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LOW NO_x PREMIXED COMBUSTION OF MBTU FUELS USING THE ABB DOUBLE CONE BURNER (EV BURNER)

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ABSTRACT

A novel combustion technique, based on the Double Cone Burner, has been developed and tested. NO_x emissions down to very low levels are reached without the usual strong dilution of the fuel for MBtu syngases from oxygen blown gasification of coal or residual oil. A limited amount of dilution is necessary in order to prevent ignition during the mixing of fuel and combustion air.

The relevant properties of the fuel are reviewed in relation to the goal of achieving premixed combustion. The basic considerations lead to a fuel injection strategy which is completely different from that for natural gas. A high speed premixing system is necessary due to the very short chemical reaction times of MBtu fuel. Fuel must be prevented from forming ignitable mixtures inside the burner for reliability reasons. A suitable fuel injection method, which can be easily added to the ABB double cone burner, is described. In common with the design of the standard EV burner, the MBtu EV burner with this fuel injection method is inherently safe against flashback.

Three dimensional flow field and combustion modelling is used to investigate the mixing patterns and the location of the reaction front. Two burner test facilities, one operating at ambient and the other at full gas turbine pressure, have been used for the evaluation of different burner designs. The full pressure tests were carried out with the original gas turbine burner size and geometry. Combing the presented numerical predictive capabilities and the experimental test facilities, burner performance can be reliably assessed for a wide range of MBtu and LBtu fuels (residue oil gasification, waste gasification, coal gasification etc.).

The atmospheric tests of the burner show NO_x values below 2 ppm at an equivalence ratio equal to full load gas turbine operation. The NO_x increase with pressure was found to be very high. Nevertheless, NO_x levels of 25 vppmd (@ 15% O_2) have been measured at full gas turbine pressure. Implemented into ABB's recently introduced gas turbine GT13E2 the new combustion technique will allow a more straightforward IGCC plant configuration without air extraction from the gas turbine to be used.

INTRODUCTION

The significant increase in gas turbine efficiency in the last decade has contributed to the economic feasibility of integrated gasification combined cycle processes. A further incentive has been provided by the very low emissions of gas turbine combustors running on clean fuels (i.e. no fuel bound nitrogen or sulfur components). The hydrocarbons used for the gasification can be residual oils, coal or industrial waste. In particular, the oxygen blown gasification of refinery residues in combination with a CC plant is expected to be widely introduced on a commercial scale. The processes deliver syngases with a heating value approximately one third of that of natural gas, whereas syngases from air blown processes have

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even lower heating values. The higher heating value (smaller fuel mass flow) facilitates the syngas desulfurisation and HCN removal processes. If the problem of excessive NO_x production during combustion of syngas fuels can be solved without resorting to the common technique of heavy dilution the surge margins of some standard gas turbines (e.g. ABB's GT13E2 or GT8C) are sufficient for direct MBtu operation.

SPECIFICATION OF MBTU FUEL PROPERTIES

Oxygen-blown gasification delivers syngases with heating values of the order of 10 to 16 MJ/kg (≈ 210-300 Btu/scf), compared to heating values of less than 5 MJ/kg (≈100 Btu/scf) for air blown processes. Different feed stock compositions and gasification processes lead to a variety of syngas compositions and heating values. As shown below, residual oil gasification syngas is the most challenging syngas composition as far as premix burner technology is concerned. Consequently, the burner tests were carried out with this fuel type.

A typical residual oil gasification fuel from oxygen-blown processes can be represented by a typical volumetric composition of 45% H_2 , 48% CO and 7% N_2 and a lower heating value of 15 MJ/kg (277 Btu/scf). The H_2/CO ratio is about 1.

Coal gasification syngas has a typical volumetric composition of typically 30% H_2 , 60% CO and 10% N_2 and a lower heating value of approx. 12 MJ/kg (234 Btu/scf). The H_2/CO ratio is only 0.5. Compared to residual oil gasification syngas, the hydrogen content and consequently the flame velocity is lower.

Reliable premixed combustion systems for gas turbines have only been developed for natural gas to date. The main reason for this situation are the unique properties of natural gas under lean premixed conditions. Long ignition delay times and high self ignition temperatures make it possible to control pre-ignition and the aerodynamic and thermoacoustic behaviour of such combustors with well designed burners (e.g. the Double Cone Burner). Conversion for other fuels is much more critical, since now combustion chemistry introduces constraints in addition to those for a natural gas combustor. The problem of ignition of oil no. 2 during the evaporation phase is well known. In order to highlight that MBtu fuels behave even worse, their basic combustion properties are briefly summarized below and compared to those of natural gas.

The laminar flame speed, the adiabatic flame temperature and the chemical reaction time of syngases with the above mentioned compositions and of natural gas are plotted in figure 1. Properties of residual oil syngas with a 55%(Vol.) dilution of N_2 are given by the dotted lines in the left column in figure 1. All values have been calculated with a one dimensional laminar flame code (Kee et al. 1992) for a pressure of 14.5 bar and a preheat temperature of 300°C. The chemical kinetics data base was that of Miller and Bowmann (1989) with 52 species and 251 elementary reaction equations.

The peak laminar flame velocity of the syngases is about an order of magnitude higher than the laminar flame velocity of methane. Since intense turbulence will increase the flame speeds significantly above the respective laminar values shown in figure 1 (Liu et al. 1989), it is obvious that the effective flame speed reaches the order of the flow speed in the burner. As a consequence, flashback into the premixing section can hardly be avoided. Wall boundary layers, wakes or local zones of low velocity (e.g. downstream of fuel jets mixing with air) are particularly critical. The highest flame velocity of the syngas/air mixture occurs at fuel rich conditions (fuel equivalence ratio approx. 2). Hence during the mixing of a fuel jet with the air, fuel rich zones in the jet mixing layer can act as flame holders and prevent the fuel from fully mixing with the air prior to ignition.

