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ANNUAL REPORT OF ACTIVITIES OF THE CANADIAN COMBUSTION RESEARCH LABORATORY

Staff
Canadian Combustion Research Laboratory

March 1980

ENERGY RESEARCH PROGRAM
ENERGY RESEARCH LABORATORIES
DIVISION REPORT ERP/ERL 80-30(TR)

1979/80

1979/80 ANNUAL REPORT

PART I

CANADIAN COMBUSTION RESEARCH LABORATORY

HIGHLIGHTS

Current combustion activities at the Canadian Combustion Research Laboratory (CCRL) reflect the increasingly important contributions that energy conservation, coal utilization and renewable fuels are expected to make in meeting Canada's future energy needs and in decreasing dependence on foreign oil. These activities follow a 5 year strategic plan, formulated in collaboration with the CANMET Energy Program Office and the Energy Policy Sector, to promote a sequence of RD&D initiatives for resolving energy utilization problems associated with degrading fuel quality, requirements for improved equipment availability and progressively more stringent environmental controls.

The in-house effort, some of which is cost shared with industry, was concentrated on three main projects:

(a) the combustion performance of pulverized coals that have not previously been used in industry
(b) CSA certification and field implementation of the domestic oil burner retrofit package for fuel economy, and
(c) the design and fabrication of a new 0.38 meter square fluidized-bed combustor for combustion and heat transfer studies with low-grade fuels.

Other important areas of in-house R&D included fuel economy and lead emission experiments on automobiles equipped with particulate traps, wood stove performance parameters and optimization of operating conditions on an industrial steam atomizing oil burner.

Extramural contracts, particularly on demonstration projects, continued to increase in dollar value and technical complexity. Last year 25 contracts with a total value of $ 2.7 million were monitored by CCRL scientific personnel with substantial effort being expended on the Coal-Oil Mixture Program and the DND Summerside Fluidized-Bed Project.

In addition to heavy demands on the scientific staff for RD&D work, technology transfer of research data to industry was achieved through publication of 8 scientific papers, over 45 media interviews, participation in 30 seminars and technical meetings and the preparation of 18 internal reports.

Two vacancies were filled during the year bringing the total staff of CCRL to 22, including 2 term positions, technologists, engineers and scientists.

RESEARCH AND DEVELOPMENT

Conventional Fuel Combustion (3.3.2.1.0.0)

Coal Combustion

Studies of the combustion characteristics of coal in conventional equipment of boilers and cement kilns or reheating furnace configurations have continued. Emphasis has been placed on providing the industry with information which will enable coal to compete with oil in terms of ease of combustion, heat transfer and environmental emissions. In addition, combustion evaluations have been made of selected Canadian coals to improve their export sales.

Combustion of Obed-Marsh Coal

An experimental combustion study to establish the flame and heat characteristics of beneficiated Obed-Marsh coal was undertaken in a refractory lined calorimetric furnace. The pulverized coal flames ignited and burned readily with combustion efficiencies greater than 99%, using burner swirl numbers of 0 and 1, at excess air levels corresponding to 3% and 5% oxygen in the flue gas. NO_x emissions were low for a refractory-lined furnace and adiabatic flame temperatures for this coal were comparable to No. 6 fuel oil.

Combustion of Bienfait Lignite Coal

A series of tests have been conducted in collaboration with Ontario Hydro to assess the effect of various modes of limestone addition to control the slagging of lignite ash. Three Bienfait lignites, containing 2%, 6 1/2% and 9% sodium, showed an increasing tendency to slag as the sodium content increased. The effect of continuous additions of limestone at 10% and 2 1/2% of the coal rate and batch additions of up to 0.42% of the coal rate at various time intervals are currently being studied.

Combustion of Blended Thermal Coals

A research project to assess the combustion performance and emission characteristics of three coal blends has been undertaken in collaboration with Ontario Hydro. Selected blends were studied which covered the expected variation in composition from a supply scenario for the Nanticoke generating station. The three coals, a bituminous mixture from Pennsylvania and Byron Creek and Coal Valley from Western Canada, are available to Ontario Hydro on a long term contract basis. Each blend was compared using Coal Valley and a U.S. coal as reference fuels. In addition to combustion performance, the slagging and fouling potential of each coal ash was assessed. The test program has now been completed and a report is currently being prepared.

Combustion of Line Creek Coal

A project has been undertaken with Crowsnest Resources Ltd to evaluate the combusiton performance of Line Creek thermal coal, which is ranked as "low volatile" bituminous by ASTM classification procedures. The tests, conducted in the CCRL polot-scale boiler, utilized blends of 20%, 40% and 60% by weight of low reactivity Line Creek coal with moderately reactive Coal Valley coal. In general the blends burned well and produced ash deposits that were soft and friable and easily removed. However, the combustible loss increased with the increasing content of Line Creek coal. All emissions of particulates, nitrous oxide and sulphur oxides were within the currently allowable North American Criteria. The results also indicated that combustible contents of less than 7% should be possible in larger boiler units and that the resistivity for this fly ash would be in the range of 10^{11} - 10^{12} ohm-cm.

