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COAL COMBUSTION ACTIVITIES OF THE CANADIAN COMBUSTION RESEARCH LABORATORY

G. K. Lee, F. D. Friedrich, H. Whaley and I.C.G. Ogle

March 1980

For presentation at the 82nd Annual General Meeting of CIM - 1980, to be held April 20-23, 1980 at the Sheraton Centre Hotel, Toronto, Canada.

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
DIVISION REPORT ERP/ERL 80-25 (OP) C. 2

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ABSTRACT

This paper reviews the coal combustion activities currently being carried out at the Canadian Combustion Research Laboratory (CCRL) as part of the Energy Research Program administered by the Canada Centre for Mineral and Energy Technology (CANMET) on behalf of the Department of Energy, Mines and Resources Canada. These activities encompass a wide range of research, development and demonstration-scale projects, with major emphasis on techniques to optimize the burning of Canadian coals under environmentally acceptable conditions.

Brief descriptions are given of projects related to improved utilization of coal in conventional pulverized-fired boilers and kilns, the use of coal-oil mixtures as a substitute fuel in equipment designed for oil firing; and efforts to accelerate the application of fluidized-bed combustion systems for low-grade coal.

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1.0 INTRODUCTION

Current coal combustion activities at the Canadian Combustion Research Laboratory (CCRL) reflect the increasingly important contribution that coal is expected to make in meeting our future energy requirements and in reducing our dependence on foreign oil. Canadian thermal coal production, which increased from about 1.0×10^7 t in 1974 to about 1.8×10^7 t in 1978, will likely reach 5.0 to 6.0×10^7 t by 1990. This escalating demand for coal will, however, be heavily dependent on the ability of conventional and emerging combustion systems to cope with disruptive conflicts caused by variations in fuel quality, on requirements for better equipment availability and on the implementation of progressively more stringent environmental constraints.

The Department of Energy, Mines and Resources is optimistic that these problems can be resolved and has embarked on a systematic sequence of R, D and D initiatives to stimulate the utilization and competitiveness of thermal coal in both domestic and export markets. Technology support for these initiatives is provided by CCRL, a constituent laboratory of the Canada Centre for Mineral and Energy Technology (CANMET), through a number of complementary in-house projects and external contracts, considered to have short- to intermediate-term benefits to industry and society.

Many of these in-house projects, particularly those on pulverized-coal and fluidized-bed combustion are funded in part by industry. The external contracts are either fully funded (100% government funding) or jointly funded (50% government - 50% project proposer).

External contracts and shared-cost projects are an important adjunct to the CCRL in-house effort on coal combustion because research data can be more effectively transferred to industry and because the commercialization of novel combustion systems can be accelerated significantly.

2.0 ACTIVITY OBJECTIVES

Overall objectives of the CCRL coal combustion activities are:

1. To develop new or improved techniques for efficiently utilizing pulverized coal as a substitute for oil in industrial processes.
2. To delineate and optimize the combustion performance of low-grade coals from new mines in pulverized-fired power utility boilers.
3. To promote the development, and where feasible, the implementation of coal-oil mixtures (COM) as a partial substitute for oil in existing oil-fired equipment.
4. To accelerate the commercialization of new technology for burning low-grade and reject coals which cannot presently be used as industrial fuels.
5. To keep abreast of domestic and foreign coal combustion developments, and where appropriate, to participate in joint R D and D projects relevant to Canadian needs.

3.0 OVERVIEW OF COAL COMBUSTION ACTIVITIES

3.1 Pulverized Coal as a Substitute for Oil in Industry

The conversion of industrial furnaces and kilns from oil to pulverized coal requires that flame and heat transfer properties for a wide range of thermal coals be clearly defined with respect to No. 6 fuel oil. This knowledge base is intended to assist equipment designers, industrial users and coal suppliers to assess the suitability of specific coals for various process applications.

3.1.1 Flame Research Furnace

Most of the work on the characterization of flame properties during the combustion of pulverized coal, is carried out in a 1 m diam x 4.25 m long, cylindrical tunnel furnace shown in Figure 1. This unique furnace, which consists of 28 parallel-connected, heat-absorbing sections, is a very versatile research facility for parametric studies of:

a) flame aerodynamics

b) burner mixing efficiency

c) flame radiation

d) pollutant formation in flames

e) coal reactivity and

f) axial heat flux distribution.

The thermal load to the furnace can be varied by either changing the coolant flow in each circuit, partially lining the inside circumference of each calorimeter with refractory or combining the two methods for controlling heat absorption.

Flame shape and length can be altered to duplicate process requirements by means of a special combustion air mixing device designed by the International Flame Research Foundation (IFRF) in Holland. This device alters the degree of swirl of rotational flow of air around the central coal pipe. Be definition a low- or no-swirl flame is one in which the combustion air leaves the secondary air annulus without a significant rotational component of velocity, whereas a high-swirl flame is one which the combustion air leaves the secondary air annulus with a significant rotational component of velocity. The shapes of typical low- and high-swirl flames are shown in Figure 2. The chief difference is the presence of a reverse flow field in the central core of high-swirl flames; as the degree of swirl increases, flame lengths tend to decrease and flame diameters tend to increase. Quantitatively, the swirl number S is the ratio of the torque to the thrust of the input air flow and can be calculated from the velocity profile using the relationship

$$S = \frac{\text{axial flux of angular momentum}}{R\,[\text{axial flux of axial momentum}]}$$

$$= \frac{\int_0^r V_x V_t \cdot 2\pi\rho r^2 \cdot dr}{R\int_0^r V_x^2 \cdot 2\pi\rho r \cdot dr + \int_0^r P.2\pi r dr}$$

where r = radial distance

V_x = axial velocity component

V_t = tangential velocity component

ρ = density

P = static pressure, and

R = characteristic burner dimension

Two recent studies with this furnace involved studies to determine the feasibility of:

1. Substituting beneficiated anthracite fines for low-Btu gas in a rotary dryer for coking coal. It was found that the heavy media used for beneficiation transformed the normally high-fusion coal ash into a highly liquid slag and that stable combustion required at least 20% low-Btu gas as a support fuel. Figure 3 shows the effect of gas support on carbon burn-out and the effect of the heavy media on ash melting.
2. Utilizing a bituminous coal of unknown burning characteristics as a replacement for No. 6 fuel oil in cement kilns. These trials established that flame temperature and heat transfer rates for this coal, shown in Figure 4 were comparable to No. 6 fuel oil. Therefore, there would appear to be no thermodynamic barriers to interfuel substitution. Emission levels due to fly ash would be higher than for oil, but this would not normally be a problem in

processes such as calcining, cement making and coal drying where dust collectors are required regardless of the fuel burned.

3.2 Expanded Use of Coal in Utility Boilers

3.2.1 Pilot-scale Research Boiler

The pilot-scale research boiler, shown in Figure 5 has been heavily utilized by the power utility industry, boiler manufacturers and coal producers since its commissioning in 1963. The furnace chamber operates at pressures of up to 25 cm and at the design firing rate of 100 kg of bituminous coal or 200 kg of lignite per hour, the boiler generates 730 kg steam per hour at 6.8 atmospheres. In addition to normal ancillary equipment such as a coal bunker, forced draft fan and an air preheater, the facility incorporates a pulverizer with an infinitely variable classifier, a coal dryer capable of reducing fuel moisture from 50% to 1%, a simulated superheater for fouling and corrosion evaluations and an experimental, 3-stage precipitator for studies of fly ash abatement.

This pilot-scale boiler, which can be controlled to closely duplicate full-scale combustion conditions, is an extremely valuable research tool because experimental procedures can be easily and rapidly modified to suit special requirements. Another advantage of pilot-scale burns is that definitive trends can be obtained from relatively small coal samples at reasonable cost.

During the past few years, emphasis has been placed on expanding the resource base for Canadian thermal coal by evaluating the grinding, combustion, slagging, fouling and emission characteristics of coals and coal blends that have not previously been burned in large steam generators. The wide scope and potential application of these evaluations is illustrated by the following five examples:

1. Improvements in the burning properties of a high-clay, sub-bituminous coal due to upgrading. These studies demonstrated that reducing the ash content of the raw coal from 52% to 18% by water washing significantly decreased both the carbon carry-over and the fly ash loading of the flue gases as shown in Figure 6. Beneficiation did not, however, alter the degree of transformation during combustion of the clayey ash to mullite, a very hard mineral that could cause severe abrasion to convection tubes;nor did it alter fly ash resistivity values.
2. Reduction of sulphur oxide emissions from lignite by lime addition. Typically, cations in lignite ash can neutralize up to 30% of the fuel sulphur and enhanced sulphur neutralization can often be achieved by lime additions to the pulverizer. Sulphur retention at 5% excess oxygen was found to increase from 32% for the raw coal to 47% when 1% by weight of lime was added to the fuel supply. This level of neutralization corresponded to 25% lime utilization by gas-phase sulphur and indicated that SO_2 emissions from this lignite can be virtually eliminated by a 2% by weight lime addition to the lignite.
3. Control of NO_x emissions from lignite by low-excess combustion air and externally recirculated flue gas. Decreasing excess oxygen levels in flue gas from 15% to 5% produced a 50% reduction in NO_x emissions and increasing recirculation ratios from 0 to 0.2 at 1% excess air produced a further 15% reduction in NO_x. Recirculation ratios above 15%, however, increased flame length noticeably and increased carbon carry-over in the flue gas to unacceptable levels as shown in Figure 7.