The maximum flame temperature for both oil and coal syngas is 2600K (4200F), which is about 200K higher than that of methane. This is not a problem if full premixing is achieved, since the (mixed) flame temperature can be selected via the overall equivalence ratio. However, if flame stabilization occurs in regions where the mixing is not yet perfect, the stoichiometry in the flame front will vary. The fuel which burns richer than average will produce very high peak temperatures with NO_x formation rates far higher than in the natural gas case.

The time scale of the chemical reaction in a premixed laminar flame is plotted in the lower row of figure 1. This time scale is the integrated time of a fluid element passing the flame's reaction zone. The reaction times for both syngases are one fifth of that of natural gas. These very small time scales emphasize the high flashback risk of burners operated on syngases. The time scale of the premixing process must be faster than the chemical time scale. The constraints resulting from Damköhler number considerations are very similar to those mentioned above: Flashback can only be avoided if no low speed flow regions exist within the mixing zone. The flame can travel upstream wherever partially premixed fluid elements have residence

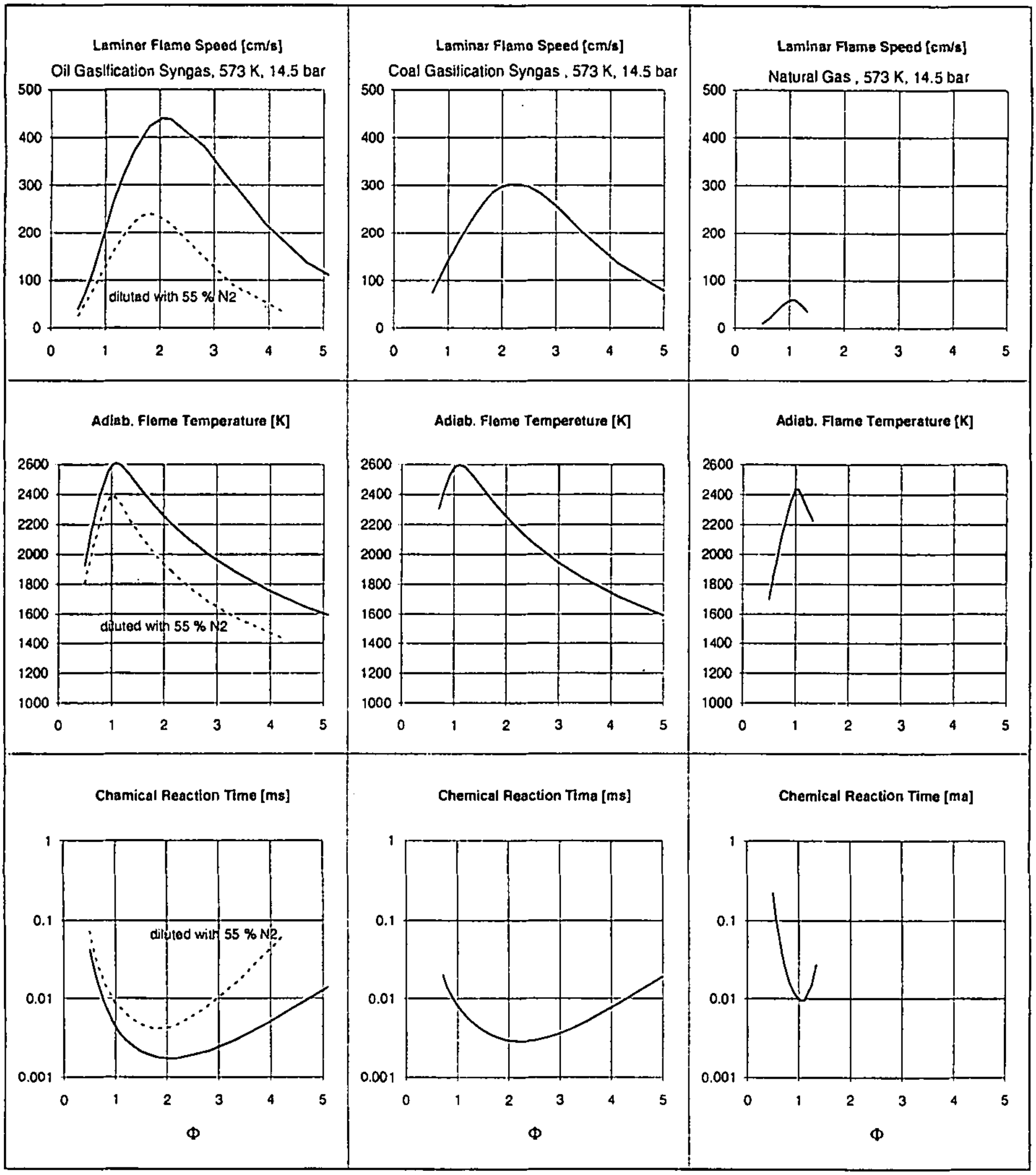


Figure 1: Flame speed, flame temperature and chemical reaction time for different syngas compositions and for natural gas

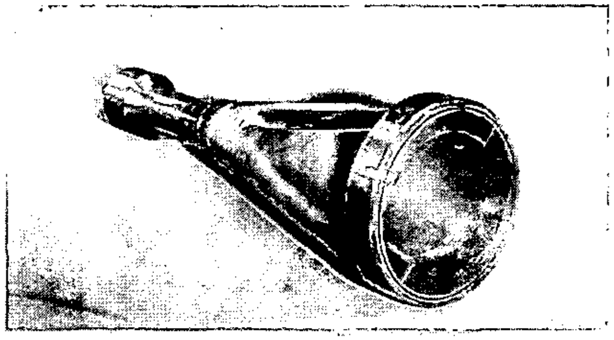


Figure 2: ABB's EV burner for natural gas operation

times longer than the chemical times, for instance in wall boundary layers or wakes.

The effect of diluting syngases with an inert gas (nitrogen in this case) is seen in the left column of figure 1 (dotted lines). With only 55% (Vol.) N_2 dilution, the flame speed can be approximately halved, while the maximum flame temperature drops to values comparable to natural gas. This effect can be exploited to delay ignition until further downstream. In practice, the effect of moderate dilution is very strong, since rich combusting zones, which are most critical for flame stabilization and NO_x production, are no longer present if the shift of the ignition point downstream is sufficient.

