Oxy-Combustion Field Demonstration Project

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ABSTRACT

The application of oxy-combustion methods to the enrichment of carbon dioxide in boiler flue gases has been a primary research focus of the CANMET Energy Technology Center since 1994. This research program has been supported by the Canadian Federal Government, the Alberta Government, an industry group composed of Canadian Electricity Generators, Babcock and Wilcox, Fluor Daniel and the US Dept of Energy.

Oxy-combustion methods show great promise for retrofit to existing pulverized coal fired boilers in order to recover the flue gas stream for sequestration. CANMET's research has concentrated on understanding how to burn pulverized coal using oxygen in a way that preserves the ability to use conventional burners and furnaces sized for operation using air for combustion. The approach taken has been to burn the fuel in a stream of recycled flue gases in order to temper the flame and establish proper heat transfer in the furnace and boiler passages. A key component in the research program has been to explore the potential for use of a Condensing Heat Exchanger (CHX)[R] to both cool and scrub the flue gases prior to recycling them to the furnace chamber.

This paper will present and discuss the next step in CANMET's program which is to apply what has been learned to design and build a technology demonstration unit. This unit will consist of a truck transportable oxy-combustion system rated at 10 Million Btu/hr. A complete product recovery train will be provided. A unique aspect of the project is the desire to make available a real product stream derived from combustion of natural gas or coal for the purpose of a real field sequestration experiment.

This project is being proposed as a collaborative effort involving CANMET, the Gas Technology Institute and Innovative Steam Technologies. The paper will discuss the research and technology development interest of each of the participants and will outline how the demonstration unit could be applied for Coal Bed Methane (CBM) Recovery or Enhanced Oil Recovery (EOR) at sites yet to be determined in Canada or the USA.

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1.0 INTRODUCTION

A strategic research program aimed at capturing CO_2 from large central utility scale electricity generating plants is underway at the CANMET Energy Technology center, a division of Natural Resources Canada. This effort began in 1993 under the direction of Dr. Kelly Thambimuthu with the planning and construction of a unique pilot scale facility located at CANMET's research park in Ottawa, Canada. The Vertical Combustor Research facility (VCRF) has been in continuous operation since it was commissioned in late 1994. This facility is capable of firing pulverized coal and/or natural gas under conditions approximating those found in industrial situations. The unit is capable of achieving firing rates up to 0.3 MWth and features generous access provisions to probe the flame envelope.

A pre-competitive research program arranged in co-operation with an international consortium of private and public sector partners has been the main mechanism used for operating this facility. The focus of the program has been to study the use of oxygen for the combustion of coal in order to enrich the CO_2 content of the flue gases produced. Douglas et al [1] reported research progress at the First National Carbon Sequestration Conference in 2001. Since that time, Phase 6 of the CANMET CO_2 Consortium research program has been executed successfully and reported to the consortium members in January of 2003. Key achievements include the development of a third generation oxy-fuel burner concept and the demonstration of a proprietary approach for multi-pollutant capture within a condensing environment – with promising results for mercury control. These two outputs directly support the development of a technology demonstration unit, which is the subject of this paper.

The Canadian Federal Government made a commitment to climate change research in the Climate Change Action Plan 2000. This program awarded CANMET $ 1.38 million CDN spread over the five years ending March 2006 to support the development of a technology demonstration unit to explore the use of oxy-combustion as a method of CO_2 recovery for sequestration purposes. Part of this funding has been applied over the last two years by CANMET towards the conceptual design of a technology demonstration unit. In mid 2002 CANMET was approached by the Gas Technology Institute to participate in this project. In late 2002 CANMET entered into a contribution agreement with Innovative Steam Technologies, a respected Canadian boiler manufacturer, for the purpose of evaluating the technical feasibility of the demonstration unit concept and designing a boiler to suit the project. Significant interest in the project has also been received from McDermott Technologies/Babcock and Wilcox, who as a partner in the CANMET CO_2 Consortium have helped guide the development of the condensing scrubbing process using their proprietary Condensing Heat Exchanger (CHX)^R design.

This paper will describe the Oxy-Combustion Demonstration Project goals/partners and report progress on the development of the CANMET oxy-combustion burner. The overall system design philosophy will be explained and anticipated performance data will be provided. Finally, future steps necessary to realize the goals of this project will be described.

2.0 PROJECT GOALS / PARTNERS

One can argue that the use of oxygen is a cross-cutting theme for clean fossil energy production in that it is a necessary component of coal gasification and oxy-combustion technologies.

Whereas the intent of coal gasification is ultimately to produce hydrogen for combustion while allowing for capture of CO_2 from within the process, the goal of oxy-combustion is to displace N_2 from the products of combustion, which in turn produces a flue gas stream consisting mainly of CO_2 and H_2O vapor. This stream is then subjected to a condensing process which removes the water vapor leaving a relatively high purity CO_2 stream.

Great emphasis is currently being placed on the role of hydrogen as a carbon free energy carrier. Hydrogen will no doubt attract interest for large gas turbine based combustion systems used for electricity generation and smaller mobile applications where it is clearly impractical to recover CO_2 coincident with the end use application. Whether hydrogen actually becomes the clean energy carrier of choice will depend a lot on the development of effective and efficient production, distribution and storage technologies.

In a similar way, oxygen can be seen as a clean fossil energy enabler for large central power stations burning coal for electricity generation. While the debate continues as to whether gasification or oxy-combustion presents a better path to a clean fossil energy future, it is important to note that oxygen production is a mature technology available today at capacities sufficient for capture of many mega-tonnes per annum of CO_2 per power station. Oxygen can be transported safely and efficiently by pipeline in large quantities and can be stored economically in liquid form. Similar to hydrogen, oxygen can also be produced using renewable energy sources, most interestingly by wind.

