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CARBON MATERIALS FOR WASTE HEAT RECOVERY IN THE AUTOMOBILE ENGINE EXHAUST

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Abstract: The energy efficient technology in the automobile is the need of hour due to energy crisis as well as environmental problems. This paper deals and describes the feasibility of utilizing the dissipated waste heat energy from the exhaust manifold of an automobile engine .It involves the vibration of nano level thin carbon material. The waste heat energy is utilized to obtain thermo elastic vibration of required frequency. By using the piezoelectric principle, generated vibrations can be converted into Electromotive Force (EMF). This paper briefs about the various carbon based material for this application and performance comparison.

Keywords: Waste heat, Carbon based materials, thermo elastic vibration, piezoelectric

I. INTRODUCTION

Present day automobile exhaust system is used to guide reaction exhaust gases away from a controlled combustion inside an engine. The entire system conveys burnt gases from the engine and includes one or more exhaust pipes. At the end of this system we use a silencer to reduce sound, but during this process there s a appreciable loss of heat energy [1]

This paper provides an idea for the efficient conversion of this heat energy into electricity, and to have a comparison of various carbons based materials that could be utilised in the above cited experiment. It involves inducing thermo elastic vibrations in membranes of carbon based material, and with this heat energy and using Piezo electric effect to generate EMF

A. Non-linear Differential Mathematics

In recent decades, great progress has been made in theoretical, numerical, experimental investigations and applications in the fields related to thermoelastic vibrations, to meet the need of scientific research and engineering. Thermoelastic vibration is about the vibration of elastic bodies when temperature and stress fields are coupled.

Citations stated that a thermoelastic free vibration of clamped circular thin plate can be formulated using nonlinear differential equation about time, using Galerkin’s method.

Also it is analysed that when the thin sheet is coupled with thermal and stress fields, the vibration is more stable and the damping is much lesser compared to those produced by lone thermal fields. When subjected to such coupled fields, the conditions necessary to produce vibrations is also much relaxed. The threshold temperature required for producing vibration falls down to a feasible value and more strikingly the vibration produced is of greater frequency for smaller initial displacement and vice-versa. The above effects are only possible only when the thermal field is coupled with stress fields.

In order to accomplish the stress fields, the degrees of freedom of the circular sheet are arrested along its diametrical end points or along its circumference, depending on the thickness of the sheet used. Doing so, the sheet vibrates along the axis passing through the centre of it. For effective frequency results, the maximum displacement produced is less than or equal to the thickness of the sheet assumed. Having the temperature distribution phenomena and correlating effects, choosing the appropriate medium for vibration is important

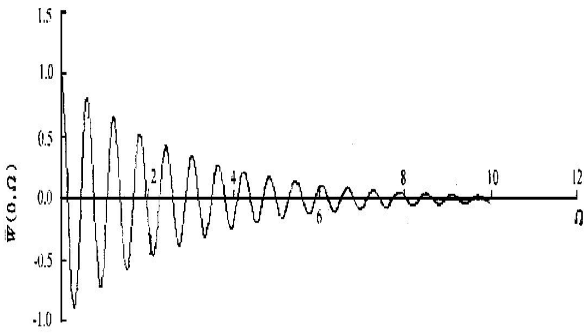


Fig 1 The decay of vibration amplitude in thermal field

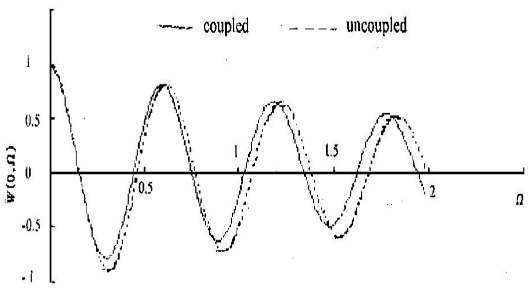


Fig. 2 The decay of vibration amplitude in coupled field with large initial displacement

