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COAL-OIL-MIXTURE RESEARCH AND DEVELOPMENT IN CANADA

by

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SUMMARY

The effect of escalating oil prices in relation to costs of coal in Canada led to the initiation of a program encompassing technologies relating to the combustion of mixtures of coal and oil. This fuel in slurry form is seen to be particularly relevant to the situation in eastern Canada which, to a large extent, depends for its energy upon imported oil. This technology provides a short to medium-term energy source which has significant potential in reducing oil consumption at power stations originally designed for oil firing. Economic factors will dictate whether or not the technology is implemented and it may also find application in the industrial and commercial sectors.

The Canadian coal-oil-mixture (COM) program embraces both demonstration-scale projects and associated research and development. The demonstration projects include COM firing of an electrical utility company boiler rated at 10 MW_e with plans for the firing of a larger unit. Research and development studies include COM rheology, preparation and combustion in various projects partly or completely funded by the Department of Energy, Mines and Resources.

An important part of the program has been the application of the Spherical Agglomeration Process to the beneficiation of coals and the integration of this process into the overall COM preparation procedures; a portion of the oil needed in the final fuel slurry is used in the preliminary cleaning step. The feed coal for the 10 MW_e demonstration project had been reduced to less than 10 per cent ash and 4-5 per cent sulphur from 20-25 per cent ash and 7-8 per cent total sulphur using oil agglomeration.

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Introduction

The present Canadian coal-oil-mixture (COM) program saw its beginnings in 1972 in the form of a limited evaluation of the preparation, handling and combustion characteristics of several coal-fuel oil suspensions using a pilot-scale calorimetric furnace at the Canadian Combustion Research Laboratory, CANMET, Ottawa. The program was discontinued because of lack of industry and electrical utility company interest caused by unattractive economics at that time. Following the 1973 Oil Crisis, interest in Canada in COM combustion again developed and evaluations of the initial studies were presented in 1976 (1,2). The present COM program began to take shape because of the effect of escalating oil prices on COM combustion economics.

COM combustion is a short to medium-term energy source which has significant potential in reducing oil consumption, especially in eastern Canada which is to a large extent directly dependent on imported oil. It is an option to direct coal (or natural gas) conversion of boilers designed for oil firing, especially where full conversion to coal imposes a substantial derating. The Technical Information Service of IEA* Coal Research has reviewed recently the literature on the conversion of power stations currently burning oil to COM (3). It was concluded that whilst only boilers designed originally for coal but currently burning an alternate fuel can be retrofitted to burn coal only, COM can be burned in the majority of

*International Energy Agency

boilers designed for coal or oil firing with only minor modifications to combustion equipment.

Specifically, the objective of the Canadian program is to advance the commercialization of COM technology in association with industry (including utility companies) by (i) addressing technical questions relating to potential industrial utilization of COM combustion technology in accordance with regional coal and oil supply logistics and environmental regulatory requirements, (ii) reducing technical and economic risks with high capital cost technology demonstrations, and (iii) transferring to potential users and relevant industrial sectors technical, environmental, and economic data collected in the program.

As mentioned above, the greatest potential for commercialization of COM combustion lies in eastern Canada. A recent study sponsored by the Canadian Electrical Association identified eleven oil-fired utility boilers with a combined generating capacity of 2015 MW which operate at load factors sufficiently high to justify conversion to COM. Equivalent oil savings by utilizing COM containing 50 per cent coal by weight amount to some 5,250,000 bbl annually or approximately 3 per cent of direct oil imports. A preliminary market analysis for Nova Scotia has indicated heavy fuel oil consumption in industrial, commercial and slow diesel applications to be about 5,000,000 bbl annually in that Province. The extent to which these markets can be penetrated by implementation of COM technology will be dependent on many factors, some of which are specific to one or more of the four market sectors. Apart from technical and environmental factors, the economics of COM technology, at a time when there are divergent views in Canada on oil pricing, will most likely be the determining factor with respect to market penetration. For example, in the Canadian situation the widening differential in prices of coal and oil now favour strongly conversion of oil-fired boilers to coal alone, provided sufficient space is available for coal storage and handling.