In stark comparison to coal gasification, oxy-combustion shows great promise for retrofitting the existing fleet of coal fired power plants. Deployment of oxy-combustion technology could dramatically impact Canada’s Kyoto commitment if the technology is demonstrated successfully at an industrial scale and becomes accepted by the electric utility industry as a viable carbon dioxide abatement strategy.

The primary goal of the Oxy-Combustion Demonstration Project outlined in this paper is to show at a meaningful industrial scale that the combustion of fossil fuels using oxygen instead of air is a viable means of creating a CO_2 rich product stream for use in Enhanced Oil Recovery (EOR) operations or more specifically in Enhanced Coal Bed Methane (ECBM) recovery operations. The second goal of the Project is to make a pilot plant available to conduct experimental oxy-combustion investigations on a variety of fuels including natural gas and coal-liquid mixtures in order to create new combustion system and steam generator performance know-how. The third goal of the Project shall be to make available a CO_2 rich product stream for a practical EOR, ECBM or other sequestration field opportunity.

The Project has been divided into four specific Phases, as follows:

Phase 1: Technical Feasibility and Cost Study
Phase 2: Engineer, Procure and Construct Modular Facility
Phase 3: Commissioning and Field Testing (in Canada)
Phase 4: Commissioning and Field Testing (in USA)

The project is currently nearing the completion of Phase 1, at which point the project partners will be finalized and funding will be solicited in Canada and the US. It is proposed that this project should be included in the joint Canada-US memorandum of understanding between Natural Resources Canada and the US Department of Energy which will facilitate multi-party collaboration on this international project. Once funding is in place, Phase 2 will require approximately 12 months to design and assemble the unit for the field portion of the work.

CANMET's role has been to develop the conceptual design for the facility. CANMET is also interested in supplying a proprietary oxy-combustion burner for the facility, and eventually the control system logic. CANMET also proposes to supply key personnel for the operation of the facility at the proposed home base for the pilot plant in Ottawa and while the equipment is being operating in the field.

Babcock and Wilcox has expressed a desire to assist with the provision of the Condensing Heat Exchanger (CHX) and an alternate oxy-combustion burner for the facility. Air Liquide Canada has indicated their interest in supplying the oxygen for this project. The Alberta Research Council has shown interest in collaborating by assisting with selection of a Canadian coal bed methane recovery site. Innovative Steam Technologies (IST) has expressed a desire to act as overall system integrator and will anchor the Canadian portion of the funding solicitation. IST also proposes to design the steam generator from first principles using its proprietary once through steam generator technology which is easily scalable to the size of this project.

The Gas Technology Institute (GTI) has expressed interest in this project in the area of downstream processing of the flue gas stream including dehydration and CO_2 capture unit operations. GTI would like to demonstrate its newly developed physical and physical-chemical solvent based CO_2 capture technology using a novel membrane contactor that can easily be included in the field portion of the work. GTI is especially interested in collaboration in the field sequestration and monitoring component of the work related to coal-bed methane recovery. GTI is specifically interested in using the oxy-combustion demonstration facility to study the effect on methane recovery of the presence of various quantities of nitrogen within the injected gas stream under actual field operating conditions. GTI has extensive experience in managing field demonstration projects in both Canada and the US and proposes to anchor the US portion of the funding solicitation. GTI also proposes to select a suitable coal bed methane recovery site in the US and supervise the operations at the US field site.

3.0 RESEARCH PROGRESS

During the winter of 2002, the Vertical Combustor Research Facility was modified to incorporate a new one meter inside diameter combustion chamber and a new third generation (MK III) oxy-combustion burner. Both were designed using CANMET's extensive experience with application of Computational Fluid Dynamics modeling techniques for simulation of oxy-combustion. The larger combustor barrel was designed to minimize wall effects on the flame, and the new burner was designed to take advantage of the larger furnace volume in order to better manage the oxygen distribution within the flame. Both effects were thought to be important by CANMET in extending the art of oxy-combustion with pulverized coal flames.

While the specific details of the burner are confidential due to the need to protect CANMET's know how in this area, the goal of the design has always been to develop a concept for retrofitting burners originally designed for combustion in air to oxy-combustion service utilizing flue gas recycle. A key goal of the development has been to preserve the operation of the burner using air if required.

The MK III oxy-burner was tested on Jan 16, 2003 and achieved successful operation during its first run. The fuel used for the initial test run was a pulverized western Canadian sub-bituminous coal (Highvale) with properties as shown in Table 1. The coal was first dried and pulverized to 70 % through 200 mesh the day before the test, then entrained using clean dry CO_2 from a bulk storage container during the day of the test. The burner was operated using recycled flue gases with approximately half of the oxygen being premixed into the recycled flue gases just upstream of the burner and the remainder of the oxygen being delivered in pure form within the overall flame envelope. Due the preliminary nature of the test, the recycled flue gases were not scrubbed for sulfur removal.

Table 1 – Coal Analysis for MK III Oxy-Burner Test

Proximate analysis (as fired)	**% by weight**
Moisture	11.85
Volatile matter	29.71
Fixed carbon	43.59
Ash	14.85
Ultimate Analysis (as fired)	**% by weight**
Carbon	54.44
Hydrogen	3.21
Nitrogen	0.74
Sulfur	0.19
Ash	14.85
Moisture	11.85
Oxygen	14.72
Total	100.00
Higher Heating Value (Btu/lb)	8957

Table 2 presents the performance results taken during the MK III oxy-burner test using the Highvale coal.