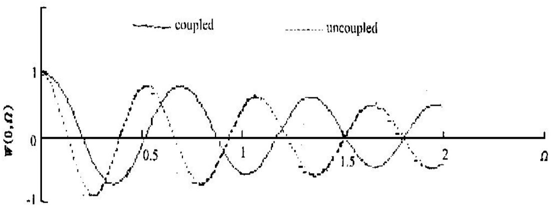


Fig. 3 The decay of vibration amplitude in coupled field with small initial displacement

CARBON MATERIAL-

It is a common observation that flat screen, slim televisions do not come with a big conical speaker mounted to its sides but are very sleek and is situated along it frame. The technology underneath is usage of a thin plastic sheet, made of the same material as water bottles, vibrates to produce sound. Clamps hold the sheet's centre still so the two sides vibrate independently to create stereo sound. The polymer generally used is Polyethylene terephthalate-PET or Polyvinylidene Fluoride-PVDF

As the above materials are not high temperature withstanding, carbon based material is used.

Amorphous carbon

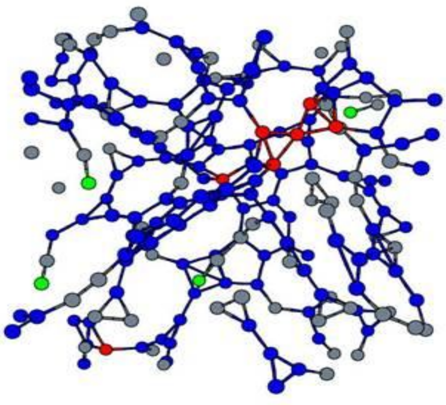


Fig 4 Amorphous carbon

Amorphous carbon or free, reactive carbon is an allotrope of carbon that does not have any crystalline structure. As with all glassy materials, some short-range order can be observed. Amorphous carbon is often abbreviated to a C for general amorphous carbon, a C:H for hydrogenated amorphous carbon, or to ta-C for tetrahedral amorphous carbon (also called diamond-like carbon).[3]

In mineralogy, amorphous carbon is the name used for coal, soot and other impure forms of the element, carbon that are neither graphite nor diamond. In a crystallographic sense, however, these materials are not truly amorphous, but are polycrystalline or Nano crystalline materials of graphite or diamond within an amorphous carbon matrix.

Buckminsterfullerene

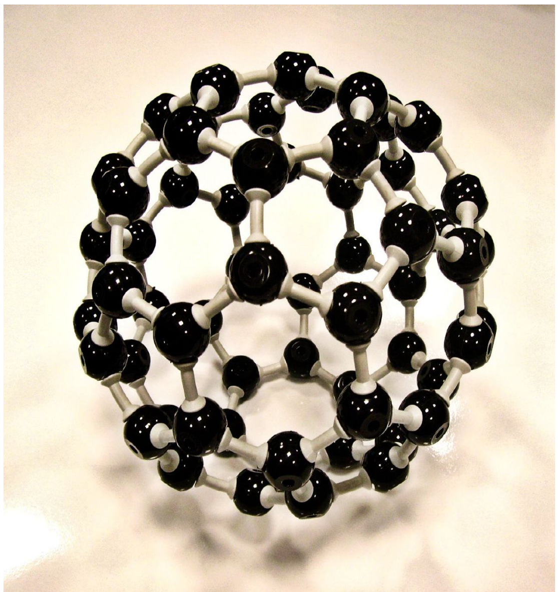


Fig.5 Fullerene-C60 Sublimed, 99.9%

The structure of buckminsterfullerene is a truncated (T = 3) icosahedrons which resembles a soccer ball of the type made of twenty hexagons and twelve pentagons, with a carbon atom at the vertices of each polygon and a bond along each polygon edge. The van der Waals diameter of a C60 molecule is about 1 nanometre (nm). The nucleus to nucleus diameter of a C60 molecule is about 0.71 nm. The C60 molecule has two bond lengths. The 6:6 ring bonds (between two hexagons) can be considered "double bonds" and are shorter than the 6:5 bonds (between a hexagon and a pentagon). Its average bond length is 1.4 angstroms [4]