In comparing residual oil and coal syngases, the flame speed is considerably lower for the latter. It is expected from the calculations that premixing can be achieved for coal derived gas with much less dilution. In contrast, the maximum flame temperature is only slightly lower for coal gasification syngas.

INFLUENCE OF THE COMBUSTION TECHNIQUE ON THE INTEGRATED GASIFICATION COMBINED CYCLE

Much higher fuel flows must be handled due to the lower heating value of MBtu gases. The fuel-air ratio at the combustor inlet will increase from 3% (for NG) to more than 12% for diluted syngases. The maximum dilution allowed is governed by the required surge margin of the compressor. The main goal of the burner development described was to provide a combustion technique with a sufficiently low degree of dilution for NO_x control, in order to avoid undesired air extraction from the compressor, which is commonly used to match the compressor to the turbine in MBtu operation.

Table 1 shows the combustor outlet volume flow with respect to the combustor inlet air flow for different fuels. The combustor outlet temperatures and pressure are constant for all cases under consideration, and the volume flows are normalized to standard conditions. A simple rule can be deduced:

From the viewpoint of compressor operation, undiluted combustion of syngas is not very different from the combustion of natural gas with a water to fuel ratio of unity. If dilution of the syngas is required (e.g. 55% N_2 dilution), operation is similar to that with natural gas and a water to fuel ratio of 2. As a consequence, standard gas turbines with high surge margins (like the GT13E2) are a good base for moderately diluted syngas combustion.

fuel	natural gas	coal syngas	oil syngas	natural gas	oil syngas 55% N_2 dilution	natural gas
water to fuel ratio	0	0.0	0.0	1.0	0.0	2.0
V_{out}/V_{air} $[m^3_n/m^3_n]$ [scf/scf]	1.047	1.091	1.087	1.101	1.193	1.172

Table 1 Combustor outlet volume flow

A major constraint for using a standard gas turbine without modifications for syngas is that the NO_x emission may not exceed the values achieved for natural gas (i.e. for ABB gas turbines considerably lower than 25 vppmd (@15%O_2) without water injection). For the NO_x control in syngas applications two different approaches can be followed, the commonly applied diffusion burner technique and the new premix burner technique. They differ significantly in their complexity and their influence on plant layout and operating characteristics.

The approach of the conventional diffusion burner technique is to lower the heating value - and thus the maximum flame temperature - to very low levels by strong dilution of the syngas with nitrogen or water, if the NO_x limitations are more stringent. This technique requires air extraction from the compressor, a high degree of integration between the air separation/gasification plant and the gas turbine. Very large volume flows of the low grade fuel have to be controlled. A considerable amount of high quality water is consumed by the gas turbine with this technique.

The premix combustion technique described below needs only moderate nitrogen dilution for NO_x control. Air extraction can be avoided for standard gas turbines if the surge margin is sufficient (see table 1). The air separation/gasification unit is operated independently of the gas turbine. Compared to the diffusion burner technique, much smaller volume flows have to be handled and no water is used for NO_x control.