4. Assessment of flue gas conditioning agents to improve the precipitability of fly ash from low-sulphur coals. Trials during which selected aqueous and gaseous additives were injected into the boiler breeching downstream of the airheater identified triethylamine as a superior conditioning agent for reducing fly ash resistivity. Results of some of these trials are shown in Figure 8.

5. Blending of high ash-fusion, low reactivity bituminous coal with low ash-fusion, high reactivity lignite to enhance average combustion performance and boiler availability. In one series of trials, a highly-oxidized bituminous coal was blended with 60% high-sodium lignite on a calorific basis, to produce a boiler fuel having excellent burning properties with no slagging or fouling tendencies.

3.3 Coal-oil Mixture Combustion

3.3.1 Background

In 1971, CCRL conducted a series of evaluations on the preparation, handling and combustion characteristics of several coal-oil mixtures (COM) in the calorimetric furnace. However, at a joint industry-government seminar on COM combustion the following year, it was clear that application of the technology was premature because of adverse economics. Further COM work was therefore deferred until 1977, when special emphasis was placed on programs to substitute coal for oil, particularly in the Atlantic provinces.

A recent study has shown that five and one quarter million barrels of oil can be saved annually by converting eleven oil-fired utility boilers located in the maritimes to 50% COM. These boilers, with a total generating capacity of 1865 MW(e), have been identified as having a high enough utilization factor to justify the capital cost of conversion. In western and central

Canada COM fuels are not as attractive as in the maritimes because there are sufficient other means of generation (nuclear, hydro-electric, natural gas or coal) . to ensure that existing oil-fired stations are kept on minimum load.

COM may also be a viable short- to medium-term fuel alternative for many industrial oil-fired boilers, particularly in parts of Ontario and Quebec that depend on supplies of imported oil.

At present three demonstration and three R & D projects related to COM are underway. All are jointly funded with industry on a shared-cost basis.

3.3.2 COM Demonstrations

3.3.2.1 Utility Boiler Trials

This project has been under way since October 1977 and at the moment is the major demonstration project in Canada for the application of coal-oil mixtures in utility boilers. The 10 MW(e) Unit No. 1 at Chatham Thermal Generating Station was chosen because (a) of its small size,(b) it is not required to supply power to the grid,and (c) it has the operational flexibility required for the COM evaluation. During Phase I of the program conducted in early 1978, 10% to 15% weight of a typical pulverized coal (75% through 200-mesh) was blended with No. 6 fuel oil and fed to the burner. In this phase it was established that pump and nozzle erosion presented major problems due to the abrasiveness of the ash in the Minto coal which averaged about 20%.

The Phase II combustion trials,which were conducted over a 650 h period between January and April 1979, incorporated the National Research Council of Canada spherical agglomeration process to beneficiate the coal prior to producing the COM. Several oil burner nozzles were also evaluated to assess their resistance to abrasion.

Phase III, now under way, will include as a major objective an evaluation of the agglomeration process in the production of a COM containing 40% coal. The role of water-in-oil emulsion will also be assessed to determine if the amount of light oil required to form the agglomerates can be reduced.

The combined COM beneficiation and preparation system shown in Figure 9 was operational in December 1979 and over 1000 h of boiler operation are scheduled for the first four months of 1980.

To supplement the work at Chatham, the Canadian Electrical Association,through a contract with Montreal Engineering Company,identified the 100 MW(e) No. 1 Unit at NBEPC's Dalhousie Generating Station as a suitable larger-scale candidate for conversion from residual oil to COM. Although originally designed for oil firing, Unit No. 1 has a slightly larger furnace volume and a wider boiler tube spacing than is typical for oil firing. The proposed demonstration at Dalhousie would include the spherical agglomeration process to reduce the ash and consequently minimize the erosion and wear problems.

3.3.3.2 Blast Furnace

Phase I of this joint project with Stelco, which was entitled "Development of Coal-oil Slurry Fuels for Blast Furnaces Injection", began in 1978 and combustion trials in a simulated tuyère were completed in 1979. Activity on this project was sub-divided into four elements as described below:

1. COM handling. The objectives of this element were to define the most suitable pumping equipment and the transmission pressure drop characteristics of a series of coal-in-oil mixtures. The data generated was used to design the fuel system for the combustion experiments.

2. Combustion trials with COM. An experimental unit comprising a fuel handling system of capacity 15-120 Igph, a system to preheat air up to 980°C and a combustor, was designed and built for the program. The combustor consisted of a single tuyère injection into a 3 m x 1 m furnace with provision for flame measurement at ten locations downstream of the tuyère. Over 50 individual flames were assessed to evaluate combinations of one coal in three carrier fluids, two load levels, three coal sizes, and three coal concentrations. These trials established a number of COM compositions that are considered acceptable for blast furnace tuyère injection.
3. A design study for three tuyère blast furnace trials incorporating the results from the combustion study described above was completed.
4. A preliminary design cost study, based on the optimum COM defined in the combustion studies, is nearing completion. This will give an approximate indication of the cost of a complete blast furnace conversion to COM and the subsequent operating costs.

3.3.2.3 Preparation Plants

Two COM preparation projects employing different wet grinding techniques are now in progress.

The first, being conducted at the University of Toronto, involves orbital grinding of both coal and oil in a novel development known as the Szego mill. The pilot-scale work, when completed in 1980, is expected to show a significant reduction in the costs of producing superfine COM dispersions and to provide scale-up information for designing a 1-3 t/h prototype mill and a 10-30 t demonstration mill.

In the second project, a Nova Scotia company known as Scotia Liquicoal has obtained the Canadian rights to a proprietary US process for manufacturing a stable COM from local coals. The project which is being jointly funded by the Nova Scotia and federal governments, comprises a laboratory development phase leading to the design and construction of a pilot-plant COM manufacturing facility. In the later phases of the project, experimental combustion and field demonstration trials are proposed in order to show the commercial viability of COM as a boiler fuel.

3.3.3 COM R and D Projects

3.3.3.1 Rheology

Rheological studies of three western Canadian coals - a lignite, a sub-bituminous and a bituminous refuse - in both No. 2 and No. 6 fuel oil were initiated at the Saskatchewan Research Council in 1978 and should be completed in April 1980. The major objective of the project was to expand and improve the available data for designing COM transfer lines to potential combustion or gasification equipment. The viscosity characteristics of various size fractions of each coal in No. 2 and No. 6 fuel oil have been delineated and work using oil sands bitumen and pitch as inexpensive alternatives to oil is nearing completion. Rheology studies on the bitumen and pitch are being conducted in a special high-temperature viscometer which operates at temperatures up to 300°C.

3.3.3.2 Combustion

The combustion R & D component of the COM program is not extensive but has been designed to complement the major demonstration projects. Basically, the small scale COM combustion research activity is designed to provide flexibility of operation and to obtain data on heat transfer and emissions characteristics which are not easily obtained on larger equipment.

Pilot- scale combustion trials have been in progress at the Ontario Research Foundation (ORF) with both COM and COM emulsified with water since June 1978. The project, which was co-sponsored by the Ontario Ministry of Energy, Ontario Hydro, Gulf Oil Canada Ltd and Stelco as well as by CANMET, included studies of coal beneficiation, COM preparation, combustion performance, ash slagging and fouling and emission characteristics.

In the coal benefication work, samples of a western Canadian low-sulphur bituminous, an eastern Canadian high-ash, high-sulphur bituminous and a Pennsylvania bituminous coal were evaluated in both laboratory and pilot-scale coal cleaning equipment using conventional froth flotation and the NRC spherical agglomeration process.

For the combustion trials the two Canadian coals were beneficiated by flotation whereas the US coal was simply screened and pulverized prior to preparation of the COM in a shear mixer. The COM containing emulsified water was prepared using a vortex mixer to produce a water-in-oil dispersion which was then blended with pulverized coal in the shear mixer. The COM contained 30% coal and 70% No. 6 fuel oil whereas the COM with water contained 30% coal, 50% No. 6 fuel oil and 20% water.

The two COM fuels were burned successfully in both a conventional and a high intensity burner over a 2:1 turndown ratio. The high-intensity burner, however, produced some wall flame impingement as expected and showed a higher tendency to produce slag and NO_x than the conventional burner.

A project involving further work on COM preparation using the vortex mixer and combustion trials in a small 240 hp boiler is currently under consideration.

3.3.3.3 Preparation

The Nova Scotia Technical College recently started work on utilizing raw and beneficiated Nova Scotia coals for a COM suitable for use in existing industrial and utility boilers with minimal retrofitting. Coal benefication is being incorporated to allow for the use of high-ash coal and coal rejects from Nova Scotian open cast mines. If a beneficiated COM can be produced it would reduce dependence on offshore oil and create additional employment and development in the region.

