

The Triple Zero Positive Appliance: Exhaust Gas Thermo Electric Generator (TEG) for Green Environment

Hare Ram Hare¹; P. Ravichandra²; Shrikrishna S Prabhu³, Utkarsh Jaiswal⁴, Naman Aggarwal⁵, Chum Bikomiyo Deori⁶

1. Assistant Professor (Marine Engineering), IMU MPC (MERI); E-mail: hareram@imu.ac.in
2. Assistant Professor (Mechanical Engineering), IMU MPC (MERI); E-mail: pravichandra@imu.ac.in
3. Final Year, B.Tech (ME), IMU MPC (MERI); Email: shrikrishnaprabhu5@gmail.com
4. Final Year, B.Tech (ME), IMU MPC (MERI); Email: utkarshjee2017@gmail.com
5. Final Year, B.Tech (ME), IMU MPC (MERI); Email: : imu.hnaman149@gmail.com
6. Final Year, B.Tech (ME), IMU MPC (MERI); Email: : chumbikomiyodeori@gmail.com

ABSTRACT

Exhaust/Flue gases from the main engine on board ship possess significant thermal energy. The energy, if recovered, can be utilized to generate substantial amount of power. Heat recovery by using a heat exchanger results in additional pressure drop and is not preferred.

*An alternate way is to analyse a vertically fitted **Thermoelectric generator (TEG)** in the exhaust pathway of a vessel for power generation. TEG's work on the principle of **Seebeck effect** in which due to temperature gradient between two electrically conductive metals / alloys/ semiconductors, flow of electrons take place which generate electricity. The TEGs in conjunction with the main can be used at immediate machinery exhaust (Incinerators, boilers etc.) which will act as if two generators are acting in series (**Thury system of connection**) and additional output can be expected. The output power can be used to power low energy requirement applications such as electric control panels of a machinery, panels in engine control room (ECR) which will make it **self-sustaining** at running hours, various sensors which require micro/milli amperes of current and many other devices. The energy can also be stored in batteries for battery powered operations. This in turn will reduce the o/p demand of the generator by significant extent thus saving fuel for running the generator. This **one-time investment** in the installation of this system of electricity generation has **minimal maintenance, zero emissions** which makes its environment friendly which is the need of hour.*

Keywords: Thermoelectric generator, Seebeck effect, Thury system

1.INTRODUCTION:

Rising need for sustainable use of resources have forced the organisations to opt for various **renewable, non-polluting and efficient sources of energy**. Harnessing the waste energy from the effluents emitted by the machinery and utilising it for running system accessories, subsystems which would reduce the load on the power generating consoles, leading to savings on fuel and capital. With this aim, **TEG's (Thermoelectric generator)** were adopted in various industrial sectors like power plants, automobiles etc. These are one of the few methods to harness waste energy into productive ones. Onboard ship, energy is lost in the form of exhaust heat. Recent study shows that the ship's exhaust has capability to generate **6.2MW** of energy which is pretty large. Thus, the use of TEG's can help in reviving some part of this waste energy and can be utilised for reduction in consumption of fuels and subsequently emissions.

2.TEG: The Core

Thermoelectric Generator (TEG), a stationary device with no moving parts generates electricity on the principle of **Seebeck effect**. The principle on which TEG's work was discovered by **Thomas Johann Seebeck**, a German physicist which states that an emf is generated between two electrically conducting metals/ alloys/ semiconductors when there is temperature difference/gradient between the two. When there is a temperature difference the charge carriers (electrons/holes/ positive particles) in the metal at the hot side flow towards the cold side metal which generates a potential difference and hence the current. TEG generates **DC electricity** and a single TEG has a capacity of about **1W to 125W**.

