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Research Article

Design and Analysis of Gas Turbine Combustion Chamber for Producer Gas as Working Fuel

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Abstract

Stationary gas turbines are preferred over other prime movers for power generation due to its low specific fuel consumption. The gas turbine power plants and steam turbine bottoming cycle are used as co-generation technique for improving overall efficiency of the plant. The utilization of fuel and its effective combustion derives the primary cycle efficiency. Hence combustion chamber of gas turbine should provide necessary chemical kinetics and species generation with effective cooling of flame tube. In the present paper the need for assessment of process design parameters of gas turbine combustion chamber is addressed. Design procedure and dimensions of combustion chamber of gas turbine working on producer gas is presented.

Keywords: *Gas Turbine Combustion Chamber, Producer Gas etc.*

Introduction

Gas turbine combustor is a device for raising the temperature of the incoming air stream by the addition and combustion of fuel. In serving this purpose, the combustor must satisfy many different requirements such as capable of initiating ignition easily and must operate stabile over a range of conditions. At all operating points, it must provide for essentially complete combustion of the fuel while minimizing the formation and emission of undesirable pollutants. To avoid damaging the turbine, sufficient mixing must achieved in the combustor to obtain an acceptably uniform exit gas temperature distribution. The combustor must also operate with as low a pressure loss as practical to maintain high overall cycle efficiency. Finally, all of these functions must be performed in a configuration which has a minimum size, weight, and cost, and which is sufficiently durable to achieve an acceptable operating life. In many respects, these requirements are mutually incompatible. Achieving an improvement in one aspect of performance very often requires a corresponding sacrifice in some other area.Most of the basic conflicts are as follows: (Mellor A. M., 1990; Lefebvre A.H, 1995)

1. The mixing within the combustor can be increased to improve the uniformity of the exit temperature distribution at the expense of increasing either the pressure loss or the combustor length.
2. Emissions of nitrogen oxides and smoke can be reduced by designing for a lean combustion zone. However, doing so results in decreased ignition performance, turndown ratio, and combustion efficiency.
3. The frontal area of the combustor can be increased to improve combustion efficiency and flame stability, but this leads to a larger and heavier configuration which becomes more difficult to cool.

Design Procedure

These are typical considerations in the design and development of a combustor for any given application. Thus, achieving a successful combustor configuration involves trade-offs among the various relevant design and performance criteria until the optimum compromise has been reached, which best satisfies all of the imposed specifications and constraints. With all these parameters, the design of combustion chamber is based on the following basic requirements: (Kulshreshtha *et al*, 2005; Kulshreshtha *et al*, 2006)

1. Maximum flame stability at all operating conditions.
2. High combustion efficiency at all operating conditions.
3. Minimum pollutant formation at all conditions.
4. Minimum pressure loss commensurate with operation and performance.
5. Satisfactory ignition and relight at altitude, as well as ground starting at low temperatures.
6. A satisfactorily outlet temperature distribution tailored to the demands of the turbine.
7. Absence of smoke and solids from exhaust, as well deposits in the combustor.
8. Minimum manufacturing cost, size and weight for the particular applications.
9. A long Operating life and ease of maintenance.

