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THERMODYNAMIC MODELING OF S.I ENGINE AND HEAT RELEASE PATTERNS

VEERAVENKATA RAMANA KOTI
14JP1D2112,
M.Tech.(THERMAL)
Department of Mechanical Engineering,
Kakinada Institute of Technological Sciences.,
A.agraharam- Ramachan drapuram East Godavari District, A.P.

Mr. A. SOMA SUNDAR
Asst. Professor, Mechanical Engineering Department,
Kakinada Institute of Technological Sciences.
A.agraharam- Ramachan drapuram East Godavari District, A.P.

KALAPALA. PRASAD
Assistant Professor,
Department of Mechanical Engineering, JNTUK.
Email:
Prasad_kalapala@yahoo.co.in

ABSTRACT:

This paper 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. The results obtained are simulated with software ANSYS 15.0.

INTRODUCTION

In 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 behaviour 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 modelled 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.

PRE -IGNITION:

Pre-ignition is the ignition of the homogeneous mixture of charge as it comes in contact with hot surfaces, in the absence of spark. Auto ignition may overheat the spark plug and exhaust valve and it remains so hot that its temperature is sufficient to ignite the charge in next cycle during the compression stroke before spark occurs and this causes the pre-ignition of the charge. Pre-ignition is initiated by some overheated projecting part such as the sparking plug electrodes, exhaust valve head, metal corners in the combustion chamber, carbon deposits or protruding cylinder head gasket rim etc. pre-ignition is also caused by persistent detonating pressure shockwaves scoring away the stagnant gases which normally protect the combustion chamber walls. The resulting increased heat flow through the walls raises the surface temperature of any protruding poorly cooled part of the chamber, and this therefore provides a focal point for pre-ignition.

Effects of Pre-ignition:

- It increase the tendency of denotation in the engine
- It increases heat transfer to cylinder walls because high temperature gas remains in contact with for a longer time
- Pre-ignition in a single cylinder will reduce the speed and power output
- Pre-ignition may cause seizer in the multi-cylinder engines, only if only cylinders have pre-ignition

KNOCK RATING OF SI ENGINE FUELS (OCTANE NUMBER):

The tendency to detonate depends on composition of fuel. Fuel differs widely in their ability to resist knock. The property of fuel which describes how fuel will or will nor self ignite is called the OCTANE NUMBER. It is defined as the percentage of Iso-octane by volume in a mixture of Iso-octane and n-heptane which exactly matches the knocking tendency of a given fuel, in a standard fuel under given standard operating conditions.

The rating of a particular SI fuel is done by comparing its antiknock performance with that of standard reference fuel which is usually combination of Iso-octane and n-heptane. Iso-octane (C8H18) which has a very high resistance to knock and therefore it is arbitrarily assigned a rating of 100octane number. N-heptane (C7H16) which is very prone to knock and therefore given a zero value.

For example: Octane number 80 means that the fuel has same knocking tendency as mixture of 80% iso-octane and 20% n-heptane (by volume basis).

A fuel having an octane number of 110 means fuel has the same tendency to resist as a mixture of 10 cc of Tetra ethyl lead (TEL) in one U.S gallon of Iso-octane.

HIGHEST USEFUL COMPRESSION RATIO:

The thermal efficiency of IC engine increases with increase in Compression Ratio. The maximum compression ratio of any SI engine is limited by its tendency to knock. HUCR is the highest compression ratio employed at which a fuel can be used in a specified engine under specified set of operating conditions, at which detonation first becomes audible with both ignition and mixture strength adjusted to give highest efficiency.

The factors which affect knocking in S.I. engines:

— Compression ratio
— Mixture strength
— Fuel characteristics (Octane number, ON)
— Initial pressure.

In these engines the limit of supercharging is fixed mainly by knocking, because the knocking tendency of most fuels is increased by increasing the inlet pressure and temperature, or both. At the same ON requirement, if the charge density is increased the compression ratio has to be decreased considering the knock limits. Thus the power by the supercharged engine is increased but at reduced thermal efficiency. Further, supercharged S.I. engines are usually to run on rich mixture, for maximum power. Therefore, S.I. engines are not generally supercharged, except to compensate for loss of power at high altitudes.