The Canadian Program

The present Canadian COM program can best be described under two headings: demonstration projects and research and development, the latter including some pilot-scale projects. One of the most interesting and important R & D components of the program is the association of oil agglomeration with the preparation of coal-oil mixtures prior to utilization. Ash (mineral matter) reduction of eastern Canadian coals, along with sulphur reduction from these generally high-sulphur coals, would be a vital factor in encouraging the penetration of COM technology based on indigenous coals into the industrial boiler and, possibly, diesel markets.

In general, operating costs of the oil agglomeration cleaning method are sensitive to the quantity and price of the oil used. However, in the cleaning of coal upstream of the formation of coal-oil mixtures, oil cost considerations are much less important than in the general case because a portion of the oil needed in the final fuel slurry can be used in this preliminary cleaning step. This factor, together with the fact that oil agglomeration is particularly effective at the extremely fine coal sizes desirable for COM combustion, makes this method very attractive for upstream cleaning of coals destined for such mixtures. Further details are presented later in this paper on the beneficiation ability of the oil agglomeration process with respect to ash and moisture rejection and coal recovery.

i) Demonstration Projects

1. New Brunswick Electric Power Commission - 10 MW_e utility boiler demonstration at Chatham, N.B. This project has been underway since 1977, through a cost-shared program involving COM in-site preparation and boiler operation on a series of COM's based on high-ash, high-sulphur New Brunswick (Minto) coal. Oil agglomeration is an integral part of the COM preparation plant. Various configurations of burner and burner tip have been investigated for erosion resistance.

2. New Brunswick Electric Power Commission - 100 MW_e oil-design utility boiler, at Dalhousie, N.B. The Dalhousie No. 1 Unit has been identified as a candidate boiler to demonstrate COM technology as applied to conversion of a large utility boiler of oil-fired design. This demonstration at Dalhousie is envisaged to commence with a 3-month trial to be followed by a 1-year trial, should the economics of retrofitting to COM as compared to full conversion to coal prove favourable for utility boilers designed for oil-firing in eastern Canada.

3. The Steel Company of Canada Limited - Injection of COM into iron-making blast-furnace tuyères (cost-shared). Phase I, initiated in 1978 and completed in April 1980 under a cost-sharing program, has addressed four aspects: (i) coal-in-oil handling, definition of pumping equipment and transmission pressure-drop characteristics for various COM's, (ii) combustion trials with over 50 individual flames conducted in a simulated tuyère using one coal and three carrier fluids; (iii) design for a three-tuyère blast-furnace trial using the most favourable COM and (iv) design and economic study for complete blast-furnace conversion (16 tuyères) to COM.

ii) Research and Development Projects

Each of the demonstration projects (described above) may also include elements of COM rheological, coal beneficiation, and COM preparation studies, as well as combustion evaluation. The New Brunswick Chatham project has included some slurry stability studies together with determinations of fuel viscosity and pumping requirements. In the blast-furnace tuyère injection project, pumping, fuel metering and the composition and stability of the COM were studied. In the R & D program, some projects such as the Ontario Research Foundation combustion project, have included elements of COM production, coal beneficiation and COM stability. The Nova Scotia Technical College project is basically COM preparation including coal beneficiation, but will include combustion evaluations in a small boiler. For convenience each project will be described under the heading most appropriate to the main area of activity.

a) COM Rheology

The Saskatchewan Research Council, under contract to the Department of Energy, Mines and Resources, has been measuring the rheological properties of COM's. The major objective of this study was to obtain sufficient experimental data on the physical properties of COM's prepared from selected coals to be able to design transfer pipelines for combustion equipment or gasification plants.