3.4 Fluid Bed Combustion

3.4.1 Background

By 1974 CCRL recognized that the technology for fluidized-bed combustion (FBC), being developed elsewhere in the world, offered significant potential benefits to Canada. Simple uncooled beds were already in commercial use as incinerators for high-moisture materials such as wood waste and sewage sludge, and more complex, cooled combustors integrated into steam boilers as shown in Figure 10 were under development. Some of the major advantages of FBC are:

1. The ability to burn high-sulphur coal with control of SO_2 emissions, by using limestone beds. This is important for eastern Canadian coals.
2. The ability to burn coals having combinations of high moisture content, high ash content and low reactivity. This is important for some western Canadian coals.
3. The ability to burn coal at atmospheric pressure as an economic replacement for oil and natural gas, in the commercial and industrial markets.
4. In the case of pressurized fluidized-bed combustion, a means for more efficient coal-to electricity cycles.

The application of these potential benefits to the Canadian energy situation was, however, somewhat problematic, since no Canadian boiler manufacturers were engaged in the development of FBC boilers at the time. It was decided at EMR that the best way to accelerate the transfer of this technology into Canada was to have the federal government assume a substantial portion of the financial risk for a carefully selected series of full-scale demonstration projects. Subsequently, the following program of five FBC demonstration projects was developed. These in turn are supported by complementary pilot-scale R & D. It should be noted that some of the FBC demonstration projects are still at the conceptual stage or are undergoing techno-economic assessments.

1. Central heating plant boiler.
2. Industrial boiler burning coal and wood chips.
3. Small utility boiler burning high-sulphur coal.
4. Coal dryer heated by coal rejects burnt in an FBC.
5. Pressurized FBC for combined cycle power generation.

3.4.2 Fluidized-bed Combustion Demonstrations

3.4.2.1 Heating Plant Boiler

This project was launched in 1977 when EMR and the Department of National Defence (DND) agreed to co-sponsor the demonstration of an atmospheric FBC boiler, rated at 18 t/h of steam, to provide space heating at CFB Summerside. The boiler is being designed to burn a 5% sulphur coal from Cape Breton, with wood chips when available, providing up to 30% of the heat input at any load. To minimize capital cost, overbed coal feed was specified. It was also required that the boiler meet federal emissions guidelines of 2.96 kg SO_2 per 10^6 kcal heat input, and 0.36 kg particulates per 10^6 kcal heat input.

Two contractors were selected to prepare conceptual boiler designs, both of which were completed in 1978. One contractor, Foster Wheeler Limited, offered US technology while the other, Intercontinental Engineering Ltd,offered British technology.

The British design features four independent bed sections, each fed by a water-cooled screw conveyor, with forced-circulation heat exchange surface in each section.

In the US design, which is similar to the natural circulation FBC boiler recently commissioned at Georgetown University, there are two bed sections. One is a "preferential" bed which is always in service and provides up to 40% of the capacity by furnace wall heat absorption. The other is a "secondary" bed which is brought into service for higher loads, and contains in-bed heat exchange surface. Both beds are fed by spreader stokers.

In 1979 the same contractors completed conceptual designs for a boilerhouse to accommodate two fluidized-bed boilers complete with handling systems for coal, wood chips, limestone and ash.

The third phase of the project got under way early in 1980, with the awarding of two identical contracts for a detailed design and a firm price proposal to construct a complete plant containing one FBC boiler with space for a second. Contractors for this phase of the project are Dominion Bridge Company Limited and Foster Wheeler Limited, the respective licensees for the British and US designs.

The two detailed design and firm price proposal contracts are scheduled for completion in January 1981. Following a detailed review of the two designs by a selection committee a construction contract will be awarded to one of the contractors. Allowing 20 to 24 months for construction, Canada's first FBC boiler should be commissioned by the end of 1982. It will then be subjected to a lengthy program of testing and demonstration which will be continuously monitored by CCRL.

The rationale for carrying two parallel sets of contracts through to the end of detailed design and price proposal is threefold; 1) a strong element of competition is maintained, which should influence both design and price; 2) two Canadian manufacturers are supported to the point of being able to offer atmospheric fluidized-bed combustion (AFBC) boilers' and 3) both American and British AFBC technology are transferred into Canada.

3.4.2.2 Industrial Fluidized Bed Boiler Demonstration

Substantial quantities of residual oil are burnt in boilers generating steam for industries such as chemical plants and pulp and paper mills. The size range is typically 50 to 250 t/h of steam;, a range in which conventional pulverized-coal-fired boilers tend to be uneconomic, particularly if they must be equipped with scrubbers to reduce SO_2 emissions. In the case of pulp and paper mills, wood waste is commonly available, but can only be utilized through the use of specialized combustion equipment.

In these circumstances it is obvious that the inherent advantages of FBC should be exploited to produce a boiler that can burn coal and wood waste in the same furnace, with built-in sulphur neutralization if required, and presumably at a more favourable investment cost than is possible with conventional technology for co-firing coal and wood.

Accordingly, EMR has invited proposals for the conceptual design of an FBC boiler of 100 t/h of steam capacity, to burn coal and wood waste, with the latter to provide up to 50% of the heat input. Proposers are to assemble a package which would include design capability, fabricating capability in Canada, and a Canadian end user willing to provide a portion of the capital cost.

EMR will select the proposal that most closely coincides with departmental objectives and a cost-shared contract will then be negotiated for the conceptual design of a fluidized-bed boiler. If the concept proves feasible construction of a demonstration unit at a specific site will be given serious consideration.

3.4.2.3 Fluidized Bed Utility Boiler

In Canada, utility applications of FBC boilers are of most interest in the Maritime provinces, where foreign oil could be replaced with indigenous high-ash, high-sulphur coal. Within Nova Scotia Power Corporation's system for example, there are three or four possibilities for using an FBC coal-fired boiler of approximately 150 MW(e), to expand capacity or to replace existing oil-fired equipment. In scaling up from existing FBC technology, 150 MW(e) seems a reasonable compromise between saving time and increasing technical risk.

Nova Scotia Power Corporation and EMR are presently co-funding a site review study by a firm of engineering consultants. Once the best site for a demonstration, probably 150 MW(e), has been established, it is likely that a conceptual design will be commissioned to establish the feasibility of building a demonstration scale plant.

3.4.2.4 FBC Burning Coal Washery Rejects

Each year millions of tons of Canadian coal, mostly coking coal destined for export, are upgraded by washing. The washed coal is then dried, commonly in equipment fired with natural gas or sometimes in equipment fired with cleaned pulverized coal. Even though the washery rejects, which are now produced at the rate of approximately 7×10^6 t per year, contain up to 50% ash and 20% moisture, they represent a potential fuel for the coal drying process. In fact, pilot-scale trials have demonstrated that such rejects can be burned in an uncooled AFBC. Utilization of washery rejects as fuel for coal drying would not only conserve expensive premium fuels, but also mitigate present disposal problems with coal and point the way to their full utilization, perhaps for electricity production.

EMR is presently co-funding with Luscar Ltd a study which will a) produce a conceptual design for an AFB combustor to serve an existing full-scale dryer, b) estimate the cost for the combustor and its auxiliaries, and c) determine the economics of the AFBC system compared with the existing system. This study should be complete by the fall of 1980, and hopefully will lead to a full-scale demonstration.

3.4.2.5 PFBC for Combined Cycle Power Generation

Interest in pressurized fluidized bed combustion (PFBC) stems from its potential for combined cycle power generation systems which might reduce fuel requirements by 10%. It is anticipated that 10 to 15 years of development work will be required to achieve commercialization. The lead role in the development and demonstration of this technology in Canada has been taken by British Columbia Hydro and Power Authority, which is studying a number of options for producing coal-based thermal power in the coming decades.

Since 1975, extensive studies have been co-funded by BC Hydro and EMR, in which comparisons were made of advanced cycles based on coal gasification, AFBC and PFBC. These studies concluded that a combined cycle PFBC system is the most promising. BC Hydro is now considering building a demonstration plant in which a PFBC would drive a gas turbine generating 70 MW(e).

3.4.3 Back-up R and D

Full-scale demonstration projects are the most convincing proof of the usefulness of FBC technology, but there is a continuing requirement for detailed information which can be more readily obtained from pilot-scale equipment. Performance characteristics of specific fuels, neutralization characteristics of specific sorbents, metallurgical aspects of erosion and corrosion; and effects of bed depth, fluidizing velocity and bed temperature on combustion, sulphur neutralization and heat transfer, are all areas where pilot-scale research can be expected to provide essential knowledge. The situation can be compared to conventional pulverized-fired technology, where the CCRL pilot-scale boiler is in constant demand to generate new information, despite the fact that pulverized firing has been established for many decades.

At CCRL, a pilot-scale FB combustor, 0.25 m diam, has been operated with a number of coals, both high in ash and high in sulphur, and with tar sands coke. In addition to producing data applicable to the design of full-scale systems, this unit provided the design basis for two larger, more flexible combustors (one at Queen's University and the other at CCRL which should be in place by mid-1980.

To complement the CCRL effort, EMR has contracted FBC work on specific topics with several agencies in Canada. For example corrosion studies in a fluidized-bed combustor at BC Research are presently under way. Also, a contract has been let to Queen's University to build a 0.38 m square FBC for studying the sulphur neutralization characteristics of various Canadian limestones and dolomites.

4.0 TECHNOLOGY INFORMATION

To keep abreast of current R D and D both in Canada and in foreign countries, CCRL participates in formal information exchanges on coal combustion technology between the Department of Energy, Mines and Resources and organizations such as the Canadian Electrical Association, the International Energy Agency (IEA) and the International Flame Research Foundation (IFRF).