LITERATURE REVIEW

Al-Sarkhi, B. Akash, J. Jaber, M. Mohsen, E. Abu-Nada,[2] Efficiency of Miller engine at maximum power density 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.

B. Akash,[1] Effect of heat transfer on the performance of an air-standard diesel cycle, 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.

M. Karamangil, O. Kaynakli, A. Surmen,[12] Parametric investigation of cylinder and jacket side convective heat transfer coefficients of gasoline engines effect of various internal combustion engines parameters in the SI engine were studied .

Al-Sarkhi, J. Jaber, M. Abu-Qudais, S. Probert,[13] Effects of friction and temperature-dependent specific-heat of the working fluid on the performance of a diesel- engine,presented the effect of having temperature dependent specific heats on various air-standard cycles such as Otto, Diesel, and Miller .

A. Al-Sarkhi, J. Jaber, S. Probert,[14] Efficiency of a Miller engine, presented the effect of having temperature dependent specific heats on various air-standard cycles such as Otto, Diesel, and Miller .

Y. Ge, L. Chen, F. Sun, C. Wu,[15] Thermodynamic simulation of performance of Otto cycle with heat transfer and variable specific heats of working fluid presented the effect of having temperature dependent specific heats on various air-standard cycles such as Otto, Diesel, and Miller .

A. Jafari, S. Hannani, [8] Effect of fuel and engine operational characteristics on the heat loss from combustion chamber surfaces of SI engines, 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.

ENGINE AND OPERATIONAL SPECIFICATIONS

Engine and operational specifications used in simulation:

Fuel :	C_8H_{18}
Compression ratio:	8.3
Cylinder bore (m):	0.0864
Stroke (m) :	0.0674
Connecting rod length (m):	0.13
Crank radius (m) :	0.0337
Clearance volume (m^3):	5.41×10^{-5}
Swept volume (m^3) :	3.95×10^{-4}
Engine speed (rpm) :	2000–5000
Inlet pressure (bar) :	1
Equivalence ratio :	1
Ignition timing :	−25° BTDC
Duration of combustion:	70°
Wall temperature (K) :	400

MODELLING AND THERMODYNAMIC ANALYSIS

The ANSYS computer software is a large-scale multipurpose finite element program that may be used for solving several classes of engineering problems. The analysis capabilities of ANSYS include the ability to solve static and dynamic structural analyses, steady state and transient problems, mode frequency and buckling eigen value problems, static or time varying magnetic analyses and various types of field and coupled field applications. The program contains many special features which allow non-linearties or secondary effects to be included in the solution such as, plasticity, large strain, hyper elasticity, creep, swelling, large deflections, contact, stress, stiffening temperature dependency, material anisotropy and radiation. As ANSYS was developed. Other special capabilities such as, sub structuring, sub modeling, random vibration, kinetostatics, kinetodynamics, free convection fluid analysis, acoustics, magnetic, piezo-electrics, coupled field analysis and design optimization was added to the program. These capabilities contribute further to make ANSYS a multipurpose analysis tool for varied engineering disciplines.

The ANSYS program has been in commercial use since 1970 and has been used extensively in the aerospace, automotive, construction, electronics, energy services, manufacturing, nuclear plastics, oil and steel industries. In addition, many consulting firms and hundreds of universities use ANSYS for analysis, research and educational use.

Modelling by using Catia

Catia is modelling software to create 3d components with accurate shapes and dimensions. Present version r19 is developed b Dassault systems.

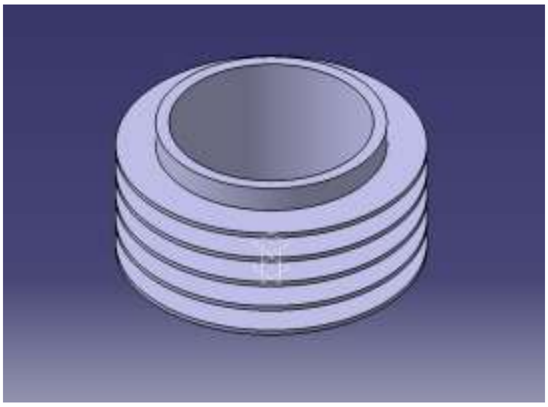

Figure: Shows the cylinder of I.C engine.