The three coals selected for the study, all from western Canada, were a lignite, a sub-bituminous coal and a fines refuse from a metallurgical coal cleaning plant, with the following proximate analyses:

		Lignite	Sub-bituminous	Fines Refuse
Moisture	%	32.7	24.6	0.4
Ash	%	10.4	10.2	21.6
Volatile Matter	%	33.1	34.4	19.3
Fixed Carbon	%	23.8	30.8	58.7
Calorific Value	kJ/kg	13,710	17,330	27,180

The coals were mixed in four size distributions, <6 mm, <840 μm 70 per cent <75 μm and 90 per cent <44 μm. Two oils, No. 6 and No. 2 fuel oils from western Canadian feedstock, were selected for the preparation of the slurries using the various size fractions of the three coals. Rheological data for all of the No. 2 fuel oil COM's were collected using a vertical-tube viscometer at room temperature, but the No. 6 fuel oil slurries were too viscous at room temperature requiring the use of a Brookfield viscometer. However, this instrument could not be used to provide corroborative data on the No. 2 fuel oil COM's since these slurries tended to channel around the viscometer spindles. Maximum and minimum shear rates for some of the slurries are given in Table 1.

Table 1 Variation in Shear Rates for COM's

Slurry Temperature Oil Type and Viscometer \ Coal and Screen Size	Lignite				Sub-bituminous	
	100%<840μm		90%<44μm		70%<75μm	
	Shear Rates, centipoise					
	Max	Min	Max	Min	Max	Min
24^{o}C						
No. 6 Oil-Brookfield	29,570	21,976	127,381	92,171	78,822	57,377
No. 2 Oil-Brookfield	*	*	3,174	369	1,986	319
No. 2 Oil-Vertical Tube	52	27	282	130	248	77
145^{o}C						
No. 6 Oil-Brookfield	112	110	364	252	283	212
No. 2 Oil-Brookfield	*	*	343	116	278	98

*Settled too rapidly for measurement

In addition, rheological properties of COM's using the three coals together with residual bitumen and pitch products available from the extraction and upgrading of western Canadian oil sands will be investigated in the near future, requiring a specially-constructed vertical tube viscometer which can operate at temperatures up to 300°C.

b) COM Preparation

A study of the continuous wet grinding of coal in oil to produce a COM is being undertaken by General Comminution Inc., of Toronto, Ontario, using the recently developed orbital grinding "Szego" mill. This mill, together with some data from two small prototypes (500 kg/h) has been described by Trass (4). The objective of the current project is to obtain performance and scale-up data leading to the design of a commercial-sized Szego mill with a throughput of 10-30 tonne/h COM having a coal size of 80-90 wt per cent less than 75 μm (200 mesh). To obtain these data, a 1-3 tonne/h COM prototype will be constructed and operated using three different coals. If successful, use of such a mill should reduce costs of grinding coal to the 10-20 μm size range resulting in improved ash and sulphur rejection during the subsequent oil agglomeration step.

A second study on coal beneficiation and preparation of COM fuels is being undertaken by the Centre for Energy Studies at the Nova Scotia Technical College, Halifax. The objective of the study is to produce and utilize COM's using local Nova Scotia coals and also coals from washery refuse piles. It includes elements of coal preparation and cleaning by oil agglomeration, combustion evaluation in a small boiler, and rheological studies in a pipeline test loop.

In a third project also in the Province of Nova Scotia, the Scotia Liquicoal Company with Nova Scotia and federal government funds has begun design and construction of a pilot plant to produce COM using local coals. The company has acquired the Canadian rights to technology developed at the Kentucky-based Liquid-Coal Corporation in which an ultrasonic reactor is used in the preparation of a COM containing 50 wt per cent coal, 30 wt per cent of No. 4 fuel oil, and 20 wt per cent water. These proportions are not fixed and it is expected that heavy fuel oil can eventually be utilized, as well as lighter grades. In the later phases of this project, it is envisaged that a combustion evaluation will be undertaken in a small industrial boiler. It is hoped to be able to establish the viability of a commercial COM production facility for marketing purposes.

c) COM Combustion

The combustion R & D component of the COM program has been designed to complement the combustion evaluations in the demonstration projects.

