MATERIALS AND TECHNOLOGIES FOR A GREEN ENVIRONMENT

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CONTENTS

PREFACE

I am pleased to introduce the book titled **"Materials and Technologies for a Green Environment"**. It comprises five chapters, covering different subjects of energy harvesting, biofuel, electric vehicle and Scramjet. All the chapters discuss the fundamentals and the recent developments in their respective subjects. This book could be beneficial to graduates, post-graduates, and researchers as it could cater to their needs. Suggestions and comments from the readers are invited in order to improve the quality of the next edition.

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CHAPTER 1

Renewable Energy Generation Using a Novel Geothermal-Solar Hybrid Power Plant Using RORC

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Abstract: A recent survey of energy consumption indicates that there has been exponential growth in the need for renewable energy and also for curbing the growth of fossil fuel reserves. To meet this future need, renewable energy sources are being explored. In this paper, we have proposed a Recuperative Organic Rankine Cycle that operates in conjunction with air-cooled condensers. Solar energy is said to be an energy source that varies periodically, unlike geothermal energy which is available round the clock, to generate electricity continuously. Hence it is a highly recommended source to meet the growing demands for electricity globally. A major contribution to geothermal power development is the progress in Organic Rankine Cycles. These plants are best known for their ability to curb harmful gas emissions, especially that of non-condensable gases. There is a significant growth in geothermal power owing to the ORC (Organic Ranking Cycle) power units that are implemented. In this methodology, the working fluid of ORC is made to go through an evaporator where a hot turbine is used to heat the liquid. In this process, the temperature of the preheated liquid is further increased with the aid of solar energy. This heat generated thus is further converted into electricity when the turbine unit causes the expansion of the fluid. Finally, an air-cooled condenser is used to condense the final exhaust of the turbine. Combining the two powerful forms of renewable energy (solar and geothermal), it is possible to generate power in such a way that the need for power begins to drop from its peak that it has achieved already. The simulated results define the decline in energy consumption of condensers based on the minimum heat transfer area of the condenser as well as the minimum power consumption of the fans.

Keywords: Duct curve, Geothermal-solar power generation, Hybrid power plant, Renewable energy, Recuperative Organic Ranking Cycle.

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1. INTRODUCTION

1.1. Renewable Energy

As the planet becomes more populated, the demand for energy also increases subsequently at a very fast pace. In recent times, this demand for energy is met with the help of fuels based on fossil. However, the use of these carbon-based fuels resulted in air quality deterioration, increased pollution and global warming. In May 2018, a report by WHO stated that about 90% of people all over the world are breathing polluted air. Because of this, there is a need for renewable energy sources and governments across the globe are investing heavily in this aspect. The Clean Energy future is made possible through the invention of renewable energy. In the beginning, energy was highly dependent on fossil fuels. However, due to the emission of carbon and other impurities that had harmful effects on the environment, there has been much need for cleaner energy usage. The introduction of wind and solar generation was a ground breaking invention that paved the way to a better and healthier atmosphere. This was further improved by the introduction of renewable energy. Renewable energy is commonly referred to as clean energy as it is generated from natural processes or sources. Though the use of natural sources as energy is thought of to be a novel concept, we have been using them for various aspects like transportation, heating, and so on. The sun has been used since ancient times to keep us warm during the day and further to kindle fire and provide warmth during the night. Similarly, windmills have been used to grind grain and wind has been used for a long period of time to sail boats.

However, during the past few centuries, the invention of many energy sources such as fracking gas and coal has led to a more polluted environment. These types of energy sources are known as non-renewable sources. These types of energy take a longer time to replenish and are available for only a limited period of time. Most non-renewable energy sources will have a harmful impact on human health and will also cause harm to the environment. Some known impacts are: drilling of oil performed using fracking might result in water pollution and cause earthquake, while a coal power plant will make the air smell foul.

The following are some of the renewable energy sources that are being used by us:

• Wind Energy: One of the most ancient ways of producing electricity is the use of wind as a source of energy. The turbines are built high and as the blades of the turbine turn, electricity is produced using an electric generator. It is also one of the cheapest forms of energy and accounts for about 23% of the total energy produced.

• Solar Energy: Solar energy has been used for a long period of time by us for various purposes like drying fruits, staying warm, and growing crops. Energy from the sun is used in many ways to power devices, and to warm water. Solar cells, also known as photovoltaic cells are built of a base metal plate of either steel or aluminum. These cells convert sunlight into electricity directly.

• Geothermal Energy: As the radioactive particles begin to decay slowly, in rocks at the earth's centre, they will be as hot as the surface of the sun, resulting in a natural hot spring. An underground well is dug up that acts as a hydrothermal resource, which can be used to create electricity.

