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A PILOT-SCALE COMBUSTION RESEARCH FACILITY FOR LOW-QUALITY FUELS

G.K. Lee, F.D. Friedrich, S.I. Steindl and H. Whaley
Canadian Combustion Research Laboratory

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Pour appuyer les initiatives du gouvernement canadien visant la sécurité en matière d'approvisionnements et l'indépendance énergétique, les industries et le secteur des services délaissent rapidement les combustibles liquides de première qualité en faveur des combustibles cendrés naturels de qualité inférieure. Les combustibles qui retiennent particulièrement l'attention comprennent le charbon provenant de gisements nouvellement exploités, le schlamm, la biomasse, le coke de pétrole, les résidus liquides des raffineries et les émulsions de bétume et d'eau. Face à l'impossibilité d'obtenir des données fiables sur les propriétés de combustion du carburant utilisé dans l'industrie, le Laboratoire canadien de recherche sur la combustion (LCRC) a mis au point récemment une nouvelle installation pilote pour évaluer les combustibles d'après les caractéristiques qui leur sont propres, telles les propriétés de combustion, les scories, l'encrassement et les facteurs de corrosion et d'émission.

Les raisons justifiant la construction d'une installation de recherche et les facteurs qui ont influencé le design et la conception ainsi qu'une description du système de combustion sont présentés dans ce document.

INTRODUCTION

In response to federal initiatives to achieve oil independence and energy security by 1990, Canadian industries and utilities are rapidly converting from premium liquid fuels to indigenous but low-quality, ash-bearing fuels. Typical fuels of interest include coal fron newly-opened deposits, coal slurries, biomass, petroleum coke, liquid refinery residues and bitumen/water emulsions. Since reliable data on the burning properties of these fuels in industrial equipment are almost non-existent, the Canadian Combustion Research Laboratory (CCRL) recently designed a new pilot-scale facility to evaluate their combustion, slagging, fouling, corrosion and emission characteristics.

The rationale for constructing the research facility, together with the key design considerations and a description of the combustion system are described herein.

RATIONALE FOR THE FACILITY

Combustion data on new fuels, which can be confidently applied or translated into practice, cannot be generated from either standard analyses or empirical relationships based on these analyses. Furthermore, it is often impractical to evaluate new fuels in full-scale burns because of:

(a) high costs;

(b) the unavailability of large tonnages of non-commercial fuel;

(c) inadequate means of measuring performance parameters;

(d) incompatability with equipment designed for a different quality of fuel and

(e) limited flexibility in changing operational conditions.

For these reasons, pilot-scale combustion rigs have been widely viewed as an acceptable compromise between the inadequacies of crucible-scale tests and the disadvantages of full-scale trials. Two pilot-scale rigs, illustrated in Figs. 1 and 2, have been successfully used at CCRL to identify and where possible to rank the severity of potential combustion problems when conventional fuels are substituted in existing plants or selected as a primary fuel in new plants. Rigs such as these closely simulate but do not exactly duplicate conditions in an operational plant because of distortions in residence times, heat release rates and surface to volume ratios. Nontheless, they have proven to be extremely useful in obtaining information on the integrated effects of interdependent variables such as fuel reactivity, fuel preparation, excess combustion air, air/fuel mixing patterns, chemical additives and firing rate on:

(a) flame stability and combustion efficiency;

(b) the physico-chemical properties and rates of build-up of fireside deposits and

(c) the nature and quality of the emissions generated.

At CCRL an unknown fuel is evaluated by comparing its pilot-scale performance with that of a reference fuel for which full-scale operational data are known. Although largely a matter of experience, the extrapolation of pilot-scale trends to operating units has been one way of effectively minimizing many of the technological risks inherent in correlating or validating the behaviour of new fuels in full-scale burns.

The existing rigs, which were designed for conventional fuels, have numerous experimental limitations when used to study low-quality fuels. To overcome these research restrictions and to meet the escalating demand for definitive information on progressively poorer grades of fuels, a new pilot-scale combustion facility has been designed. This new facility will have provisions for extended combustion residence times, adjustable rates of heat transfer in the flame zone, detailed flame probing and improved means of studying ash build-up on radiative and convective heat transfer surfaces.

DESIGN CONSIDERATIONS

Functional Requirements

The new facility for suspension firing was conceived as a multi-purpose rig for evaluating the effect of operational parameters and fuel quality on:

(a) fuel comminution or atomization;

(b) combustion performance;

(c) fouling and slagging tendency;

(d) high- and low-temperature corrosion potential;

(e) fly ash collectability;

(f) SO_x, NO_x and organic emissions;

(g) trace element fixation in ash.

Basic Criteria for Full-scale Simulation

Based on past experience at CCRL and elsewhere with pilot-scale combustion rigs, the new facility was designed to closely duplicate typical full-scale specifications for:

(a) solid fuel fineness or liquid atomization;

(b) excess combustion air;

(c) combustion air distribution;

(d) carbon burn-out;

(e) furnace exit temperature;

(f) superheater gas velocities.

The efficiency of carbon burn-out was considered to be significantly more important than duplicating full-scale residence times because of the detrimental effects of high carbon carryover on combustion, deposition, corrosion and emission measurements.

Conceptual Features

The conceptual features incorporated into the facility design were dictated by currently perceived needs for combustion data on new fuels in general, and on slow-burning fuels in particular. Proven experimental concepts from the existing rigs, which were designed for high-reactivity fuels, were also incorporated and these are marked with an asterisk:

(a) *optional pre-drying of solid fuels prior to pulverizing;

(b) *adjustment of fuel moisture content and fineness during pulverization or atomization;

(c) *direct firing, using two burners for flame stability;

(d) *nominal thermal input of 2500 MJ/h (0.7 MWt);

(e) capability for firing non-conventional liquid and gaseous fuels;

(f) roof-firing with provision for sidewall, front wall or tangential firing modes;

(g) multiple ports for flame observations and measurements;

(h) adjustable furnace heat extraction;

(i) stepwise changes in furnace residence time;

(j) uncooled and cooled platens for slagging propensity;

(k) *air-cooled superheater tube module for fouling tendency;

(l) *monitoring of CO, CO_2, O_2, NO_x, SO_x and fly ash emissions;

(m) fly ash collection efficiency by electrostatic precipitator or baghouse and

(n) *pressurized combustion system to prevent air ingress at sampling and probing ports.