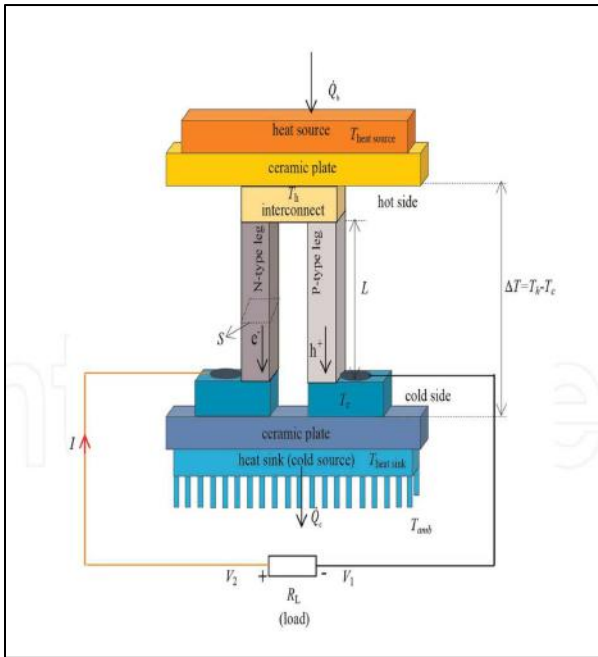


Fig.1: Seebeck Effect

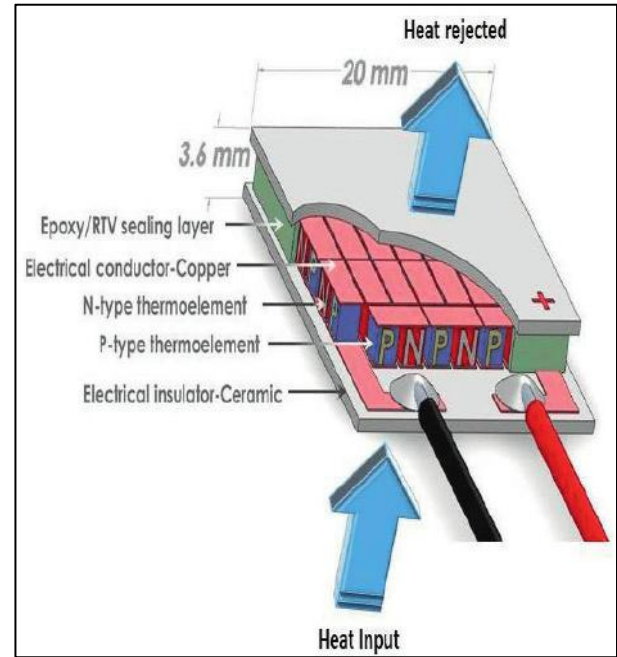


Fig.2: TEG Single Unit

2.1 Materials used in manufacturing TEGs:

- Semi-Conductors like Bismuth telluride (Bi_2Te_3), lead telluride (PbTe), and silicon germanium (SiGe).
- Metals like stainless steel, copper compounded with semiconductor for high temperature applications.

The efficiency of the TEG is about **10%-20%** and is directly proportional to the Temperature Gradient (ΔT). The electrical and thermal conductivities are usually high or low in a material as the energy is transferred through electrons. Recent developments in the field of ceramics have seen materials that can possess high electrical conductivity and low thermal conductivity which would keep the temperature gradient as high as possible and favour an increase in efficiency.

3. EGTEG: The Solution:

In the exhaust funnel of the ships TEG modules can be installed vertically which would allow the exhaust to flow without any interruption (horizontal arrangement would lead to back pressure formation in the funnel). There are no fins in the hollow vertical chamber. The

temperature of flue gases in combined exhaust funnel is about 200°C- 250°C after passing through turbochargers and exhaust gas economizers. The individual exhaust of auxiliary machinery such as incinerator is about 800°C-900°C which is again an ideal location for TEG installation.

