DEVELOPMENT OF A GAS TURBINE COMBUSTOR STRATEGY

For Gasification Cycles

PROJECT SUMMARY 355

CLEANER FOSSIL FUELS PROGRAMME
– CLEANER COAL R&D PROGRAMME

OBJECTIVES

The main objectives of this project were to:

- Compare the current low calorific value (LCV) diffusion flame combustion system design against a lean premix combustion system (based on the ALSTOM G30 design) and a catalytic combustion design approach.
- Provide a recommendation on the way forward for the commercial exploitation of the LCV and medium calorific value (MCV) gas fuel market, particularly for biomass and underground coal gasification applications.

SUMMARY

The project evaluated the relative merits of three different systems for burning low calorific value gas. These were a diffusion flame combustion system (current Värnamo/ARBRE build), a lean premix combustion system (based on the ALSTOM-Lincoln premium fuelled G30 design) and a catalytic combustion system. The evaluation was based on assembly and analysis of

- The significant existing test data for the diffusion flame combustion system and bench-mark testing using a high pressure rig at Cranfield University.
- High pressure rig testing of the lean premix combustion system at Cranfield University.
- Data on catalytic combustion from the open literature and from a previous Foresight Challenge funded project.

The scope of the high pressure testing was increased from that defined in the original proposal, to include medium calorific value (MCV) fuel gas testing of the diffusion flame combustor. This was introduced to assess the suitability of the combustor for underground coal gasification, as applicable to the proposed UK scenario (ie oxygen blown gasification at 600-1200m depth).

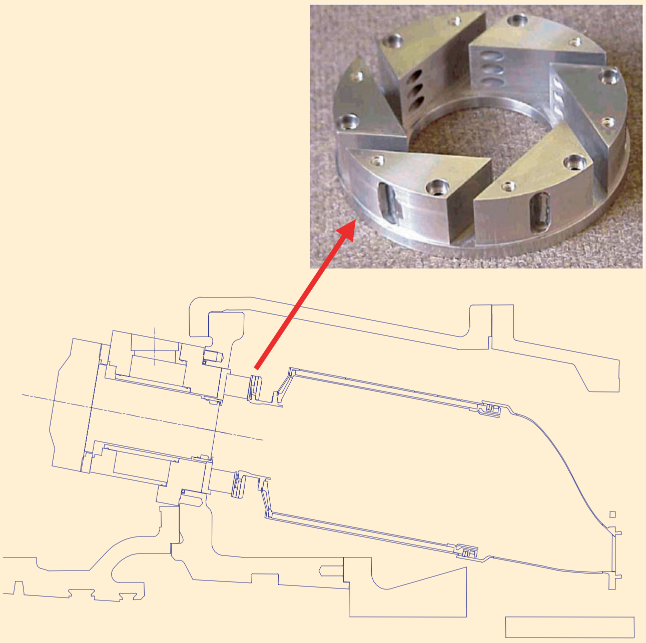

Figure 1: G30 based LCV combustor

The recommendation for short/medium term combustor development to exploit the biomass and coal gasification markets is to use the diffusion flame combustor as a basis. The passive purge system would need further refinement to burn premium fuels at full load. The combustor would benefit from utilising the G30 combustor liner to provide a fully impingement cooled system. For MCV gas fuels, the preferred option would be to add nitrogen or steam diluent to create a fuel compatible with the LCV combustion technology. In the longer term, a catalytic combustor approach may provide the best means of controlling NO_x derived from fuel bound nitrogen (FBN). As an intermediary step in the short/medium term, a catalytic FBN removal system upstream of the gas turbine, could form part of the fuel gas clean up system.

BACKGROUND

ALSTOM has been active in the field of gas turbine combustion development for coal and biomass derived fuel gases for a number of years. The current ALSTOM combustion technology was developed initially as part of an advanced clean coal power generation system known as the Air Blown Gasification Cycle (ABGC). The design was based on a generic combustor design of diffusion flame principles.

This combustor design was applied successfully to ALSTOM's Typhoon gas turbine. Two combined cycle plants, each incorporating a Typhoon gas turbine equipped with a dual fuel (liquid and LCV gas fuel) combustion system were successfully demonstrated in the field. The first plant is in Värnamo, Sweden and the second plant is in Morwell, Australia.