FACILITY DESCRIPTION

Fuel Delivery and Preparation

All fuel will be delivered and stored in 200-ℓ, sealed barrels. Immediately prior to use, liquid or pumpable fuels will be blended in a 2000-ℓ heated tank before being transfered as required to a 600-ℓ supply tank. Liquid fuel from this tank, as shown in Fig. 3, will be pumped and heated to atomizing temperature by an adjustable in-line heater. Both the blending and the supply tank are electronically weighed and tared to an accuracy of 0.2 kg in 10,000 kg.

In the case of solid fuels, the barrels will have plastic liners to prevent moisture loss from the "as received" fuel. The fuel will then be either pre-dried or fed directly to a hammer-mill for crushing to minus 6 mm as shown in Fig. 4. After being hammer-milled, the product will be elevated to a 5-tonne, electronically weighed bunker which supplies a ring-roller mill for directly firing pulverized coal to the furnace. This mill will be rated at 90 kg/h of bituminous coal or 180 kg/h of lignite at a Hardgrove grindability index of 50. Coal fineness will be adjustable from about 50% to 90% less than 75 µm by means of an integral, rotary classifier. In-mill drying, which will provide pulverized fuel temperatures up to 80°C, will normally be accomplished with air at 230°C. If necessary, a blend of hot air and flue gas at temperatures up to 490°C will be provided for pulverizing high-moisture fuels. A riffle at the pulverizer outlet will suppress roping and equally distribute the fuel to each burner.

Furnace Confirguration and Combustion System

The U-shaped furnace, illustrated in Figs.5 to 8, will consist of a vertical refractory shaft and a vertical steam boiler connected at the bottom by a horizontal refractory tunnel. It is anticipated that highly-reactive fuels will burn efficiently when fired through opposed low-swirl burners located in the sides of the membrane-walled boiler. For fuels that are difficult to burn, because of particle size, moisture or reactivity constraints, residence times and combustion zone temperatures will be increased to obtain good burn-out by relocating the twin burners on the roof of the vertical refractory shaft; intermediate residence times, if required, can be obtained by removing one or both modules which make up the vertical shaft.

With opposed burners in the boiler section, the combustion chamber residence time at full load will be about 0.5 s. This time will increase to about 1.7 s with the burners mounted on the roof of the vertical refractory shaft. The combustion chamber heat release rate with either of these burner arrangements will be about 0.35 $MJ/s/m^3$.

The three sections of the furnace, which will have strategically located access ports for flame probing and insertion of slag deposition surfaces, are being designed to operate at a pressure of 250 mm of water. Furnace exit temperatures will be controlled between 900°C and 1250°C by adding cooled wall panels in the refractory shaft or by partially insulating the water walls of the boiler.

After leaving the furnace, the combustion gases will pass through a simulated superheater section, a four-pass heat exchanger for preheating pulverizer and combustion air, and a long horizontal sampling duct. At the end of the sampling duct, a portion of the gas stream will be diverted into either a small bag filter or an experimental precipitator. A heat exchanger located mid-way along the sampling duct will allow combustion gas temperatures within the duct to be varied between 150°C and 300°C.

Slag Probes

Furnace slag probes will consist of two air-cooled, heat flux meters and an uncooled refractory block mounted flush with the furnace wall. One of the air-cooled probes will be kept clean and the other will be allowed to accumulate a slag or dry ash deposit. The difference in heat flux rates between the two meters should provide a quantitative measure of the effect of any slag or ash deposits on heat transfer. The refractory block will simulate boiler surfaces that have already been covered in ash or slag.

Simulated Superheater Section

The simulated superheater section for evaluation of ash fouling tendency will consist of seven, staggered 50 mm OD tubes, mounted vertically between two stainless steel headers as shown in Fig. 9. The tubes will be air cooled and will be held in place by stainless steel tension rods through the centre of each tube. Tube metal temperature will nominally be set at 560°C and will be monitored by thermocouples on the front of a front centre tube and on the front of the rear centre tube. A staggered superheater arrangement was selected to accelerate ash build-up with inlet gas velocities of 10 m/s to 18 m/s.

Flame and Combustion Gas Instrumentation

Instrumentation for flame measurements will all be of International Flame Research Foundation (IFRF) design. These will include velocity and temperature probes, radiation and heat flux meters and narrow angle radiometers.

Continuous gas analysis equipment will include infrared analyzers for CO, CO_2, and SO_2, a paramagnetic analyzer for O_2 and a chemiluminescent analyzer for NO and NO_x. Intermittent measurements will include SO_3 by wet chemistry, dust burden by isokinetic sampling, in-situ electrical resistivities of ash by a point-plane probe and acid dewpoint by a conductivity probe.

Present Status

The facility is being purchased and installed in a staged manner to minimize disruptions to several priority research projects scheduled for the existing pilot-scale rigs over the next two years. The coal drying system is now in operation and the new pilot-scale furnace system has been received. Design work to adapt the new furnace to the existing pulverizer, air heater and emission abatement systems is in progress with commissioning of the new facility planned for 1983.

Consideration is currently being given to acquiring a beater-type mill for low-rank, high-moisture fuels and a system for detailed sampling of trace element and organic emissions.

SELECTED BIBLIOGRAPHY OF CCRL REPORTS

1. Lee, G.K., Friedrich, F.D. and Mitchell, E.R. "Effect of fuel characteristics and excess combustion air on sulphuric acid formation in a pulverized-coal-fired boiler"; J Inst Fuel, London, England; September 1967; 397-405.

