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OPERATION OF A UTILITY BOILER ON COAL-OIL MIXTURE

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OPERATION OF A UTILITY BOILER ON COAL-OIL MIXTURES

by

H. Whaley*, P. J. Whalen** and F. W. Davies***

ABSTRACT

A cooperative project to determine the feasibility of burning coal-oil mixtures in a small utility boiler has been undertaken by the New Brunswick Electric Power Commission and the Department of Energy, Mines and Resources Canada. This paper describes the boiler operation during two phases 1977/78 and 1978/79. In the initial phase no major equipment modifications were undertaken except the addition of the coal-oil mixing system.

However, in the later phase, coal beneficiation by spherical agglomeration was incorporated into the COM preparation to reduce environmental emissions of fly ash and sulfur dioxide and to minimize the burner tip and equipment erosion previously experienced and directly attributable to the coal ash in the fuel. The environmental emissions of fly ash and sulfur dioxide as well as the operating efficiencies are given for baseline oil firing and for a 10-15 wt% COM both with and without coal beneficiation.

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1. INTRODUCTION

The dependence of the maritime provinces of Canada on imported oil, particularly for electric power generation, has become a matter of national concern. As the federal agency responsible for formulating and implementing energy policy, the Department of Energy, Mines and Resources has been encouraging the substitution of coal for premium fuel oil. One such program with this objective is the coal conversion program which supports jointly funded research with industry in the areas of coal liquefaction, gasification and substitution. Coal-oil mixtures (COM) fall into the last category and are being supported as a short to medium-term solution to the conversion of oil-fired boilers to partial coal firing when full conversion is not immediately possible.

A major demonstration project for the application of coal-oil mixtures to utility boilers has been undertaken by the New Brunswick Electric Power Commission in using a small boiler located at Chatham, New Brunswick. This project is one of four currently in progress and that have been described previously (1).

The New Brunswick Electric Power Commission (NBEPC) is the largest user of residual fuel oil in the province currently consuming about 8 million barrels of oil a year in its oil-fired generating stations. The Commission is interested in the development of methods by which local high sulfur (7%), high ash (20-30%) coals can be used in greater quantities in an environmentally acceptable manner in its operations. The development of economically viable means of burning coal in existing oil fired boilers and of improving the coal quality both have significant impact on these objectives.

The Chatham Thermal Generating Station, Unit No. 1 10 MW(e) generating capacity was selected for undertaking a COM evaluation in 1977. This boiler was chosen because of its small size and in not being required to supply to the grid has the operational flexibility required for the COM study.

The boiler is a Foster Wheeler Type "SA" rated at 16.6 kg/s (140,00 lb/h) steam flow. This boiler is dual fired, having the capability for independently firing coal or oil. The boiler is also capable of simultaneously burning coal and oil using separate streams (e.g. two burners on coal and two on oil). Results of the first year of operation in which a 10 wt% coal-No. 6 fuel oil mixture was fired have been previously reported in detail (2).

The 1978/79 research project was basically undertaken with two objectives; one being a continuation of the 1977/78 COM combustion trials and equipment evaluation and the second being an investigation of an oil agglomeration process to beneficiate the coal. The system was operated for a total of 800 hours, 630 of which were on COM firing.

The initial phase of the program basically used a cyclone and baghouse combination to separate pulverized coal from the primary air stream from the mill. Afterwards, this coal was mechanically mixed with No. 6 fuel oil in a blender and transported using screw type oil pumps to existing steam-atomized oil burners. Neither the pumps or burners were specifically chosen for handling COM and as a consequence significant wear problems attributable to the coal ash were encountered.

Modifications were made to the COM preparation system during the 1978/79 Phase II program to accommodate a wet scrubbing and coal-oil agglomeration systems. The purpose of the agglomeration process is to beneficiate the coal by partial ash and sulfur removal with a corresponding reducion in materials erosion and stack fly ash and SO_2 emissions. The wet scrubbing system was used to replace the former cyclone-baghouse combination to facilitate collecting the pulverized coal in water for secondary grinding by a wet mill. Also incorporated were new fuel delivery pumps specially selected for supplying COM to the burners. Two types of burner tips were tried, a "skew-jet" type and a "Y" jet nozzle with replaceable inserts.

1.1 Coal-Oil Agglomeration

The application of a spherical oil agglomeration process in coal preparation provides an attractive method for cleaning fine coal to form compact oil-bonded pellets. Capes et al at the National Research Council of Canada have published several papers on the subject (3, 4, 5). In principle the separation of the inorganic ash fraction from the carbonaceous constituents in coal by the agglomeration process depends simply on the difference in their respective surface affinitives towards water. The organic carbonaceous fraction is hydrophobic in nature and therefore repels water, while the inorganic ash fraction is hydrophilic and readily unites with water.