Combustion of Tent Mountain-Vicary Creek Coal Rejects

A collaborative research program was undertaken with Coleman Collieries to investigate the combustion performance in the CCRL pilot-scale boiler of a 4.5-tonne sample of beneficiated coal, reclaimed from the Tent Mountain and Vicary Creek refuse piles. Moderate levels of nitric oxide emissions were produced and sulphur oxide emissions were considerably less than current allowable North American guidelines. The resistivity of the fly ash, being generally between 10^{11} and 10^{12} ohm-cm, indicates that

electrostatic precipitation will be more difficult than for the higher sulphur coals. The combustion, fouling and emission characteristics of the beneficiated coal were similar in most respects to those of the Coal Valley reference coal and a 40:60 beneficiated Coal Valley blend.

Combustion of Coal-Oil Mixtures

A collaborative project, undertaken with the New Brunswick Electric Power Commission, was initiated in October 1977 and at the present time is the major demonstration project in Canada for the application of coal-oil mixtures to utility boilers. The 10 MWe, Unit No. 1 at Chatham Thermal Generating Station, was chosen because of its small capacity, and because it was not required to supply power to the grid. These features gave it the operational flexibility required for the COM evaluation. Phase I of the program, conducted in 1978, did not attempt an elaborate COM preparation. In this phase, pulverized Minto coal (containing 20% ash) was mixed with No. 6 fuel oil in a blender and fed to the burner as a 10% coal-oil mixture. This work established that pump and nozzle erosion presented a major problem due to the abrasiveness of the ash in Minto coal. Phase II combustion trials, conducted in 1979, incorporated a spherical agglomeration process to beneficiate the coal prior to the formation of the COM. In addition, special burner nozzles are being evaluated to assess their resistance to abrasion. A report on Phase II will be completed in May 1980. Phase III, which is now under way will include as a major objective an evaluation of the agglomeration process in the production of an acceptable COM. The role of water in an oil emulsion will be assessed to see if the use of light oil used to form the agglomerates can be reduced in this way. In addition, the coal content of the COM will be increased to 40%.

A second collaborative project, at the Ontario Research Foundation, entitled "Combustion of Coal/Oil Slurries and Coal/Water Emulsions", was initiated in June, 1978 and a report on the combustion trials which were completed in 1979 is in preparation. Project co-sponsors besides EMR/CANMET are the Ontario Ministry of Energy, Ontario Hydro, Gulf Oil Canada Ltd and Stelco. The project included the following elements: coal beneficiation, COM preparation, combustion performance and evaluation, slagging and fouling assessment and emission characteristics. The three coals selected for COM evaluation were Coal Valley, Prince Mine and a Pennsylvania blend.

In the coal beneficiation work, samples were obtained of each of the three coals and evaluated in both laboratory and pilot-scale coal cleaning equipment prior to COM preparation and combustion. In the COM combustion trials the two Canadian coals were cleaned and the US coal was simply crushed, double screened and pulverized, prior to COM preparation. A simple shear-mixing tank was installed to provide the COM fuel with a vortex mixing device to produce an emulsion which was used to form a COM with micro-dispersed water, and this was tested and compared to COM alone.

In the combustion evaluation of COM, the three coals were mixed to form a 30 wt % COM and also a 30% COM containing 20% water. Tests were conducted at two firing rates, 7 GJ/h and 3.25 to 4 GJ/h, using two different types of burner; a high intensity burner developed at ORF with Gulf Oil and known as the Vortometric burner, and a standard Peabody burner. Both burners performed well in the tunnel furnace arrangement of the test facility, despite the fact that the Vortometric produces a highly swirling flame with some wall flame impingement. At the moment, the tests have not been fully evaluated but it is anticipated that a final report will be available to the co-sponsors by the end of the year. A program involving further work on COM preparation using the vortex mixer and combustion trials in a small 240 hp boiler is currently being negotiated.

Liquid Fuel Combustion

Improved combustion efficiency and novel energy utilization strategies continued as priority elements of work on conventional oil combustion. Current CCRL projects are concentrated in automobile fuel economy, domestic heating and industrial heat processes.

