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UTILIZATION OF EXHAUST GASES IN INDUSTRIAL GAS TURBINE PLANTS

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CONTENT

1. Present status of the gas turbines.

More than 20 years ago, the first industrial gas turbine went into operation. During the intervening years, the gas turbine has shown that it is in many cases a suitable and economical machine for the production of electrical energy, both in power supplies companies and for industrial purposes. In many cases, the gas turbine has shown itself superior to Diesel, hydraulic or steam power.

The majority of gas turbines in operation are of the open cycle type. The open cycle machine is simple and operates safely; its reduced dimensions and weights are particularly appreciated where space conditions are tight. The gas turbine has been equally capable of handling base and peak loads. The quick starting of gas turbines has proved particularly advantageous in plants where repeated starts and stops are required or where emergency service is to be given very quickly.

Gas turbine manufacturers have always been concerned with the utilization of exhaust gases, with the idea that by suitable utilization of such gases the thermo-dynamic efficiency of the gas turbine could be increased. Of particular interest is the utilization of gas turbine gases for the production of process steam.

The recuperation of heat contained in the exhaust gases has presented a number of problems, which have been investigated very carefully. The solutions found are of the greatest interest, both from the technical and the economical points of view.

2. Advantages of the utilization of exhaust gases for industrial purposes

It is clear that the industry has always attempted to reduce as much as possible the cost of energy which it requires for production. The steel industry, for instance, has for years utilized gases resulting from its processes to produce power. As we shall see later, the steel industry now also utilizes gases such as blast furnace gases in gas turbine plants. Other industries have obtained a reduction of the cost of electrical energy, by expending the process steam which they require through back pressure or extraction steam turbines. Although this has meant putting in larger boilers for higher steam and temperature conditions,

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the all over economy has, been improved considerably.

Today's gas turbine is equally capable of being utilized advantageously in cases where both kWs and heat are required.

As the majority of gas turbines operate at moderate gas inlet temperatures, they produce a large volume of exhaust gases with temperatures which are favourable to their further utilization. In the following table we have indicated the approximate quantity of disposable gases for a number of different types of gas turbines:

Output of the gas turbine in (kW)	Volume of exhaust gases at atmospheric pressure in (m^3/hr.)	Equivalent approximate fuel consumption (kg/hr.) a/	Temperature of gases (°C)
4,000	187,000	1,640	320
6,200	245,000	2,280	350
11,000	486,000	3,770	310
22,000	486 000	3,700	300

a/ Fuel has been assumed with a calorific value of 10 000 Kcal/Kg

The large volumes of exhaust gases indicated above can be utilized in various ways, such as:

a) For the direct generation of low pressure saturated steam for processing purposes (textile, food, paper industry, etc.)

b) As combustion gases for large boilers or furnaces.

c) In heat exchangers for heating air or other gases, also for the purpose of dehydration of de-humidification.

It is clear that the temperature of the exhaust gases will vary with the load. If, therefore, a constant production of steam is required with variable electric load, it will be necessary to provide auxiliary burners for the recuperation boilers mentioned under a) above.

/3. Improvement of

3. Improvement of the efficiency of gas turbines combined with exhaust gases utilization

The only disadvantage of the gas turbine as compared to other machines used in the production of power is its lower thermal efficiency. However, with the utilization of exhaust gases combinations have been evolved whose total efficiency is equal or superior to that of other forms of generation.

It is well known that the efficiency of the gas turbine can be improved by passing the exhaust gases through a heat exchanger, the latter being inserted between the gas turbine compressor outlet and the combustion chamber. However, the effect of this heat exchanger is limited by economic considerations. The larger the heat exchanger, the higher the cost of the plan becomes. With a waste heat boiler, fed with gas turbine exhaust gases a combined thermal efficiency of 38 per cent can be obtained, although the temperature of the exhaust gases is not higher than 370°C.

4. Limitation to the utilization of exhaust gases

The majority of fuels used in gas turbines are divided from mineral oil, blast furnace gases and natural gas. In regard to liquid fuels, the latter can easily be utilized in the gas turbine chamber, provided that:

The viscosity be suitable,

The content of vanadium oxyd be within certain limits,

The content of sodium be less than 10 per million,

The total ash content not exceeds 300 per million,

The total sulphur content not exceeds 3.5 per cent,

Natural gas is particularly interesting in gas turbines for its high calorific content.

Blast furnace gas has found a great number of applications in gas turbines, notwithstanding its low calorific content and even though gas boosters are required before the gas enters in combustion chambers.

All the above fuels produce exhaust gases, which consist of a mixture of CO_2, steam, nitrogen, oxygen, SO_2 and ash. The SO_2 in combination with steam can form sulphuric acid.

/For fuels

For fuels containing 3.5 per cent sulphur, SO_2 and steam will combine at a temperature of approximately 140°C and lower. The above temperature is, therefore, the limiting temperature at which the exhaust gases can be utilized in a recuperation process. Lowering the temperature below 140°C would be synonymous to producing sulphuric acid, whose removal would complicate the process and produce unfavourable effects in ducts, chimneys, heat exchangers etc.