2. Friedrich, F.D. "Pulverized coal combustion research at the Canadian Combustion Research Laboratory"; Proceedings Dominion-Provincial Coal Conference Index 67, Regina, Saskatchewan, August 1967;60-73.

3. Friedrich, F.D., Mitchell, E.R., Lee, G.K. and Whaley, H. "The CCRL tunnel furnace design and application"; Proceedings of thw Second Members Conference, International Flame Research Foundation, IJmuiden, Holland; May 1971, Chapt. XV, XV-XV-18.

4. Lee, G.K., Mitchell, E.R., Friedrich, F.D. and Draper, R.G. "Fireside corrosion and emission from crude oil combustion"; Trans ASME-J Eng Power; New York, April 1972; 154-158.

5. Friedrich, F.D., Lee, G.K. and Mitchell, E.R. "Combustion and fouling characteristics of two Canadian lignites"; Trans ASME - J Eng Power; New York, April 1972; 127-132.

6. Lee, G.K., Friedrich, F.D., Whaley, H. and Ogle, I.C.G.; "An overview of coal activities at the Canadian Combustion Research Laboratory"; Canadian Institute of Mining and Metallurgy; Can Min Metall Bull, Montreal; October 1980; 62-64.

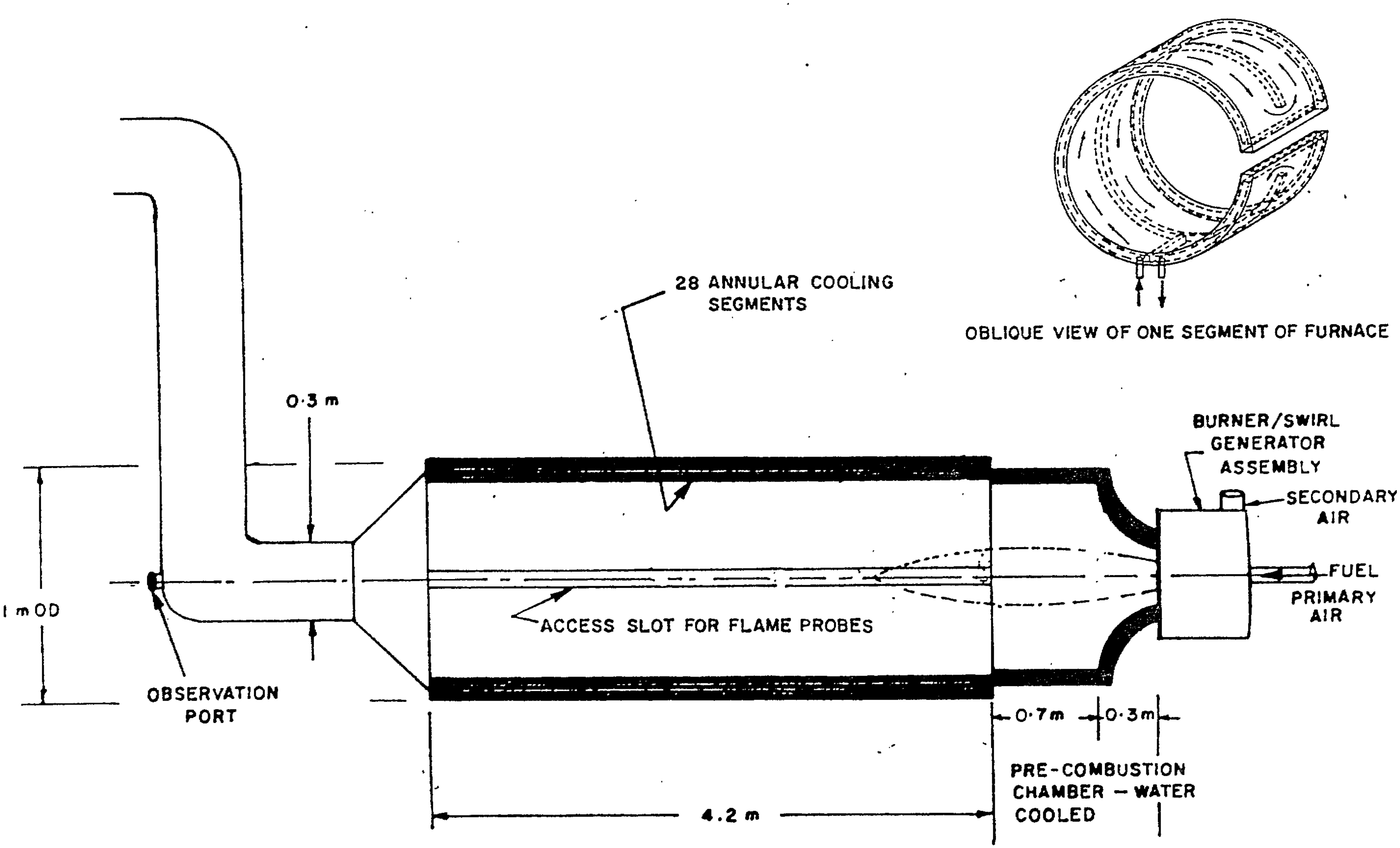