Automobile Fuel Economy

Since 1973 CCRL has been studying the effect of Canadian weather conditions on automobile fuel consumption. After an exploratory in-house project had demonstrated that fuel economy decreased noticeably with decreasing temperature, a series of contracts were awarded to Shell Canada Limited for detailed evaluations of the effect of various advanced engine technologies on fuel consumption and pollutant emissions under closely-controlled, cold-room chassis dynamometer conditions. In phase IV of this program five 1979 model cars featuring advanced engine designs have been evaluated in

terms of fuel consumption, exhaust emissions, driveability and other characteristics at temperatures representing Canadian summer, spring-fall, and winter conditions. The test fleet consists of a California model car with a 4 cylinder, gasoline engine and a three-way catalyst exhaust system; a North American 4 cylinder turbocharged car, with a 2.3 L-2V gasoline engine; a V8 gasoline engine, with a variable venturi carburetor; a North American 4.3 LV8 diesel engine and a German 5 cylinder turbocharged 3.0 L diesel engine.

The results showed that all five cars met the current Canadian emission standards at 25°C, but the hydrocarbon and carbon monoxide emissions from the three gasoline powered cars rise sharply at low ambient temperatures. At -10°C, these emissions are 150% to 430% above the allowable standard. The emissions from the two diesel powered cars were not significantly affected by variations in temperature and were less than half the regulated emissions, even at the coldest temperatures. The fuel consumption of all five cars increased with reduction in ambient temperature; however, the increase is significantly less for the diesel powered cars and the turbocharged 4 cylinder car than for the other two test cars, as shown in the table below. When compared in terms of the combined EPA fuel consumption rating per tonne of inertia weight, under summer conditions, the two diesel powered cars were 37% better than the three gasoline powered models, with an even greater advantage at lower ambient temperatures. The driveability of the three gasoline powered cars were rated as ranging from fair to good, while the driveability of the diesel powered cars were rated as excellent.

Increase in urban fuel consumption
with decreasing ambient temperature (relative to 25°C)

Vehicle	% Increase in Fuel Consumption	
	+5°C	-10°C
3-way catalyst 4 cylinder	+13.4	+20.9
350 CID V8 variable venturi	+16.5	+50.6
Turbocharged 4 cylinder	+ 8.7	+17.7
4.3 L V8 diesel	+ 4.5	+14.9
Turbocharged 5 cylinder diesel	+ 7.8	+16.8

Lead Trap Trials

Over the past two years CCRL has conducted road tests to determine the effectiveness of traps mounted on automobiles to collect solid particulates in the exhaust gases from leaded-gasoline powered vehicles. These trials have involved eight vehicles from the Department of National Defence (DND), with four of the vehicles unequipped to act as controls. The results of these tests indicate that about 80% of the lead is collected by the traps. This equipment offers the benefit of using lead to obtain the desired octane numbers in gasoline for better fuel economy without incurring energy penalties at the refinery to produce unleaded higher-octane gasoline.

Domestic Oil Heating

Continuing laboratory and field trials show that fuel savings up to 20% can be obtained on existing oil-fired domestic heating systems in Canada by improving burner performance and by reducing the degree of oversizing of the furnace/boiler. These savings can be achieved by retrofitting existing oil burners with a retention head, coupled with downsizing of the firing rate. Other equipment which can be retrofitted to improve efficiency even further are a delayed action solenoid valve and a positive chimney damper.

In 1979 CCRL participated in the development of a CSA standard for retrofit retention head kits for existing oil burners so that the retrofitting might be done quicker and more effectively. Over the past year, at the request of provincial governments, CCRL staff conducted six 2-day seminars in various regions of the country to train provincial officials and oil company representatives on this new technology, and to increase the speed for its implementation. At the same time an "Efficiency Manual" was prepared to explain in detail both the many ways in which the efficiency of oil heating systems can be improved, and the proper burner retrofit techniques. This manual is being distributed by CREB to all licensed servicemen in Canada, as well as provincial and municipal officials, designers and builders. The manual has been acclaimed by the industry as an important and essential contribution to training and upgrading in this field.

Because of concerns expressed by one province on the effects of the higher flame temperatures of retention head burners on combustion chambers and heat exhangers of existing furnaces, metal temperatures were measured at CCRL in two warm-air furnaces considered to have potential for overheating.

One furnace was equipped with a stainless steel combustion chamber and the other with a ceramic combustion chamber. The results indicate that no problems should be encountered due to overheating of the combustion chamber or primary heat exhanger, provided the stainless steel chamber is lined with ceramic fibre and the maximum allowable firing rate is reduced by one size. Both of these requirements now exist in the CSA code for retrofitting retention heads.

Water-Oil Emulsions

This program forms part of a continuing program to evaluate energy conservation strategies applicable to residential, commercial and industrial boilers. A report has been prepared, based on studies in a small package boiler at CCRL, in which up to 20% of water in No. 6 and No. 2 fuel oils was used. The addition of water to form emulsions of No. 2 and No. 6 fuel oils have shown no significant changes in the generation of soot, and boiler efficiency and was shown to deteriorate with increasing water content. The baseline conditions used for comparison were typical of poorly operated boilers and provided an ideal environment for emulsions to reduce smoke emissions and to remove existing soot deposits thereby improving heat transfer. Gas-borne soot emissions were essentially unaffected by the use of emulsions and any catalytic combustion reactions due to the water were considered to be insignificant. The CCRL boiler system indicated that water in fuel oil emulsions are unlikely to be a viable energy conservation or emissions control strategy.

