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Acoustic analysis of a liquefied petroleum gas-fired pulse combustor

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Abstract

Experimental investigation of acoustic characteristics of a Helmholtz type liquefied petroleum gas-fired pulse combustor is presented. In the experiments, the length of the tail pipe was changed from 1.9 m to 1.3 m by 10 cm intervals. Sound level measurements were taken from the exhaust side (outlet) and air flapper side (inlet) at a distance of 1 m from both sides. With decreasing lengths of the tail pipe, the sound pressure level increased. At the measurements related to the exhaust side, the maximum value of equivalent continuous sound pressure level, LEQ was 96.6 dB when the length of the tailpipe and fundamental frequency were 1.3 m and 63 Hz, respectively. Same kinds of measurements were performed at the air flapper side, but the LEQ value was stronger at the exhaust side than the one at the air flapper side. It was also observed that the effect of the type of gaseous fuel on the acoustic efficiency of the pulse combustor can be neglected when the results of the acoustic efficiencies were compared to those in the literature. In order to compare the accuracy of frequencies measured by the sound level meter, a suitable dynamic pressure transducer and a spectrum analyzer were used to perform amplitude and frequency measurements. The average deviation between the measurements performed by the sound level meter and dynamic pressure transducer was 2.4 Hz (3.8% errors) while the average deviation was 3.8 Hz (6% errors) between the sound level meter and spectrum analyzer.

Keywords: Combustion; Pulse combustion; Sound pressure; Frequency measurement

1. Introduction

Pulse combustion technology has been known since twentieth century, firstly published documents in 1906 and reached importance with the invention of the V-1 Buzz Bomb in World War II Giammer–Putnam and Putnam et al. [1,2]. The importance of this technology has been increasing because of increasing the thermal efficiency and productivity of a huge amount of energy concentrated industrial processes, reducing contaminant emissions, and providing a way for the efficient combustion of a variety of difficult-to-burn fuels Zinn [3].

In addition to the advantages of pulse combustion technology, the disadvantage associated with this technology is the noise generated during the combustion process in the pulse combustors. The noise of the water heater designed by Reynst [4] was said to have been heard for several kilometers. Pulse combustors having a noise level more than 130 dB were mentioned in the literature Putnam et al. [2]. Depending on the type of the application, the noise level can not be a problem in industrial applications, but it must be reduced to a certain level in the pulse combustors used in domestic heating applications.

There have been several studies based on reducing the noise level of the pulse combustors or designing a new combustor with a lower level of noise Ohiwa et al. and Unui et al. [5,6]. A pulse combustor having a noise pressure level between 55 and 70 dB was successfully operated by working the current pulse combustor at a partial burning rate of 15–35% and the noise pressure level of present pulse

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Nomenclature

AF	mass based air-fuel ratio (kg air/kg fuel)
c_{peg}	average specific heat of gases (kj/kg °C)
f_c	octave band center frequency (Hz)
$\bar{h}_f^0$	enthalpy of formation (kj/kmol)
$\Delta\bar{h}$	enthalpy difference between the specified state and the standard reference state of 25 °C and 1 atm. (kj/kmol)
h_{via}	enthalpy of saturated vapor at entering air temperature (kj/kg)
h_{weg}	enthalpy of superheated vapor at exhaust gas temperature (kj/kg)
h_{lia}	enthalpy of saturated liquid at the entering air temperature (kj/kg)
$L_{eq,T}$	continuous steady state sound pressure level (dB)
MAXL	maximum RMS level for all the spectra averaged (dB)
MAXP	maximum peak level for all the spectra averaged (dB)
MINL	minimum root mean square (RMS) level for all the spectra averaged (dB)
$\dot{m}_f$	mass flow rate of the fuel throughout the gas line (kg/s)
η_a	acoustic efficiency
p_0	reference sound pressure = 20 (μPa)
$p(t)$	time varying sound pressure (μPa)
Q_{hc}	heat of combustion (kj/kmol fuel)
Q_t	total heat transferred from the pulse combustor (kj/kg fuel)
q_{hl1}	heat loss in dry flue gases (kj/kg fuel)
q_{hl2}	heat loss caused by water vapor in the entering air (kj/kg fuel)
q_{hl3}	heat loss from water vapor in exhaust products (kj/kg fuel)
r	distance between the sound level meter and the exhaust side or inlet side of the pulse combustor (m)
SP	emitted sound power (kW)
T	time interval over which the sound pressure measured (s)
t_{ia}	entering air temperature (°C)
t_{eg}	temperature of gases at the exhaust side of the pulse combustor (°C)
W_i	input energy to the pulse combustor (kW)
w_{dg}	mass of dry gases per kg of fuel (kg/kgY)
x_{ia}	humidity ratio of the entering air (kg water vapor/kg dry air)

combustor was also decreased more, around 5 dB, by changing the cross-sectional area of the tailpipe from 5 cm^2 to 2.5 cm^2 Ohiwa et al. [5]. In the study performed by Unui et al. [6], the noise level of the experimentally developed pulse combustor was decreased by 6.5 dB by designing two combustors in a parallel configuration and mounting a communicative passage between the exhaust decouplers of the combustors and dividing the firing rate of the heat input into two equal quantities in the designed combustor.

A few numerical and analytical model have been developed to investigate the acoustic Characteristics of gas-fired pulse combustor Barr et al. and Margolis [7,8]. In the numerical model developed by Barr et al. [7], it was mentioned that the acoustic time scale could be either changed by varying the tail pipe length or temperature distribution in the tail pipe and was also demonstrated that stronger pulsations could be obtained by increasing the acoustic time scale. The study presented Margolis [8] is based on the effect of nonlinear dynamics controlling acoustic mode interactions in a typical combustion-driven device and it was claimed that the method developed can be applied to other combustion driven acoustic problems, such as those in rocket motors.

Some researchers experimentally investigated the effect of acoustic characteristics on the thermal structure of a propane diffusion flame McQuay et al. [9] and the combustion characteristics of a hydrogen-stabilized ethanol spray flame Dubey et al. [10] in a Rijke-tube pulse combustor. It was observed that the fluctuating frequencies for the different acoustic modes were not exact multiples of the fundamental frequency and a significant change in flame height and structure occurred with the beginning of acoustic fluctuations McQuay et al. [9]. In the existence of acoustic field, the Sauter-mean and the arithmetic-mean diameters of the ethanol spray reduced 15% and 20%, respectively. But, in the case of water spray, acoustic field had a negligible effect on the atomization and droplet dispersion processes Dubey et al. [10]. In the study performed by Dec–KellerIchiro Hongo [11], the oscillating flow caused by an acoustic resonance in the tail pipe of a pulse combustor was experimentally investigated by means of a laser doppler velocimetry. The characteristics of this flow, such as frequency, velocity, combustion chamber pressure, etc. were determined and compared with those of steady turbulent flow.

In this experimental work, the acoustic characteristics of a Helmholtz type gas-fired pulse combustor were examined by means of a sound level meter. For comparison the measurements performed by the sound level meter, the other more precise instruments that are used for analyzing the frequency of a system, namely, dynamic pressure transducer and spectrum analyzer, were also employed in the experiments. In the studies related to the acoustic analysis of pulse combustor in the literature, a sound level meter was generally used only to determine noise level of the