DE-AC22-90PC90156-10

DEVELOPMENT AND TESTING OF A COMMERCIAL-SCALE COAL-FIRED COMBUSTION SYSTEM – PHASE III

Quarterly Technical Progress Report No. 10
Report Period: January 1, 1993 to March 31, 1993

By A.F. Litka and R.W. Breault

We have no objection from a patent standpoint to the publication or dissemination of this material.

Mark Dvorscak 1-22-96

Mark Dvorscak Date
Intellectual Property Law Dept.
DOE Chicago Operations Office

May 1993

Work Performed Under Contract No. DE-AC22-90PC90156

Tecogen
A division of Thermo Power Corporation, a Thermo Electron company
45 First Avenue
P.O. Box 8995
Waltham, Massachusetts 02254-8995

Available from the National Technical Information Service, U.S. Department of Commerce, Springfield, Virginia 22161.

Price: Printed Copy A02
Microfiche A01

TR4510-017-93 DE-AC22-90PC90156-10

DEVELOPMENT AND TESTING OF A COMMERCIAL-SCALE COAL-FIRED COMBUSTION SYSTEM – PHASE III

Quarterly Technical Progress Report No. 10
Report Period: January 1, 1993 to March 31, 1993

By
A.F. Litka and R.W. Breault

May 1993

Work Performed Under Contract No. DE-AC22-90PC90156

Prepared for
PETC Project Manager: Mr. Douglas Gyorke
Pittsburgh Energy Technology Center
U.S. Department of Energy
P.O. Box 10940
Pittsburgh, Pennsylvania 15236-0940

Prepared by
Tecogen
A division of Thermo Power Corporation, a Thermo Electron company
45 First Avenue
P.O. Box 8995
Waltham, Massachusetts 02254-8995

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

Coal is the most plentiful energy resource in the United States, and in 1987 it provided approximately one third of the quads of total energy consumed in the United States. Its use, however, has been largely restricted to utility power generation since World War II for environmental and economic reasons.

Within the commercial sector, oil and natural gas are the predominant fuels used to meet the space-heating needs of schools, office buildings, apartment complexes, and other similar structures. In general, these buildings require firing rates of 1 to 10 million Btu/hr. The objective of this program is to demonstrate the technical and economic viability of a coal-fired combustion system for this sector.

The development program includes all aspects of the process, from fuel selection and preparation to pollution control and waste disposal. In attempting to restore coal to small users such as residential and commercial space heating, it is important to recognize that fuel form is an important consideration because of its impact on handling and emissions. Ease of handling is an important criterion at the small sizes since complex equipment will add greatly to the overall system costs. Furthermore, manpower is not available to perform manual functions or keep complex equipment working. Emission levels, if not currently regulated, can be expected to be regulated at low levels in the future. The levels considered acceptable will be reduced over time, following the current environmental trends. Preparation and use of a coal-water slurry (CWS) fuel can aid in meeting these criteria. CWS use eliminates the need for dry pulverized coal with its attendant handling and dusting problems as well as its explosive potential. In addition, CWS is amenable to coal washing since coal cleaning technologies are generally water-based processes requiring fine grinding of the coal. For these reasons, the program objective will be met through the development of a CWS-fired system.

Although the CWS fuel in commercial practice will be manufactured by coal companies or fuel suppliers at regional facilities and transported to the user much as is done today with oil, the program includes the construction of a slurry production facility. In this way, all aspects of the fuel's use – from coal selection to combustion properties – can be evaluated and an economic evaluation of the process can be carried out.

The commercial-scale CWS-fired space heating system is a scale-up of a CWS-fired residential warm-air heating system developed by Tecogen under contract to the Department of Energy (DOE), Pittsburgh Energy Technology Center. This system included a patented nonslagging combustor known as IRIS, for Inertial Reactor with Internal Separation. The combustor concept employs centrifugal forces combined with a staged combustion process to achieve high carbon conversion efficiencies and low nitrogen oxides generation. Along with the necessary fuel storage and delivery, heat recovery, and control equipment, the system includes pollution control devices to meet targeted values of SO_2 and particulate emissions. In general, the system is designed to match the reliability, safety, turndown, and ignition performance of gas or oil-fired systems. Table 1.1 summarizes the performance goals of the system. Figure 1.1 is a process flow diagram for the system.

The successful development and future marketability of the heating system require a strong, dedicated team with expertise in a broad range of areas including CWS preparation, coal combustion, pollution control, component manufacture, and

TABLE 1.1

PERFORMANCE GOALS

• Thermal Input	– 4 million Btu/hr
• Thermal Efficiency	– >80%
• Combustion Efficiency	– >99%
• Emissions	– 1.2 lb SO_2/MMBtu 0.3 lb NO_x/MMBtu 0.03 lb Part./MMBtu
• Turndown	– 3:1
• Ignition	– Fully automatic startup with system purge and ignition verification
• Reliability/Safety	– Comparable to oil-fired commercial boilers
• Ash Removal	– Dust free and automatic or semi-automatic
• Routine Maintenance	– Less than one manhour per day and an additional two manhours per week
• Service Life	– >20 years

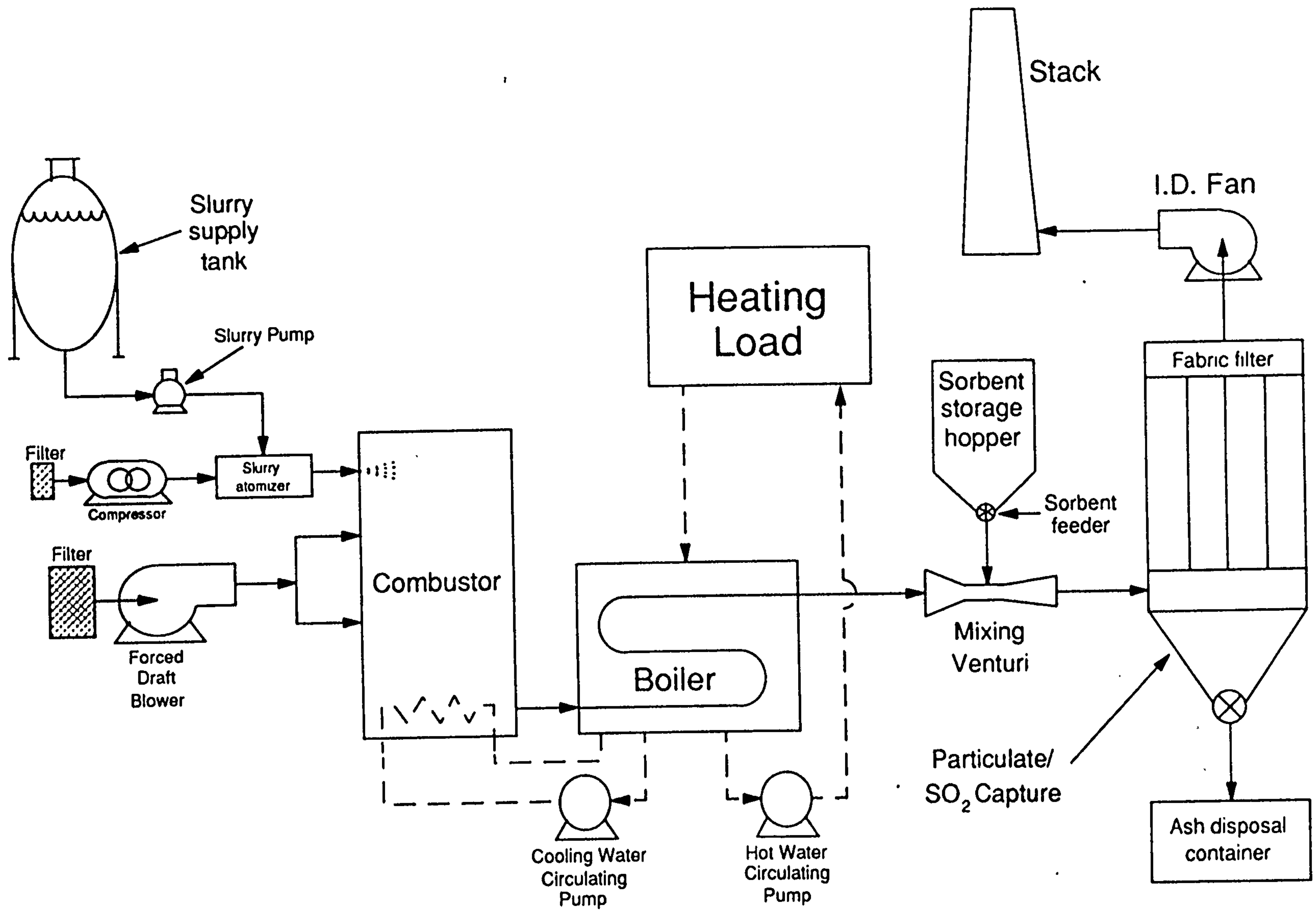


Figure 1.1 Process Flow Diagram

systems integration. Such a team has been assembled and includes the following organizations: Tecogen, Donlee Technologies, AMAX Coal, and Southern Illinois University.

Tecogen is the prime contractor and is responsible for overall program management, combustor development, and integration of the subsystem components and installation of the system at the field test site. AMAX has extensive experience in CWS preparation and serves as the principal coal supplier. Donlee Technologies is responsible for the boiler/heat exchanger design and manufacture. Donlee has over 70 years experience in the commercial boiler business and is a potential commercializer of the technology. Southern Illinois University (SIU) is the host for the field test portion of the program. The heating system will provide space heating at the SIU Coal Research Center.

The development program has been divided into three stages covering a time span of 39 months. The first stage of the program which covered 16 months focused on component design and manufacture. Once the major components were manufactured, system integration was completed and initial system tests conducted. These tests verified the design and operation of the system components as well as provided a data base for setpoints, process variables, and performance for subsequent proof-of-concept testing.

