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Effect of Specific Heat Parameters on Performance of SI Engine

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Abstract--- This Research Work presents Thermodynamics analysis of spark-ignition (SI) engine. A theoretical model of standard Otto cycle having temperature dependent specific heats has been implemented. It was compared to that which uses constant temperature specific heats. Wide range of engine parameters was studied. In most cases there were significant variations between the results obtained by using temperature dependent specific heats with those obtained at constant specific heats especially at higher engine speeds. Therefore, it is more realistic to use temperature dependent specific heat. This should be considered in cycle analysis especially that temperature variation in the actual cycles is quite large. Numerical experiments are performed by writing a computer code in C and heat release, in cylinder pressure and temperature histories are predicted.
Key words- spark-ignition (SI), temperature, Specific heats, Pressure

I. INTRODUCTION

The thermal design of the internal combustion engines most researchers use air-standard power cycle models to perform their thermodynamic analyses. Such models are used for comparison reasons in order to show the effect of varying engine parameters, conditions, fluid properties, etc. In most previous studies on air-standard power cycles, air was assumed as the working fluid as an ideal gas with constant specific heats without taking into consideration temperature dependence of the specific heats of the working fluid. However, due to the high rise in combustion temperature this assumption becomes less realistic. Although air-standard power cycle analysis gives only approximation to the actual conditions and outputs, it would be very useful to compare the performance of air standard power cycles using constant- and variable-specific heats assumptions. In a recent study the effect of various internal combustion engines parameters in the SI engine were studied. Some studies presented the effect of having temperature dependent specific heats on various air-standard cycles such as Otto, Diesel, and Miller. However, the model used for temperature dependent specific heats was a linear model. Constant specific heat models may be used for very small temperature variations. Also, linear models can be applied with moderate temperature changes. However, for large changes in temperature, more accurate models are needed. In this study a more realistic approach on the behavior of variable specific heats will be implemented on the performance evaluation of the SI engine.

In most air-standard power cycle models air is assumed to behave as an ideal gas with constant specific heats. The values of specific heats are usually used as cold properties. This assumption can be valid only for small temperature differences. However, the assumption would produce greater error in all air-standard power cycles. In order to account for the large temperature difference encountered in air-standard power cycles, constant average values of specific heats and specific heat ratios are sometimes used. These average values are evaluated using the extreme temperatures of the cycle, and are believed to yield better results. Obviously, this remains a rough simplification and can result in significant deviations from reality. Thus, the incorporation of variable specific heats in air-standard power cycle models can improve their predictions and bring them closer to reality.

Gas pressure in the cylinder of an engine varies throughout the Otto four-stroke engine cycle. Work is done on the gases by the piston during compression and the gases produce energy through the combustion process. These changes in energy combined with changes in the volume of the cylinder lead to fluctuations in gas pressure. The ability to accurately predict the pressure allows for better understanding of the processes taking place in the cylinder such as the interactions between the gases, oil film, piston and liner. In the first phase of this project, a computer model was developed to predict pressure based on initial conditions and engine geometries. Spark firing was estimated to be at 25° before top dead centre (BTC) and the burn duration is approximately 70°.

The model, which was programmed in C language, predicts the cylinder pressure throughout the compression, combustion and expansion processes. Pressure was modeled as a function of the angle of the crank. The individual processes of the engine cycle, intake, compression, combustion, expansion and blow down/exhaust are discussed below.

II. OBJECTIVE AND METHODOLY

“To Analye in this study a more realistic approach on the behavior of variable specific heats will be implemented on the performance evaluation of the SI engine”.

Consider a single engine cylinder with the piston at BDC (beginning of the compression stroke) containing a mixture of fresh air and fuel mixture at a given initial pressure (P) is zero and temperature (T) I zero. The following assumptions were made in modeling the compression and power strokes:

A. All thermodynamic variables were assumed to be spatially uniform throughout the engine at any instant of time (zero-dimensional model).

