and fired with coal. The plant was bought in 1983 by the Passamaquoddy Indian Tribe. In 1988 the Tribe agreed to sell the plant to CDN (USA), a wholly owned subsidiary of a consortium of Spanish cement producers with an existing cement distribution operation based in Boston, MA. During the period of Passamaquoddy ownership, Dr. Garrett Morrison directed a considerable effort to mitigate environmental problems at the plant and succeeded in making Dragon the first plant in the country which had been scheduled by the EPA as "non-compliance" to be brought back into compliance with emission regulations.

Cement manufacture involves the mining and blending of raw materials to give tightly defined composition of, principally, calcium carbonate (limestone) and silica with lesser proportions of aluminum oxide and iron oxide. The raw mixture is ground to a fine powder which, in the wet process, is a slurry with some 30% water. The slurry is fed to the back of a long rotary kiln which is fired at the discharge end. As the slurry progresses down the kiln it is first dried, then calcined (evolution of carbon dioxide from calcium carbonate), and partially fused and reacted to form calcium silicates and aluminates which are hydraulically active. The material discharged from the kiln is a black nodular clinker. Clinker is interground with a small proportion of gypsum to give cement. The critical step in this process is the kiln burning. This involves a substantial fuel consumption (3-5 million BTUs per ton of clinker produced) so that the kiln exhaust gas contains combustion products, carbon dioxide evolved from heating the limestone, and entrained particulates carried back from the kiln. The gas is normally treated for dust collection (by a baghouse in the case of Dragon) before release from the stack. Thus, while particulates are largely, though not totally removed, gaseous components such as SO<sub>2</sub> pass to atmosphere. The layout of the Dragon cement plant is shown in Figure 2 and its process flow in Figure 3.

Maine state regulations limit the sulfur content of fuel to not more than 1.92 Lb SO<sub>2</sub> per million BTU unless exhaust gas scrubbing is practiced; this translates to approximately 1.0% sulfur in coal. An early development at Dragon was a low-cost scrubbing system using the alkaline leachate from the kiln dust stock-pile sprayed into the kiln exhaust to scrub

SO<sub>2</sub>. The resulting alkali sulfates condense and are extracted with the baghouse dust. This system enabled Dragon to burn higher sulfur coal of lower cost. However, the dust had still to be wasted.

Wasting of kiln dust is a fairly common problem for cement kilns where high concentrations of alkalis (K,Na), sulfur and chloride entering with raw materials and fuel become concentrated in the dust. In such cases, disposal of the dust is essential to prevent kiln operating and product quality problems which otherwise result from the build up of cycles of these volatile species in the kiln and ultimately their discharge in the clinker.

Stockpiling of kiln dust is objectionable for several reasons. It is a waste of raw materials which have been mined, ground and blended; it involves additional handling; leachate from the stockpile must be monitored and treated; and, with increasing regulation, the legal liability for such a stockpile is cause for concern.

In looking for ways to obviate dust stockpiling, Dr. Morrison recognized the alkalinity of the leachate and, thence, developed the idea that an aqueous slurry of the waste dust could serve as a scrubbing reagent for flue gas. In the Dragon materials, potassium and sulfur were the only volatiles present in significant quantity so that the product of reaction was potassium sulfate of a purity adequate for use as commercial fertilizer. Also available from the flue gas was sufficient waste heat to effect the evaporation of the leachate in order to yield potassium sulfate in crystallized form. After separation of the leachate, the remaining slurry solids were satisfactory for returning to kiln feed.

It was, therefore, apparent that the technology could solve two major pollution problems faced by many cement plants and that, by considering such factors as the value of the recovered kiln feed, the avoided cost of dust landfilling, the sale of potassium sulfate, and, potentially, the sale of SO<sub>2</sub> emission trading credits, the system would at least offset its construction and operating costs and might, in certain applications, generate a commercial return on investment.

Both laboratory and small-scale slip-stream testing confirmed the practicability of the technology and, in 1987, the management of Dragon Products Company decided to proceed with

a prototype full-scale installation. Patents were then and subsequently obtained for various configurations of the Recovery Scrubber.

While the chemistry of the process was innovative, the equipment involved was largely standard. However, given the scale of the undertaking and the probability of significant commissioning and modification costs, some assistance with funding the installation was considered essential and application was duly made to the Department of Energy in May 1988 for consideration under Round 2 of the Innovative Clean Coal Technology Program. The Department accepted the proposal and offered matching funds up to a total of \$5,900,000.

During 1988, however, an unsolicited offer from CDN (USA) for the purchase of the Dragon cement plant was accepted and ownership passed to CDN. When the Tribe sold the cement plant, they retained the technology and set up a new company, Passamaquoddy Technology L.P. to develop and commercialize the system. The new owners, after independent technical and economic assessment of the project, decided to proceed with the installation and an agreement was accordingly concluded between Dragon Products Company and Passamaquoddy Technology L.P.

Construction began in April 1989 and the plant was first started up in December 1990. 1991 and 1992 were depressed years for the construction industry in New England and the cement plant suffered extended down-time due to lack of sales. This, of course, has adversely affected the ability of the Recovery Scrubber to run continuously and the necessary modifications to, and adjustment of, the installation have been protracted.

From the outset, SO<sub>2</sub> scrubbing efficiency has been at 90% or better depending upon input levels, and all dust has been processed and returned to the cement plant. While potassium sulfate leachate has been produced and crystallized, it has not yet been pelletized in satisfactory form. This is due to marginally excessive moisture in the crystallizer product and correction is being effected.

Figure 2 - Dragon Cement Plant Layout

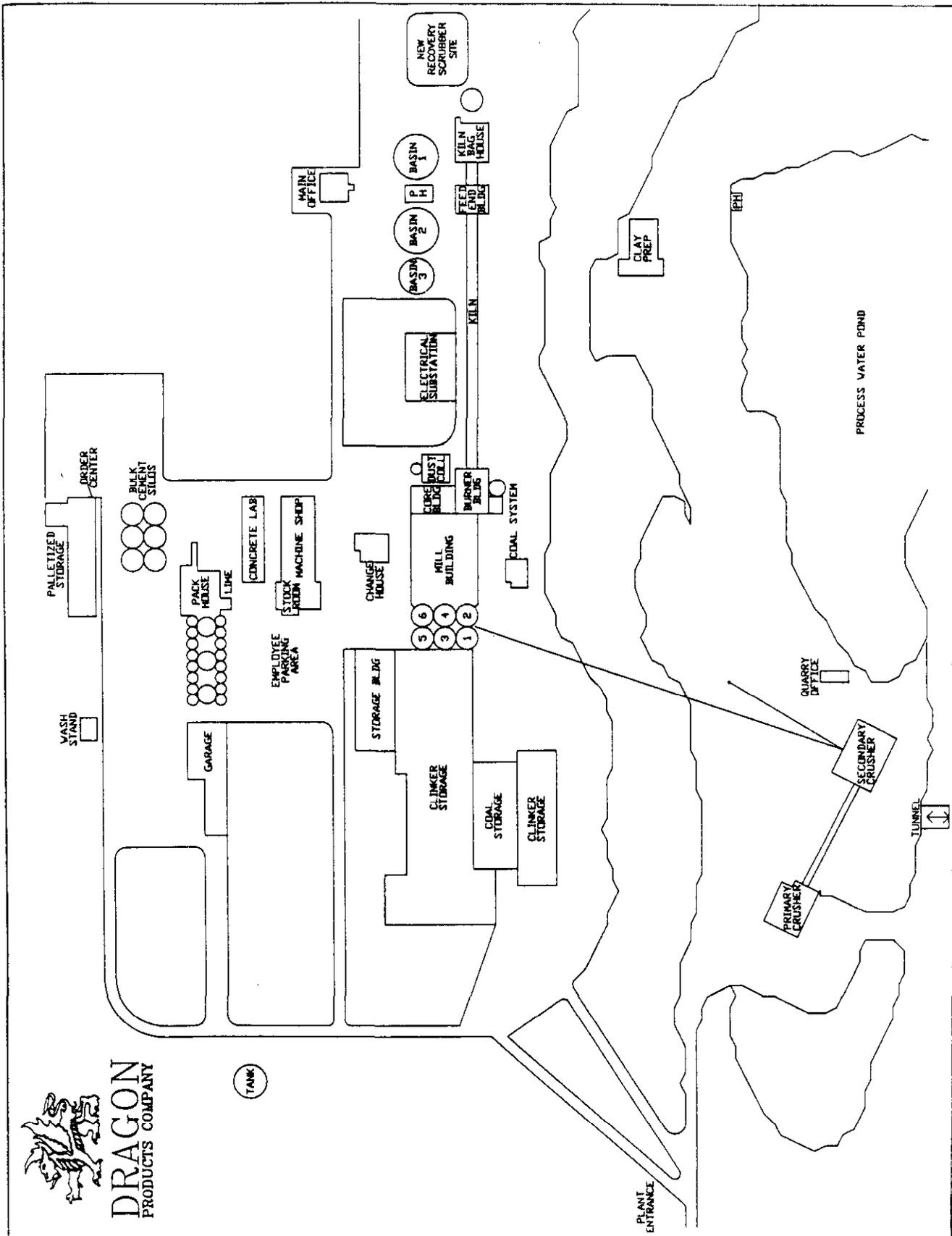
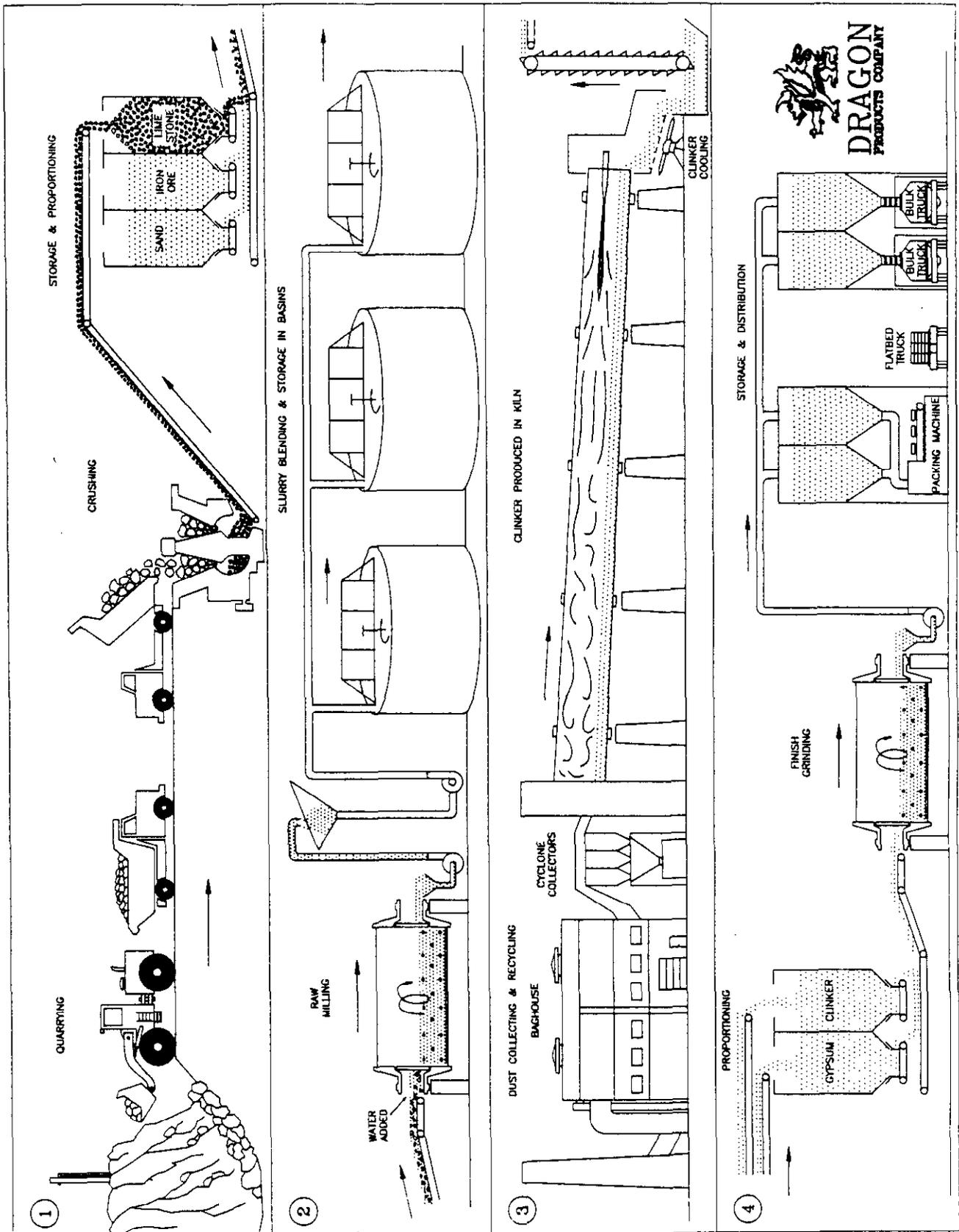