The second stage of the program covered eight months and focused on evaluating the overall performance of the system through Proof-of-Concept Testing. The testing was of sufficient duration to simulate a commercial application with individual tests of up to 48 hours in duration. Combustion and thermal efficiencies; tendencies to slag, foul, erode and corrode, and gaseous and particulate emissions were evaluated.

The final stage of the program which is currently underway will involve integration of the system in an actual installation and operation of the system over the course of a heating season. This demonstration stage is schedule to cover an 18 month period. Figure 1.2 gives the work breakdown structure for the overall program.

This report documents the work carried out in the tenth quarter of the program. During this period, detailed design of the host site installation was completed, and preparation of the space heating system and slurry production facility equipment for shipment to the host site was initiated. Also, additional system operation was conducted to further evaluate system upgrades and to evaluate the performance of an optional SO_2 control reactor.

TF84-491

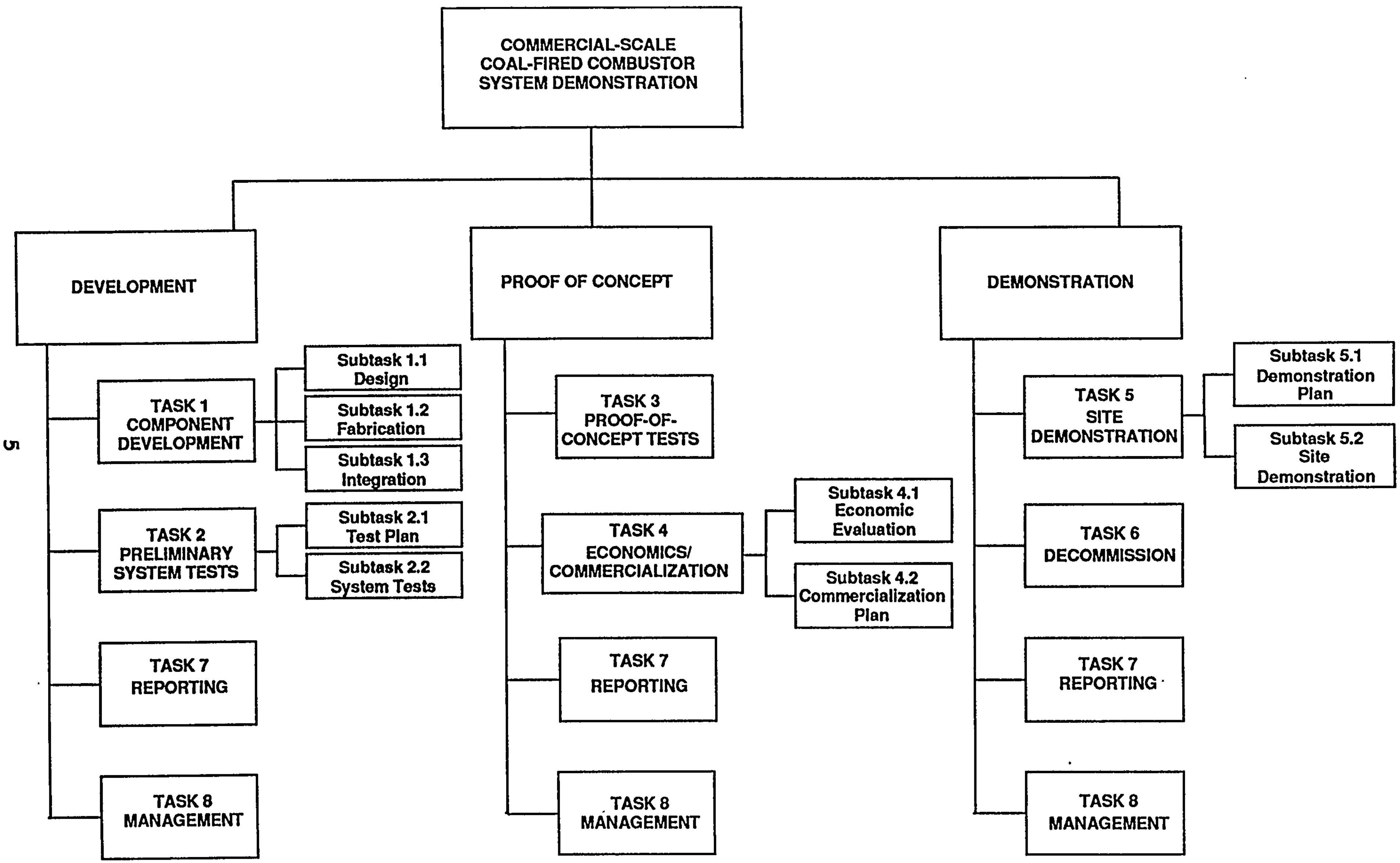


Figure 1.2 Work Breakdown Structure for Entire Project

2. PROJECT STATUS

During the tenth quarter of this program, the bulk of the program activities were centered around finalizing the host site installation design and preparing the equipment for shipment to the Illinois Coal Development Park (ICDP) facility. One final equipment upgrade aimed at eliminating ash deposition in the combustor/boiler connecting zone was evaluated. Also, an optional SO_2 reactor designed to enhance sorbent utilization through increased residence time and sorbent/gas contact was installed and tested.

2.1 DEMONSTRATION STAGE EQUIPMENT UPGRADES

Boiler Entrance Modification

During Proof-of-Concept testing there was a gradual build up of ash in the entrance region of the boiler. Although this accumulation did not limit system operation, a design change was made to reduce the build-up and make cleaning easier. Figure 2.1 shows the original configuration. Ash accumulation was greatest on the refractory surfaces in this region and there was a slight bond between the refractory material and the ash which made removal somewhat difficult.

To help reduce the ash accumulation and make clean-out easier, a metal liner was installed extending the length of the transition region between the transition chamber exit and boiler entrance. Figure 2.2 illustrates this arrangement. Approximately 60 hours of system operation demonstrated that material accumulation in this region was greatly reduced. The material that did accumulate could be easily removed through the transition chamber access port upon shutdown. Since the material did not readily adhere to the liner, on-line cleaning may be possible with the use of a simple air lance. If necessary, on-line cleaning will be evaluated during the course of the demonstration testing.

SO_2 Reactor Testing

To eliminate bridging and material handling problems associated with the use of an ultra fine (80% passing 325 mesh) sodium bicarbonate, testing was performed with a courser grade material (30% passing 325 mesh) which due to its larger particle size exhibited greatly improved flowability. In addition, the courser grade (Church & Dwight USP 1) is more readily available from local distributors. Testing with this larger sorbent was carried out with an emissions control reactor installed between the boiler exit and baghouse entrance. The reactor shown in Figure 2.3 uses the principles of fluid mechanics and particle dynamics in an innovative way to enhance the capture of SO_2 by various sorbents. The emissions control reactor is a vortical flow device designed to separate sorbent particles and then confine them within the reactor. The separation of particles within the reactor substantially increases their residence time relative to the gas and therefore provides an effective sorbent-to-sulfur ratio within the reactor that is many times greater than that injected, providing a very high sorbent particle surface area concentration. Additionally, the increased particle residence time allows for complete thermal decomposition of the raw sorbent material further enhancing utilization. Figure 2.4 illustrates the sorbent injection configuration.