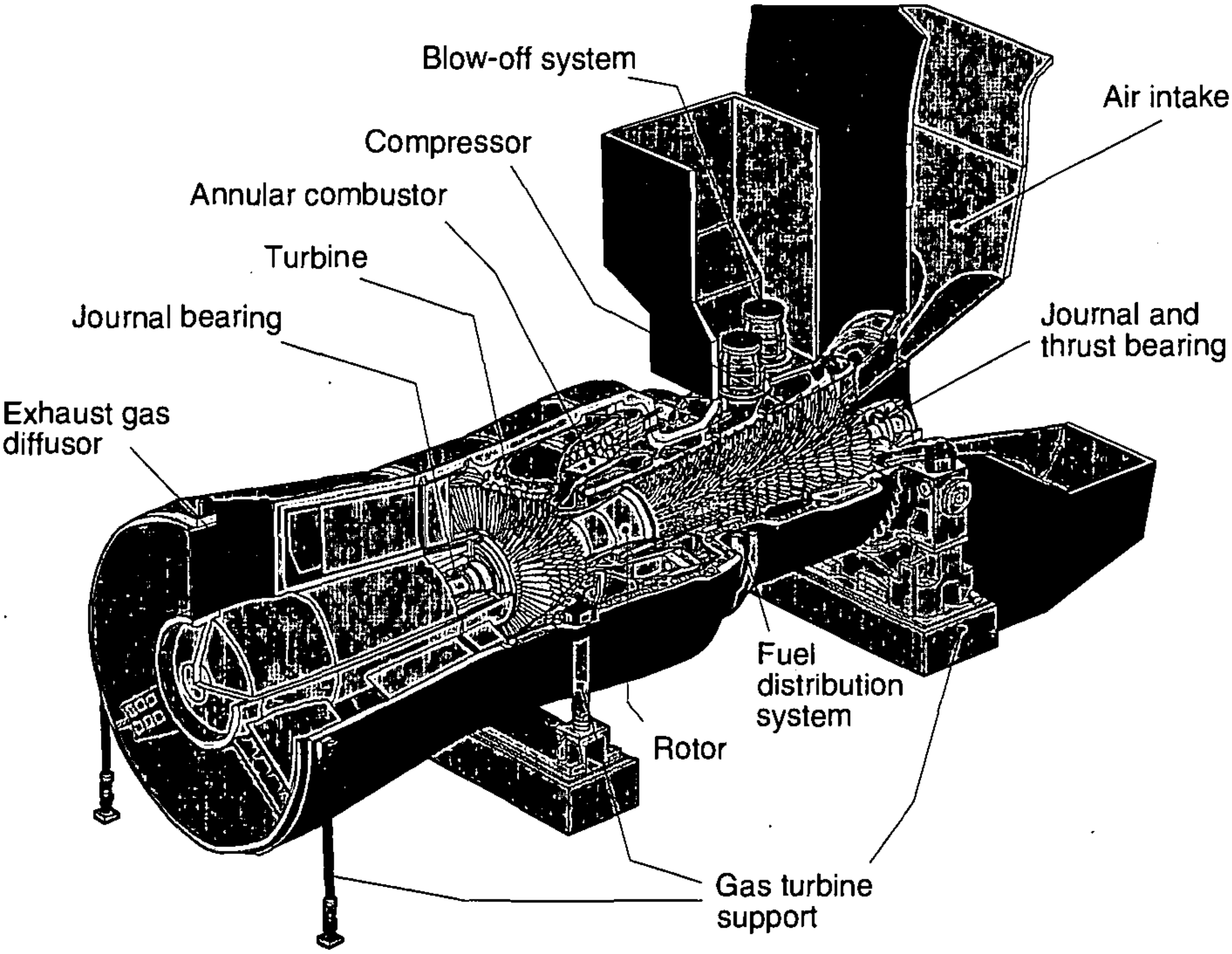


Figure 3: ABB's GT13E2 thermal block

It can be shown that the total plant efficiency (Döbbeling et al. 1993) of the non-integrated concept with premix burners exceeds that of fully or partly integrated concepts using the conventional diffusion burner technique.

DESCRIPTION OF THE EV BURNER AND THE MBTU FUEL PREMIXING SYSTEM

Basic Operation Principle of the EV Burner

ABB's EV burner is also known as the Double Cone Burner, because it consists of two half cones moved apart perpendicular to their centerlines. Two inlet slots of constant slot width (see Figure 2) are formed. Air entering through these slots is mixed with gaseous fuel emerging from a large number of holes along each of the slots. Since the slot width is constant and the diameter of the burner cross section increases from the cone tip (upstream end of the burner) to the end of the cone (downstream end of the burner), the swirl number (defined by the ratio of axial to circumferential momentum flux) of the air entering the burner increases continuously. If the swirl number exceeds a certain threshold, vortex breakdown occurs on the axis of the swirling flow. With a suitably adjusted slot width, cone angle and burner length, this central recirculation zone is formed on the centerline at the end of the burner and serves as an aerodynamic flame holder. The burner flow field and the vortex breakdown can be predicted by an analytic calculation described in detail by Keller et al. (1991). Stable combustion is possible due to the central recirculation zone even at conditions close to extinction with flame temperatures well below 1500°C, without the need for pilot flames (Sattelmayer et al. 1990 and Aigner et al. 1990). It can be shown by reaction kinetics that if high combustor outlet temperatures are required (as is the case for modern high efficiency gas turbines), a system without the need for piloting flames is the best solution for minimum NO_x emissions. The burner is inherently safe against flashback since the fuel is injected and mixed in the inlet slots where flow velocities are very high. No fuel is present upstream of the burner.

EV Premix Burner Operation in Gas Turbines

A large amount of operating experience has been accumulated for ABB's Double Cone Burner operating on natural gas with NO_x emissions of less than 15 ppmvd (@15% O_2). ABB's GT8, GT9, GT10, GT11 and GT13 type machines use this burner in multi burner assemblies either in silo combustors or in annular combustors. Details on the operation experience with silo EV combustors are given by Aigner and Müller (1992), annular combustor operation experience is described by Strand (1993). Figure 3 shows the thermal block of the GT13E2 with its annular combustor, which is well suited for syngas applications. A detailed description of the combustion technology for natural gas and oil No. 2 for this machine is given by Senior et al. (1993). Excellent temperature pattern factors are achieved due to the relatively small size of the burner. ABB's strategy is to use one burner geometry for all of ABB's gas turbines.

Modification of the EV Burner for MBtu Fuels

An appropriate injection method for MBtu gases has to take the critical properties of these fuels into account. An attempt to apply mixing principles suitable for natural gas to more critical fuels will not provide the necessary performance. Injection of the fuel along the inlet slots is no longer appropriate due to the high flame velocities of hydrogen-containing fuels and the higher volume flux, which distorts the incoming airflow profile. At high hydrogen content, flames stabilize at the gas injection holes and premixing cannot be achieved. This does not compromise the reliability of the EV burner but does increase the NO_x emissions.

The specialized flow field of the Double Cone Burner provides an excellent basis for the implementation of a very rapid injection method, since the vortex breakdown blocks most of the cross sectional area near the outlet. The desired high air velocities are found in a layer close to the cone halves. As a consequence, the fuel can be injected into this layer of maximum axial velocity. In order to prevent ignition in unmixed regions, injection of fuel into the inner and outer recirculation zones is avoided. A number of plain holes facing radially inward close to the burner end serve as fuel injectors as shown in figure 4. Since no fuel is found inside the burner and care

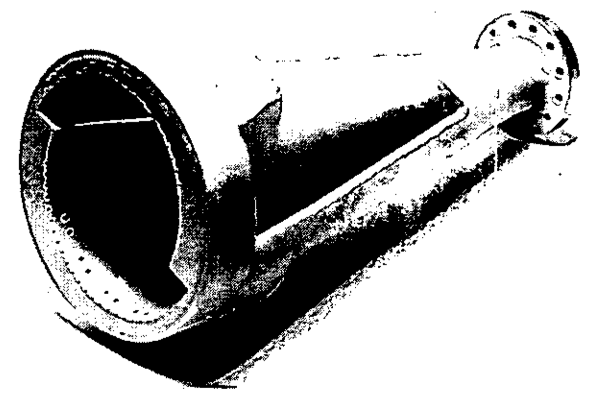


Figure 4: ABB's MBtu EV burner

has been taken to keep the outer recirculation zone free from unmixed fuel, safe and reliable operation of the burner even with high hydrogen content fuels is achieved. Due to the high velocity of the gas injection, the flame stabilizes downstream of the burner, where the fuel jets reach the hot recirculation zone (see figure 5). The air leaving the burner is quickly entrained into the fuel jets. The injector can easily be combined with the standard EV burner. Operation in premix mode with natural gas is possible independently of the MBtu injector. If oil No.2 is chosen as backup fuel, the natural gas fuel channels in the burner are used with slight modifications for the MBtu fuel. In the case of natural gas as backup fuel, additional fuel channels to supply the MBtu injection holes at the end of the burner are provided. Despite the completely different injection methods for MBtu gases and natural gas, the flame shape and the location of the reaction front is essentially the same in both cases.