Table 2 – Performance Results During MK III Oxy-Burner Test

Fuel : Highvale coal fired in dry pulverized form
Mode of Combustion: Oxy-combustion with flue gas recycle
Excess Oxygen : 3.4 % by volume dry basis
CO_2 Concentration : 77 % by volume dry basis

Measured Emissions: averaged over duration of test

Averaged Emissions	ppm by vol dry
CO	25 ppm
SO_2	384 ppm
NO	800 ppm

Estimated Emissions: calculated, Ng/J basis

NO = 97 ng/J or 0.23 lb/MM Btu

Figure 1 illustrates the test conditions (excess O_2 and CO_2 concentration) during the test.

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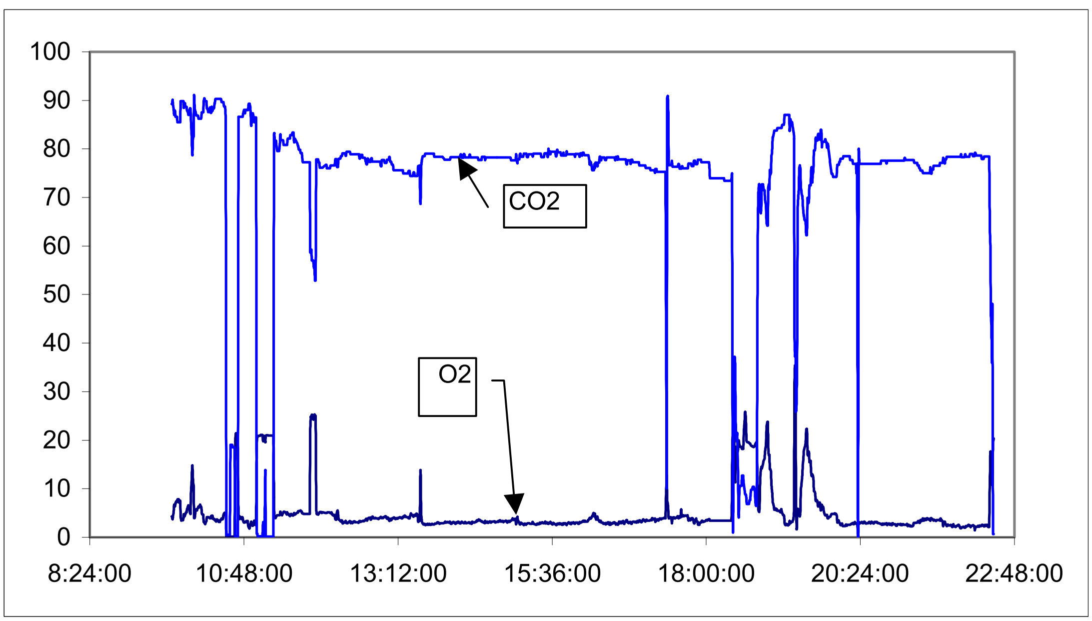

Figure 1 – MK III Oxy-Burner Test Conditions: Excess O2 (%) and CO_2 (%) on dry basis

Figure 2 illustrates the gaseous emissions (CO, SO_2 and NOx) during the test.

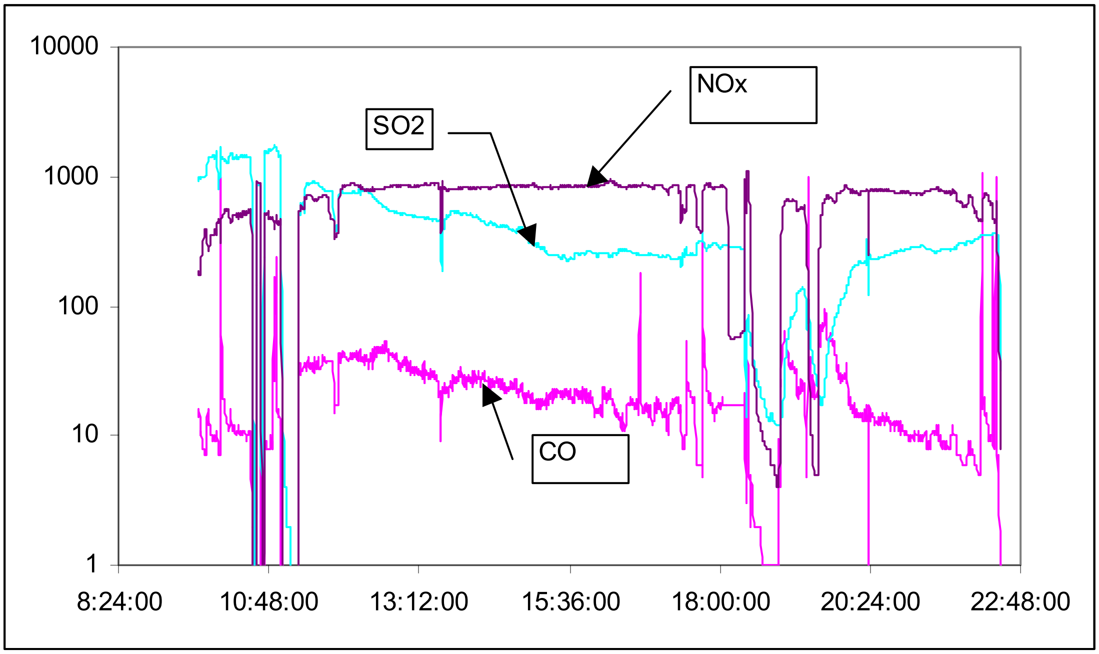

Figure 2 – MK III Oxy-Burner Test Emissions : CO, SO_2 and NOx in ppm on dry basis

Notice that the period from about 13:30 to about 16:00 was characterized by stable fuel delivery and stable emissions. The period after 18:00 experienced some fluctuations due to system trips (High O_2 limit breached in the secondary stream for the first one and a contractor shutting off the CO_2 by accident for the second one).