B. All thermodynamic variables varied temporally during the engine cycle.

C. Compression and expansion were assumed to take place in a series of quasi-equilibrium processes. The compression stroke began at $\theta = 0^0$ and the expansion stroke ended at $\theta = 360^0$.

D. Woschni’s model was used to compute heat loss from the cylinder. Woschni’s model was used in this study since it is one of the most popular models for evaluating the heat loss in spark ignition engines.

E. Effect of soot formation on the reduction of the flame temperature (due to radiation) was neglected.

F. (C_8H_{18}) Is used as a fuel in SI engine.

G. For constant specific heats, assume k=1.4 during the period of compression, combustion and k=1.37 during the period of expansion.

H. For variable specific heats, the equation for, k is

$$k[n] = 1.338 - \left(6\times10^{-5}\times T[n]\right) + \left(10^{-8}\times T[n]^2\right)$$

The energy equation expressing the relationship between pressure and crank angle was solved to obtain the work output and cycle efficiency. The temperature of fresh intake air (T_a) as well as the engine pressure P (0) at the start of compression is all available in a typical SI engine from a standard sensor set, hence assumed known for this study. All computations in this study assume the cylinder pressure to be 1 bar (typical of a boosted system) with T_a=60^{0}C. In this study, spark ignition was assumed to begin before TDC. The duration of combustion was assumed to 70^0. As mentioned above, the energy equation was solved numerically to obtain the temporal variation of temperature and pressure during the compression and power strokes. Effects of temporally varying mixture averaged k and heat loss were included in the solution of the energy equation. Energy equation is solved by using first order finite difference equation. The model, which was programmed in C language, predicts the cylinder pressure throughout the compression, combustion and expansion processes. Pressure was modeled as a function of the angle of the crank.

III. RESULTS AND DISCUSSION

Effect of engine speed on p vs. v diagram using constant-specific heats:

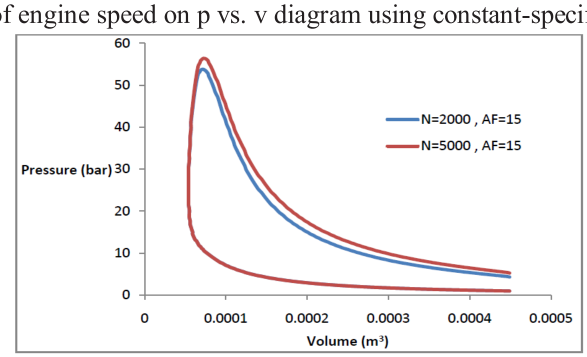

Fig.1 P –V Diagram of constant-specific heat

In order to examine the validity and sensitivity of the presented model, cylinder pressure is presented in Fig.1 It shows the variation of cylinder pressure versus volume for SI engine using constant-average specific heats running at piston speeds of 2000

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and 5000 rpm at a given air–fuel ratio of 15. It is obvious that cylinder pressure is higher at higher engine speeds.

Effect of engine air –fuel ratio on p vs v diagram using constant-specific heats:

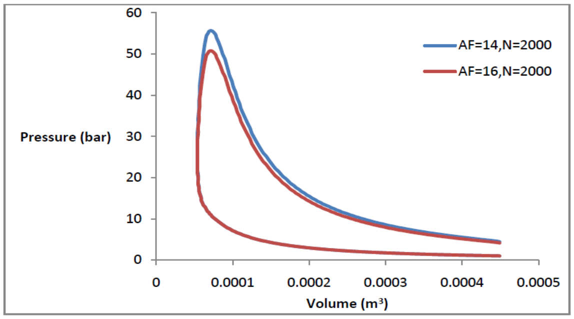

Fig.2 P –V Diagram of air –fuel ratio at constant-specific heats.

The variation of cylinder pressure versus volume for SI engine using constant-average specific heats running at air-fuel ratios of 14, 16 at a given engine speed of 2000 rpm. It is obvious that cylinder pressure is higher lower air-fuel ratios.