Figure 3 - Dragon Cement Plant Process Flow



### 1.3 OBJECTIVES OF THE PROJECT

The purpose of the project was to demonstrate on an industrial scale that the technology would provide a feasible and viable means of solving both the acid gas emission and solid waste disposal problems of cement kilns.

### 1.4 SIGNIFICANCE OF THE PROJECT

The reduction of sulfur dioxide and carbon dioxide emissions has become a key element of environmental policy. The combustion of low rank coal with 3% sulfur can give rise to more than 8 Lb of SO<sub>2</sub> per million BTU compared to a limit on utilities of 2.5 Lb required under the 1990 Amendments to the U.S. Federal Clean Air Act for enforcement by 1995 and a limit of 1.2 Lb by 2000. Note that in 1990, 65% of coal shipped to utilities exceeded the latter limit and it has been estimated that the cost of compliance will be \$15-20 billion.

Available methods for compliance are switching to low sulfur fuel or scrubbing exhaust gas. A significant proportion of coal users switching to low sulfur coal will, inevitably, enhance the price premium which such fuels will command. Scrubbing, usually with lime or limestone, solves the SO<sub>2</sub> emission problem but substitutes a problem of disposal of the desulfo-gypsum produced. Also, the scrubbing reaction with calcium carbonate, or the calcination of limestone to produce calcium oxide reagent, both give rise to carbon dioxide emissions which are now also becoming subject to environmental concern and regulation.

The Recovery Scrubber offers an alternative in certain coal burning applications. By facilitating the use of high sulfur coal in a process which employs pre-existing alkali waste as scrubbing reagent and which results only in reusable products, the Recovery Scrubber is considered to offer constructive support to the continued production of high sulfur coal.

The technology developed for, and demonstrated on, a cement kiln is obviously applicable to any combustion process where the required stoichiometric balance between alkali waste materials and acidic gaseous pollutants either exists naturally or can be arranged. Such arrangement could be either the incorporation of waste from a nearby process or

the employment of commercial alkali. Potential application has also been identified in the pulp & paper industry and in waste incineration.

Cost justification for a Recovery Scrubber installation is a combination of required pollution control and economic benefits. The latter comprise revenues from products of the process (recovered kiln feed, saleable salt product) and avoided costs (landfilling of dust, alternative dust collection equipment, high-sulfur fuel cost savings). The avoided costs are largely related to regulatory control which is progressively tightening.

#### 1.5 DOE'S ROLE IN THE PROJECT

In December 1987, Public Law No 100-202, as amended by Public Law No. 100-446, authorized the Department of Energy to administer a \$575 million fund to assist the development of Innovative Clean Coal Technology. In February 1988, DOE issued a Program Opportunity Notice (PON No. DE-PS01-88FE61530) inviting proposals for projects which would demonstrate new technology to effect significant reduction of sulfur dioxide and/or nitrogen oxide emissions from existing coal-burning facilities and which were cost effective and capable of commercialization. The program offered cost-sharing assistance for the critical, but financially risky, step of scaling up laboratory or pilot plant systems to a full-scale demonstration which would facilitate commercialization.

Of 55 proposals, DOE eventually selected 16, including the Recovery Scrubber, for assistance. The Cooperative Agreement between DOE and Passamaquoddy Technology L.P. was signed in December 1989.

DOE has since monitored the progress of construction and operation and approved payments to the project against progress reports submitted by Passamaquoddy Technology confirmed by periodic site visits by DOE staff.

Monthly and quarterly reports have been submitted to DOE continuing through the first 13 months of operation. Due to the extended shut-downs of the cement plant necessitated by the depressed cement market over the past three years, the operating period has been extended to August 1993.

## 1.6 PROJECT MANAGEMENT

The owner of the installation, Dragon Products Company, Inc. reserved the right to manage the project but did not, in fact, dedicate a full time project manager. Passamaquoddy Technology, L.P. has a Memorandum of Agreement with Dragon dated October 11, 1988 for the construction of the Recovery Scrubber in which it was agreed that any financial assistance awarded by DOE would be transferred in total by PTech to the Project.

PTech acted during all stages of the Project as consultants and contractors to Dragon with an advisory but not a management function towards engineering, construction and procurement.

Process design was a total responsibility of PTech. Preliminary detailed engineering was performed by E.C.Jordan Co. During the course of the project, however, E.C.Jordan Co. was purchased by Combustion Engineering Corporation who in turn were acquired by ABB Ltd., and the local design capability was largely dissipated. The design function was thereupon transferred to Cianbro Corporation who were also contracted by Dragon as Main Contractor, but who did not at that time have a significant design capability. Equipment and materials procurement was handled jointly by Dragon and Cianbro.

Key people involved in the organization of the project were:

Dragon Project Director - P.E. Cianchette, VP of Operations  
Dragon Project Manager - M. Walton, Cement Plant Manager

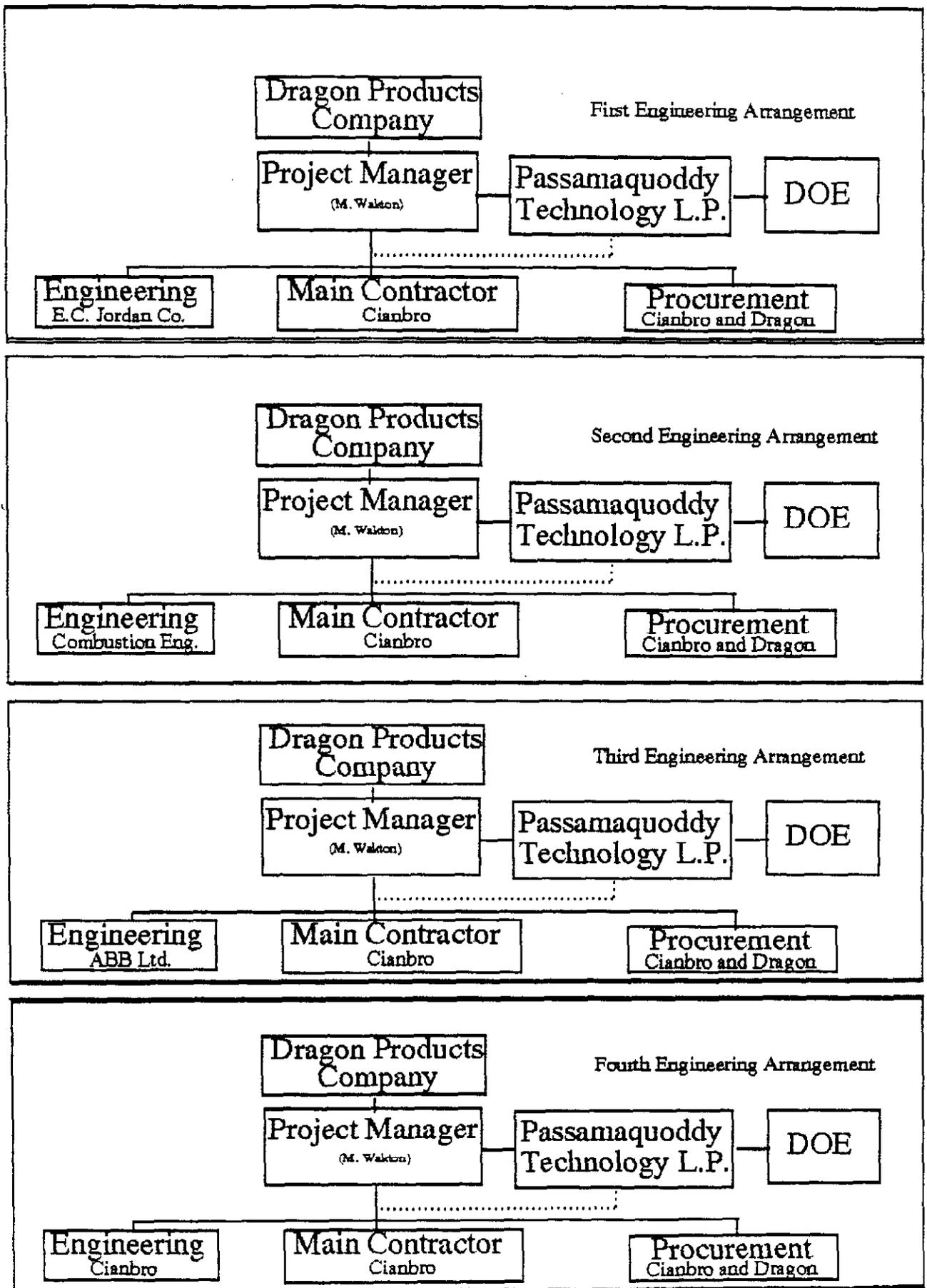
PTech Project Director - Dr. G.L. Morrison, President & CEO  
PTech Project Manager - R.C. Turcotte

DOE Contracting Officer - R.D. Rogus  
DOE Project Manager - J.C. McDowell

Cianbro Project Manager - R. Rebel

The project organization chart is shown in Table 1.