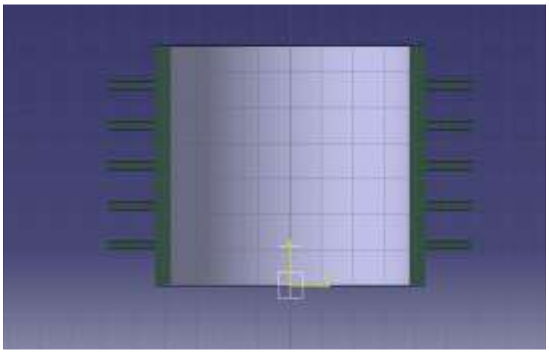

Figure: Shows the sectional model with fins

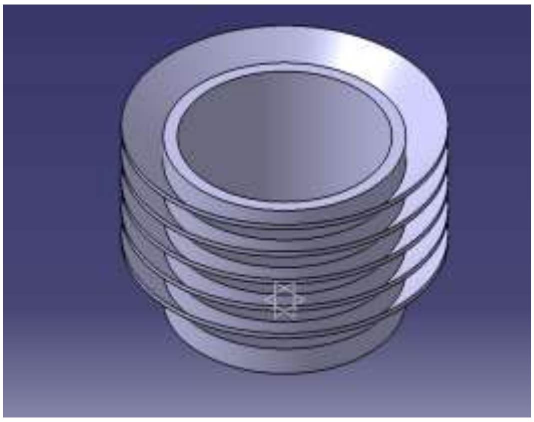

Figure: Shows the fin structure

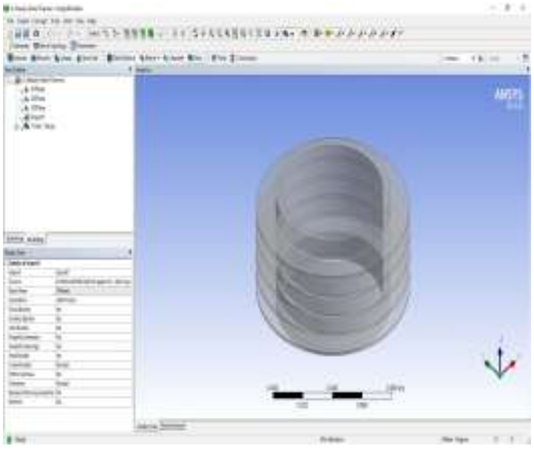

Figure: shows meshing of object

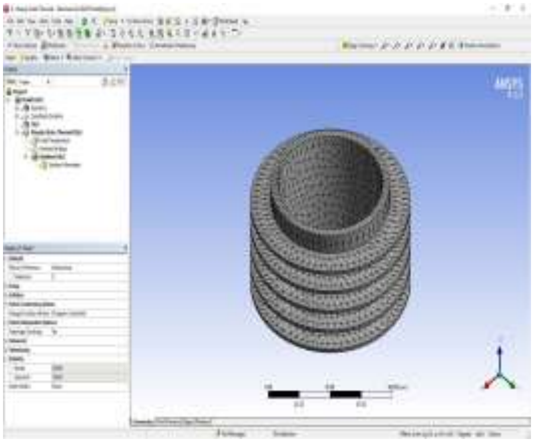

Figure: shows clear mesh of model.

RESULTS AND DISCUSSION

Parametric studies have been performed based on the numerical solution of Eq. The study covers wide range of dependent variables such as engine speed, air–fuel ratio and others, taking into consideration the variation of the specific heat with temperature.

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

In order to examine the validity and sensitivity of the presented model, cylinder pressure is presented in Fig. It shows the variation of cylinder pressure versus volume for SI engine using constant-average specific heats running at piston speeds of 2000 and 5000 rpm at a given air–fuel ratio of 15. It is obvious that cylinder pressure is higher at higher engine speeds.