The test was considered a success as it demonstrated stable operation of the MK III burner concept. Following the initial test, a second test was performed on Feb 19, 2003 using Highvale coal, followed by tests on Apr 1, 2003 and Apr 23, 2003 using a Saskatchewan lignite coal. The results of these tests were also very successful and will be reported in the future. Additional tests are planned in 2003 to optimize NO_x emissions.

It should also be mentioned that during the summer of 2002, two tests were performed using eastern bituminous coal prepared as a coal water mixture and fired in air. These tests were done to gain first hand experience preparing and firing such coal water mixtures. The first such test used micronized eastern bituminous coal fired at a solids concentration of 55 % and the second test was done using a run-of-the-mill pulverized eastern bituminous coal at a solids concentration of 50 %. Both were successfully fired using a single air atomized axial injection orifice on the centerline of the older smaller combustor (0.6 M ID). The purpose of these two tests was to demonstrate the potential to fire coal in the field demonstration unit using a coal water mixture for convenience.

4.0 SYSTEM DESIGN PHILOSOPHY

The combustion system, steam generator and balance of plant equipment shall be designed to serve the needs of a single injection well while the unit is located in the field.

The system has been sized to yield 300,000 SCFD of injection gases which is considered sufficient to conduct a meaningful sequestration demonstration while ensuring the single burner provided is sufficiently large to represent industrial practice. It is proposed that the entire system be shop assembled in a series of truck transportable modules requiring only interconnection in the field. Larger system capacities could be considered depending on the available funding, although increasing the capacity of the unit raises operating costs and is ultimately constrained by truck transport limitations.

The firing system shall be designed to use natural gas or alternatively propane while in the field and shall be rated at 10 million Btu/hr firing such gaseous fuels. The unit shall be capable of limited periods of operation at loads up to 6.5 million Btu/hr firing a coal water mixture to simulate the flue gas composition and sulfur species that would be present during coal firing.

Figure 3 illustrates the proposed configuration of the combustion system.

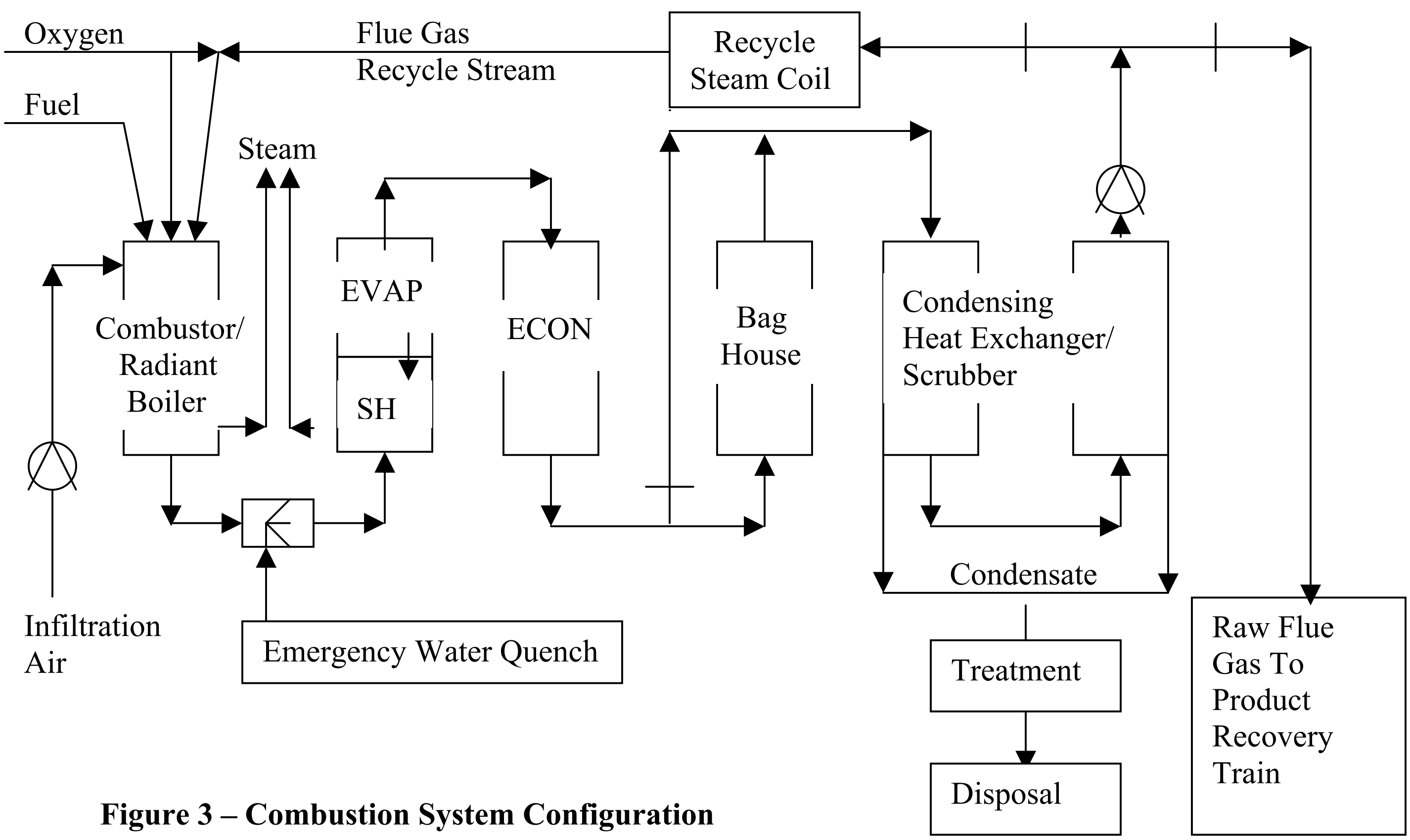

Figure 3 – Combustion System Configuration

The unit shall be designed to start in air and transition to oxy-firing in a smooth and continuous manner such that a constant volume of recovered flue gas can be produced with a variable CO_2/N_2 ratio.