Table 1 - Project Organization Chart



## 2.0 TECHNOLOGY DESCRIPTION

A number of industrial processes involving combustion also give rise to solid or liquid wastes containing appreciable quantities of alkali metal compounds (K,Na).

The Recovery Scrubber is designed to exploit the chemical reactions between acidic and alkaline waste components; specifically between acidic exhaust gas constituents and alkaline solid wastes. The products of reaction are salts of alkali metals which can be isolated for profitable disposal while the waste streams are cleaned for harmless emission or economic recovery.

The Recovery Scrubber involves a reaction tank in which flue gases are intimately mixed with a liquid waste or a solid waste in slurry form. Such a reaction system is versatile, and allows for a variety of waste treatment processes according to the particular needs of each application.

At Dragon, waste cement kiln dust from the baghouse, hot flue gas from the kiln induced draft fan, and make-up water are the process input materials. Figure 4 shows the detailed process flow and Figure 5 the Scrubber layout.

Flue gas from the kiln exhaust is cooled in the heat recuperator. This is a dual purpose operation in that the gas is cooled before reaction with the scrubbing medium, and the heat recovered during cooling is extracted for use later in the process. The cool (approximately 140°F) gas is then conveyed to, and scrubbed in, the reaction tank.

Cement kiln dust is mixed with water to form an alkaline slurry and then used in the reaction tank as the scrubbing reagent for reaction with acidic components of the flue gas. In the reaction tank, the acid gas and caustic kiln dust undergo neutralization and dissolution reactions in which gas is used to process dust, and dust is used to process gas.

The products are separated into solids which are returned to the kiln as raw material, and leachate, containing dissolved materials, which is pumped to the crystallizer for evaporation and crystallization of dissolved potassium sulfate.

Energy for evaporation is derived from the flue gas during cooling. The collected heat is transferred to the evaporator and discharged as steam. The steam is condensed and the



Material streams pertaining to Figure 4

<p>A <u>Flue gas feed:</u>            CO<sub>2</sub> 142,600 Lb/H            O<sub>2</sub> 57,940 Lb/H            SO<sub>2</sub> 132 Lb/H            H<sub>2</sub>O 96,670 Lb/H            N<sub>2</sub> 457,000 Lb/H            Total 754,342 Lb/H            (225,000acfm @ 245°F)</p>	<p>H <u>Treated dust returned to kiln feed:</u>            Solids 22,552 Lb/H            H<sub>2</sub>O 12,000 Lb/H</p>
<p>B <u>Conditioned gas:</u>            H<sub>2</sub>O 93,205 Lb/H            Temp. 140°F</p>	<p>I <u>Leachate:</u>            K<sub>2</sub>SO<sub>4</sub> 850 Lb/H            Other 150 Lb/H            H<sub>2</sub>O 20,300 Lb/H</p>
<p>C <u>Exhaust gas:</u>            CO<sub>2</sub> 140,000 Lb/H            H<sub>2</sub>O 96,588 Lb/H            Temp. 141°F</p>	<p>J <u>Centrifuged K<sub>2</sub>SO<sub>4</sub>:</u>            K<sub>2</sub>SO<sub>4</sub> 850 Lb/H            Other 150 Lb/H            H<sub>2</sub>O 50 Lb/H</p>
<p>D <u>Kiln dust feed:</u>            SiO<sub>2</sub> 2,937 Lb/H            Al<sub>2</sub>O<sub>3</sub> 469 Lb/H            Fe<sub>2</sub>O<sub>3</sub> 296 Lb/H            CaO 9,186 Lb/H            MgO 687 Lb/H            SO<sub>3</sub> 1,166 Lb/H            K<sub>2</sub>O 683 Lb/H            Na<sub>2</sub>O 62 Lb/H            Total 20,820 Lb/H            Temp. 70°F</p>	<p>K <u>Pelletized K<sub>2</sub>SO<sub>4</sub>:</u>            1,000 Lb/H</p>
<p>E <u>Slurry circulation to vortex mixer:</u>            500 gpm</p>	<p>L <u>Make-up water:</u>            13,468 Lb/H (27 gpm)</p>
<p>F <u>Slurry circulation to sieve tray:</u>            9,000 gpm</p>	<p>M <u>Acidic condensate:</u>            Solids 30 Lb/H            H<sub>2</sub>O 11,970 Lb/H            (24 gpm)</p>
<p>G <u>Slurry feed to settling tank 1:</u>            Solids 25,473 Lb/H            H<sub>2</sub>O 73,928 Lb/H            Temp. 141°F</p>	<p>N <u>Crystallizer condensate:</u>            21,250 Lb/H (42.5 gpm)            Dissolved solids 1 Lb/H</p>
	<p>O <u>Water evaporation:</u>            Settling tank 1                              2,000 Lb/H            Settling tank 2                              500 Lb/H</p>



condensate is returned to the process as part of the make-up water requirement.

Process chemistry is based on the relative solubilities of limestone ( $\text{CaCO}_3$ ), gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), and potassium sulfate ( $\text{K}_2\text{SO}_4$ ), and on the ability to maintain a reaction solution saturated in carbon dioxide obtained from the flue gas. Both calcium carbonate and gypsum are present in the scrubbing medium and flue gas provides a constant input of both carbon dioxide and sulfur dioxide. The solubility of gypsum is approximately 0.22% and that of calcium carbonate 0.002%. That is, gypsum is more than 100 times more soluble than calcium carbonate. As gypsum from waste kiln dust dissolves in the slurry to approach saturation (0.22% in solution), the  $\text{Ca}^{++}$  ion is continuously precipitated as calcium carbonate due to the constant presence of carbon dioxide in solution. The gypsum, therefore, cannot reach saturation and gypsum scaling is avoided. Alkali, for example potassium from the dust, is available to combine with  $\text{SO}_4^-$  liberated from  $\text{CaSO}_4$  to form a highly soluble salt. The  $\text{SO}_4^-$ , therefore, remains in solution.

The slurry solids, including precipitated  $\text{CaCO}_3$ , and liquid are then separated for recovery. Solids are returned to the kiln as raw material and the liquid is evaporated for recovery of the crystallized products. The solids as recovered are free of alkali and sulfate and are suitable as raw material for cement manufacture. The liquid contains dissolved salt which, at Dragon, is predominantly potassium sulfate. In other applications, the salt product may be a mixture of compounds, for example potassium sulfate with ammonium sulfate or sodium chloride. Mixed salts may require separation by selective crystallization to maximize by-product value.

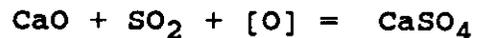
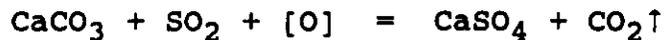
The chemistry requires an approximate stoichiometric balance between cationic K & Na and anionic  $\text{SO}_3$  & Cl. This commonly occurs naturally in cement manufacturing processes. Where an imbalance occurs, most usually a deficiency of alkali, the alkali must be augmented either by incorporating an alkali-rich waste material such as biomass ash, or by using commercial alkali such as KOH or ammonia. As ammonia typically costs US\$160 per ton and yields nearly four times its weight of  $(\text{NH}_4)_2 \cdot \text{SO}_4$ , which wholesales for about \$55 per ton, the economics can be attractive.

A minor, but significant, effect of the Recovery Scrubber is the absorption of carbon dioxide from processed gas. The

absorption results from recarbonation of, primarily, calcium oxide in the dust, and recovery is typically in the range 1-3% for a cement kiln.



This does, however, contrast with lime and limestone scrubbers where  $\text{CO}_2$  release is essential to  $\text{SO}_2$  absorption.



Installation of a Recovery Scrubber normally involves no interference with operation of the host plant. Tie-in of gas ducting with appropriate dampers can be made during a maintenance shut-down. The ash or dust stream is, almost by definition, presently being sent to landfill so that handling is external to the plant. Operation of the Recovery Scrubber has been confirmed not to impact operation of the host process.

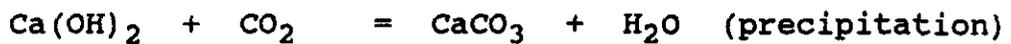
### 2.0.1 RECOVERY SCRUBBER CHEMICAL REACTIONS

Significant reactions which occur include:

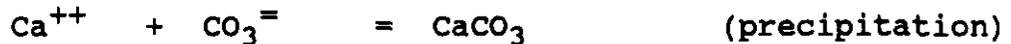
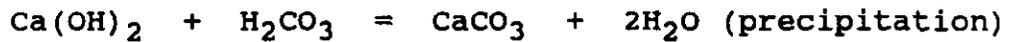
#### Reactions involving exhaust gas



#### Reactions involving kiln dust



#### Reactions between exhaust gas and kiln dust components



## 2.1 BRIEF DESCRIPTION OF THE TECHNOLOGY BEING USED

Feed streams to the Recovery Scrubber are:

### 1 Kiln exhaust gas with typical composition:

Flow rate, scfm	120,000
Temperature, °F	240
H <sub>2</sub> O, % (vol)	24
CO <sub>2</sub> , % (vol)	14
SO <sub>2</sub> , ppm (vol)	200
NOx, ppm (vol)	450
Particulates, gr/scf	0.017

### 2 Kiln waste dust with composition:

Feed rate, T/H	8.0
SiO <sub>2</sub> , % (wt)	14.1
Al <sub>2</sub> O <sub>3</sub> , %	2.3
Fe <sub>2</sub> O <sub>3</sub> , %	1.4
CaO, %	44.1
MgO, %	3.3
SO <sub>3</sub> , %	5.6
K <sub>2</sub> O, %	3.3
Na <sub>2</sub> O, %	0.3
LoI, %	27.0

### 3 Make-up water:

The dew point of the flue gas is slightly above the operating temperature of the reaction tank so that there is a small recovery of water from the gas.

