

Cooling of Combustion Chambers

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Abstract

To improve the gas turbine performance further the pressure ratio in the compressor and the working temperatures must increase. This will lead to an increase in temperatures in the combustion chamber. Therefore the thermal stresses on the liner walls inside the combustion chamber will increase. Thermomechanical behavior and lifetime of these parts requires the improvement of parietal cooling methods efficiency using optimally the available cooling air.

Nomenclature

A_{w1} [m ²]	area of liner, inside
A_{w2} [m ²]	area of liner, outside
C_1 [W/m ²]	convection, gas to liner
C_2 [W/m ²]	convection, liner to annulus air
K [W/m ²]	conduction, along liner wall
K_{1-2} [W/m ²]	conduction, through liner wall
k_w [W/(mK)]	thermal conductivity
R_1 [W/m ²]	radiation, flame to liner wall
R_2 [W/m ²]	radiation, liner to casing
T_{w1} [K]	liner wall temperature, inside
T_{w2} [K]	liner wall temperature, outside
t_w [m]	thickness of liner wall

1 Introduction

Thermal efficiency of a gas turbine can be improved by increasing the compressor pressure ratio and the turbine inlet temperature. When doing this, the thermal stresses in the combustion chamber will increase and the need for effective cooling becomes more and more apparent.

Most modern gas turbine uses film cooling and about 40 percent of the air leaving the compressor will be needed in the cooling process.

The combustion chamber can be described as an outer casing and an inner liner where the hot gases are flowing. They are separated by the cold air withdrawn from the compressor. When the compressor pressure ratio is increased the amount of heat transferred to the liner wall by radiation will raise. The increase in pressure will also result in higher combustor inlet temperature that will reduce the annulus air capacity to cool the wall by convection. ¹

¹ Letebvre, Arthur. H, *Gas Turbine Combustion*, 1983, Chapter 8: Heat Transfer.

The purpose of this rapport is to give a brief summary over the heat transfer process that occurs when cooling air is used to bring down the liner wall temperature. It also brings up the most common how to do this.

2 Heat-transfer process

The heat-transfer process in a combustion chamber consists mostly of radiation and convection. Loss of heat by conduction along the liner wall is usually very small and may often be neglected. The liner is heated by radiation and convection from the hot gas. It is cooled by radiation to the casing and by convection to the annulus air. The equations to be solved therefore are those concerning radiation and convection on both sides of the liner and the conduction through the liner wall due to the temperature gradient within it. To calculate these equations steady-state conditions is assumed and therefore the heat transfer in and out the liner wall must be equal. For an element inside the liner, ΔA_{w1} , and outside, ΔA_{w2} ,

$$(R_1 + C_1 + K) \cdot \Delta A_{w1} = (K_{1-2}) \cdot \Delta A_{w1} = (R_2 + C_2) \cdot \Delta A_{w2}$$

The liner wall is usually thin and to simplify the equation the elements on both sides are taken to be equal in size. As mentioned the conduction along the liner, K , is often very small compared to the radiation and the convection and may be neglected. The simplified equation then reads

$$R_1 + C_1 = R_2 + C_2 = K_{1-2}$$

K_{1-2} is the conduction through the liner and may be expressed as

$$K_{1-2} = \frac{k_w}{t_w} \cdot (T_{w1} - T_{w2})$$

When combining these two equations the liner wall temperature can be calculated. Figure 1 below shows the basic heat transfer process. The internal and external components are calculated separately. First, the uncooled case is studied and after that the cooled case. With cooling the expressions for the radiation and convection remains the same except for the internal convection, C_2 , which will be altered due to the changes in velocity and temperature of the hot gas.²

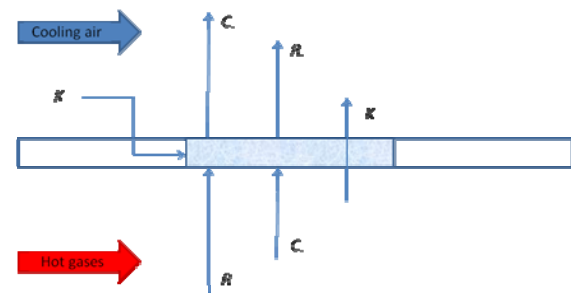


Figure 1: Basic heat-transfer process ^[1]

Radiation

Internal

Internal radiation stands for a sizable portion of the heat transferred from the gas to the liner. When film cooling forms a thermal barrier it is the only way by which heat can be transferred. Combustion gases emit radiation in two ways

²Letebvre, Arthur. H, *Gas Turbine Combustion*, 1983, Chapter 8: Heat Transfer.

1. Radiation from nonluminous gases such as CO₂ and H₂O
2. Blackbody radiation from luminous particles, namely soot

Radiation from nonluminous gases occurs at very narrow bands over the infrared spectra. It occurs at wavelengths that correspond to the vibration frequency of the atoms in the gas molecule.

When hydrocarbon fuels are burned, soot particles are formed. At atmospheric pressure those particles are too small and insignificant in number to play a vital role in the radiation. But when the pressure is increased, they grow both in size and number. The soot particles start to act as blackbodies and emit radiation. The only way to avoid this is by controlling the amount of soot particles.³

External

As mentioned the external radiation is often much smaller than the external convection and may be neglected at low temperatures. At higher temperatures the surfaces of the casing and liner is approximated with calculations for grey surfaces.⁴

3 Film cooling

The most common way to protect the combustion chamber and liner in particular is by film cooling. A number of slots in the liner wall provide it with a thin layer of cooling air that protects it from the hot gases. The slots are

placed in intervals about 4-8 cm apart along the axial depth of the liner. Unfortunately this method has some disadvantages. The thin film will gradually be destroyed by turbulence between the slots and the cooling effect will be lost. To avoid this phenomena the air closest to the slot is overcooled. This leads to great amounts of cooling air being wasted.