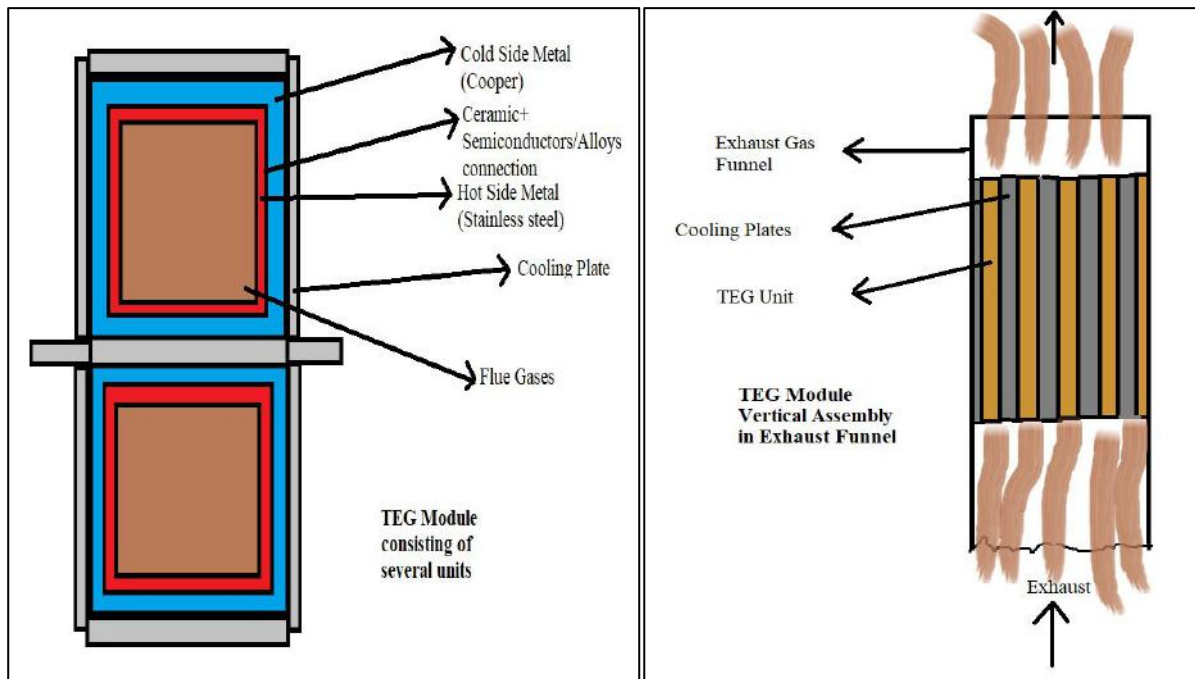


Fig.3: EGTEG cross sectional and longitudinal view

The above Fig.3 gives a brief idea of TEG installation across exhaust funnel covering total diameter of the funnel. TEG units are coupled together to form a module and these modules are supplied with good amount of cooling fluid (mostly water) to maintain the temperature gradient as high as possible for efficient TEG operation. Cooling system of the module can be connected with normal fresh water-cooling lines which cool the auxiliary machineries. The approximate temperature gradient created is about:

$$(\Delta T) = T_{\text{hot side}} - T_{\text{cold side}} \rightarrow 250^{\circ}\text{C} - (30-40)^{\circ}\text{C} \approx 210^{\circ}\text{C}$$

This system is subjected to high temperatures and hence the semiconductors cannot be directly exposed to the flue gases as they might be damaged. Thus, the TEG unit is made up of Stainless steel and copper compounded together with the internal unit. Stainless steel and copper are used as steel has very good thermal conductivity and copper has very good electrical conductivity. Semiconductor unit is sandwiched between these two plates with a ceramic liner on both sides of semiconductor which acts as thermal refractor and promotes working temperature range of the semiconductors.

For much better output TEGs of much higher tolerance towards elevated temperatures and heat can be used at individual machinery exhausts. For instance, at incinerator exhaust funnel where flue gas temperature ranges between 800°C-900°C or at boiler uptake. The material of TEG needed for such cases is about to enter in production stage and is said to be improvised version of steel with its lattice consisting of semiconductor structures with low thermal conductivity but enough for semiconductor to function properly, resulting in high temperature gradient and more efficiency hence the power.