Oxygen will be delivered to the burner by evaporating high purity liquid oxygen product stored on site in a cryogenic storage vessel. Air is delivered to the burner by a forced draft fan sized for start-up conditions only. Air injection can also be used to blend nitrogen into the flue gas stream as required.

Combustion temperatures in the furnace shall be maintained close to those experienced in air by re-circulating cool dry flue gas and by application of radiant cooling surface located inside the combustor. The recycled flue gas shall be drawn from an indirect contact condensing heat exchanger/scrubber and preheated sufficiently above the dew point so as to keep the ductwork and burner dry under all conditions.

The combustor shall be configured as a cylindrical down-fired radiant cooler with inside dimensions of approximately 6 Ft. diameter x 20 Ft. high. A bare tube helical once-through steam generating circuit shall be mounted adjacent the inside face of the insulating lining. The combustor shall be rated at up to 5000 Lbs/hr of steam production at 750 Psig. / 750 F.

The Heat Recovery Steam Generator (HRSG) shall be a bare-tube in-line once-through steam generating circuit mounted in a lined duct. The HRSG shall consist of superheater (SH), evaporator (EVAP) and Economizer (ECON) surfaces arranged for counter-flow operation. All surfaces shall be arranged horizontally and shall be fully drainable in order to lay up the unit dry with minimum effort during winter conditions. The HRSG shall be capable of accepting flue gas temperatures up to 1500 F and shall be rated at up to 2500 Lbs/hr of steam production at 750 Psig. / 750 F.

Clean water shall be made available for quenching the flue gases leaving the combustor during periods when the combustor exit temperature is too high or when it is desired to increase the moisture content of the flue gas stream going through the HRSG for data collection purposes.

A baghouse will be provided to remove fly ash during coal firing. The water temperature entering the economizer will be controlled to maintain the flue gas temperature entering the baghouse appropriately for prevention of condensation on the baghouse filter cloth. The baghouse will be by-passed at all times when firing gaseous fuels including start-up.

A Condensing Heat Exchanger (CHX) shall be provided to cool the flue gases to near ambient conditions prior to recycling. The CHX shall be provided by Babcock and Wilcox and will consist of a fully Teflon lined gas side and a stainless steel condensate hold-up hopper. The tube side shall be cooled by re-circulating a glycol type fluid to a mechanical draft cooling coil. The gas side of the tubes shall be washed by a suitable SO_2 scrubbing reagent that is circulated from the hopper at the bottom of the tube bank to a distribution header at the top of the tube bank. The SO_2 scrubbing solution will cascade over the tubes maintaining good gas/liquid contact with a low liquid/gas mass ratio. A bleed stream will be taken from the liquid hold up hopper for treatment prior to disposal. It should be noted that the unit water balance will be strongly positive due to the condensation of the water from the flue gas stream in the condensing cooler and the subsequent intercooler stages on the flue gas compressor.

A fully functional Product Recovery Train (PRT) will be provided to recover, dry, purify and compress/pump the recovered product stream for injection into suitable geologic reservoirs. The PRT will include a multistage, inter-cooled piston type compressor, dehydration system and propane refrigeration system designed to recover a high purity liquid CO_2 stream that will then be pumped to the required well-head pressure.

Two distinct modes of operation for the PRT will be possible:

1) For Enhanced Oil Recovery (EOR) trials, or any trials targeting more than 95 % CO_2 purity in the recovered product stream, the PRT will draw from the raw flue gas stream and compress the mixture to between 300 Psig. (for low air infiltration cases) and 450 Psig. (for high air infiltration cases) in order to create a suitable working point to refrigerate and condense a liquid phase product stream that is enriched in CO_2. This condensed liquid phase product stream will then be pumped to the required reservoir injection pressure (1200 to 2200 Psig).
2) For Enhanced Coal Bed Methane (ECBM) trials, the variable composition CO_2/N_2 raw flue gas stream will simply be compressed to the required reservoir injection pressure (1200 to 2200 Psig) using a suitable wellhead compressor.

The PRT shall be capable of recovering up to 90 % of the CO_2 stream at 98 % purity treating a 75 % CO_2 by volume dry basis input stream for EOR operations. The PRT shall also be capable of compressing and dehydrating the raw product stream containing between 20 and 75 % CO_2 by volume dry basis for ECBM operations.

All equipment in contact with the flue gases downstream of the CHX shall be rugged and easily maintained in the field using a minimum of tools and expertise. Materials of construction shall be carefully selected to be resistant to acid attack. Specific attention shall be given to making it easy to remove the small amounts of fly ash that will inevitably accumulate in the system.

Figure 4 illustrates the proposed configuration for the steam system.