Glassy carbon

Glassy carbon, also called vitreous carbon, can be fabricated as different shapes, sizes and sections, is a non-graphitizing carbon which combines glassy and ceramic properties with those of graphite. The most important properties are high temperature resistance, hardness (7 Mohs), low density, low electrical resistance, low friction, low thermal resistance, extreme resistance to chemical attack and impermeability to gases and liquids. Glassy carbon is widely used as an electrode material in electrochemistry, as well as for high temperature crucibles and as a component of some prosthetic devices [5]

Fig 6 A small rod of glassy carbon

Glassy carbon has a fullerene-related structure. Note that glassy carbon should not be confused with amorphous carbon. This from IUPAC: "Glass-like carbon cannot be described as amorphous carbon because it consists of two-dimensional structural elements and does not exhibit 'dangling' bonds. It exhibits a conchoidal fracture.

Graphene

Graphene is a one-atom-thick planar sheet of sp^2-bonded carbon atoms that are densely packed in a honeycomb crystal lattice. It can be visualized as an atomic-scale chicken wire made of carbon atoms and their bonds. Graphite itself consists of many graphene sheets stacked together.

The carbon-carbon bond length in graphene is about 0.142 nm. Graphene is the basic structural element of some carbon allotropes including graphite, carbon nanotubes and fullerenes. It can also be considered as an infinitely large aromatic molecule, the limiting case of the family of flat polycyclic aromatic hydrocarbons called graphenes.[6]

The thermal conductivity of graphene was measured to be between $(4.84\pm0.44)\times10^3$ to $(5.30\pm0.48)\times10^3$ $Wm^{-1}K^{-1}$. These measurements, made by a non-contact optical technique, are in excess of those measured for carbon nanotubes or diamond. It can be shown by using the Wiedemann-Franz law, that the thermal conduction is phonon-dominated. Potential for this high conductivity can be seen by considering graphite, a 3D version of graphene that has basal plane thermal conductivity of over a 1000 W/mK (comparable to diamond). In graphite, the c-axis (out of plane) thermal conductivity is over a factor of ~100 smaller due to the weak binding forces between basal planes as well as the larger lattice spacing.

Despite its 2-D nature, graphene has 3 acoustic phonon modes. The two in-plane modes (LA, TA) have a linear dispersion relation, whereas the out of plane mode (ZA) has a quadratic dispersion relation. Due to this, the T^2 dependent thermal conductivity contribution of the linear modes is dominated at low temperatures by the $T^{1.5}$ contribution of the out of plane mode. Some graphene phonon bands display negative Grüneisen parameters. At low temperatures, where most optical modes with positive Grüneisen parameters are still not excited, the contribution from the negative Grüneisen parameters will be dominant and thermal expansion coefficient is negative. The lowest negative Grüneisen parameters correspond to the lowest transversal acoustic ZA modes. Phonon frequencies for such modes increase with the in-plane lattice parameter since atoms in the layer upon stretching will be less free to move in the z direction. This is similar to the behaviour of a string which is being stretched will have vibrations of smaller amplitude and higher frequency. This phenomenon is called "membrane effect".

This graphene sheet when clamped along its boundaries, behaves like drum-like resonators. It has been experimentally observed for the non-linearity.

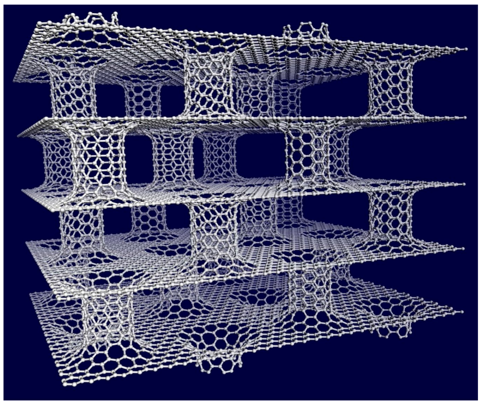
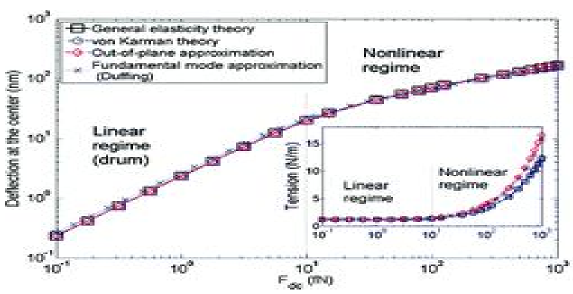


