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Published in:

Proceedings of the 24th Intersociety Energy Conversion Engineering Conference

Link to article, DOI:

[10.1109/IECEC.1989.74834](https://doi.org/10.1109/IECEC.1989.74834)

Publication date:

1989

Document Version

Publisher's PDF, also known as Version of record

[Link back to DTU Orbit](#)

Citation (APA):

Frederiksen, O. P., & Qvale, E. B. (1989). The generation of electricity by gas turbines using the catalytic combustion of low-Btu gases. In Proceedings of the 24th Intersociety Energy Conversion Engineering Conference (Vol. Volume 5, pp. 2555-2560). IEEE. <https://doi.org/10.1109/IECEC.1989.74834>

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THE GENERATION OF ELECTRICITY BY GAS TURBINES USING THE
CATALYTIC COMBUSTION OF LOW-BTU GASES.

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ABSTRACT

Low-Btu gases are found in connection with unsuccessful oil and gas exploration, landfills, industrial waste and mining operations. The total chemical energy is, on the average, sufficient to sustain the operation of a gas turbine.

Alternative systems for the utilization of low-Btu gases from coal mines for power generation by use of gas turbines and catalysts have been studied and optimized. A catalytic combustion chamber has been investigated experimentally thus demonstrating the feasibility of the system.

INTRODUCTION

Background

Low-Btu gases are found in connection with unsuccessful oil and gas exploration, landfills, industrial waste, agricultural waste and mining operations.

Environmental concerns motivate efforts to process these gases. They very often contain noxious components that have to be removed in order to open for the exploitation of other resources such as hydrocarbons (in partly successful oil and gas wells), or they have to be removed for health reasons, (ventilation of coal mines, and removal of industrial waste gases), or they should be processed in order to remove odours (land-fills or agricultural waste),

or their removal is needed in order to refine a product (manure and biomass).

The processing and/or removal of these gases may be quite costly in terms of equipment and energy. Their energy content is in many cases, on the average, high enough to establish gas-turbine level temperatures, and thus serve as a base for the production of heat and electricity. But the fuel is evenly distributed in non-combustible gas, and there are therefore problems with both igniting and sustaining the combustion.

In gas turbines, the compression of the extra non-combustible gas contained in the fuel, may lead to matching problems and off-design operation with consequent reduction of power.

Materials

Today, land-fill gases are used as fuel both for gas turbines and gas engines, and gases from agricultural waste are used to fuel gas engines. However, this can be done only for fairly high hydrocarbon concentrations. Furthermore, there may be chemically aggressive constituents of the gases, that may make operation problematic, in particular for gas engines.

Some of these problems could be eliminated by using combustion chambers, boilers, or catalytic reaction chambers with steady flow and no moving parts. The temperatures in simple combustion chambers tend to be

too low for combustion, however, and preheating through recuperation is required. This would require the use of costly high-temperature materials.

Stationary versus Mobile Plants

In many cases, the thermodynamically most advantageous plant would be a combined cycle gas-turbine steam-turbine plant. However, in most cases that have been considered, the life span of the source of gas is short or uncertain. It is therefore desirable to have a mobile plant or at least a plant that can be dismantled reasonably easily. This eliminates the steam-turbine as a contender with its requirements to, among others, cooling towers.

Systems

With the above background the remaining candidate systems are limited to catalytic combustion chambers with or without support firing in connection with gas turbines.

Economics

The primary motivation or justification for processing the gases arises from environmental concerns. This means that a processing plant has to be established. The electricity generating unit is then added on to a processing plant that is already necessary and paid for in order to protect the environment. The cost of generating electricity then becomes marginal, and both the short pay-back times and low cost of the extra equipment make these extremely attractive.

State-of-the-Art

The number of projects in this area that have been described in the open literature

is limited. However, studies of the use of gas engines in connection with biogas and land-fill gases exist [1]. Gas turbines, being fuelled by ventilation gases from coal mines and landfills, have been installed [2, 3]. Finally, a study of a gas turbine with a high-temperature combustion chamber has been reported [4].

Previous studies of a catalytic combustion chamber for utilization of Low-Btu gases in gas turbines are not known.