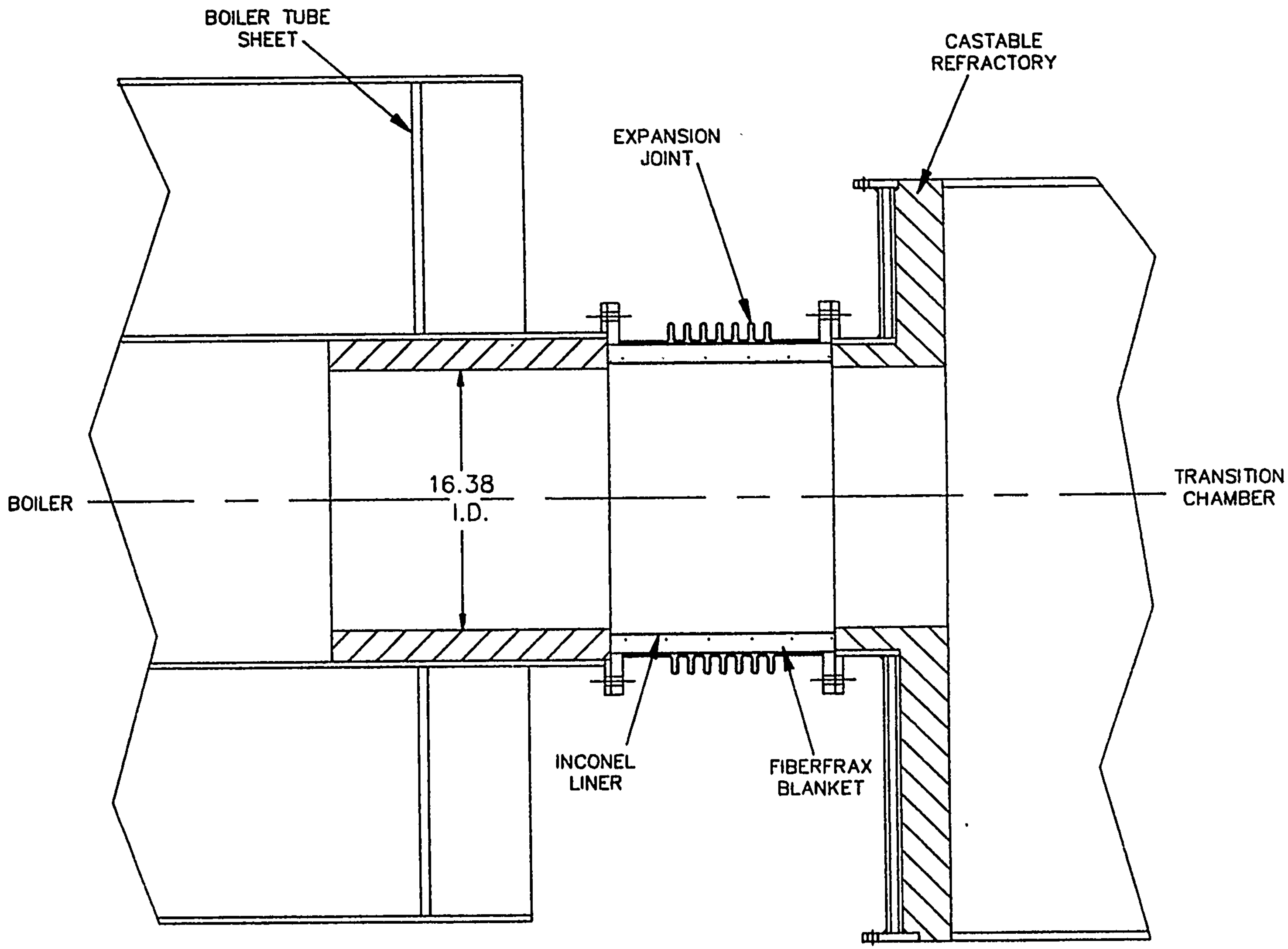


Figure 2.1 Transition Chamber/Boiler Connection with Refractory Liner

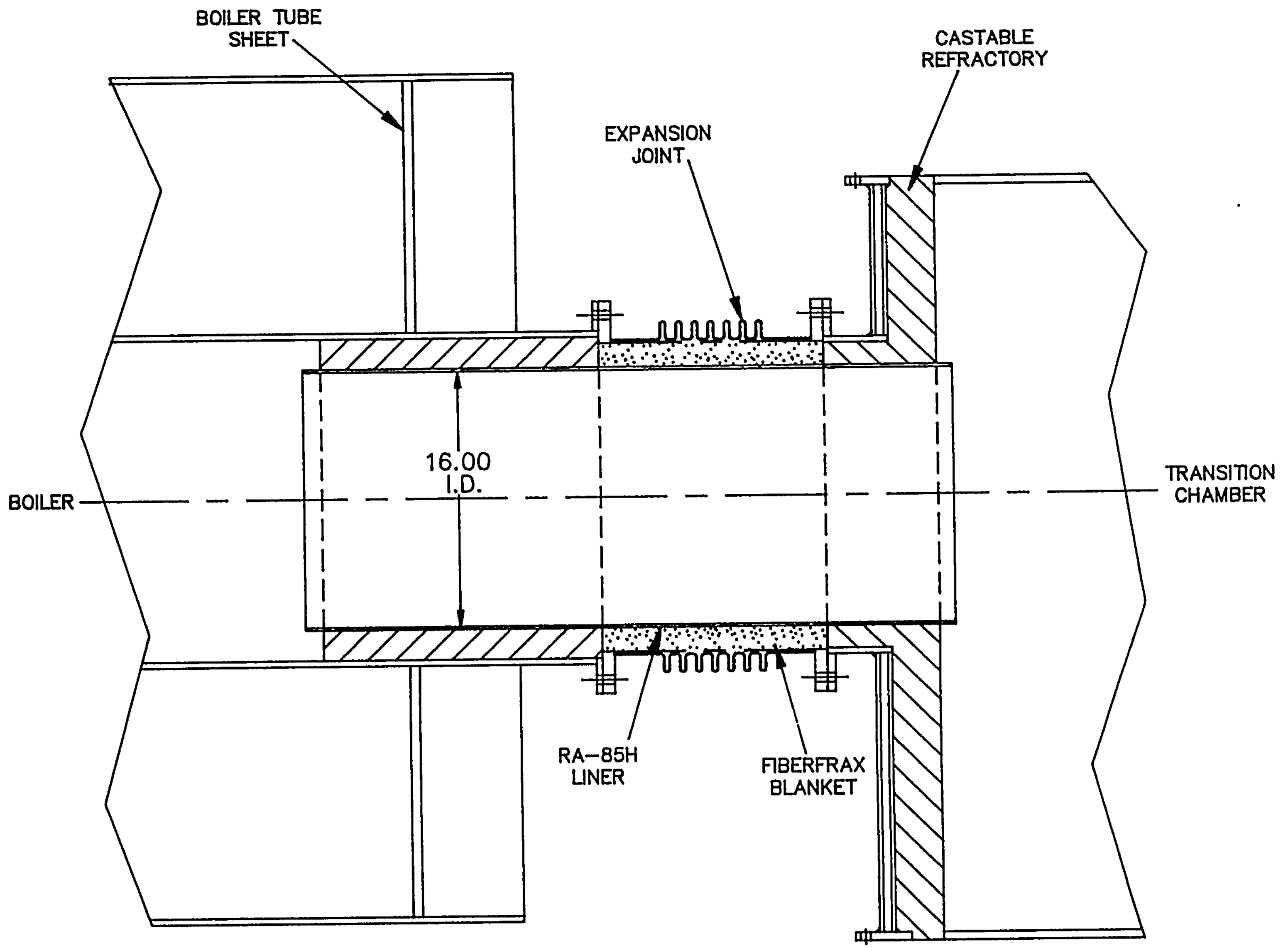


Figure 2.2 Transition Chamber/Boiler Connection with Metal Liner

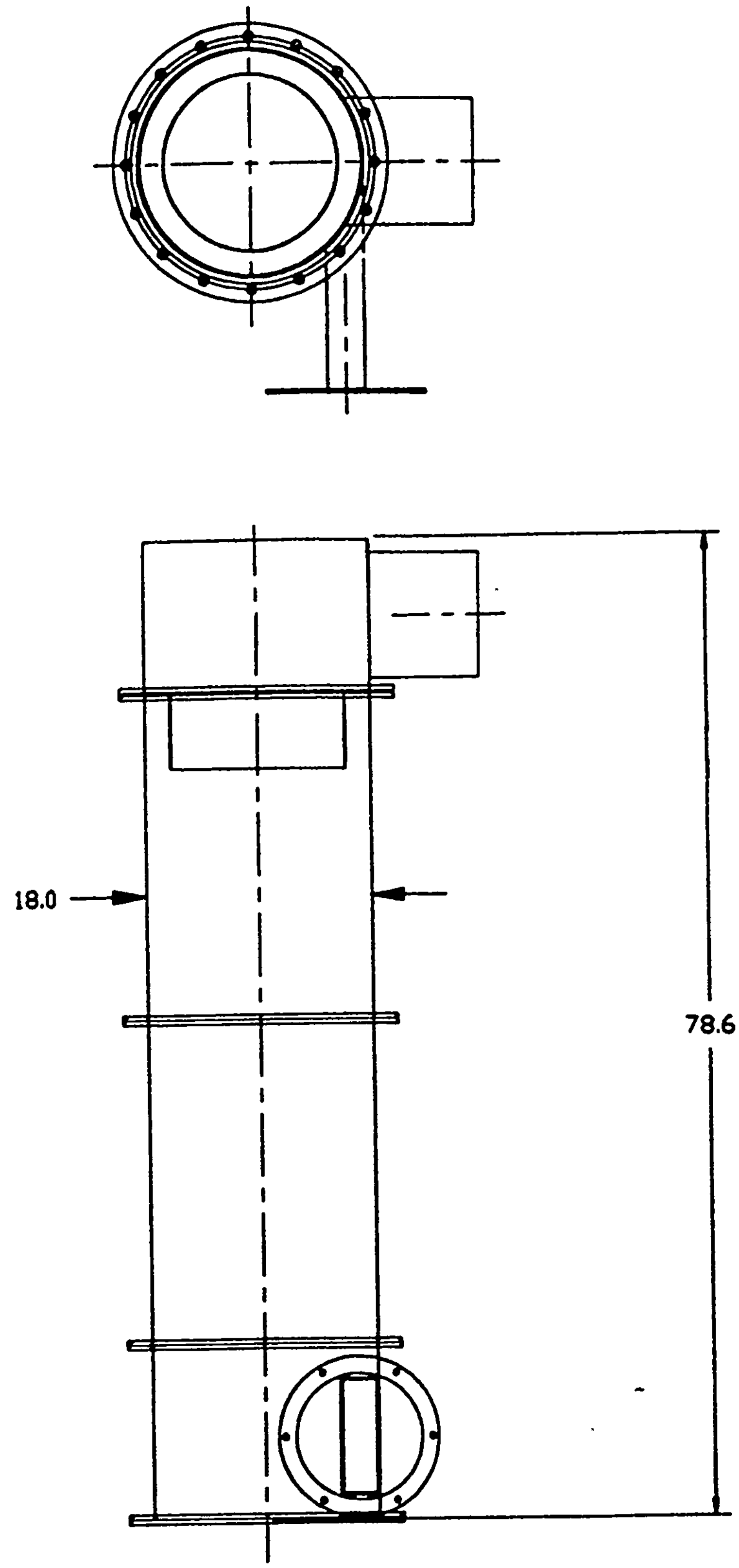


Figure 2.3 SO_2 Reactor

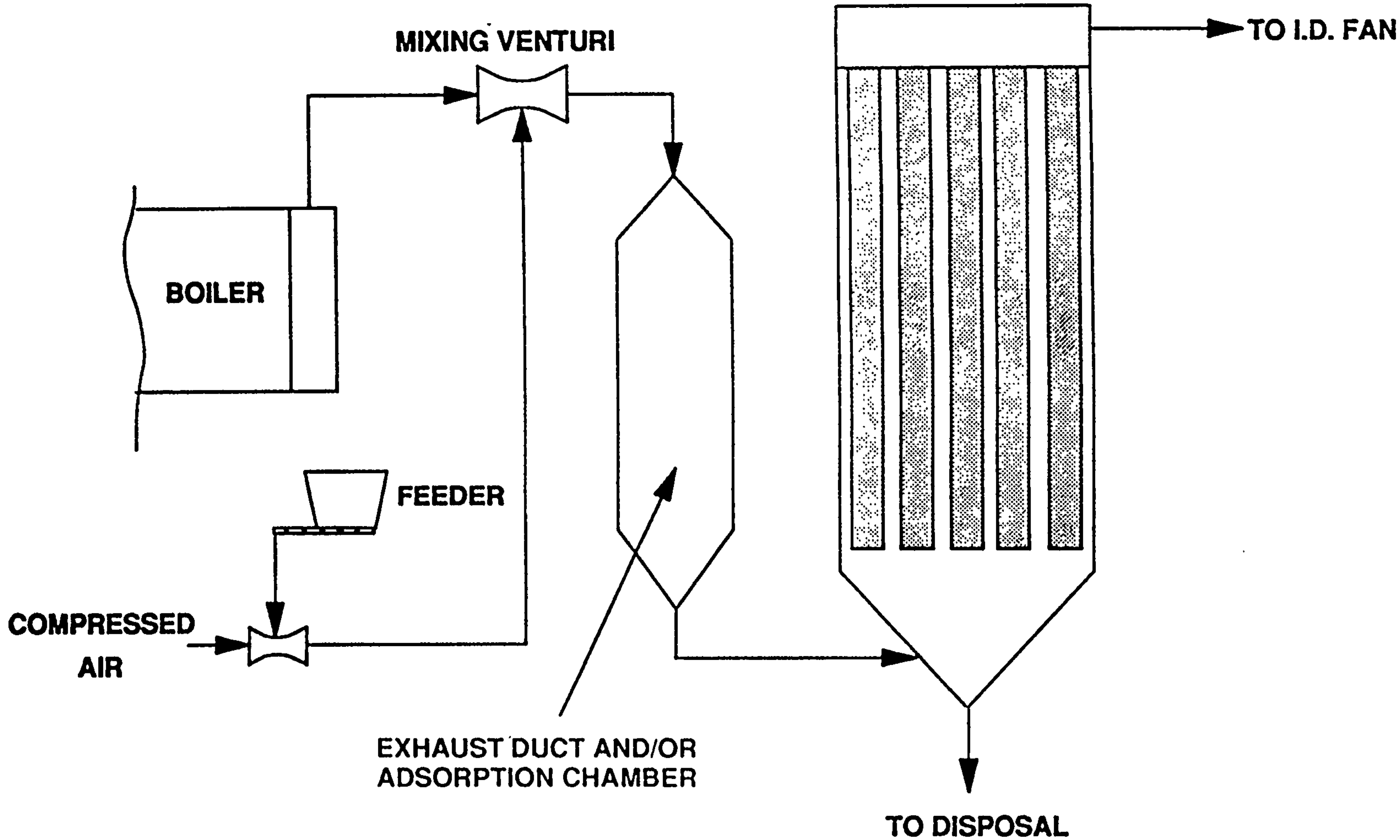


Figure 2.4 Sorbent Injection Configuration

Figure 2.5 shows the sulfur removal obtained with the combination of the larger sorbent and emissions control reactor and compares these results with previously obtained data with the finer sorbent as well as reported EPA data. Also shown is the degree of removal obtained with the reactor alone. Although the percent removal in the reactor ranges from 30 to 40%, this is at a much shorter gas residence time than the overall system and the overall sulfur capture in the system is improved even with the larger particle sorbent. Figure 2.6 compares the results to those obtained at the University of Tennessee[1]. Although the data is limited, these results indicate the ability of the reactor to enhance sorbent utilization with course sorbent material. Since the courser material is easier to handle, more readily available and in some cases less expensive, the reactor can improve both the performance and economics of the sulfur removal system.

Further operation with the larger particle size sorbent will be carried out during demonstration operation. Provisions have been made for the installation of the emissions control reactor at the host site, if this proves necessary.

2.2 HOST SITE DESIGN AND PREPARATION

During this reporting period, work continued on the planning and detailed engineering of the host site equipment installation. A host site agreement between Tecogen and SIU was prepared and signed by both parties. Detailed work packages describing the work involved with installation of the space heating system at the ICDP have been prepared and sent to general contractors for bid. As part of the work package, detailed electrical drawings for both the slurry production facility and space heating system were prepared (Figures 2.7 thru 2.13).

With the conclusion of laboratory testing, the slurry production and space heating system equipment was disassembled and refurbished in preparation for shipment to the demonstration site. Where necessary, changes were made to piping runs to match the demonstration site installation.

A concrete pad was installed outside the ICDP High Bay Building to support the coal grinding stand, pulverizer and auxiliary equipment as well as the externally located space heating system components. Electrical power feeds and load centers were installed for both the slurry production facility and the space heating system.

