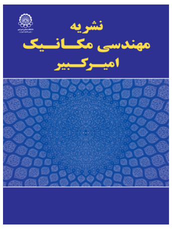

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 53(5) (2021) 717-720
DOI: 10.22060/mej.2020.17679.6646

Investigation of the Response of a Multi-Zone Simulation Code Equipped with Blow-By Sub-Model in a Dual Fuel Spark-Ignition Engine

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ABSTRACT: In the present study, a single-cylinder research engine was utilized to capture experimental data at 9 compression ratio and 1800 rpm engine speed for dual fuel mixtures of 100%, 90%, 75% and 60% gasoline and the rest natural gas in skip-fire mode. Then, a gasoline- natural gas multi-zone thermodynamic entrainment simulation-code equipped with blow-by sub-model was developed. Two 200-cycle sets of free residual motoring and firing cycles were separated from the experimental data to check the response of the code. In motoring-case, the ensemble-average P-θ of the motoring set was compared with that of the code and the blow-by sub-model was verified. Next, in the firing-case, the results obtained from the code were compared with the ensemble-average P-θ of the firing set in each fuel combination and the code was validated. In the firing-case, the leakage to crevices was estimated to be considerably more than that of the motoring-case. In the firing mode of the code, the deviation of the obtained results of the code without blow-by option from the experimental results was more serious as compared to those of the code with blow-by, emphasizing the importance of the blow-by sub-model in the code.

Review History:

Received: Jan. 07, 2020
Revised: Mar. 29, 2020
Accepted: Jun. 20, 2020
Available Online: Jul. 02, 2020

Keywords:

Multi-zone model
Blow-by
Gasoline-natural sas
Dual fuel
Spark-ignition engine

1. Introduction

Basic functional research, as well as pollution and combustion studies, are required for developing the dual-fuel spark-ignition engine and upgrading the existing single-fuel engines to dual-fuel ones, necessitating a laboratory platform as well as a simulation model. A simulation model is considered as one of the well-established solutions in order to save time, costs, limitations and laboratory problems in the development of these engines [1]. Blow-by is also one of the most important problems in spark-ignition engines. blow-by through the piston-cylinder resulting from the pressure difference in the combustion chamber and the piston-cylinder crevices affects the engine performance.

The main structure of the equations in thermodynamic models is based on the mass conservation and thermodynamic rules [2] and therefore, this study aims to develop a thermodynamic simulation model of dual-fuel gasoline-NG spark-ignition engine and verify this model with experimental data.

The first simulations of spark-ignition engines were based on basic thermodynamics and focused on engine performance. For example, Patterson and Van Wylen [3] can be regarded as the pioneers in this field. Other combustion models include the Eddy burning model developed by Blizard and Keck [4]. In the present study, a multi-zone dual fuel gasoline-NG thermodynamic model is developed with the entrainment combustion sub-model and the blow-by sub-model and is verified by experimental results.

2. Thermodynamic Simulation Model

Given that the simulation code can predict different conditions in the approved range by observing the principle of mass conservation and thermodynamic rules, the present work focuses on the development and validation of a multi-zone dual fuel gasoline-NG thermodynamic simulation code using a blow-by sub-model. During the combustion, cylinder chamber is divided into two main zones of the burnt and unburned gases in the quasi-dimensional thermodynamic simulation model of the spark ignition using a common buffer layer called the entrained zone. The fuel/air mixture (unburned gases) and combustion products (burned gases) is assumed to be homogeneous in their zones and the chemical equilibrium between the species is established in each zone. The main equation for engine modeling is extracted from the energy conservation equation for cylinder volume [2]. To determine the turbulent burning velocity, the Zimont model based on the Reynolds and Damköhler numbers was used [5]. Zimont obtained the turbulent burning velocity as Eq. (1).

$$u_t = Cu' Da^{0.25} + u_l \tag{1}$$

where u' is the turbulence intensity, u_l is the laminar burning velocity, and Da is the Damköhler number. Moreover, the entrained unburned mixture mass to the flame front is calculated using the entrained turbulent burning

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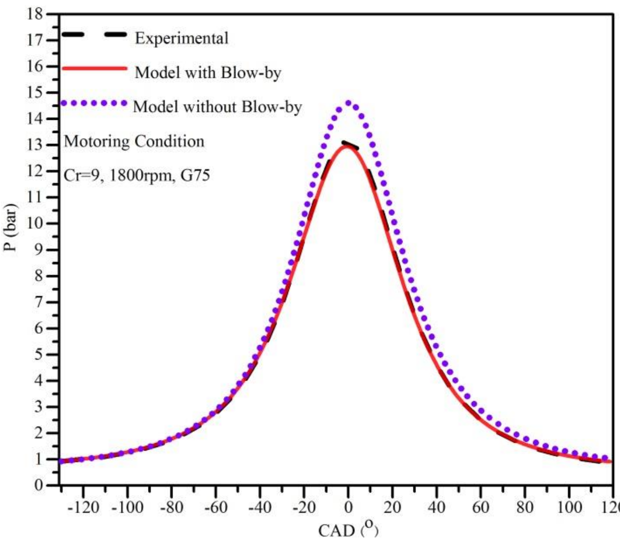