The Värnamo demonstration project utilised biomass within an Integrated Gasification Combined Cycle (BIGCC), to produce 6MWe of power and 9MWth of heat for district heating, from a total fuel input equivalent to 18 MW. The net electrical efficiency was 32% and total net efficiency was 83%. The Morwell plant utilised lignite as fuel in a hybrid cycle similar to the ABGC. Both of these plants are no longer operational, having achieved their objectives of demonstrating the technology for such combined cycle systems. For example, the BIGCC demonstration plant at Värnamo achieved over 3600 operating hours on 100% LCV gas fuel, produced using a range of biomass fuels which included wood, forestry wastes, wood/bark mixtures, straw and Refuse Derived Fuel (RDF).

A Typhoon gas turbine, equipped with a diffusion flame combustion system design similar to that described above, has been incorporated in a further commercial BIGCC demonstration project in the

UK. This project is known as the ARable Biomass Renewable Energy (ARBRE) project. The biomass fuel source of wood chips is derived from forestry residue products and purpose grown short rotation coppice (typically willow).

Whilst the diffusion flame combustor design has worked well as part of the above demonstration projects in terms of general operability, there was an issue regarding the level of carbon monoxide (CO) emissions over the engine operating envelope. CO emissions of around 200ppmv were measured at the BIGCC in Värnamo during part load operation.

DLE COMBUSTOR DESIGN

The first activity within the project was to design a combustion system to burn LCV gas fuel with very low emissions of thermal nitrogen oxides (NO_x) and carbon monoxide (CO). The approach adopted was to take ALSTOM's standard G30 Dry Low Emissions (DLE) combustion system as the basis for the proposed combustion system design to burn LCV gas fuel (Figure 1), based on the following considerations:

- The near term commercial application of gasification technologies will most probably utilise a wet gas clean-up approach. This method will remove substantially the FBN compounds within the fuel gas so that the gas turbine combustion system must control, primarily, the thermally derived NO_x component.
- A DLE based combustor may be the most appropriate design for a range of fuel calorific values, from the view point of thermal NO_x emissions control.
- A G30 based design would provide commonality and standardisation of components for a range of fuels.

A key consideration in the design of the G30 based LCV gas fuel combustor is the properties of the LCV gas fuel compared to the premium fuels of natural gas and distillate oil. The fuel type influences the stoichiometric combustion temperature, therefore affecting NO_x emissions for a given fuel. The stoichiometric flame temperature (assuming complete adiabatic combustion with no dissociation) for a LCV gas fuel produced within an ABGC is relatively low at approximately 2000K. This compares to a temperature of approximately 2500K for UK pipe-line natural gas.

The design operating conditions for the combustor are shown as Table 1.

	Air Inlet P bara	**Air Inlet Temp K**	**Air Mass Flow kg/s**	**Fuel Mass Flow kg/s**	**Turbine Entry Temp K**
Full Load, no bleed	15.129	679	2.78	0.556	1261
Full Load, 11% bleed	14.521	672	2.44	0.630	1376
75% Load, no bleed	14.208	668	2.79	0.455	1167
40 % Load, no bleed	12.774	648	2.80	0.309	1014
20% Load, no bleed	11.904	635	2.81	0.225	918

Table 1: Design Operating Conditions

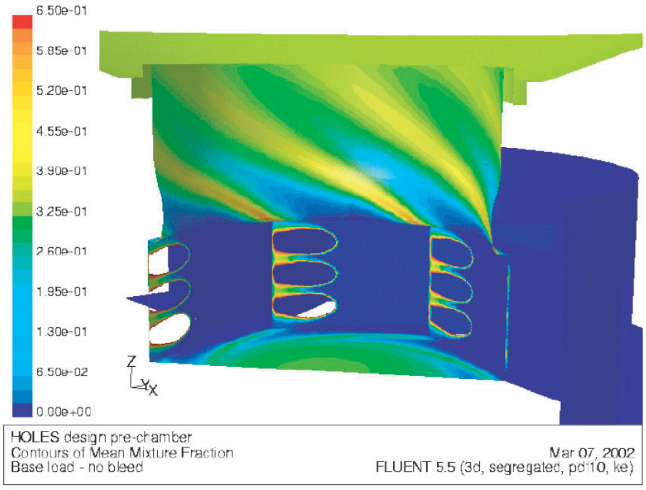

Figure 2: Mean Mixture Fraction Contour on Pre-chamber Wall (Full Load)

The combustor design activity was carried out in conjunction with isothermal and reacting flow modelling studies (Figure 2).