Areas of technical co-operation through the CEA and the IEA include a) emission products from coal burning processes, b) coal-oil mixtures, c) fluidized-bed combustion, d) co-generation cycles and e) low-NO_x coal burners for utility boilers.

As EMR's representative at the IFRF, CCRL has access to results of IFRF research on industrial-type flames and has collaborated in a number of IFRF sponsored in-house seminars and research projects. Direct benefits to CCRL have included the purchase of special combustion probes, exchange visits of scientific personnel, advice on research equipment designs and consultations on experimental methodologies.

Technical liaison with universities, government laboratories and industrial research organizations in Great Britain, Scandinavia, West Germany, Australia, the United States, Japan and Italy as well as in Canada is also maintained on a continuing basis. These informal links have resulted in numerous scientific contacts around the world and the circulation of knowledge on subjects of mutual interest prior to publication in the open literature.

5.0 RESEARCH NEEDS

In view of the expected increase in the demand for Canadian thermal coal, the following problem areas are suggested as topics for priority R and D.

1. Reliable and preferably rapid in-situ techniques to sample and analyze trace elements and potentially undesirable hydrocarbons in flue gas.

2. Improved analytical methods to better evaluate coals with high-ash, high-moisture and high-fusinite contents. Current standard methods for example do not indicate whether a) the volatile matter is combustible or non combustible, b) the moisture is associated with the coal or the mineral matter c) the major coal macerals are reactive or non-reactive, or d) the nitrogen is in the fixed carbon or the volatile matter.

3. Rapid, bench-scale methods for screening burning performance of coals for use in pulverized-fired or fluidized-bed systems prior to implementing pilot-scale burns.

4. Development of bench-scale methods for predicting slagging and fouling characteristics of ash. Standard ash fusion temperatures, being subjective, do not provide definitive data for assessing ash behaviour during combustion and deposition.

6.0 CLOSURE

Canada's vast coal reserves can contribute significantly to meeting our future energy needs. Domestic coal consumption is expected to reach 50×10^6 t and could go as high as 75×10^6 t by the year 2000.

Coping with such a large increase in future coal demand presents a formidable challenge for both the coal industry to escalate production and the manufacturing industry to build equipment suitable for processing or burning a wide range of coals in an efficient, economic and environmentally acceptable manner. Coal has an important role to play in achieving energy self-sufficiency and the co-ordinated energy research and demonstration program initiated by EMR are seen as a positive contribution toward stimulating the development of new technology in Canada.

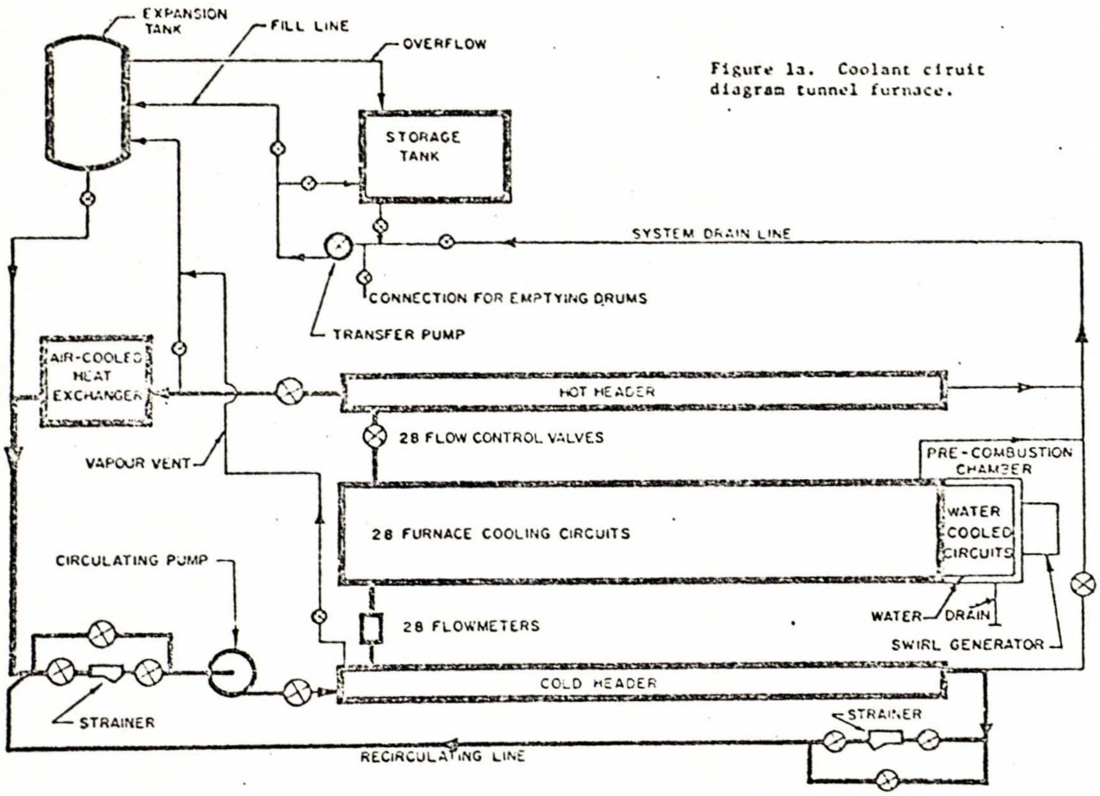
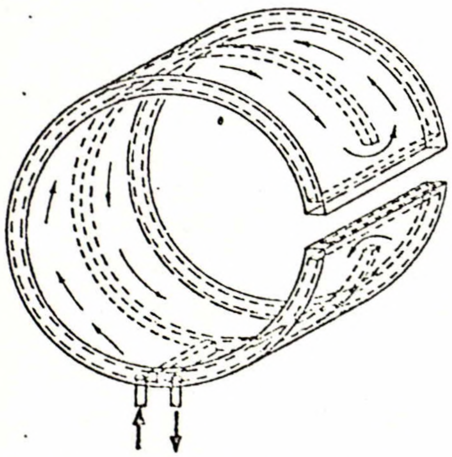


Figure 1a. Coolant ciruit diagram tunnel furnace.



OBLIQUE VIEW OF ONE SEGMENT OF FURNACE

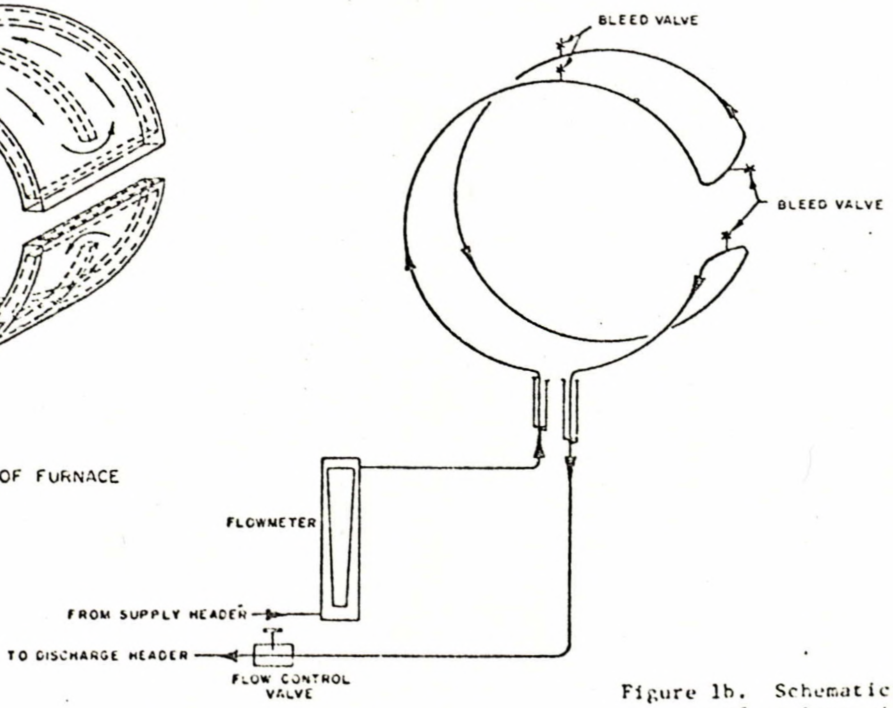


Figure 1b. Schematic of one segment of coolant circuit.