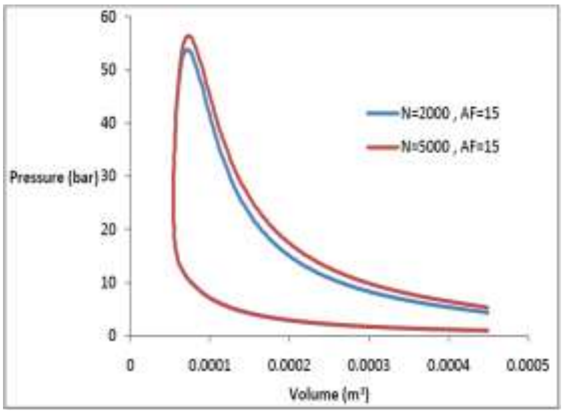

Fig: Variation of cylinder pressure versus volume for SI engine using constant-specific heats running at 2000 rpm and 5000 rpm at air-fuel ratio of 15.

Effect of temperature dependent specific heats on cylinder pressure profile:
In order to study the effect of temperature dependent specific heats, Fig. is presented. It shows variation of pressure 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 pressure with constant specific heats is significantly over-estimated in comparison with results obtained with variable specific heats.

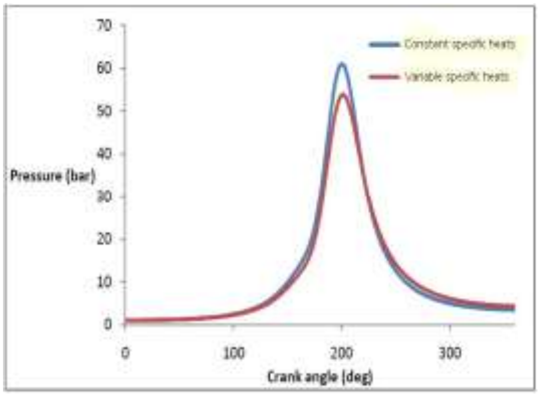

Fig: Variation of cylinder pressure versus crank angle for SI engine using variable and constant specific heats running at 5000 rpm and air-fuel ratio of 15.

Effect of spark ignition timing on in-cylinder gas temperature:
Shows the sensitivity of the gas temperature to the ignition timing where the curves vary significantly. As shown from Fig., advanced spark ignition timing leads to high levels of temperature in the cylinder. For advanced spark ignition most of combustion is taking place while the piston is moving toward the TDC. Therefore, the temperature 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 levels of temperature encountered in advanced spark ignition timing. However, an interesting observation is that for 30 degrees after the TDC, the temperature 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.

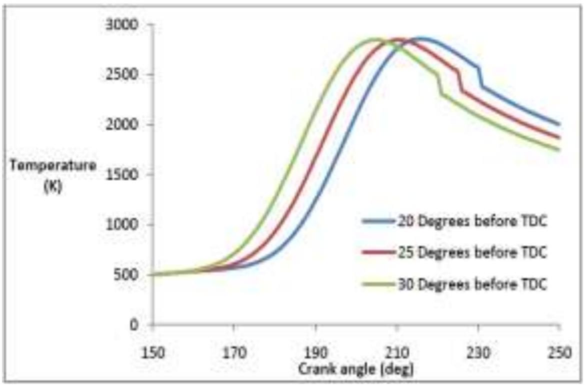

Fig: Variation of gas temperature versus crank angle for different spark ignition timings.

