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RESEARCH ON THE PERFORMANCE OF WASTE HEAT RECOVERY FOR THE THERMOELECTRIC POWER GENERATION.

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Abstract - Non-renewable energy resources, which account for about 85% of worlds' energy (68% fossil fuels are used for electric power generation), are getting exhausted rapidly. As predicted by the Institute of Sustainable Energy Policies, by the year 2050, only 33% of non-renewable energy resources will be available for electric power generation. Hence, to meet the required demand, the remaining 67% has to be replaced by renewable energy sources. This demand in electric power generation has to be met by a pollution free, low-cost, clean energy resource, which is the need of the hour. The present research targets towards two main applications for generating power using the biomass energy based resources. They are domestic based application – burning biomass wood and utilizing the heat for generating power, industrial based application – combustion of gasified de-oiled Pongamia cake and utilizing the heat energy for generating power.

***Key Words*:** TEG, SEEBECK EFFECT, ENERGY CONVERSION

1.INTRODUCTION

Over the last few decades, problems related to energy such as oil crisis, climatic and environmental changes and considerable growth in electrical power demand due to population explosion have seen a global increase. The nonrenewable energy resources are not only used for electric power generation; but also for domestic needs, commercial requirements, transportation purposes, etc. Hence, these resources are getting exhausted at an increased rate. Reckless use of these resources results in increased carbon emissions leading to increase in green house gas emissions and global warming effects. Majority of electrical energy is obtained by conversion of thermal energy, either by combustion of materials or nuclear decay of isotopes. They have a negative effect on the environment and hence dependence on thermal energy sources is not sustainable. The demand in electricity has to be met by a pollution free, low-cost, clean energy resource. Recently, efforts are being taken to shift from non-renewable energy sources to renewable energy resources. Renewable energy sources, alsotermed as green or clean energy, comprises of wind, solar, hydro, geothermal and biomass. Depending upon the resource availability, power can be generated either close to the resource area or away from populated load centres. Distribution generation allows generation of electric power from renewable resources at the resource site. Hence, they reduce long distance transmission losses with improved power quality. Now-a-days, much attention is paid to power generation from Biomass-based resources (waste-heat recovery, waste management) effectively. This dissertation deals with effective electric power generation using hybrid thermoelectric generator from biomass wood waste for

domestic purposes and biomass crops such as non-edible, gasified, de-oiled pongamia cake, with synthetic oil suspended with graphene nano-particles as heat

2. THERMOELECTRIC GENERATORS

Thermoelectric generators (*TEG*) are capable of recovering waste heat energy as effective useful energy and play a major part in reduction of fossil fuel consumption. *TEGs* serve as a potential boon for small scale power production (Ismail et al. 2008). Several researchers have experimentally investigated the conversion of various harvested waste heat energy into useful electrical energy and a survey of their findings is as follows: Liu et al. (2014) carried out experiments on different semiconductor materials and concluded that a *Bi2Te3* semiconductor with less insulator plate thickness was not only economically feasible but also had the highest power cost ratio. A prototype employing 96 thermoelectric modules to generate 500W electrical power at a temperature gradient of 80ºC was proposed. It was found that the overall expenses of a *TEG* system was lower than those of *PV* and wind power systems. Nuwayhid et al. (2005) developed and tested a low cost, high performance thermoelectric module fitted to the upper right hand corner side of a common domestic

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wooden stove. A maximum of 4.2W was obtained from a single *TEG* module at a temperature difference of 88ºC.

3. SCOPE FOR THERMOELECTRIC POWER GENERATION

This research is focused on two main applications for generating power. They are domestic based application – burning biomass wood and utilizing the heat for generating power; industrial based application – combustion of gasified de-oiled *Pongamia* cake and utilizing the heat energy for generating power. Electric power is generated using hybrid (*Bi2Te3 – PbTe*) *TEGs* using synthetic oil suspended with various concentrations of nano particles as heating fluid. The input temperature of the *TEG* is varied from 200 - 250ºC and the cold side temperature is maintained at 30ºC. The mass flow rate is varied from 0.5 - 1.5l/Min. Pressure is being maintained at 0.176kg/cm 2 . The performance parameters of the hybrid *TEG* under various temperature, load and series conditions are experimentally studied. Prediction of performance parameters of the hybrid *TEG* under the afore-mentioned conditions up to the maximum allowable hot side temperature of 350ºC using Artificial Neural Networks (*ANN*) is done. Finally, practical implementation of the laboratory based findings using a known mass of biomass waste is done and the obtained power output is used to charge a 12V lead-acid battery

