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UTILITY BOILER DEMONSTRATION OF COAL-WATER MIXTURE COMBUSTION AT CHATHAM, NEW BRUNSWICK

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ABSTRACT

Energy, Mines and Resources Canada (EMR) has identified coal-water mixture (CWM) fuels technology as a priority for development in Eastern Canada. Under the Special Atlantic Initiatives Coal Utilization Program, funding has been provided to build a CWM preparation plant, to develop suitable burners and to demonstrate combustion of the fuel in utility boilers typical of the region. Under a cooperative agreement between EMR, the New Brunswick Electric Power Commission and Cape Breton Development Corporation, a pilot-plant CWM preparation facility (4 t/h) has been built to produce fuel for testing in two small utility boilers located at Chatham, N.B. An update is given of the status of this program as well as plans for the future program in Eastern Canada.

DÉMONSTRATION D'UNE CENTRALE ALIMENTÉE AUX MÉLANGES COMBUSTIBLES CHARBON-EAU À CHATHAM, NOUVEAU-BRUNSWICK

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RÉSUMÉ

Énergie, Mines et Ressources (EMR) Canada a identifié le développement de la technologie des mélanges combustibles charbon-eau dans l'Est du Canada comme étant un projet prioritaire. En vertu d'un programme spécial de l'Atlantique sur l'utilisation du charbon, des crédits ont été accordés en vue de construire une usine de préparation des mélanges charbon-eau, de mettre au point des brûleurs appropriés et de démontrer la combustion des mélanges dans des chaudières typiques de la région. Suite à une entente mutuelle entre EMR, la *Electric Power Commission* du Nouveau-Brunswick et la *Cape Breton Development Corporation*, une installation de préparation des mélanges charbon-eau à l'échelle pilote (4 t/h) a été construite afin de produire du combustible pour fins d'essais dans deux petites chaudières qui se trouvent dans le laboratoire de Chatham au Nouveau-Brunswick. Le rapport traite de la situation actuelle du programme ainsi que des projets futurs dans l'Est du Canada.

INTRODUCTION

Interest in coal-liquid mixtures as potential oil replacement fuels has been continuing in Canada since the early 70's (1,2,3). The initial motives for this interest were the rapidly rising cost of oil coupled with an insecurity of supply. The possibility of recurring extreme energy price and supply fluctuations is the reason for continued efforts in the development of coal-liquid-mixtures (CLM) and specifically CWM for utility boiler applications.

CWM offers a means of replacing oil by coal where direct substitution of a solid fuel is impossible or uneconomic. Utilities and other industries which might use CWM are generally not in a position to switch until there is proof that it can be burned reliably and safely. Eastern Canada is the only part of the country where power generation is from oil, which is usually imported. Therefore, the decision was taken to investigate the potential use of CWM in Eastern Canada because of its most urgent need, because of the possibility of environment benefits, and because there are more smaller utility boilers of a suitable size and configuration for demonstration in the east.

The present program seeks to demonstrate the combustion of CWM at a small utility-scale in two small coal-capable units. It is then planned to proceed to demonstrations in a small oil-designed unit and ultimately in oil-designed units of normal utility-scale. Once all of these demonstrations have been completed it is anticipated that normal commercial practice will take advantage of the technology, when it is economic to do so. This paper and two others to be given later in the symposium report the progress in the development of CWM technology to meet these requirements.

BACKGROUND

In April 1982, Energy, Mines and Resources Canada (EMR), the New Brunswick Electric Power Commission (NBEPC) and Cape Breton Development Corporation (CBDC) entered into a collaborative agreement to demonstrate the preparation of CWM and its utilization in utility boilers. This agreement provided for the construction of a 4 t/h CWM pilot plant based on the Carbogel process to be located in Sydney, N.S. It also specified that burners should be developed and tested in the 12.5 MW(e) Unit 1 front-wall fired boiler and the 22 MW(e) tangentially fired unit located at the Chatham, N.B. generating station. The project is administered by a management committee, comprising representatives of EMR Canada, NBEPC, CBDC, the Nova Scotia Power Commission (NSPC) and AB Carbogel. Technical input to the project is through a technical committee, which in addition to management committee members, includes representatives of the National Research Council (NRC), Ontario Hydro, New Brunswick Research and Productivity Council and the Centre for Energy Studies of the Technical University of Nova Scotia.