Water is added to the dust to form slurry but, as this forms the leachate which is recovered by distillation in the crystallizer, there is again no net loss. If the distilled water were to be used for other purposes, an equivalent make-up would be required; some 50 gpm. However, in this installation the distilled water is returned to the reaction system. Small quantities of water are injected as pump seal water and this is approximately balanced by evaporation from the settling tanks.

The gas is cooled to approximately 140°F by water sprays in the heat recuperator and the dust is mixed with water to form a slurry of 20% solids content before the two are brought into intimate contact on a sieve tray in the reaction tank.

The reacted gas is passed through a chevron demister before release to atmosphere with typical composition:

Temperature, °F	140
H <sub>2</sub> O, %	25
CO <sub>2</sub> , %	15
SO <sub>2</sub> , ppm	5
NOx, ppm	400
Particulates, gr/scf	0.006

The slurry, during the period of its circulation over the sieve tray (see Section 2.0), undergoes various reactions which were summarized in Section 2.0.1.

## 2.2 PROPRIETARY INFORMATION

The Recovery Scrubber process is covered by U.S. and foreign patents so that most general design information can be included in this report. However, specific sizing of vessels, retention times, temperatures, pressures, and sub-system flow rates are not given in all cases as optimum values are the result of considerable investigation and testing and their determination in this and subsequent applications is considered proprietary information. Similarly, intermediate process solution concentrations are not disclosed.

Pertinent U.S. Patents are:

- U.S. Patent # 4,716,027 (December 29, 1987)  
Method of simultaneously scrubbing  
cement kiln exhaust gas, removing  
alkalis from kiln waste dust, and  
recovering salt product in solution.
- U.S. Patent # Re 33031 (August 22, 1989)  
Reissue of Patent # 4,716,027
- U.S. Patent # 4,915,914 (April 10, 1990)  
System for simultaneously scrubbing  
cement kiln exhaust gas, removing  
alkalis from kiln waste dust, and  
recovering salt product in solution.
- U.S. Patent # 5,100,633 (March 31, 1992)  
General method of scrubbing combustion  
gases with alkaline solution and  
recovering crystalline salt products.

### 3.0 DESIGN BASIS

#### 3.1 FEED STREAMS

The Recovery Scrubber was designed to handle the actual gaseous emissions and solid waste of the Dragon kiln while using a high sulfur coal.

The gas and kiln dust rates and compositions are as shown in section 2.1. The coal used for kiln firing was:

Source	Tanoma Coal Sales Inc., Latrobe, PA.
Usage	13 ST/H (98,000 ST per year at 85% operation)
BTU/Lb (as recd)	13,170
S	3.0 %
Moisture	5.3 %
Ash	7.8 %

System capacities, however, were designed to accommodate considerable variation in quantity and composition of feed streams. In addition, it was assumed that in the future Dragon would recover their existing dust stockpile and accept outside waste materials such as biomass ash (with their relatively high contents of alkalis and other volatile species) for incorporation in kiln feed.

Gas flow - design maximum	225,000 acfm
- normal operation	160,000 acfm

Dust + other solid process feed materials	
- design maximum	13.5 T/H
- normal fresh CKD	8.0 T/H

The composition of feed material to the Recovery Scrubber is largely constrained by the requirements of kiln raw material and fuel chemistry. The process is designed, however, to handle up to 50% substitution of biomass ash for kiln dust.

Within overall handling capacity limits, the process seeks an approximate stoichiometric balance between alkalis (K, Na) and volatile anions (SO<sub>2</sub>, Cl). Acceptable operation can result, however, within a fairly wide margin of imbalance; an excess of alkalis results in production of alkali carbonates which are also valuable fertilizers, and excess of sulfur (chloride would be preferentially extracted into the salt product) can be returned to kiln feed up to a limit of approximately 1.0% SO<sub>3</sub>.

### 3.2 PRODUCT STREAMS

The product streams are recovered kiln feed, cleaned flue gas, salt product, and distilled water.

The solids returned to kiln feed are, inherently, of similar composition to fresh kiln feed and the process ensures that the concentrations of objectionable volatile components (K, Na, SO<sub>3</sub>, Cl), as returned, are no greater than in fresh material. It is possible to reduce the concentrations virtually to zero but, as returned material is usually less than 10% of the total kiln feed, the aggregate effect of complete removal would be negligible. The moisture content of the returned solids was designed at 50% purely for Recovery Scrubber process convenience; for a wet process kiln this is of no consequence as the overall kiln feed moisture content of about 30% can be easily obtained by adjusting the make-up water addition.

The flue gas scrubbing efficiencies expected from design were:

- SO<sub>2</sub> - better than 90%
- CO<sub>2</sub> - 2% (recovery is related to the quantity of CaO and Ca(OH)<sub>2</sub> in the solids)
- Particulates - below 20mg/NM<sup>3</sup> (this level could be further reduced, if required, by additional mist elimination).

The salt product was intended to comply with commercial K<sub>2</sub>SO<sub>4</sub> specifications after subtracting residual CaSO<sub>4</sub> which would be considered inert:

- K<sub>2</sub>O - 50.0% minimum
- Na<sub>2</sub>O - 1.0% typical
- S - 17.7% typical
- Cl - 1.5% maximum
- H<sub>2</sub>O - 1.0% typical
- Metals - Below applicable specification limits

Distilled water was specified at less than 50ppm total dissolved solids.

### 3.3 PROCESS CONDITIONS

By design, the flue gas is cooled to about 140°F, both to recover heat for use in the Crystallizer and for optimum reaction temperature between gas and slurry. Similarly the slurry in the reaction system is brought to the same temperature, partly due to warming by gas contact and partly from exothermic hydration reactions.

The flue gas is saturated at the discharge temperature. This is not a problem at Dragon but the resulting plume could be avoided by partial reheat if required.

The Recovery Scrubber was designed to have no impact on kiln operation. Gas flow rate is a critical control parameter for the kiln and to avoid interference, the system fan is controlled to maintain pressure at the base of the kiln stack at the same value (approximately -0.5 inches H<sub>2</sub>O) which would occur if the Scrubber were not installed. The system fan is then designed to induce gas flow through the pressure drop across the system (approximately 6 inches H<sub>2</sub>O).

The Recovery Scrubber is operated from a desk-top computer terminal in the cement plant central control room by the kiln operator. No additional staff are required for scrubber operation.

## 4.0 DETAILED PROJECT INFORMATION

### 4.1 OVERALL DESIGN DESCRIPTION

The Recovery Scrubber is a "bolt-on" installation which can be as easily retrofitted as designed into a new plant. The Dragon unit is spread over approximately 0.5 acres. A smaller area would suffice but the space was available at Dragon and there were advantages for a prototype to be of a fairly open design to allow for modifications.

Although the Recovery Scrubber concept and chemistry are innovative, the equipment employed is largely standard. The system comprises:

- A water spray heat recuperator
- Flash tank and shell-and-tube heat exchangers
- A vortex mixer
- A sieve-tray reactor
- Settling tanks
- An evaporative crystallizer
- Centrifuge, pin-pelletizer, fluid-bed dryer
- Fan, Pumps, valves, vacuum pumps, instrumentation

One particular concern was the corrosive nature of the moist flue gas before neutralization in the reactor. Materials used in this part of the Scrubber included stainless steels, fiberglass and vinyl ester resin linings.

Control is largely automated using an Allen Bradley Adviser System with 525 processors. Operation by the cement plant central control room operator is effected using a CRT screen and keypad. No dedicated manning is required either for operation or for maintenance.

The feed streams are flue gas and waste kiln dust. Gas ducting is much more expensive than dust conveying so that priority goes to locating the Recovery Scrubber as close as possible to the gas take-off and at Dragon the heat recuperator was positioned immediately adjacent to the existing stack. Actual lay-out is shown in Figure 5.

Gas connection was made by cutting a 6x4 ft hole at the base of the kiln stack opposite to the inlet from the kiln ID fan. Dampers were installed both in the stack and at the new outlet by means of which kiln gas can be vented through the stack for kiln start-up and then diverted through the Recovery Scrubber without disturbing kiln operation.

The cleaned slurry is pumped back to the cement plant through a 2 inch pipe terminating either at the raw mill or at a spare slurry basin depending upon cement plant raw mill operation.

Gas flow through the system fan is controlled by the inlet damper. The gas is blown into the heat recuperator, a fiberglass vessel equipped with high volume water sprays and a sump with water circulating through a (heat exchanger) flash tank and thence back to the sprays. The duct between system fan and recuperator vessel is of stainless steel and is equipped with a quench spray which operates when temperatures exceed 240°F to protect the fiberglass vessel.

From the recuperator vessel, the gas, cooled to about 140°F, is ducted to the plenum beneath the perforated tray of the reaction tank. The design of the plenum and its inlet section are critical to ensure even gas distribution over the area of the tray. The gas passes up through the tray and percolates through the slurry which flows across the top; this is the site of most of the chemical reactions which occur in the Recovery Scrubber. The gas then passes through a chevron-type mist eliminator to remove any slurry droplets which may have become entrained in the turbulence on the tray surface and is vented to atmosphere through a short stack above the reaction tank.

Waste kiln dust is conveyed from its existing holding tank by screw conveyors and bucket elevator to the top of the slurry storage tank which is adjacent to the reaction tank. The dust is mixed with a circulated stream of slurry in a vortex mixer and falls thence into the storage tank. The design of this mixing vessel is critical to avoid the gypsum build-up which normally forms on any adjacent surfaces when kiln dust is mixed with water.

