SIMULATION AND EXPERIMENTAL STUDY OF BIOGAS EXPLOSION

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I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

College of Engineering
UNIVERSITI MALAYSIA PAHANG

APRIL 2021

ACKNOWLEDGEMENTS

In the name of Allah, the Most Merciful, the Most Compassionate, the Most Beneficent, the Most Gracious. All praises belong to Almighty Allah, the Lord of the worlds. Prayers and peace to Prophet Muhammad SAW (Peace Be Upon Him). His servant and messenger who has guided mankind towards human perfection, morality, justice and knowledge. Alhamdulillah, I am thankful to Allah, for His help, blessings and guidance by giving me the opportunity, courage, energy and love to complete this research.

First and foremost, I would like to extend my genuine gratitude and appreciation to my supervisor, Ir Ts Dr. Siti Zubaidah binti Sulaiman for her inspirational guidance, assistance, advice, motivations, supports and encouragements throughout the processes of researching and writing this thesis. I also would like to thank her for the time spared to review this thesis and for her valuable comments and insights to improve this thesis. This accomplishment would not have been possible without her tremendous help.

Besides, my grateful acknowledgements are given to Dr. Lau Woon Phui for her tremendeous efforts in helping me to use CFD using Ansys Fluent. Furthermore, not to forget my thanks to Miss Nur Hazwani Fatihah bt Mohd Zaidi from UTM for also teaching me about CFD. Without their help, this thesis cannot be completed. Further acknowledgements go to Dr. Jolius Gimbun, for giving me the permission to use Ansys Fluent in computer simulation laboratory located in CARIFF, UMP Gambang.

Furthermore, my deepest appreciation to my family members especially my parents, Noor Azmi bin Said and Shakina bt A Rahman for their constant loves, supports, sacrifices, patience and encouragements throughout the course of this study. My hearty thanks to my siblings, Syazwani, Syazwan, Syazlee and Syazryqal for being there through my ups and downs moments.

In addition, my sincere thanks to all my friends, my roommates, and my research mates for their endless support and encouragements. Thank you for all the great times we have together and fun times we shared. Last but not least, my greatest sense of gratitude to one and all, who directly or indirectly, have lent their hand in this research.

ABSTRAK

Biogas merupakan pengganti yang menarik kepada bahan api petroleum konvensional kerana mereka mempunyai kebaikan iaitu ianya sangat murah dan boleh diperbaharui semula secara natural. Beberapa teknik sudah dibangunkan untuk mengelak kemusnahan yang menghancurkan kepada loji-loji biogas dalam industri. Langkah mengelak letupan yang paling praktikal ialah pemasangan alat pelepasan gas. Kajian tentang letupas gas dan debu yang dilepaskan sudah menunjukkan evolusi kawasan pelepasan dengan tekanan bergantung kepada keadaan campuran bahan letupan (komposisi, tekanan dan suhu awal, pergolakan sebelum pencucuhan) dan kepada ciri-ciri bekas letupan (dimensi, bentuk, kehadiran halangan dan lain-lain). Kefahaman terhadap mekanisme bagaimana tekanan terbentuk dalam proses letupan yang dilepaskan adalah penting dalam mereka bentuk langkah pelepasan letupan dan kepada penyiasatan insiden. Pendekatan yang lain menggunakan alat pelepasan letupan ialah termasuk dengan kehadiran saluran pelepasan. Walaupun alat pelepasan letupan adalah penyelesaian yang biasa kepada langkah mengelak letupan tidak sengaja dalam alatan industri, jumlah kajian mengenai saluran pelepasan letupan adalah sangat kecil. Dalam kajian ini, penyiasatan terhadap ciri-ciri letupan biogas-udara dan metana-udara pra-campur dilakukan melalui analisis kepada tekanan letupan maksimum dan kelajuan nyalaan. Faktor-faktor yang menyumbang kepada ciri-ciri letupan pra-campuran bahan api-udara yang dinilai ialah panjang dan diameter saluran pelepasan letupan, kepekatan campuran dan juga kehadiran karbon dioksida. Selain daripada itu, penyebaran nyalaan daripada bahan api dan udara dalam letupan yang dilepaskan melalui saluran dan tanpa saluran turut disiasat. Keputusan numerik daripada kajian CFD dibandingkan dengan pemerhatian daripada kerja-kerja eksperimen. Pemerhatian kepada kontur tekanan 2D untuk kedua-dua letupan yang dilepaskan kepada saluran dan tanpa saluran didapati daripada program Fluent menunjukkan bacaan tekanan untuk letupan yang dilepaskan kepada saluran mempunyai nilai maksimum di dua kawasan di di dalam paip letupan. Kehadiran saluran pelepasan mempengaruhi kawasan nyalaan dan seterusnya tekanan yang direkod sementara untuk letupan yang dilepaskan tanpa saluran, kontur tersebut menunjukkan reaksi letupan dan proses penyebaran nyalaan yang lebih mudah. Penilaian mendapati kesan panjang saluran yang berbeza membuktikan bahawa bacaan tekanan maksimum untuk kedua-dua jenis campuran gas ialah pada saluran dengan panjang 0.50 m. Bacaan tekanan yang direkodkan ialah 4.66 bar dan 5.99 bar sementara untuk kelajuan nyalaan masing-masing ialah 146.22 m/s serta 149.65 m/s untuk campuran biogas-udara dan metana-udara. Selain itu, untuk faktor diameter saluran yang berbeza, rekod bacaan tertinggi bagi tekanan dan kelajuan nyalaan ialah pada diameter 0.05 m (4.66 bar dan 146.22 m/s untuk campuran biogas-udara sementara 5.99 bar dan 149.65 m/s untuk campuran metana-udara). Siasatan terhadap kesan kepekatan campuran kepada tekanan maksimum dan kelajuan nyalaan menunjukkan nilai tertinggi direkod ketika ER=1 iaitu pada keadaan stoikiometri. Semua kerja-kerja eksperimen bersandar kepada kerja-kerja numerik dan siasatan terhadap kesan nisbah keseimbangan ER yang berbeza dilakukan sepanjang paip. Selain itu, berdasarkan bacaan tekanan maksimum yang direkod melalui kerja-kerja eksperimen menunjukkan campuran metana menghasilkan letupan yang lebih teruk berbanding campuran biogas. Akhir sekali, graf tekanan maksimum melawan masa bagi kedua-dua kerja numerik dan eksperimen dikaji. Selain daripada beberapa perbezaan, kedua-dua graf adalah dalam persetujuan bersama. Perbezaan yang terjadi mungkin disebabkan oleh andaian yang dibuat dalam ANSYS Fluent dan hanya persamaan reaksi kimia mudah yang dipertimbangkan di dalam model simulasi.