At Chatham, New Brunswick, the demonstration project on a 10 MW_e boiler has a significant combustion R & D component. It has been established that the combustion characteristics of COM are excellent, but that the major problem is progressive erosion of the burner tips which causes deteriorating flame stability. In the current phase of operation, January to April 1980, the performance of several novel burner tips and tip insert materials are being studied in order to resolve this problem.

In addition, staff of the Canadian Combustion Research Laboratory has undertaken measurements of total heat and radiative fluxes from the COM flames at Chatham when operating on 15 to 25 wt per cent coal. These measurements should enable heat transfer predictions to be made on scale-up to larger oil-fired boilers. Simultaneous measurements of in-situ flyash resistivity from COM combustion in the boiler will provide data for the adequate design of dust collection equipment for scale-up purposes.

In the Stelco blast-furnace tuyère injection demonstration project, a combustion study of COM's has been completed. An experimental unit comprising a fuel handling system (1-5 kg/h COM), a system to preheat air to 980°C, and a combustor was designed and built for the project. The combustor consisted of a tuyère injecting into a 3 x 1 m furnace with provision for flame measurement at ten locations downstream of the tuyère. The measurement capability therefore extended beyond the boundary of the simulated blast-furnace raceway. Over 50 individual flames have been assessed in this system. These flames reflect combinations of one coal in three carrier fluids, two load levels, three coal size distributions and three COM coal concentrations. These combustion trials have established that a number of COM's are acceptable for blast-furnace tuyère injection. The next phase of the project is a design study for a three-tuyère blast-furnace trial, incorporating the results from the combustion study.

The Ontario Research Foundation (ORF) has undertaken pilot-scale combustion studies of COM's and COM's containing emulsified water. The project began in June 1978 and the combustion trials were completed by the end of August 1979 (5). Project co-sponsors besides Energy, Mines and Resources, were the Ontario Ministry of Energy, Ontario Hydro, Gulf Oil Canada Ltd. and Stelco. In addition to the combustion evaluation, the program includes coal cleaning and COM preparation. Slagging and fouling assessments of COM's were made as well as detailed pollutant emissions tests. The three coals selected were a western Canadian low-sulphur bituminous, an eastern Canadian high-ash, high-sulphur bituminous and a Pennsylvania bituminous coal.

In the coal beneficiation work, samples of each of the three coals were 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 U.S. coal was simply crushed, double-screened, and pulverized prior to COM preparation. The preparation of the COM had originally included use of a vortex mixing device so that the coal and oil or an oil emulsion could be mixed to form the COM which would then be passed to the burner without contacting a pump. This arrangement would eliminate potential pump erosion problems such as those which had been experienced in the Chatham demonstration project. However, preliminary work at ORF on COM preparation using the vortex mixer indicated that the mass throughput was too low to form a COM suitable to be fed directly to the burner. Consequently, work on this aspect of COM preparation was deferred and a simple shear-mixing tank was installed to provide the COM fuel. The vortex mixing device, however, was used to produce an emulsion which itself was used to form a COM with micro-dispersed water, and this was tested and compared to COM alone.

In the combustion evaluation, the three coals were mixed to form a 30 wt per cent coal COM and also a 30 per cent COM containing 20 per cent water. Tests were conducted at two firing rates, 2.1 MW and 1.0-1.2 MW and using two different types of burner, a high-intensity burner developed in conjunction with Gulf Oil (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 burner produced a highly swirling flame with some wall flame impingement.

iii) Beneficiation of Coals for Coal-Oil Mixtures using Oil Agglomeration

As already mentioned, a key part of the Canadian coal-oil-mixture program is the adaption and integration into the slurry preparation stages of the Spherical Agglomeration Process developed by Puddington and co-workers (6,7) at the National Research Council of Canada in Ottawa. The advantages to the overall COM preparation-combustion system of this method of cleaning fine coals, together with interest shown in this aspect of the program from other countries, merit a special section in the present paper.