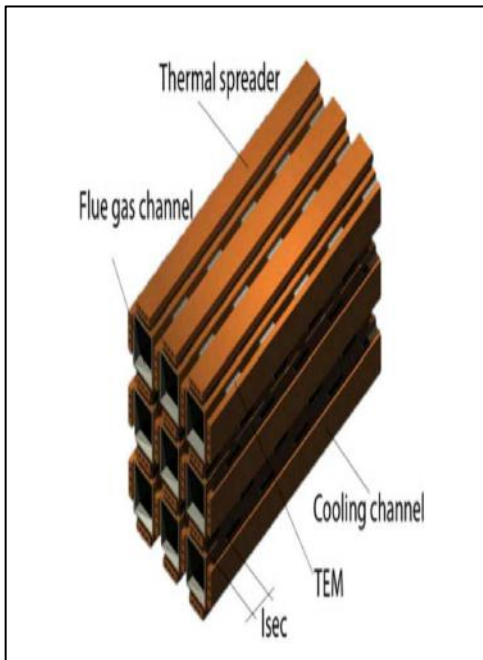


Fig.4: Actual TEG Module interconnection

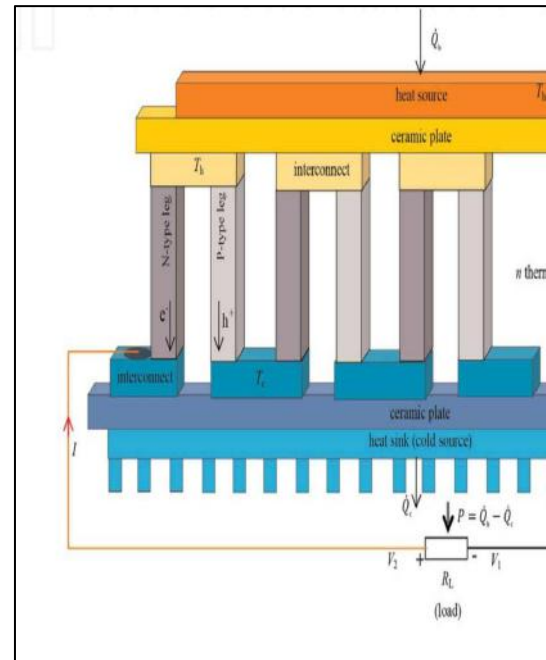


Fig.5: Module Formation. This will be similar for

Such two major modules (Main and Auxiliary (Incinerator)) can be coupled together for more power output using “THURY SYSTEM OF CONNECTION OF SERIES GENERATOR”. This complete system acts as if generators are connected in series (Fig.5). In this case the opposite nodes/ semiconductor plates of a module with respect to the module to be connected are coupled. This leads to generation of more current with constant voltage. This will be very effective for power generation. Also, the generated DC current by the unit after converting into AC can be used to run AC devices and panels. The conversion system (Fig.6) consists of an inverter made up of IGBT / SCR which converts DC to AC.