A second project was undertaken in collaboration with Public Works Canada and Environment Canada. In this project CCRL conducted a series of full-scale boiler performance trials to measure efficiencies when burning both No. 6 fuel oil alone and No. 6 fuel oil emulsified with about 5% water. The trials were conducted on Unit No. 3, a high-temperature, hot water generator, at the Central Heating Plant of the Central Experimental Farm, in Ottawa, using an ultra-sonic emulsifier system to produce water emulsified in fuel oil on demand. The objective of the trials was to evaluate the capability of the Folland-Enertec Emulsifier System to reduce excess combustion air requirements and to produce a 6% increase in fuel efficiency as specified by Folland-Enertec Ltd. in their guarantee of performance. After completion of the tests, it was concluded that the equipment did not meet the guaranteed

performance specifications. The fuel efficiencies only varied by about ±1%, whether burning No. 6 fuel oil alone or as an emulsion. These variations are less than the accepted overall accuracy of the A.S.M.E. indirect method used to calculate the efficiencies.

Industrial Process Heating

A cooperative project between CCRL and the Ferrous Energy Research Association (FERA) combustion sub-committee was undertaken to investigate the performance of a typical industrial steam-atomised residual-oil burner. In this project, the influence of steam oil ratio, oil and steam temperatures and various burner hardware changes were studied. It was concluded that steam-oil ratios had the most significant effect on the heat transfer and emission characteristics of the flames. The oil and steam temperatures and the burner hardware changes were shown to be insignificant in terms of heat transfer and emissions of soot and gaseous pollutants.

Control of Combustion Products

The increased utilization of coal in industrial boilers and process equipment, caused by rapidly escalating oil prices and insecurity of supply, has resulted in some environmental concerns. Consequently a number of coal combustion projects have, as a major objective, an environmental assessment requirement.

Flyash Conditioning

As part of the on-going collaborative program with Ontario Hydro, studies are being made of the precipitability of flyash to minimize the environmental impact of coal-burning. It has been found that flyash resistivities from low-sulphur coals can be reduced to the desirable range of 10^8-10^{10} ohm-cm by coal blending and by limestone addition. The latter is essentially a slagging control method but has the side effect of reducing resistivity. The performance of a pilot-scale electrostatic precipitator has corroborated these findings.

Plume Dispersion

In 1979 the continued evaluation of the data from the CANMET/-Industry plume dispersion program has resulted in a paper to the Air

Pollution Control Association's annual meeting. The main conclusion of this paper, is that plume dispersion in the Rocky Mountain foothills is so greatly influenced by lateral and vertical air turbulence that standard predictive methods cannot be used. Consequently more complex models, with measurement validation programs will be required.

A second invited paper to a panel of experts at the Atmospheric Environment Service, Toronto, emphasized that plume spread parameters are in general much wider horizontally and usually much thinner vertically than the standard reference methods predict. This significantly influences the prediction of ground-level impingement concentrations for environmental assessment.

In addition to the above papers, two dispersion computations were made, using data from the dispersion program. The first was for Cominco Ltd. and concerned the design of a stack for a proposed smelter being constructed in Tasmania. The second computation was an impact assessment of the effect of burning a high sulphur coal at the Springhill Correctional Institution. This computation was made at the request of the Technical Services Division of the Correctional Services of Canada.

Development of Low NO_x Burner

CCRL represents EMR on an IEA research program to elucidate the mechanism of NO_x formation during the combustion of pulverized coal. Canada, together with the U.S.A., Denmark and Sweden are funding burn trials at the Energy and Environmental Research Laboratories in California on some 50 coals from around the world. Canada has contributed 8 thermal coals, representative of those which are now or soon will be in commercial production. Based on the results of these exploratory burns, Canada will decide on whether to participate in an expanded project involving larger-scale burns and field demonstrations.

Development of Low-Btu Gas Burner

Phase II of the low-Btu gas burner development at the Canadian Gas Research Institute proceeded on schedule. A 125,000 Btu/h burner, suitable for dirty gas, was designed and evaluated for flame stability over a wide range of excess air levels and the experimental data has been applied to a 300KW prototype burner design. Negotiations for phase III field testing of

the prototype burner have been completed and a contract has been forwarded to CGRI by DSS.

Developing Energy Technology (3.3.2.2.0.0)

Background to the EMR Program for Fluidized Bed Combustion

In recent years many EMR staff, both in CANMET and in the Coal Policy Sector, have been convinced that the fluidized bed combustion (FBC) technology, being developed elsewhere in the world, could be of great benefit to Canada. Simple uncooled beds are already in commercial use as incinerators for high-moisture materials such as wood waste and sewerage sludge. More complex, cooled combustors integrated into steam boilers are still under development, but seem to offer the following benefits.