Fig. 1. Cylinder pressure variation according to the crank angle in the motoring under experimental conditions, the model with and without blow-by

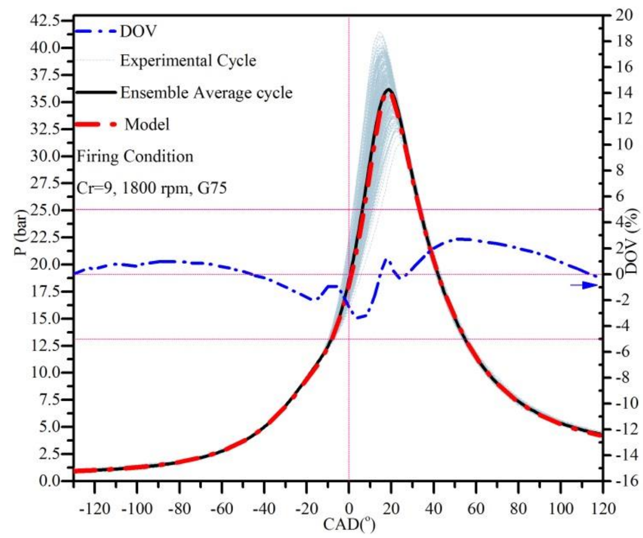

Fig. 2. Cylinder pressure variation according to the crank angle in the firing conditions for the experimental data and simulation model

velocity. In the entrainment model proposed by Blizard and Keck [4], entrained unburned mass rate into turbulent flame front is expressed as Eq. (2).

$$\frac{dm_e}{dt} = \rho_u A_f u_{te} \tag{2}$$

where m_e is the entrained mass, ρ_u is the unburned mixture density, A_f is the average area of the flame front, u_{te} is the entrainment turbulent burning velocity. According to the entrainment combustion model, burning rate is achieved using the differential equation as follows:

$$\frac{dm_b}{dt} = \frac{m_e - m_b}{\tau_b} \tag{3}$$

where m_b is the burnt mass, τ_b is the burning time scale that is defined as follows:

$$\tau_b = K_\tau \frac{l_X}{u_l} \tag{4}$$

where K_τ is the constant of proportionality, l_X is the characteristic of length scale and u_l is the laminar burning velocity.

3. Experiment Methodology

In the present study, a single-cylinder spark-ignition research engine coupled with an asynchronous dynamometer with speed adjustability is used. Engine management systems, equipment for measuring and recording the values were similar to those in [6-8].

In this study, the engine was set up and data mining was carried out to extract the experimental results under the stoichiometric equivalence ratio, at 1800 rpm full load and compression ratio of 9 with skip fire mode for different combinations of G100, G90, G75 and G60 (designated as 100% gasoline, 90% gasoline, 75% gasoline, 60% gasoline and NG as the rest) .In each combination, data-mining was carried out at least for six different spark advances, and at each advance, 1400 consecutive cycles with seven-cycle alternation including four consecutive motoring cycles, and three consecutive firing cycles. Then, the raw data were processed using computer code to the results for each cycle.

Out of 200 seven-cycle consecutive alternations, the first firing cycle of each alternation, which is easily considered to be free of residual gases [9] was selected and 200 firing cycles free from residual gases were provided as a suitable set for the development of simulation code in the free residual gas mode. Accordingly, 200 cycles of the last motoring cycle of each alternation were collected as a set of the motoring cycles with the fuel and free from the residual gas in order to validate the code. Then, the first firing cycles were used in spark ignition to validate the firing conditions.

4. Results and Discussion

First, experimental experiments were carried out. Then, the simulation code was used in motoring of G75 combination (between the combination of gasoline-NG with gasoline as the dominant fuel) with and without the blow-by sub-model and the $P-\theta$ results were compared with the experimental results of the motoring condition. Fig. 1 shows the cylinder pressure variation in terms of the crank angle in the motoring mode of the G75 combination in experimental conditions, the model with and without blow-by. The results of the model with the blow-by are consistent with experimental results and there is a significant difference between the results without blow-by and the experimental results.