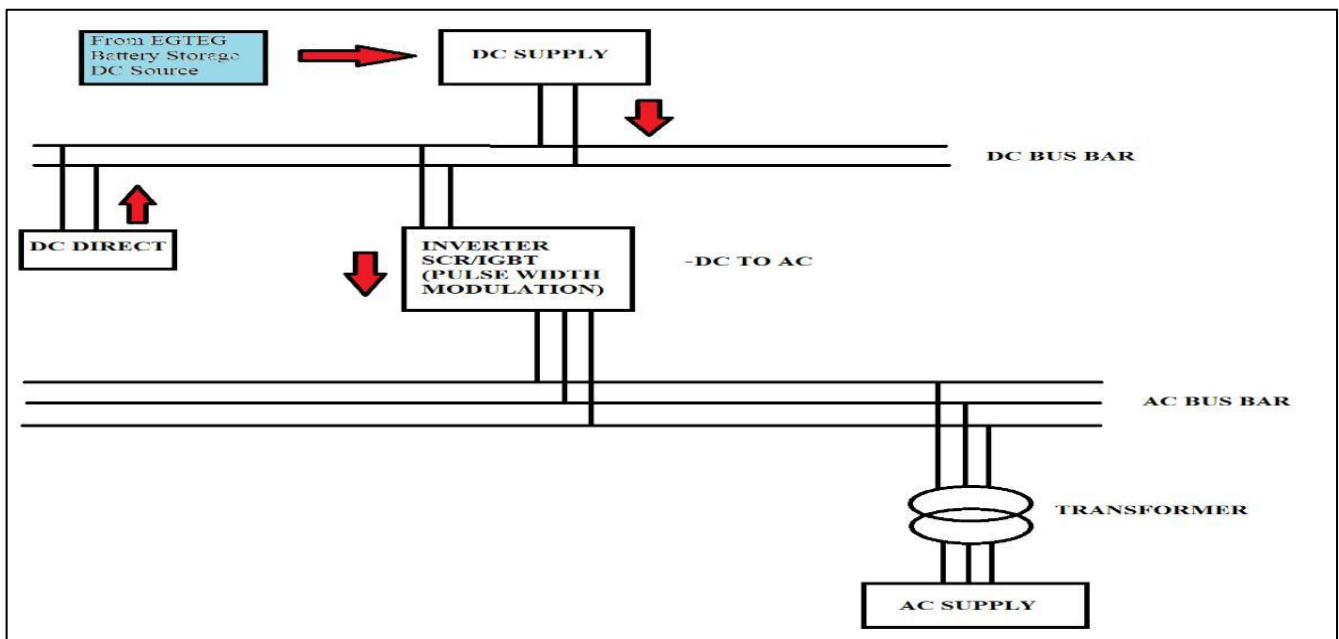


Fig.6: System for DC to AC

4. Operational Design and Specifications:

Table1: Design Specifications

Parameter	Measurements	Units
Exhaust gas velocity	35-50	m/s
Exhaust gas pipe diameter (assumed)	1500	mm
Module Parameters:		
Length of the module- L	800	cm
Cross sectional side (available in funnel) (square)-A	106.066	cm
Actual module side (square)- A*	100.00	cm
C/s Area available with appendages*- a	11249.99	cm ²
C/s Area for module/ total area of operation-a*	10000	cm ²
TEG Cell Parameters:		
Square TEG side	6.4	cm
Surface area available for heat transfer	40.96	cm ²
TEG Single Unit Parameters:		
Side length (2 cells per unit) -Square	12.8	cm
Cooling walls thickness w.r.t. enclosed TEG unit-t	2	cm
Total side length including cooling walls (both sides)	16.8	cm
Total Calculations:		
TEG units across c/s of square	25 units	-
TEG units across length (800cm)	125 units	-

*Appendages include the holding bars, angle bars, girders to hold the EGTEG in the exhaust funnel

Table 1 shows the design specifications of the EGTEG module for the exhaust funnel of 1500mm diameter. For different values of diameter of exhaust funnel, the module can be altered for no of units, dimensions of the cells and units. The installation of any system in a flowing chamber causes formation of backpressure in the chamber and this is not being exempted in this system. The standard set by various organisations state that when the engine is operating at its MCR, the back pressure in the exhaust funnel should not exceed **0.035bar** after the turbocharger unit. Exceeding this amount of backpressure may lead to frequent surging of turbocharger, damage to its components and ultimately failure. The governing factors for the back pressure consists of gas velocity and the diameter of the pipe/ free area available for flow and is related by the equation (3)

$$\text{Gas velocity} \propto 1/(\text{Diameter of exhaust funnel})^4 \quad (3)$$

As a countermeasure for this issue the design of the EGTEG consists of nozzle type arrangements (Fig.7) at the exhaust entry point of the module. This arrangement helps in reducing the obstruction to the flow caused by the end points of the module (at the entry of

exhaust). The direction of nozzle type arrangement is such that the convergent end is in the direction of the flow. This helps in creating a low-pressure region at the starting point facilitating the exhaust to flow in same direction, rather than creating back pressure at the entry point of the module. Also, this arrangement favours rapid flow of exhaust over the coarse surface of TEG units leading to efficient heat extraction.