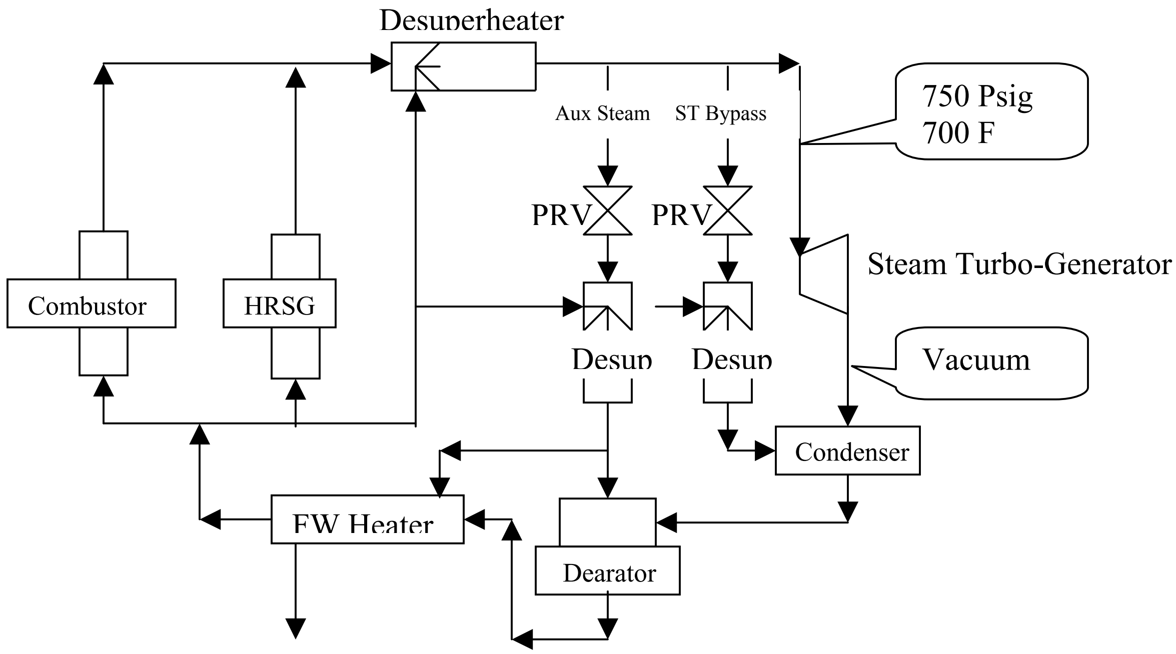

Figure 4 – Steam System Configuration

The steam generator shall consist of two circuits arranged in parallel. Each circuit shall be controlled and monitored independently such that a heat balance can be performed on each of the two circuits. The steam generating circuits shall be designed for once through operation with final conditions of 750 Psig. / 750 F. The combined output of both circuits shall be approximately 7500 Lbs/hr. An outlet desuperheater shall be used to control the steam temperature to 700 F.

The combined output of the radiant combustor and the convective Heat Recovery Steam Generator (HRSG) will be directed to a condensing steam turbo-generator to produce only enough power to satisfy the auxiliary power needs of the demonstration site, with excess steam being dumped to the condenser when necessary. No export power shall be provided. A 100 % capacity steam turbine by-pass shall be provided to allow the turbine to be run at any load independent of the boiler steam generation with minimum loss of feedwater. Silenced steam vents shall be provided for start-up and emergency operations.

The steam turbine itself shall be a single stage, impulse type machine rated at approximately 350 KW, discharging to a vacuum condenser. The condenser shall be cooled by re-circulating a glycol type cooling fluid to a mechanical draft cooling coil. A portion of the main steam will be directed to the auxiliary steam system for feedwater pre-heating and recycle flue gas re-heating duties.

It should be noted that the design of the steam system has been optimized for ease of start-up and control of this experimental facility and is not meant to reflect the efficiency of modern steam plant equipment and practices.

5.0 ANTICIPATED PERFORMANCE

The system shall be capable of operating over a wide range of ambient conditions in order to provide maximum flexibility in locating sites for the field-testing. Key design assumptions include:

- Plant elevation range from sea level to + 4500 Ft.
- Ambient temperature range from – 40 F to + 104 F.
- Oxygen available at 99 % purity or greater
- Natural gas available at 95 % CH_4 content or greater
- Standard commercial propane available

The Coal Water Mixture (CWM) fuel was assumed to be prepared using a typical eastern bituminous coal with less than 2.5 % sulfur and less than 10 % ash prepared by pulverizing to at least 70 % through 200 mesh and mixed with water to a minimum firing strength of 60 % solids by weight.

Preliminary sizing/performance data have been proposed by CANMET using proprietary software tools developed specifically for predicting radiant and convective heat exchange in flue gas mixtures containing variable amounts of H_2O, N_2, and CO_2. Preliminary sizing of the combustor was accomplished using a 1-D four zone model that allows for the correct physics of radiant exchange between participating zones and surfaces. A rough sizing of the Heat Recovery Steam Generator was developed using proprietary heat transfer extensions developed for use in HYSYS.

Table 3 provides the anticipated performance of the system for two key design cases:

- Case A: 10.4 MM Btu/hr firing natural gas, 1 % air infiltration, + 104 F ambient
- Case B: 6.5 MM Btu/hr firing CWM, 1 % air infiltration, + 104 F ambient

Innovative Steam Technologies have optimized the proposed design concept and have developed engineering/design information for the boiler and all associated auxiliaries in order to validate the feasibility of constructing this demonstration facility [2]. Further work is planned in 2003 to identify and optimize the cost of the facility.