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. A coal-burning technology which is economic in small as well as large sizes, and thus might provide a means for utilizing coal to replace 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.

In view of Canada's large resources of low-grade and high-sulphur coal, the foregoing advantages have great significance and FBC technology has been given a correspondingly high priority in the CANMET energy program. Prior to 1977 no Canadian boiler manufacturers were engaged in the development of FBC boilers. It was therefore concluded that the best way to transfer this technology into Canada quickly was for the federal government to assume a substantial portion of the financial risk for a selected series of full-scale demonstration projects. Subsequently, the following program of five demonstration projects was developed, these in turn are supported by a program of pilot-scale R&D. It should be noted that some of these demonstration projects are still in a conceptual stage and may not proceed in their present form.

1. Heating plant boiler using FBC (Summerside)

2. Industrial boiler burning coal and wood chips via FBC.
3. Small utility boiler burning high-sulphur coal via FBC (Nova Scotia Power Commission).
4. Coal dryer heated by rejects burned in an FBC (Luscar Ltd).
5. Pressurized FBC for combined cycle power generation (B.C. Hydro).

The EMR Demonstration Plant Program

Heating Plant Boiler Demonstration

This project was launched in 1977 when EMR and the Department of National Defence (DND) agreed to co-sponsor the demonstration of an atomospheric FBC boiler in the heating plant at CFB Summerside. DND defined its needs as a new heating plant containing two steam boilers, each having a capacity of 18,000 kg/h. Since no boiler manufacturers, Canadian or foreign, had designs available in the desired size range, the following program was planned:

Phase 1: Conceptual boiler design
Phase 2: Conceptual boiler plant design
Phase 3: Detailed design and price quotation for a plant with one boiler
Phase 4: Construction of a plant with one boiler
Phase 5: Testing and demonstration of the boiler
Phase 6: Installation of the second boiler.

To accelerate the transfer of FBC technology to Canada it was decided to have phases 1, 2 and 3 each carried out by two competing agencies, each to identify a Canadian source for the FBC boiler. Thus at the end of Phase 3 two Canadian companies would be in a position to offer FBC boilers. It was agreed that CANMET would provide the scientific authority for contracts under Phases 1, 2, 3 and 5. Defence Construction Limited would handle the contracts for construction (Phases 4 and 6).

Accordingly, Supply and Services Canada invited proposals for the conceptual design of a heating boiler, 18 tph steam capacity. The design fuel was specified as a 5% sulphur coal from Cape Breton, with wood chips to be a supplementary fuel capable of supplying 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; 2.96 kg SO_2 per 10^6 kcal heat input, and 0.36 kg particulates per 10^6 kcal heat input.

From the proposals received, two contractors were selected to prepare conceptual boiler designs. One, Foster Wheeler Ltd., offered the technology of its American parent. The other was Integ, a Vancouver based consulting firm, which offered British technology through a working relationship with Coal Processing Consultants (CPC) which is a British firm jointly owned by Babcock and Wilcox, UK, and the UK National Coal Board.

The contractors completed the conceptual boiler designs in late 1978. The British design features four independent bed sections, each fed by a water-cooled screw conveyor, with forced-circulation heat exhange surface in each section. The U.S. design is similar to the FBC boiler recently installed at Georgetown University, and now in operation. There are two bed sections, one being the "preferential" bed which is always in service and provides up to 40% of the capacity. The other, "secondary" bed is brought into service for higher loads and it contains natural-circulation heat exchange surface. Both beds are fed by means of spreader stokers.

In the past fiscal year the same contractors completed conceptual designs of a plant accomodating two fluidized-bed boilers complete with all handling systems for coal, wood chips, limestone and ash. The third phase of the project got under way early in 1980, with the issuance of two identical contracts for detailed design and firm price proposal to construct a complete plant containing one FBC boiler with space for a second. This can only be undertaken by a manufacturing firm, and the Integ - CPC team has been replaced by Dominion Bridge Co. Ltd., which is licenced to build the British design in Canada. Foster-Wheeler Ltd. remains as the other contractor.

Tender closing date for the detailed design and firm price proposal contracts has been set for January 5, 1981, when a selection committee will review the two designs in terms of price and design criteria. A construction contract will then be awarded to one of the contractors. Allowing 20 to 24 months for construction, Canada's first FBC boiler may be commissioned by the end of 1982. It will then be subjected to a lengthy program of testing and demonstration.

Two additional contracts relating to the CFB Summerside Project were issued during the past fiscal year. One was a solid waste disposal study,

contracted to Integ for the purpose of 1) determining the quantity and nature of bed residue which would be produced by the FBC boilers, 2) assessing the environmental effects of disposing of it by landfill, keeping in mind its caustic nature, and 3) exploring possible uses for it, such as construction fill, cement block namufacture, or agricultural soil conditioning. This study has been largely completed and an interim report has been submitted, but some analytical work may be carried out when samples become available. A representative of Environment Canada served as Scientific Authority.