The major objectives of the project were to build a pilot plant which would produce 6000 t of CWM for burner and boiler evaluations to be undertaken in the two Chatham units, after the necessary preliminary burner testing had taken place at the manufacturer's test facilities. Since the agreement called for the burner development program to run concurrently with the CWM pilot-plant design and construction, 550 t of CBDC coal was shipped to Sweden for design fuel

Table 1 - Comparative properties of coal feed, CWM and No. 6 fuel oil

	Washed Coal		CWM	
	As rec'd basis	Dry basis	As rec'd basis	Dry basis
Moisture %	8.0	-	30.0	-
Ash %	2.8	3	1.2	1.7
Sulphur %	1.1	1.2	0.6	0.9
Volatile matter %	33.6	36.5	26.0	37.0
BTU/lb	13,550	14,750	10,500	15,000
MJ/kg	31.5	34.3	24.4	34.9

	No. 6 Fuel Oil	CWM
Specific gravity	0.95	1.18
BTU/gallon	180,000	124,000
Viscosity centipoise ($35 s^{-1}$)	100 (heated 75°C)	1000(ambient)
Maximum particle size	-	250 m

manufacture. This fuel was then used for burner evaluation, prior to installation in the Chatham units.

CWM PILOT-PLANT

The CWM pilot plant, is operated by CBDC at its Victoria Junction coal washery plant site in Sydney, N.S. At present the feedstock is 4% ash, 1.5% S, metallurgical grade coal, which is cleaned to about 1.6% ash and 0.9% S in the CWM preparation plant. The plant capacity in the original design was 4 t/h during the period immediately after the Chatham tests. Table 1 shows typical properties of the coal feed, the CWM and a comparison with No. 6 oil. Details of the plant flowsheet were previously reported (4).

Final installation of the equipment was completed in June 1983 and the plant start-up was in July with the first shipment to Chatham in mid-July. Production at the plant was implemented without any commissioning tests and a number of problem areas were identified:

a) Grinding - the ball mill charge proved to be of too hard a material, causing breakdown and down-stream pluggage problems.

b) The correct feed rate/size distribution configuration had to be ascertained and fine tuned.

c) Size classification (cyclone and sieve blend) - proved to be inadequate, thereby overloading the secondary ball mill shaft.

The overall result was that fuel quality was variable during the initial two to three months of operation, which resulted in some problems at Chatham. These problems have now been largely overcome and plans are in hand to increase the capacity of the plant to 7 t/h. At the time of writing, about 3000 t of CWM have been produced, shipped and burned in the Chatham units and another 3000 t will be needed to complete the program. During the past winter a cold weather handling and utilization program was conducted and much useful information was accumulated on this aspect of the use of CWM. The present schedule at the pilot plant will include the addition of improved screening capability for particle-size control and quality control procedures for each component of the plant. These actions are to take place during April-May 1984, leading to resumption and completion of the burner/boiler evaluation at Chatham during the summer (5).

BURNER AND BOILER COMBUSTION EVALUATIONS AT CHATHAM

The agreement between the three parties provided for the development and evaluation of CWM burners and boiler performance for the two units of the Chatham generating station. Consequently, after a management committee selection process, NBEPC awarded two contracts for the development, design, and supply of burners for the two units. One contract was awarded, for the testing and supply of burners for the Chatham No. 1 unit. This unit is a front-wall fired balanced draft boiler, designed with a capacity of 12.5 MW(e), when burning New Brunswick coal. It was converted to burn No. 6 fuel oil in the early 60's and was used to conduct a coal-oil mixture (COM) evaluation during 1977-1980 (6). A second contract was awarded by NBEPC for the development, testing and supply of burners for unit No. 2. This unit is a tangentially-fired balanced-draft unit of 22 MW(e). It was also designed to burn New Brunswick coal, with subsequent conversion to burn No. 6 fuel oil.

Working with each of the burner developers, NBEPC developed a detailed test program for the two units. The objective of the test program was to evaluate the wear characteristics of the burner nozzle materials and particular burner atomizers and to evaluate burner performance with respect to carbon conversion efficiency, excess air and burner aerodynamics and NO_x, SO_x and CO emissions. Assessments of boiler performance, efficiency changes with heat rate, and studies of the auxiliary equipment used in the fuel handling system were included.