SYSTEM SOLUTIONS. PRINCIPLE

In order to illustrate the principles and the principal problems and challenges, a few different types of systems will be shown.

High-Pressure Gases

High-pressure gases that may be considered in the present context are exclusively byproducts of hydrocarbon exploration. In a significant fraction of drilled wells, the hydrocarbon fraction is relatively low, at the same time as the contents of noxious gases are too high. Thus, in order to exploit this type of finds, it is necessary to process the gas and extract the condensable heavy-hydrocarbon fraction. The gas to be processed contains a large fraction of nitrogen N_2 , a small fraction of Methane (CH_4) and significant quantities of hydrogen sulfide and mercaptanes.

The present presentation will be limited to low-pressure gases.

Low-Pressure Gases

Low-pressure gases include waste gases from industry, agriculture and biomass, landfills and coal mines.

A simple system for the utilization of low-Btu gases from sources at atmospheric temperatures and pressures are shown in Figure 1.

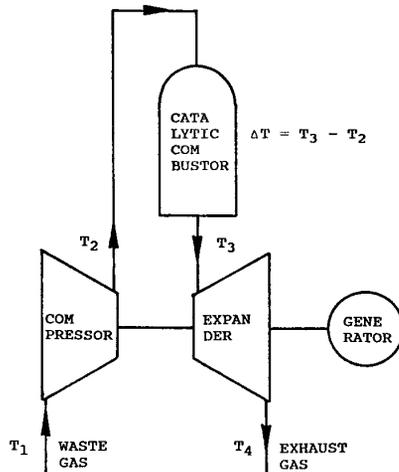


Figure 1. A Simple System for the Utilisation of Low-Btu Gases.

This system has two basic weaknesses. Firstly, the catalyst entrance temperature is quite low, which leads to slow reactions in the catalyst, and consequently the need for a large catalytic combustion chamber. Secondly, the energy release is often limited, leading to a low turbine inlet temperature and a consequent low process efficiency. The efficiency is shown in figure 2 as a function of compressor outlet temperature and energy release, expressed by the temperature rise over the catalytic combustion chamber (ΔT), non-dimensionalized by the compressor inlet temperature T_1 .

A more complex system is shown in Figure 3. The recuperator is used to raise the catalyst inlet temperature in order to accelerate the reactions in the catalyst, and consequently reduce the required catalyst size. Furthermore, the turbine inlet temperature is increased and the

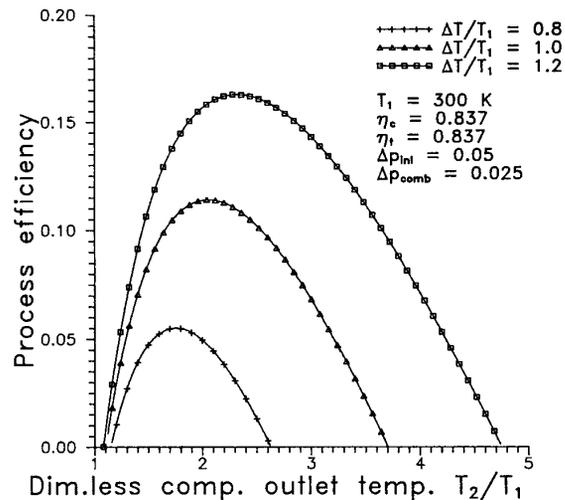


Figure 2. Efficiency of the Simple System (of Figure 1) for three Different Energy Releases (Expressed by the Temperature Increase ΔT over the Catalytic Combustion Chamber).

process efficiency, therefore, increase substantially.

Results for one specified energy release, expressed by the catalyst temperature rise, for one given recuperator effectiveness is given in Figure 4. Similar curves have been derived for other values of recuperator effectiveness, but are not presented here. The problem with the catalyst entrance temperature of the system in Figure 1 exists in the new system also, although less pronounced. But even in this new system the performance parameters are dependent on each other in an inflexible manner. For one gas quality, the optimum compressor temperature is given. But with this temperature ratio it may be impossible to reach a practical catalyst inlet temperature even for a highly efficient recuperator.