#### 4.2.1 MATERIALS BALANCE

##### 1 Process Materials Analyses for pre-existing operation:

	Kiln <u>Feed</u>	Waste <u>Dust</u>	<u>Clinker</u>
SiO <sub>2</sub> %	14.00	14.10	21.83
Al <sub>2</sub> O <sub>3</sub> %	3.15	2.25	5.03
Fe <sub>2</sub> O <sub>3</sub> %	2.20	1.42	3.54
CaO %	43.20	44.10	67.27
MgO %	2.75	3.30	4.22
SO <sub>3</sub> %	0.22	5.58	0.80
K <sub>2</sub> O %	0.77	3.28	0.80
Na <sub>2</sub> O %	0.20	0.30	0.30
LoI %	34.0	27.0	-
T/H	98.5	8.0	58.0

##### 2 Fuel Analysis:

	<u>Coal</u>
Ash %	8.0
S %	3.0
H <sub>2</sub> O %	5.0
T/H	13.1

##### 3 Exhaust Gas:

	<u>Stack</u>
Flow rate, scfm	120,000
Temp °F	240
H <sub>2</sub> O %	24.0
CO <sub>2</sub> %	13.9
SO <sub>2</sub> ppm	200
NOX ppm	450
Particulates gr/scf	0.017

##### 4 Miscellaneous:

Kiln operating time	85% (7446H/Y)
Kiln feed:clinker ratio	1.70

4.2.1.5 Sulfur and alkali materials balance:

		<u>INPUT</u>		<u>OUTPUT</u>	
SO <sub>3</sub>	Lb/H KF		433	Stack	640
	Coal		1965	Dust	893
				Clinker	928
	Total Lb/H	2398		Total Lb/H	2461
	LbEq	59.9		LbEq	61.5
K <sub>2</sub> O	Lb/H KF		1517	Stack	-
	Coal		-	Dust	525
				Clinker	928
	Total Lb/H	1517		Total Lb/H	1453
	LbEq	32.2		LbEq	30.8
Na <sub>2</sub> O	Lb/H KF		394	Stack	-
	Coal		-	Dust	48
				Clinker	348
	Total Lb/H	394		Total Lb/H	396
	LbEq	12.7		LbEq	12.8

Then stoichiometric balance of volatiles in and out of system:

	<u>INPUT</u>	<u>OUTPUT</u>
Total LbEq/H SO <sub>3</sub>	59.9	61.5
Total LbEq/H K <sub>2</sub> O+Na <sub>2</sub> O	44.9	43.6

The Recovery Scrubber addresses only volatiles in dust and flue gas; the balance for these is:

Total LbEq/H SO <sub>3</sub>	38.3
Total LbEq/H K <sub>2</sub> O+Na <sub>2</sub> O	12.7
Alkali deficit, LbEq/H	20.7

This excess of SO<sub>3</sub> is returned to kiln feed with the reacted slurry solids and translates into a 0.6% increase in clinker SO<sub>3</sub>.

#### 4.2.2 HEAT BALANCE

- 1 Heat available from flue gas:  
(120,000scfm @ 240°F and 24% H<sub>2</sub>O)  
Then dew point:  
Total gas, LbM = 120,000x60/359 = 20,056  
H<sub>2</sub>O, LbM = 120,000x60x0.24/359 = 4,813  
Dry gas, LbM = 20,056-4,813 = 15,243

$$\begin{aligned} \text{H}_2\text{O}/\text{dry gas} &= 4813/15243 = 0.316 \\ \text{Then dew point} &= 150^\circ\text{F} \end{aligned}$$

Assuming that the gas is cooled to 140°F,  
12,500Lb/H of water will be condensed resulting  
in specific and latent heat recuperation of:  
34.7 million BTU/H

In addition, heat injected by power consumption  
of system fan and slurry circulation pumps:  
1.9 million BTU/H  
and heat of hydration of K<sub>2</sub>O, Na<sub>2</sub>O and CaO in  
dust:  
1.0 million BTU/H

Then total heat input = 37.6 million BTU/H

Note: Some heat is lost by radiation but this is  
not considered significant.

- 2 Heat required to evaporate 1000Lb/H salt product  
in 3% solution:  
Water evaporated = 32,300Lb/H (65gpm)  
Then heat required = 34.0 million BTU/H

- 3 Then there is approximate balance between the  
heat available from flue gas and the heat  
required for evaporation. Actual evaporation is  
effected at reduced temperature under vacuum.

## 4.3 CRYSTALLIZER SUB-SYSTEM



HPD Incorporated

HPD Place • 305 E. Shuman Blvd.  
Naperville Illinois 60563

telephone 708.357.7330  
fax 708.717.2247

### Externally mounted forced circulation single pass evaporators

As its name suggests, this evaporator consists of a one-pass vertical shell-and-tube heat exchanger mounted external to the vapor body of the evaporator.

Recirculation piping connects the heater to the vapor body via the recirculation pump. Evaporator liquor is pumped up through the heat exchanger and then enters the vapor body.

Boiling of liquor in the tubes is suppressed by the difference between the height of liquid in the vapor body and the top tubesheet elevation of the heat exchanger.

The externally mounted single pass evaporator has many useful applications, including:

1. Scaling liquors requiring submerged operation.
2. Viscous liquors requiring high tube velocities.
3. Liquors requiring low  $\Delta T$ s and high tube velocities with uniform heat distribution and close control of temperature.

Because of its versatility in application and design, the externally mounted single pass evaporator is one of the systems most frequently found in industry. As with all other forced circulation evaporator designs, there is a recognized higher cost for equipment and operation, but this cost is offset by the ability to apply closer controls over volume, velocity, temperature, concentration, and boil-out requirement.

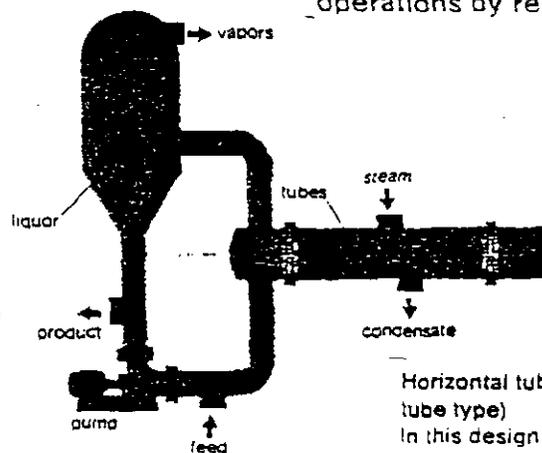
Design variables such as tube velocity, submergence, and tube diameter allow the designer to select an arrangement ideally suited to any given application. The HPD evaporator engineering team can help you design the most efficient and economical system for your needs.

### What is an evaporator?

In simplest terms, evaporation is the process of separating a solvent from a solution by boiling. Any device for accomplishing this operation is called an evaporator.

In terms of modern industry, evaporation systems are highly complex heat transfer units in which evaporation takes place under closely controlled conditions.

Evaporation is employed for concentrating solutions and for recovery of the solvent. The systems also help reduce pollution by concentrating solutions for re-use as fuel or in recovering solvents for secondary uses. HPD evaporators assist in waste disposal operations by reducing waste volume.



### Horizontal tube forced circulation evaporators (submerged tube type)

In this design the heat exchanger is arranged horizontally instead of vertically. The horizontal heat exchanger configuration allows the vapor body of the evaporator to be lowered wherever circumstances may restrict the head room.

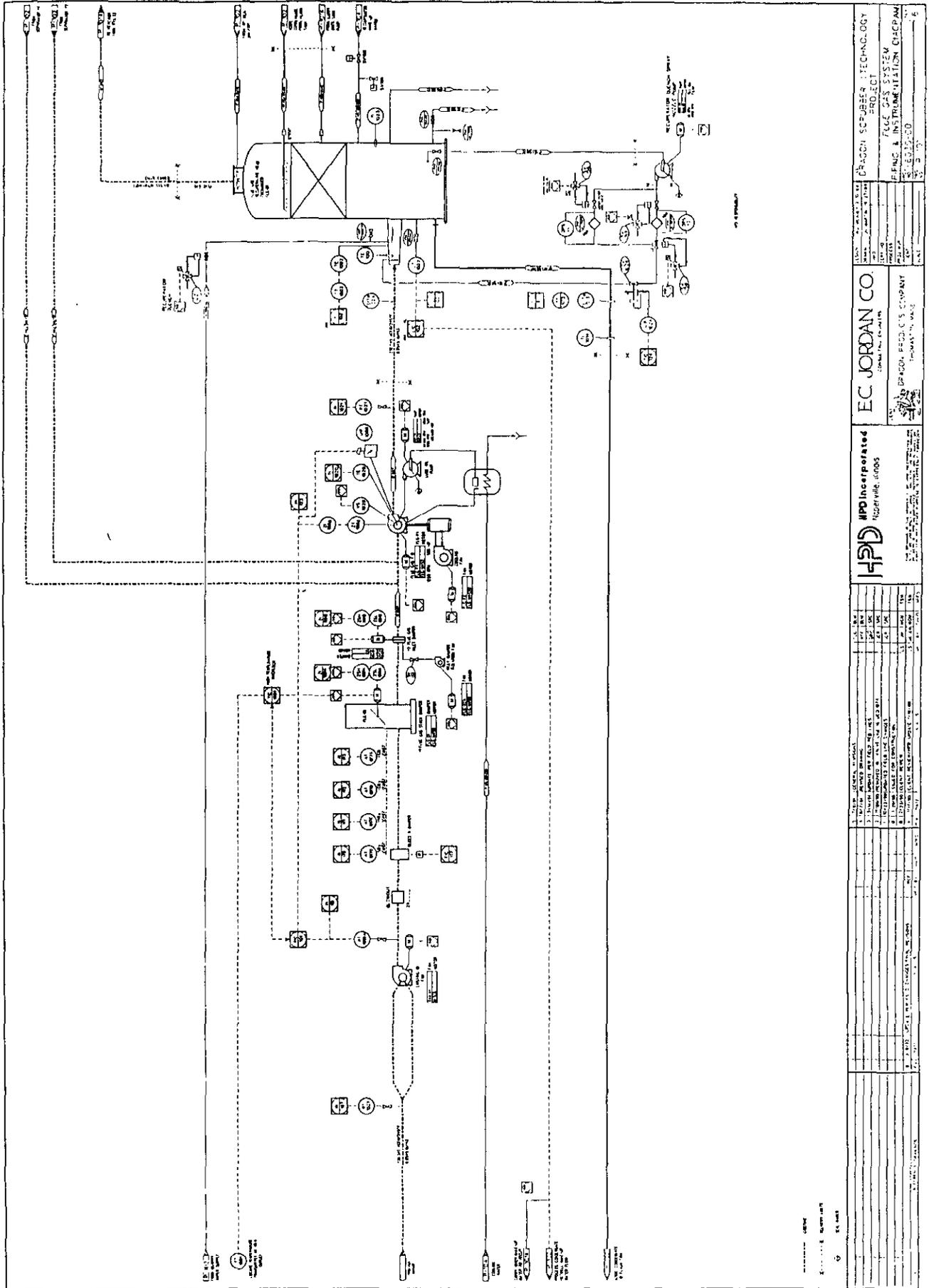
The heater is usually two-pass on the tube side and the horizontal arrangement permits easy access to the tubes for cleaning and maintenance. Operating characteristics of the horizontal tube forced circulation evaporator are similar to those of other forced circulation designs.