Effect of temperature dependent specific heats on gas temperature profile:

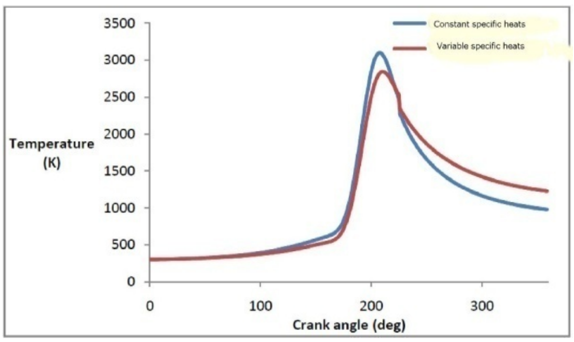

Fig.3 T- Ө Diagram of variable and constant specific heats.

In order to study the effect of temperature dependent specific heats, Fig.3 is presented. It shows variation of gas temperature versus crank angle using variable and constant-average specific heats running at engine speed of 5000 rpm and in-cylinder air–fuel ratio of 15. It is obvious that there is some difference when temperature dependent specific heat is used instead of constant specific heat. Although they have similar trends, the maximum temperatures with constant specific heats are significantly over-estimated in comparison with results obtained with variable specific heats.

Effect of temperature dependent specific heats on peak gas temperature by varying the engine speed:

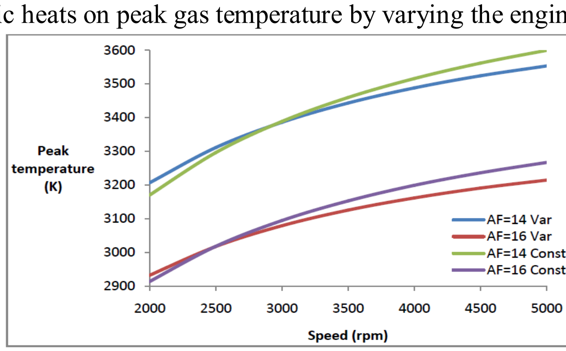

Fig.4 Temperature and engine speed at different air-fuel ratios at constant and variable specific heats.

Fig.4 Shows presents the maximum gas temperature versus engine speed at air–fuel ratios of 14 (rich mixture) and 16 (lean mixture). Higher values of maximum temperatures are obtained at higher engine speeds and lower air–fuel ratios. Again, as noted previously, the effect of temperature dependent specific heat is very significant on the reported maximum gas temperatures.

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Heard release pattern:

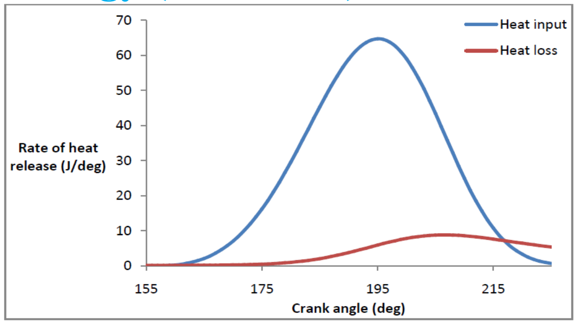

Fig.5 Rate of heat release versus crank angle

A rate of heat release model for SI engine, taking into consideration the heat transfer in the engine and variable specific heats of air, using simple wibe function .The combustion in SI engines can be considered as totally premixed. Heat release by the premixed combustion which is very rapid. The duration of the combustion is 70^0.

In-cylinder gas temperature profile**:**

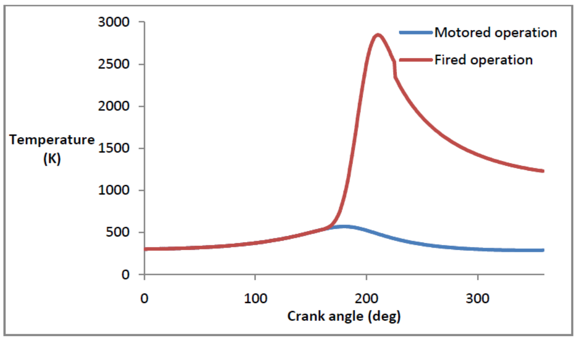

Fig. 6. Temperature versus Crank angle for SI engine.