The curves shown in Figures 2 and 4 are the results of design studies. But additionally they reflect the sensitivity of the performance to arbitrary variations in

the gas quality, for a given system design.

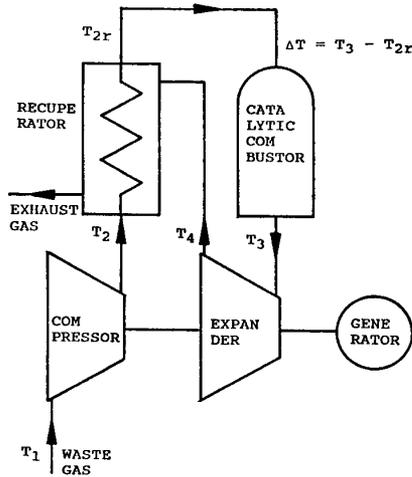


Figure 3. System with Recuperator for Low-Btu Gases.

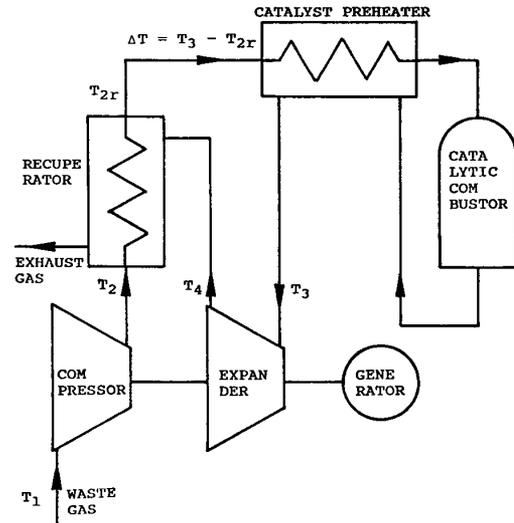


Figure 5. System with both Recuperator and Catalytic Preheater.

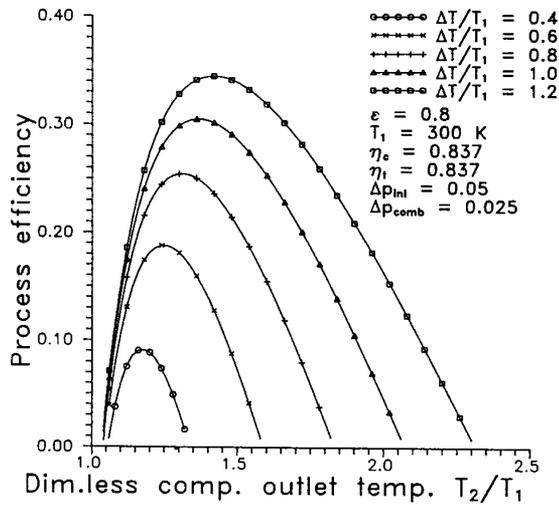


Figure 4. Efficiency of the Recuperation System (of Figure 3) for Varying Energy Release ΔT , for a Given Recuperator Efficiency ϵ .

It is seen that the performance, as expected, is quite sensitive to variations in gas quality.

The problem with the catalyst entrance temperature may be solved by using a third

system, shown in figure 5. This system incorporates both recuperation and catalyst preheater.

The presence of the two heat exchangers gives greater freedom in optimizing process parameters.

Surprisingly the performance curves are identical to the ones presented in Figure 4. But, because of the presence of the preheater, it will always be possible to reach a specified catalyst entrance temperature. This then implies that one is free to choose the compressor temperature ratio and hence the compressor design, to give optimum cycle efficiency for a given gas quality.

COMPONENT PERFORMANCE AND DESCRIPTION

General

The most important components in the systems that have been studied are the turbines (expanders), compressors, catalytic combustion chamber, and the heat

exchangers. Below, their limitations and the mathematical descriptions that have been used in the system studies are reported.

Turbines

Available manufacturers' literature and personal communication limit the temperatures of unprocessed gas to about 350 °C. For processed gas, the temperature limits are the same as in normal applications. In the system studies their performance is characterized by an isentropic efficiency.