Results of simulation code in firing conditions for G75 combination were extracted and compared with experimental results. Fig. 2 shows the cylinder pressure in terms of the crank

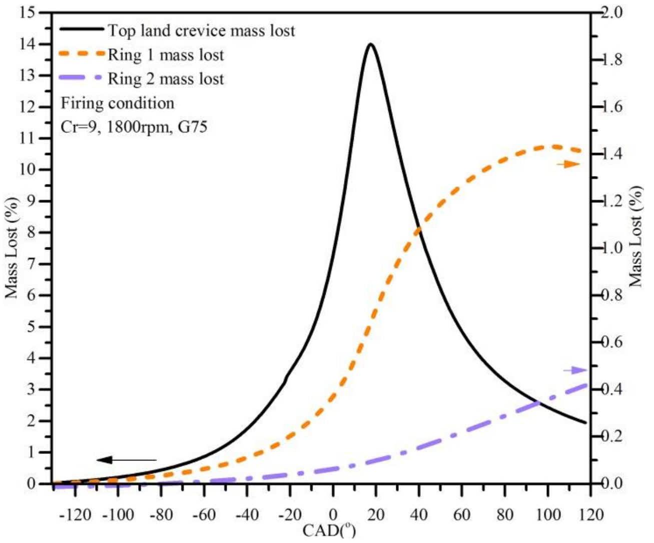

Fig. 3. Percentage of mass blow-by from crevices according to the crank angle in the firing conditions of the G75 combination

angle under the firing conditions for the experimental data and simulation model with the percentage of deviation. It is observed that the results of the simulation code are consistent with the ensemble average cycle of the experimental results and that is in the middle of the experimental cycles and the maximum deviation is below 4%. Fig. 3 shows the mass blow-by to the top land crevice percentage and the crevice between the first and second rings. The maximum mass blow-by to the top land crevice percentage is 14%, the maximum percentage of mass flow of the first ring and the second ring is 1.43% and 0.43%, respectively.

5. Conclusions

The research engine used in this study was a single-cylinder spark-ignition engine equipped with an electronic control system by the user. Experimental data were extracted under the conditions of a gasoline-NG with the gasoline as the dominant fuel and using the skip fire technique. The resulting database contains experimental data of $P-\theta$ consecutive cycles in different combinations and different spark advances, at 1800 rpm and compression ratio of 9. Experimental data were used to verify the thermodynamic simulation model in the stoichiometric equivalence ratio and were processed by a computer code in the FORTRAN. The following results can be summarized in the review and approval of the thermodynamic simulation model using the experimental data obtained from skip fire technique:

* Simulation model in motoring conditions with fuel as well as firing conditions at 1800 rpm and compression ratio of 9 in different combinations were analyzed and compared with experimental results and the deviation percentage was below 4%.

* According to the study of appropriate data compliance of $P-\theta$ the model with the experimental results in motoring and firing conditions, the percentage of deviation below 4, the appropriate adaptation of the mass fraction burn of the simulation model and the experimental results of each combination, the thermodynamic simulation model can be considered valid.

References

[1] K. Suzuki, M. Nemoto, K. Machida, Model-based calibration process for producing optimal spark advance in a gasoline engine equipped with a variable valve train, 0148-7191, SAE Technical Paper, 2006.

[2] S. Verhelst, C. Sheppard, Multi-zone thermodynamic modelling of spark-ignition engine combustion–an overview, Energy Conversion and management, 50(5) (2009) 1326-1335.

[3] D. Patterson, G.J. VAN WYLEN, A digital computer simulation for spark-ignited engine cycles, 0148-7191, SAE Technical Paper, 1963.

[4] N.C. Blizard, J.C. Keck, Experimental and theoretical investigation of turbulent burning model for internal combustion engines, 0148-7191, SAE Technical Paper, 1974.

[5] V. Zimont, Theory of turbulent combustion of a homogeneous fuel mixture at high Reynolds numbers, Combustion, Explosion and Shock Waves, 15(3) (1979) 305-311.

[6] M. Sarabi, E. Abdi Aghdam, Single-Cylinder SI Engine Performance in Dual-Fuel (Gasoline-NG) Mode with Gasoline Dominant Fuel under Stoichiometric Conditions, Modares Mechanical Engineering, 20(2) (2020) 287-295. (In Persian)

[7] M. Sarabi, E.A. Aghdam, Experimental analysis of in-cylinder combustion characteristics and exhaust gas emissions of gasoline–natural gas dual-fuel combinations in a SI engine, Journal of Thermal Analysis and Calorimetry, 2019; (113):1-14.

[8] E. Abdi Aghdam, M. Ataee Tarzanagh, The Effect of Burned Residual Gases on Optimum Ignition Timing using Skip Fire Technique, The Journal of Engine Research, 50(50) (2018) 67-75. (In Persian)

[9] C. Robinet, P. Higelin, Crossed Study of Residual Gas Rate-Firing Device for a Better Understanding of SI Engines Cycle-to-Cycle Variations, 0148-7191, SAE Technical Paper, 1998.

HOW TO CITE THIS ARTICLE

M. Sarabi, E. Abdi Aghdam, Investigation of the Response of a Multi-Zone Simulation Code Equipped with Blow-By Sub-Model in a Dual Fuel Spark-Ignition Engine, Amirkabir J. Mech. Eng., 53(5) (2021) 717-720.

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