The principle of the method is that fine particles in suspension can readily be agglomerated by the addition under agitation of a bridging liquid which preferentially wets the solid particles and is immiscible with the suspending liquid. In the cleaning of coals by grinding in water to release impurities, the carbonaceous constituents can be agglomerated and recovered with many different oils as a collector liquid, while the inorganic constituents remain in the aqueous suspension and are rejected. Conventional gravity methods for the cleaning of coals are not practical for particles finer than about 100 mesh (0.15 mm) and methods such as froth flotation which depend upon differences in surface chemistry of coal and foreign matter are used for the finer sizes. Flotation, however, becomes less effective where extremely fine sizes of coal must be processed or if there is considerable clay slime present. The Spherical Agglomeration Process provides an attractive method for the cleaning and recovery of these ultrafine coal particles in the form of compact, oil-bonded aggregates.

This ability to work with fine coal particles is particularly useful for coals which contain finely-disseminated impurities. These coals can be ground in water to a size sufficiently fine to liberate the required amount of impurities and reconstituted as oil-bonded agglomerates free of the liberated mineral matter. Alternatively, fines contained in waste slurries from conventional cleaning operations can be recovered by oil agglomeration as a low-cost source of clean fine coal. This latter aspect is particularly important where friable coals are being mined. The coal beneficiation ability of the oil agglomeration process will now be considered with respect to ash and moisture rejection and coal recovery. Pilot-scale equipment used for on-line coal cleaning during COM firing at the Chatham, New Brunswick, demonstration project will be described together with some initial cleaning results in this and related applications.

a) Impurity Reduction and Coal Recovery

The ability of the oil agglomeration process to work with extremely fine sizes of coal is illustrated by the results in Fig. 1.