4. Research Methodology – Work Flow Pattern

As discussed in earlier sections, studying the power generation from combustion and gasification of biomass waste using hybrid thermoelectric generators and real-time implementation of the present study along with battery charging considerations is the main objective of this work. The detailed research methodology for achieving the scope and objectives of the present study is schematically explained. It is divided into two main categories – biomass waste management and thermoelectric power generation.Under biomass waste management, the study is focused on wood waste and crop waste. Under thermoelectric power generation experiments are performed using solid copper block and hollow copper block filled with graphene nanoparticles under various volume concentrations. Finally, practical implementation is done and the *TE* power generated is used for charging a 12V lead-acid battery. An experimental test facility is fabricated and the schematic of the experimental test rig used to investigate the performance of the hybrid thermoelectric generator.

4.1. HEAT RECOVERY FROM BIOMASS WASTE

Biomass is a fuel that is obtained from organic waste materials such as agricultural crops - left behind organic matter from the edible and non-edible crops, compost and certain types of waste residues such as wood scraps, mill residuals and forest remains, municipal solid waste. Biomass conversion is the process of burning these organic materials and producing a renewable and sustainable energy resource for green energy production such as neutral carbon electricity or other forms of power. This chapter deals with combustion of biomass wood and combustion and gasification of biomass crop – de-oiled *Pongamia Pinnata* seed cake and utilizing the obtained waste heat energy for generating electric power using hybrid thermoelectric generators.

4.2. BIOMASS WOOD

A small set-up is fabricated with bricks to burn the biomass wood waste. In order to avert the heat loss through the walls of the set-up, a thin metal skirting is placed at the inside surrounding the walls. Four k-type thermocouples were placed on the front, rear, left and right wall of the set-up and named as *T11*, *T33*, *T22* and *T44*.

4.3. GAS CHROMATOGRAPHY

Gas chromatography is usually done to separate and analyze the different compounds that can be vaporized without any decomposition at higher temperatures. When the gas mixture is separated into individual components, it is easy to qualitate and quantitate the amount of the individual samples present in the mixture. Initially, the biomass waste is burnt in a reactor powered by a dimmerstat to analyze the gas samples and perform gas chromatography. On complete combustion, the combusted gases are collected in a bladder through a gas

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tube. The football bladder is then connected to the gas chromatograph for gas separation and further analysis.

The gas samples were analyzed using *SHIMADZU GC-2014* equipped with *TCD* detector and shin carbon *ST* column (100/120 mesh, 2m and 1mm I.D). Nitrogen is

used as the carrier gas and the flow rate is maintained at 10ml/min. The nitrogen gas is passed through the purifier before entering in *GC* and gas sample (about 0.5ml) is injected into the injection port using a gas sampler. The gas samples are vaporized in the injection port. The vaporized gases (solutes) are transferred to the column using the carrier gas. The column is usually placed in a temperature controlled oven

and the oven temperature is kept at 40ºC for 3 minutes and then raised to 250ºC at a rate of 8ºC/min and then the same temperature is maintained for about 10 minutes.

Now, the solutes move through the column at different rates. The fastest moving solute leaves the column first pursued by the other solutes in the consequent order.

The standard gas with known composition is used for calibration prior to the analysis of gas samples. The eluted solutes enter the heated detector. When a solute

hits the detector, a signal is being generated. The size of the generated electronic signal is recorded using a data processor and a graph is plotted against the elapsed

time to create a chromatogram. 30

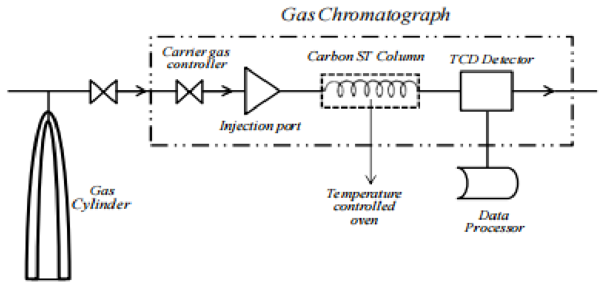

Fig: Process structure of a basic gas chromatograph.

