CHAPTER 1

INTRODUCTION

1. Introduction

According to statistics on country-by-country petroleum consumption from 2000 to 2014, India is the third biggest consumer of petroleum, accounting for approximately 3.9 % of global reserves. (*International - U.S. Energy Information Administration (EIA)*, n.d.). The usage of fossil fuel in automobiles is becoming a growing source of worry due to negative environmental consequences. CO_2 is produced as a by-product of the combustion of fossil fuels in automobiles, which contributes to global warming. The Geomorphological Research Laboratory in Colorado's CO_2 measurement system has recorded an 11.5 % increase in global atmospheric CO_2 over the last decade. (*International Energy Statistics*, n.d.).

India is one of the largest producers of carbon emissions, accounting for more than 6% of global CO_2 emissions, according to Figure 1.1 from a World Bank study on country-by-country carbon emissions in the automobile sector from 2000 to 2014. (*NOAA ESRL Global Monitoring Division*, n.d.). The Indian government is proposing to solve New Delhi's air pollution problems by 2030 by enacting a bold plan to convert all light-motor vehicles to electric vehicles.

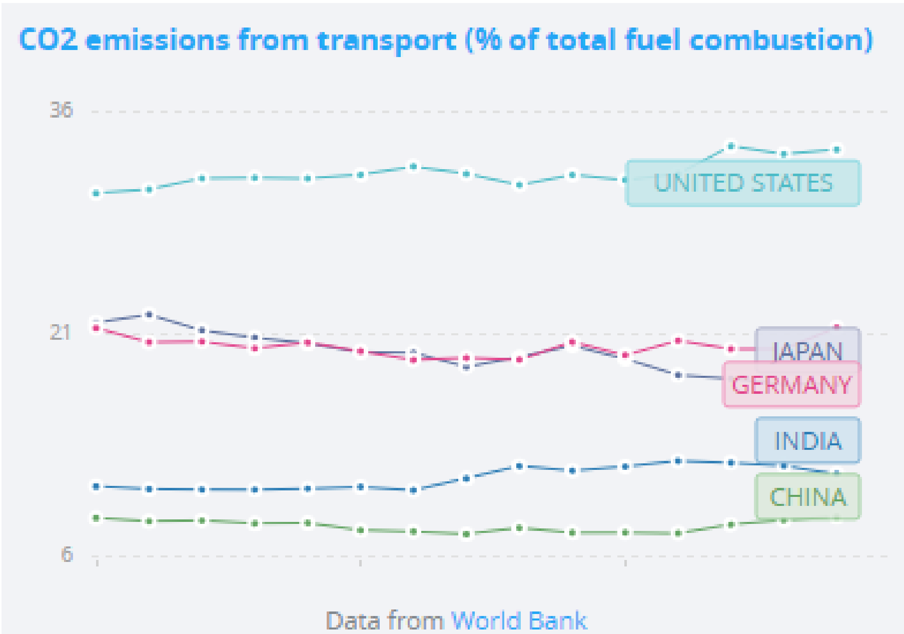

Fig. 1.1 Country-wise CO_2 Emissions (*NOAA ESRL Global Monitoring Division*, n.d.).

The automotive industry plays a prominent role in the economic development of a country. However, industry's growth is depended on advancements in vehicular technology. Research and development in automotive technology is facing challenges of achieving lower emissions, higher safety and better performance. Electric, autonomous and connected mobility are the most focused areas for improvement. In case of electric mobility as a solution to pollution the approach needs to be streamlined.

The Indian government's current CO_2 emission target (based on the Paris Climate Treaty) is 113 g/km by 2021. Furthermore, electric vehicles may account for 40 to 50 % of new vehicle sales by 2030. (*CO_2 Emissions from Transport (% of Total Fuel Combustion) | Data*, n.d.). Such local differences could be minimized by continuous improvements in charging techniques and battery. Therefore, market share for hybrid and electric vehicles will be increased.

According to the International Energy Agency, 336,000 electric vehicles were sold in China in 2016 and 160,000 in the United States, whereas only 450 electric vehicles were sold in India last year, accounting for less than 1% of the total market. (Rajat Dhawan et al., n.d.). By 2020, the government estimates that six million electric vehicles will be on Indian roads. This shows that adoption of electric vehicles is not easy in India. Even with 30% electric car penetration in 2030, there will be a 3-4 percent increase in power demand on the grid (Von Paul Gao et al., n.d.). The stage of shifting to electric vehicle from conventional one involves adoption of hybrid electric vehicle. In fiscal year 2015-16, hybrid passenger vehicles accounted for approximately 1.3 percent of all passenger vehicle sales in India, up from nearly nothing in fiscal year 2012-13. (Shikha Rokadiya, n.d.). Hybrid vehicles have the potential to reduce CO_2 emissions from road transportation significantly.