The agglomeration process basically consists of taking a mixture of pulverized coal in water and adding light oil in a flocculating tank. The coal particles tend to agglomerate in the oil phase while the inorganic constituents of the coal, which have been liberated by the grinding process, remain in the water phase. These fractions are eventually separated by a screening process.

1.2 Environmental Aspects

One very important consideration in development of COM technology is related to the environmental impact of fossil fuel burning. Most provinces in Canada have adopted air quality regulations which stipulate the maximum allowable ground-level concentration of various pollutants. Of particular concern to industrial scale fossil-fuel users are regulations pertaining to sulphur oxides and particulate matter emissions. In order to confirm to the latter requirements it is usually necessary to install some form of fly ash collection equipment. Currently, sulphur dioxide control using flue gas desulphurization (FGD) methods is not required in Canada and tall stacks which meet stipulated ambient impingement concentrations are used.

Eastern Canadian coal typically exhibits a lower heating value, higher ash content and higher sulfur content than many other coals. The combination of coal and oil together represents an excellent compromise between the advantages of both fuels. The COM preparation system offers two significant environment benefits in that both inorganic sulphur and ash fractions in the coal may be reduced by up to 50% prior to combustion.

2. COM SYSTEM DESCRIPTION

As mentioned earlier the system used during the 1978/79 program was basically that from the 1977/78 trials with modifications made to the coal-oil mixture preparation by the installation of a wet scrubbing system and an agglomeration process. Other changes to the existing system were the addition of a nuclear density gauge for COM quality control and replacement of the oil pumps delivering the COM to the burner front.

2.1 Coal Supply System

A schematic drawing of the coal delivery system is given in Figure 1. In this part of the process the raw coal was pulverized down to average particle size of about 11 μm after two stages of grinding.

