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Full Length Article

Analysis of dry, wet and superwet in situ combustion using a novel conical cell experiment

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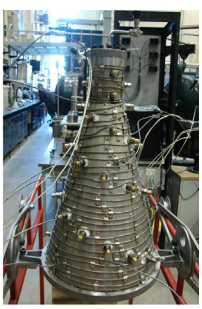
GRAPHICAL ABSTRACT

A conical combustion cell was conceived and utilized in dry, wet and super wet combustion experiments at the In Situ Combustion Research Group at the University of Calgary to investigate the effect of continuous in situ air flux drop on the dynamics of the combustion process and to identify the characteristics of the process most importantly the extinction air flux. Minimum injected air flux at the termination of the experiments was calculated; gas phase combustion parameters were analyzed. Some of the features specific to combustion experiments in conical cells were investigated. Combustion performance analysis using oil recover/volume burned calculations for dry conical tests and oil recovered vs. volume steamed and oxygen oil ratio vs. volume burned as the crucial economical parameters of the design of wet combustion processes were calculated. This study greatly enhances the understanding of the complexity of the combustion process and illustrates its characteristic behavior at or close to its exhaustion.



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ABSTRACT

A conical combustion cell was built and utilized in combustion experiments at the In Situ Combustion Research Group at the University of Calgary to investigate the effect of continuous in situ air flux drop on the dynamics of the combustion process and to identify the characteristics of the process most importantly the extinction air flux. Nine set of top-down (gravity stable) dry, wet and superwet combustion experiments were conducted at different injection rates in sand packs representing typical Athabasca heavy oil reservoirs. The temperature profiles, the produced combustion gases and liquids as well as the unpacked core were examined. Minimum injected air flux at the termination of the experiments was calculated; gas phase combustion parameters were analyzed. Some of the features specific to combustion experiments in conical cells were investigated.

It is believed that the formation of fuel rich condition especially in presence of water at the location of the combustion front at certain locations of the core at certain circumstances tends to prevent energy generation at the combustion front even at high air injection rates. Also, it was shown that the counter current convection/diffusion of fuel gases from the combustion front to upstream locations of the core also known as the roll cell effect adversely influences the advancement of the high temperature combustion front which in turn impacts the oil mobilization and recovery.

Combustion performance analysis using oil recovered/volume burned calculations for dry conical tests and oil recovered vs. volume steamed and oxygen oil ratio vs. volume burned as the crucial economical parameters of the design of wet combustion processes were calculated. This study greatly enhances the understanding of the complexity of the in situ combustion process and illustrates its characteristic behavior at or close to its exhaustion.

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Nomenclature

Symbol	Definition
a_R	Air Requirement [sm^3/m^3]
AOR	Air to Oil Ratio [sm^3/m^3]
AFR_I	Injected Air Fuel ratio [sm^3/kg]
AFR_R	Reacted Air Fuel ratio [sm^3/kg]
AWAT	Area Weighted Average Temperature [°C]
E_{O2}	Oxygen Utilization Efficiency [fraction]
$f_{O_2}^R$	Reacted Oxygen Converted to Oxygen Oxides [fraction]
h	Hour [h]
HTO	High Temperature Oxidation
HTR	High Temperature Range
H/C	Apparent Atomic Hydrogen to Carbon Ratio [fraction]
ISC	In Situ Combustion
ISCRG	In Situ Combustion Research Group at the University of Calgary
k	Permeability [m^2]
L	Litre [L]
LTO	Low Temperature Oxidation
LTR	Low Temperature Range
m_R	Fuel Requirement [°C]
MT	Middle Temperature [°C]
NMT	Near Middle Temperature [°C]
NWT	Near Wall Temperature [°C]
φ	Porosity [fraction]
R	Ratio of Injected Nitrogen to Oxygen [ratio]
S	Saturation [fraction]
S_O	Oil Saturation [fraction]
S_W	Water Saturation [fraction]
s	Standard [s]
t	Time [h]
T	Temperature [°C]
TC	Thermocouple
u_a	Air Flux [$sm^3/m^2{\cdot}h$]
v	Molar Concentration [$mole/m^3$]
v_b	Front Velocity [m/h]
WT	Wall Temperature [°C]
WTM	Wet Test Meter