This design is recommended for applications in which:

1. Higher temperature rise per pass is acceptable.
2. Submergence to the steam temperature is required. This is achieved by increasing the height between the heater and the liquid level in the vapor body.
3. Higher tube velocities than those attainable in the single-pass design are required.

Typical applications of these units—as designed by HPD—include processing of highly scaling liquors in evaporator/crystallizer systems and processing of wastes for disposal. The horizontal tube forced circulation evaporator has the further advantage that if submergence is not a criteria, it can be placed into low-headroom structures.

# 4.4 PIPING & INSTRUMENTATION DRAWINGS

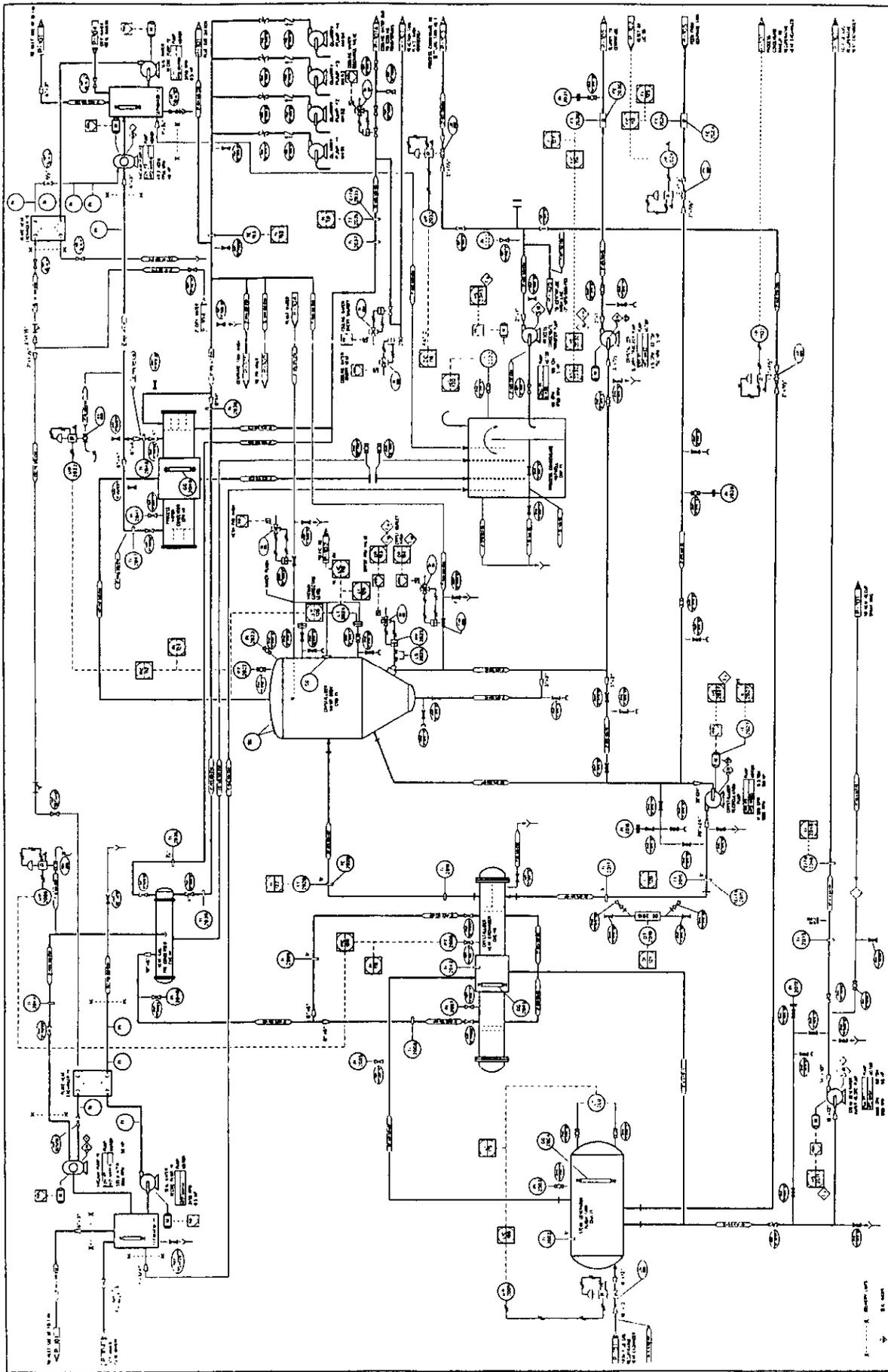


<b>HPD Incorporated</b> Houston, Texas		<b>EC JORDAN CO</b> Houston, Texas		BRANCH SCHEMES TECHNOLOGY PROJECT NO. 100-100-100 PLANT: FUSE GAS SYSTEM SHEET: INSTRUMENTATION DIAGRAM DRAWN BY: [Name] CHECKED BY: [Name]	
NO.	DATE	BY	CHKD.	REVISION	DESCRIPTION
1	10/1/78	[Name]	[Name]		ISSUED FOR CONSTRUCTION
2	10/15/78	[Name]	[Name]		REVISION TO INSTRUMENTATION
3	11/1/78	[Name]	[Name]		REVISION TO INSTRUMENTATION
4	11/15/78	[Name]	[Name]		REVISION TO INSTRUMENTATION
5	12/1/78	[Name]	[Name]		REVISION TO INSTRUMENTATION
6	12/15/78	[Name]	[Name]		REVISION TO INSTRUMENTATION
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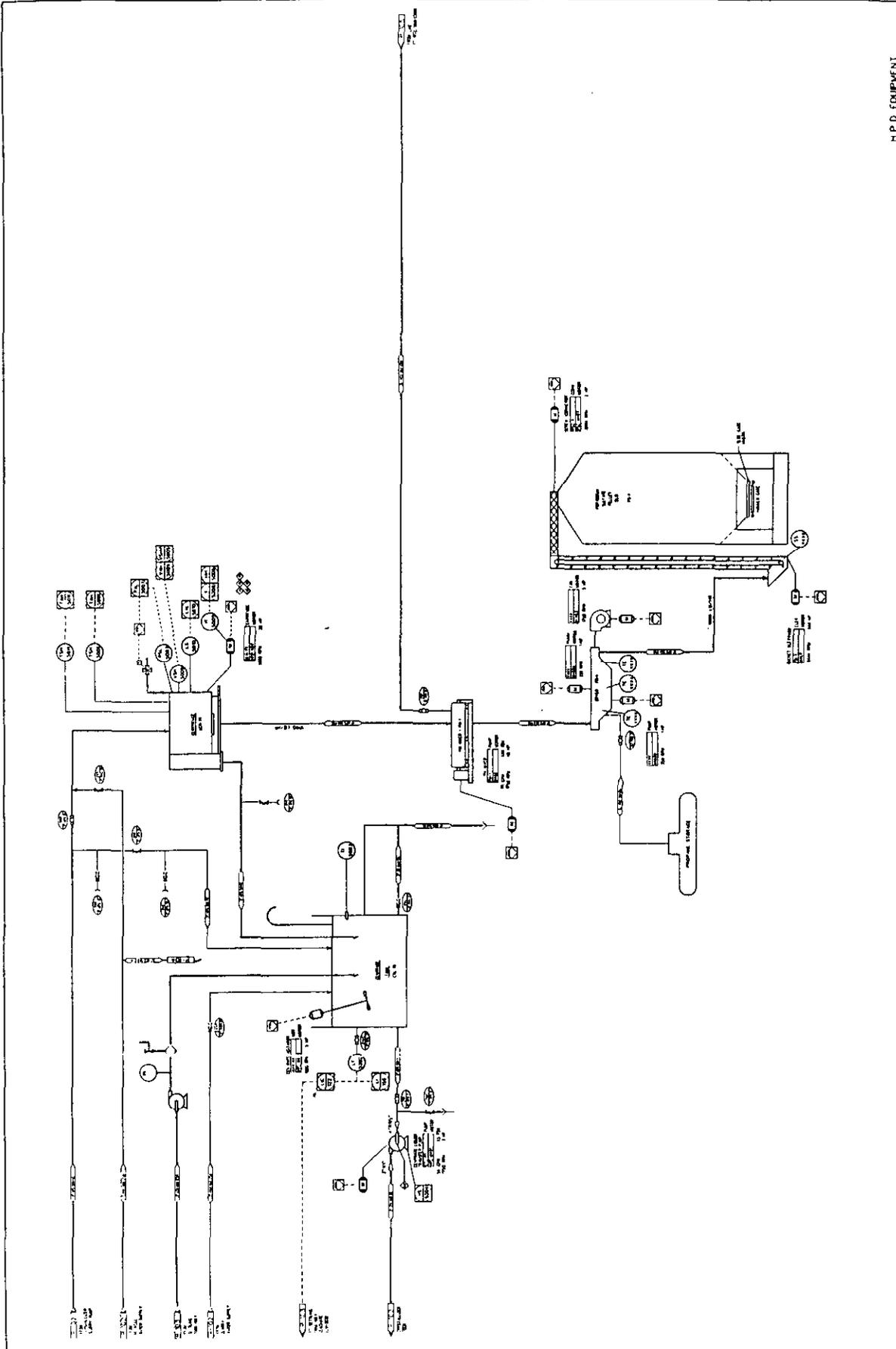