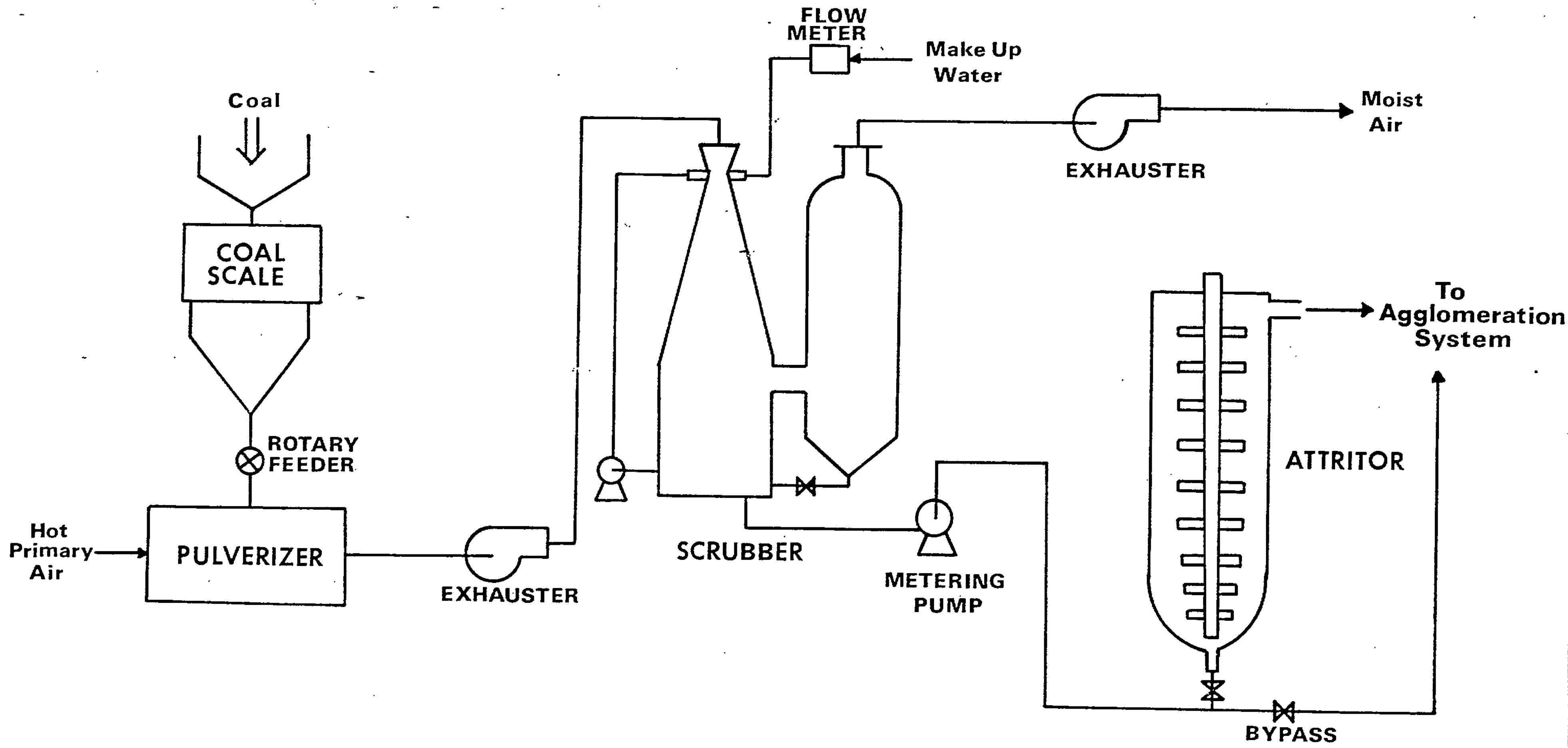


FIGURE 1 Schematic of Coal Delivery System

Since the original coal-handling equipment was still in place on Unit 1 an existing pulverizer and exhauster was used. Coal from the bunkers was fed through a set of scales via feeders to the mill where it was pulverized to a fineness equivalent to 80% through 200-mesh (75 μm). The pulverizer coal was transported by the exhauster to a wet scrubbing system where the coal particles are separated from the primary air stream by water spray. The scrubbing system comprises a venturi scrubber and cyclonic separator. The scrubber employs a spray nozzle to direct a fine water spray on the incoming pulverized coal particles and the interaction causes the particles to be retained in the water medium. Due to the relatively large quantity of water required for efficient separation a recycle stream is installed to maintain a high concentration of coal. The cyclonic separator basically serves as a final collecting chamber to recover any coal particles which have not yet settled into the holding tank. At this point the relatively clean, but moist air is drawn by an exhauster and discharged to atmosphere. Flowrates of process water to the scrubbing system can be adjusted to achieve a discharge of approximately 40% coal by weight in the water. This stream is supplied to the attritor via a metering pump in order to have some control on residence time which is a major factor in determing the final coal fineness.

2.2 Agglomeration System

The oil agglomeration system was designed for beneficiation of the coal prior to final preparation of the COM, Figure 2, illustrates the system used in the later phase of this project. The pulverized coal-water end product from the wet-mill is fed to the first of two flocculating tanks where the light oil is added and the coal-oil agglomerates are formed. The mixture in these tanks is constantly agitated by two recirculating pumps and an additional mixer installed on the second tank. The light oil is sprayed through a nozzle into the pump inlet. It is in these tanks that the separation of the carbonaceous oil agglomerates and the inorganic ash constituents in water occurs.

The coal-oil-water mixture from the first tank overflows into the second tank which allows additional residence time required for the separation. Here an optional extra quantity of light oil may be added depending on the formation of the agglomerates. From the second tank the agglomerate-water stream overflows onto a stationary dewatering screen. The underflow from this screen contains the rejected ash and sulfur contaminants and is eventually