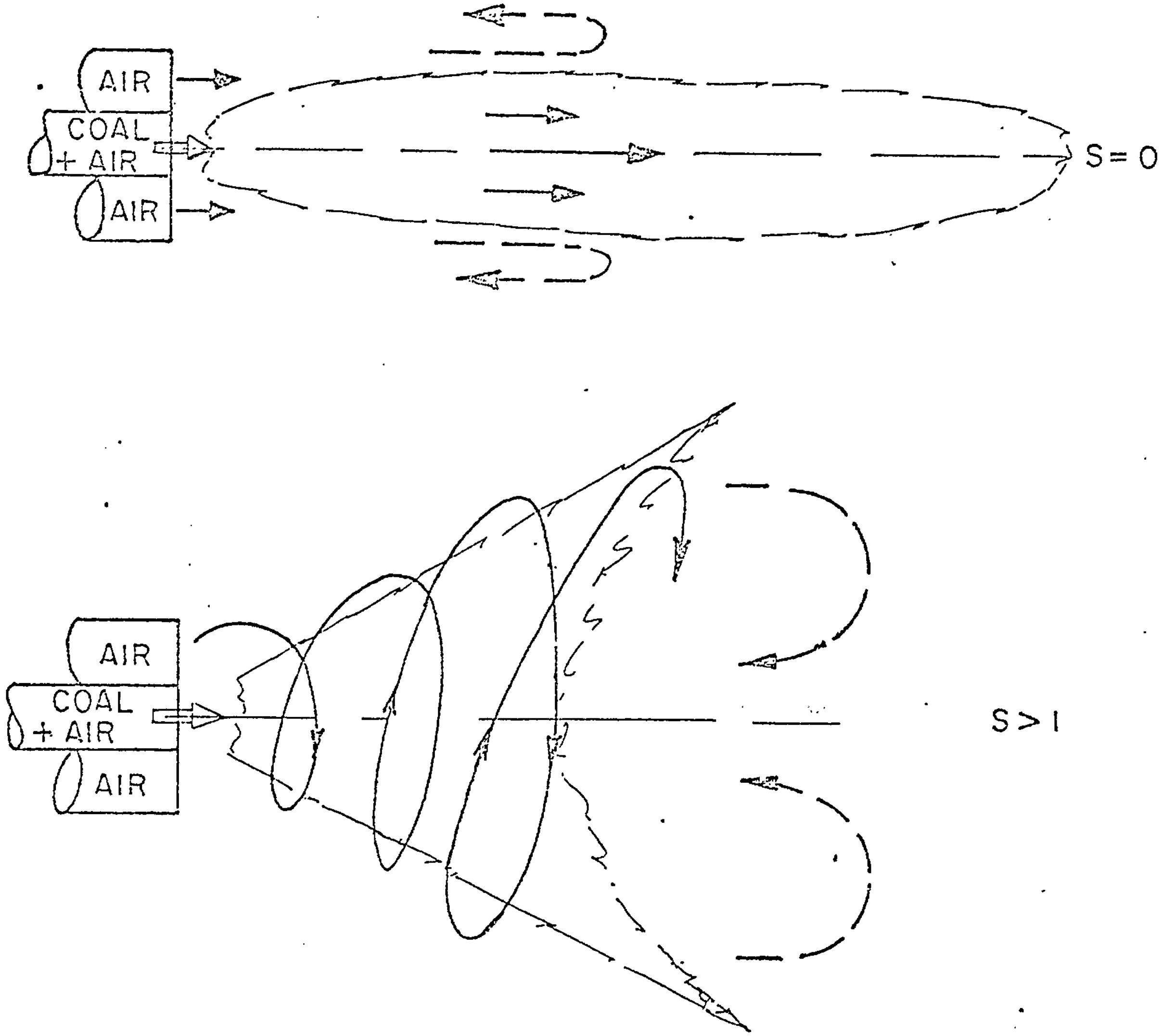


FIGURE 2: EFFECT OF SWIRL ON FLAME GEOMETRY

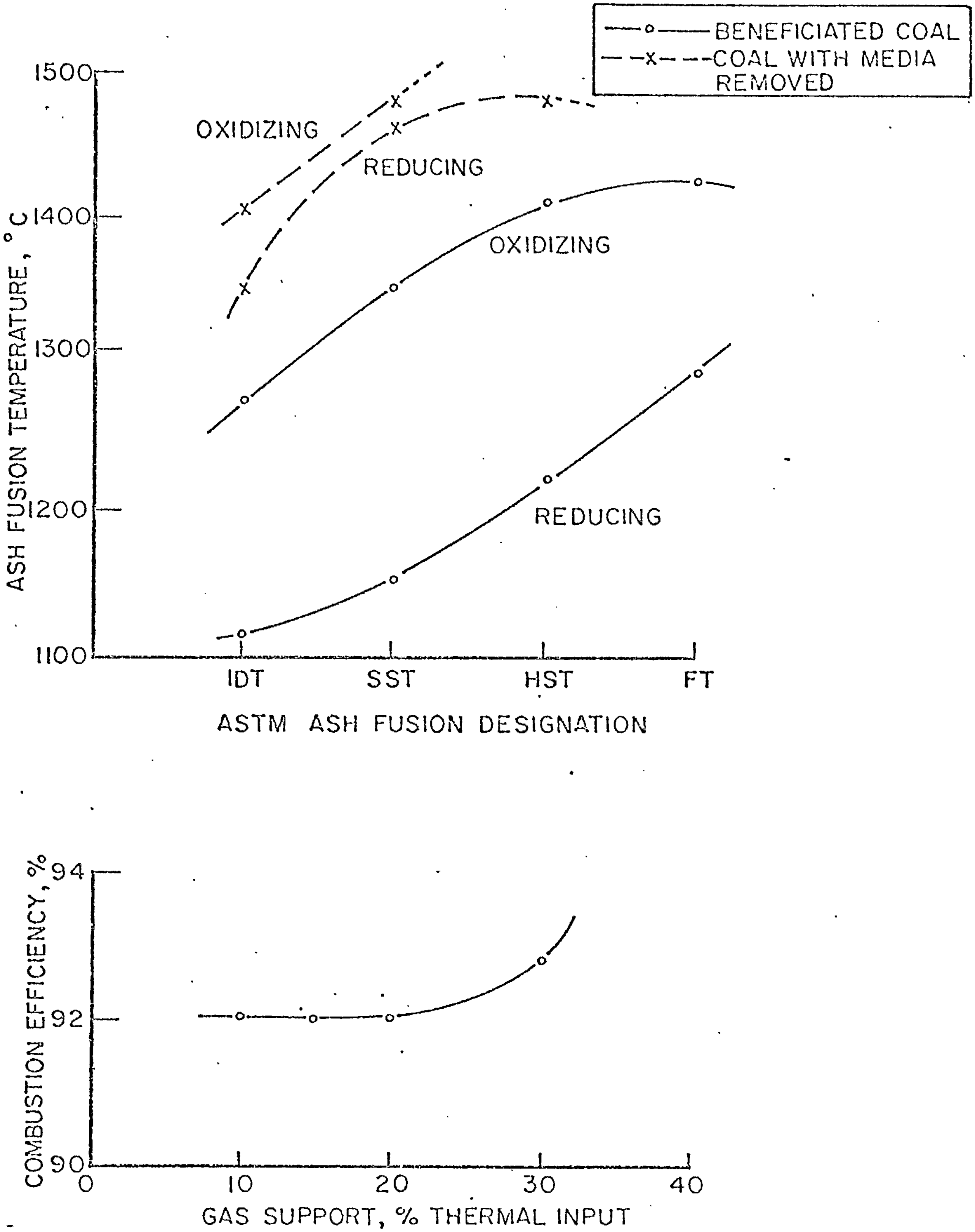


FIGURE 3: EFFECT OF GAS SUPPORT ON COMBUSTION EFFICIENCY AND HEAVY MEDIA ON ASH FUSION

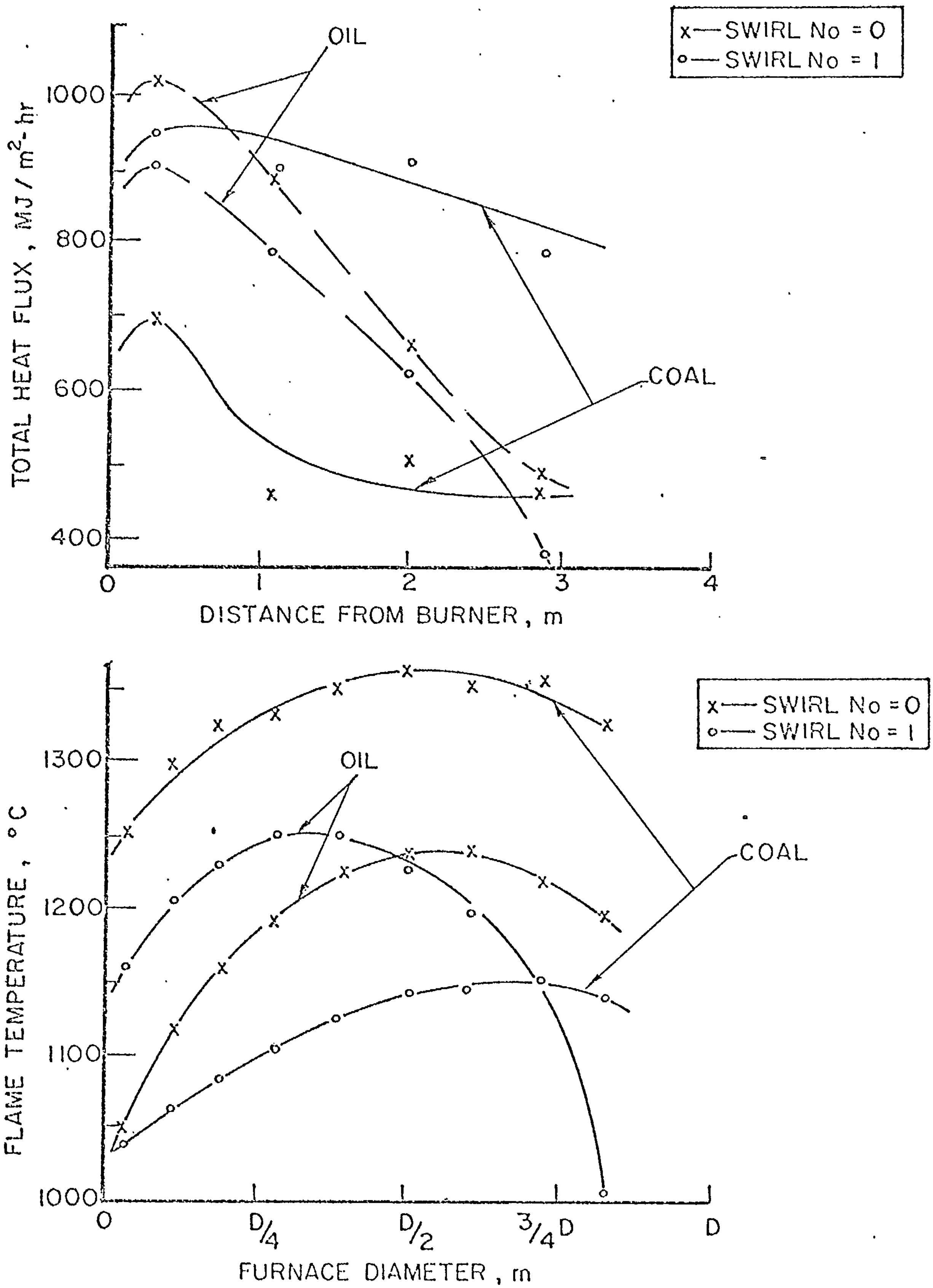