Compressors

The performance of the compressors is quite sensitive to off-design conditions and is characterized by an isentropic efficiency.

Heat Exchangers.

There are no well-defined temperature limits for heat exchangers. Shell and tube heat exchangers are able to withstand high temperatures (above 800 °C). However, their dimensions in the present systems will be overwhelming. Plate heat exchangers, represent a realistic alternative. Some manufacturers claim tolerance up to a temperature of 800 °C. Our laboratory tests have shown that they are able to withstand at least 600 °C.

Catalytic Combustion Chamber

The catalytic combustion chamber is based on a catalyst developed and delivered by a Danish company [5].

It was tested extensively in order to determine ignition temperatures, and completion of the chemical reactions as a function of pressure and gas flow.

Typical heat release curves are shown in Figure 6.

The performance data serve as a base for the dimensioning of the combustion chamber and hence determines the cost of this component.

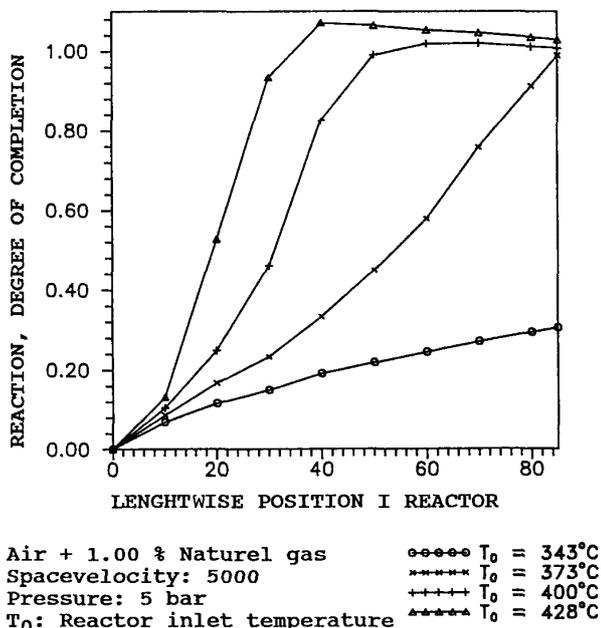


Figure 6. Typical Heat Release Curves for Catalytic Combustion Chamber.

ECONOMICS

The economics of the systems that have been designed is quite difficult to assess. However, in all cases considered the motivating force has been environmental concerns, and the gas has to be processed. What is of interest to us then is the economics of the added investment associated with the power generation. In the cases considered the pay - back periods have been estimated at 3 years for industrial waste gases and 1 year for coal mine ventilation.

CONCLUSION

Various systems for the generation of electricity by gas turbines using catalytic combustion of low-Btu gases have been investigated. Parametric studies of three configurations that are deemed to be practically feasible have been completed. It is shown that thermodynamic efficiency of these systems may be quite high. The system design has been made to comply with generally accepted limitations on the operation of the compressors, turbines and heat exchangers. The catalyst has been investigated experimentally in order to establish design information. The system design has been carried out on the basis of these experiments and of commonly accepted limits on the operation of compressors, turbines, and heat exchangers.

The return on the marginal investment of the components required to generate electricity is extremely high with a payback period of 1 to 3 years.

ACKNOWLEDGEMENTS

The investigation was supported by the Danish Ministry of Energy. The catalyst was supplied by the company Haldor Topsøe A/S. Mr. Peter Schoubye from that company supplied guidance and advice throughout the project.

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LEGEND

(used in the figures)

- p_o - ambient pressure [bar]
- p_2 - pressure out of compressor [bar]
- Δp_c - Combustion chamber pressure drop [bar]
- $\Delta p_{comb} = \frac{\Delta p_c}{p_2}$
- Δp_i - Inlet section pressure drop [bar]
- $\Delta p_{ind} = \frac{\Delta p_i}{p_o}$
- T_1 - Compressor inlet temperature [K]
- T_2 - Compressor outlet temperature [K]
- T_{2r} - Waste gas temperature after recuperator
- ΔT - Catalyst temperature increase [K]
- ϵ - Recuperator effectiveness
- η_c - Compressor efficiency
- η_t - Turbine efficiency