The other supplementary contract was issued to Foster-Wheeler Limited for pilot-scale tests with the design coal, design limestone and wood chips. The fuel and limestone samples were shipped to the test site in Livingston, New Jersey in the fall of 1979, but experimental equipment failures delayed test work until late February, 1980. A test report should be available by May 1980, as will bed residue samples for completion of the waste disposal study.

Industrial Fluidized-Bed Boiler Demonstration

Substantial quantities of residual oil are burned in boilers generating steam for industries such as chemical plants and pulp-and-paper mills. The size range is typically 50 to 250 tph 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 seems 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 favorable investment cost than is possible with conventional technology for coal and wood.

One possibility for a demonstration applicable to the industrial size range is to retrofit an atomospheric FBC to a 110 tph pulverized-fired boiler installed at the Chatham station of the New Brunswick Electric Power Commission. A conceptual design study, sponsored by the Canadian Electrical Association, was carried out by NBEPC and the boiler manufacturer. However,

the study indicated that retrofitting a fluidizing bed to the existing boiler would result in a 40% reduction in capacity. The estimated cost, furthermore, appears comparable to that for a new boiler.

As a possible alternative demonstration, EMR has invited proposals via the DSS Research Bulletin for conceptual design of an FBC boiler, approximately 100 tph of steam capacity, to burn coal and wood waste, the latter to provide up to 50% of the heat input. Proposers are expected 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. When proposals are received EMR will select one which most closely coincides with departmental objectives, cost-shared contracts for the conceptual design and construction of a fluidized-bed boiler may then be negotiated.

Fluidized-bed Utility Boiler

In the United States, the main goal for FBC technology is to develop large utility boilers capable of burning high-sulphur coal. In Canada, utility applications of FBC boilers are of most interest in the Maritime provinces, where foreign oil could be replaced with indigenous high-sulphur coal. Within Nova Scotia Power Corporation's system there are three or four separate possibilities for using an FBC coal-fired boiler of approximately 150 MWe capacity to replace oil-fired capacity, using existing turbogenerator equipment. In scaling up from existing FBC technology, 150 MWe seems a reasonable compromise between saving time and increasing technical risk.

EMR and Nova Scotia Power Corporation are presently co-funding a site review study by a firm of engineering consultants. Once the best site for a demonstration, probably 150 MWe, has been established, it is likely that a conceptual design will be commissioned, but it is too early to say whether an actual demonstration plant will eventually result.

A CCRL staff member is providing technical support to Energy ~~Policy~~ Coal in an attempt to get the desired program under way, and has attended several meetings with NSPC and the consultants.

FBC of Coal Washery Rejects

In Canada, each year millions of tons of coal, mostly coking coal destined for export, are upgraded by washing. The washed coal is then dried,

commonly in equipment fired with natural gas, sometimes in equipment fired with cleaned pulverized coal. Washery rejects are produced at the rate of approximately seven million tons per year. Even though the rejects contain up to 50% ash and 20% moisture, they represent a potential fuel for the drying process, since it has been demonstrated in pilot-scale work sponsored by CANMET in 1976 that such rejects can be burned in an uncooled AFBC. Utilization of washery rejects as fuel for coal drying would not only save expensive premium fuels, it would mitigate the disposal problem that rejects presently represent, and would point the way to their full utilization, perhaps for electricity production.

As a result of an Unsolicited Proposal from Luscar Ltd., CANMET has signed a contract to co-fund a study which will a) produce a conceptual design for an AFB combustor to serve Luscar's full-scale dryer at Coal Valley, Alta., b) produce a cost proposal for the combustor and its auxiliaries, and c) determine the economics of the AFBC system compared to the existing system.

A CCRL staff member is serving as Scientific Authority (SA) for the contract. The conceptual design and capital costing will be subcontracted by Luscar to a potential supplier. The SA has participated in discussions with two possible suppliers; a decision will likely be made within a few weeks. Economic analysis will be carried out by Luscar, and the study is expected to be complete by November 1980.

EMR may then participate in funding a demonstration plant, which hopefully will point the way to utilizing, as fuel, all the washery rejects being produced.

PFBC for Combined-Cycle Power Generation

Interest in pressurized fluidized-bed combustion stems from its potential for combined cycle power generation systems which might reduce fuel requirement by 10%. It is expected that ten to fifteen years of development work will be required to achieve commercialization. In Canada, the lead in development and demonstration has been taken by B.C. Hydro, which expects to depend progressively more on coal-based thermal power in the coming decades.

Since 1975, extensive studies have been co-funded by B.C. 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. B.C. Hydro is now considering building a demonstration plant in which a PFBC would drive a gas turbine, generating 70 MWe. If work goes forward, commissioning might take place about 1985.