Fig. 1 - Calorimetric tunnel furnace for characterization of flame properties

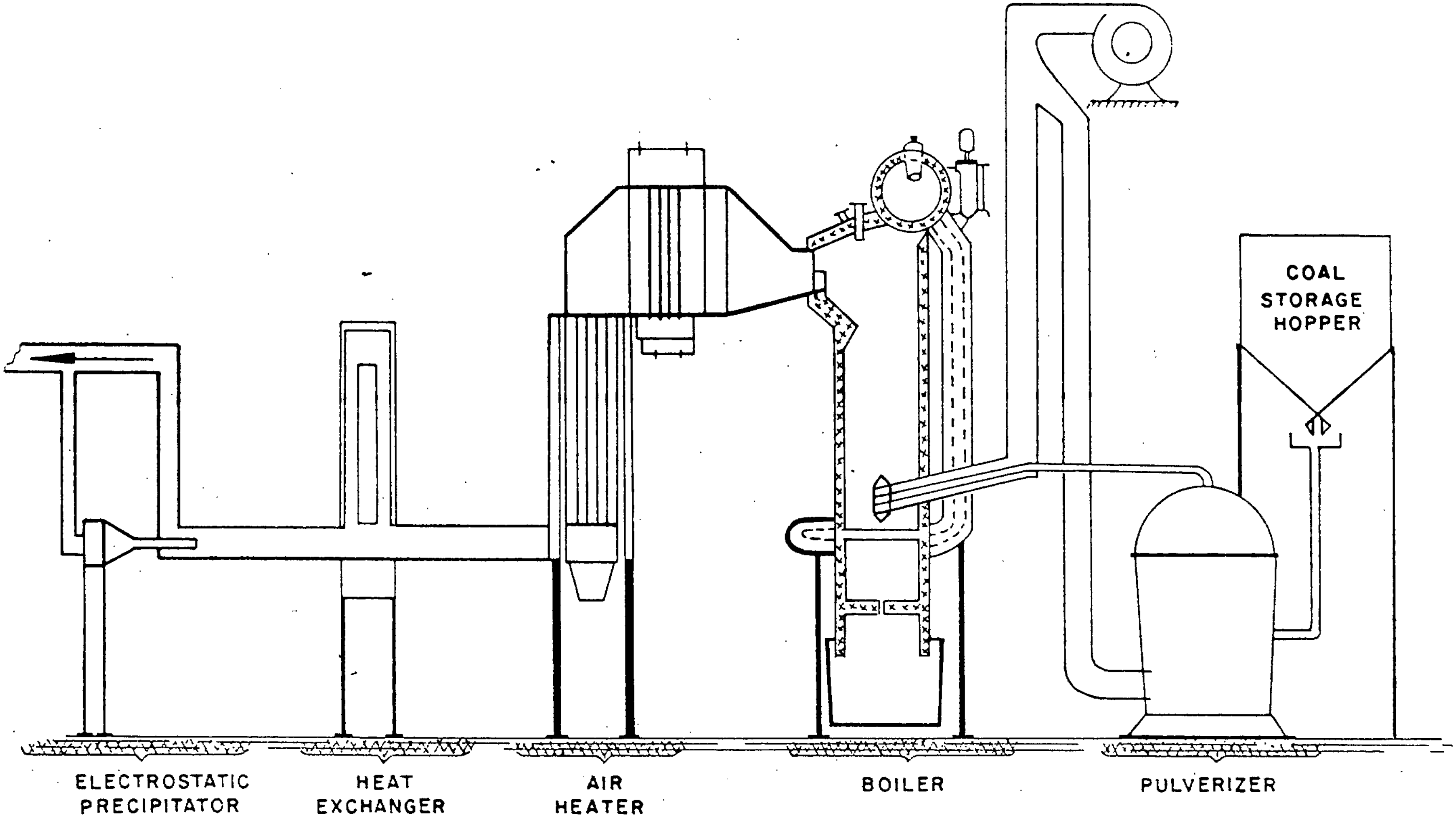


Fig. 2 - Schematic illustration of existing pilot-scale boiler

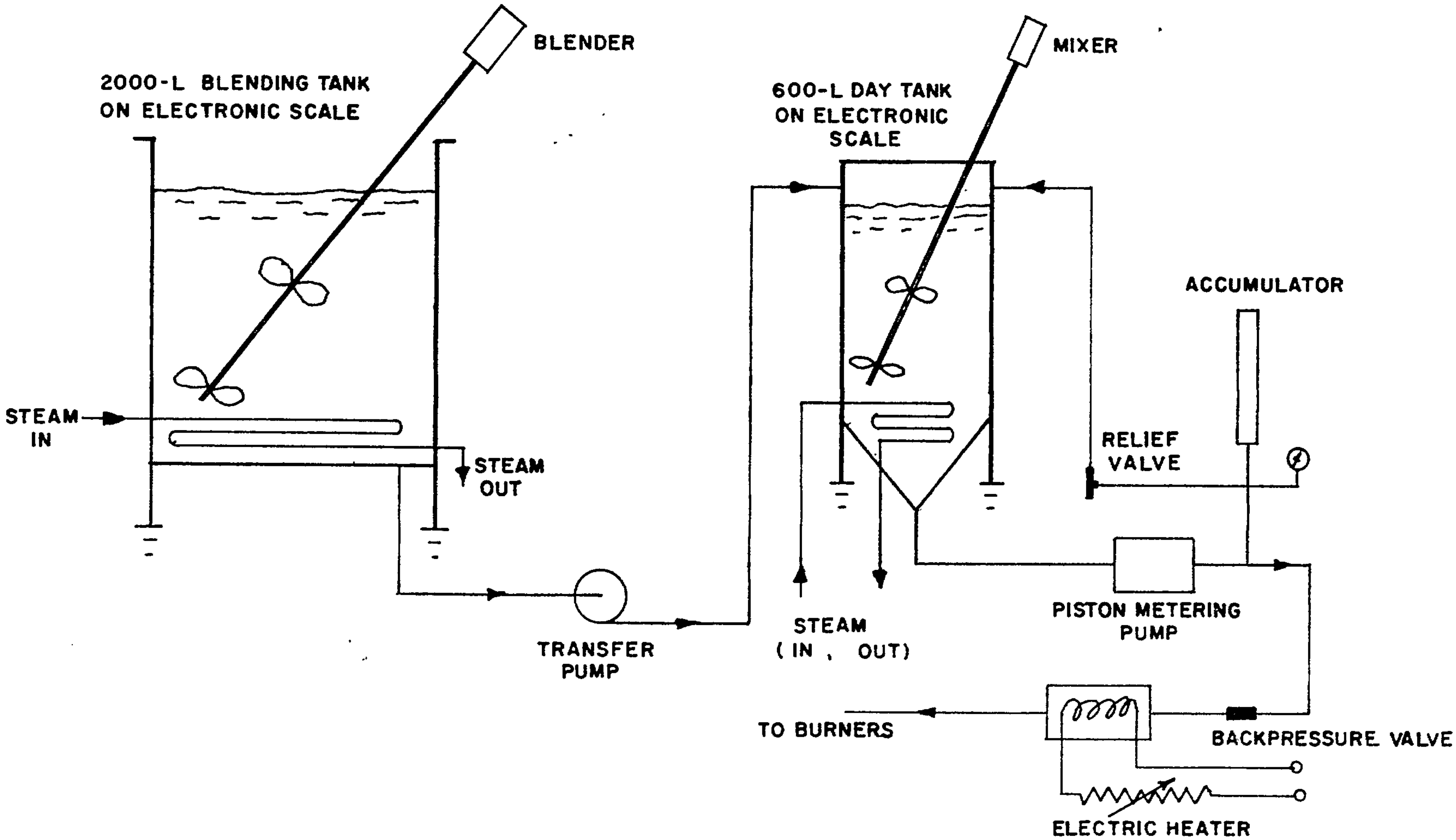


Fig. 3 - Schematic layout of liquid fuel preparation system

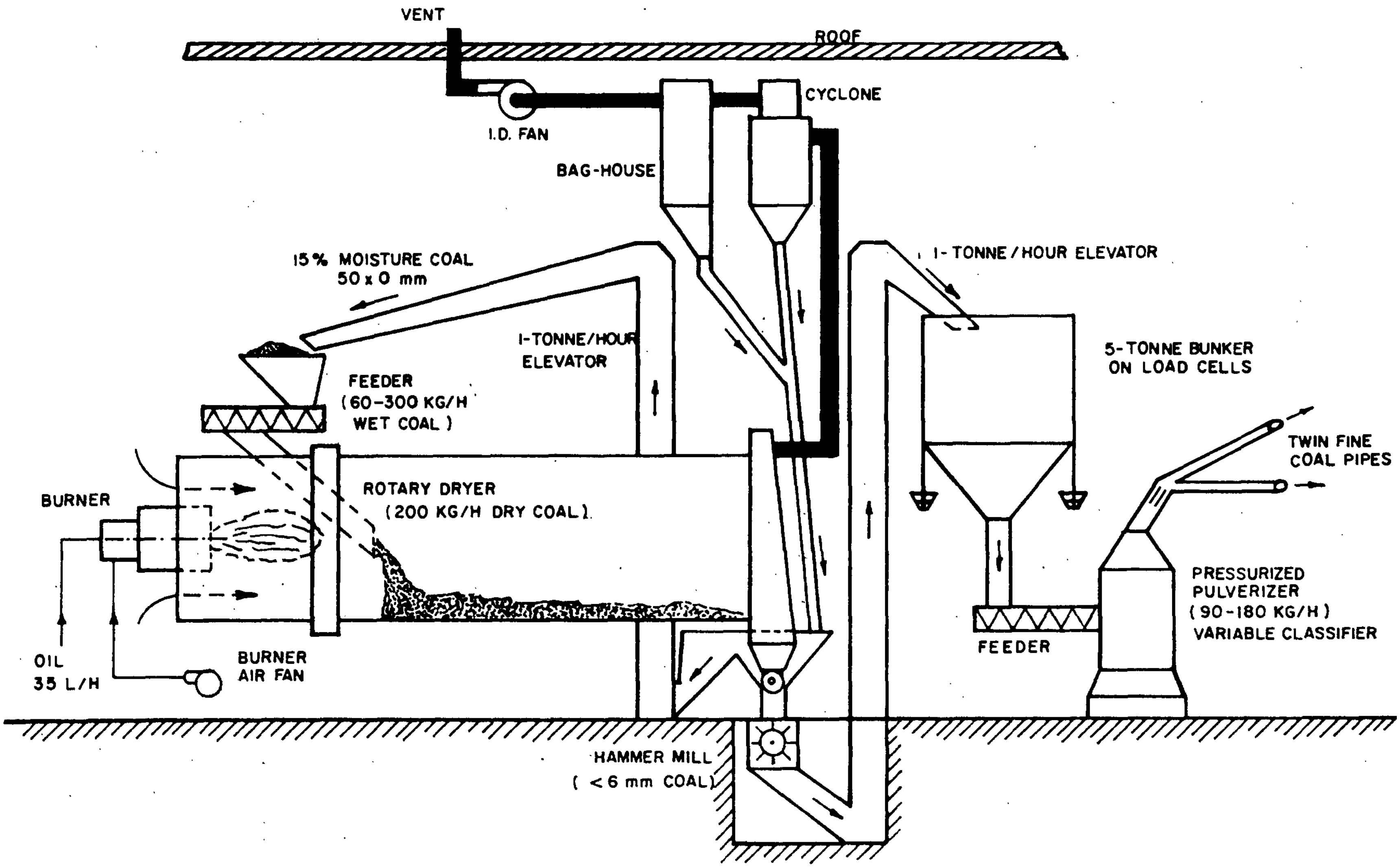


Fig. 4 - Schematic illustration of solid fuel drying and grinding system

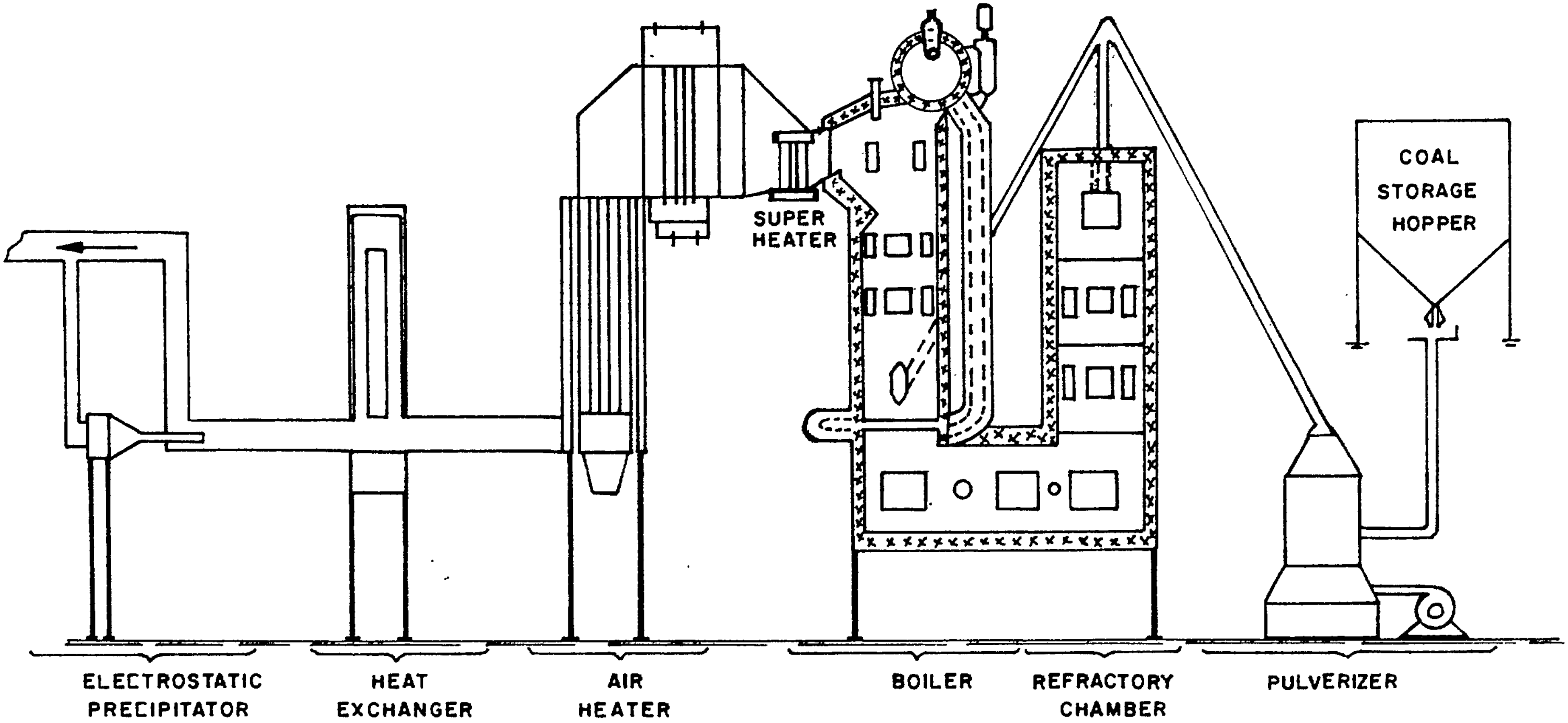


Fig. 5 - Schematic illustration of new pilot-scale combustion facility for low-quality fuels

