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Effect of Heat Expansion in an Internal Combustion Automotive Engine

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ABSTRACT
One of the most challenging aspects of designing and building an internal combustion engine is determining the thermal effects on the components. The purpose of this study was to determine the effect of heat expansion in an internal combustion automobile engine. Overheating has catastrophic consequence; allowing the engine to overheat even for a short period of time (minutes) cause the piston and rings to expand to the point that they are too large and tight in the cylinders. When this happens the cylinder damaged beyond repair. The result of these findings reveals that rapid expansion excess overheating, system leakages, wrong coolant, bad thermostat, faulty radiator and the use of dissimilar metals in the combustion chamber.
Keywords: *Heat, Expansion, Combustion, Automotive Engine*

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I. INTRODUCTION

An internal combustion engine (ICE) is a heat engine where the burning fuel occurs with oxidizer (usually air) in the combustion chamber which is an integral part of the working fluid flow circuit. In an internal combustion engine the expansion of the high-temperature and high-pressure- gases produced by combustion apply direct force to some component of the engine. The force is applied typically to pistons, turbine blades, or a nozzle. This force moves the component over a distance, transforming chemical energy into useful mechanical energy. The proportion of the chemical energy released as heat that gets converted to mechanical energy depends on the "expansion ratio", that is the ratio between the volume in the cylinder when the charge is ignited and the volume when the exhaust valve opens. The higher the expansion ratio the more of the heat energy and pressure can be used to push the crankshaft around (Britannica.com, 2012).

II. PROCESS OF COMBUSTION IN THE ENGINE

Automotive fuels such as gasoline are made mostly of two elements: hydrogen and carbon. They have the chemical symbols H and C. This type of fuel is a hydrocarbon (HC) fuel. During complete combustion in the engine, these two elements unite with a third element, the gas oxygen (O). Oxygen usually in the form of free oxygen (O_2) makes up about 20 percent of the earth's atmosphere. Mathematically, the mixtures of Fuel + Air => Hydrocarbons + Nitrogen Oxides + Carbon Dioxide + Carbon Monoxide + Sulphur Dioxide+ water (Nationalgeographic.com, cited in Amaechi & Thomas, 2015).

During combustion, each oxygen atom unites with two hydrogen atoms. Each carbon atom unites with two oxygen atoms. Oxygen uniting with hydrogen produces H_2O. Or water. Carbon uniting with oxygen produces CO_2, or the gas, carbon dioxide. As the fuel air mixture combust, the burning gases get very hot. Their temperature goes as high as 6000°F [3316°C). This high temperature produces pressure in the engine that makes it run and produce power.

Combustion can occur as complete (perfect combustion) or as incomplete combustion (imperfect combustion).

(a) **COMPLETE-COMBUSTION**

Complete combustion occurs when all the hydrogen and all the carbon in the gasoline would unite with oxygen. The exhaust gas would contain only harmless H_2O (water) and CO_2 (carbon dioxide).

$CH_4(g) + 2O_2 (g) = CO_2 (g) + 2H_2O(g)$………………………… (1)

Methane (CH_4) + Oxygen ($2O_2$) = Energy + carbon dioxide (CO_2) + water ($2H_2$) ………(2)

(b) **INCOMPLETE COMBUSTION**

Incomplete combustion occurs when there is not enough oxygen to allow the fuel to react completely to produce carbon dioxide and water. It also happens when the combustion is quenched by a heat sink, such as a solid surface or flame trap.

For most fuels, such as diesel oil, coal or wood, pyrolysis occurs before combustion. In incomplete combustion, products of pyrolysis remain unburnt and contaminate the smoke with noxious particulate matter and gases. Partially oxidized compounds are also a concern; partial oxidation of ethanol can produce harmful acetaldehyde, and carbon can produce toxic carbon monoxide.

The incomplete (partial) combustion of a hydrocarbon with oxygen produces a gas mixture containing mainly CO_2, CO, H_2O, and H_2 (ASM, 1964).