Table 3 – Anticipated Performance Data

Item	Units	Case A	Case B
Ambient Temperature	F	104	104
Fuel Type		Natural Gas	CWM
Fuel Consumed	Lbs/hr	460	500
	Tonnes/day	5.00	5.44
	MM Btu/hr	10.4	6.5
Flow to Product Recovery Train	MM SCFD dry	0.300	0.300
Oxydant Type		99 % oxygen	99 % oxygen
Oxydant Consumed	Lbs/hr	1805	1200
	Tonnes/day	19.64	13.06
Infiltration Air	Lbs/hr	80	60
Recycle to Combustor	%	70	70
Combustor T adiabatic	F	3620	3590
Combustor heat loss	%	10	10
Combustor leaving temperature	F	1550	1450
Emergency quench	Lbs/hr	160	n/a
Resulting flue gas temperature	F	1450	1450
Steam Temperature out	F	700	735
Steam Pressure out	Psig	750	750
Feedwater Temperature in	F	240	325
Combustor steam generation	Lbs/hr	5000	3300
Superheater:			
Gas temperature in	F	1450	1450
Gas temperature out	F	1330	1300
Steam temperature in	F	517	517
Steam temperature out	F	700	735
Steam pressure out	Psig	750	750
Heating Surface (approximate)	Sq feet	30	30
Evaporator:			
Gas temperature in	F	1330	1300
Gas temperature out	F	700	640
Water temperature in	F	517	517
Steam temperature out	F	517	517
Heating Surface (approximate)	Sq feet	300	300

Table 3 – Anticipated Performance Data (continued)

Item	Units	Case A	Case B
Economizer:			
Gas temperature in	F	700	640
Gas temperature out	F	400	400
Water temperature in	F	240	325
Water temperature out	F	517	517
Heating Surface (approximate)	Sq feet	300	300
Baghouse bypass		Open	Closed
Condenser/Scrubber:			
Gas temperature in	F	400	400
Gas temperature out	F	132	132
Water Temperature in	F	122	122
Water Temperature out	F	176	173
Cooling water flow	Lbs/hr	22500	16000
Condensate flow	Lbs/hr	860	426
Recycle Steam Coil:			
Gas temperature in	F	132	132
Gas temperature out	F	250	250
Steam Pressure in	Psig	75	75
Steam Temperature in	F	Saturated	Saturated
Condensate Flow	Lbs/hr	167	104
Anticipated Steam generation:			
Combustor	Lbs/hr	5000	3300
Heat Recovery Steam Generator	Lbs/hr	2300	1600
Total	Lbs/hr	7300	4900
Raw Flue Gas to PRT:			
Volume	MM SCFD dry	0.300	0.300
Temperature	F	132	132
% CO_2 by vol dry	% by vol dry	84	90

6.0 SITE LAYOUT

It is proposed that the system shall be built in a series of truck transportable modules that will be inter-connected in the field. Maximum use of shop assembly shall be employed to minimize field craft labor. Unless otherwise stated, all equipment shall be designed for outdoor operation recognizing Canadian winter conditions.

The system shall be designed as an experimental pilot plant. Every attempt shall be made to arrange the equipment so that instrumentation can be located appropriately for extracting high quality data. Special attention shall be placed on locating instrumentation, control elements and prime movers so that they can readily be accessed for inspection and maintenance with a minimum of downtime, personnel and service equipment.

The system shall be designed to generally recognized industrial standards for safety and reliability. Due consideration shall be given to the fact that the equipment shall not be put into commercial service. The equipment shall be selected recognizing that the facility will see many start-stop cycles and severe operating conditions.

The overall design philosophy shall be to maximize reliability by reducing the complexity of the plant, reducing the number of items of plant, simplifying control schemes and purchasing quality equipment that is easy to service in the field. Preference shall be given to provision of variable frequency drives to simplify part load operation and reduce starting currents. The plant shall be designed and built to the highest standards of workmanship and finish. Use of corrosion resistant materials shall be considered where necessary so that the unit will remain in first class condition despite years of use, abuse, knock down and transportation to remote sites.

Prior to going to the field, the equipment modules shall be assembled and commissioned in Ottawa at a facility to be provided by CANMET. This facility shall be capable of providing the following utilities:

1) natural gas for main fuel
2) propane for back-up fuel
3) coal water mixture and delivery system for alternate fuel
4) oxygen from bulk liquid storage vessel and evaporator
5) AC power
6) Compressed air
7) Instrument air

While in the field, the scope of supply shall be expanded to include the provision of all utilities. Every effort shall be made to consider the use of rental equipment where possible to minimize capital and operating costs. It is anticipated that the unit will require a rented start-up/standby generator.

The unit shall at all times, regardless of the site location, be capable of safe and orderly start-up, operation and shut-down using trained and qualified personnel on-site.

An operations trailer shall be included to house the electrical devices and the control room. The SCADA system shall be capable of manual/automatic control while providing for interlocking of start-up and operational sequences. A dedicated burner management system shall be provided. The SCADA system shall be capable of being monitored remotely while allowing process data to be queried and transferred off-site.

Figure 5 outlines the proposed key equipment modules and a suggested site layout.