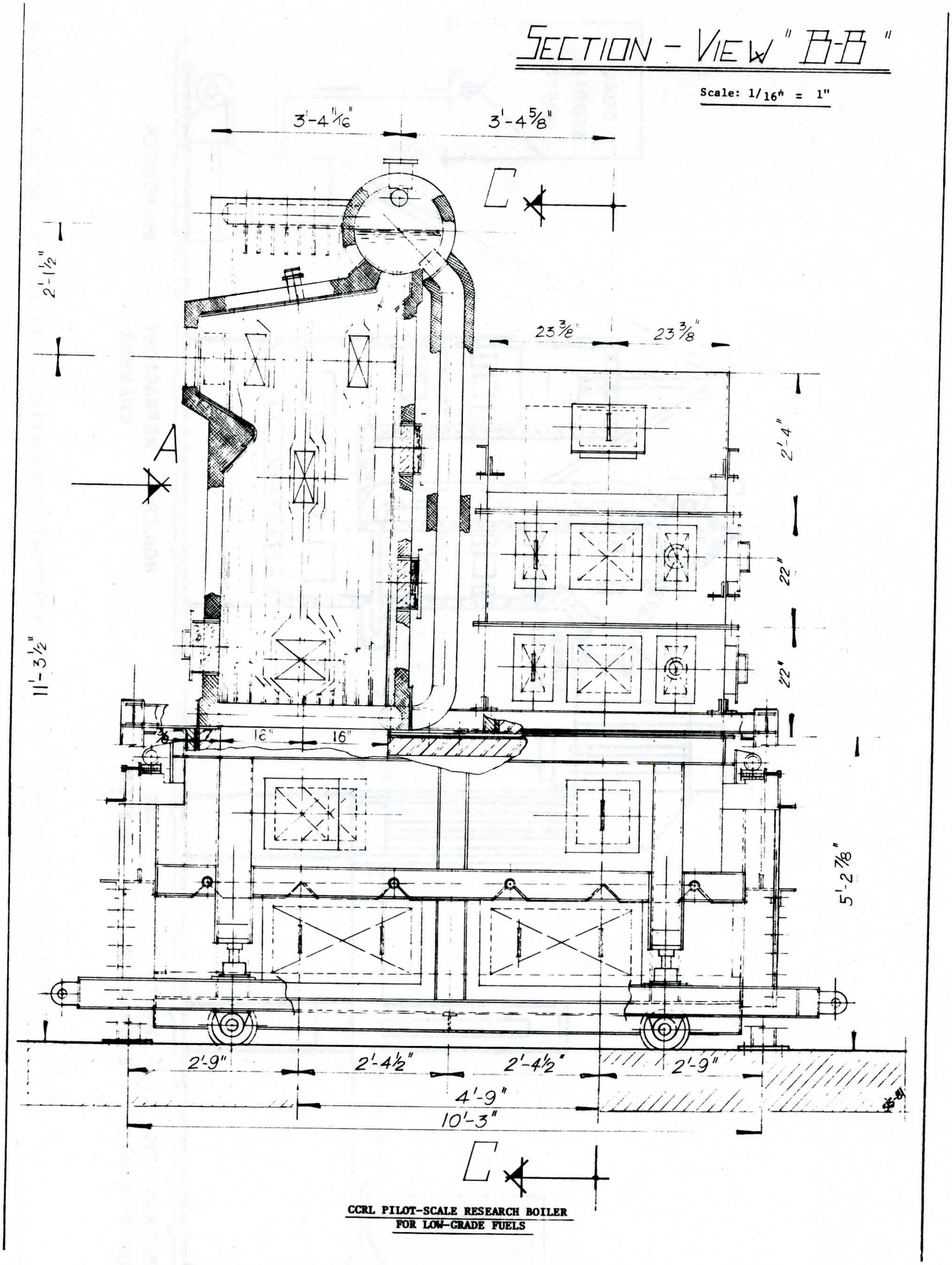


Fig. 6 - Side view of new pilot-scale combustion facility

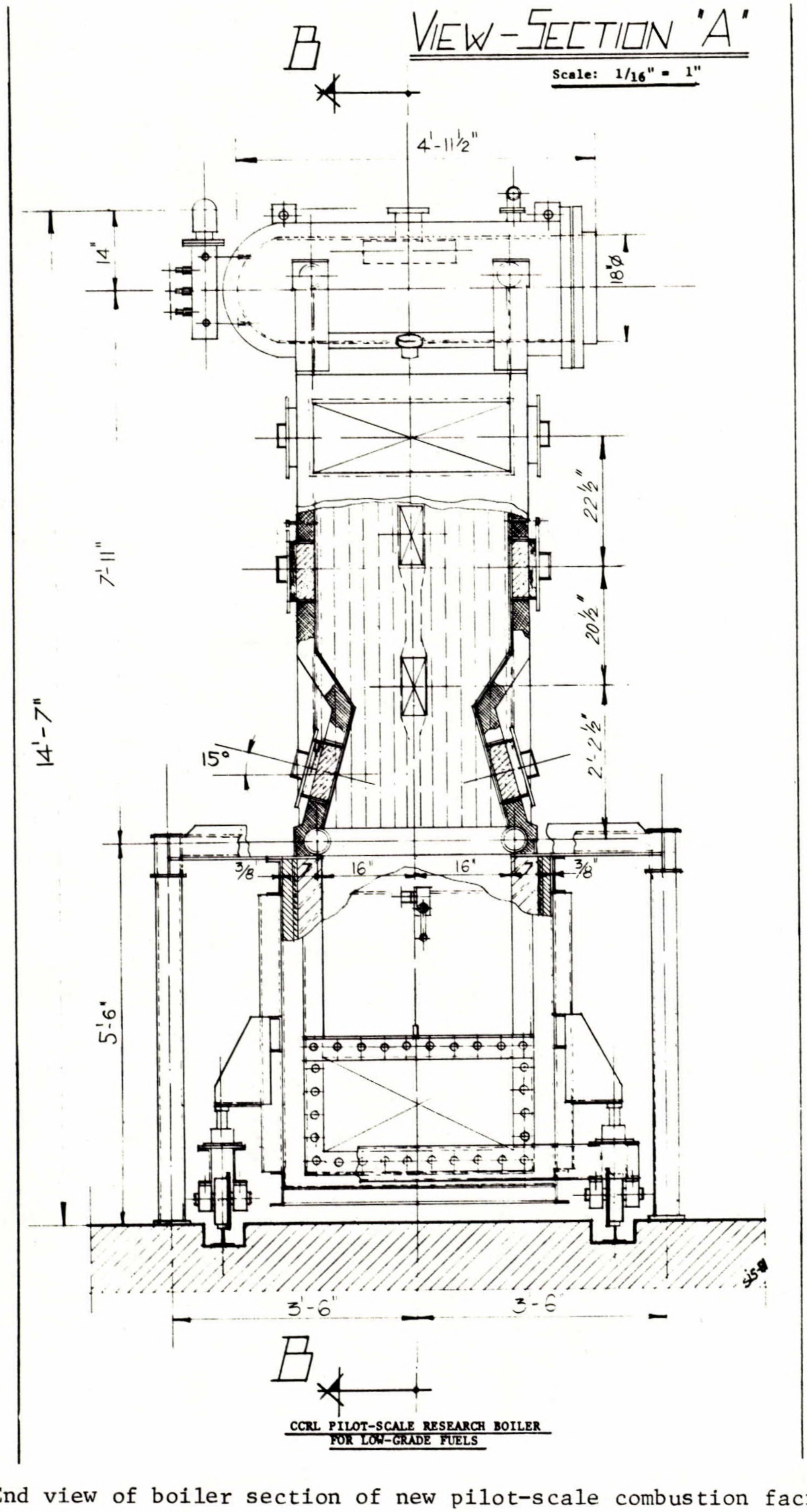


Fig. 7 - End view of boiler section