The general reaction equation for incomplete combustion of one mole of a hydrocarbon in oxygen is:

$$C_xH_y + zO_2 \rightarrow zCO_2 + bCO + cH_2O + dH_2 \quad \text{………………(3)}$$

The simple word equation for the incomplete combustion of a hydrocarbon in oxygen is: Fuel- oxygen- water + hydrogen + carbon dioxide + carbon monoxide………(4)

For stoichiometric (complete) combustion, z = *x* + *dy*. When *z* falls below roughly 50% of the stoichiometric value, CH_4 can become an important combustion product; when *z* falls below roughly 35% of the stoichiometric value, elemental carbon may become stable. The products of incomplete combustion can be calculated with the aid of a material balance, together with the assumption that the combustion products reach equilibrium (ExoCalc, 2013).

For example, in the combustion of one mole of propane (C_3H_8) with four moles of O_2, seven moles of combustion gas are formed, and *z* is 80% of the stoichiometric value. The three elemental balance equations are:

Carbon: a + b = 3 ……………………………………………………….(5)

Hydrogen : 2c + 2d = 8………………………………………………….(6)

Oxygen : 2a + b + c = 8 …………………………………………………(7)

These three equations are insufficient in themselves to calculate the combustion gas composition. However, at the equilibrium position, the Water gas shift reaction gives another equation:

$$CO + H_2O + CO_2 + H_2 ; Keq = \frac{a \times d}{b \times c} \quad \text{……………………(8)}$$

For example, at 1200K the value of K_{eq} is 0.728. (Reaction-Web, n.d)

Solving, the combustion gas consists of 42.4% H_2O, 29.0% CO_2, 14.7% H_2, and 13.9% CO

Carbon becomes a stable phase at 1200 K and 1 atm pressure when z is less than 30% of the stoichiometric value, at which point the combustion products contain more than 98% H_2 and CO and about 0.5% CH_4.

III. PHYSICS OF SOLID EXPANSION

According to the kinetic theory of gases, a gas has a large number of small particles viz atoms or molecules all of which are in constant, random motion. These moving particles collide with each other and with the walls of the container on a constant basis. The kinetic theory explains the macroscopic properties of gases, such as pressure, temperature, or volume is explained by considering their molecular composition and motion.

IV. BEHAVIOUR OF MATTER

There are five states of matter; Solids, liquids, gases, plasmas, and Bose-Einstein Condensates (BEC) there are different states that have different physical properties. Each of these states is also known as a phase. Elements and compounds can move from one phase to another when specific physical conditions change (Encyclopedia.com).

The particles in solids, liquids and gases all behave in different ways but result in a similar way. They all expand when heated up.

SOLIDS

The particles in solids vibrate more and knock against each other when heated and result in taking up more space. The property of solids (metal) expansion makes it possible to join two metal pieces without welding.

V. EXPANSION

When a material gets hot it expands - this is because the molecules in it are moving about mo re vigorously and so need more room. As solid is heated, the molecules vibrate more violently and the solid expands in all directions let us consider the increase in length of solid for simplicity. The hotter it gets and the longer it was to tart with the more the solid expands. Different materials expand by different amounts for the same rise in temperature.

The amount of expansion depends on the followings:
(a) The type of material
(b) The amount of rise in temperature
(c) The time taken for expansion to occur

VI. EXPANSION IN AN INTERNAL COMBUSTION ENGINE

At compression and power strokes the heat energy is generated, some are used by the engine to do work while some are absorbed by cylinder, piston, rings and other components. As more heat are produce the more they absorb, as a result the particles or atoms of these component begin to vibrate and colliding with each other, there kinetic energy keep increasing and the material component begins to increase in length or size this is what is called expansion. When piston and rings in the cylinder expand more than there limit they are damaged under the heavy pressure and can cause knock to the engine.

VII. COMMON CAUSES OF ENGINE OVERHEATING

According to Airtex & ASC Industries (2013) an overheated engine can be caused by anything that decreases the cooling system's ability to absorb, transport and dissipate heat; therefore engines can overheat for a variety of reasons. Some of the most common causes are;

Cooling System Leaks

This is the primary cause of engine overheating. Possible leak points include hoses, the radiator, water pump, thermostat housing, heater core, head gasket, freeze plugs, automatic transmission oil cooler, cylinder heads and block. Perform a pressure test. A leak-free system should hold pressure for at least one minute.

Wrong Coolant Concentration

Be sure to use the coolant recommended by your vehicle's manufacturer. The wrong type of coolant and/or mixing the incorrect concentration of coolant and distilled water can also result in engine overheating. The best bet is to perform a complete flush and fill.