5. THEORETICAL ANALYSIS OF HYBRID THERMOELECTRIC GENERATORS

A theoretical model is a description of a system using mathematical notions and language. The process of developing a theoretical model is termed as theoretical modeling. In this chapter, theoretical modeling has been done to study the effect of various components of the system and to predict their performance under different environments. Based on the results obtained from the theoretical modeling of the hybrid thermoelectric system, the input parameters at which maximum output is obtained at different load conditions are chosen for carrying out further experimental work.

5.1. ONE-DIMENSIONAL STEADY STATE ANALYSIS

Thermoelectric generators (*TEGs*) are solid-state semiconductor devices that convert direct heat into electricity as long as the hot side is at a higher temperature than the cold side. The thermoelectric (*TE*) effect includes three individually identified effects: the *Seebeck* effect, *Peltier* effect and *Thomson* effect.

A typical thermoelectric module consists of a large number of *n-type* and *p-type* pellets connected together by a metal plate through soldering. Conversion of

temperature difference directly into electricity is termed as *"Seebeck effect"*. When current flows through a junction between two conductors, heat is either generated or removed at the junction. This is termed as "*Peltier* effect". The heating or cooling effect of a current carrying conductor with a temperature gradient is described by the "Thomson effect". The *TEG* working principle is based on the *TE* effect

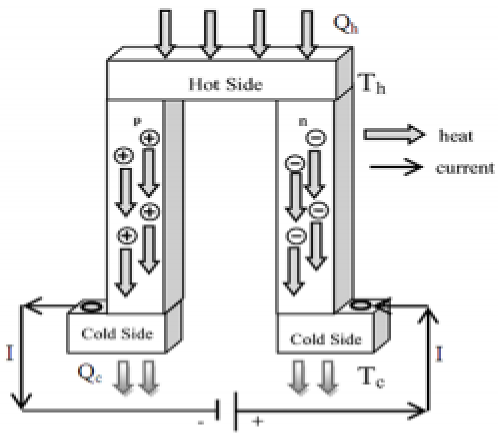

Fig:5.1 Schematic of a single thermoelectric couple

The material's thermoelectric properties such as – electric resistance, thermal conductance and *Seebeck* co-efficient vary depending upon the manufacturing processes. When an external heat *Qh (W)* is applied over the hot side to create a temperature gradient, *ΔT (ºC)* between the hot and cold sides, an electrical current *I (A)* is induced in the circuit. This is given in terms of '*Seebeck* effect'. According to Zhang et al. (2010) it is difficult to obtain the module parameters electric resistance - *Rm,* thermal conductance - *Km* and *Seebeck* coefficient from the *TEG* manufacturers as they are prone to protect their manufacturing materials and processes. The module parameters *Rm, Km* can be

obtained from *TEG* module operating parameters

5.2. PERFORMANCE EVALUATION

A hybrid thermoelectric power module (*TEG1-PB-12611-6.0*) composed of *n-type* Bismuth Telluride (*n-Bi2Te3*) and *p-type* Lead Telluride (*p-PbTe*) semiconductor material supplied by Thermal Electronics Corporation, Canada is considered for the analysis. The

main parameters considered for analysis include output voltage, output current, output power, maximum power output, open circuit voltage, *Seebeck* co-efficient, electrical resistance, thermal conductance, figure of merit, efficiency, heat absorbed and heat removed based on maximum conversion and power efficiency. If the temperature gradient across the thermoelectric module is higher, the electrical output will be higher. The load resistance also plays a major role in influencing the output of the thermoelectric module.

5.3. EXPERIMENTAL INVESTIGATION OF HYBRID THERMOELECTRIC GENERATORS

. In order to do this, an experimental test facility is designed and constructed. The experimental test

facility consists of a *TEG* test-section with high accuracy measuring device for measuring hot-side temperature, cold-side temperature, water inlet and outlet temperature. A multi-channel data logger is used to record the signals automatically from these devices. High accuracy voltmeters and ammeters are used for measuring the voltage and current at the input and output side. The post processing of the data is done using *MS EXCEL* for estimation of performance parameters such as temperature gradient across the hot and cold sides, output power, efficiency, figure of merit, electrical resistance and thermal conductance. The test facility is validated using the experimental results with solid copper block over hot side, synthetic oil as heating fluid with nanoparticles suspended in the concentration ratio of 0.01%, 0.03% and 0.05% against the published results. This chapter deals with the working principle of the of the test facility, measurement devices used in the facility, actual experimentation procedure, data reduction and uncertainty analysis of the study