• Biomass Energy: Trees, waste wood, crops, carcasses of animals, and withered plants are used to make biomass. Chemical energy is liberated in the form of heat from burning biomass. This in turn can be used to generate electricity. Though this form of energy is considered to be a cleaner and greener alternative, it still produces a large amount of carbon emissions.

• Hydroelectric Power: The source of hydroelectric power is water which descends rapidly from a higher end to the foot of the river. This force of water can be converted into electricity.

• Ocean: Though the production of tidal energy through the waves of the ocean is currently in an experimental phase, it still remains a good option to harness power.

According to energy statistics 2020, a report released by the Ministry of Statistics and Programme Implementation, Government of India, there is an abrupt increase in the use of renewable resources of energy in India. The report states that about 28.18 GW of electricity is generated using solar power, which is a 12.23% increase from the previous year. This is also reflected in decreasing the cost of solar electricity, thereby attracting more people to use the same.

Estimated potential of renewable energy sources is tabulated in Table 1. Here Jammu & Kashmir, Maharashtra and Rajasthan are the states that contribute highly to using renewable energy in India.

Table 1. Usage of Renewable Sources in India.

State	Use of Renewable Energy
Andra Pradesh	8%
Gujarat	11%
Himachal Pradesh	3%

CHAPTER 2

Energy Harvesting Through Thermoelectric Generators

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Abstract: Thermoelectric generator (TEG) converts waste heat energy from automobiles into valuable electrical power and has no moving parts compared to conventional thermoelectric motors. The functioning of TEG is dependent on the design and the material used. TEGs are classified as small and medium power outputs. Small power outputs are in the range between 5 μW to 1W, and high power outputs are higher than 1W in a TEG. Thermoelectric power generators offer fast, economical storage methods for wearable and mobile applications. Macro heat waste application is recovered through in-house, industrial and solid waste. Moreover, an immense amount of waste fuel, such as recycling and power plants, is emitted from the industry; this can be utilized in a useful manner by TEGs. This chapter discusses the TEG study of the fundamental operating principles, TEG products, micro applications and energy generation techniques.

Keywords: Applications, Energy storage, Heat engines, Power generation, Thermoelectric generator, Waste heat recovery.

1. INTRODUCTION

The majority of the operating expense of a gas turbine is due to turbine fuel, and much energy is lost from the flue gas after combustion to the atmosphere. Up to 40% of the fuel is released from exhaust energy. The technology of semicond-

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uctors helps to solve energy problems by procuring waste heat sources [1, 2].

The immensity of the global energy is calculated to be the product of effective thermal energy-saving technologies that can conserve atmospheric energy as heat, generating approximately 40% or less. Thermo-energy waste can improve the power efficiency of the electricity base. The gas turbine, vehicle exhaust, steam and method of production produce waste thermal energy and transform it into energy using a thermoelectrical generator [3].

In recent years, the principal objective has been to increase energy production to improve its economy, methods of transport and quality. Researchers and commercial activities have in particular, tried to enhance resource efficiency through improved energy systems performance since the energy crisis [4].

The energy costs (oil, gas and charcoal) have risen at unpredictable rates over recent years. Consequently, renewable energy is more conventional in producing electricity, since it produces lower emissions. By converting heat energy, the device is converted into electric power. It is suitable for space exploration and satellite exploration and for devices that are unmanned. Modern electrical systems include photovoltaic cells, piezo-electric modules for human motion and thermo-electric heat modules. The aim is to provide electricity efficiency to the human organism with its limited resources [5].

The schematic diagram of the conversion of ambient energy into electrical energy is shown in Fig. (**1**). The energy supply (solar, mechanical, thermostat, RF) is converted into electrical energy. In order to store extracted power, the energy storage device is almost always required. Since the charge energy and the storage area have different voltage levels, it is necessary to have a voltage controller. Electrical charge typically includes one or more sensors, an RF transceiver, and a microcontroller that wirelessly transmits the sensed information [6].

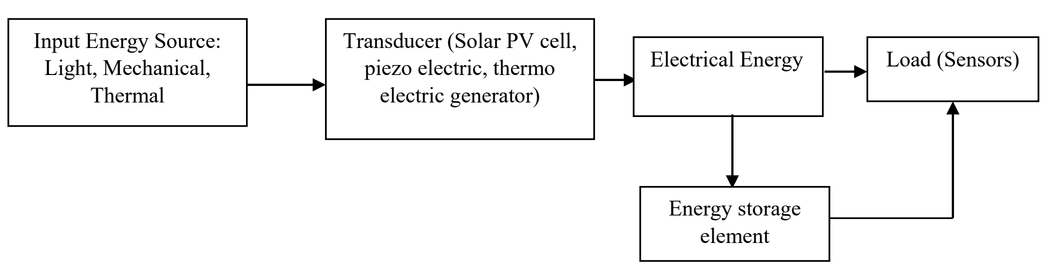

Fig. (1). Schematic Diagram of Ambient Energy is converted to Electrical Energy [6].