Fig. 6 Shows the variation of in-cylinder gas temperature profile versus crank angle during motoring and fired operation, considering temperature dependent specific heats. In-cylinder gas temperature reaches a higher value of around 2800 K during fired operation and around 500 K during motoring operation.

Effect of spark ignition timing on heat input:

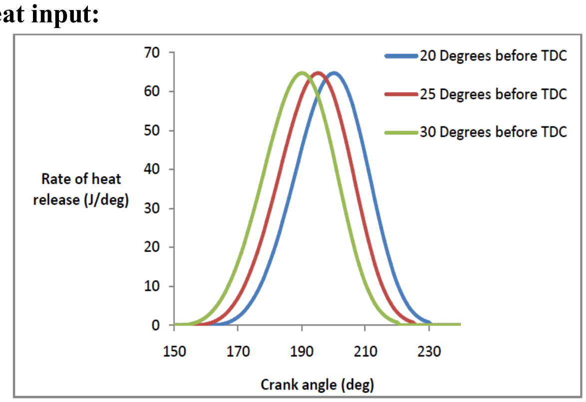

Fig.7 Temperature and crank angle for different spark ignition timings.

One of the most important parameter affecting the performance of SI engine is the instant when combustion starts. In advanced spark ignition timing most of the heat releases before piston reaches the top dead centre. Fig.7 Shows the variation of heat release profile versus crank angle for different spark ignition timings. In the figure in all the three cases same amount of heat releases but in advanced spark ignition timing compression and combustion simultaneously takes place, it will affect the performance of SI engine.

Effect of spark ignition timing on in-cylinder pressure:

Fig.8 shows the sensitivity of the pressure to the ignition timing where the curves vary significantly. Advanced spark ignition timing leads to high levels of pressure in the cylinder. For advanced spark ignition most of combustion is taking place while the piston is moving toward the TDC. Therefore, the pressure increase is due to twofold effect namely the compression of gases, due to movement of the piston, and the heat release during to combustion. This explains the higher level of pressure encountered in advanced spark ignition timing. However, an interesting observation is that for 30 degrees after the TDC, the pressure in the cylinder is highest for late ignition timing, why because for late ignition timing heat release still continues even after piston crosses the TDC.

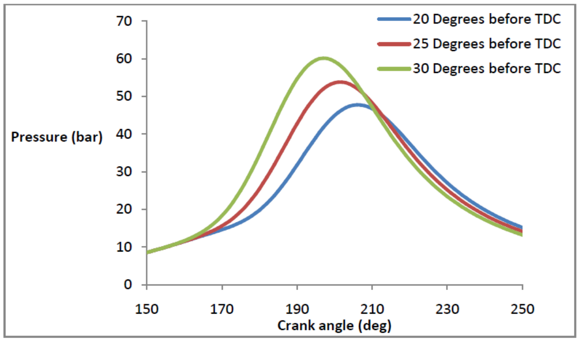

Fig. 8 Variation of cylinder pressure Vs crank angle for different spark ignition timings.

IV. CONCLUSIONS

Therefore, it is more realistic to use temperature dependent specific heats during the investigation of air-standard power cycles. This should be considered in the practical cycle analysis, especially, in the actual cycles the temperature variations are quite large.
The results are expected to provide significant guidance for the performance evaluation and improvement of real SI engines.
By advancing the spark ignition timing most of the heat release while piston is moving towards the top dead centre, which causes increase in burning velocity and convection heat transfer coefficient.
By advancing the spark ignition timing higher levels of pressure is developed inside the combustion chamber.

