Preliminary Design Methodology For Multifuel Gas Combustor

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Abstract–

The present work shows a preliminary design methodology for multi fuel gas turbine combustor. The goal is obtain a basic combustor configuration based in the operating conditions and taking into account changes in the fuel. The methodology assumes a series of empirical and semi-empirical correlations that have been development through the time those equations has been modified to considerer different fuels and also includes the use of a chemical reactor network CRN to calculate the gas temperature inside the combustor. The selection criteria for a suitable combustor is based on calculation of the geometric parameters of combustor, gas temperature profile, liner wall temperatures and position of air admission holes according with the selected fuel.

Keywords: gas turbine combustor, gas turbine, preliminary design, multiple fuel, chemical reactor network CNR

I. Introduction

Gas turbine operates in a wide range of conditions, thus the combustor must be designed to operate stably in each of these range of conditions. A combustor must satisfy a wide range of requirements as: high combustion efficiency, high reliability and rapid ignition, optimal flame stability at all operating conditions, have a homogeneous temperature distribution at combustor chamber outlet, minimal formation of pollutants at all operating conditions, minimum pressure loss, low fuel consumption, multi-fuel capability. These requirements are desired for aircraft and industrial gas turbine combustors, those requirements are more rigorous aircraft combustors [1].

The aim of the present work is to provide information for conventional combustors preliminary design methodology that considers different types of fuels and does not represent the most advanced design methodology for gas turbine combustors. However, the combination of empirical and semi-empirical correlations with the use of chemical reactor network makes it a method of rapid implementation and easy execution, capable to provide a preliminary combustor design that attends gas turbine operating conditions. This methodology exhibits limitation in different areas especially in combustor scaling and implementation of new combustion technologies.

The selection criterion for a suitable combustor is based on calculation of the basic geometric parameters of combustor, gas temperature profile, liner wall temperatures and position of air admission holes. Conventional combustors consist of an inlet diffuser, a fuel injector, a swirler, and three combustion zones, primary, secondary and dilution.

II. Preliminary Design Procedure

The preliminary combustor design procedure proposed in this work is based on the Melconian and Modak (1985)[2] model and also includes the use of a chemical reactor network (CRN)[3] to calculate the gas temperature inside the combustor; This allows obtain a first approach of combustor model. The methodology assumes that the inlet combustor conditions are known from the engine cycle analyses.

The proposed methodology allows calculate the basic geometric parameters of combustors as: the total length of the combustor, length of each zone of the combustor, diameter or height of the flame tube and the casing, dimensions of the diffuser, geometric parameters of swirler, yielding positioning and size of primary and secondary air admission holes, film cooling system and temperature profile. The design methodology for a gas turbine combustor operating with different types of fuels is presented Fig. 1.

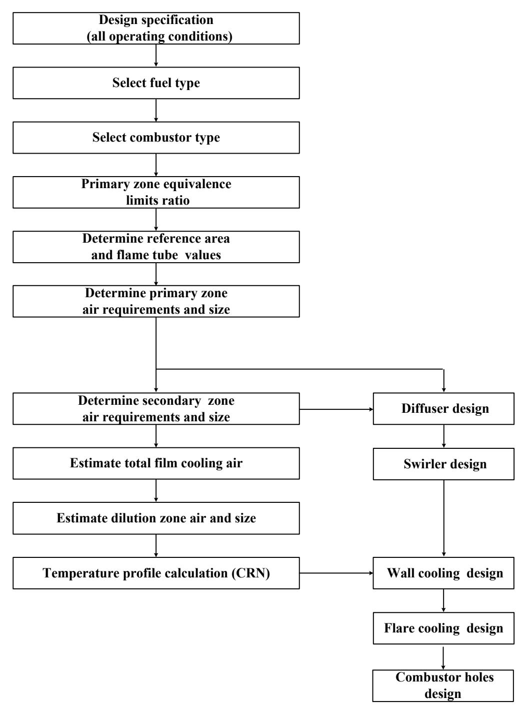

Fig. 1 Proposed Preliminary Design Procedure (Melconian and Modak, 1985).

The main difference with the model proposed by Melconian and Modak (1985) is the implementation of a CNR to calculate the temperature along the combustor chamber length. The combustor was divide into four main regions:

recirculation zone, remainder primary zone, secondary zone and dilution zone, where the recirculation zone is represented by a perfectly stirred reactor (*PSR)* connected in series, the remainder primary zone have five *PSR*, the secondary zone have five *PSR* and dilution zone has been modeled with a plug flow reactor; which are interconnected to form a network, each of which is fed by the products of the preceding one as is show in the Fig.2

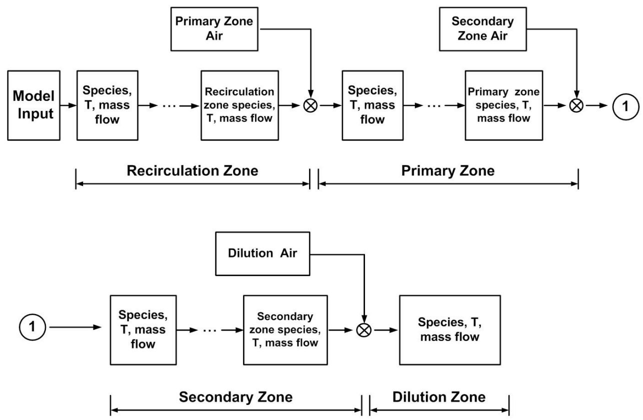

Fig. 2 Diagram of the combustor model CNR

III. Example of Design

The combustor is proposal for a stationary industrial turbine, with can annular configuration with six combustors, which operates with natural gas, ethanol and kerosene. With a maximum power of 14.41 MW, compressor exit area of 0.290 m^2, air velocity at the outlet of the compressor is assumed as 150 m/s. Tables I and II presents the design operating conditions. Where condition 1 corresponds to 100% of engine rotation, i.e. 11.200 rpm, the second condition corresponding to 80% with 8.960 rpm, the third condition corresponds to 60% of 6.720 rpm rotation and the fourth condition corresponds to 40% of the 4.480 rpm rotation.