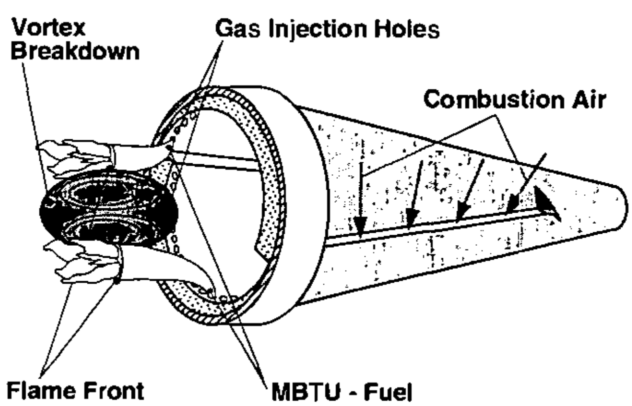


Figure 5: Sketch of the radial jet mixing system for the MBtu EV burner

DESCRIPTION OF THE TEST FACILITIES

Two full scale test rigs are used for a systematic testing program for EV burners, one operating at ambient pressure the other at gas turbine pressure. A wide range of measurements are possible and some of the techniques which have been used for the development of the MBtu EV burner are described here. The major components of the metrology for both test rigs are temperature measurements with thermocouple probes and the exhaust analysis for CO, CO_2, O_2, NO, NO_2 and UHC with infrared absorption, paramagnetic, chemiluminesence and flame ionization detectors. These instruments are controlled by a microcomputer. An automatic calibration can be requested. The probe technique is a suction, water quenched, heated line system.

Atmospheric Test Rig

The atmospheric test rig provides excellent optical access through the exhaust duct and via large windows in the air plenum chamber upstream of the burner. A full range of fluid supply services are metered, automatically monitored and logged by a microcomputer. These include full temperature, non-vitiated combustion air up to 3000 kg/h and two separate combustor cooling air supplies. Apart from the standard fuel supply of natural gas and light oil, CO, H_2 and N_2 are available from pressurized cylinders in sufficient quantities to run on full load conditions for several hours.

The single burner test rig was constructed to permit the use of EV burners identical to those found in ABB's gas turbines. Care has also been taken to ensure that the burners tested in the atmospheric rig can be transferred directly without modification to the high pressure test facility described below.

High Pressure Test Rig

In October 1991, a high pressure test facility was commissioned, which allows quick, cost effective and therefore extensive testing of single EV machine burners. Figure 6 shows the test rig along with the combustor liner. An axial compressor and then a two-stage radial compressor with intercooler are followed by a high pressure air preheater to provide up to 5.5 kg/s (12 lb/s) non-vitiated combustion air at 16 bar (232 psi) and 500°C (932F). The test rig consists of a plenum chamber upstream of the burner, two water cooled tubular pressure vessels with 0.6 m inner diameter and the rectangular chamber liner. The hot exhaust gases are quenched before the pressure reduction throttle and discharge to the chimney. A process control unit is used to operate the test rig independently from the microcomputer data logging system. Measurements relevant for the safe operation of the rig, such as fuel and air mass flows and a number of temperature and pressure readings, are directly connected to the process control unit and then passed on to the data logging system.

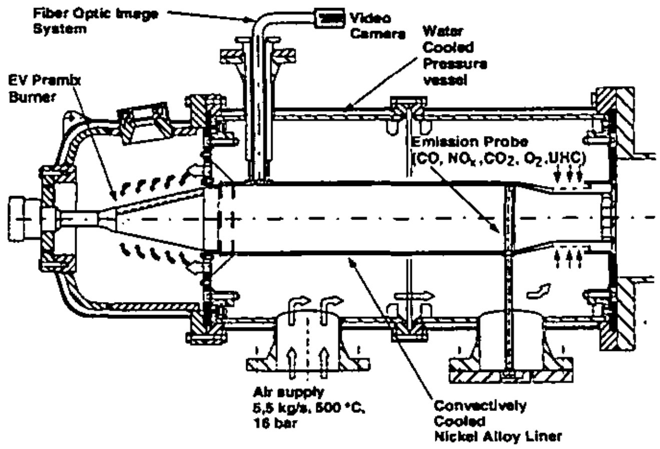


Figure 6: High pressure test rig

The liner is a nickel-base alloy construction, cooled convectively in order not to obscure genuine burner emissions by film cooling air effects. Optical access is provided by a fiber optical video system, which is mounted downstream of the burner in the flame tube. In addition, the plenum upstream of the burner is equipped with several windows, enabling direct observation of the mixing zone through the burner slots. Four water cooled suction probes are mounted at different axial stations and are connected to the computer-controlled gas analysis system. Pressure fluctuations as well as static pressures are monitored at different positions in the flame tube. Temperature is measured at 40 different locations in the burner and the liner walls. Due to the easy accessibility of the burner and the water cooling of the test section, two separate burner studies can be carried out in less than 8 hours.

CO and H_2 are supplied in pressurized cylinders, liquid nitrogen is evaporated from a supply tank and subsequently mixed with the CO and H_2. The three mass flows are separately controlled and metered. The fuel supply system allows the syngas composition and dilution to be changed during a test run which makes the testing very flexible and cost effective. About 30 minutes of full load operation on syngas is possible with the amount of CO and H_2 stored in the pressurized cylinders.

RESULTS OF AMBIENT AND HIGH PRESSURE BURNER TESTS

Burner tests have been carried out with a fuel composition equal to the oil gasification syngas (45% H_2, 48% CO and 7% N_2). Oil gasification syngas is more difficult to burn in a premix flame (higher flame velocities) and will also give higher NO_x emissions (higher maximum flame temperature) than coal gasification syngas. NO_x emission values measured with this syngas composition in the full scale high pressure experiments can therefore be regarded as conservative estimate for coal gasification fuel in the gas turbine combustor. A burner capable of burning residual oil gasification syngas in a premix flame can also be operated on coal gasification syngas and will produce even lower NO_x emissions.