The preceding discussion underlines that hybrid electric vehicles will be the future of transportation growth. As a result, improving a hybrid electric car's performance is critical. The market share of hybrid electric vehicles will grow as manufacturing costs are reduced and overall efficiency is improved through creative scientific research. This could be accomplished by using waste energy as an alternative to battery charging.

1.1. Hybrid Electric Vehicle (HEV)

HEVs are propelled by a combination of an internal combustion engine and an electric motor powered by battery energy. HEVs combine the benefits of both systems, offering improved fuel economy and lower exhaust emission while sustaining the range and power of regular cars.

HEV uses an electric motor which downsizes the engine capacity, providing lower fuel consumption. The auxiliary loads are also power by bigger battery and engine start stop function avoids fuel loss in engine idling. When these parameters are combined, they result in improved fuel efficiency without losing performance.

The electrical current needed to start a car and other electronic devices is stored in a rechargeable automobile battery. When the engine starts, the alternator starts charging and, in some cases, delivers electricity to auxiliaries. A vehicle battery delivers maximum current in a short amount of time. Vehicle batteries are sometimes known as Starting, Lighting, and Ignition batteries or SLI batteries. In cars, lead-acid and lithium ion batteries are the most often used batteries. When compared to other commonly used batteries, lithium-ion batteries have a high power density, a high energy density, a long service life, and are ecologically friendly. Lithium-ion batteries are employed in a variety of ways in hybrid and electric vehicles. Li-ion batteries store far more energy and are significantly lighter than lead-acid batteries.

Some of the energy sources involved in vehicle battery charging include alternator/generator, regenerative braking, plug-in charging, fuel cells, solar, and thermoelectric. A hybrid electric car is more efficient and environmentally benign when various alternative energy sources are combined. A conventional hybrid electric vehicle's battery cannot be charged by hooking it into off-board power sources. The mild and micro hybrid vehicle recovers energy lost while braking by charging the battery with an electric motor that acts as a generator.

1.1.1. HEV Architectures

HEVs can be mild or full hybrids, with full hybrids available in series or parallel configurations.

- Mild hybrids – Micro hybrids are another name for these. According to the vehicle's functionality, it uses a battery and an electric motor to act as a starter and generator.

It allows the engine to switch off in traffic and save idling losses. The engine is started by the motor whenever it is needed. During engine operation, the same motor functions as a generator to charge the battery. These vehicles have a large battery capacity. In a modest HEV, there is no need for a starter motor. Vehicles equipped with mild hybrid systems are unable to run entirely on electricity. These vehicles are usually less expensive than full hybrids, although they offer poorer fuel efficiency.

- Full hybrids have more powerful electric motors and larger batteries, allowing them to travel small distances at low speeds. These cars are much more costly than mild hybrids, but they get superior gas mileage.

Integrating the energy of the electric motor with the engine can be done in a variety of ways. A parallel hybrid is the most popular HEV design. Both the engine and the motor have the ability to drive the wheels separately or in tandem. A series hybrid is a vehicle with only one motor driving the wheels and a small engine generating electricity to charge the batteries on a continuous basis. This configuration is most commonly used in plug-in hybrids, where the larger battery can be charged from the grid as well.

- Plug-In Hybrid Electric Vehicles

PHEVs combine the use of batteries to power an electric motor with the use of another fuel source, such as petrol or diesel, to power an internal combustion or other form of propulsion. The batteries of plug-in hybrid electric vehicles (PHEVs) can be charged utilising charging equipment and regenerative braking. Using electricity from the grid to power the car for some or all of the time saves operational expenses and fuel usage when compared to conventional automobiles. Depending on the source of power and how often the vehicle is driven in all-electric mode, PHEVs may also emit less pollution.

Several light-duty PHEVs are currently available, and medium-duty vehicles are on the way. Medium- and heavy-duty vehicles can also be converted to PHEVs. PHEVs are often more expensive than equivalent conventional and hybrid vehicles, despite the fact that they are more fuel efficient. (Millner et al., 2010).

HEV performance is improved through the use of best-suited architecture, the development of energy management algorithms based on the equivalent consumption minimization strategy (ECMS), regeneration, and recuperation. The common regeneration system used in HEV is regenerative braking system. Whereas, there is another waste energy zone i.e. heat lost to the environment, which has an ample potential, if utilized.

1.1.2. Advantages of HEVs

Compared to traditional automobiles, HEVs have a lot of advantages. They can achieve higher operating efficiency since they use small gas engines, which result in reduced internal energy loss.

Regenerative braking is used in HEVs to recover energy lost in the form of heat when typical vehicles brake. This absorbed energy can be stored in the HEV's battery, which again is especially handy during modern city traffic's stop-start driving cycle.

