Application of a Turbojet Engine for Fire Extinguishing

A. F. Slitenko* and SooYong Kim**
Thermal Fluid Environmental System Department
Korea Institute of Machinery & Materials (KIMM)
P.O. Box 101, Yusung, TaeJon, Korea
soykim@kimm.re.kr

Abstract

Present study deals with performance analysis of an inert gas generator (IGG) which can be used as effective means to suppress fire. The IGG uses a turbo-jet engine to generate inert gas for fire extinguishing. It is generally known that a less degree of oxygen content in the product of combustion will increase the effectiveness of fire extinguishing. An inert gas generator system with water injection has advantages of suffocating and cooling effects that are very important factors for fire extinguishing. Some aspects of influencing parameters, such as, air excess coefficient, compressor pressure ratio, air temperature before combustion chamber, gas temperature after combustion chamber, mass flow rate of water injection etc. on the performance of IGG system are investigated.

Key Word : gas turbine, fire suppression, afterburner, oxygen content

NORMENCLATURE

C	Compressor	Subscripts	
G	Mass flow rate of steam gas mixture	0	Atmospheric condition
Lg	Stoichiometric air fuel ratio	1	Compressor inlet
M	Mass flow rate of air, gas, mean value	2	Combustor inlet
P	Pressure	3	Turbine inlet
T	Temperature, turbine	4	Turbine exit
W	Water mass flow rate	a	Air
X	Position of water injection	b	Bleeding air
α	Air excess coefficient	c.c.	Combustion chamber
η	Efficiency	f	Fuel
		s.c.	Stoichiometric condition

Introduction

Sometime fires happen on chemical plants, oil and gas wells, production areas, public and living building, forests and so on. The fires often bring large damages to the facilities and in many cases human sacrifices too. Extinguishing of large fires is extremely difficult, long, expensive and

* Senior Researcher
** Professor

dangerous process, particularly at the burning places of oil, gas and chemical plants. Therefore, great attentions have been given to the creation of an effective and comparatively cheap equipment for fire extinguishing [1]. Employing of a turbo-jet engine as an effective mean to produce inert gas for fire suppressing has been reported in the open literatures [2-4]. Effectiveness of such inert gas for fire extinguishing depends on several important factors.

Main principles of inert gas production by a turbo-jet engine

Simple scheme of a turbo-jet engine for inert gas production is shown in the Figure 1. Principle of its working is as follows. The atmospheric air comes into the compressor(c) to increase its pressure. Then this air passes to the combustion chamber(c.c.), where it is heated. The fuel burns and products of combustion are drawn into the turbine(t), where the temperature and pressure of the gas decrease through expansion process. The turbine produces enough power to drive the compressor, fuel and oil pumps and other auxiliary systems. From the turbine, combustion products pass to exit nozzle(N) from where powerful high speed jet is directed to the seat of fire. A large kinetic energy of this jet stream knocks off the fire flame and prevents its spreading. Besides, the combustion products contain an oxygen content essentially less than the atmospheric air, thereby a large amount of exhaust inert gas can be used for the fire suppressing. It is known that the decrease of temperature in the fire zone diminishes evaporation intensity of combustible substances and consequently it diminishes intensity of fire spreading. Therefore, it is expedient to inject water in the exhaust gas by a special spray device, which can be installed in the exit nozzle of a turbo-jet engine. The water will be supplied to this device by a water pump which is operated

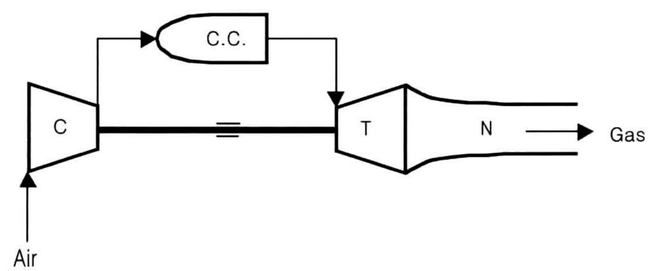

Fig. 1 Simple scheme of a turbo-jet engine gas turbine.