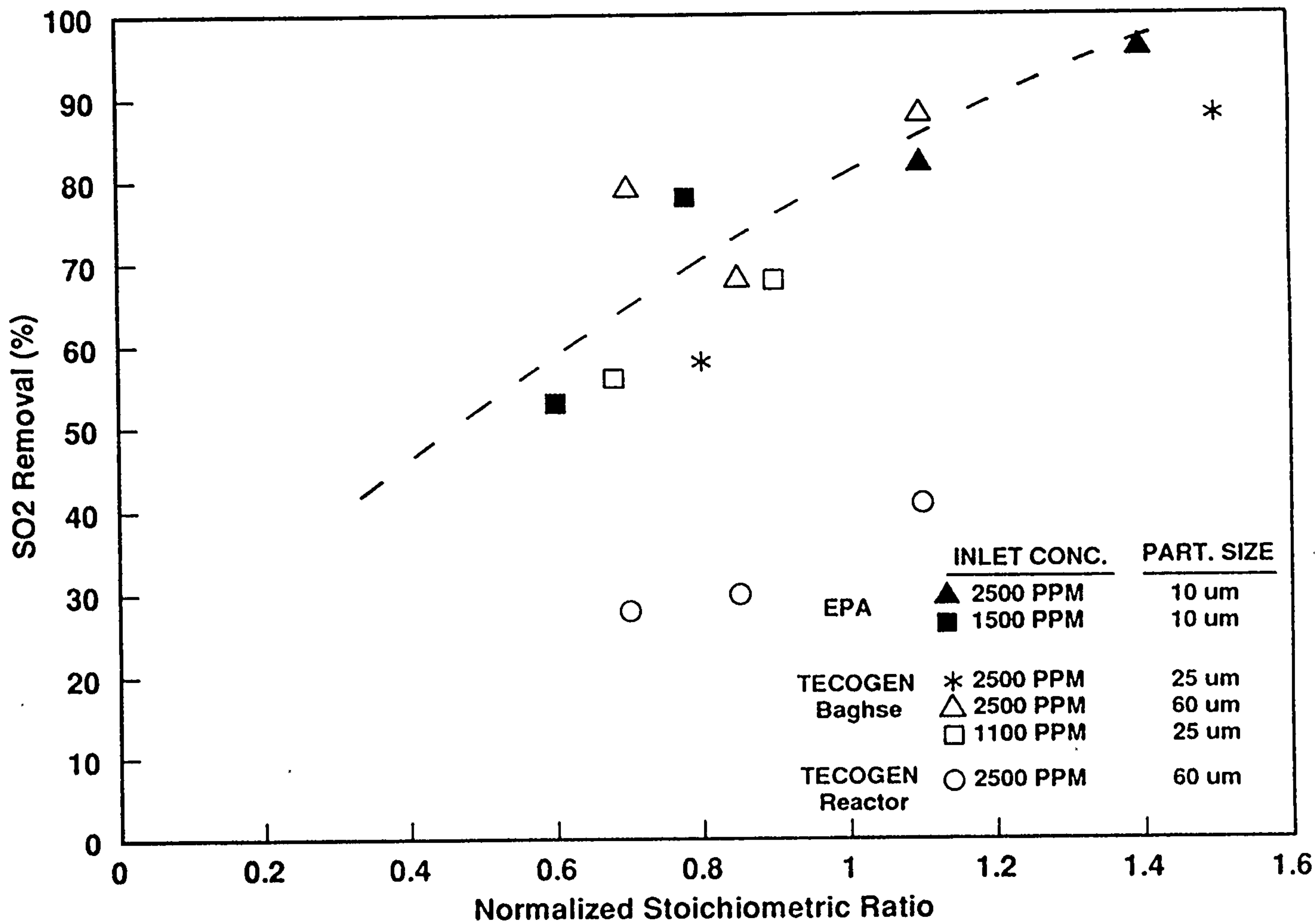


Figure 2.5 SO_2 Removal Summary

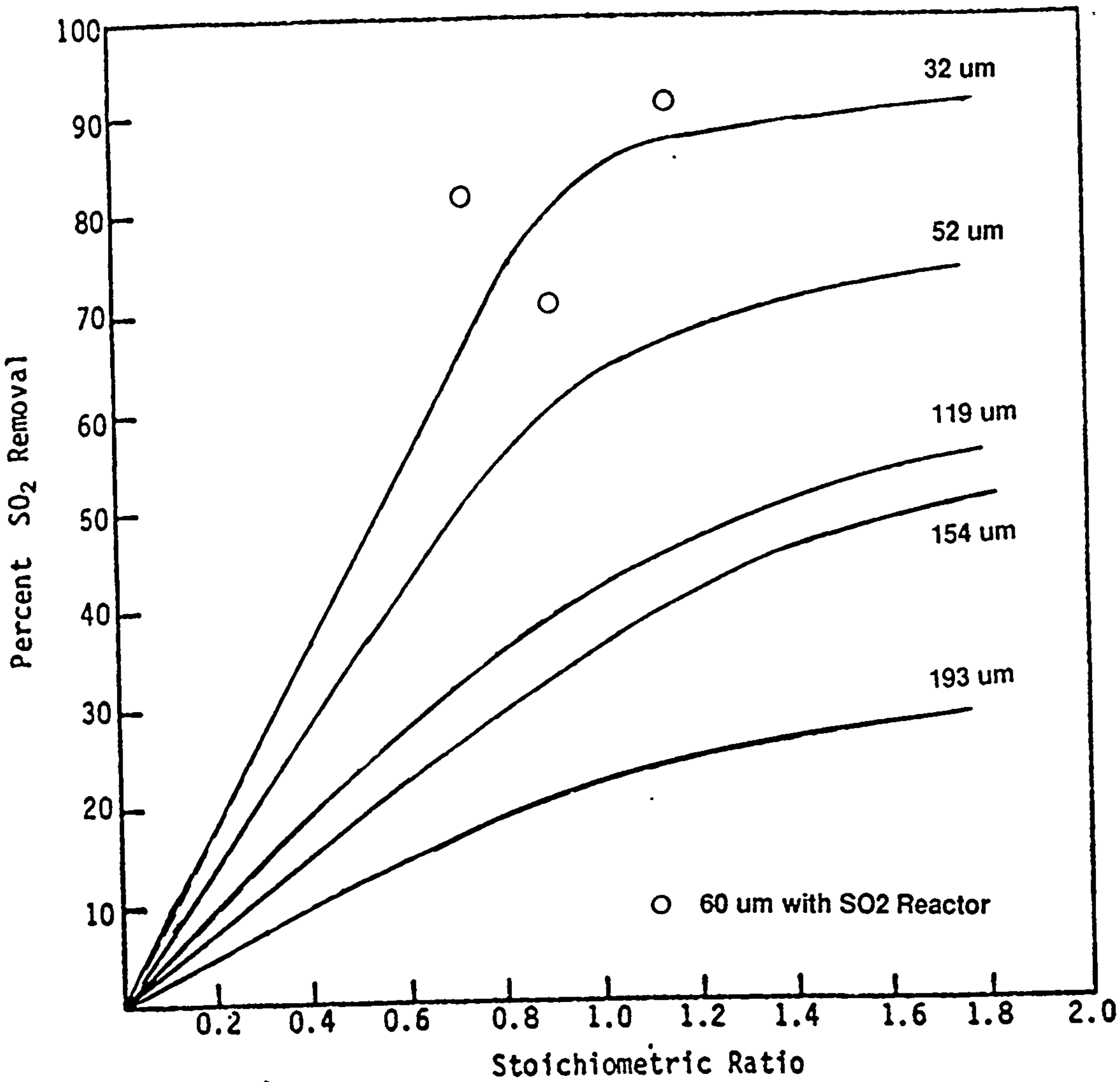


Figure 2.6 SO_2 Removal with Reactor Compared to Duct Injection Data

NOTE: ABOVE CURVES FROM U. OF TENNESSEE DATA.[1]