Bad Thermostat

A thermostat is a heat-sensitive valve that opens and closes in response to engine temperature. Heated engine coolant passes through to the radiator when the thermostat is in the open position. In the closed position, it prevents the flow of coolant to speed up the warming of a cold engine. When the thermostat gets stuck in the closed position, coolant stays in the engine and quickly becomes overheated, resulting in engine overheating.

Blocked Coolant Passageways

Rust, dirt and sediment can all block or greatly impede the flow of coolant through the cooling system. This can limit the system's ability to control engine temperature, which may result in higher operating temperatures and engine overheating. Once again, a flush and fill is recommended to remove debris.

Faulty Radiator

By passing through a series of tubes and fins, coolant temperature is reduced in the radiator. Leaks and clogging are some of the most common causes of radiator failure. Any disruption in the radiator's function can lead to elevated engine temperature and overheating.

Worn/Burst Hoses

A hose that contains visual cracks or holes, or has burst will result in leaks and disrupt the fib w of engine coolant. This can result in overheating.

Bad Radiator Fan

A fan blows air across the radiator fins to assist in reducing the temperature of the coolant. A fan that wobbles spins freely when the engine is off, or has broken shrouds will not be able to reduce the temperature to proper level, thus possibly resulting in engine overheating.

Loose or Broken Belt

A belt is often the driving link that turns the water pump at the correct speed for proper coolant flow through the cooling system. If a belt is loose or broken, it cannot maintain the proper speed, thus resulting in poor coolant flow and ultimately, engine overheating.

Faulty Water Pump

Known as the 'heart' of the cooling system, the water pump is responsible for pressurizing.anc ('propelling engine coolant through the cooling system). Any malfunction of the water pump, including eroded impeller vanes, seepage or wobble in the pump shaft, can prevent adequate coolant flow and result in engine overheating.

VIII. CONDITIONS THAT CAUSES EXCESSIVE PRESSURE IN THE INTERNAL COMBUSTION

Detonation causes a very high and sharp pressure spike in the combustion chamber but it is of a very short duration. A pressure trace of the combustion chamber process, enhance the normal turn as a normal pressure rise, but suddenly there is a very sharp spike when the detonation occurred. 'That spike always occurs after the spark plug fires. The sharp spike in pressure creates a force in the combustion chamber. It causes the structure of the engine to ring, or resonate, much as if it were hit by a hammer (Allen, 2000).

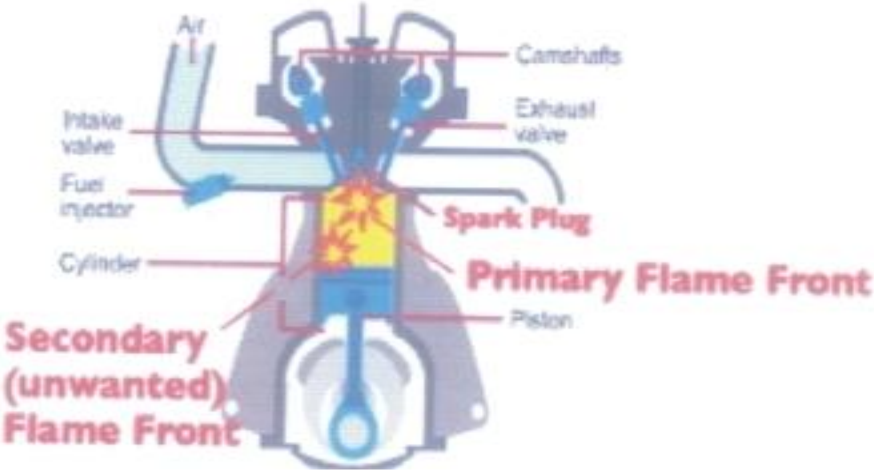

Fig 1: Layout of a combustion chamber

Heat /flame in the internal combustion engine

Combustion Instabilities are typically violent pressure oscillations in a combustion chamber. These pressure oscillations can be as high as 180 dB, and long term exposure to these cyclic pressure and thermal loads reduces the life of engine components. In rockets, such as the F1 used in the Saturn V program, instabilities led to massive damage of the combustion chamber and surrounding component (Wil1iam, 2008 and Xuesong, 2010).