6. RESULTS AND DISCUSSION

The experiments conducted in the present study are divided into three main parts namely, Experimental study of the performance parameters of the hybrid

thermoelectric generator (*TEG1-PB-12611-6.0*) with (1) copper block , (2) synthetic oil, (3) synthetic oil with nanoparticles suspension. The above results are compiled and discussed in this chapter. In the first part, the effect of flow rate of the coolant, variation in temperature gradient on the performance of three hybrid *TEG*s connected in series under various temperature and loading conditions are presented and discussed. In the second part, Experimental investigation using *Therminol-55* as heat transfer fluid over the hot side of the hybrid *TEG* with water and air cooled techniques employed over the cold side is done and the results are discussed in detail. In the third part, *Therminol-55* with graphene nanoparticles suspended in various concentrations such as 0.01%, 0.03% and 0.05% are used as heat transfer fluid and the enhancement in output power and efficiency due to nanoparticles suspension in synthetic oil is demonstrated and the results presented. Experiments are conducted till 250ºC hot side temperature. But, experiments can be performed till 350ºC hot side temperature. Hence, using the sample experimental values, the artificial neural networks tool in *MATLAB* is utilized and the performance of the

hybrid thermoelectric generator upto a hot side temperature of 250ºC and at ambient cold side a condition (about 30ºC) is analyzed. The simulated *ANN*72 parameters are compared with sample experimental results and based on the closeness between both the methodologies; the performance of the

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thermoelectric system (upto a maximum temperature gradient of 320ºC) is estimated even without

actually performing the experiments. *ANN* simulation has been carried out for all the three parts the results are discussed. Finally the experimental results are

compared with the existing published results and the findings are presented and discussed in the following sections.

6.1. COPPER BLOCK

The heater temperature is varied between 150 - 250˚C. The flow rate of the cooling fluid is varied between 0.5 - 1.5l/min. A pressure load of 0.176kg/cm 2 is applied to hold tightly the hybrid *TEG* module in order to reduce the thermal contact resistance. Also, the effect of flow rate of the coolant, variation in temperature gradient on the performance of three hybrid *TEG*s connected in series

6.2. PRACTICAL IMPLEMENTATION

The main objective of this work is to practically store the thermoelectric power generated from a known mass of biomass waste by employing a hybrid thermoelectric system, using a lead-acid battery. Practical implementation has been done and the thermoelectric power generated is used to charge two 6V, 4.5Ah leadacid batteries connected in series. A summary of the terminologies used and the detailed description of the step up voltage circuit, charging and discharging voltages along with their charging and discharging times are discussed below.

6.3. TERMINOLOGIES

It provides an introduction to the battery basics, variables used to describe the present condition of a battery and explain the specifications provided in the technical specification data sheet.

 Cell, modules and packs - A cell is the smallest, packaged form of battery. A module consists of several cells connected together in either series or parallel, depending upon the application. A battery pack is obtained by connecting modules together, either in series or parallel

 Battery Classifications - Manufacturers often classify the batteries either as high-power or high-energy as the main trade-off in the battery development is between power and energy.

 Primary and Secondary Cells - A primary battery is one that cannot be recharged. A secondary battery is one that is rechargeable. Batteries used for hybrid and plug-in applications, electric vehicles are secondary batteries.

 State of charge (SOC)(%) – It is an expression of the present battery capacity as a percentage of maximum battery capacity. It is used to determine the change in battery capacity over a period of time.

Depth of discharge (DOD)(%) – It is an expression of the present battery capacity as a percentage of the battery capacity that has been discharged over a period of time.

Terminal Voltage (V) – The voltage between the two terminals of the battery with the application of load.

Open-circuit Voltage (V) – The voltage between the two terminals of the battery with no application of load.

.**Internal Resistance –** It is the resistance that is developed within the battery depending on the battery state of charge. As internal resistance increases, the battery efficiency decreases with reduced thermal stability.

Nominal Voltage (V) – It defines the reference or normal voltage of the battery.

.**Cut-off Voltage (V) –** It refers to the minimum allowable voltage which defines the empty state of the battery.

 Nominal Capacity (Ah) – It refers to the total Amp-hours available when a battery is discharged at a certain discharge current from hundred percent SOC to the cut-off voltage.

 Charge Voltage (V) – It is the voltage that the battery is charged to under full capacity. Charging schemes generally consist of constant current charging until the battery voltage reaches the full capacity; constant

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voltage charging that allows the charge current to diminish until it becomes very small.

 Charge current (A) – The ideal current at which the battery is initially charged under constant current charging scheme.