by the power extracted from the turbine. A part of this water evaporates and gas-stream-water mixture will be generated. This gas-stream-water mixture can be directed to the seat of fire for suppression. The injection of water significantly decreases the temperature of combustor exhaust gas. Besides, as a result of water evaporation, the relative oxygen content in the gas-stream mixture is less than that in the combustor exhaust gas by approximately 3~5% depending on variation of involved parameters. Therefore, such mixture is more effective for the fire suppressing than the initial combustion product. But calculations and experimental investigations from open literatures showed that such gas-steam mixture is sufficiently chemical active because it usually contains 14~15 % of oxygen [5]. Sometimes special substances, for example, freon. CO_2 and others, are added to the products of combustion to decrease the weight or volumetric oxygen content in the exhaust jet [6]. But using a large quantity of such substances makes fire extinguishing process significantly more expensive and also environmentally harmful. Therefore, it is thought very important to make the inert gas with less oxygen content with lower temperature and minimal cost if it is to be used as a good fire suppressant.

Investigation and results

The calculative investigation of factors that have influence on the oxygen content and temperature of the exhaust jet using the developed computer code was carried out. It is generally known that oxygen content in the combustion products depends on air excess coefficient α in the combustion chamber, which is again dependent on the combustor inlet T_2 and exit temperature T_3. As generally described in the textbook of gas turbine theory the compressor exit or combustor inlet temperature can be calculated as,

$$T_2 = T_1 \times (1 + \frac{1}{\eta_c} \times (\pi_c^{(\frac{\gamma-1}{\gamma})} - 1)) \quad (1)$$

Practically, for fire suppressing, a standard gas turbine engine with a compressor pressure ratio π_c = 12~20 and the combustor exit temperature T_3 = 1300~1400 K can be used. Take for example, a gas turbine engine with a turbine inlet temperature T_3 = 1350 K, a compressor pressure ratio π_c = 16 and accordingly a compressor exit temperature about T_2 = 778 K, then air excess coefficient α =4.36 and the weight oxygen content in the combustion products G =17.5 % will result. The decrease of the combustor inlet temperature T_2 and the increase of the combustor exit temperature T_3 lead to the decrease of air excess coefficient α and to reduction of oxygen content in the combustion product as shown in the Fig. 2 and Fig. 3, respectively. One of the ways to decrease the inlet combustor temperature is using air-water heat exchanger, where the temperature at the compressor exit can be lowered by heat exchange with water from the water tank. However, this will make the whole system larger and more complex. Another way to decrease

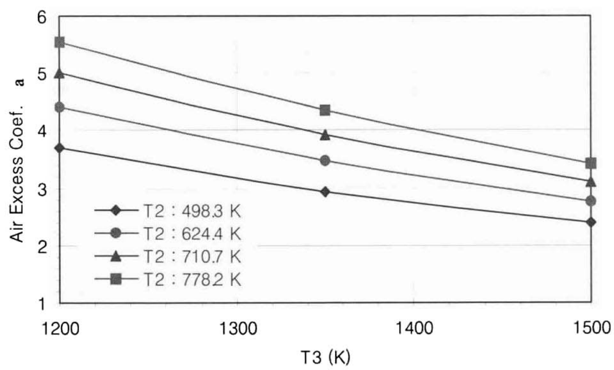

Fig. 2. Air excess coefficient variation with combustor exit temperature for different combustor in let temperature

the combustor inlet temperature is reduction of pressure ratio in the compressor. The calculation showed that if we take the compressor pressure ratio π_c = 8 with the compressor exit temperature T_2 = 624 K and combustor exit temperature T_3 = 1350 K, then, as a result, we shall obtain the air excess coefficient α =3.47. The relative weight oxygen content in this case will be reduced to 16.2 %. On the other hand, if we take a pressure ratio in the compressor π_c = 8, but increase the gas temperature T_3 to 1500 K, then the air excess coefficient α will be decreased to 2.77 and the relative weight oxygen content will also be reduced to 14.4%. Here, the air excess coefficient α is defined as [7]:

$$\alpha = (\frac{m_a}{m_f}) / (\frac{m_a}{m_f})_{s.c.} \quad (2)$$

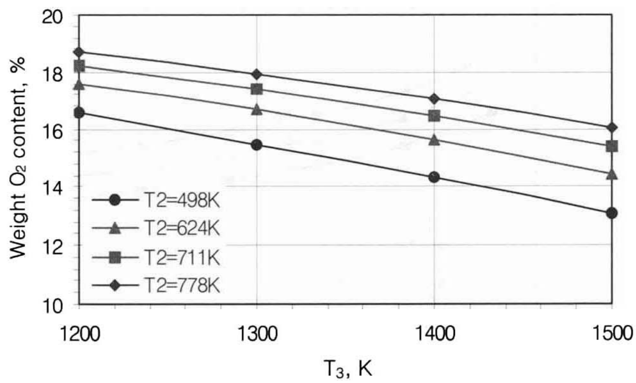

Fig. 3. Weight O2 content variation with combustor exit temperature for different combustor inlet temperature.

where, 'm' indicates mass flow rate, suffixes 'a' and 'f' specify air and fuel respectively and 's.c.'-stoichiometrical conditions. The mass of oxygen in the flow can be calculated as [7,8]:

$$G_{O2} = 0.232 \times (1 - W_{L)} \times L_O \times (\alpha - \eta_{cc}) \tag{3}$$

where W_L is the moisture mass in 1 kg of air, L_O is the air-fuel ratio such that whole oxygen is consumed, and η_{cc} is a combustion chamber effectiveness and was 0.995.

So the calculation results showed:

- increasing of the combustor exit temperature T_3 by 150 K (from 1350 K to 1500 K) at the constant combustor inlet temperature T_2 = 624 K leads to reduction of the relative weight oxygen content in the combustion product by 1.8 % (from 16.2 % to 14.4 %).

-decreasing of air temperature before combustion chamber T_2 by 154 K (from 778 K to 624 K) at the constant combustor exit temperature T_3 = 1350 K will lead to reduction of the relative weight oxygen content in the combustion product by 1.3 % (from 17.5 % to 16.2 %).

At all these cases, we have to take into account that as the inlet combustor temperature is decreased by decreasing compressor pressure ratio, the turbine expansion ratio is decreased too and in the result the gas temperature behind turbine is increased. For example, at the turbine inlet temperature T_3 =1150 K and turbine expansion ratio π_t =5.5, we receive turbine exit temperature T_4 = 793 K. But at the same T_3 and turbine expansion ratio π_t =3.0, the exit turbine temperature will be equal 904 K. if we use the turbine expansion ratio π_t =1.15 we shall receive the exit turbine temperature T_4 = 1110 K. The turbine exit temperature can be calculated using the equation,

$$T_4 = T_3 \times \left\{ 1 - \eta_t \times \left(1 - \frac{1}{\pi_t^{(\frac{\gamma - 1}{\gamma})}}\right) \right\} \tag{4}$$

The compressor and turbine efficiencies used in the present calculation are 0.74, 0.88, respectively. Figure 4 shows the influence of turbine expansion ratio on the exit turbine temperature. The inert gas temperature in exit jet depends on this value. Earlier, it was shown that the increase of combustor exit temperature reduces the relative weight oxygen content in the combustion product.

But increasing of a combustor exit temperature and a turbine inlet temperature T_3 leads to increasing of the turbine exit temperature T_4 and the turbine expansion ratio. For example, at turbine expansion ratio π_t =5.5 and turbine inlet temperature T_3 =1150 K, we have the exit

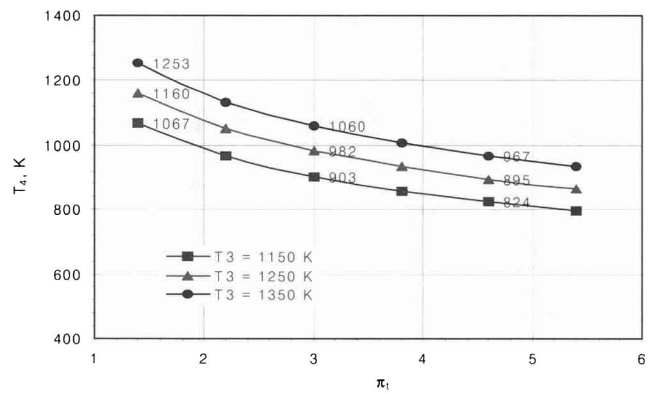

Fig. 4. Exit turbine temperature T4 for different inlet turbine temperature T3 and turbine expansion ratio πt.