Fig 2: Effect of excessive heat in an internal combustion engine.

Improper Combustion Process

An engine can ping (or knock) due to an improper combustion process. A "spark knock" is the result of combustion occurring too early. Early combustion can occur from carbon buildup inside the combustion chamber, a lean air/fuel mixture, and advanced ignition timing (spark plug firing too soon). In a properly-firing cylinder, the spark plug ignites the air fuel mixture and a flame front starts on one side of the piston and burns across the top to the other side, which creates a rapid and evenly-expanding gas that pushes down on the top of the piston. When the air fuel mixture is ignited prior to the spark plug firing, the two flame fronts collide, causing the pinging/knocking noise (Turcotte , Donald, Schubert & Gerald, 2002).

Fig. 3: Showing normal combustion

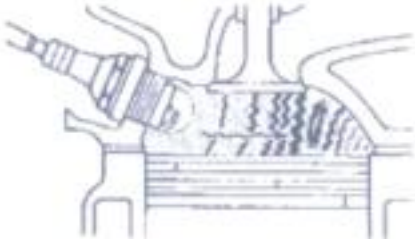

Fig. 4: Showing detonation

Fig 3 on the left shows completion of normal combustion. While fig 4 on right shows a detonating cylinder, where the last portion of the air/fuel mixture self-ignites and collides with the normal combustion front

Engine Is Too Hot
An engine can ping because it is too hot. This is another uneven combustion scenario that is caused by the air-to-fuel mixture "lighting off" by itself. If the cooling system does not keep t he engine's combustion chamber temperature in check, the air-to-fuel mixture will begin to spontaneously explode. This is also called "pre-ignition." A hole in the middle of the piston, particularly a melted hole in the middle of a piston, is due to the extreme heat and pressure of pre-ignition.

Fig. 5: showing Parts of badly damaged piston due to pre-ignition and excessive heat in the combustion chamber

Improper Gasoline Octane
In addition to cooling system problems, pinging can be caused by improper gasoline octane. An overly lean air-to-fuel mixture or a lack of proper exhaust gas recirculation. The exhaust gas, recirculation system (EGR) was created to neutralize engine pinging by adding a small amount of exhaust gas to the air-to-fuel mixture going in to the combustion process, which limits the peak combustion chamber temperature.

Fig. 8 and 9: Defected piston due to premature combustion.

Knocking: In an internal combustion engine sharp sounds caused by premature combustion of part of the compressed air-fuel mixture in the cylinder. In a properly functioning engine, the charge burns with the flame front progressing smoothly from the point of ignition across the combustion chamber. However, at high compression ratio, depending on the composition of the fuel, some of the charge may spontaneously ignite ahead of the flame front and burn in a p-uncontrolled manner, producing intense high-frequency pressure waves. These pressure waves force parts of the engine to vibrate, which produces an audible knock.

SUMMARY
The internal combustion engine is a heat energy engine, it convert heat generated from burnt fuel to useful work. Heat as a form of energy has effect on matters ranging from solids to Bose-Einstein condensates; the combustion chamber is not excluded, when the temperature rises above its designed thermal conductivity as a result of excessive heat generated caused by faulty system or malfunction of the engine or use of inappropriate gasoline or fuel, expansion occurs and when it is not controlled, it leads to further damages of engine components.

IX. CONCLUSION

When a solid is heated, its atoms vibrate faster about their fixed position. The relative increase in the size of solids when heated is therefore very significant in the study of thermal expansion in an internal combustion engine. The sudden rise in high pressure wave force and extreme, high temperature generated when pre- ignition, detonation, combustion instabilities, spark knock etc. occurs could result to excessive expansion or buckling or damage of components parts of the engine. Since a piston is subjected to very high temperature condition along with extreme and sudden compression and tensile forces on combustion as well as on thrust sides, it calls for a material which has very high strength to weight ratio and has very high heat conductivity in order minimize thermal fatigue.

Knocking can cause overheating of the spark-plug points, erosion of the combustion chamber/surface, and rough, inefficient operation. It can be avoided by adjusting certain variables of engine design and operation, such as compression ratio and burning time; but the most common method is to burn gasoline of higher octane number.

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