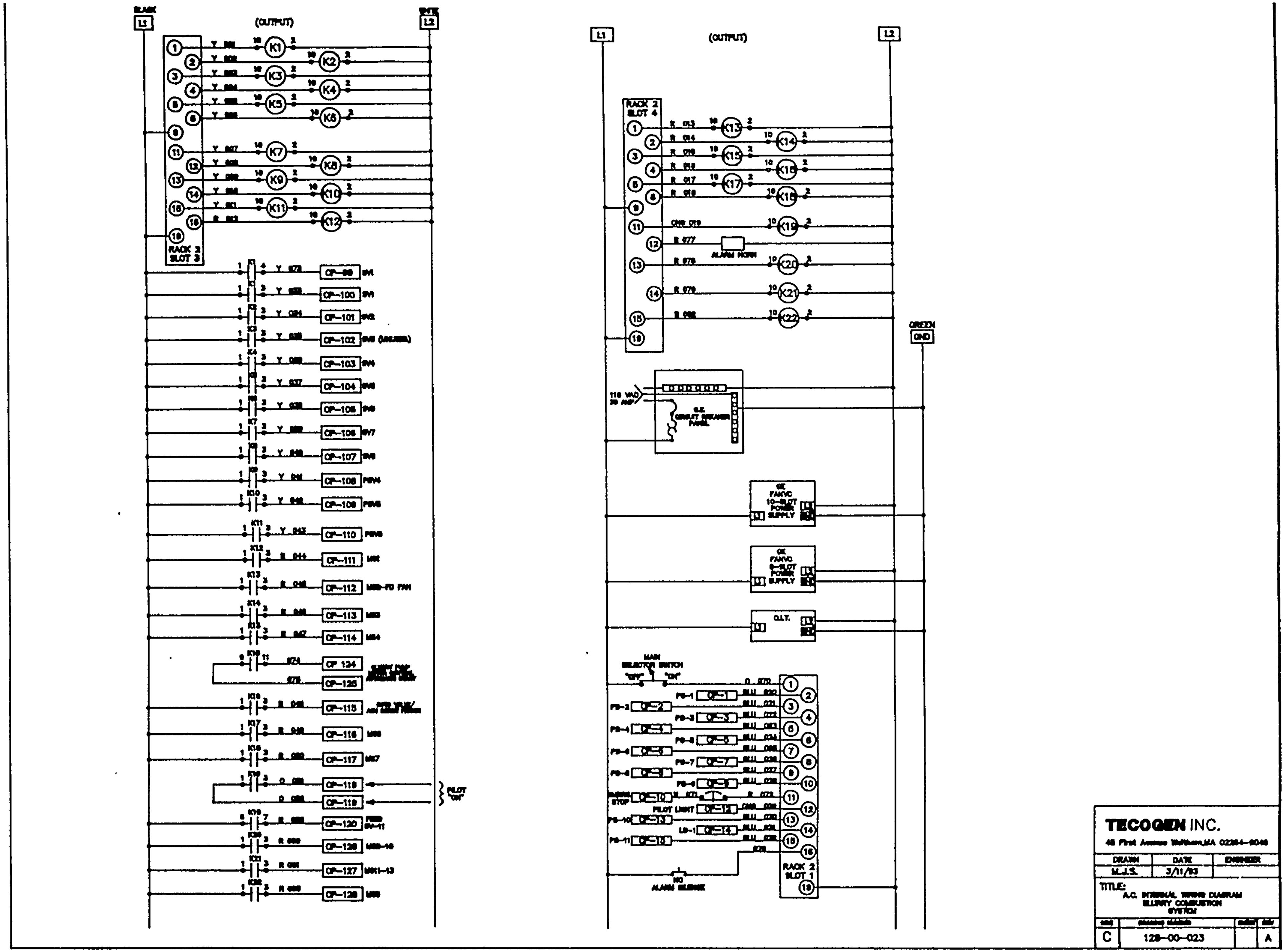


Figure 2.7 Space Heating System - A.C. Internal Wiring Diagram

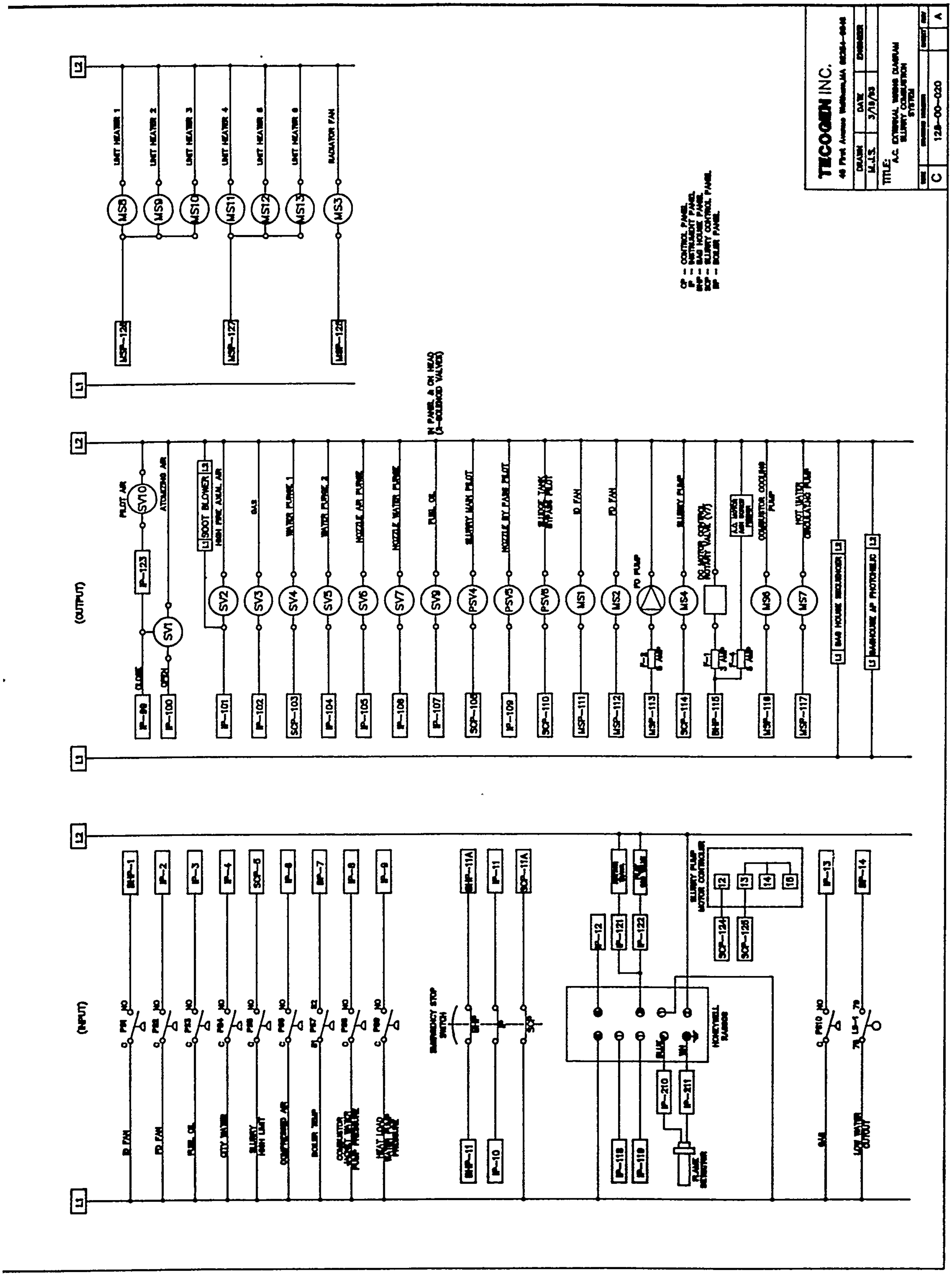


Figure 2.8 Space Heating System - A.C. External Wiring Diagram

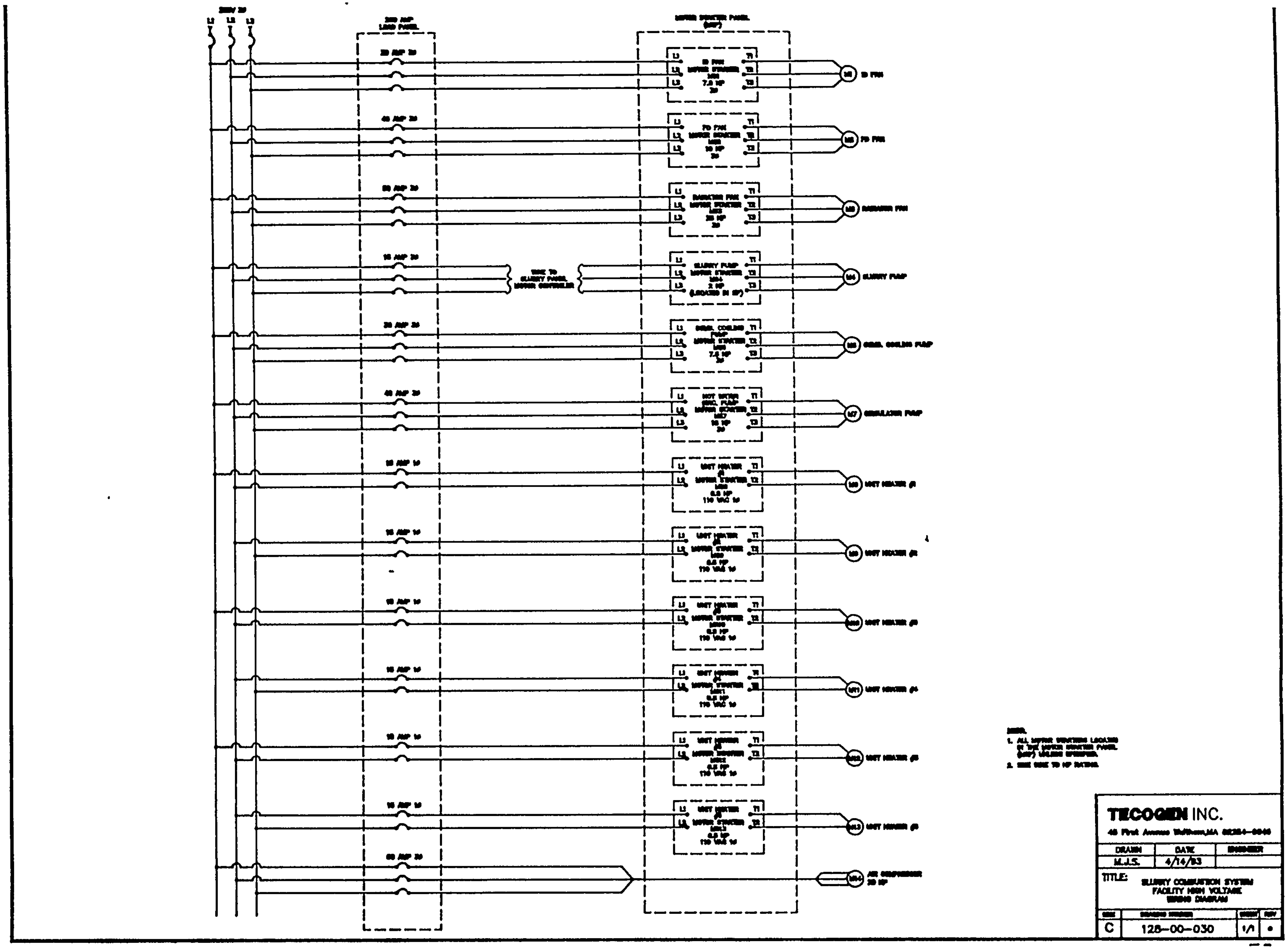