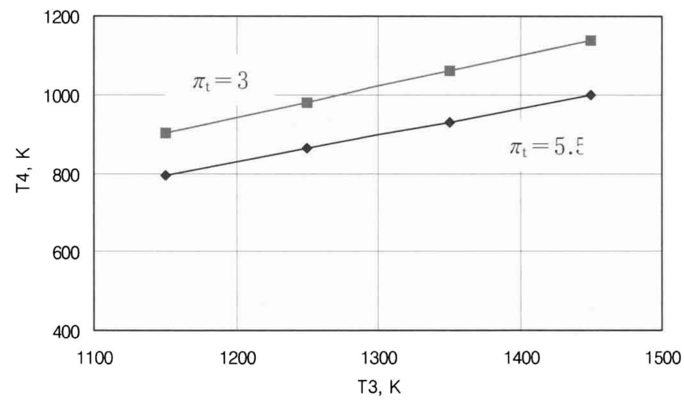

Fig. 5. Variation of turbine exit temperature T4 for different turbine inlet temperature T3.

turbine temperature T_4 = 793 K, but if we increase the temperature T_3 to 1350 K at same turbine expansion ratio π_t =5.5, we shall receive a temperature T_4 = 885 K. The turbine exit temperature variations for different turbine inlet temperature are shown in Fig. 5. It is known that temperature of the exit jet has a large influence on the effectiveness for fire extinguishing. However it is also necessary to indicate that decreasing the pressure ratio in the compressor and increasing the exit combustor temperature not only lead to the decease of air excess coefficient and therefore reduction of the relative weight oxygen content but it also increases the exit jet temperature too. Usually increasing gas temperature after combustion chamber T_3 has more significant effect on reduction of the relative weight oxygen content in the combustion products than decreasing of the combustor inlet temperature T_2. However, increasing the gas temperature after combustion chamber causes disadvantageous effect for turbine part, demands additional cooling of some elements, complicates its design and manufacturing, and also decreases the operating safety. One of the several ways to overcome these difficulties is the injection of sprayed water into the combustion chamber or into a special mixer located after the combustion chamber. Sprayed water evaporates in the mixer, forms the gas-stream mixture and passes into the turbine. The temperature of this gas-steam mixture is significantly lower than the temperature of the combustion product before water injection. Therefore, the condition of turbine operating becomes better. It is possible that the desired temperature of the gas-stream mixture before the turbine can be controlled by the quantity of injected water. Water can be fed by a water pump which is driven by the turbine power. The water injection into the combustion chamber or the mixer has other important advantages: the relative weight or volumetric oxygen content in the gas-steam mixture is essentially lower than in the initial combustion product. If, for example, for a compressor pressure ratio π_c = 16, that means, the temperature before the combustion chamber T_2 equals 778 K, and when the combustor exit temperature T_3 is 1500 K, with the injection of such quantity of water to receive a temperature of gas-steam mixture before turbine T_m = 1150 K, the relative weight oxygen content in the mixture becomes 14.6% which is 1.5% lower than without water injection. During the expansion process in turbine, the temperature of gas-steam mixture decreases but is still high enough to be used as a proper fire suppressant. In order to increase the fire extinguishing effectiveness it is required to decrease temperature of the mixture. This problem can be resolved by additional water injection after the turbine. It is possible to control the quantity of injected water so that temperature of mixture will be approximately equal to 373 K. In this case, the relative weight oxygen content in the exit gas-steam mixture will be equal 12.3 %. If the temperature of the exit gas-steam mixture will be decreased to 347 K by additional water injection in the exit gas-steam jet, oxygen content will be equal to 7.1%. In all these calculation the fuel mass flow rate is calculated by