Ambient Pressure Tests

A large number of different injection geometries have been screened in atmospheric tests. Filled circles in figure 7 represent the NO_x emissions at atmospheric conditions for the injection geometry that yielded the lowest emissions at high pressure.

The emissions are plotted as a function of the nitrogen dilution. The air preheat and the combustor outlet temperature were set in order to match typical gas turbine operation conditions. From approximately 20 ppmvd (@ 15% O_2) for the undiluted syngas, emissions decrease to less than 2 ppmvd if the syngas is diluted with nitrogen to a heating value of 7.5 MJ/kg (175 Btu/scf). Measured CO emissions are less than 8 ppm over the whole range of heating values. No burner overheat or flashback was observed. Interestingly, the optimum gas turbine configuration did not deliver the best data in atmospheric tests. Much lower values could be measured for other configurations: Data values marked with filled triangles show the best configuration found for atmospheric conditions with NO_x emissions in the order of 2 ppmvd (@ 15% O_2) at 12 MJ/kg heating value. Atmospheric testing proved not to be of great value for defining the best injector.

High Pressure Tests

Data values marked with open circles in figure 7 show the results of the high pressure tests at 16 bar (232psi). The air preheat and the combustor outlet temperature were set in order to match typical gas turbine operation conditions. It is seen that the NO_x emissions are in the order of 350 ppmvd (@ 15% O_2) for undiluted syngas and decrease to less than 25 ppmvd (@ 15% O_2) if the syngas is diluted to 7.5 MJ/kg (175 Btu/scf). At a

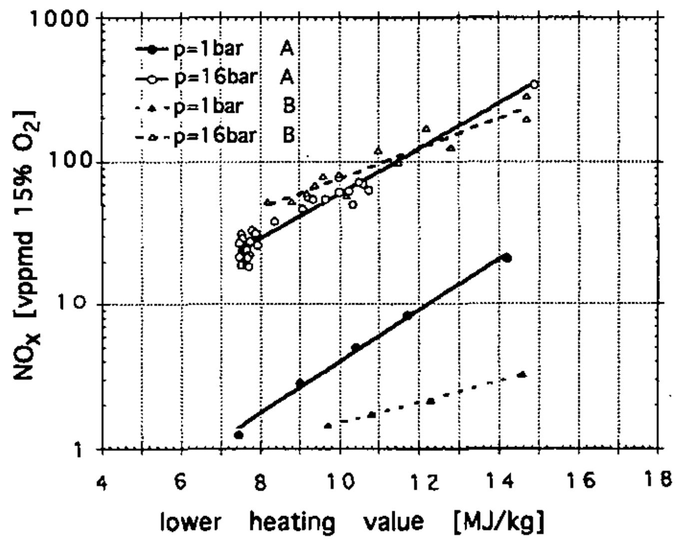


Figure 7: NO_x emissions as a function of the lower heating value for MBtu fuels

heating value comparable to coal gasification syngas (12 MJ/kg) the NO_x emissions are 120 ppmvd (@ 15% O_2), but one has to keep in mind that oil gasification syngas diluted to 12 MJ/kg (234 Btu/scf) has a higher hydrogen content than coal derived gas.

During the tests burner temperatures were always close to the inlet air temperature, even if undiluted gas was used. This ensures that safe operation (with higher NO_x emissions) is possible if the nitrogen dilution supply fails or if large heating value fluctuations occur during load changes of the gas turbine or the gasifier/ASU plant. The MBtu EV burner is of the same inherently safe design as the standard EV burner for natural gas operation. Burner noise was observed to be even lower than for natural gas operation. Due to the very compact reaction zone and the rapid mixing, perfect CO burnout was achieved. The strong decrease in NO_x emissions with falling heating value is caused by a more complete premixing of fuel and air. With increasing dilution the flame stabilizes downstream of the fuel injection nozzles, whereas in the undiluted case only partial premixing is possible upstream of the stabilization zone.

The NO_x emissions scale with pressure to the power of 0.8 to 0.9. This indicates that perfect premixing is not achieved with this type of fuel injection. It should be noted, that other injection geometries gave lower emissions at atmospheric conditions, but had pressure scaling with exponents of more than 1.2, i.e. emissions at high pressure were 40 times higher than at ambient pressure. An example for this is given by the open and filled triangles in figure 7. For case A (triangles) the cross section area of the injection holes was decreased by 40% compared to case B (circles). It must be concluded that low emissions at ambient pressure tests are a necessary but not a sufficient condition for low emissions at high pressure. The reason for this is the strong nonlinear interaction of flame temperature, fuel/air mixing and NO_x formation. Additionally, burners of smaller size produce considerably lower emissions in comparison to full scale burners. However this effect is not found for natural gas operation, since the characteristic mixing time of the injector (which is linearly coupled to the burner size) is only of major importance for MBtu combustion. In summary, it was found that only full scale full pressure burner experiments give reliable data concerning safe burner operation and emission values.

Part Load

The part load performance was investigated in ambient pressure tests for injection geometry A. Figure 8 shows tha NO_x emissions for burner thermal loads from 70 to 100%. As expected, NO_x emissions decrease with lower load (higher air equivalence ratio). In this load range, CO emissions were well below 8 ppmvd (@ 15% O_2) even at atmospheric conditions, which usually produce CO emissions substantially higher than high pressure tests. Furthermore, if the compressor mass flow can be reduced by approx. 30% with a variable inlet guide vane system, these very low emissions can be sustained down to less than 50% gas turbine power output without the need for fuel staging. The high hydrogen content in the moderately diluted fuel and the rapid mixing in the near field of the burner are very advantageous in this context.