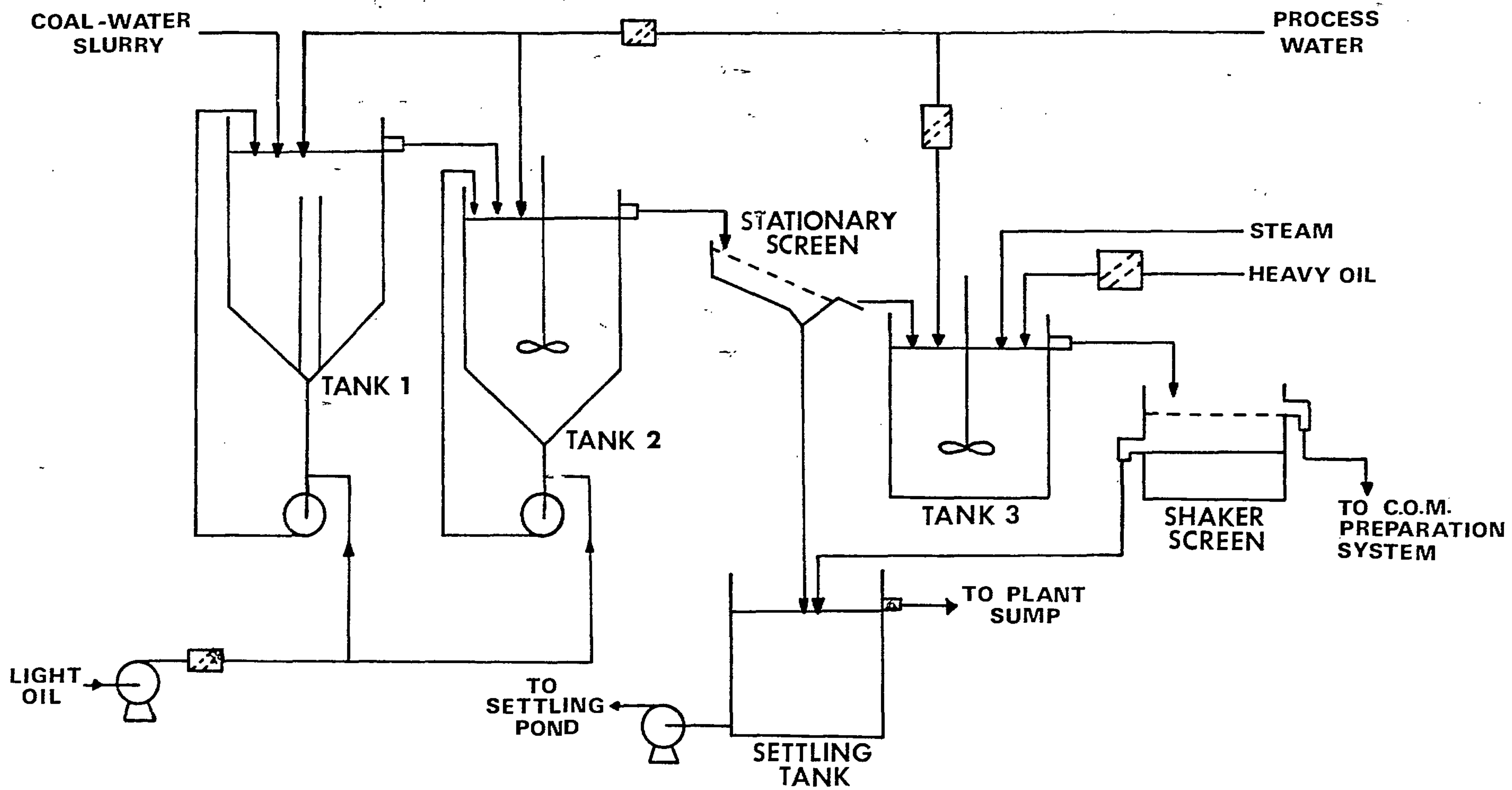


FIGURE 2 Schematic of Coal Agglomeration Process

discharged to a settling pond. The agglomerates collected on the screen typically contain 30 percent moisture and are discharged to a third flocculating tank. Here, No. 6 fuel oil and water are added and the mixture is maintained at approximately 50°C (122°F). The heavier oil enhances the formation of larger agglomerates with a corresponding decrease in total surface area. Hence, there is a reduction in surface water adhering to the agglomerates. Overflow from this tank is dewatered on a shaker screen, where the final coal-oil agglomerates are directed to the COM preparation system. The underflow from the shaker screen is discharged to the settling pond.

2.3 COM Delivery System

The agglomerates are fed to a blender where hot No. 6 fuel oil is added to redisperse them to form the COM. The blender consists of paddles fixed to a horizontal shaft and basically achieves thorough mixing by direct contact with the two streams. It is noted that no attempts have been made to add any stabilizing agents and that some COM recirculation from the burners back to the blender has proved to be satisfactory to keep the coal in suspension.

Using specially selected pumps the COM is passed through a conventional oil heater to the burner front. Basically, the pumps consist of two half circle lobe type impellers on externally gear driven shafts such that there is no physical contact between the rotating lobes. An on-line nuclear density meter was installed on the COM supply line to the burner front whose purpose was to indicate relative percentage by weight of coal in oil and alert the operators to sudden fluctuations.

Several burner tips were used for the combustion trials. The "skew-jet" tip, by design had small internal channels which were thought unsatisfactory for resisting erosion from COM's. Burner tips employing replaceable inserts were used and are illustrated in Figures 3 and 4.

It should be noted that throughout the agglomeration process and COM piping, provisions were made to provide access for cleaning or purging the lines wherever possible.