Analysis results case study-2

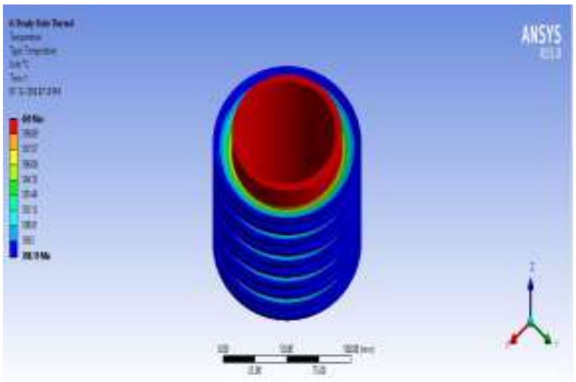

Figure: Shows the maximum temperature area contours

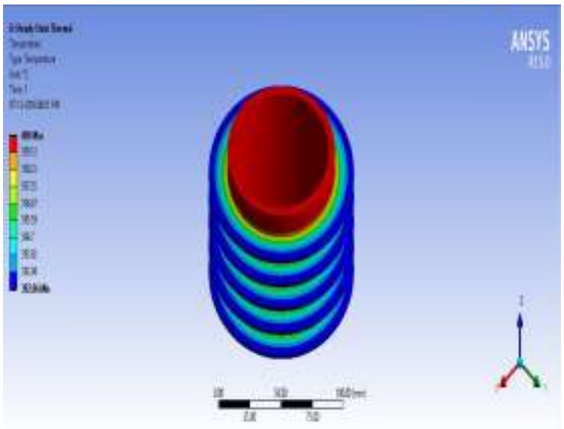

Figure: shows the temperature distribution

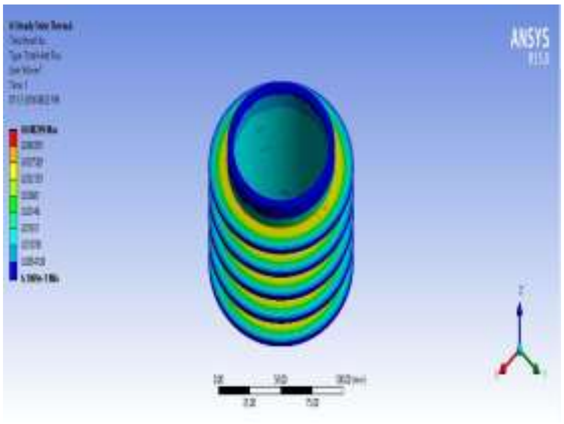

Figure: Shows total heat flux

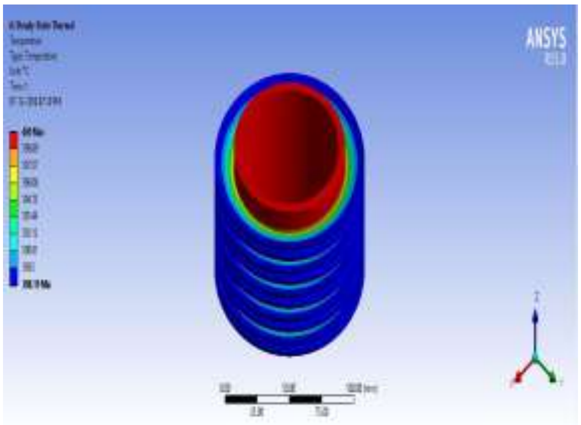

Figure: Shows the temperature distribution at fins

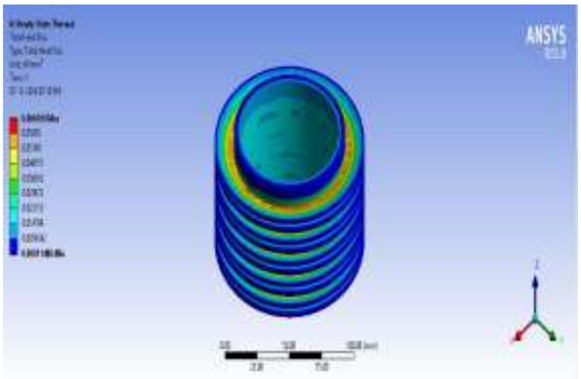

Figure: Shows the heat flux along fins.

CONCLUSIONS

It is concluded that engine working parameters are affected by variable specific heats, significantly. The results show that there is a great effect of the temperature dependent specific heat of the working fluid on the performance of the standard Otto cycle.

Therefore, it is more realistic to use temperature dependent specific heat during the investigation of 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. On related to this simulation analysis of SI engine cylinder with fins which is on a role of heat releasing part gives an idea to future analysis of project.

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AUTHOR DETAILS:

Name: **VEERAVENKATA RAMANA KOTI**
Roll No: **14JP1D2112**
Course : M. Tech (THERMAL)
Department Of Mechanical Engineering,
College: Kakinada Institute Of Technological Sciences, A.Agraharam-Ramachandrapuram East Godavari District.
College Code: JP

Name of the Guide : Mr.A. SOMA SUNDAR
Designation: Asst.Professor Mechanical Engineering Department.
College: Kakinada Institute Of Technological Sciences, A.Agraharam-Ramachandrapuram East Godavari District.