of new pilot-scale combustion facility

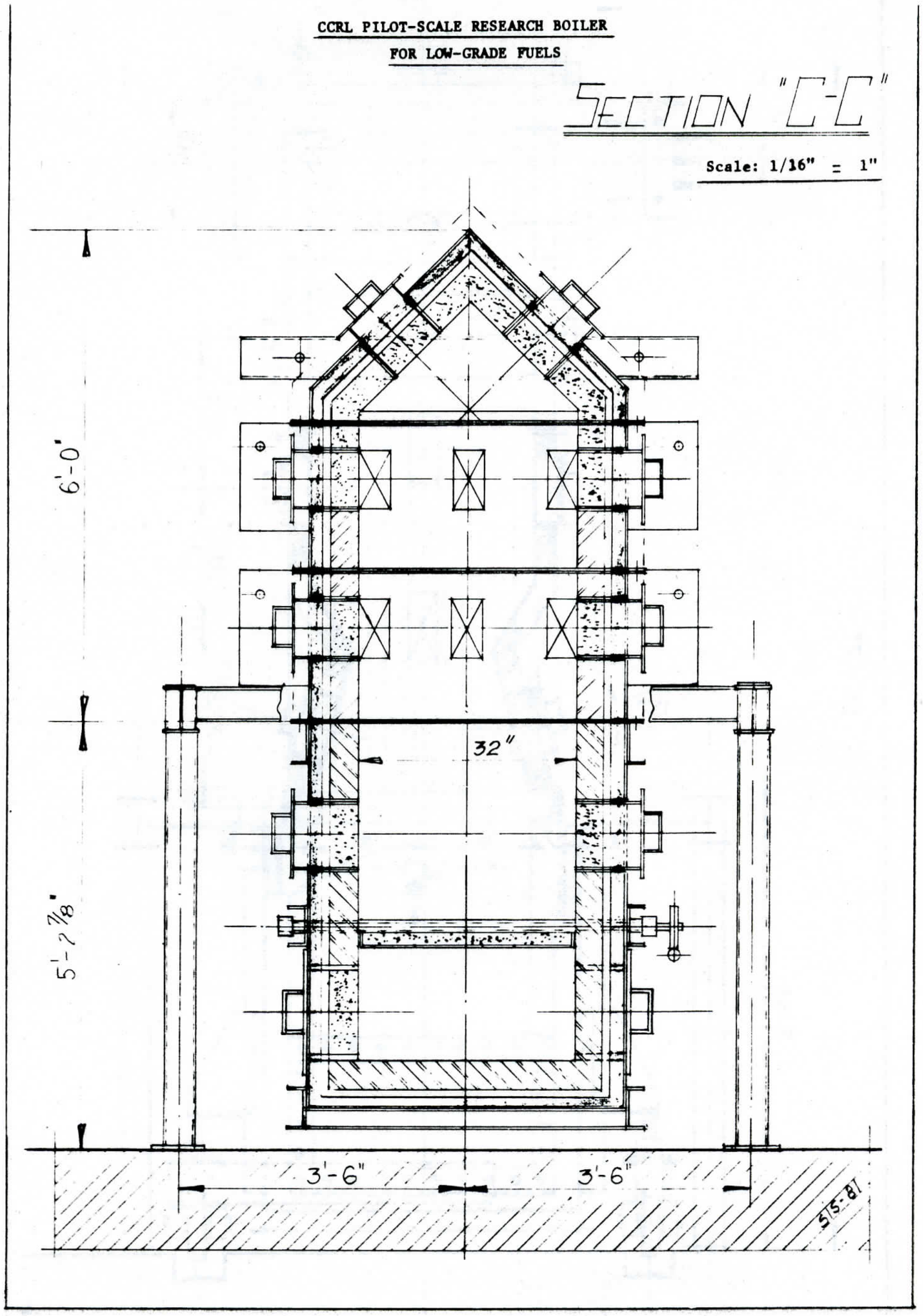
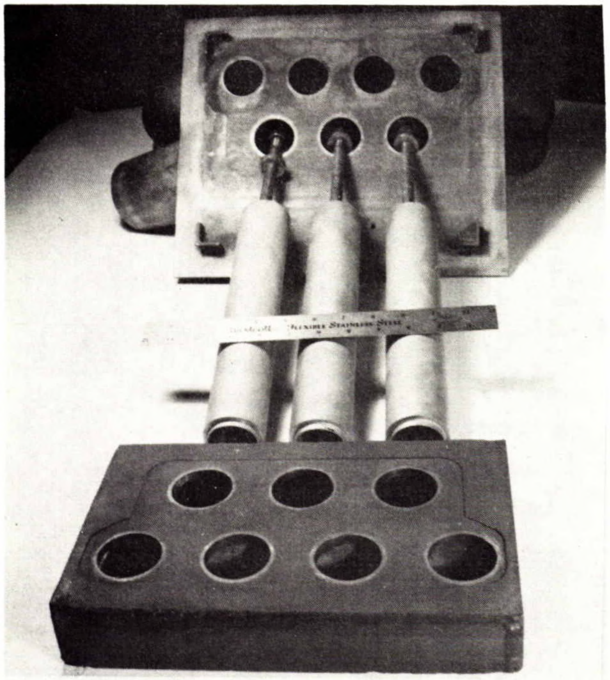
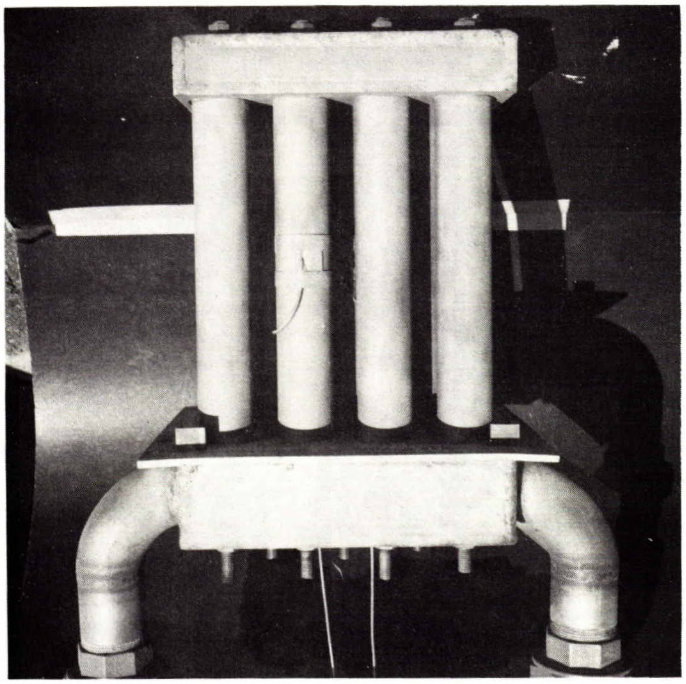


Fig. 8 - End view of refractory section of new pilot-scale combustion facility



(a) exploded view



(b) assembled view

Fig. 9 - Simulated air-cooled superheater for evaluation of ash fouling