At present, CCRL input to this project consists of technical advice to Energy Policy (Coal). In this capacity, two CCRL staff members visited the PFBC pilot-scale facilities of Curtiss-Wright and Exxon Research, both in New Jersey, and took part in meetings to assess what contribution these facilities might make to the B.C. Hydro project. A greater involvement, either as Scientific Authority or technical liaison for EMR, will be required if the B.C. Hydro demonstration program proceeds.

The CANMET Pilot-Scale R&D Program

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 often be obtained from pilot-scale equipment. Performance characteristics of specific fuels, neutralization characteristics of specific sorbents, metallurgical aspects of erosion and corrosion, 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. CANMET supports R&D both at a pilot-scale FBC at CCRL and via contracts at two other agencies.

The CCRL Fluidized-Bed Pilot Plant

CCRL began to develop a pilot-scale FBC facility in 1975 on a part-time basis and by 1978 had a fully usable rig in place. It consists of a partially cooled combustor, approximately 20 cm ID, with an expanded freeboard and a cyclone dust collector. Instrumentation includes an electronic weigh scale to monitor fuel feed rate, gas analyzers to continuously monitor CO, CO_2, O_2 and NO_x in the flue gas, and an adequate complement of flowmeters, thermocouples and pressure sensors. Most of the intrumentation is connected into a data logger.

The major objective of the R&D program, underway since 1978, is to provide data for extrapolation to the design of full-scale fluidized-bed combustors. To accomplish this, a variety of Canadian coals and other solid fuels are burnt in the pilot-scale combustor, under a range of input parameters. Typically, bed temperatures, feed rates and oxygen levels are

varied, while measuring carbon carry-over, ash carry-over and pollutants such as SO_2 and NO_x. In FY 1978/79 such tests were carried out with Hat Creek coal waste and with tar sands coke. More elaborate tests were also begun with an Alberta sub-bituminous coal (Highvale) and with a New Brunswick bituminous coal (Minto). In the latter tests, a complete sulphur balance was carried out to establish the extent to which sulphur is captured by the coal ash constituents. In FY 1979/80 three reports were drafted describing the pilot-scale facility, and tests with Hat Creek coal, coal waste and with tar sands coke. In addition, the test work with the Highvale and Minto coals has been completed and data analysis is nearly complete. The coal feed system was modified to permit overbed feed of sized coal (25 mm x 0) containing up to 8% surface moisture, and some tests were carried out under a cost-shared contract with Crowsnest Resources Limited, on an oxidized coal from Line Creek. The overbed feed system was found to cause excessive carbon carry-over, so futher modifications were undertaken to screw-feed the wet, sized coal directly into the fluidized-bed. These modifications, along with others to provide a more durable combustor lining, are nearly complete.

The present combustor design has several inherent drawbacks. The amount of heat which can be extracted from the bed is essentially fixed, and sharply limits the possible combinations of bed temperature and firing rate. As there are no cooling tubes in the bed, measurement of heat transfer rate is not possible. The combustor lining requires frequent maintenance, resulting in excessive downtime. Finally, the bed is too small for reliable extrapolation of results to full scale. To overcome these problems, a new combustor has been designed, as described in following section.

The New CCRL Fluidized-Bed Combustor

Substantial effort was expended in designing a new, more versatile combustor to fit into the existing CCRL pilot plant. Design objectives were as follows:

1. A bed section 0.38 m square
2. Variable heat transfer surface
3. Capability for measuring heat transfer rates
4. Robust, maintenance-free construction
5. Provision for both overbed and inbed feeding

of sized, wet coal

6. Good access for sampling probes and measurements
7. Means for visible inspection of the bed

To meet these objectives, the design calls for a combustor shaft made up of several sections stacked one upon the other. Each section consists of a hard refractory brick liner backed by insulating brick and encased in a steel shell. The bed may be operated adiabatically or with a water header assembly for immersing 48 cooling tubes in the bed. This permits heat transfer to be varied at will and provides the capability for measuring heat transfer rates. By means of a double-screw system, coal may be fed either into the side of the bed below the heat exchanger tubes, or above the bed. Numerous access ports are included and a sapphire window will be incorporated to provide a view of the bed surface.

Detailed design and working drawings were completed in December 1979 and contracts for fabrication let early in 1980. Construction should be completed by May and then installation of the new combustor at CCRL will proceed as rapidly as possible.

Fluidized Bed R&D Contract, Queen's University

In response to an unsolicited proposal from the Chemical Engineering Department at Queen's University, CANMET has signed a two-year contract to support Queens in developing and operating a pilot-scale fluidized-bed combustor. It is hoped that the work at Queen's will supplement the work at CCRL, particularly in two areas; characterization of Canadian limestones and dolomites for sulphur neutralization and the effects of sorbent additives in enhancing sulphur capture.