ABSTRACT

Biogas is an attractive substitute to conventional petroleum fuels because they have the advantages of being very cheap and are renewable in nature, and thereby not contributing to the net atmospheric concentration of the greenhouse gas, carbon dioxide. Several techniques have been developed to prevent the destructive damage to biogas plants in industries. Studies on vented gas and dust explosions have shown the evolution of venting area with pressure depending on the nature and state of the explosive mixture (composition, initial pressure and temperature, pre-ignition turbulence) and on the vessel characteristics (dimension, shape, presence of obstacles and others). An understanding of the mechanisms by which pressure is generated in vented explosions is important in the design of explosion reliefs and to the investigation of incidents. Another approach using venting system also included venting with a presence of venting duct. While venting devices are common solutions for the mitigation of accidental explosions in industrial equipment, study about duct venting are still very small. Researches on biogas explosion in cylindrical vessel are also very limited. In this study, the investigation of explosion characteristics of the premixed biogas-air and methane-air were analysed through the explosion maximum overpressure and flame speed. The factors that contributed to the premixed fuels-air explosions characteristics was evaluated which are the venting duct length and diameter, the mixture concentration as well as the presence of carbon dioxide by comparing biogas-air and methane-air explosions. Moreover, the flame propagation of fuels-air in duct vented and simply vented explosion were investigated by using numerical simulation. The numerical results were compared with the observation from experimental works. From the observation of 2D pressure contours for both duct vented and simply vented explosion obtained from Fluent, for duct vented explosion, the pressure readings were at maximum at two areas of the pipe. The presence of the duct affected the flame area and consecutively the overpressure recorded while for the simply vented (ductless) explosion, the contour gave observations of a simpler reaction and flame propagation. From the evaluation, the effect of different duct length proved that the highest maximum overpressure recorded for both gases were at duct length of 0.50 m. The overpressure recorded were 4.66 bar and 5.99 bar as well as 146.22 m/s and 149.65 m/s of flame speed for biogas-air mixture and methane-air mixture respectively. Apart from that, for factor of different duct diameters, the highest maximum overpressure and flame speed recorded for both mixtures are at 0.05 m (4.66 bar and 146.22 m/s for biogas-air while 5.99 bar and 149.65 m/s for methane-air mixtures). In the meantime, the investigation on effect of mixture concentration on maximum overpressure and flame speed shows the highest values for these two explosion characteristics were recorded at ER=1 which is stoichiometric condition. All the experimental works validate the simulation works by carrying the experiment along the pipe for different ER. Apart from that, based on the recorded maximum overpressure in experimental works of biogas-air and methane-air mixtures explosions, it can be elucidated that methane produced higher explosion severity than biogas. This was due to the dilution effect of CO_2, which has a higher heat capacity than methane. Lastly, both graphs of maximum overpressure versus time from numerical and experimental works were presented and studied. Besides several differences mentioned previously, the graphs were in agreement with each other. The differences might be due to the assumption made in ANSYS Fluent and only a simple chemical reaction equation was considered in the model.

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μ	Viscosity
°C	Degree celcius
ε	Rate of dissipation of turbulent kinetic energy
ρ	Density
σ	Variance
χ	Wrinkling factor

LIST OF ABBREVIATIONS

2D	Two-dimensional
A_c	Tube cross-sectional area
A_f	Flame surface area
C	Specific heat
CFD	Computational Fluid Dynamics
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
$Concentration_{fuel}$	Fuel concentration
D_D	Duct diameter
DOSH	Department of Occupational Safety & Health
D_v	Vessel diameter
ER	Equivalence ratio
f	Friction factor
h	Enthalpy
H_2	Hydrogen
H_2O	Water
H_2S	Hydrogen sulphide
k	Turbulent kinetic energy
L_D	Duct length
L_e	Lewis number
L_v	Vessel length
N_2	Nitrogen
NFPA	National Fire Protection Association
O_2	Oxygen
P_{max}	Maximum overpressure
POEFB	Palm oil empty fruit bunch
POME	Palm oil mil effluent
$Pressure_{air}$	Air pressure
$Pressure_{fuel}$	Fuel Pressure
R	Reaction rate

R_e	Reynold’s number
S	Burning velocity
S_F	Flame speed
S_g	Unburned gas velocity
S_L	Laminar burning velocity
t	time
T	Temperature
u	Gas velocity
υ	Kinematic viscosity
Y	Mass or molar fraction
ρ_b	Burned gas density
ρ_u	Unburned gas density

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