A series of base line tests was conducted on No. 6 fuel oil, at 50%, 75% and 100% load. The general concept of the test program was to run a series of tests with reference liquid fuel and then, after the shakedown period, run a second set of tests with the CWM using the same test levels and, insofar as possible, the same loads. Emphasis was placed on the quality and accuracy of the data acquisition during the test program. In addition to the standard input/output boiler efficiency, pressure and temperature measurements, a number of gas side test points were added to obtain indirect boiler efficiency in accordance with ASME PTC 4-1. Oxygen and temperature grids were installed between the superheaters and steam generating banks to identify air in-leakage, gas stratification and temperature profiles. Similar oxygen temperature grids were installed at the boiler outlets and the air-heater outlet gas side.

The test program for each unit was essentially the same, with only minor changes necessitated by their different configurations. A fuel system was set up which was capable of unloading from three rail-tanker-car positions directly into one of the coal bunkers, which had been converted for the storage of CWM fuel in the plant. The fuel was then recirculated to the burner front of the particular unit being tested, using progressive cavity pumps. This system was set up to facilitate switching from unit 1 to unit 2.

A detailed inspection was conducted of the No. 1 boiler to identify potential problems. No attempt was made to bring the unit to an "as new" condition but emphasis was placed on the ability to obtain reproductible results during the extended period of testing on oil and CWM. Considerable importance was placed on reducing air infiltration through the boiler casing and the insulation and refractory were replaced where necessary. The boiler and air-heater gas passes were cleaned and the sootblowers were examined. These were found inoperable and were left so due to the problems of obtaining spare parts.

Four independent burner windbox assemblies were supplied and installed in the boiler to accommodate the new burners. Modifications were required to both the front wall and the combustion air ducting. Five front-wall tubes were replaced to accommodate the larger burner throats. Brick work and refractory around the throats were modified and the combustion air-ducts were changed to fit the deeper burner windboxes. Balancing dampers were removed from the duct work and incorporated as sleeve-type damper burner registers.

Each of the new CWM burners was rated at 40 GJ/h thermal output. Ignition and support energy provided by two light-oil pilots were each rated at 6 GJ/h. Each burner was provided with numerous adjustments, some of which, are not normally present on commercial burners. These were provided to allow for the precise adjustment necessary to optimize burner performance. Some of these adjustments are inner-throat position, swirler position, fuel-gun position, igniter position and HESI position. The same burner was used to fire heavy oil by changing the fuel atomizer tip and position of the primary air damper. No other modifications were necessary, and change over was effected rapidly.

The No. 1 boiler is operated manually by the operators, located directly in front of the burners. There is no burner management or flame supervisory system other than the viewing ports at each burner. All burner valves and controls are manual and were arranged for ease of change-over from CWM to oil. Fuel flow was controlled by a manual pinch valve on the recirculation line from the burner front. A second small valve, in parallel with the main control valve, is used to adust the flow according to minor changes in load. The recirculated fuel returns to storage.

A similar detailed inspection was carried out on unit 2 and the necessary modifications were made. The boiler casings were inspected, the tubular air heater was cleaned and spacers were installed in the superheater to return the elements to near their original position.

The test report, from the prototype burner tests at the CE combustion testing laboratory indicated that steam-atomizing was feasible with the selected atomizer. Therefore, in order to provide a wide range of steam pressures for atomizing during the tests at Chatham, a new pressure reducing station was installed.

The windbox air-pressure is very low on the Chatham units (about 0.5 kPa) and in order to supply higher pressure air to the CWM compartment of the burners a booster fan was installed. New burners were supplied and installed on the unit. At each burner location there is a supply of purge water, air for atomizing and purging, steam for atomizing both oil and CWM, light oil for ignition, No. 6 fuel oil for oil firing and CWM fuel.

The No. 2 boiler is also operated manually by the operator, located adjacent to the boiler. There is no burner management system or flame supervisory system other than viewing ports and a television camera which views all four burners from above. All burner valves and controls are manual and are arranged for ease of change-over from CWM to oil. Fuel flow is controlled by a manual pitch valve on the recirculation line from the burner front. A second small manual valve, parallel with the main control valve, is used to trim the flow according to minor changes in load.