Fig. 7 Graphene Structure



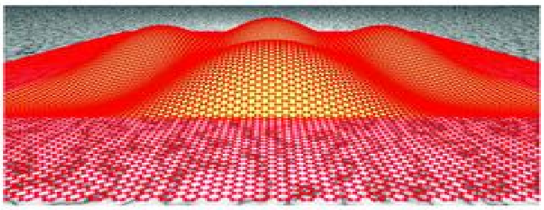


Fig. 8 Elasticity of Graphene

II. EXPERIMENTAL PROCEDURE

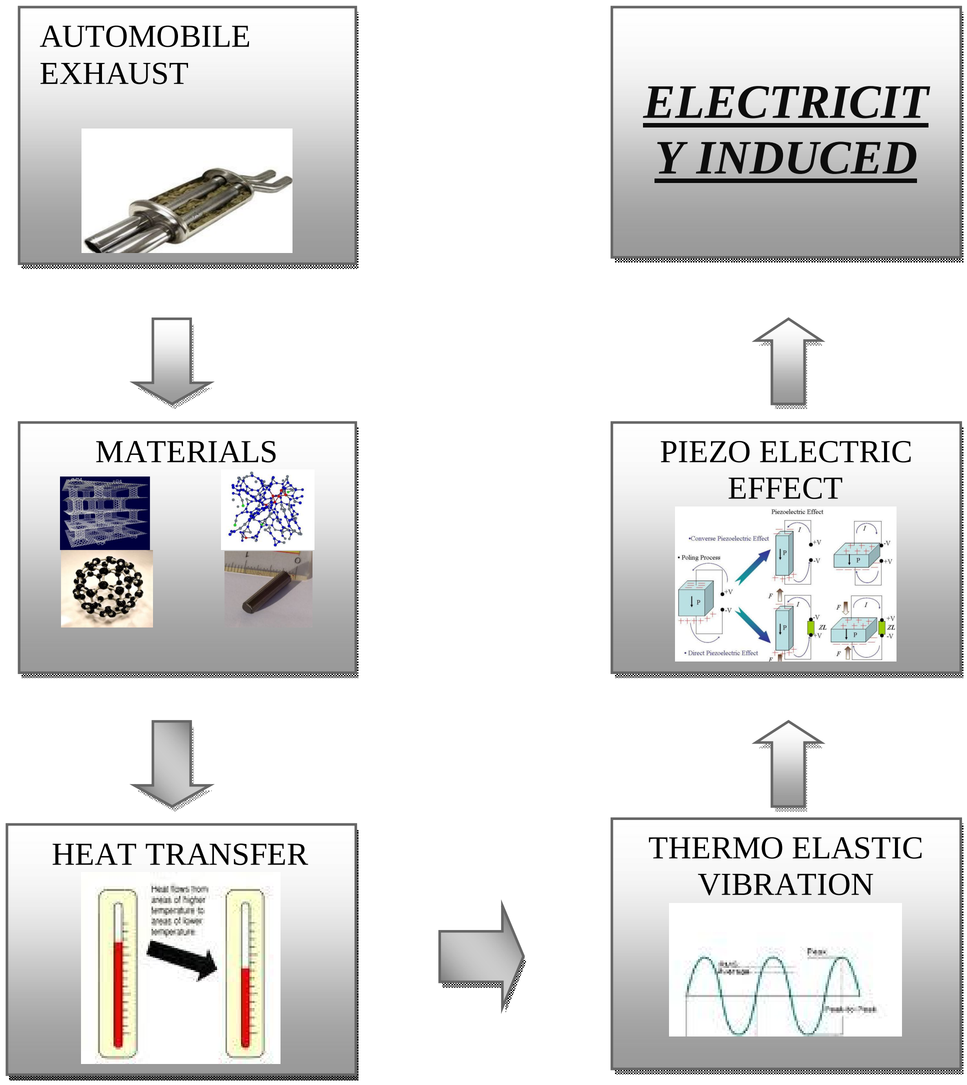


Table 1 Comparison of working material

MOLECULAR FORMULA	THERMAL CONDUTIVITY ($Wm^{-1}K^{-1}$)	BOND LENGTH (nm)	MECHANICAL PROPERTIES
C	$(4.84\pm0.44)\times10^3$ to $(5.30\pm0.48)\times10^3$.	0.1420.	200 times greater than steel
C60	0.4	0.1458	100 times greater than steel
C	150-200	0.3420	Comparatively higher than steel
C-H	0.3-10	0. 1415	Comparatively higher than steel