FIGURE 4 : COMPARISON OF HEAT FLUX AND FLAME TEMPERATURES FOR BITUMINOUS COAL AND NO. 6 OIL

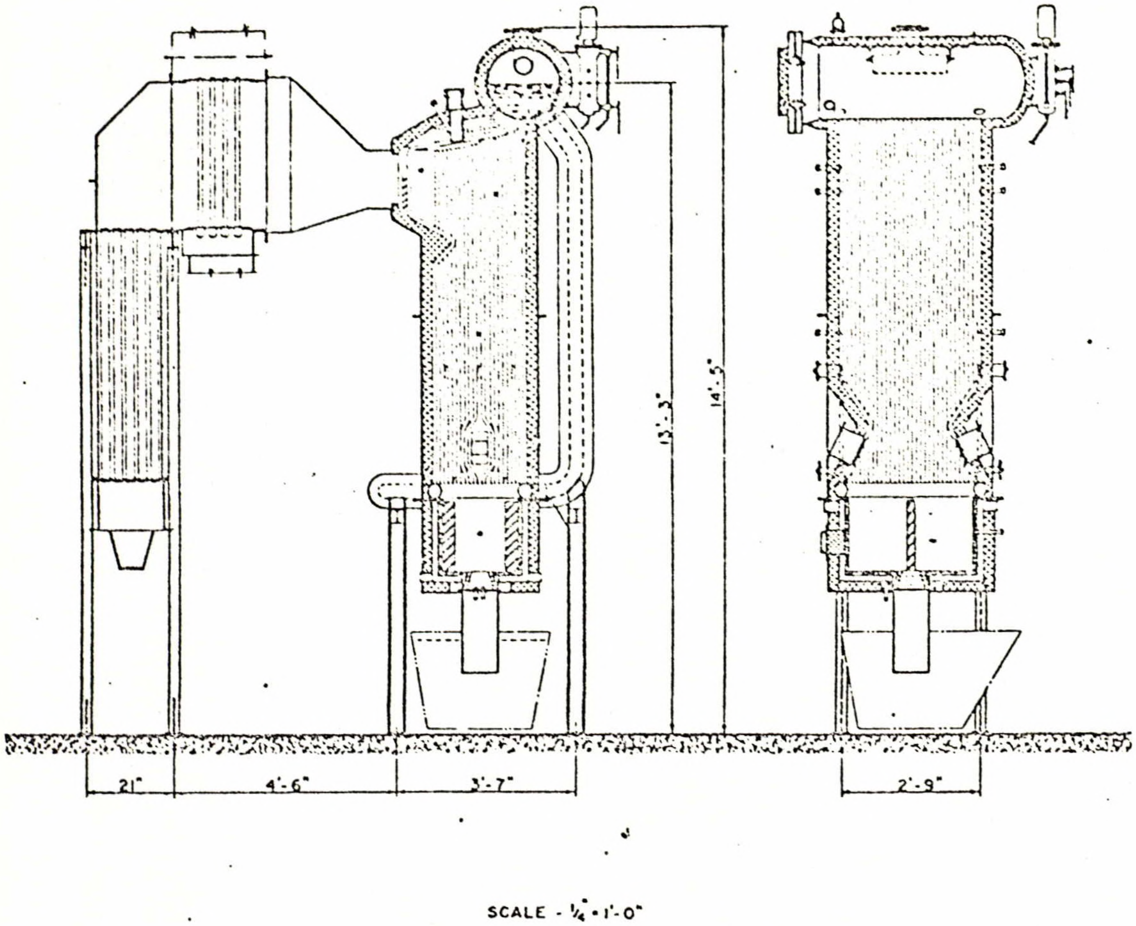


FIGURE 5: SCHEMATIC VIEW OF THE CCRL PILOT-SCALE RESEARCH BOILER

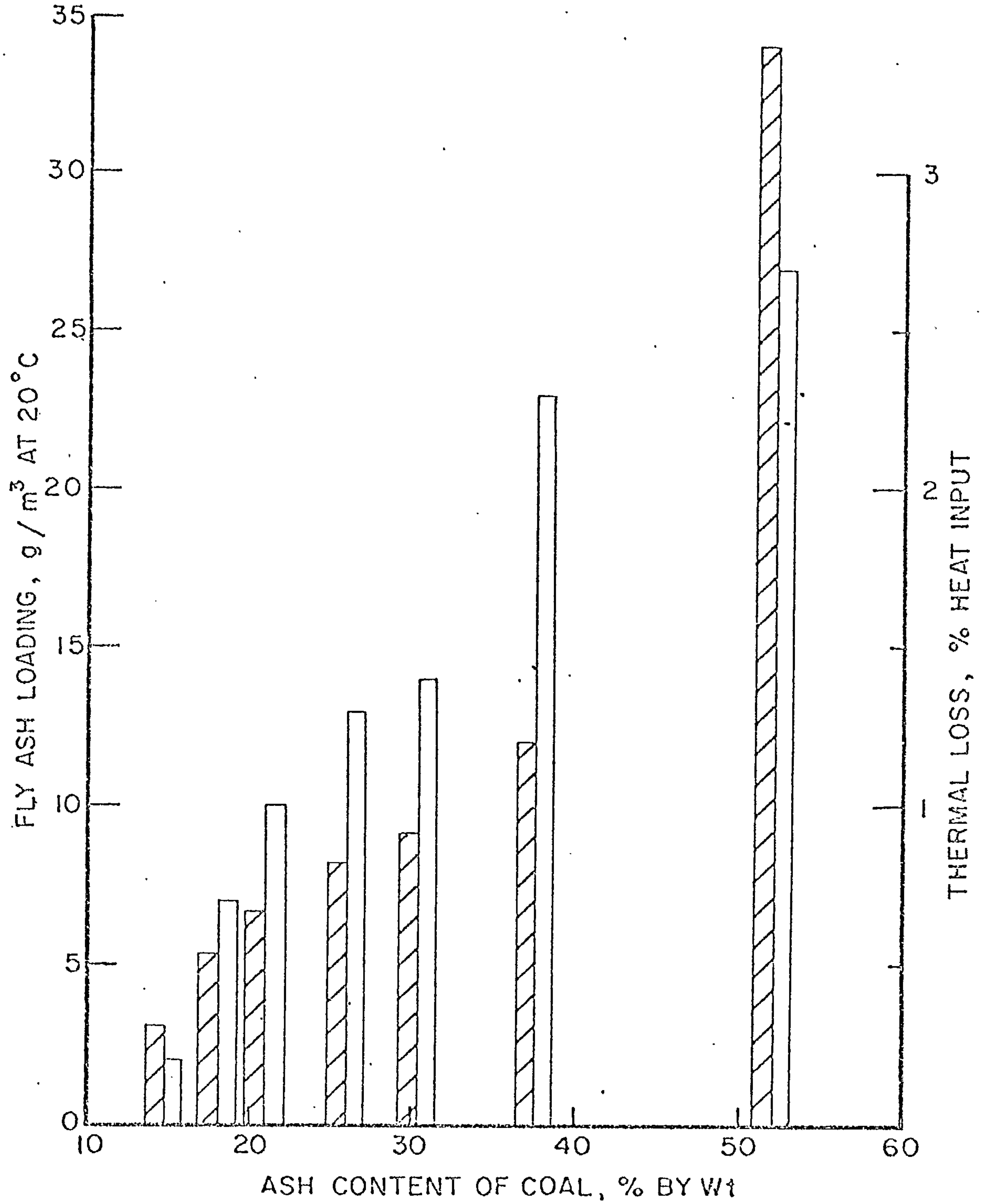


FIGURE 6: EFFECT OF ASH REDUCTION ON FLY ASH LOADING AND THERMAL LOSS DURING COMBUSTION OF A SUB-BITUMINOUS COAL