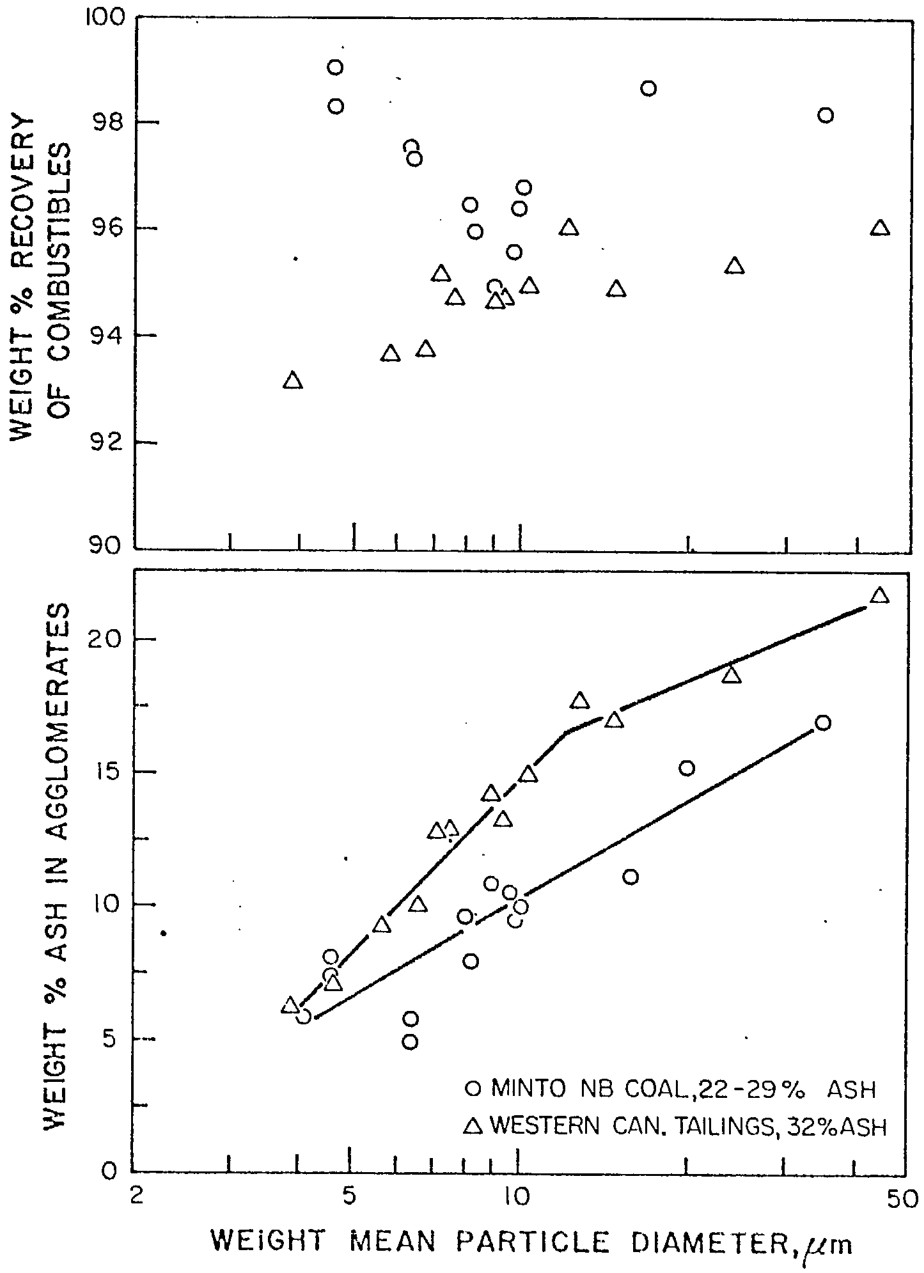

Fig. 1 - Effect of size reduction on ash content and recovery of agglomerates formed from two Canadian bituminous coals.

These laboratory data were obtained using two Canadian bituminous coals, one a run-of-mine thermal coal from the Minto area of New Brunswick and the other a tailings sample produced at a preparation plant treating British Columbia coking coal. Very fine grinding was required to liberate the ash-forming impurities from these coals and produce agglomerates with less than 10 per cent ash. Even with grinding to finer than 10 μm however, selective oil agglomeration was able to recover a low-ash product at combustible recoveries in excess of 90 per cent. Other fines cleaning methods, such as froth flotation, might be capable of recovering a low-ash product even with extreme fines, but the yield and recovery of carbon matter is generally much less than that of the agglomeration method.

The properties of the hydrocarbons used as collectors are important as they affect the wetting of the coal particles, and hence the selectivity and recovery of the process. With bituminous coals, most hydrocarbons are acceptable and result in recoveries of combustible matter in excess of 90 per cent provided intimate oil-particle contact is achieved in the mixing. Regarding selectivity, however, the lighter, more refined oils lead to more consistent ash rejection as shown in Fig. 2. The reasons for this behaviour are,