COMBUSTOR TESTING

Combustion testing of the baseline diffusion flame combustor and the prototype G30 based LCV combustor was carried out using ALSTOM's existing high pressure test rig, installed within Cranfield University's School of Engineering test facilities (Figure 3). This rig required modification to the fuel and air delivery systems to the combustor, and to the rig end-plate, in order to carry out the test programme. The rig used the Cranfield synthetic fuel gas (syngas) delivery system altered under the Higher Education Funding Council for England (HEFCE) Laboratory Refurbishment Initiative, with a contribution from Cranfield private funds, (Figure 4).

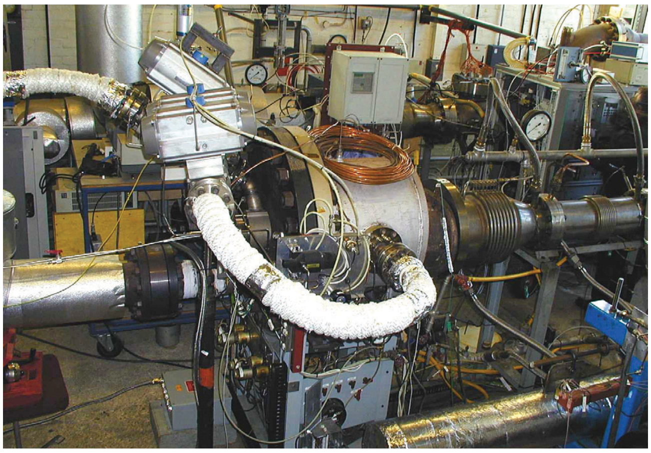

Figure 3: Alstom High Pressure Rig at Cranfield University

Component or property	**Syngas Fuel**	
	LCV	**MCV**
CO % Volume	17.63	48.26
H_2 % Volume	12.81	30.09
CH_4 % Volume	5.03	2.35
N_2 % Volume	50.20	3.63
H_2O % Volume	-	-
CO_2 % Volume	14.33	15.67
NH_3 (ppmv)	50	50
Tar (g/m^3)	-	-
Low Calorific Value (at 101325 Pa & 298.15 K) (MJ/kg) (MJ/m^3)	 4.597 5.403	 10.181 10.181
Stoichiometric AFR	1.334	2.723
Molecular Weight (no NH_3) (kg/Mol)	26.373	22.414
Adiabatic stoichiometric temperature (K) at air temperature (K) and gas temperature (K)	2108 679 523	2631 671 523

Table 2: Nominal Syngas Compositions

This system provided the nominal syngas mixtures as shown in Table 2.

To achieve operation on MCV gas fuel, the patented passive purge feature within the fuel injector of the baseline diffusion-flame combustor was modified to increase the geometric area from 2 rows each of 32 holes of 3mm diameter to 32 slots of 12mm length and 4mm width (Figure 5). This feature prevents burner overheating and hot products recirculation into the LCV gas fuel burner, when operating on supplementary fuel. When operating on LCV gas fuel, it is effectively an aerodynamic variable geometry device (ie as LCV gas fuel flow increases, the air flow to the combustor primary zone through the main swirler is reduced).

Figure 4: Cranfield High Pressure Rig Syngas Delivery System

This modification increases the gas fuel injection velocity and was performed to protect the injector from:

- The high flame temperature (approximately 2630°C) for the synthetic gas chosen to simulate MCV gas fuel.
- The higher laminar flame propagation speed for this mixture, compared to LCV gas fuel (for which the original injector was designed). This would result in an increased probability of flashback and a closer flame proximity to the injector leading to high injector tip temperatures.