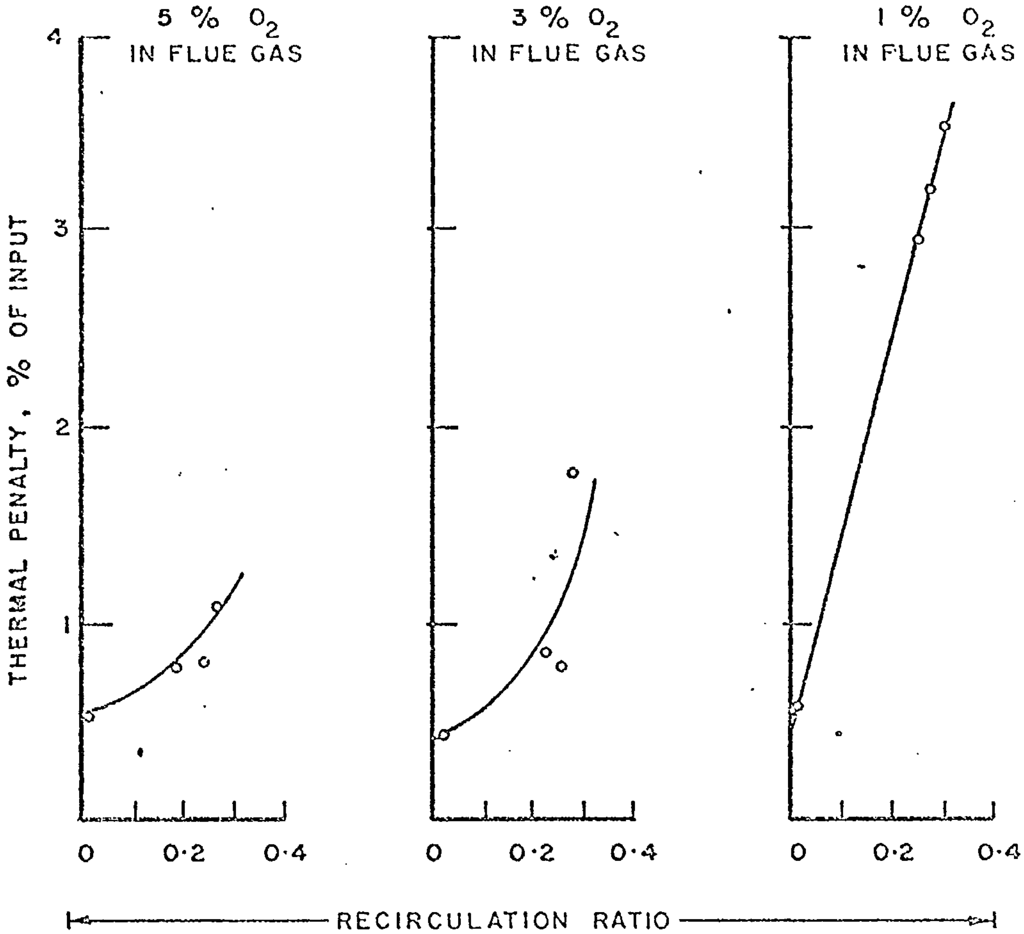


FIGURE 7: REDUCTIONS IN NO_X EMISSIONS FROM LIGNITE BY LOW-EXCESS AIR AND FLUE GAS RECIRCULATION

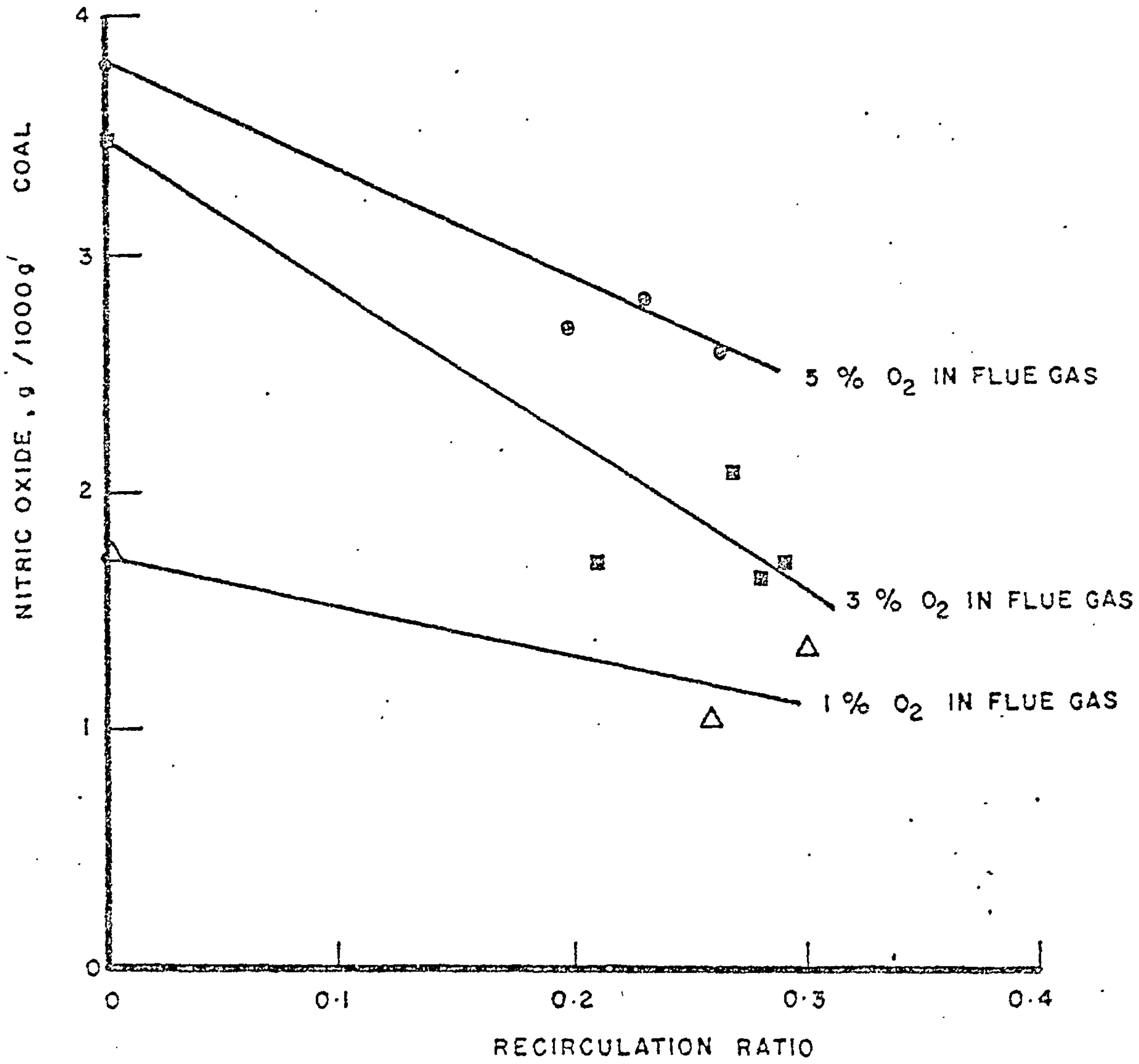


Figure 7A The Effect of Recirculation Ratio on Nitric Oxide Emissions from Saskatchewan Lignite Combustion