$$m_f = (m_a - m_b)/(\alpha \times L_g) \tag{5}$$

So, for receiving a maximum effectiveness of fire suppressing, it is important to take into following factors: decrease of air temperature before combustion chamber, increase of gas temperature after combustion chamber, injection of water before turbine and additional injection of water after turbine. In result, it is possible to obtain a high speed jet of gas-steam mixture with low relative oxygen content and sufficiently low temperature for fire suppressing. Fig. 6 shows the scheme of a turbo-jet engine with water injection for inert gas generation. This scheme consists of a centrifugal compressor(C), combustion chamber(CC), axial turbine(T), mixer(M) between combustor and turbine, exit nozzle(N), water tank(WT) and water pump(WP). Such a scheme of turbo-jet engine with water injection is effective than initial scheme which is shown in Fig. 1. For example, at pressure ratio π_c =1.4 the air temperature after the compressor is equal to 349 K. With a fixed compressor exit temperature T_2, and a combustor exit gas temperature T_3 =1350 K, it is possible to obtain a relative weight oxygen content in the combustion product 13.5 %, and after first water injection before turbine (at the temperature of gas-steam mixture equal 1150 K) O_2 content =12.8 %, after second water injection behind the turbine (at the temperature of gas-steam mixture equals 373 K) O_2 content =9.6 %, and after additional water injection in the exit nozzle (at the temperature of exit gas-steam-water jet equal to 343 K) O_2 content =5.5 %. If for example, a gas temperature after the combustion chamber T_3 =1500 K with a fixed compressor exit temperature as before, the relative weight oxygen content will become respectively: G_1 =11.8 %; G_2 =10.8 %; G_3 =8.05 %; G_4 =4.6 %. The calculation result of the relative weight oxygen content at the temperature T_3 =1500 K and different temperature T_2 are presented in Fig. 7. Here on the horizontal axis the points 1 ,2, 3, 4 indicates positions of combustor exit, before turbine, after turbine, and nozzle exit, respectively. The water injection has a large influence not only on the decrease of the exit jet temperature and reduction of the relative weight oxygen content but it also increases the total volume of inert gas in the exit nozzle as the injected water is transformed into steam and, as a result, a larger volume of gas-steam mixture will be produced. For example, if we use the simple turbo-jet engine without injection of water, then with an air mass flow rate m_a =3.5 kg/sec, combustor exit temperature T_3 =1500 K, and compressor pressure ratio π_c =1.4, the mass flow rate of inert gas becomes G_{ig} =13,090 m^3/h. But, with water injection into the mixer, G_{ig} becomes 14,275 m^3/h and G_{ig} =22,160 m^3/h with water injected both in the mixer and behind the turbine (in all these cases the exit jet temperature was maintained at 373 K). Fig. 8 shows the influence of

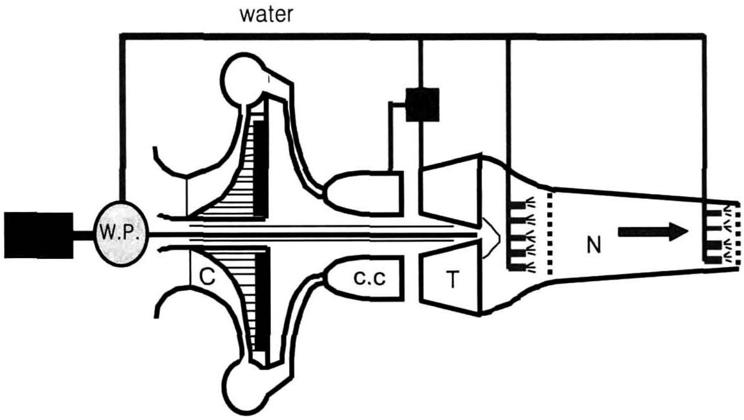

Fig. 6. A scheme of turbo-jet engine with water injection for fire extinguishing.