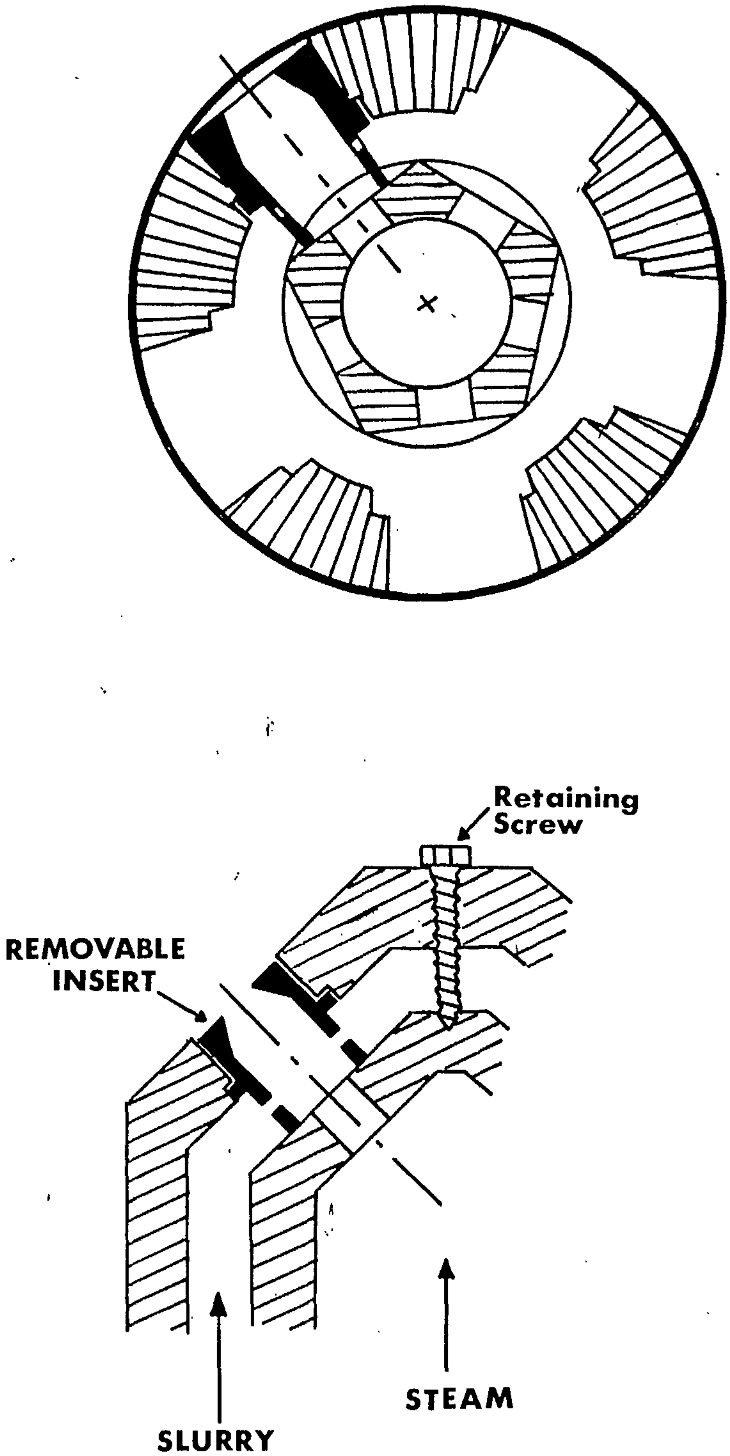
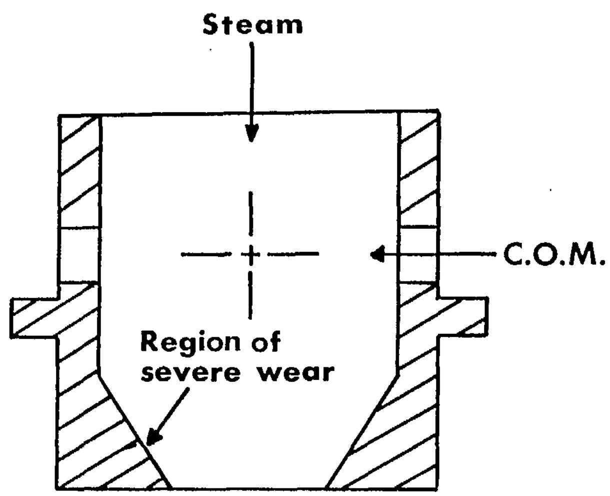
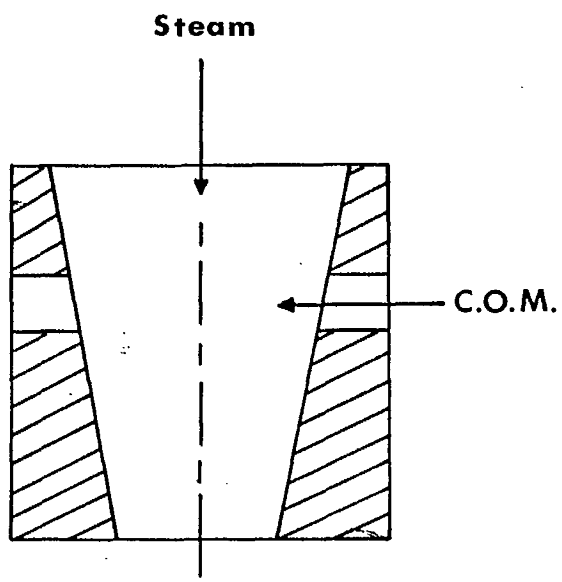