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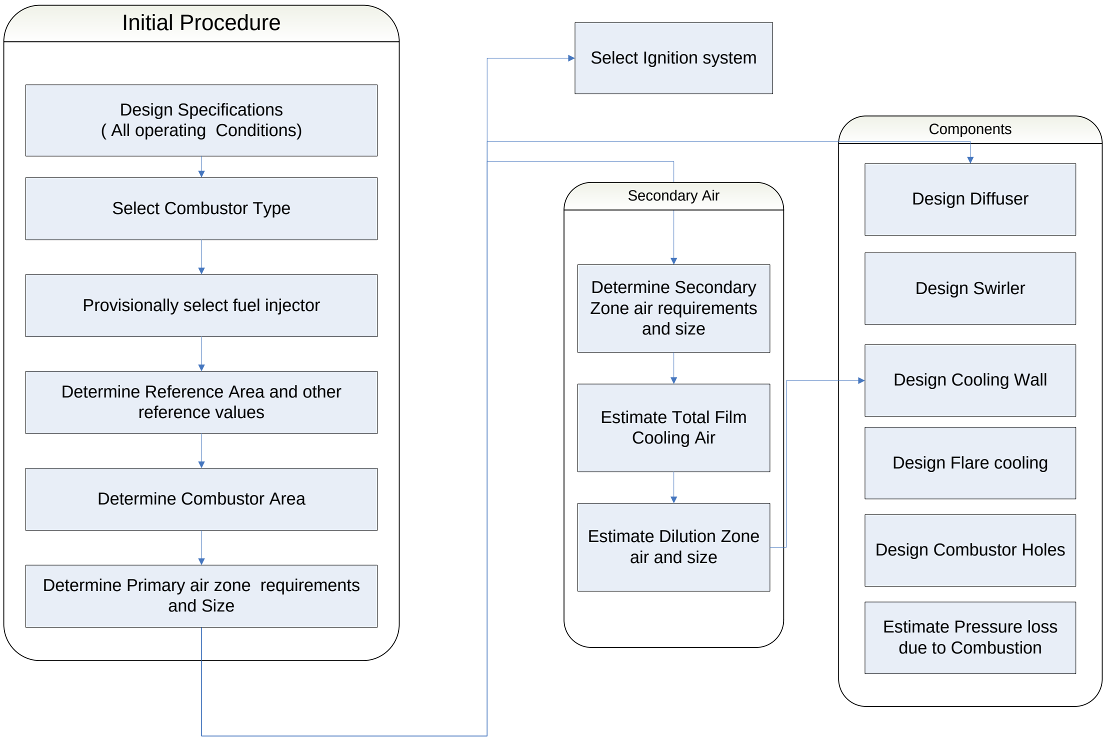


Preliminary Design Procedure

The design of the combustion chamber was carried out using the initial conditions as obtained from the compressor outlet. The combustor design parameters are listed as from brayton cycle analysis:

1. Temperature of air entering the Combustion chamber after compression in centrifugal compressor = 428 K
2. Inlet Pressure = 1.5 bar
3. Air Fuel Ratio (Mass flow rate of Air / Mass flow rate of producer gas) = 0.8333
4. Fuel used is producer gas of following % composition (Odgers, 1973; Bridgewater, 2003)

H_2	Co	CO_2	H_2o	CH_4	N_2
19.48	20.63	5.035	3.238	1.319	50.3

5. Calorific value of Producer gas = 7000 kJ/ m^3
6. Density of producer gas = 1.3 kg/m^3
7. Mass Flow rate of Producer gas = 12 kg/ Sec

Evaluation of Reference Area

The combustion chamber design has to achieve with many constraints. The overall size is dictated by compressor and turbine. The combustor has to depend on the compressor exit conditions and the combustion exit conditions should be decided on the required turbine inlet conditions for maximized turbine performance. The reference area is determined either by chemical or pressure loss limitations. The dimensions of a combustor might be determined either aerodynamically or by reaction rate control. If the combustor is sized to meet a specific pressure loss it will be large enough to accommodate the chemical reactions.

$$A_{Ref} = [\ K\ ((m_3 \sqrt{T_3})/P_3\ )\text{^}2 \left(\frac{\Delta P3-4\ /\ qRef}{\frac{\Delta P3-4}{P3}} \right)]^{0.5} \qquad (1)$$

(Zainal *et al,* 2003)