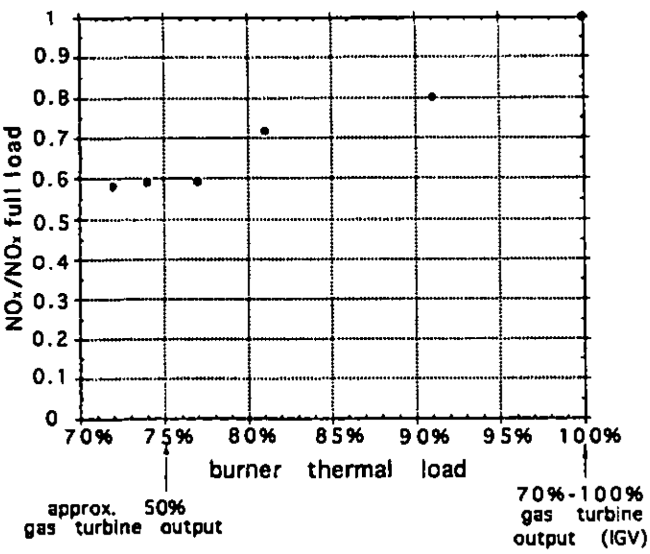


Figure 8: NO_x emissions at part load

Steam Dilution

The effect of steam dilution was also investigated in the atmospheric test rig and compared to nitrogen dilution of a mixture with approximately equal volumetric content of hydrogen and carbon monoxide. Figure 9 shows that steam is more effective than nitrogen when a comparison is made on the basis of the lower heating value of the mixture. On the other hand, the nitrogen dilution technique is often economically superior to steam, due to the unfavorable costs of high quality water. Additionally, a higher total plant efficiency can be reached with N_2 (Döbbeling et al. 1993). Steam dilution is an alternative if no nitrogen is available.

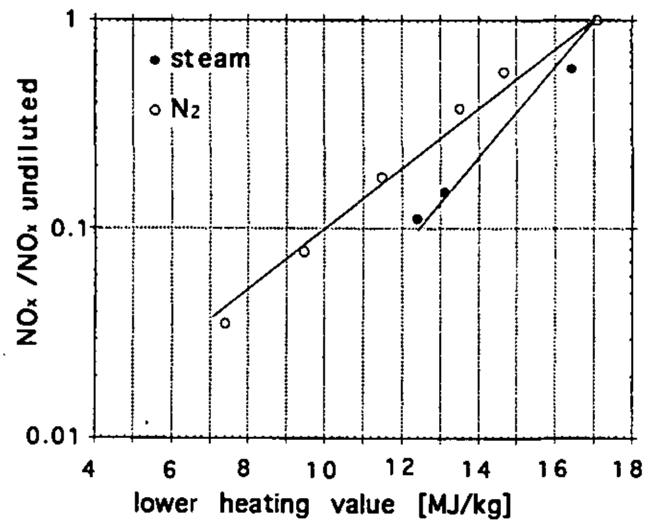


Figure 9: NO_x emissions with steam injection compared to N_2 dilution

NUMERICAL FLOW FIELD SIMULATION

The optimization of the hole geometry and distribution requires appropriate numerical tools. A three dimensional flow field simulation was used to study different injection geometries. A finite volume code with the k-ε turbulence model and a species transport equation for the fuel was used. With the knowledge of the local equivalence ratio and the temperature in the fuel air mixing zone, local laminar flame velocities and chemical time scales could be determined. Additional information on the turbulent properties of the flow field, allows application of empirical correlations for the local turbulent flame velocity (Liu et al. 1989). A comparison of this turbulent flame velocity with the local convective velocity yields the zones where flame stabilization is most likely to occur. It is obvious that only those flames which stabilize far enough downstream of the fuel injection will allow the fuel to premix with sufficient quantities of air. For the numerical simulation, the flow field in the burner was assumed to be cyclically repetitive within the sector between two MBtu injection holes. With this simplification, a large number of grid cells can be used to discretize the fuel injection and premixing region. A total number of 50000 computational cells was used.

Figure 10 shows a surface where the calculated turbulent flame velocity is 5 m/sec in the burner flow field. A sector of the burner containing three MBtu injection holes is shown. The rapid decrease of the concentration on the axis of the fuel jets restricts high turbulent flame velocities to the near field of the injection nozzles and the interaction region of adjacent fuel jets, where turbulence levels are high.

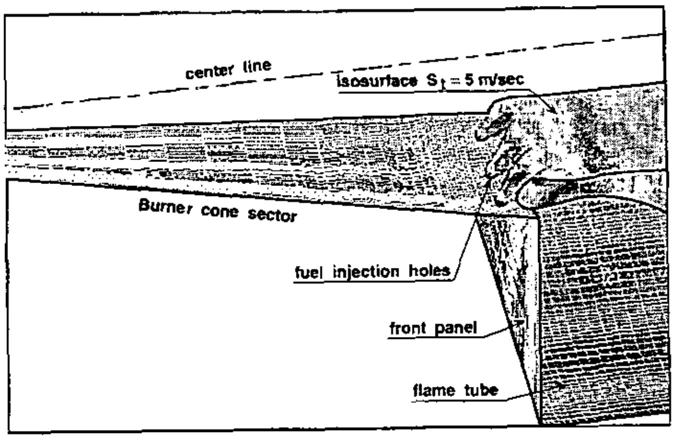
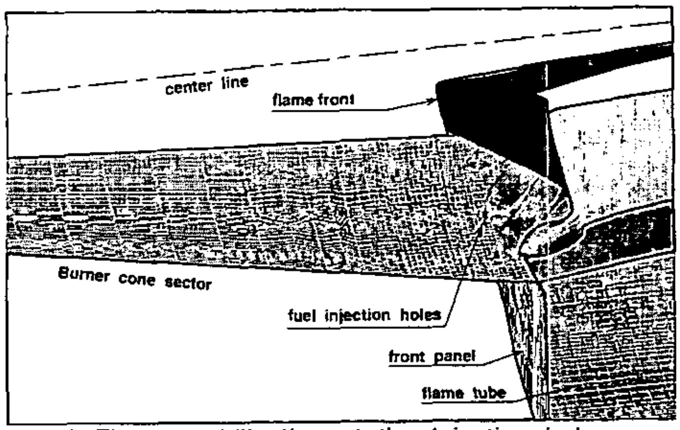