Queen's will build a combustor identical to the new CCRL design. This conserves time and design effort and means that results from one rig are directly applicable to the other. During FY 1979/80, approximately $78,000 was spent from a CANMET contract and DSS bridge funding to acquire instruments, feeders, supplies and as much of the combustor as could be completed by the end of the fiscal year. For FY 1980/81, $130,000 has been allocated, with which it is expected to complete fabrication of the combustor, complete the installation of the pilot plant, obtain additional instrumentation, carry

out commissioning trials, and conduct calibration runs with one or two coals.

A CCRL staff member is serving as Scientific Authority for the contract, and CCRL is providing substantial technical support to Queen's in the selection and arrangement of equipment and instrumentation.

Energy Recovery (3.3.2.3.0.0)

Energy Cascades

An overview of the technologies involved and the potential for improved fuel utilization by energy cascading was produced by CCRL staff.

Combining energy uses in a cascade can result in significant overall reductions in fuel requirements. The simplest applications for a cascade are in the recovery of waste heat from existing processes using special boilers or turbines.

Specific applications of more complex energy cascades for Canada are discussed. A combined cycle plant at a chemical refinery in Ontario is a world leader in energy efficiency. Total energy systems for commercial buildings, such as one installed in a school in Western Canada, offer attractive energy and operting cost benefits. A cogeneration plant proposed for the National Capital Region, generating electricity as well as steam for district heating, allows the use of a low grade fossil fuel-coal, greatly improves energy transformation efficiency, and also utilizes an effectively renewable resource - municipal garbage.

Despite the widespread availability of equipment and technology of energy cascades, the sale of steam and electricity across plant boundaries presents a barrier. More widespread use of cascades will require increased cooperation among industry, electric utilities and the various levels of government, if Canada is to realize the high levels of energy efficiency potentially available.

Biomass Technology (3.3.7.2.0.0)

Domestic Wood Heating

Because of increased costs of the conventional heating fuels (oil and natural gas) as well as the fear of possible shortages of these fuels, homeowners are beginning to look to other means of heating their homes.

One result has been a dramatic increase in interest in heating with

wood, particularly in using wood stoves as space heaters. In turn, this has led to a search by consumers for an "efficient" wood stove. They become dismayed by the wide variety of claims and judgements thrown at them by each manufacturer and retailer, each touting their unit as "the most efficient stove on the market", or that it is capable of heating x square feet, or capable of operating at such and such an efficiency. However, there is usually very little objective data on which to base such claims.

CCRL has been developing a technique to measure the efficiency of wood stoves. In evaluating the technique, the laboratory is examining the performance of a number of wood stove types. Results indicate that sidedraft - and horizontal baffle-design stoves offer significant performance improvements over stoves of conventional design, both from the point of view of reducing creosote formation and improved efficiency. Field trials have indicated that, while built-in fireplaces actually increase fossil fuel consumption, a good sidedraft stove, properly located in a major living area can operate at a higher seasonal efficiency than a conventional oil or gas furnace, reducing premium fuel requirements significantly.

Tests were also carried out to compare the performance of a representative dry hardwood, maple, and a proposed new fuel, compressed wood briquettes, in three wood stove types. Two airtight stoves and one non-airtight Franklin stove was used. In the airtight box stove, the briquettes tended to lead to greater hydrocarbon and carbon monoxide emissions than for the maple, indicating more incomplete combustion. In the airtight (Scandinavian) baffled stove, no significant performance difference was observed between the two fuels. A potential fire hazard arose with the non-airtight Franklin stove, with uncontrollably high flue gas temperatures. As a consequence, it is recommended that the briquettes not be used in a non-airtight stove.

Conventional Burning of Renewables

In a collaborative program with Shell Canada Ltd, CCRL conducted studies of comminution and combustion performace of pelletized wood waste. The wood pellets were evaluated in the pilot-scale research boiler which normally fires pulverized coal. The 1/4 in. diam x 3/4 in. long wood pellets contained 7% to 11% moisture and 1.5% to 48% ash, and consisted of roughly equal proportions of wood chippings and bark. Their calorific value was

about 8000 Btu/h, which is comparable to lignite in heating value.

Because the bulk density of the pulverized wood pellets was less than one half that of coal, they tended to rapidly plug the pilot-scale CCRL pulverizer. However, this is unlikely to occur in full-scale pulverizers where critical dimensions are at least two orders of magnitude larger than in the CCRL equipment.

Combustion of the pulverized pellets was good even with reduced oil support, but the wood fuel alone would not maintain combustion for more than a few minutes without oil support.

The pulverized wood pellets with 35% to 60% oil support produced very low emission levels. Nitric oxide levels ranged from 180 ppm to 270 ppm and solid loadings from 0.6 gr/sft^3 to 0.2 gr/sft^3; the latter contained negligible combustible material, indicating complete burn-out was occurring.