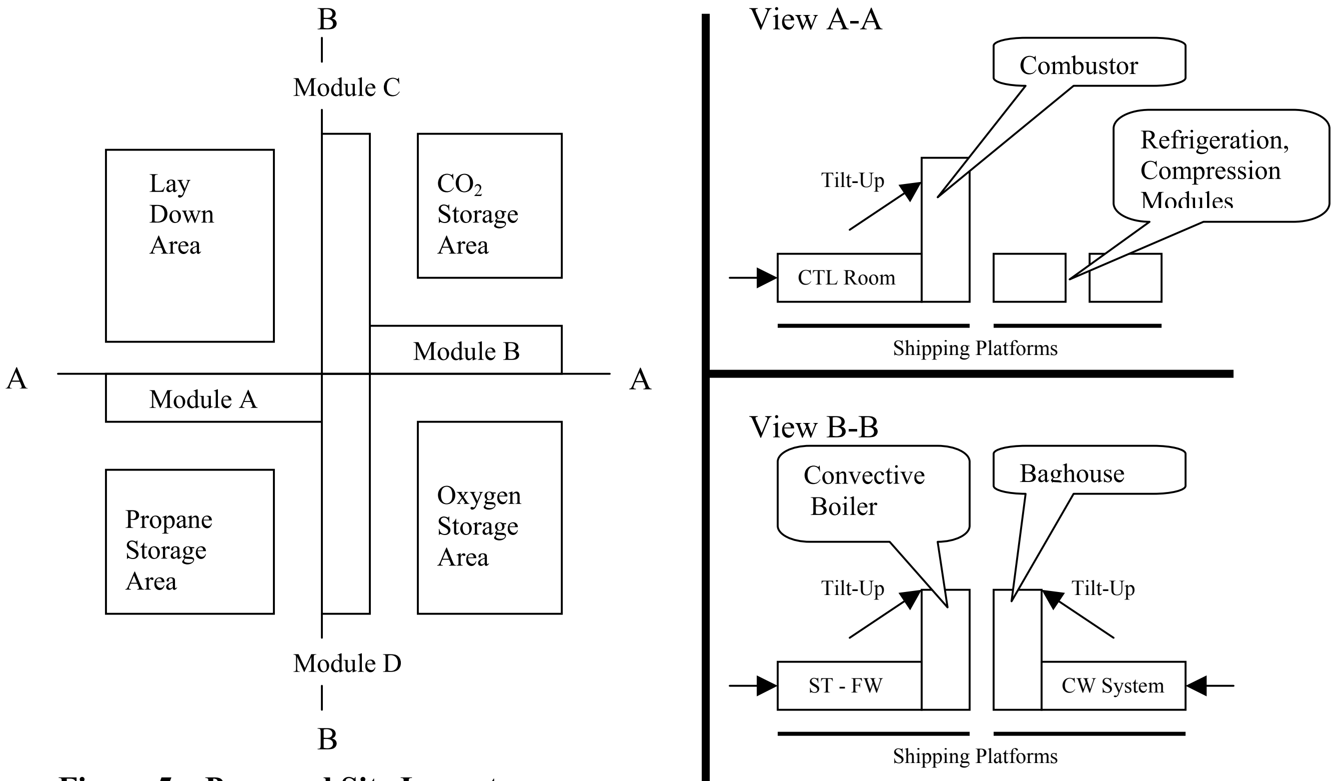

Figure 5 – Proposed Site Layout

The key equipment modules shall be shop assembled and transported to the field on custom designed shipping platforms. These platforms shall be placed on a gravel base in the field and shall serve as a rigid, interconnected steel foundation system for all equipment. The intent of this approach is to minimize site preparation requirements and eliminate the need for equipment foundations and permanent structures. Module A shall be installed by tilting up the combustor and mounting the control room/electrical room unit housed in a shipping container. Module B shall consist of shop mounted non-enclosed skids for the refrigeration system and compressor. Module C shall be installed by tilting up the convective boiler/condensing cooler and mounting the non-enclosed steam turbine (ST) generator skid and the enclosed feedwater (FW) system skid. Module D shall be installed by tilting up the baghouse and mounting the non-enclosed cooling water (CW) system skid. Three gravel-based areas will be used to accept self-supporting bulk storage vessels for oxygen, propane and the recovered product stream.

7.0 RESEARCH CAPABILITIES

The proposed oxy-combustion pilot plant will be designed to facilitate the following research activities:

While located at CANMET's research park in Ottawa...

- Oxy-combustion trials with natural gas, propane or a variety of coal water mixtures to demonstrate the radiant and convective performance of the boiler using various flue gas recycle rates
- Oxy-combustion trials to demonstrate the safe start-up, transfer to coal firing and shut-down of various burner designs by CANMET and others
- Multi-pollutant capture studies using the condensing scrubbing environment
- Commissioning and performance verification of all equipment modules prior to going to the field.
- Control system logic optimization for start-up and shut-down
- Training of personnel for oxy-combustion operations

While located in the field….

- Steady state oxy-combustion trials with natural gas or propane to demonstrate the hydrocarbon recovery and the sequestration potential of the reservoir using various CO_2/N_2 ratios
- Time varying oxy-combustion trials to optimize the hydrocarbon recovery using various CO_2/N_2 ratios
- Process trials to test the performance of new product recovery train concepts
- Durability trials to validate the performance of key auxiliary components

8.0 FUTURE ACTIVITIES

The following Project activities are proposed for completion in the current fiscal year ending March 2004:

- CANMET / IST / GTI to develop a firm capital and operating cost budget for the overall project
- CANMET to capture the participation of the partners in a formal agreement
- ARC / AL to identify candidate sites in Canada
- GTI to identify candidate sites in the USA
- Partners to apply for project funding in Canada through the federal governments Technology Early Action Measures (TEAM) program
- Partners to apply for project funding in the USA through the US Dept of Energy

As well, the following research activities are planned for completion in the current fiscal year ending March 2004:

- CANMET to engage the National Research Council located in Ottawa, Canada to design and supply a proprietary Coal Water Mixture burner tip sized for this application
- CANMET to construct a full-scale prototype of its MK III oxy-capable burner and perform preliminary testing using a 10 ft long section of the proposed combustion chamber. This testing will provide valuable information about the scale up of CANMET's proprietary burner concept and will also confirm the combustion chamber sizing for this application

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