Figure 10: Calculated turbulent flame velocity in the MBtu EV burner

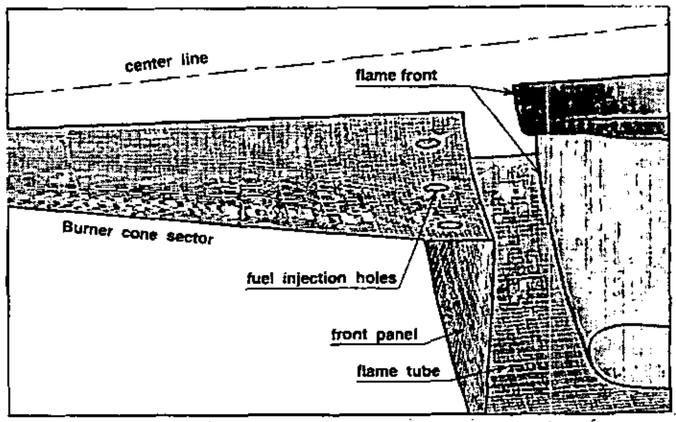
Two principal modes of flame stabilization are shown in figure 11 a and b for two different injection geometries. In figure 11 a the flame front is seen to stabilize immediately downstream of the injection locations of each individual fuel jet, whereas in figure 11 b flame stabilization is found far downstream of the fuel injection holes in a region where the jets reach the hot recirculation zone. A fuel injection geometry which stabilizes in regions of high fuel concentration (figure 11 a) is certainly producing very high NO_x values. The very low NO_x values which can be achieved with premixed combustion of MBtu fuels need suitable fuel injection geometries which delay flame stabilization until the fuel and air is mixed (see figure 11 b).

CONCLUSIONS

The ABB Double Cone Burner can be used for the premixed combustion of MBtu fuels, if a



a.) Flame stabilization at the injection holes



b.) Flame stabilization downstream of the burner (premix mode)

Figure 11 a,b: Calculated flame front location in the MBtu EV burner for two different injection geometries.

suitable fuel injection system is used. A full scale burner has been tested at 1 and 16 bar pressure. It was found that with moderate nitrogen dilution of the syngas, NO_x emission levels less than 25 vppmd (@15% O_2) can be achieved at full gas turbine conditions. Since the properties of syngas fuels differ strongly from natural gas, and since the NO_x emissions exhibited a complicated, geometry specific pressure dependency, only full-scale full-pressure tests give reliable results with respect to emissions and safe operation of a burner. The use of premix burners allows easy adaptation of standard gas turbines to MBtu fuels. Air extraction and water saturation or steam injection can be avoided. Numerical methods can be employed to predict the flame front location and to optimize the injection geometry of MBtu burners for minimum emissions. These numerical predictions will be used to extrapolate the experimental findings to different syngas compositions and gas turbine operating conditions.

REFERENCES

M. Aigner, A. Mayer, P. Schiessel, W. Strittmatter, 1990, "Second Generation Low-Emission Combustors for ABB Gas Turbines: Tests Under Full-Engine Conditions", Paper No.90-GT-308 presented at the Gas Turbine and Aeroangine Congress and Exposition, Brussels, Belgium, June 11-14

M. Aigner and G. Müller, 1992, "Second Generation Low-Emission Combustors for ABB Gas Turbines: Field Measurements with GT11N-EV", Paper No. 92-GT-322 presented at the Gas Turbine and Aeroengine Congress and Exposition, Cologne, Germany, June 1-4

K. Döbbeling, H.P. Knöpfel, T. Sattelmayer, P. Müller, K. Reyser, 1993, "ABB's Medium Btu EV Burner for Syngas Applications .- Test Results and GCC Integration Concept" Paper to be presented at the Twalfth EPRI Conference on Coal Gasification Power Plants, San Francisco

W. Jury, P. Müller, K. Reyser, 1992, "Gas Turbine (GT) Air Separation Unit (ASU) Integration for GCC A Study based on ABB EV Burner Technology for Gas Turbines", presented at the EPRI Conferenca on Clean Coal Combustion Technology, San Francisco

R.J. Kee, J.F. Grcar, M.D. Smooke, J.A. Miller, 1992, "A Fortran Program for Modeling steady laminar One-dimensional premixed flames", Sandia Report Sand85-8240.UC-401

J.J Keller, T. Sattelmayer and F. Thüringer, 1991, "Double Cone Burners for Gas Turbine Type 9 Retrofit Application", Paper No. G01, presented at the 19th International Congress on Combustion Engines (CIMAC), Florence

Y. Liu, B. Lenze and W. Leuckel, 1989, "Investigation on the Laminar and Turbulent Burning Velocity of Premixed Lean and Rich Flames of CH_4-H_2 Mixtures", Paper presented at the 12. Int. Coll. on the Dynamics of Explosions and Reactive Systems (ICDERS), Ann Arbor, USA

J.A. Miller, C.T. Bowmann, 1989, Prog. Energy Combustion Sci. 15,287

Th. Sattelmayer, M.P. Felchlin, J. Haumann, J. Hellat and D. Styner, 1990, "Second Generation Low-Emission Combustors for ABB Gas Turbines: Burner Development and Tests at Atmospheric Pressure", Paper No. 90-GT-162 presented at the Gas Turbine and Aeroengine Congress and Exposition, Brussels, Belgium, June 11-14

P. Senior, E. Lutum, W. Polifke and T. Sattelmayer, 1993, " Combustion Technology of the ABB GT13E2 Annular Combustor", Paper No. G22presented at the 20th Intarnational Congress on Combustion Engines (CIMAC), London

T. Strand, 1993, "Retrofitting a Low Emission Combustor to a Twin Shaft Gas Turbine",Paper No. G13 presented at the 20th International Congress on Combustion Engines (CIMAC), London