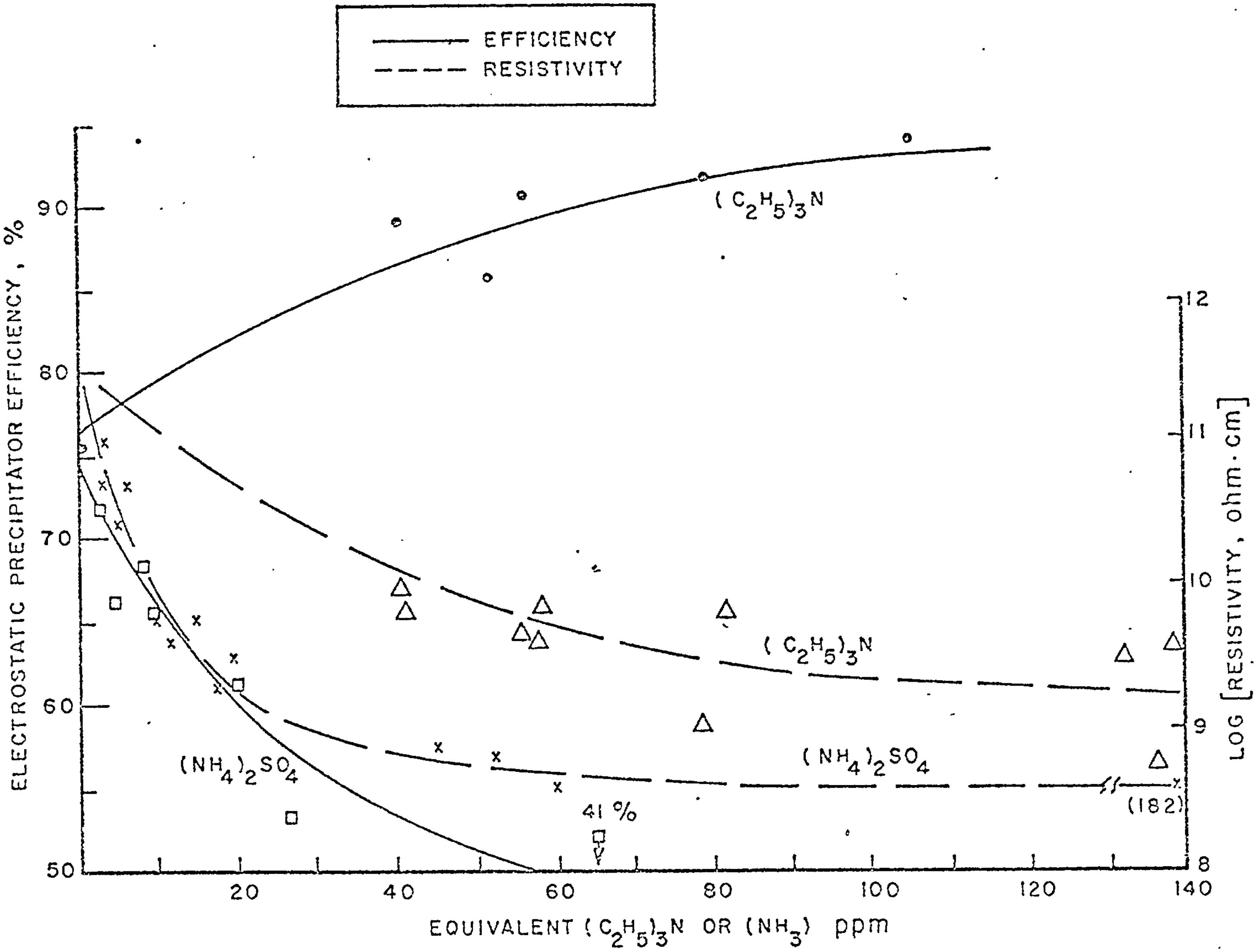


FIGURE 8: EFFECT OF FLUE GAS CONDITIONING AGENTS ON FLY ASH RESISTIVITY AND COLLECTION EFFICIENCY

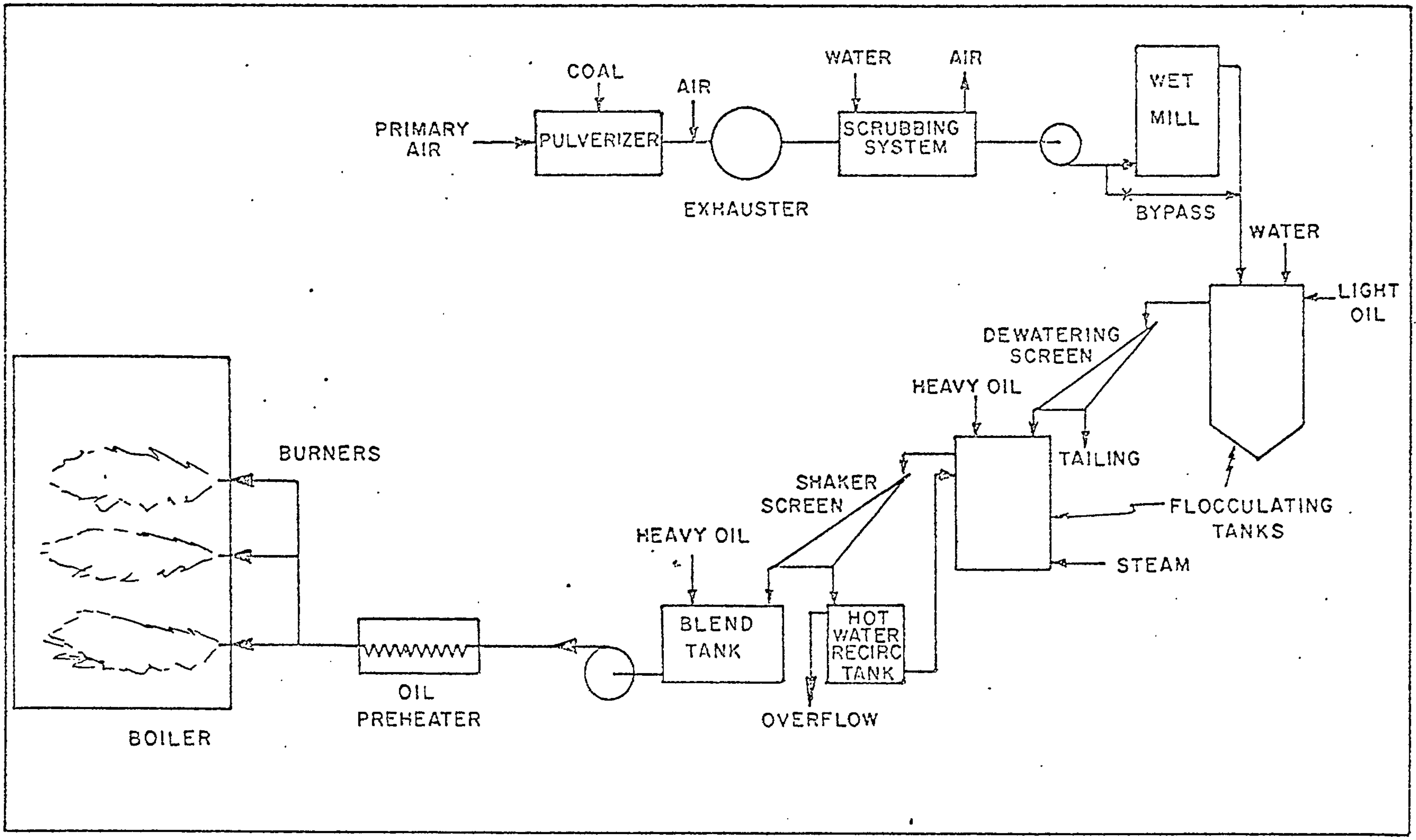


FIGURE 9: SCHEMATIC OF COM COMBUSTION SYSTEM

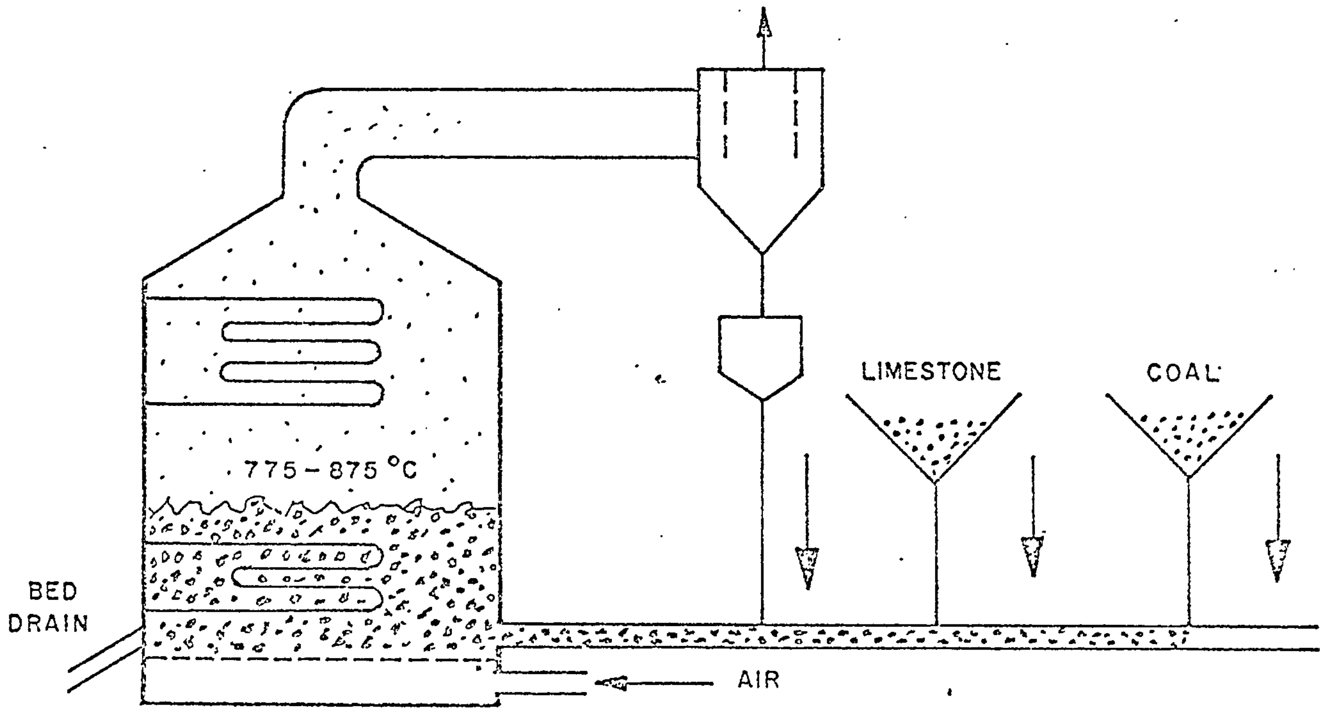


FIGURE 10: SCHEMATIC OF FLUIDIZED-BED COMBUSTOR