6.4. CHARGING CONSIDERATIONS

6.4.1. Design Problems

Some of the major problems faced while charging a 12V lead-acid battery using thermoelectric generators is that:

 The output voltage and current vary immensely with the hot side and cold side temperatures.

 The discharge from the lead-acid battery into the thermoelectric generator must be avoided when no input heat is available.

 Further, over-charging the lead-acid battery must also be avoided. The charging circuit designed is simple and cheap, to charge any standard 12V leadacid battery and find application in remote areas.

6.3.2.Design Solutions

Initially, when the input heat applied to the thermoelectric generator is low, the output voltage to the 12V lead-acid battery is also found to be low (less than 15V). Hence, a boost converter is required to increase the output voltage of the thermoelectric generator. This may lead to over-charging of the lead-acid battery. Hence, under practical conditions, some kind of an artificial load which automatically switches on to take up the charging current when the battery is full and switches itself off when the battery is being charged is needed. An excellent artificial load is constructed using a constant 15V Zener diode and a rectifying diode that is connected across the lead-acid battery. As the battery approaches full capacity, its terminal voltage gradually rises and starts to turn ON the Zener. Henceforth, any more current will be absorbed by the Zener diode.

6.3.3. Working Principle

The block diagram illustrating the working principle of the charging unit. The output voltage of the hybrid thermoelectric generator is very low (0 – 5V). Hence, it is stepped up using a boost converter and the obtained output voltage (15V) is used to charge two 6V lead-acid batteries connected in series.

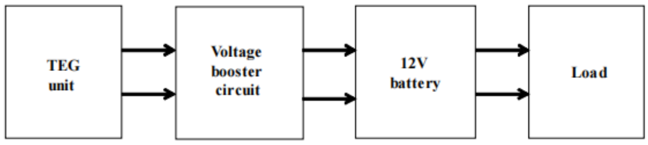

Fig: 6.3.3 Working principle – charging unit

7. CONCLUSION AND FUTURE WORK

This dissertation envisages the generation of thermoelectric power from Biomass based wastes using hybrid thermoelectric generators. A survey of published literature has indicated the need for the study of power generation using biomass based waste heat, preferably, a solution to Biomass waste management and small scale electricity production. Hence, the present work targets towards two main applications - Domestic based application by burning biomass wood and utilizing the heat energy for generating power; Industrial based application combustion of gasified de-oiled *Pongamia* cake and utilizing the heat energy for generating power. Based on the observations from this study, the following

conclusions are drawn:

7.1. HEAT RECOVERY FROM BIOMASS WASTE

Now-a-days, waste management plays a major role in managing waste right from the instigation to its final disposal. In order to have effective waste management and proper utilization of the recovered biomass waste heat, the following conclusions are drawn:

 The de-oiled seed cakes of *Pongamia Pinnata* can neither be used as animal feed or fertilizer due to its bitterness, acidic and toxic nature. It is, therefore, recommended to use this de-oiled seed cake for "syngas" generation.

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 Gasification of the de-oiled *Pongamia* seed cake resulted in production of “syngas”. Heat energy produced on combustion of generated “syngas” is

used for direct conversion of heat into electricity using a thermoelectric generator.

 The slag left behind gasification process was mixed with cow-dung and used as an organic fertilizer.

 Proximate and Ultimate analysis of *Pongamia* de-oiled seed cake showed the presence of high amount of carbon content which on combustion resulted in higher energy content biomass waste heat with a temperature of about 250 - 350ºC.

 Gas chromatography of biomass based wood waste and crop waste was done and chromatogram results showed that the percentage concentration of gas components (mainly *CO* and *CO2*) was found to be present well within the standards.

8. **SCOPE FOR FUTURE WORK**

The performance of hybrid thermoelectric generators with solid copper block and hollow copper block, filled with synthetic oil and synthetic oil-graphene nanofluid under 0.01%, 0.03% and 0.05% concentrations as the heat transfer medium is theoretically and experimentally analyzed. In the previous studies by other researchers, power generation using ordinary *Bi2Te3* modules has received the maximum attention. Till date, no experiments have been carried out using hybrid thermoelectric generators. Moreover, no published literature suggests the use of synthetic oil as heat transfer medium in thermoelectric generators. Also, this

research work suggests a solution to disposal of de-oiled *Pongamia* seedcake, thereby playing an important role in Biomass Waste Management. Practically implementing the suggested solutions for effective power generation from Biomass waste using hybrid thermoelectric generators should receive greater attention in the near future.

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133

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