FIG. 3. SCHEMATIC OF C.E.A. BURNER TIP



a) ORIGINAL REPLACEABLE INSERT



b) SIMPLIFIED IMPROVED INSERT

FIGURE 4 REPLACEABLE INSERTS FOR C.E.A. TIPS

3. PROCESS EVALUATION

Evaluation of the agglomeration process involved considerable analyses of all input fuel streams and of the beneficiated coal. Several flue gas parameters were measured during the COM combustion trials. Results of the 1978/79 program have been reported in detail (6). The following comments apply to specific areas of the boiler operation on COM.

3.1 Coal Particle Size Analysis

There appears to be two main problems in the removal of pyritic sulfur from coal. The fine dissemination of pyrites in the coal matrix of Minto coal, requires very fine grinding to accomplish liberation. The coal and pyrites appear to be both hydrophobic in surface nature (5), which complicates separation by oil agglomeration.

The first stage of grinding in the conical ball mill pulverized the raw coal down to size equivalent to 80% below 75 μm (200-mesh). A typical particle size analysis for three samples of pulverized coal from this mill indicates that 95% is smaller than 53 μm. In the second stage of particle size reduction by wet milling, a residence time of about 3.5 minutes allowed the coal to be reduced down to an equivalent of 75% less than 20 μm with a mean diameter of 11 μm.

3.2 Ash and Sulfur Removal

One of the primary objectives of the later program was to incorporate the agglomeration process and to evaluate its effectiveness. The system used produced approximately one half tonne per hour of coal. The amounts of ash and sulfur removed were determined by analyses of various flow streams and by performing mass balance about the system. Results of these determinations are summarized in Table 1. The amounts of ash and sulfur reductions were less than had been expected suggesting that the liberation particle size for ash and pyrite should be much smaller for the particular coal used. Experiments conducted at the National Research Council in which the wet milled product from the project was further milled to 3.3 μm showed that reductions in ash of up to 65% with about 50% sulfur reduction could be attained with this coal.

TABLE 1

ASH AND SULFUR REDUCTION BY AGGLOMERATION PROCESS

Date	Coal Feed (kg/h)		Agglomerates (kg/h)		% Reduction	
	Ash	Sulfur	Ash	Sulfur	Ash	Sulfur
March 26 1/	81.1	26.9	78.9	25.4	2.7	5.6
March 27 1/	83.9	28.7	75.8	31.8	9.7	-
April 10 2/	155.1	56.0	104.6	50.4	32.6	10.0
April 11 2/	182.8	64.8	99.4	54.0	45.6	16.7

NOTE: 1/ without Attritor
2/ with Attritor

$$\dagger \ \% \text{ Reduction} = 100 - \left(\frac{\text{Quantity from Agglomerates}}{\text{Quantity from Coal}} \times 100 \right)$$

3.3 Flue Gas Characteristics

A series of stack emission tests were conducted in conjunction with the project. All tests were conducted at a unit load of approximately 10 MW under steady boiler conditions. It must be noted, however, that while results are reasonably consistent for each firing mode, direct comparison between tests is difficult for several reasons: the final coal-in-oil concentrations varied from 11% to 13% and there was substantial variation in the coal composition.

Results of the stack emissions for both oil and COM firing tests are summarized in Table 2. Test results of the 1977/78 COM trials, in which the oil agglomeration process was not incorporated, are also given for comparison. The high excess air measured in the boiler is due mainly to air inleakage through the casings and poor design of the oil burner installation, all attributable to the age of the unit.

4. COMBUSTION EVALUATION

The steam atomized "Y" type burners with replaceable nozzle inserts were used for firing the 10% to 15% coal by weight COM. The "skew-jet" tips which were also supplied had not been designed for firing COM and therefore were not used. It was speculated that the relatively small internal passages and sudden fuel stream direction changes of this tip would result in rapid deterioration if used on COM firing. The Y-tips employing replacement inserts had been specifically selected for COM firing but the material of the inserts supplied did not give satisfactory abrasion resistance to the COM.