Figure 2.9 Space Heating System - High Voltage Wiring Diagram

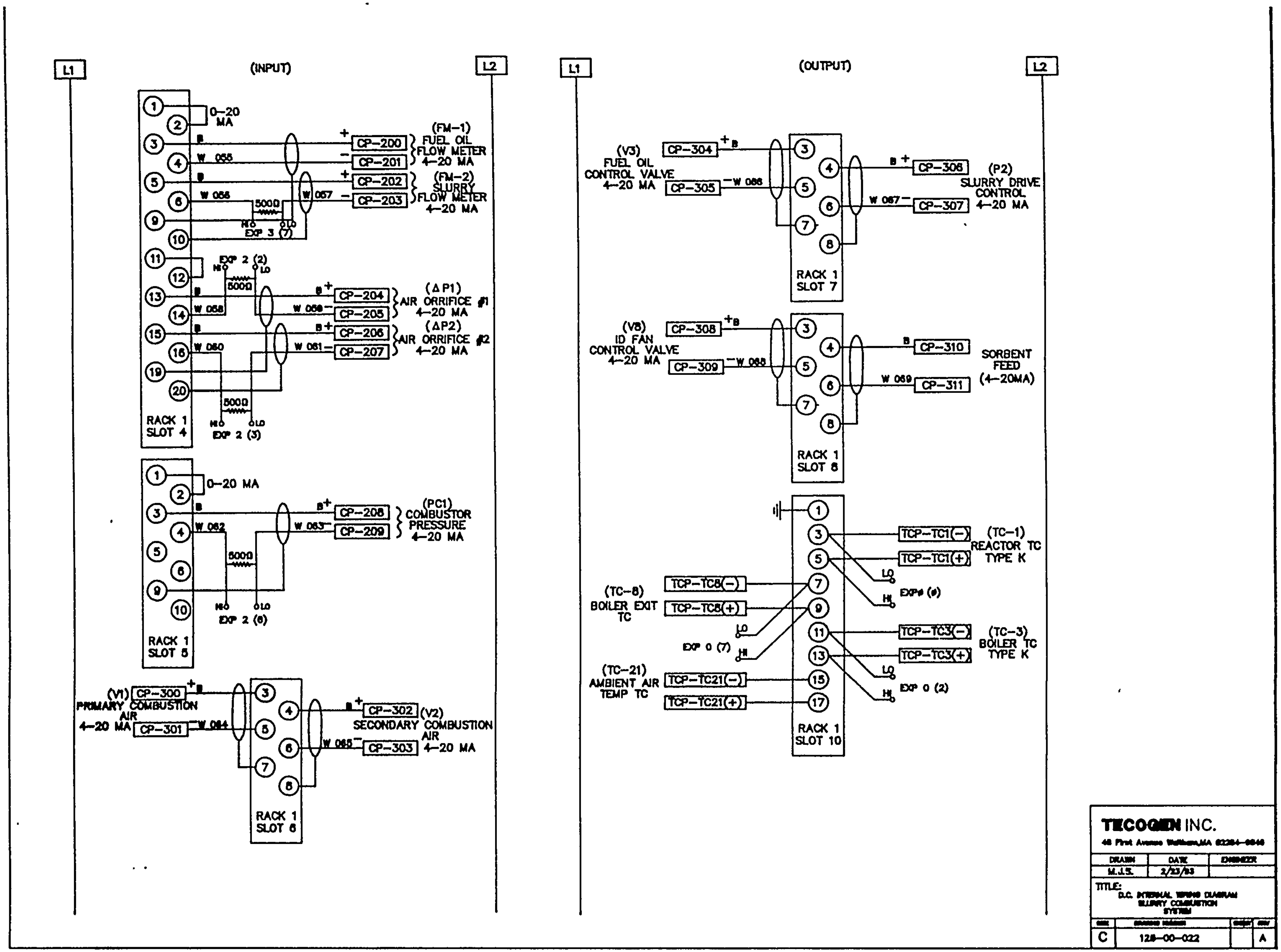


Figure 2.10 Space Heating System - D.C. Internal Wiring Diagram

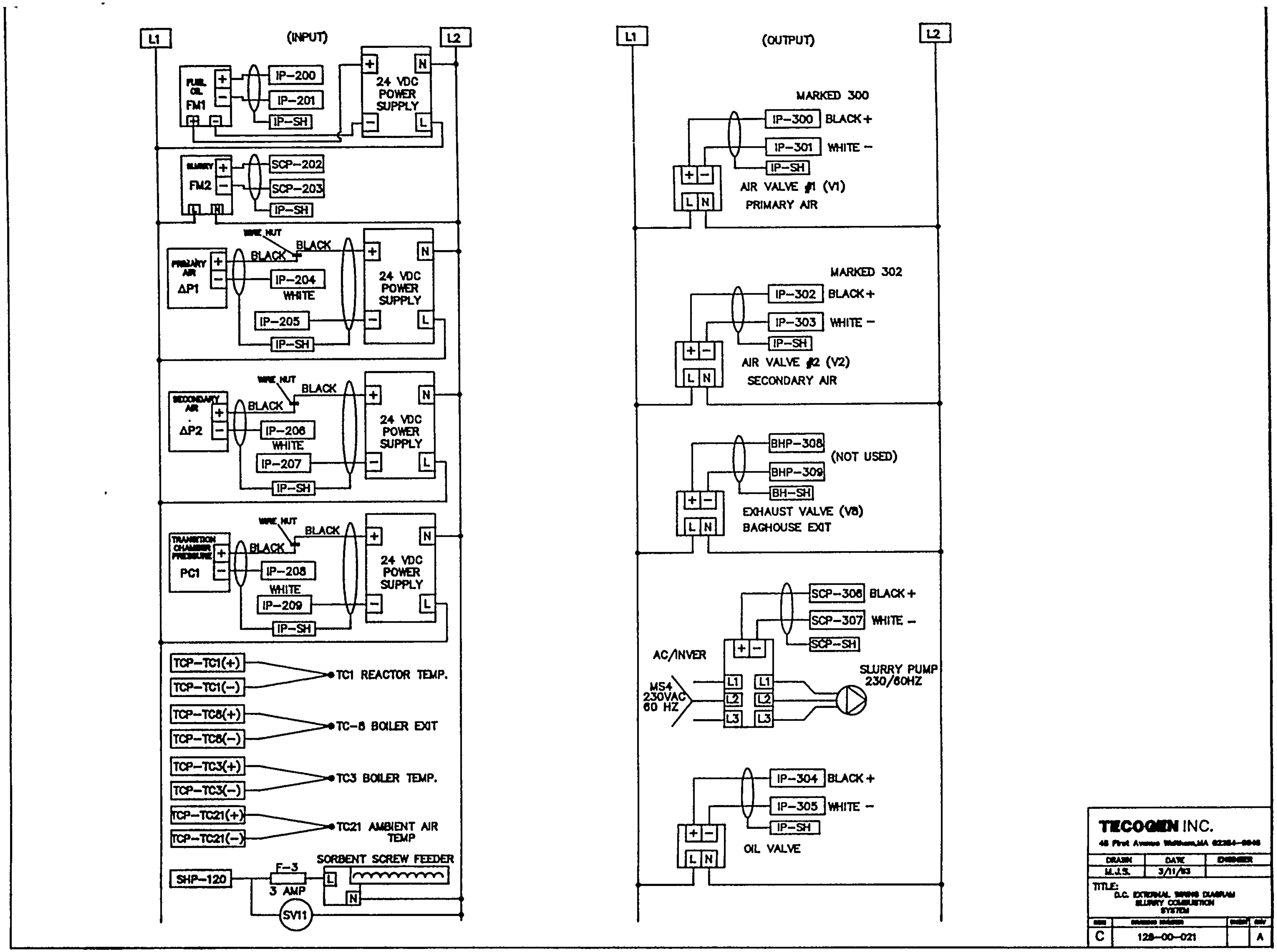