<b>DRAGON SCRIBER TECHNOLOGY PROJECT</b> <b>POTASSIUM SULFATE FURNACE CRYSTALLIZER</b> <b>PIPING &amp; INSTRUMENTATION DIAGRAM</b>	
SHEET NO. 1 DATE 11/11/83	DRAWN BY CHECKED BY
PROJECT NO. 11111 UNIT NO. 11111	
SCALE: 1" = 10'-0"	
PROJECT: DRAGON SCRIBER TECHNOLOGY	
UNIT: POTASSIUM SULFATE FURNACE CRYSTALLIZER	
SHEET: PIPING & INSTRUMENTATION DIAGRAM	
DRAWN: 11/11/83	
CHECKED: 11/11/83	
APPROVED: 11/11/83	
HPD Incorporated Houston, Texas	
PROJECT NO. 11111 UNIT NO. 11111 SHEET NO. 1	
SCALE: 1" = 10'-0"	
PROJECT: DRAGON SCRIBER TECHNOLOGY	
UNIT: POTASSIUM SULFATE FURNACE CRYSTALLIZER	
SHEET: PIPING & INSTRUMENTATION DIAGRAM	
DRAWN: 11/11/83	
CHECKED: 11/11/83	
APPROVED: 11/11/83	



<p>DRAGON SCRUBBER PROJECT</p> <p>POTASSIUM SULFATE CRYSTALLIZER PUMP AND INSTRUMENT DRAWING</p> <p>2-1533-DC</p> <p>2-1533-DC</p>	
<p>EC JORDAN CO.</p> <p>COMPANY NUMBER</p> <p>DRAGON PRODUCTS COMPANY</p> <p>INDUSTRIAL VALVE</p>	
<p>HP D EQUIPMENT</p>	
<p>1. QUANTITY (INCLUDE ONE EACH) (INCLUDE THE EQUIPMENT)</p> <p>2. LOCATION (INDICATE THE LOCATION)</p> <p>3. DRAWING NUMBER (INDICATE THE NUMBER)</p> <p>4. DRAWING TITLE (INDICATE THE TITLE)</p> <p>5. DRAWING SCALE (INDICATE THE SCALE)</p> <p>6. DRAWING DATE (INDICATE THE DATE)</p> <p>7. DRAWING REVISION (INDICATE THE REVISION)</p> <p>8. DRAWING APPROVAL (INDICATE THE APPROVAL)</p> <p>9. DRAWING CHECK (INDICATE THE CHECK)</p> <p>10. DRAWING DESIGN (INDICATE THE DESIGN)</p> <p>11. DRAWING ENGINEER (INDICATE THE ENGINEER)</p> <p>12. DRAWING PROJECT (INDICATE THE PROJECT)</p> <p>13. DRAWING SHEET (INDICATE THE SHEET)</p> <p>14. DRAWING TOTAL (INDICATE THE TOTAL)</p>	

#### 4.5 SUMMARY EQUIPMENT LIST

##### 1 Vessels:

	<u>Material</u>	<u>Capacity</u>
1 Heat recuperator	Fiberglass	44ft(H) x 20ft(D)
2 Carryover tank	Polypropylene	1,500gals
3 Flash tank	Hetron 980 resin	12ft(L) x 8ft(D)
4 Heat exchanger (shell & tube)	HMO 1925	20ft(L) x 5ft(D) HTSA* 4660 ft <sup>2</sup>
5 Reaction tank	Carbon steel with vinyl ester lining	48ft(W) x 36ft(L)
6 Tray wash tank	Polypropylene	500gals
7 Chevron spray tank	Polypropylene	1,500gals
8 Storage tank	Carbon steel	72,000gals
9 Vortex mixer	Carbon steel	6ft(H) x 4ft(D)
10 Settling tank 1	Carbon steel	35,000gals
11 Settling tank 2	Carbon steel	25,000gals
12 Centrate tank	Vinyl ester FRP	6,000gals
13 Crystallizer vessel	Carbon steel with vinyl ester lining	26ft(H) x 16ft(D)
14 Condenser (shell & tube)	Carbon steel	22ft(L) x 5ft(D) HTSA* 6100 ft <sup>2</sup>
15 Hot well	Vinyl ester FRP	400gals
16 Salt product silo	Carbon steel	300Tons

\*Note: HTSA = heat transfer surface area

##### 2 Powered Equipment

	<u># of units</u>	<u>Service</u>	<u>Rated HP</u>
1 Stack butterfly damper drive	1	int	5
2 System inlet damper drive	1	int	
3 System fan (radial blade)	1	cont	700
4 Fan damper drive	1	int	
5 Reaction tank sump pump	1	cont	3
6 Reaction tank circulation pumps (axial flow)	2	cont	50
7 Storage tank discharge pump	1	cont	3
8 Settling tank 1 discharge pump	1	cont	3
9 Settling tank 2 discharge pump	1	cont	30
10 K <sub>2</sub> SO <sub>4</sub> pin mixer	1	cont	40
11 K <sub>2</sub> SO <sub>4</sub> dryer	1	cont	1
12 Reaction tray HP spray	1	int	60

4.5.2 (contd.)

	<u># of</u> <u>units</u>	<u>Service</u>	<u>Rated</u> <u>HP</u>
13	1	cont	25
14	1	cont	2
15	1	cont	15
16	1	cont	0.2
17	3	cont	2
18	1	int	25
19	1	cont	10
20	1	cont	3
21	2	cont	15
22	1	int	1.5
23	1	cont	5
24	1	cont	3
25	1	cont	5
26	1	cont	7.5
27	1	int	15
28	1	cont	150
29	1	cont	150
30	1	cont	40
31	1	cont	50
32	1	cont	30
33	1	cont	3
34	1	cont	
35	4	2-3 cont	60
36	2	cont	1.5
37	5	cont	1
38		int	
	10		
39			
41			

Note: int = intermittent operation  
 cont = continuous operation  
 All pumps are centrifugal unless otherwise specified.

#### 4.5.3 Other Equipment

- 1 Electrical supply is from existing plant power distribution at 4160 volts. Dedicated equipment includes a General Electric dry type 4160 -460 volt transformer rated at 194 KVA which feeds two low-voltage GE AKD-8 circuit breakers. The system fan operates at 4160 volts, all other equipment at 460 volts.
- 2 Instrumentation monitoring and system control employs an Allen Bradley Adviser system with 525 processors.
- 3 System fan is a Robinson Type JB, Size 62, with radial blades.
- 4 Dust weigh feeder is a Schenk Model DMC with a 30-inch belt.
- 5  $K_2SO_4$  centrifuge is a Bird Model 1350 solid bowl type operating at 5000rpm.
- 6  $K_2SO_4$  pelletizer is a Mars Mineral Model 12D/54L pin pelletizer.
- 7 Ducting:
  - 1 Take-off from existing stack is 8ft x 8.5ft. The ducting is carbon steel except for quench section at the inlet to the Recuperator which is Inkonel 625.
  - 2 Recuperator to Reaction tank connection is 12ft  $\phi$  and made from fiberglass.
  - 3 Exhaust stack is 12ft  $\phi$ , discharges at 125ft above ground level, and is also made of fiberglass.

#### 4.6 UTILITY REQUIREMENTS

##### 1 Electrical power

Under normal operation, electricity consumed is:

System fan (4160Vx78Ax $\sqrt{3}$ x0.85/1000)	=	483 KW
Other (460Vx450Ax $\sqrt{3}$ x0.85/1000)	=	<u>304 KW</u>
Total power	=	787 KW

##### 2 Make-up water

The kiln flue gas as it enters the Recovery Scrubber has a dew point of approximately 150°F so that there is a small net gain of water due to condensation from the flue gas.

Water is required to effect solution of the salt product but this is recovered in the crystallizer condenser and recycled.

Cooling water for the crystallizer condenser is circulated from a natural drainage pond in the limestone quarry. On returning to the pond, the water is cooled by evaporation in a spray and from the pond surface. Evaporation loss is estimated at some 50 gpm; this loss being naturally replenished.

##### 3 Fuel

The salt product dryer consumes approximately 0.5 gallons per hour of propane.

#### 4.7 CONSUMABLE REQUIREMENTS

Apart from maintenance parts and lubricants, no purchased materials are consumed by the Recovery Scrubber.

#### 4.8 WASTE STREAMS

The process is, by design, zero-discharge. There are no waste streams from the Dragon installation.

## 5.0 TECHNICAL PERFORMANCE

The Dragon installation began operation on 20 December 1990. As a result of subsequent operation and testing, a number of modifications and developments have been effected. The unit is now considered operational and is providing flue gas scrubbing and solid waste reclamation for the cement kiln.

### 5.1 SYSTEM MODIFICATIONS

In addition to routine plumbing and electrical malfunctions, significant problems were encountered in the following areas:

1 Tray Flatness

Gas-liquid contact in the Recovery Scrubber is achieved using a sieve-tray reactor. CKD slurry flows across the top of the perforated tray while gas percolates upwards through it. Initial construction gave level variations exceeding specification, the resulting variation in slurry depth above the tray gave rise to uneven gas flow and to slurry leakage through the tray. The tray was leveled and the associated operating problems were eliminated.

2 Gas Distribution

The gas duct inlet to the reaction tank and the plenum beneath the tray did not initially meet specification for uniformity of gas pressure at the tray. This was corrected by installation of turning vanes and baffles in the duct and the plenum.

3 CKD Mixing

The kiln dust was originally mixed with water in a paddle mixer which gave rise to serious gypsum, scaling of the mixing vessel, pump and lines. This system was replaced by a vortex mixer directly above the storage tank to which the dry dust was conveyed and mixed with recirculated slurry.

4 Undertray Washing

Residual entrained dust particles in the gas stream were found to build up in the tray perforations causing increased gas pressure drop across the tray. An intermittent, travelling, high-pressure wash system was installed which has eliminated the problem. The water thus introduced was made part of the required make-up water so that total water input has not been increased.