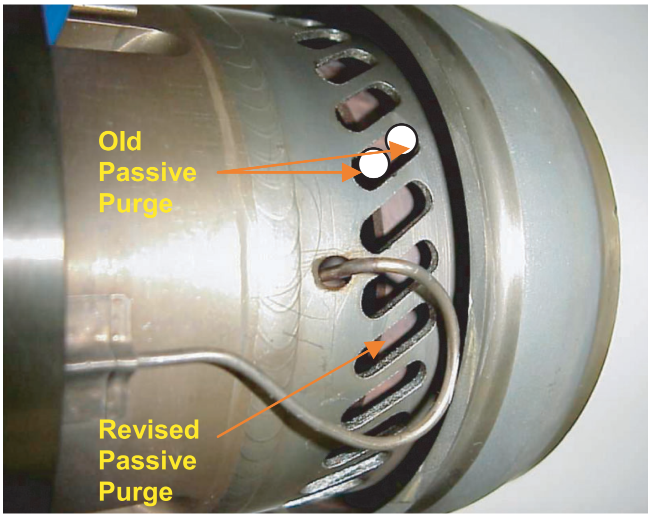

Figure 5: Revised Passive Purge Arrangement

In addition, prior to carrying out the high pressure tests, the G30 based combustor designs were tested firing distillate oil, at atmospheric pressure, at ALSTOM Power's Lincoln site. The atmospheric testing was introduced into the project to define the operating envelope, including fuel change over, for the subsequent high pressure testing.

RECOMMENDATIONS

Short/Medium Term

- The development of the LCV gas fuel combustor should be based on the turbulent diffusion-flame process. The combustor would benefit from being cooled using impingement cooling, with no film cooling in the primary zone. The G30 combustor liner could be used as a basis for this.
- In order to address NO_x emission from FBN, the air staged rich-lean configuration may be employed. The passive purge design should be used to re-set the primary zone stoichiometry from rich on LCV gas fuel to stoichiometric or lean on the auxiliary liquid. The passive purge airflow should be used to improve liquid fuel atomisation. Inclusion of the above features would help to avoid carbon deposition during liquid starting.
- The LCV gas fuel combustion technology should be applied on ALSTOM engines of 10 to 15MW range, as this range has a large market potential.
- The aerodynamics of the combustor/injector should be optimised for MCV gas fuel with diluent injection for NO_x control.
- Alternatively, the MCV gas fuel could be diluted with nitrogen or steam upstream of the combustor and therefore reduce the flame speed and flame temperature to a similar level to that of the LCV gas fuel. The resultant fuel should be then used in the air-staged based turbulent diffusion-flame process.

Long Term

A number of alternative longer term options are available. These should be aimed primarily at the control on NO_x emissions from fuels containing FBN.

- To develop a suitable catalyst which will oxidise ammonia exclusively to nitrogen without oxidising CO or H_2.
- Alternatively, to develop catalysts which will selectively oxidise ammonia to NO without oxidising CO or H_2, so that the subsequent reduction of NO with CO (or H_2) can occur.
- To develop an environmentally friendly method to clean the LCV gas fuel from FBN.

COST

The total cost of the project was £627,011 with the Department of Trade and Industry contributing £313,506 (50%). ALSTOM Power provided the balance of the project funding.

DURATION

36 Months – February 2000 to January 2003

CONTRACTORS

ALSTOM Power
Technology Centre,
Cambridge Road,
Whetstone, Leicester,
LE8 6LH

ALSTOM Power UK Limited,
PO Box 1, Waterside South,
Lincoln, LN5 7FD

In association with:

Cranfield University, School
of Engineering, Cranfield,
Bedfordshire, MK43 0AL

Queens University Belfast,
Stranmillis Road, Belfast,
County Antrim, BT9 5AG

Further information on the Cleaner Fossil Fuels Programme, and copies of publications, can be obtained from:
Cleaner Fossil Fuels Programme Helpline, Building 329,
Harwell International Business Centre, Didcot, Oxfordshire OX11 0QJ
Tel: +44 (0)870 190 6343 Fax: +44 (0)870 190 6713
E-mail: helpline@cleanercoal.org.uk
Web: www.dti.gov.uk/cct/

Printed on paper containing a minimum of 75% post-consumer waste.

DTI/Pub URN 04/1036