It is interesting to note that while only 10% to 15% coal by weight in the COM were fired, there was little visual difference between the flames with COM and with No. 6 fuel oil. However, as erosion of the tips progressed on COM there was noticeable deterioration in flame stability and slagging of the tip and burner throats became evident. Fly ash emissions were approximately in proportion to the percentage of coal in the COM relative to either coal or oil firing separately.

4.1 Boiler Efficiency

Tests were performed on the boiler to compare the difference in efficiencies between firing No. 6 fuel oil and COM calculated by two methods, the input-output and heat losses methods. The heat loss method resulted in higher values and this is probably the result of inappropriate assumptions made for unaccounted losses due to the age of the boiler (i.e. leaks). The determined

TABLE 2

STACK EMISSIONS DATA SUMMARY

Parameter	No. 6 Fuel Oil	COM Firing (without Attritor)	COM Firing (with Attritor)	COM Firing (1977-78)
Excess O_2 (%)	8.3	9.0	8.3	6.0
Total Ash Input To System (kg/h)	-	86	168	86
Particulate Loading (g/m^3)	0.20	0.81	0.94	1.0
Particulate Emission Rate(kg/h)	20	69	81	83
(lb/M Btu)	0.28	1.02	1.20	1.26
Total Sulfur Input (to System (kg/h)	104	120	159	122
SO_2 Concentration (ppm)	815	960	1200	1100
SO_2 Emission Rate (kg/h)	186	225	284	249
(lb/M Btu)	2.68	3.31	4.19	3.78
SO_3 Concentration (ppm)	22	18	19	3.3
SO_3 Emission Rate (kg/h)	6.4	5.0	5.4	0.9
(lb/M Btu)	0.09	0.08	0.08	0.01
Moisture (%)	7.4	7.1	7.2	6.6
Opacity (%)	5-20	20-30	25-35	35-70
Combustion In Fly Ash (%)	82.3	21.3	19.1	12.7

1/ Firing with insert type burner.
2/ Particulate loading are at 21.1°C (70°F) and 101.3 Kpa (1 atm).

values for COM firing varied from 83.2% to 88.9% by the input-output method and from 86.6% to 89.6% based on the heat losses method. The results do not indicate a significant improvement in efficiency (less than 1%) for COM over straight oil firing.

4.2 Boiler Condition

The boiler was inspected following approximately 630 hours of COM firing. During the test period, the unit was also operated for about 170 hours of baseline oil firing. The sootblowers were not operated at any time during the test period. The furnace walls were very clean having a light brown deposit that could easily be wiped away.

The breeching to the stack was also inspected and found to be relatively clean. When it is considered that during the COM trials, 200 tonnes of coal were burnt, there appears to have been little ash deposited throughout the boiler compared to the situation if an equivalent amount of coal had been fired alone. This appears to indicate that ash from COM combustion of low coal percentages (10-15 wt%) is deposited in the boiler and that the overall furnace condition resembles more closely that of an oil-fired unit.

5. EQUIPMENT WEAR

Equipment erosion problems experienced during the 1977/78 combustion trials were quite severe particularly with regard to operation of the burners and fuel delivery pumps. This had been anticipated since no attempt had been made to specifically select equipment suitable for handling COM.

Erosion of burner tips remained the principle concern during the later COM trials and has been reported in detail (6).

5.1 Burners

In an effort to overcome the wear problems, burners were selected with replaceable nozzle inserts. These have been previously mentioned and are illustrated in Figures 3 and 4. The inserts supplied were manufactured of steel and silver steel composition. Some tool steel inserts manufactured at the Chatham plant and a machinable ceramic insert made at the University of New Brunswick were later tried. All of these were eroded quite quickly by the 10 wt% COM. The hardness, life, and chemical composition of the various materials tried are given in Table 3. None of the steels is highly alloyed and all are capable of being heat-treated to obtain a wide range of mechanical properties. Two of them were hardened whereas one, the silver steel was annealed. As was expected, life increased with hardness, however, all materials tried were significantly lower in hardness than the gangue of the Minto coal, which typically is about 750 on the Vickers scale.

The machinable ceramic insert which was tried failed by breaking into several pieces rather than by wear. If the insert were to be changed from its original design where it is supported on a central flange, to the design shown in Figure 4b where support is wholly from the base, then the tensile stresses immediately below the supporting flange would be removed and mechanical failure might be averted. Very hard metals, and ceramic materials generally, tend to be brittle and tensile stresses should be avoided when they are being used. However, even if mechanical failure could be avoided, the machinable ceramic is too soft (150-200 HV) in relation to the coal gangue (750 HV)to expect prolonged life using COM.