5 Mist Eliminator

A mesh-pad type mist eliminator was first employed to capture slurry droplets entrained by turbulence on the tray surface. A slurry build-up on the mesh-pad resulted which increased pressure drop and which proved difficult to control by washing. A chevron type mist eliminator was substituted, washed by recirculated water, and this has proved effective and trouble free.

6 Potassium Sulfate Pellet Formation

The crystallizer is designed to concentrate slurry leachate by evaporation to 20-30% suspended solids (principally, but not entirely  $K_2SO_4$ ). A stream of solution containing the suspended solids is drawn off and centrifuged, the solids being pelletized, dried, and conveyed to storage. The pelletizer installed (a pin-mixer type) requires less than 12% moisture in the material fed to it. It was discovered that the small proportion of syngenite (a double salt of potassium/calcium sulfate) which crystallized as a fine needle mesh, prevented dewatering in the centrifuge to below 12%. A filter circuit has been introduced to the crystallizer system for the removal and resolution of syngenite which is expected to allow adequate dewatering of potassium sulfate in the centrifuge. If this proves unsuccessful, an extrusion type of pelletizer which can handle feed materials with higher moisture contents will be substituted.

## 5.2 OPERATING PERFORMANCE

### 5.2.1 CKD RECOVERY

The Recovery Scrubber now treats and returns to the kiln feed system all of the CKD which would otherwise be discharged to landfill. The treated dust, as returned, meets the specification of the cement plant for kiln feed and no kiln operating or quality problems have been encountered during Recovery Scrubber operation.

### 5.2.2 FLUE GAS CLEANING

The Recovery Scrubber removes 90-98% of SO<sub>2</sub> from kiln exhaust gas depending upon the level of SO<sub>2</sub> at the system inlet.

A reduction of 5-15% in NO<sub>x</sub> has been observed and this is believed to reflect removal of the NO<sub>2</sub> fraction.

Some 2% of total CO<sub>2</sub> is removed. This results from recarbonation of CaO and Ca(OH)<sub>2</sub> occurring in the kiln dust. It provides, however, an interesting contrast to the effect of lime and limestone SO<sub>2</sub> scrubbers which cause a net increase in CO<sub>2</sub> emissions.

Stack testing has shown a particulate content of 13mg/NM<sup>3</sup> in the gas released by the Recovery Scrubber. Concentration at the inlet was not determined but is expected to be in the range 30-50mg/NM<sup>3</sup>. It should be noted that, as a wet scrubbing process, the Recovery Scrubber efficiently captures even superfine particulates so that emission levels could be further reduced by more stringent demisting of the scrubbed gas before release; albeit at a cost in fan power to overcome an increased system pressure drop.

Following the system modifications described in Section 5.1, the Recovery Scrubber has operated with 95% availability.

## 6.0 COSTS

### 6.1 PROJECT CAPITAL COSTS

#### 6.1.1 Actual cost:

Total project costs to April 1993 comprise:

Engineering design	E.C. Jordan	\$ 604,510
Contractor	Cianbro	12,188,651
Crystallizer	HPD	1,947,118
Process design, supervision and consulting	PTech	1,358,328
Project management, control system, miscellaneous construction and modification	Dragon	1,258,855
Miscellaneous engineering and consulting		<u>18,205</u>
		\$17,375,667

#### 6.1.2 Estimated "as-built" cost:

During April 1991, a detailed cost analysis was commissioned by Passamaquoddy Technology to determine the cost of the installation "as built" net of modifications and rework. Although further changes have been made since the cost analysis, it is not considered that this has had any significant effect upon the "as built" estimate. The estimate is summarized below.

Cost summary by discipline area:

Civil	20%	\$1,997,000
Mechanical	65%	\$6,566,000
Electrical & Instrumentation	15%	<u>\$1,527,000</u>
Total		\$10,090,000

Cost summary by system. Indirect costs including labor overheads, profit, construction equipment and engineering have been allocated:

Gas related	24%	\$2,393,000
Dust related	9%	916,000
Product related	33%	3,356,000
Common	34%	<u>\$3,425,000</u>
Total		\$10,090,000

Estimated confidence limits were:   +6.8%   \$686,000  
  -7.4%   \$747,000

Estimates were based on the following premises:

- 1990 northern New England non-union labor with average total cost of \$36.32/man hour
- 1990 materials and equipment prices
- Profit of 10% assumed on direct costs plus labor overheads
- Engineering cost assumed 5% of total
- Construction interest excluded
- Sales taxes excluded
- Performance bond excluded
- Site permitting excluded

## 6.2 OPERATING & MAINTENANCE COSTS

Insufficient operating time has yet been accumulated to allow meaningful operating costs to be generated from actual records. The installation comprises, however, standard equipment such as pumps and valves for which many cement and other process plants have existing maintenance records. Annual maintenance costs, including part replacement over a 20 year life, are estimated to be:

Total maintenance	\$150,000
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A detailed breakdown is given in Table 2.

Power costs, based on 787KW, a mean tariff of \$0.06/KWH, and 85% operation, are estimated:

	\$350,000
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Therefore total annual operating cost = \$500,000

Note that, as no dedicated staffing or maintenance equipment is required, effectively all operating costs are variable.

Table 2 - MAINTENANCE COST ESTIMATES

	<u># of units</u>	<u>Annual maintenance cost</u>
1 Stack butterfly damper drive	1*	\$ 500
2 System inlet damper drive	1*	500
3 System fan	1	12,000
4 Fan damper drive	1*	500
5 Reaction tank sump pump	1	500
6 Reaction tank circulation pump	2	8,000
7 Storage tank discharge pump	1	1,000
8 Settling tank 1 discharge pump	1	1,000
9 Settling tank 2 discharge pump	1	1,500
10 K <sub>2</sub> SO <sub>4</sub> pin mixer	1	2,000
11 K <sub>2</sub> SO <sub>4</sub> dryer	1	2,000
12 Reaction tray HP spray	1*	3,000
13 Vortex mixer slurry pump	1	500
14 K <sub>2</sub> SO <sub>4</sub> conveying	1	1,000
15 Seal water pump	1	500
16 Dust rotary feeder	1	1,000
17 Tank rake arms	3	1,500
18 Chevron spray	1*	1,000
19 Dust screw (high level)	1	1,000
20 Dust elevator	1	1,000
21 Dust screws (low level)	2	2,000
22 Reaction tank HP spray drive	1*	3,000
23 Distilled water (hot well) pump	1	500
24 Leachate (centrate) pump	1	500
25 Crystallizer discharge pump	1	500
26 Recuperator spray pump	1	1,000
27 Recuperator carry-over pump	1*	500
28 Recuperator circulation pump	1	3,000
29 Crystallizer circulation pump	1	5,000
30 Flash tank vacuum pump	1	5,000
31 Crystallizer vacuum pump	1	5,000
32 K <sub>2</sub> SO <sub>4</sub> centrifuge	1	5,000
33 Centrate tank mixer	1	500
34 System inlet damper purge fan	1	500
35 Quarry water pumps	4**	10,000
36 Leachate filter pumps	2	1,000
37 Misc. seal water and lube pumps	5	3,000
38 Air activated slurry line pinch valves	10*	5,000
39 Heat tracing		2,000
40 Dust weigh feeder		2,000
41 Instrumentation		10,000
42 Electrical distribution		10,000

	<u>Annual maintenance cost</u>
43 Corrosion repairs	10,000
44 Slurry line abrasion repairs	5,000
45 Clearing lines, cleaning, misc.	20,000
Total annual maintenance cost	= \$150,000

Note: \* - indicates units which operate intermittently  
 \*\* - there are four quarry pumps of which only 2 or 3  
 are normally running.

### 6.3 COST/BENEFIT ANALYSIS

It must be emphasized that this technology, while providing pollution control, also generates both revenues and avoided costs which offset the capital and operating costs.

These benefits comprise both avoided costs already effective and (Dragon's) projected revenues:

	<u>\$/Year</u>
Value of kiln feed recovered (8T/Hx7446H/Yx\$5/T)	298,000
Avoided cost of landfilling (8T/Hx7446H/Yx\$5/T)	298,000
Recovery of existing dust stockpile (5T/Hx7446H/Yx\$3/T)	112,000
High sulfur fuel cost savings (13T/Hx7446H/Yx\$2/T)	193,000
Revenue from sale of salt product (0.4T/Hx7446H/Yx\$200/T)	596,000
Revenue for acceptance of waste materials and avoided cost of equivalent raw materials (100,000T/Yx\$35/T)	3,500,000
	<hr/>
Total annual benefits =	\$4,997,000

Then after allowing for operating costs (Section 6.2),

Net annual benefits = \$4,497,000

#### 6.4 SCALING CONSIDERATIONS

Scaling of the system can be related to the three principal material streams:

Gas flow  
Dust  
Salt product

The system can be broken down into items primarily related to each of these streams (see Figure 6) which then allows cost scaling to be performed on three sub-systems together with a common element. Sizing of sub-system units (eg sieve tray area, crystallizer capacity) is then largely, but not wholly, a matter of simple ratio.

The cost analysis for the Dragon installation given in section 6.1, was compiled both by discipline (civil, mechanical, etc) and by sub-system to facilitate scaling for subsequent cost estimating. The break-down for Dragon is:

Gas related	\$2,393,000	24%
Dust related	916,000	9
Salt product related	3,356,000	33
Common	<u>3,425,000</u>	34
Total	\$10,090,000	

Cost scaling can then be performed using a standard formula such as:

$$\frac{\text{cost 1}}{\text{cost 2}} = \frac{(\text{size 1})^e}{(\text{size 2})^e}$$

See, for example, Remer & Chai, Chemical Engineering Progress, August 1990, pp.77-82 for appropriate values of "e".

The effect of the sulfur content of coal is considered in the basic process calculations where stoichiometric balance is sought between alkalis (K,Na) and acidic anions (SO<sub>3</sub>,Cl). If the necessary alkalis are internally available, or can be separately introduced, then a higher coal sulfur content will increase the quantity of salt product, and the effect upon equipment sizing and cost can be estimated as indicated above.

The Dragon application is a relatively simple one. Other installations may involve, for example:

- a) Buffer storage and handling for outside materials.
- b) Separation of mixed salt product (eg  $K_2SO_4$  and  $KCl$ ).
- c) Drying of reacted dust.

While these are straightforward processes involving existing technology, they will, of course, affect construction and operating costs.