1. Introduction

Measurement of the air flux that is requisite for the generation, sustenance and propagation of combustion front is necessary [1] to calculate the minimum required capacity of the air injection facility and match this capacity to the volume of reservoir which is to be swept by the thermal zone [2]. It is essential to know the injection air flux at which the fire front extinguishes.

The combustion literature annals various experimental tools introduced to investigate not only the physical and chemical aspects of a fireflood process during air injection based enhanced oil recovery processes at different conditions but also the strength and weakness of each experimental tool. Pressurized differential scanning calorimeters (PDSC) are traditionally used to see the effect of temperature and time on heat generation rate under oxidizing atmosphere, to identify temperature ranges for significant mass transfer effects, and to obtain activation energies corresponding to different heat generation events. However, heat flow traces coming off of PDSC's are known to be

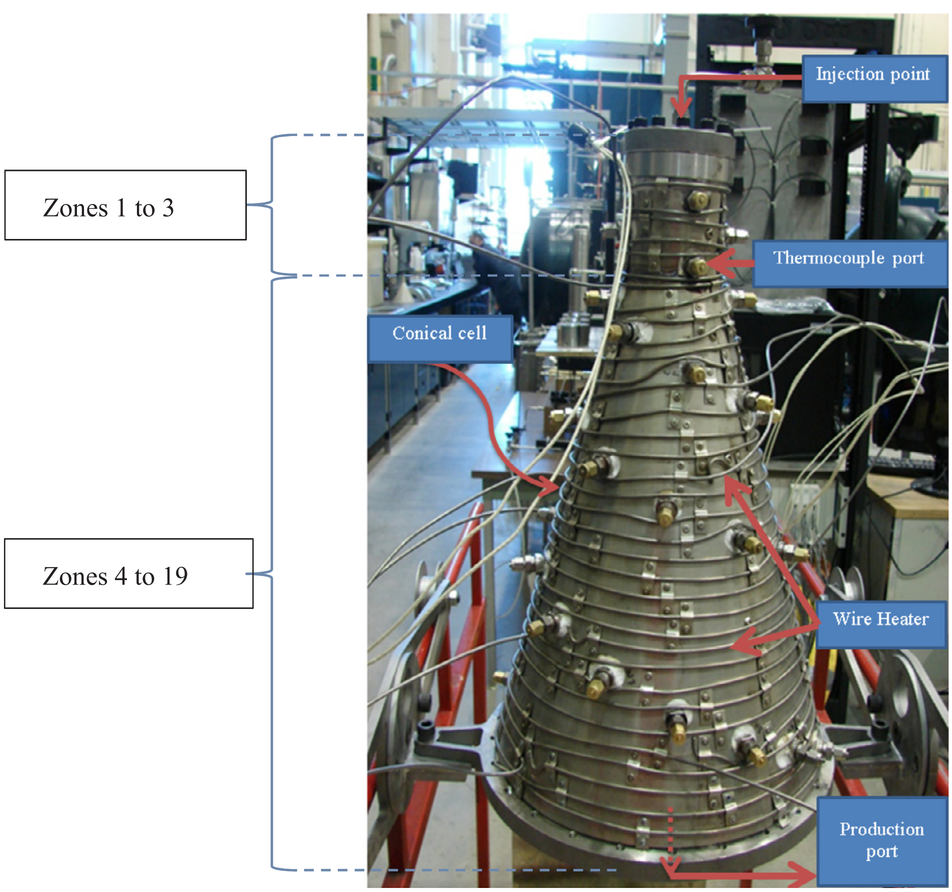

Fig. 1. Conical combustion cell as fabricated.