Figure 2.11 Space Heating System - D.C. External Wiring Diagram

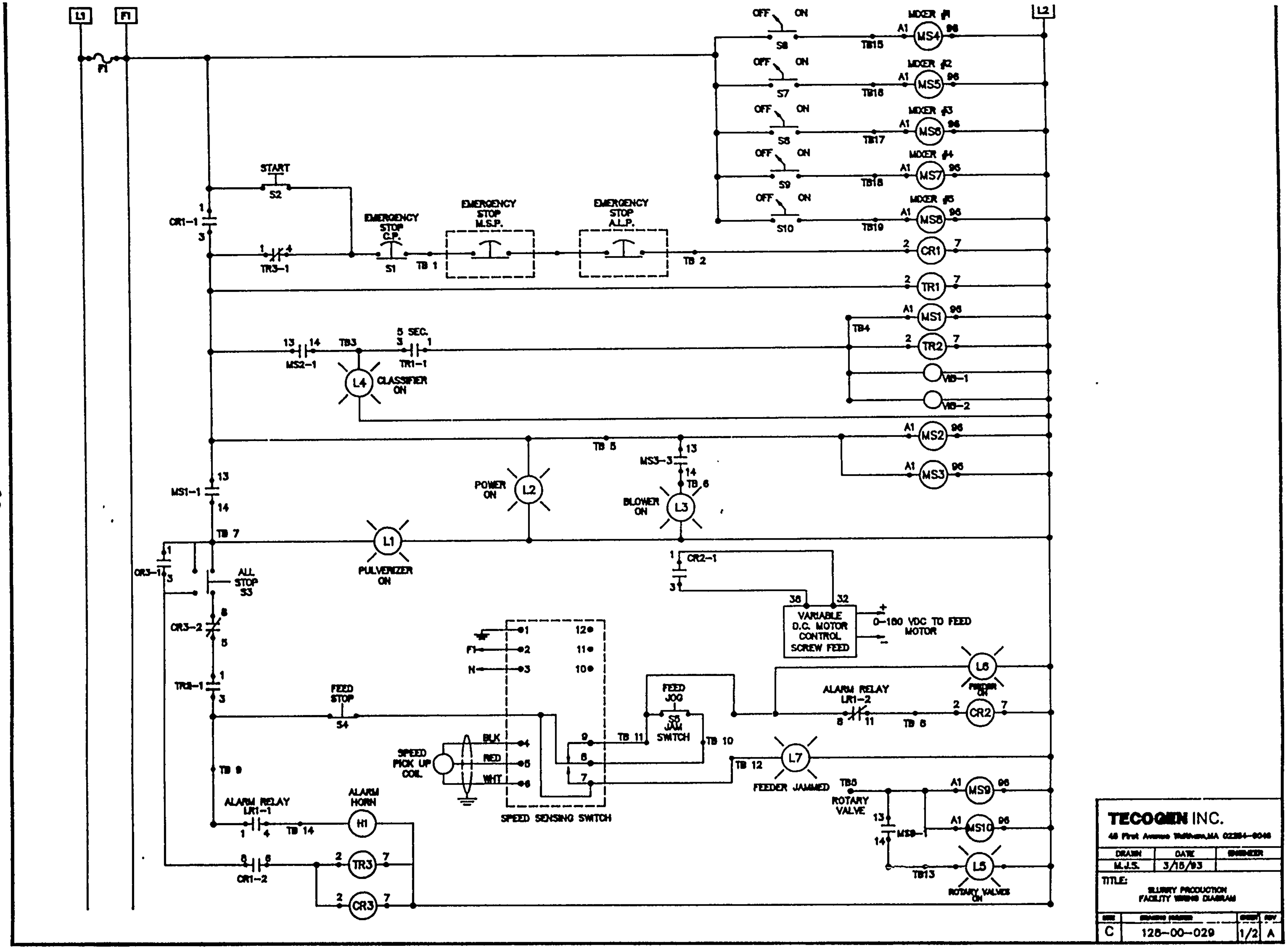


Figure 2.12 Slurry Production Facility Wiring Diagram

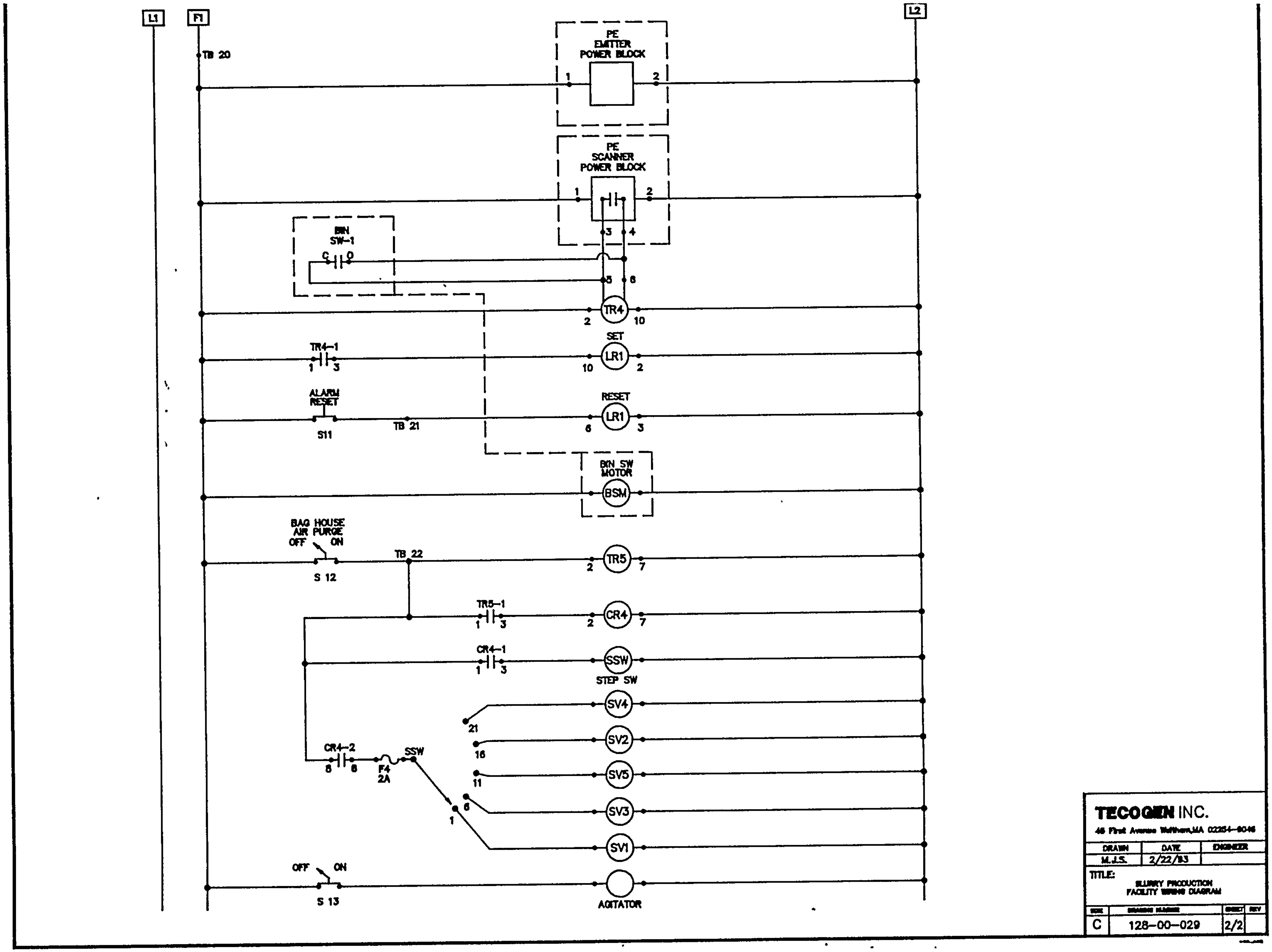
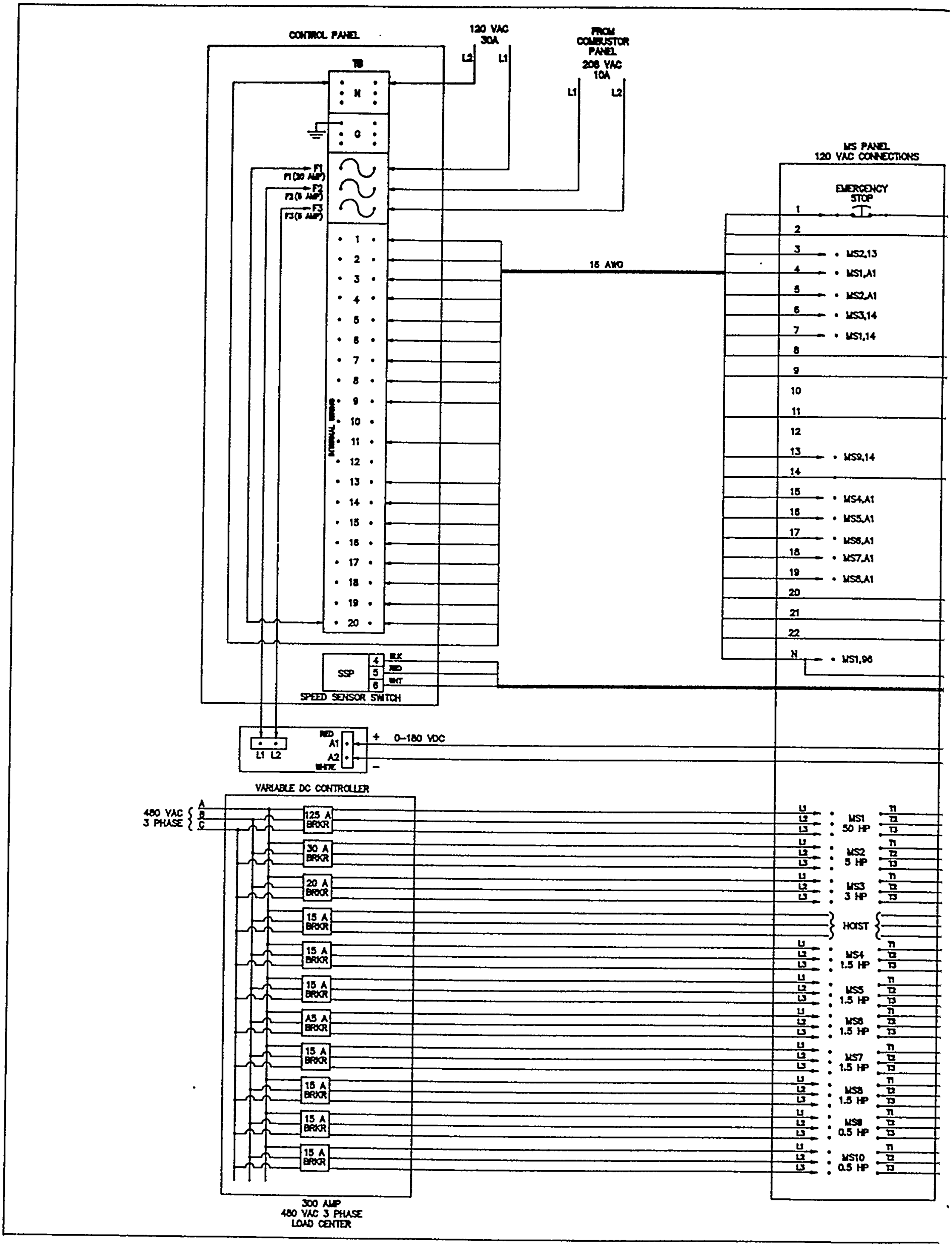