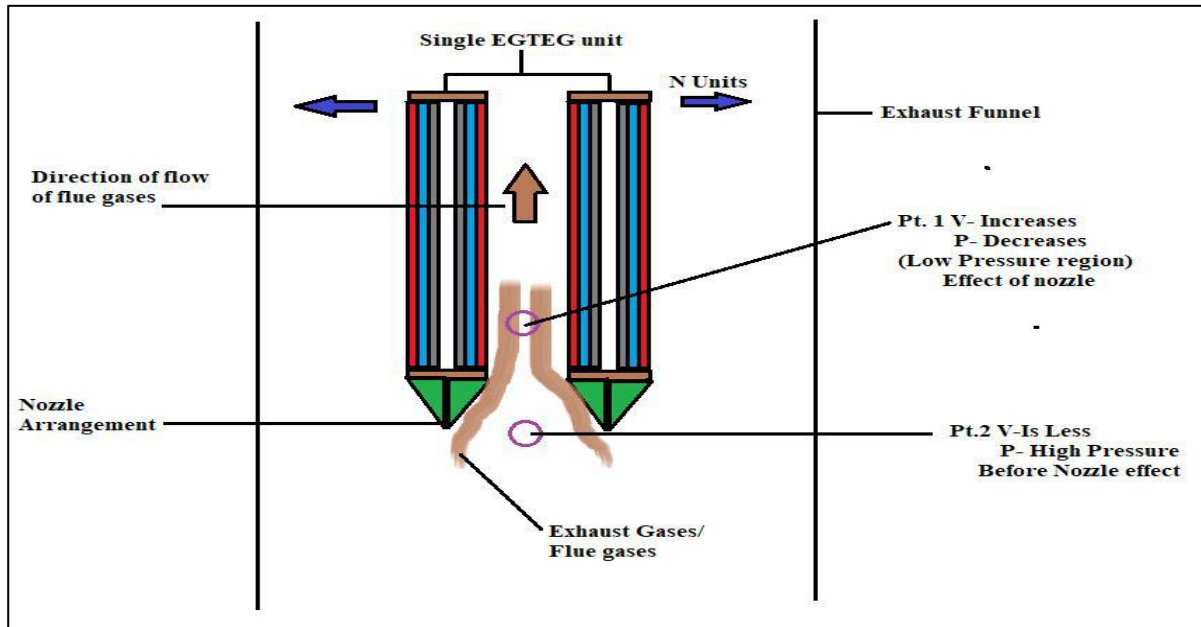


Fig.7: Nozzle arrangement as countermeasure

5.Fuel Saving Calculations: As per estimated calculation for **MAN B&W 175D**, 2000kW power output of the generator, about **650 litres** of fuel per day will be saved on running the generator & Monthly savings will be **19500 litres** of fuel.

6.Strengths of EGTE

- AC systems can also be operated by AC power generated from the inverter.
- For running hours, exhaust emitting machineries e.g.: incinerator, boilers can be made electrically **self-sustaining**.
- Burning of less fuel in generator will thus **reduce emissions**.
- Furthermore, utilization of waste energy is achieved other than economizers and turbochargers.
- The system is relatively **cheap**, requires **very less/ annual maintenance** since it has no moving parts and thus adding **no extra load** on ship's crew.
- EGTEG doesn't generate any system emissions (**zero emissions**) and hence **environment friendly** which is the need of hour.
- EGTEG total costing will be **totally refunded** by the savings made on fuel expenses within years and yield some amount of **profit** in the preceding years.
- **Most** of the small requirements of power to electric panels, sensors etc can be met by the power generated by this system.

7. Restrictions and Challenges for EGTEG

- EGTEG installation is complex as coupling it with sub systems and power storage units demand heavy cabling and connection work.
- The system can only be operated when there is ample flow and temperature of flue gas. It needs to be backed up by regular power solutions available on ship for better redundancy.

8. Conclusion:

EGTEG utilization could be one of the revolutionary measures in the shipping world as it serves the purpose of **GREEN ENVIRONMENT**.

References:

[1] TEG: Harvesting and Principles: Diana Enescu

[2] Waste Heat Recovery Systems: N.R. KRISTIANSEN, G.J. SYNDER, H.K. NIELSEN & L. ROSENDAHL 1.—Technical Department, TeamTec AS, 4902 Tvedestrand, Norway. 2.—Materials Science, California Institute of Technology, Pasadena, CA 91125, USA. 3.—Faculty of Engineering and Science, University of Agder, 4898 Grimstad, Norway. 4.—Department of Energy Technology, Aalborg University, 9220 Aalborg, Denmark: Published: 2012

[3] MAN B&W: Waste heat recovery system: Reduction of emissions: <https://mandieselturbo.com/docs/librariesprovider6/technical-papers/waste-heat-recovery-system.pdf>

[4] Electrical Machines: B.L Thereja : DC machines: Generator in series.

[5] <https://espressomilkcooler.com/teg-cascade-800c-hot-side-thermoelectric-power-modules/>- Teg dimensions

[6] <https://www.marineinsight.com/main-engine/exhaust-gas-system-of-main-engine-on-ship/> - Exhaust system details.

[7] <https://www.man-es.com/marine/products/four-stroke-engines> - Generator details

[8] <https://www.man-es.com/marine/products/two-stroke-engines> - Engine details.

[9] GHG and Energy Efficiency in the Shipping Industry- IMO