It is clear that for fuels that do not contain sulphur, such as some natural gases and blast furnace gases, the minimum temperature can be lower. Those gases can, therefore, be utilized to a lower temperature, thus increasing the all-over efficiency of the gas turbine plant.

It is quite clear that the utilization of exhaust gases must be investigated carefully in every individual case. It can be said, however, that most manufacturers of gas turbines have now considerable experience in the various possibilities of utilization and machines and arrangements have been developed which provide adequate and economic solutions to a number of problems and applications.

5. Practical examples of the utilization of exhaust gases in gas turbines

As has been pointed out previously, the utilization of exhaust gases depends on the following:

a) Type of fuels available.

b) Cost of Fuel.

c) Cost of installation.

d) Cost of maintenance and operation.

e) Conditions pertaining to the operation of the plant (load conditions, process requirements).

As far as point a) is concerned, Mexico is in a particularly advantageous position with regard to natural gas. Prices for natural gas particularly in the northern regions of Mexico, are favourable to production of energy by gas turbines and a number of such plants are now in operation or in the course of construction in those parts of the country. As far as points c) and d) are concerned, it has already been

/pointed out

pointed out that the cost of installation of the gas turbine is lower than that of other conventional power producing machinery. The addition of a waste heat boiler or a reasonably dimensioned heat exchanger is feasible at a reasonable cost, those items should generally not exceed 15 per cent of the cost of the gas turbine. Under special circumstances, however, it has been found economical to resort to more complicated and to a certain extent more costly cycles, as for instance the Korneuburg installation in Austria, or the installation of a gas turbine with waste heat boilers for the supply of heat to buildings for the town of Bremen (Germany). A further interesting utilization of exhaust gases is found in the cement industry, whereby the exhaust gases are utilized in the cement kiln.

Reverting to the first case, the exhaust gases are utilized in a waste heat boiler installed in the chimney of the gas turbine. With this arrangement, 0.063 Kg. of steam are produced for every Kilo of gas per second. The steam is saturated and obtainable at a pressure of 3.8 Kg/cm^2_{abs}. With a gas turbine of an output of 3,000 kW, 9,100 Kg of steam per hour are produced for a paper mill.

In the second case, the Korneuburg plant, a gas turbine, generating 30 MW, is combined with 2 waste heat boilers. The gas turbine produces 175 Kg/sec if exhaust gases are at a temperature of 310°C. The two waste heat boilers are equipped with auxiliary burners and will generate 100 t/h of steam at 14 ATA and 440°C. This steam is utilized in a steam turbine down to a vacuum of 0.02 ATA, thus producing 27.72 MW.

In the third case, the Vahr plant, there is a more complicated arrangement, whereby a two-shaft turbine is used with 2 combustion chambers. In order to obtain a more efficient compression of the combustion air, the latter is recooled during compression in addition a water cooled. Heat exchanger is provided wherein the turbine exhaust gases are cooled from 293°C, to 180°C. The water inlet temperature is 60°C and the outlet temperature is 130°C.

As there are variations of the electrical load, the plant includes 5 additional boilers, which will maintain the water temperature to 130°C under all conditions of load. Three boilers are equipped to burn fuels, whereas 2 boilers are electrical.

/The characteristics

The characteristics of the heat exchanger are:

Capacity	17.2 Gcal/h
Quantity of water	310 t/h
Volume of the exhaust gases	133 Nm^3/sec.
Temperature of inlet gases	293°C
Temperature of exhaust gases	180°C

The additional boilers are designed to the following conditions:

Service pressure	8 Kg/cm^2
Normal evaporation (each boiler)	5.4×10^6 Kcal/h
Maximum evaporation	6.1×10^6 Kcal/h
Fuel	Bunker C.
Calorific value of fuel	9,600 Kcal/Kg

In the final case, use of the gas turbine exhaust gases in a cement kiln, a two-way recuperation of heat is obtained, one from the kiln and the other from the exhaust gases of the turbine.

The gases from the kiln leave the latter at a temperature of 750°C, pass through a dust separator and enter the heat exchanger, leaving the heat exchanger at a temperature of about 250°C. Inducted draft fans are required to extract the gases from the heat exchanger.

In the gas turbine cycle, air is admitted at atmospheric pressure to the compressor. The air leaves the compressor at a temperature of 190°C. It passes then through the heat exchanger, increases its temperature up to 550°C, and thus utilizes the heat that has been extracted from the gases emanating from the cement kiln. From the heat exchanger, the air is lead to the combustion chamber, where its temperature is increased to 650°C. After the combustion chamber, the gases enter and leave the gas turbine in the conventional manner. It is, however, possible to utilize the exhaust gases from the gas turbine in the cement kiln.

The above described system effects a reduction of the fuel consumption by approx. 35 per cent. In adittion there is a saving of 12.2×10^6 Kcal/h by utilizing gas turbine exhaust gases in the cement kiln.

/6. Conclusión

6. Conclusion

There are a great number of applications for the exhaust gases produced by gas turbines. Some applications increase the thermodynamic efficiency, specially if the cost of fuel is high; other applications result in reducing the cost of electrical energy by generating steam as a by-product. Finally with the application of heat exchangers, energy is available in one form or another for multiple industrial purposes.