HEVs use less fuel while giving equivalent performance to traditional vehicles with internal combustion engines. This increased fuel efficiency reduces expenditures as well as the amount of hazardous gases discharged from the exhaust. Due to greater fuel efficiency, HEVs offer a longer range than comparable-sized conventional vehicles.

In HEVs, other efficiency-improving technologies can be applied. Start-stop technology turns off the engine when the vehicle is stationary, avoiding wasteful energy usage. Similarly, HEVs normally only run the air conditioner, power steering, and other electric pumps when they're needed, whereas traditional vehicles run them continually via engine belts, which is inefficient.

Finally, to achieve maximum the fuel efficiency attained through the use of battery bank and electric power generation, HEVs intended for fuel efficiency commonly use energy-saving strategies such as better aerodynamics and lower rolling resistance tyres.

1.1.3. Electric Energy Demand in Vehicles

Table 1.1. Energy Demand

Parameters	Power demand
Full Load applications	300-1500 W
Normal driving conditions	250-350 W
For converting mechanical to electric Engine cooling system.	200-800 W
For converting mechanical to electric AC system.	3000-5000 W

The Table 1.1 highlights the electric energy demand of a passenger car. This clearly shows the need of alternate energy sources in a vehicle.

1.2. Waste Heat Recovery

Automotive vehicle emission regulations are getting tougher and strict due to environmental issues. The regulations will be focusing for reduction in CO_2 emissions. This can be achieved by either increasing IC engine efficiency or by hybridization of conventional vehicle with electric drives. In both cases intelligent use of IC engine is more important. The new trend of automotive research is hence moving towards hybridization and electrification. In case of hybridization the automotive engine still have a significant role. It is evident from numerous theoretical and experimental results that automotive engines have more heat losses and hence this brightens the scope of waste heat recovery methods for improving overall efficiency of a vehicle.

Therefore, every possible way of restoring the waste energy is needed to be explored. Waste heat recovery method to convert direct heat to electricity has a huge scope to improve vehicles performance in terms of lower emission and higher range. Internal combustion engine's heat is lost through various parts such as water jackets, cooling system, exhaust system, lubrication system. Although the majority of research is focused on recovering heat though exhaust as it is complex to construct a device and assemble in combustion chamber.

1.2.1. Direct Energy Conversion Methods

Direct energy conversion is one of the growing areas of research leading to sustainable development. Energy generation and storage are seemed to be affecting each other in terms of energy utilization. Approaching to superior technologies and advanced materials is best constructed path to achieve the maximum conversion efficiency. Energy crises are enforcing the researchers to concentrate towards alternative yet effective ways for sustainable energy utilization. Currently in India the contribution of renewable energy sources for electricity generation is less. Whereas non renewable energy sources used today have waste heat energy issues to be resolved. Here the direct energy conversion can play a vital role. One of these ways is to convert direct heat to electricity by following direct energy conversion methods.

Thermoelectric (5 percent), thermionic (20 percent), pyroelectric (12.5 percent), thermoacoustic, and thermomagnetic (17, 19 percent)* are solid state energy generating technologies. (Conversion efficiency is shown by an asterisk). Despite their low energy conversion efficiency, the electric power density of these converters ranges from 4 nW/mm2 to 324 mW/mm2. This means that direct energy conversion compares favourably to other traditional energy producing technologies. Electron transport and thermoelectric behaviour are important in solid state energy conversion.

Recent automotive research has focused on developing a thermoelectric generator that uses the seeback effect to convert heat to electricity. Thermoelectric material has three sides: a hot side, a cold side, and heat exchangers. Energy from an engine's coolant or exhaust can be converted into electricity. As a result, lost energy is recovered, and the thermoelectric generator can lower the engine's electric generator load, cutting fuel consumption.

Thermoacoustic energy converters used in exhaust of a light duty truck have an electrical output of 1 KW. Whereas a test setup used to measure electric output from a car engine exhaust heat using thermoelectric generator have shown 54 Watts. Another study on waste heat recovery of light duty diesel engines using thermoelectric devices demonstrates that it is possible to recover approximately 25-30% of the energy in exhaust gases (Khalid et al., 2016). Because of its electron emission theory, thermionic energy conversion outperforms all of the other solid state converters. It works by sending electrons from a hot surface (cathode) to a collector via thermionic emission (anode).

1.3. Thermionic Emission

During his investigations in 1880, Thomos Edison looked into thermionic emission for the first time. Later, until 1956, J.J. Thomson and Langmuir worked on the device's development. Owen Willans Richardson and Saul Dushman did the pioneering work on thermionic emission, produced an expression for thermionic emission, and came up with Richardson-equation Dushman's for emission current.