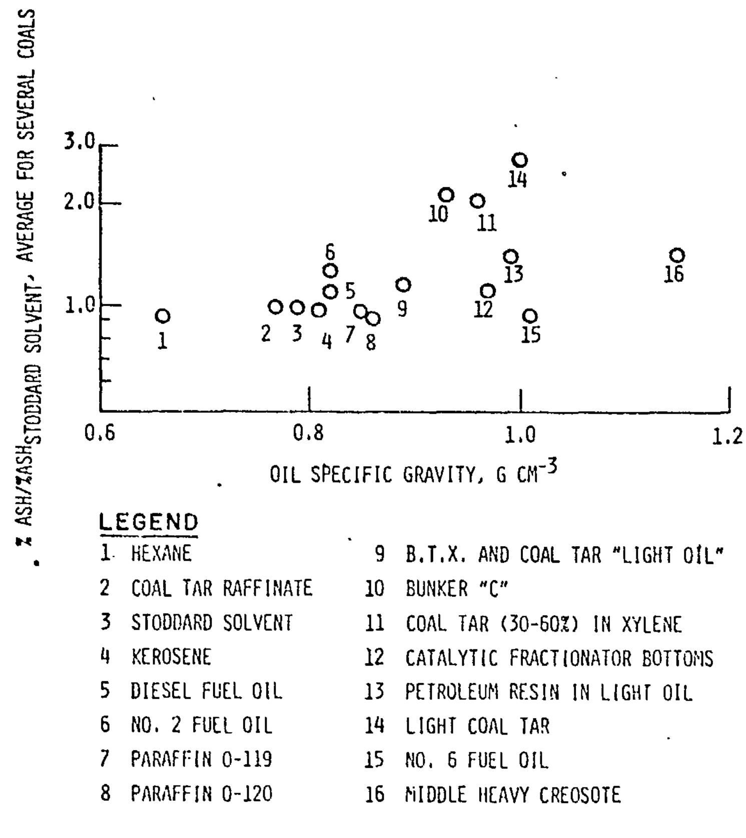

Fig. 2 - Ash content of agglomerates of bituminous coals using various oils as bridging agent.

of course, complex and related to the chemical and physical properties of the oils. If economics allow, hydrocarbons of density less than 0.9 g/cm^3 should normally be used for best selectivity. These lighter oils also achieve efficient and economical coating of the coal particles in the mixer. As indicated in Fig. 2, some heavier hydrocarbons may achieve acceptable ash rejection but laboratory tests are necessary to determine the results to be expected with a particular residual oil source.

b) Moisture Reduction

The adsorption of oil on coal fines during agglomeration displaces moisture from the interior of the agglomerates. The moisture content of the recovered agglomerates is then primarily made up of surface moisture, which in turn depends inversely on the agglomerate size. As shown in Fig. 3, the moisture content of coal fines may be reduced

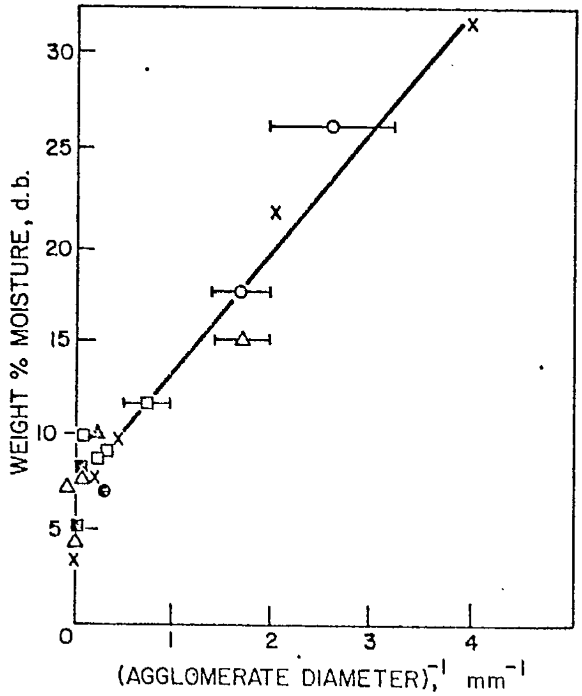

Fig. 3 - Moisture content for coal agglomerates for and for unagglomerated coal as a function of the reciprocal of diameter (2). (Data refers to gravity drainage on screens. X refers to unagglomerated coal of various sizes; Δ, □, O, ▲, ⊠, ⊕, refer to coal fines wetted by oil to form agglomerates of various sizes.)