TABLE I
DESIGN OPERATING CONDITION

Operating Condition	P_3 [Mpa]	p_3 [Mpa]	T_3 [K]	M_3 [kg/s]
1	1.732	1.696	678	50
2	1.195	1.168	609	39
3	0.831	0.81	547	28
4	0.641	0.623	506	17

The value of pressure loss ($\Delta P_{3-4}/q_{ref}$) was assumed as 30 [2], which correspond a can annular type combustor and the number of combustor was six. The operating limits for equivalence ratio was found through the parameters presented for each fuel at Table I. Is important recall that the calculations was perform to four operation condition and for the tree types of fuel as result the most critical values was assumed for each operating condition for these reason the percentage of air in the primary zone is 44% that correspond to the case of combustor using ethanol as a fuel; with this condition the internal diameter of the combustor chamber is set as 0.22 m.

TABLE II
DESIGN OPERATING CONDITION

Operating Condition	ϕ Overall	Pattern Factor	Comb. Eff. % Min	$\Delta P_{3-4}/P_3$
1	0.314	20	99	0.04
2	0.186	20	99	0.04
3	0.162	20	98	0.04
4	0.157	20	96	0.04

The Table III shows the mass flow rate for each fuel for the established operating conditions.

TABLE III
MASS FLOW RATE

Operating Condition	Gas natural mf_3 [kg/s]	Ethanol mf_3 [kg/s]	Kerosene mf_3 [kg/s]
1	0.9118	1.744	1.068
2	0.4285	0.807	0.4945
3	0.2747	0.5046	0.309
4	0.1601	0.2971	0.1819

For the calculation of diffuser was assumed a value pressure loss of 1 % and a coefficient of discharge of Snout Cd,s of 1 and was assumed the following conditions: stagger angle of the 60º, mass air flow through the swirler 6%, loss pressure inside of the snout of 25%, atomizer diameter of 0.041m corresponding to 12.5% of the reference diameter, wall thickness of 0.0012m and blades type curved. The parameters of the recirculation zone were obtained assuming the length of the recirculation zone as 0.133 m.

The execution of the CRN was carrying out using software CHEMKIN Collection 3.7 code, the package AURORA [4] was used for simulated the PSR and package PLUG [5] to simulated PFR. The calculation was performed for the tree types of fuel and for each operating condition. This code used a detailed mechanism of reaction for gas natural [6], ethanol [7], and kerosene [8].

The positioning of cooling slots was perform based on the temperature profile, placing a greater number of slots in hottest area of the combustor, in this case three slots are positioned into recirculation zone and primary zone. For calculations were assumed the following values: Slot height (s) = 0.002m, the Slot Lip Thickness (t) = 0.0012m, wall thickness (tw) = 0.0015 m, wall material is steel stainless and material of the steel casing. The gas is assumed as non-luminous.

The percentage of air available for zone of combustors is: 33,93% or the primary zone, 8,27% for the secondary zone and 18,9% for dilution zone.

The Table IV show the basic configuration for can-annular combustor operating with natural gas, ethanol and kerosene.

TABLE IV
BASIC CONFIGURATION FOR CAN-ANULAR COMBUSTOR

Parameter	Results
Reference diameter D_{ref} [m]	4.20E-01
Flame tube diameter D_{ft} [m]	2.30E-01
Internal diameter d_i [m]	2. 20E-01
Total length [m]	6.37E-01
Primary zone length [m]	1.73E-01
Secondary zone length [m]	1.15E-01
Dilution Zone Length [m]	3.50E-01
Length of recirculation zone [m]	1.35E-01
Length of difusser [m]	2.61E-01
Length of dome [m]	7.01E-02
Swirler diameter D_{sw} [m]	6.70E-02
Numbers of holes at Primary Zone	18
Numbers of holes at Secondary Zone	24
Numbers of holes at Dilution Zone	20
Primary zone holes diameter [m]	3.99E-02
Secondary zone holes diameter [m]	1.43E-02
Dilution zone holes diameter [m]	2.74E-02

IV. CONCLUSIONS

The present paper shows a methodology for a multi fuel gas turbine combustor preliminary design. The methodology has ability to design conventional combustors, taking in to account different fuel. As was mentioned, the objective of present work is provide a methodology of rapid implementation and execution that will be capable to provide a preliminary combustor design that attends gas turbine operating conditions. Also it is important remember that methodology here proposed allows obtained a preliminary design and it is necessary continue with the optimization process through numerical analysis tools as Computational Fluid Dynamics codes and several test. It is important to emphasize that the design operating conditions must be closer as possible to real condition; the time spent in the refining process will be less. The use CRN proved to be a useful tool to calculate the temperature of the gases, which takes into account not only the conditions of operation also takes into consideration the fuel characteristics.

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