Where A_{Ref} = Reference area in m^2, m_3= air mass flow rate at combustor inlet in kg/s, T_3 is the total temperature at the combustor inlet in Kelvin, P_3= Total pressure at combustor inlet in Pascal, $\Delta P_{3\text{-}4}$ = Cold loss in Pascal= Pressure drop in diffuser + Pressure drop in liner. However pressure drop in liner = $\frac{\rho_3 V_3{}^2}{2}$; Aq_{Ref} is the reference dynamic pressure as specified in Equation (2) in Pascal

$$q_{Ref} = \frac{1}{2} \rho_3 {V_{Ref}}^2 \qquad (2)$$

where ρ_3 is the air density at the combustor inlet in kg/m^3
$V_{Ref}$the reference velocity,

$$V_{Ref} = \frac{m_3}{\rho_3 A_{Ref}} \qquad (3)$$

The constant k has the value of 143.5 and above equation−1 is used to calculate the reference area, using aerodynamic consideration. For any given Fuel/ Air Ratio, the combustion efficiency η, is given as a function of the correlating parameter, θ,

$$\text{Where } \theta = \frac{P3^{1.75}\ A\, ref\ D^{0.75}\ e^{\frac{T3}{b}}}{m3} \qquad (4)$$

(Hassan, *et al*, 2010)

All combustors have combustion efficiencies close to 100 % at a value of $\theta = 73\times10^{-6}$ and the value of temperature correction factor, b, for a constant A/F ratio is given by $b = 245(1.39 + \ln(\varphi))$ for $0.6 < \varphi < 1.0$. The primary zone is designed to use 14 to 24 % of total air for value of φ corresponding to 1.5.

$$\frac{\Delta P3-4}{P3} = 6\%,\ \frac{\Delta P3-4}{q\ Ref} = 53,\ \frac{m\ 3\sqrt{T3}}{A\ Ref\ P3} = 3 \times 10^{-3} \qquad (5)$$

Condition	P3	T3	M air	T4	φ	η	M pgas	$\frac{\Delta P3-4}{P3}$
Ground	1.5 Bar	428 K	12	1387	1.2	99.5	12.5	0.06

Determination of Combustor Area

For Single can combustor, the combustor area is given by the relation $A_{ft} / A_{Ref} = 0.7$. Hence $A_{ft} = 0.7 * A_{Ref}$.

Liner air Admission Holes

The need of the liner holes is to provide enough air in the primary zone for complete combustion primary zone equivalence ratio of 1.2 selected, to provide enough air to the cooling the products of combustion and to provide a uniform temperature profile at the exit in the dilution zone and to cool the liner wall configuration. The diameter of the air admission holes depends on the maximum penetration required. The effective diameter of the holes will be calculated by the following equations: $\frac{\Delta P3-4}{P3} = \frac{143.5\ Mh^2\ T3}{P3^2 Cd^2 Ah^2}$, where Ah is the area of admission holes. The procedure for calculation of air admission holes is given below.

1. $\frac{\Delta P3-4}{P3} = 6\%$
2. $Assume\ Cd = 0.65$
3. Estimate Area of Hole using equation $\frac{\Delta P3-4}{P3} = \frac{143.5\ Mh^2\ T3}{P3^2 Cd^2 Ah^2}$ (Sawyer, 1985)
4. M_h= Mass flow rate through hole in kg/s
5. Calculate α = Hole air Ratio = Hole Area/ Annulus Area
6. Calculate β = Bleed Ratio = mass flow through hole / mass flow through annulus
7. Calculate μ = β/α
8. Calculate K using the relation $K = 1 + 0.64[\ 2\mu^2 + [\ 4\mu^4 + 1.56\ \mu^2(4\beta - \beta^2)]^{0.5}$
9. Calculate Cd and iteratively check for correctness of equation by the relation

$$Cd = \frac{k-1}{0.6\ [\ 4\ k^2\ - k(2-\beta)^2]^{0.5}} \qquad (6)$$

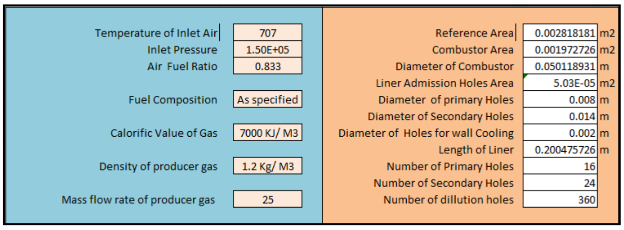
Liner Length

The length of liner is a function of the pattern factor (PF)and the liner diameter(D_l). The length can be calculated using the following equation

$$L_l = D_l\ [A \times \frac{\Delta P3-4}{q\ Ref} \ln(1/(1-PF))]^{-1} \qquad (7)$$