At the time of writing (April 1984), baseline oil tests have been completed on unit 1 and 10 MW(e) was selected as full load on the unit. The unit has been operated at full load on CWM without oil support and ignition has proved to be straight forward, using a single igniter. This igniter can be removed at 20% load, without loss of ignition. CWM flames in the unit have been stable at excess levels, comparable to pulverized coal firing. Nozzle material evaluation has been completed for a number of materials and wear resistant material has been selected for longer term evaluation. About 100 h of this evaluation has been completed. Switching between CWM and oil fuel was achieved rapidly and without problems. The initial CWM baseline tests have been completed and full performance tests should be proceeding soon.

The burner and boiler evaluation on unit 2 has not yet been completed, although some preliminary tests have been made. These tests indicated some problems and it was decided to install windbox modifications and refractory panels on the side walls. These have now been completed for the tests in June or July 1984. A schedule for the tests at Chatham is given in Fig. 1.

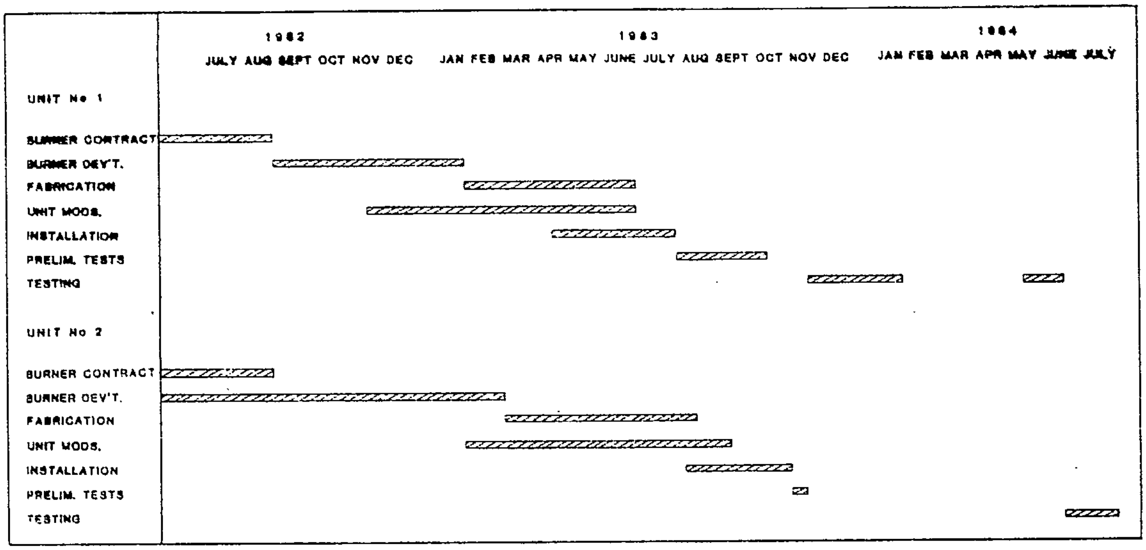

Fig. 1 - Bar chart showing schedule of Chatham tests

FUTURE PROGRAM

The major emphasis of the current program is to assess whether CWM is feasible for use in utility boilers. There will obviously be many side benefits of the program in the industrial sector, particularly in the area of burner development for CWM. Because of the much wider variety of industrial boilers and process combustors it is clear that the non-utility development of CLM technology will be much more difficult. However, whilst much scale-up information will be generated as larger utility demonstrations proceed, the smaller Chatham units are typical of many industrial boilers which may directly utilize the operating experience gained there. Consequently, at the conclusion of the CWM mixture program in Canada, some of the industrial sector, particularly large kilns and boilers, may convert to CWM as fuels. There will also be a need for significantly more R & D support for the penetration of CLM into the industrial, marine and diesel markets.