The thermionic emission is used in various electronic devices such as diodes, cathode ray tubes etc. Thermionic emission occurs at higher temperatures i.e. >1500^0 C. A discussion on recent developments and research needs in design, materials, fundamental understanding, testing and validation of TEC, and its applications for terrestrial conditions has explored its applications (Go et al., 2017) Thermionic emission occurs by heating the material to temperatures >1200^0 C such that a small number of electrons in the material gets thermal energy to overcome the work function.

1.3.1. Thermionic Energy Converter (TEC)

A thermionic energy converter (TEC) is a device that uses this concept to harvest electrical power from heat; unlike thermoelectric converters, it operates best in a vacuum or low-pressure gas environment. Thermionic devices, in contrast to thermoelectric devices, are often operated at temperatures considerably above red heat to achieve high thermionic emission currents. It's similar to a heat engine that operates at maximum efficiency when the temperature differential between the emitter and the cooled collector is large.

In the 1950s and 1960s, TEC technology was investigated for solar technology and heat recovery from nuclear power plants. The majority of advances in TEC methods and design for efficiencies exceeding 15% are focused on cathode stability, maintaining close electrode spacing, collector reflection losses, and magnetic field generation; however, technical issues such as cathode stability, maintaining close electrode spacing, collector reflection losses, and magnetic field generation remain unresolved. As a result, the TEC gadget was developed solely for use in space exploration, where compact kilowatt electrical power generation is required. During operation, electrons exiting the hot emitter create space charge, which, according to the Child–Langmuir Law, limits the current flow from emitter to collector. As a result, such criteria are taken into account when designing and developing a thermionic emission system.

TEC uses interelectrode gap filled with either vacuum or inert gas environment. When the cathode is heated, electrons escape through the gap and create a potential difference between the electrodes. This generates an electric current. There are two types of TEC: vacuum TEC and vapour TEC. Thermionic Energy Converter (TEC) is a high power density energy conversion device that uses electron gas as the working fluid to convert thermal energy directly into electrical energy. The TEC have got about 20% experimental conversion efficiency. The conversion efficiency depends upon interelectrode gap, electrode work functions, emitter temperature, and interelectrode environment.

1.3.2. Low work Function Materials

Metals have complex microstructural and thermionic characteristics, making solid state thermionic energy conversion (TEC) difficult. Furthermore, due of their greater work-function value, using metals as a cathode in thermionic energy converters is not cost-effective. It appears difficult, given the requirement for low work function materials and technology to reduce the space charge impact. Higher theoretical conversion efficiencies have been demonstrated as a result of advancements in such material architectures and processes (64 percent). Investigations into work function reduction, space charge effect mitigation, geometric structuring, thermal isolation, and other creative approaches are significant components in thermionic energy conversion.

The low work function materials either directly or by coating gives better results in electricity generation at relatively lower temperature. Recent work on enhancing thermionic emission have explored many methods and materials. Space charge limitation methods include dual electric field, magnetic field, negative electron affinity collectors, and so on, whereas material research reveals the use of low work function materials such as cesium iodide, carbon nanotubes, and diamond coatings for thermionic emission at relatively lower temperatures, i.e. 800^0 C.

Advances in thermionic emission technology shows significant results in terms of achieving higher conversion efficiencies and reducing the space charge effect. Automotive sector today is concerned with its fuel consumption and emission reduction challenges. Effective utilization of the available energy is also the main objective behind developing advanced technologies. In case of automotive vehicles using thermionic regeneration system could make a significant change.

1.4. Reverse Engineering for Design

The technique of analysing or reproducing a product's design using a physical item as a starting point is known as reverse engineering. During the design process for a new product, clay models and various sorts of prototypes will be made in order to test, assess, and validate the conceptual design. This is frequently an iterative procedure that demands a number of adjustments to the original concept. As a result, reverse engineering can be a useful approach for deriving dimensions from freeform shapes like handmade models, clay models, and prototypes. You might even get the 3D geometry of an existing thing so that you can include some of its features into your new product design.

A 3D scanning solution can also be a useful tool for documenting and archiving different design versions. Obtaining the object's dimensions properly and rapidly, as well as collecting the essential information from the resulting scan in order to develop a new design with the appropriate look and functionality, are critical tasks in reverse engineering.

1.5. Modelling and Simulation

In the process of design and development of a new system, it becomes critical and expensive to produce the design physically and test it accordingly. Hence, software modelling based on mathematical and physical expressions replicating the real world scenarios is the best approach. The models created represents the practical outcomes along with fundamental laws. Software based simulation reduces the expenses on repetitive experimentations. In this research the multiphysics models considering heat transfer, thermionic emission and charged particle tracing are created and simulated. Automotive vehicle modelling simulation is done to analyze vehicle performance in terms of acceleration, engine speed vs. torque and fuel consumption.