The first combustion chambers with cooling were constructed as several sections with increasing diameter and clearance in between. This allowed a film of cooling air to be injected along the inside of the liner and lower the wall temperature. The technique was developed and later on the sections started to overlap each other. Today, a great variation in design is available.⁵

4 Alternative cooling methods

In modern day combustion chambers, the film cooling often is combined with other forms of cooling to increase the effectiveness. New materials that withstand extremely high temperatures and different coating techniques that protect the metal inside make it possible to raise the pressure.

Multiholed Walls

A very effective way to lower the amount of air needed for cooling is the multiholed liner wall. A segment of a plate is shown in Figure 2.

³ Sundén B, *Värmeöverföring*, 2006, Chapter 12: Strålning.

⁴ Letebvre Arthur. H, *Gas Turbine Combustion*, 1983, Chapter 8: Heat Transfer.S

⁵ Letebvre Arthur. H, *Gas Turbine Combustion*, 1983, Chapter 8: Heat Transfer.

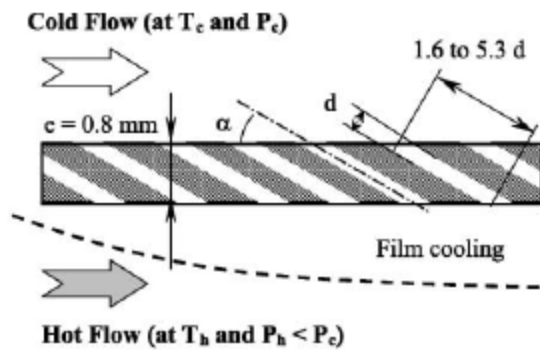
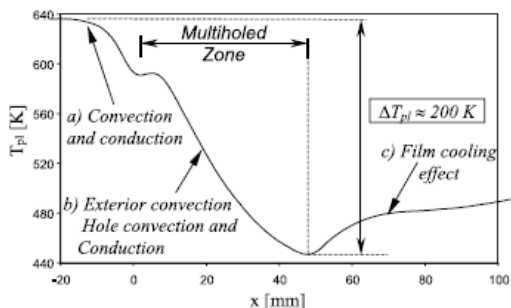


Figure 2: Geometrical configuration of multiholed plate [2]

Studies performed in France show a decrease in wall temperature from 640 K to 440 K. This decrease occurs along a 50 mm long multiholed zone. After this zone, a film cooling effect is obtained that keeps the temperature low without any supplementary air. Figure 3 shows how the decrease proceeds.



Figur 3: Heat transfer in test plate [3]

The effectiveness is due to the increase in convection inside the holes. The convection heat transfer process depends on the heat transfer coefficient, the surface inside the holes and the air flow temperature. Geometry and placing of the holes also plays an important role in determining the air velocity through the hole. Optimizing the geometrical parameters to provide necessary

convection with minimum amount of air is the goal.⁶

Transpiration

The problem with film cooling, as mentioned, is the over cooling that leads to wasteful use of cooling air. If the wall is kept a consistent maximum temperature, this waste could be reduced to a minimum. The best way to do this is by constructing the liner wall from a porous material. The pores provide a very large area over which heat transfer can occur. They also provide the inner surface with a uniform film of cooling air.⁷

But, as with many other new techniques, there are some problems. There are not many porous materials available on the market and problems with clogged pores made the scientists look for other alternatives. The researches lead to the development of multilaminate sheets. Transply, a structure developed by Rolls-Royce, is such a sheet. Transply consists of high-temperature alloy sheets brazed together containing channels that allow the air to flow through the liner wall. The air first cools the material and then a thin film on the inside wall. Tests show that temperatures up to 1173 K not will reduces the lifetime of the material. This temperature can be kept

⁶ Leger B, Miron P and Emidio J.M, *Geometric and aero-thermal influences on multiholed plate temperature: application on combustor walls*, 2002.

⁷ Letebvre, Arthur. H, *Gas Turbine Combustion*, 1983, Chapter 8: Heat Transfer.

with less than one third of the normal cooling-air requirement.⁸

5 Conclusion

Heat transfer in combustion chambers is a very complex process. The basic equations regarding radiation, convection and conduction can be calculated by putting up a heat balance over the inner and outer surface. This process is influenced by the compressor pressure ratio, with increasing ratio the temperature will raise.

The most common way of cooling liner wall is by film cooling. Holes along the liner provide a thin film of air to protect the inner wall. Often this leads to vast amounts of air being wasted. If the film cooling is combined with other techniques, the effectiveness can be increased.

6 References

Books and articles

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Pictures

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[2] Leger B, Miron P and Emidio J.M, (2002), *Geometric and aero-thermal influences on multiholed plate temperature: application on combustor walls*, Elsevier Science Ltd.

[3] Leger B, Miron P and Emidio J.M, (2002), *Geometric and aero-thermal influences on multiholed plate temperature: application on combustor walls*, Elsevier Science Ltd.

⁸ Rolls-Royce, *The Jet Engine*, 2005.