The next stage planned for the CWM utility demonstration program in Eastern Canada will be the selection and testing of burners in a 20 MW(e) oil-designed front-wall fired boiler located in Charlottetown, P.E.I. and operated by Maritime Electric Company Ltd. This stage will not only test burner technology similar to Chatham, but will indicate boiler-side feasibility of the fuel in the more compact oil-designed unit. It is hoped that the Charlottetown demonstration will be completed by mid-1985. Following the Chatham and Charlottetown demonstrations, scale-up is the next obvious step. Design of burners for front-wall or tangentially fired boilers in the 50 to 150 MW(e) range is planned as a third phase of the CWM program. A start has been made on a generalized derating study which uses modelling techniques to predict boiler performance, when boilers designed for oil are fired with CWM (7,8). At present, specific derating effects cannot be accurately predicted, because there is insufficient experience connecting the formation of ash from CWM flames burning finely ground coal in an atomized spray to the slagging or erosive effects on boiler tube surfaces. Also, it appears that the emissivity and burning characteristics of CWM are unlike pulverized coal flames and this will significantly influence derating. When more information concerning ash properties, ash formation, and combustion characteristics is available from the current work, the program will continue to include specific application studies to 100-150 MW(e) oil-fired boilers in Atlantic Canada. These studies will determine the minimum overall cost, by balancing the costs of boiler operation and derating against those of fuel preparation and beneficiation.

There are eight oil-designed steam generators in the Maritimes, in the range 100-150 MW(e), which are amenable to CWM conversion. In selecting candidate steam generators most suitable for conversion, the technical and economic merits of each unit will need careful consideration. On one side of the techno-economic equation, there is the differential fuel cost specific to the site, between No. 6 fuel oil and CWM. This differential cost, over the remaining plant life, must be expected to be in excess of the following total debits:

1. Capital (investment) cost of all CWM support equipment, including any steam generator modifications.
2. Change, i.e., increase in operating and maintenance costs.
3. Remaining life of the rest of the plant equipment.
4. Change of steam generator availability due to an increase in forced outage rate.
5. Derating penalty.
6. Change in unit heat rate, caused by a decrease in steam generator thermal efficiency.
7. Environmental impact

These system liabilities are expanded upon below:

1) Capital Investment

To convert a steam generator, originally designed for No. 6 fuel oil, considerable investment will be required; such as the provision of reliable equipment necessary to transport the CWM to the burners as well as all peripheral equipment, e.g., sootblowers, ash handling systems and new, or modifications to existing, automatic boiler control equipment. In addition burners will have to be provided, including windbox modifications, to burn the CWM and equipment for meeting emission standards for NO_x, SO_x and particulates.

2) Operating and Maintenance Costs

The operating and maintenance costs for heavy fuel oil are relatively low, since they principally include handling, pumping and heating, oil burner maintenance and replacement and a modest amount of ash handling and disposal. The costs may also include high and low temperature gas side component replacements, due to the corrosive effects of vanadium and sulphur oxides. Such costs for these factors are well established from the operation of pulverized-coal fired units.

For CWM there may be reduced heating costs and no vanadium attack on high temperature gas side components. There will, however, be a considerable increase in operating and maintenance costs due to the handling of an abrasive liquid. Pumps, pipework, and burner replacements are all expected to increase by an order of magnitude over fuel oil. Sootblower maintenance will also increase and hence so will make-up water requirements.

Even with beneficiated CWM of 1.5% ash, the problem of bottom and fly ash removal and disposal will be an order of magnitude greater than for fuel oil. While no specific figures are available for CWM operating and maintenance costs, it would seem reasonable to assume that costs for any CWM conversion will be similar to comparable pulverized-coal fired units.

3) Remaining Plant Equipment

If, in converting a steam generator from fuel oil to CWM, the unit capacity factor increases, then consideration should be given to the extra costs that could be incurred by the interim balance of plant replacements. These costs could include expensive items like low pressure turbine blades, condenser re-tubing and existing ash disposal site enlargement. Any increase in capacity factor should also be included in steam generator interim replacements, such as superheater and reheater tube life, air heater elements or tubes and low temperature gas ductwork.

4) Change in Steam Generator Availability

It is a statistical fact that forced and partial forced outages for steam generators burning fuel oil are less than those burning pulverized coal. The problems associated with the handling and burning of a homogeneous, non-abrasive fluid, are clearly less than those associated with the handling and burning of an abrasive liquid fuel. This being so, where does CWM fit into availability statistics? While mechanical handling problems are seen to be less for CWM than for pulverized coal, a bigger problem is expected from the slagging and fouling potential in the first pass superheater and/or reheater. This is due to the reduced furnace dwell time and reduced first pass tube spacing of units designed to burn fuel oil. The ash characteristics of CWM could also have a strong influence on slagging and fouling. Since there are no figures on availability for CWM, but because of the foregoing, it would again seem prudent to assume that CWM units will have availability statistics similar to pulverized-coal units.