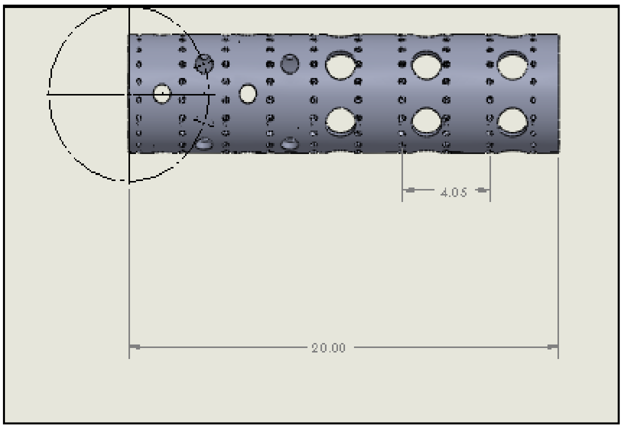
Dimensions of Flame tube of Combustor

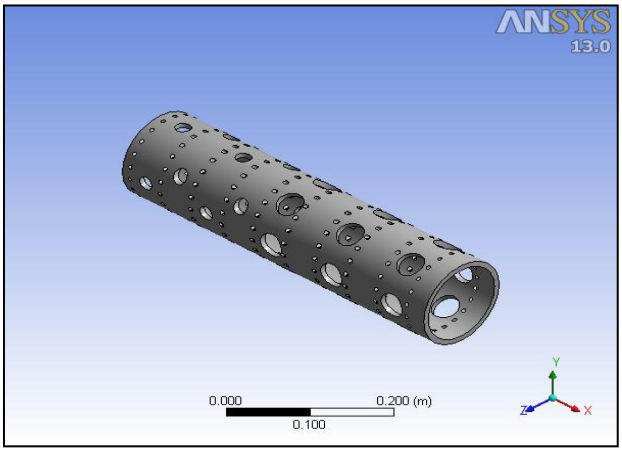
The Dimensions of the flame tube are calculated, which will with stand a temperature of approximately 1200 K all over the skin of the Flame tube. The dimensions are arrived using the procedural steps discussed in the earlier sections and the tube is drafted using Solid Works software. The operating data and calculations for flame tube and casing dimensions are presented.

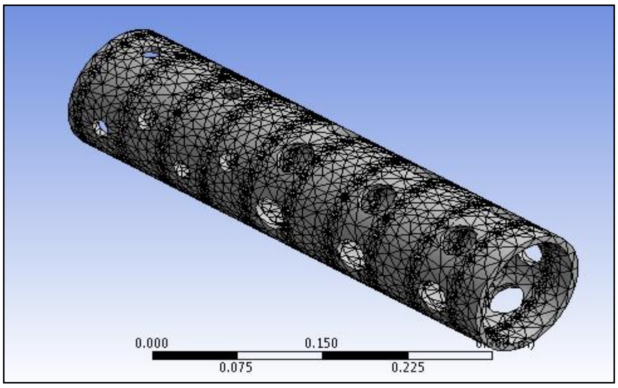


Temperature of Inlet Air	707
Inlet Pressure	1.50E+05
Air Fuel Ratio	0.833
Fuel Composition	As specified
Calorific Value of Gas	7000 KJ/ M3
Density of producer gas	1.2 Kg/ M3
Mass flow rate of producer gas	25