V. ACKNOWLEDGMENT

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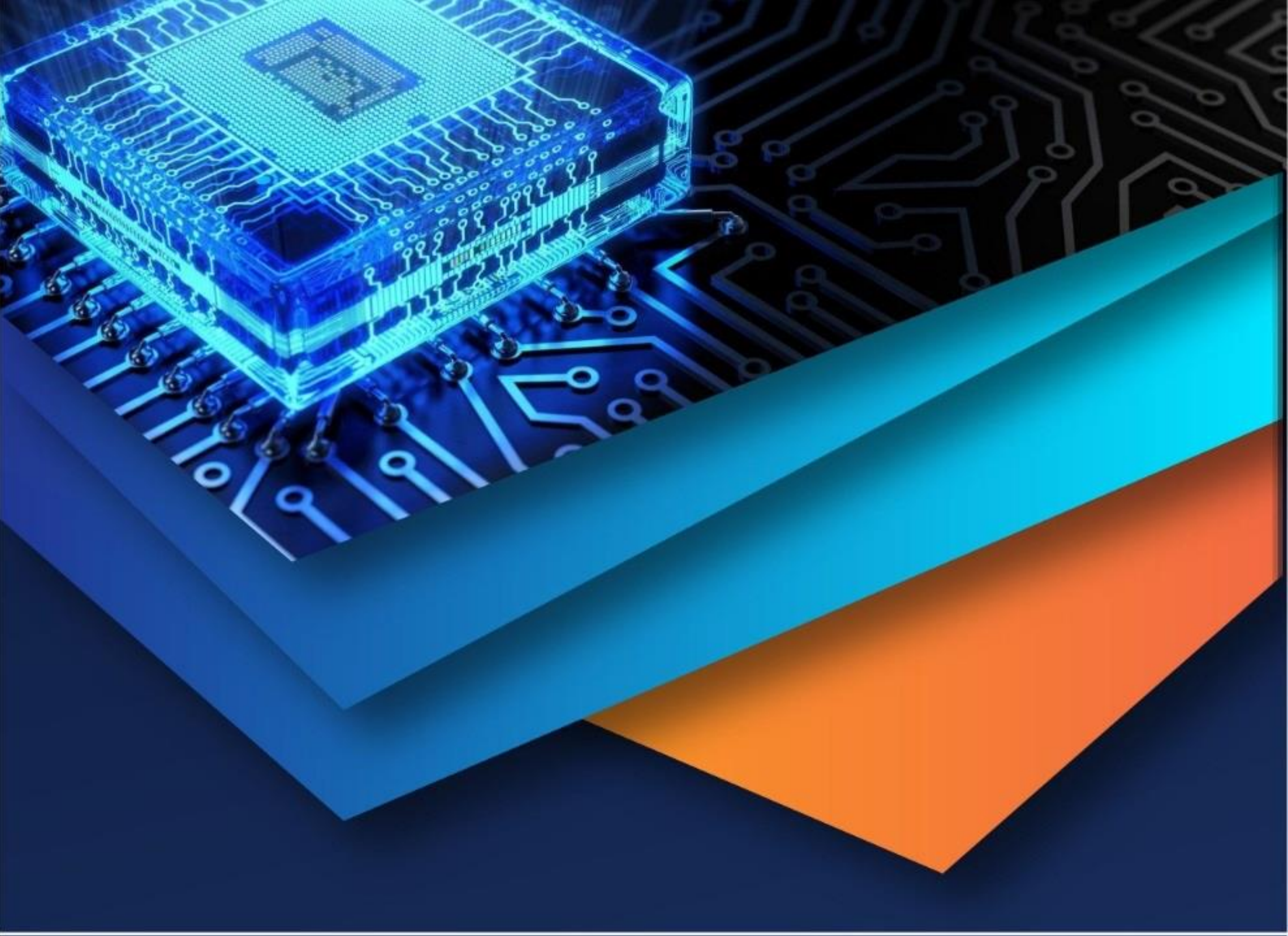

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