III. HEAT TRANSFER

The main element for all the above presented to happen is heat. Heat when transferred to the graphene sheet by suitable means, the sheet vibrates in relation to the above theory presented. The suitable means preferred is transfer of heat by convection using a hot and cold heat exchanger if needed.[7]

IV. SOUND AND ELECTRICITY

A. Sound

This heat energy raise is in relation to the amount of heat energy required to give the small initial displacement for the thin sheet to start vibrate.

When the thin sheet vibrates, the frequency produced is so large that the sound produced is near ultrasonic ranges. The experimental values obtained from the citations prove that as little as a 90-degree Fahrenheit temperature difference produced sound at 135 decibels - as loud as a jackhammer. Fahrenheit difference but much higher as in the range 200 to 300 degrees, hence larger would be the sound produced.[8]

The clamping of the graphene is done in such a way that, the sound produced dies out much before the audible range is reached, therefore null chances for noise pollution

B. Electricity

The sound waves thus produced are ducted to the piezoelectric devices that are squeezed in response to pressure, including sound waves, and change that pressure into electrical current. Piezoelectricity is the ability of some materials to generate an electric field or electric potential in response to applied mechanical stress. The effect is closely related to a change of polarization density within the material's volume. If the material is not short-circuited, the applied stress induces a voltage across the material. The word Piezo means to squeeze or press.

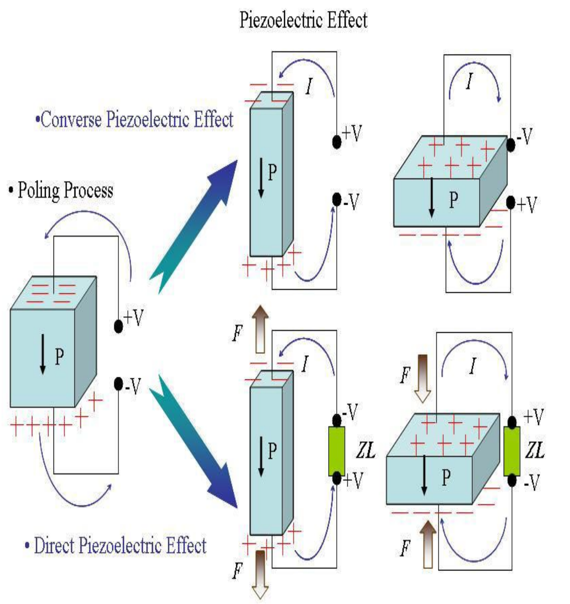


Fig.10 Piezoelectric effect

The first demonstration of the direct piezoelectric effect was in 1880 by the brothers Pierre Curie and Jacques Curie. They combined their knowledge of pyroelectricity with their understanding of the underlying crystal structures that gave rise to pyroelectricity to predict crystal behaviour, and demonstrated the effect using crystals of tourmaline, quartz, topaz, cane sugar, and Rochelle salt (sodium potassium tartrate tetrahydrate). Quartz and Rochelle salt exhibited the most piezoelectricity [9]

Fig. 11 Quartz and Topaz crystal

Using direct piezoelectric effect which is the production of an electric potential by application of stress, the sound produced can be converted to electricity. For very high frequencies of sound, large voltages are produced. This type of electricity harnessing is much common and less complex.

V. CONCLUSIONS

Using a thin sheet of graphene, heat energy available from the exhaust of an automobile can be very much converted in to a useful form of electrical energy using a modest economic way. The theory supports a liable method to convert the unused heat energy. Futuristic applications include the usage of the same to reduce heat generated in laptops and personal desktops in a smaller scale using very large scale integrations.

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