Hence, in the techno-economic analysis, an extra penalty will be invoked by CWM over fuel oil due to a decrease in availability leading to higher replacement energy costs.

5) Derating

As mentioned earlier, derating in the smaller more compact oil-designed steam generators is expected to be significant (7,8). However, there are many types of utility boiler configurations in the Canadian maritimes, ranging from coal-capable units to those only designed for oil firing. Coal contains considerable ash and the quality usually varies for a bituminous coal from 3% to 25%. At the temperatures existing in the furnace, the ash may become fluid and often will remain adhesive, until the temperature is reduced to about 1100°C.

Coal also has constituents such as sulphur, sodium, iron, and chlorine which can cause corrosion in the high temperature components of the boiler as well as in the low temperature air heater and ductwork components. When designing a coal-fired unit, these fuel characteristics must be considered. The furnace must be of sufficient size to provide time for complete combustion of the fuel, must be arranged with sufficient clearance from burners to walls, and clearance between burners to minimize furnace slagging, and must have sufficient heating surface to cool the products of combustion to a temperature low enough so that the ash particles will not cause fouling in the convection passes.

Since the superheater and reheater surfaces are often installed when the gas temperature is in the order of 1300°C and the slag is usually fluid at this temperature, the superheater and reheater tubes in this section of the furnace are designed with liberal spacing to prevent ash build up. For low ash fusion temperatures, first pass tube spacings of 2 m are not uncommon. The convection surfaces, beyond the furnace outlet, must also be arranged with wide tube spacing starting at about 60 cm at the furnace outlet and decreasing to 45 cm, 30 cm and 23 cm further back as the flue gas temperature is reduced and the ash particles have solidified. By comparison, fuel oil-fired boilers usually have the convection surface tubes arranged on no more than 15 cm centres. Furthermore, for coal-firing, bank depths must be kept to a minimum so that sootblowers can do an adequate job of cleaning the ash which adheres to the heating surfaces.

In present day designs for pulverized coal-fired units, the velocity of the flue gas over the convection surface is limited to about 15 m/s to minimize erosion of boiler parts. By comparison, flue gas velocities for oil-fired units are in the order of 25 m/s. Sootblowers must be provided for cleaning ash from the furnace walls and from the convection heating surface. Hoppers must be provided at the bottom of the furnace and at other strategic points throughout the unit to remove the ash. From the foregoing, it can be see that steam generator designed for fuel oil, will in all likelihood incur a considerable derating penalty when converted to CWM. Because derating is such an important parameter in the techno-economic evaluation, and because it is site specific, it is believed that the best estimations on derating penalties will come from the boiler designer when more information on the combustion characteristics of CWM is available.

6) Changes in Unit Heat Rate

The overall boiler efficiency will decrease, primarily because of an increase in wet flue gas loss, and to a lesser extent, an increase in dry flue gas loss. The latter will depend on the extra excess air requirements and the final flue gas exit temperature compared with design levels. Depending on the extra sootblowing requirements, there will also be an increase in make-up water requirements. These losses should all be factored into the economic equation, since cumulatively they could decrease the overall boiler efficiency by as much as 3%. There may also be increases in fan power requirements and unburnt carbon losses.

7) Environmental Impact

The impact of air quality will change when converting from fuel oil. The changes will be mostly reflected in SO_x, NO_x and particulate emissions. Depending upon the sulphur content of the CWM in relation to the design fuel, ambient SO_2 might significantly increase. The fuel bound nitrogen and the combustion configuration of the boiler would also impact on NO_x emissions. If predicted ambient NO_x concentrations exceed legislated guidelines, there may be a requirement to increase the stack height. Particulate matter for CWM firing will increase by at least an order of magnitude over fuel oil. This may require upgrading of existing or installation of new high-efficient (99.5%) dust removal equipment.

CONCLUSIONS

CWM has been fired without support energy and ignition of the fuel has proved to be straight forward. Switching to and from fuel oil can be achieved with relative ease and with minimum load disruption. Initial tests with steam atomization on the unit 2 burners showed some promise and these tests will be pursued in the future program. Variation of load with CWM fuel has been proven feasible, (from 25% to full load).

Fuel has been transported and handled in severe winter conditions with few unexpected problems. The CWM consistency has proven to be more problematic than anticipated and the utility and supplier have agreed on a simple quality control procedure to minimize this kind of problem at source.

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