to less than 10 per cent by agglomeration followed by mechanical dewatering, without the need for thermal or vacuum drying, provided the agglomerate diameter is larger than a certain minimum size. This minimum size is about 2 mm in Fig. 3 where the agglomerates were simply recovered on a stationary 100 mesh (0.15 mm) screen. More rigorous mechanical dewatering, such as with a centrifuge, will produce moisture contents below 10 per cent even with smaller agglomerates.

c) Cleaning of Coal for Admixture with Oil

A schematic diagram of the pilot plant equipment used for on-line coal cleaning prior to COM firing at the Chatham, New Brunswick, plant is shown in Fig. 4. Run-of-mine coal is first dry pulverized

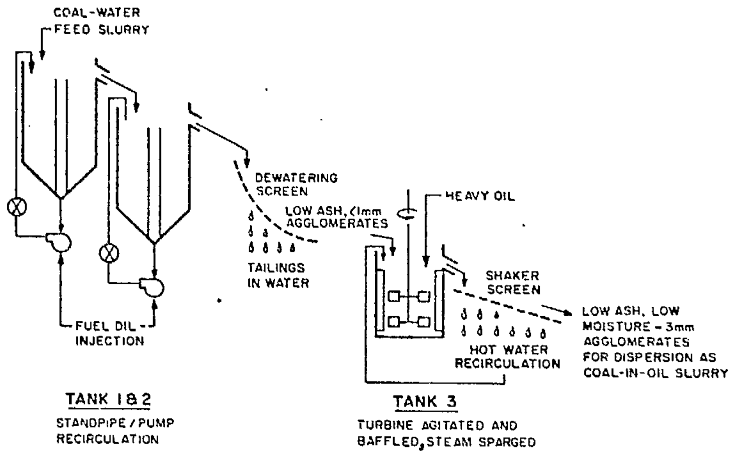

Fig. 4 - Schematic diagram of pilot plant for coal cleaning by Spherical Agglomeration upstream of coal-oil mixture preparation.

to 80 per cent minus 200 mesh and collected into a water slurry by means of a dry cyclone, wet scrubber and mixing system. A wet attrition mill is then used for further size reduction to liberate impurities to produce ash contents of 10 per cent or less in the final recovered agglomerates (cf Fig. 1).

The aqueous coal slurry is then pumped to the agglomeration system shown in Fig. 4. Two agglomeration stages are used to take advantage of the superior de-ashing obtained with No. 2 fuel oil, compared with No. 6 fuel oil (cf Fig. 2). In the first two agglomeration tanks, No. 2 fuel oil is injected into the impellers of the recirculating pumps to form small agglomerates which are then separated from the mineral matter retained in the water phase passing through a stationary inclined screen. Steps are being taken to minimize the requirement for No. 2 fuel oil by using emulsification with water.

The small agglomerates from this initial de-ashing step are then resuspended in hot (approximately 60°C) water in a turbine-agitated tank and mixed with heavy fuel oil (of the type normally used in the power station) to form larger (2 to 3 mm diameter) agglomerates. These agglomerates are sufficiently large, and contain essentially only surface moisture, so that when treated on a final vibrating screen, they dewater to 10 per cent moisture or less (cf Fig. 3). These agglomerates are then readily dispersible in heavy fuel oil to form the COM for combustion with controlled ash and water content.

The feed coal used in the Chatham demonstration project is a particularly difficult one because of its high level of finely-disseminated impurities. It contains 20-25 per cent ash and 7-8 per cent total sulphur (2 per cent organic sulphur) whereas the product of Spherical Agglomeration is targeted to contain less than 10 per cent ash and 4-5 per cent sulphur.

To attain this level of impurity release, as indicated in Fig. 1, the coal will initially require grinding to an ultrafine size. Most coals release their impurities at much coarser sizes. For example, the same pilot equipment shown in Fig. 4 agglomerated coal with 10 per cent ash content from the 31 per cent ash flotation tailings of a West Virginia thermal coal preparation plant (8). Combustible recovery was 95 per cent and no added grinding of the tailings prior to agglomeration was needed to attain this level of impurity rejection.

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