Reference Area	0.002818181	m2
Combustor Area	0.001972726	m2
Diameter of Combustor	0.050118931	m
Liner Admission Holes Area	5.03E-05	m2
Diameter of primary Holes	0.008	m
Diameter of Secondary Holes	0.014	m
Diameter of Holes for wall Cooling	0.002	m
Length of Liner	0.200475726	m
Number of Primary Holes	16	
Number of Secondary Holes	24	
Number of dillution holes	360	







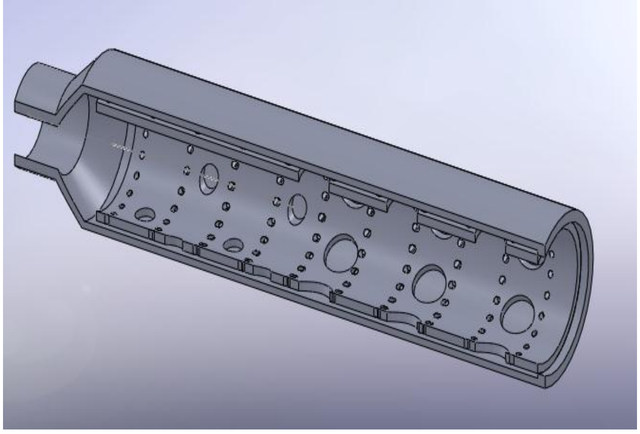


Figure 1: (a) Flame tube with primary, secondary and wall cooling holes. (b) Mesh (c) Assembled view of Flame tube and Outer casing

Conclusions

The designed combustion chamber should assist the distribution of primary air required for ignition near the burner, and quenching of Flame by secondary air distribution with flame tube cooling. In conventional combustion chamber design, the primary air is always less than the secondary air, whereas for producer gas, as A/F ratio is ranging between 0.8 –1.2 (due to varying gas composition) the primary air and secondary air ratio is almost 0.93. As energy density of producer gas with Air is more than methane, and other conventional liquid fuels, the generation of NO_X is predicted at higher temperatures. Hence estimation of adiabatic Flame temperatures, exhaust temperature of gases leaving the combustion chamber, limiting it to turbine exit temperature is a parameter of design match. The design of complete combustion chamber involves swirler design, burner design, and location of igniter. In the present work the flame tube is designed with distribution of primary and secondary air.

Future Scope of Work

The Future work involves CFD simulation of turbulence zones, Chemical kinetics, with species transport mechanism using producer gas.

References

Mellor A. M., Design of Modern Turbine Combustors (US: Academic Press Inc., 1990).

Lefebvre A.H., Gas Turbine Combustion Chamber (2nd ed., USA: Taylor and Francis, 1999).

Kulshreshtha, D.B. andChanniwala, S.A. (2005), Simplified Design of Combustion Chamber for Small Gas Turbine Application, Proc. of ASME IMECE2005 – 79038, Florida, USA.

Kulshreshtha, D.B., Channiwala, S.A. and SaurabhDikshit.(2006), Numerical Simulation of Tubular Type Combustion Chamber, Proceedings of ASME International Mechanical Engineering Congress and Exposition, Florida.

Odgers, J. (1973), Current theories of combustion within gas turbine chambers, Trans. Am. Soc. Mech. Eng., pp 1321–1338.

Bridgewater,A.V. (2003), Renewable fuels and chemicals by thermal processing of biomass, Chemical Engineering Journal, 91, pp 87–102.

Zainal, Z.A., Ali, R., Lean, C.H. and Seetsramu, K.N. (2003), Predictions of performance of downdraft gasifier using equilibrium modeling using different biomass materials, Energy conservation and management, 44.pp.459–469.

Hassan, S., Zainal, Z.A., Miskam, M.A. (2010). A preliminary investigation of compressed Producer gas from down draft gasifiers, Journal of applied sciences 10(5), pp 406–412.

Sawyer, J.W., (ed), 1985. Sawyer's Gas Turbine Engineering Handbook.Third Edition. Norwalk, CT: Turbomachinery International Publications.