Figure 2.12 (Cont'd) Slurry Production Facility Wiring Diagram


CONTROL PANEL
120 VAC 30A
L2 L1
FROM COMBUSTOR PANEL 208 VAC 10A
L1 L2
TB
N
G
F1 F1 (30 AMP)
F2 F2 (5 AMP)
F3 F3 (5 AMP)
INTERNAL WIRING
15 AWG
MS PANEL 120 VAC CONNECTIONS
EMERGENCY STOP
MS2,13
MS1,A1
MS2,A1
MS3,14
MS1,14
MS9,14
MS4,A1
MS5,A1
MS6,A1
MS7,A1
MS8,A1
MS1,96
SSP
BLK
RED
WHT
SPEED SENSOR SWITCH
RED
WHITE
0-180 VDC
VARIABLE DC CONTROLLER
480 VAC 3 PHASE
125 A BRKR
30 A BRKR
20 A BRKR
15 A BRKR
A5 A BRKR
MS1 50 HP
MS2 5 HP
MS3 3 HP
HOIST
MS4 1.5 HP
MS5 1.5 HP
MS6 1.5 HP
MS7 1.5 HP
MS8 1.5 HP
MS9 0.5 HP
MS10 0.5 HP
300 AMP 480 VAC 3 PHASE LOAD CENTER

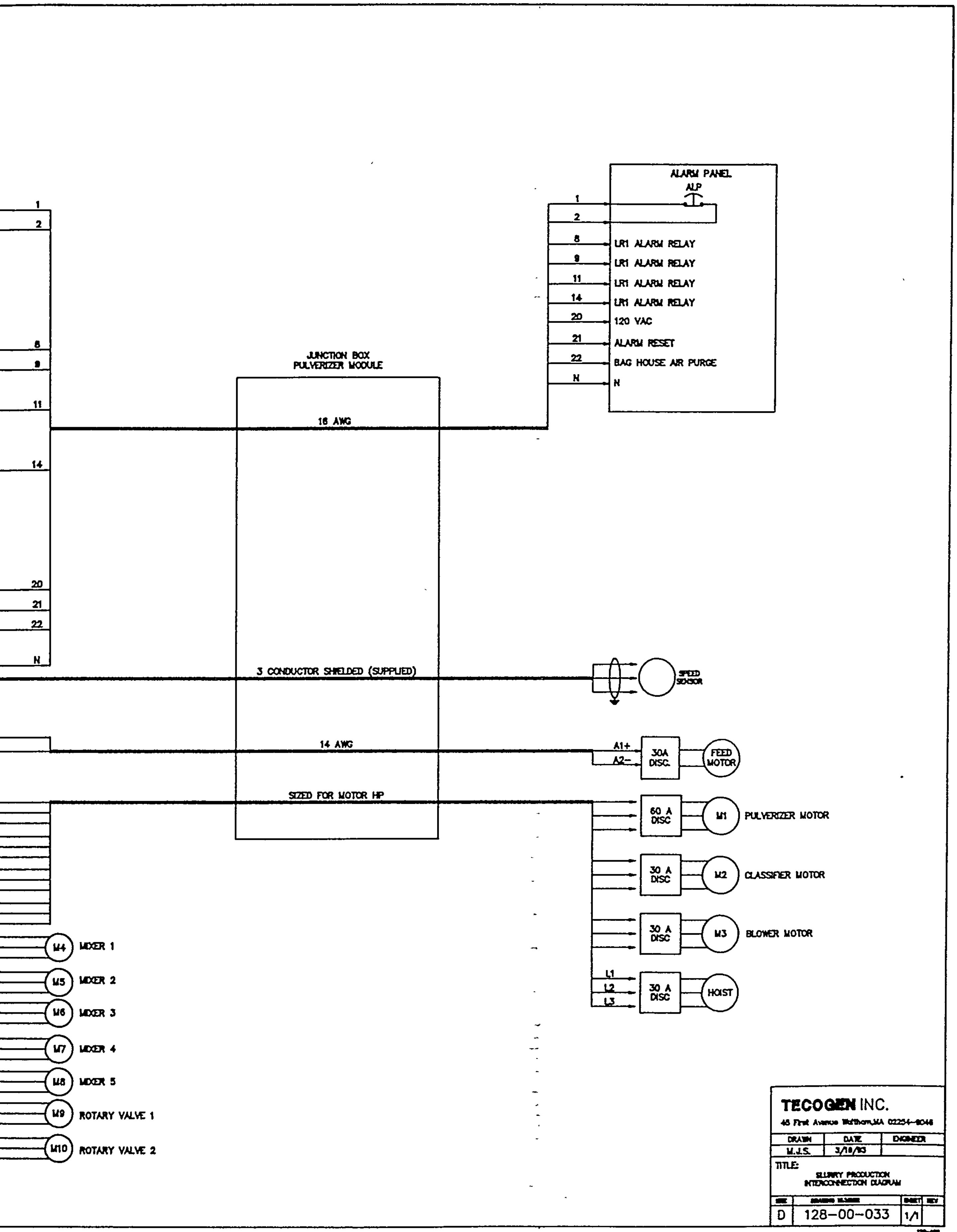


Figure 2.13 Slurry Production Facility Interconnection Diagram

3. PLANNED ACTIVITIES

During the next quarter, the slurry production facility and space heating system equipment will be installed at the host site. Once installed, shakedown testing will be initiated.

4. SUMMARY

During the past quarter, the bulk of the program activities were centered around finalizing the host site installation design and preparing the equipment for shipment to the ICDP facility.

One final equipment upgrade aimed at eliminating ash deposition in the combustor/boiler connecting zone was evaluated. Refractory surfaces in the entrance region of the boiler were eliminated by installing a metal liner the length of the transition region between the transition chamber and boiler. This configuration greatly reduced the ash accumulation in this region and simplifies removal of the material which is deposited.

An optional SO_2 reactor designed to enhance sorbent utilization through increased residence time and sorbent/gas contact was installed and tested. This reactor increases the residence time of the sorbent particles relative to the gas and therefore provides an effective sorbent-to-sulfur ratio within the reactor that is many times greater than that injected, providing a very high sorbent particle surface area concentration. High slip velocities between the particles and gas within the reactor further enhance sorbent utilization. With the reactor, sulfur emission goals can be met with larger sized sorbent material which is freer flowing, more readily available, and less expensive than the finer material.

REFERENCE

1. Keener, Timothy C., "Thermal Decomposition of Sodium Bicarbonate and its Effect on the Reaction of Sodium Bicarbonate and Sulfur Dioxide in a Laminated Flue," Doctorate Thesis, University of Tennessee, Knoxville, 1982.