Three alternative materials for the inserts which might fulfill the hardness requirement are alumina, cemented carbide and nitrided steel. Ceramic inserts made from alumina are readily available with Vickers hardness of about 1000. The hardness of cemented carbide inserts is between 1400 to 1800 HV depending upon the grade chosen. Nitriding suitable steels will produce surface with 750 - 950 Vickers hardness. This is considerably softer than cemented carbide, but costs considerably less and may be adequate for COM use.

It is interesting to note that little erosion could be detected in the interior channels of the burner nozzles which were in contact with the COM. The erosion problem appears to be caused primarily by the atomization process where the steam is accelerated up to sonic velocity before contacting the fuel. High shear rates are achieved during contact and the momentum of the COM is accelerated to high velocity within the nozzle. The kinetic energy of the abrasive coal particles is sufficient to cause the erosion of the metal surfaces in contact at this point.

5.2 COM Supply System

There was little noticeable erosion of most of the piping used throughout the COM supply system. However, most of the pipes were large diameter resulting in low fluid velocities which minimized wear. Most of the valves used to control flow encountered wear, but these had not been chosen to be abrasive resistent. All pumps which had been specially selected for abrasive service proved satisfactory and those not specifically selected experienced severe wear.

TABLE 3

HARDNESS AND LIFE OF BURNER NOZZLE INSERTS

Nozzle Insert	Vickers Hardness (5 kg)	Life
1	270	Typically less than one day
2	210	Typically less than one day
3	560	From 2 to a maximum of 6 days
4	150-200	Fractured after a few minutes

NOTE: Minto NB Coal Ash is about 750 Vickers hardness.

STEEL NOZZLE INSERT CHEMICAL COMPOSITIONS

Nozzle Insert	C	Mn	Si	Cr	Ni	Mo	W	V
1	0.54	0.54	0.32	1.13	1.39	0.12	n.d	n.d
2	1.26	0.44	-	0.48	0.14	0.05	n.d.	n.d
3	0.69	0.29	-	1.62	0.14	0.14	0.7	0.16

Identification

1. Original CEA inserts.
2. CEA silver-steel inserts.
3. Chatham GS tool steel inserts.
4 U of NB ceramic inserts.

The COM burner supply was constructed from 5.1 cm (2 in.) schedule 80 steel pipe and inspection at several points indicated negligible wear. Total fuel supply to the burners was only in the order of 1.5 ℓ/s (25 US gpm) which resulted in fluid velocities of 5.1 - 7.6 cm/s (2-3 ft/s). At such a low velocity it is expected that there would be little erosion, however, it is also noted that COM velocities of the order of 25.4 cm/s should be maintained to help prevent coal settling.

A slurry pump was employed to pump the COM from the blender through the oil heater and to the burners. The twin lobe externally gear driven construction of the pump showed no noticeable wear. However, leakage of oil through the shaft packing had been experienced from the first day of operation. This packing probably served to retain coal particles in physical contact with the shaft resulting in wear of the drive shafts, in this region. The erosion produced some grooves 0.03 - 0.04 cm (0.010 - 0.015 in.) deep; however thus far, this has not caused any significant deterioration in pump performance. A possible solution to the wear of the pump shafts is to install an oil purge on the casing between the outer seal and pump interior to counter leakage of COM past the packing. Also a better choice of harder shaft materials may minimize wear.

A major objective of the 1978/79 program was to operate and evaluate the agglomeration process and consequently material erosion problems were neglected in many areas. All the wear problems experienced on the pumps could be easily rectified by proper material selections and minimum design modifications. The consideration given to the selection of the COM delivery pumps proved worthwhile with regard to their reliability.

6. CONCLUSIONS

Operation of a 10 MW(e) utility boiler on a 10-15 wt% beneficiated coal-oil mixture has shown that:

1) COM can be fired in conventional oil handling equipment providing sufficient attention is paid to materials selection and equipment design.

2) The erosion of the burner nozzles increases radically with decreasing material hardness. This severely affected flame stability as erosion progressed.

3) Boiler operating efficiencies do not vary significantly between firing 10 wt% COM or No. 6 fuel oil. However, it has not yet been determined if there is any derating of the unit on COM.

4) Boiler slagging and fouling is not significantly increased when firing 10% COM compared to No. 6 fuel oil.

5) An on-line oil-agglomeration coal beneficiation process has been shown to be feasible to produce COM. Laboratory tests indicate that this process is capable of removing 70% of the ash and 50% of the pyritic sulfur in Minto NB coal, a factor which should significantly reduce materials erosion and environmental emissions from COM utilization.

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