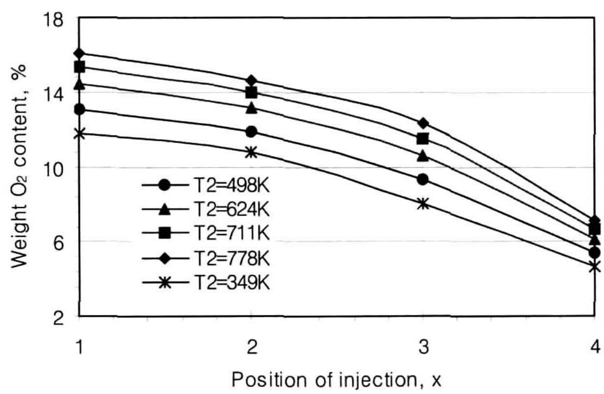

Fig. 7. Weight oxygen content variation along the positions of water injection for different T2 at T3 =1500K and Tm =1150 K.

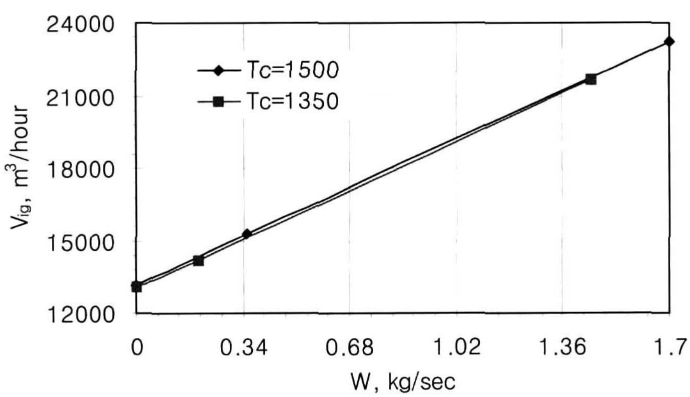

Fig. 8. Influence of water injection on the total inert gas volume per 1 hour in the exit jet.

water injection on the total inert gas volume per 1 hour in the exit jet at the π_c =1.4. The result of calculations showed that the scheme with water injection has a low weight oxygen content in the exit nozzle and such a gas-steam mixture can be effective for fire suppressing. The total amount of water needed to maintain the nozzle exit temperature of 100°C is estimated to be approximately 5-6 tons/h.

Conclusion

The investigation of performance of IGG using a turbo-jet gas turbine engine which can produce low temperature inert gas to suppress the fire is carried out. Results indicate that the combustor inlet and exit temperatures, injection of water in the mixer and behind the gas turbine strongly influence the properties of the produced inert gas. The oxygen content in the exhaust gas decreases with lowering the combustor inlet temperature, increasing its exit temperature and the amount of water injection. The resulting IGG system will have a simple design, low cost, high effectiveness for fire suppressing and will operate with reliability. The content presented in this paper is protected by patent No. 10-1999-32466.

Acknowledgement

The authors wish to gratefully acknowledge the support given by Ministry of Science and Technology and Ministry of Commerce, Industry & Energy's funding through the Dual Use Technology project.

References

1. Buborodko M. D., 1982, "Fire Car", Leningrad Machinery

2. Tahir Hussain, 1994, "Extinguishing of Kuwaiti Oil Fires- Challenges, Technology, and Success", Atmospheric Environment Vol. 29, No. 13, p.p. 2139-2147

3. Navolotskiy L. N. et al., 1993, "Method for suppression of gas, oil and gas-oil well gusher fire", Patent WO 93/18823, 1993.

4. Preobrazhenskii Yu B, Prokhorenko K.V., and Volkov, V.F., 1997, "Fire Extinguishing procedure for Machinery with a gas turbine drive", Patent No. 97-50121700-WPI9746001

5. Von Nebojsa Gasparovic, 1981, "Einflu β der Gasturbinen parameter auf die Emission der Stickoxide", Eletrizitatswirschaft Jg, 80, Heft 5.

6. Bayern CHEM Flugchemische Antriebe GMBH, 1997, "Compact, lightweight fire extinguishing gas generator for use in confined space, Patent No. 97-227754000-WPI9721001.

7. Philip P. Walsh and Paul Fletcher, 1988, "Gas Turbine Performance", Blackwell Science", Ch. 5.

8. Soudarev A.B. and Antonovsky B.I., 1985, Gas Turbine Plant Combustor, Leningrad publishing.