1.1. Peltier Effect

The Peltier effect is a phenomenon where heat is absorbed at a link between materials; heat is released at a different intersection, as shown in Fig. (**2**), when a current (I) flows through the material [7, 8],

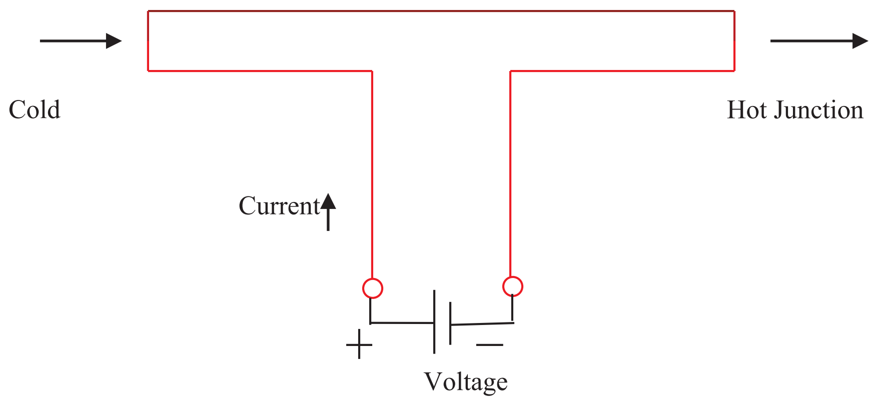

Fig. (2). Schematic diagram of Peltier effect [8].

The Peltier effect is used to describe the sum of Q_P for heat absorption and heat release in the following equation [9]:

$$Q_P = \Pi_{ab} . I \quad \textbf{(1)}$$

1.2. Thomson Effect

The Thomson effect is a phenomenon where heat is absorbed or emitted as the current passes through the material. Thomson effect is expressed in the following equation as quantities of heat (Q_T) absorption or heat discharge per unit volume [9]:

$$Q_T = \tau J \frac{dT}{dl} \quad \textbf{(2)}$$

1.3. Figure of Merit

A Figure of merit (ZT) shall be a number used in comparison with its alternatives to differentiate between systems, devices or processes. Figure of merits are also

CHAPTER 3

Solar Electric Vehicle Charging and Grid Interaction: An Integrated Module

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Abstract: Electric mobility is one of the key technologies for the replacement of non-renewable energy sources in the long term; creating new markets, opportunities, and new technologies, as the old energy order comes to an end with the evolution of new ones. With the passing of around two centuries, electric vehicle technology has developed to different levels across the globe. Norway has the highest percentage of electric vehicles, while China has the highest number of electric vehicles sold per year in the world. India is catching up with electric vehicle penetration. As per 2018 data, 49% of the total vehicles sold in Norway were electric. In 2019, China registered the maximum number of electric vehicles sold – 1.15 million vehicles. The key advantages of e-mobility are a reduction in GHG emissions, a reduction in the dependency on fossil fuels, higher efficiency compared to ICE vehicles, fewer noise emissions, and the flexibility of EVs becoming a platform for collaborative development of autonomous cars and shared mobility and MaaS. The key challenges are the total cost of ownership, charging infrastructure, reliance on the imported content and parts, customer acceptance of EVs, vehicle range anxiety and battery manufacturing, and availability of raw materials. This research investigates in detail the opportunities created by technologies such as solar-powered vehicle charging, the second life of traction battery, smart grid integration, connected and autonomous CAVE and vehicle light-weighting to enable e-mobility as a more commercial means of transportation.

Keywords: CAVE, GHG, ICE vehicles, MaaS.

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1. INTRODUCTION

A disruptive innovation is an innovation that creates a new market and a value network and eventually disrupts an existing market and value network, displacing established market-leading firms, products, and alliances. There was a disruption in computer technology that started in 1970s and ended with a revolution in speed, structure, communication and size as shown in Fig. (**1**).

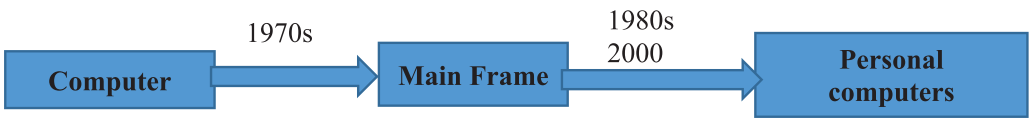

Fig. (1). Tipping point and disruptions.

Similar to the computer technology disruption, the first working electric motor and electric vehicle was built by Thomas Davenport, an American from Vermont, in 1834. It was a small locomotive that used two electromagnets, a pivot and a battery. There were other inventors like Robert Anderson of Scotland (1830s) who had created a fully electric carriage. The evolved architecture EV is shown in Fig. (**2**).

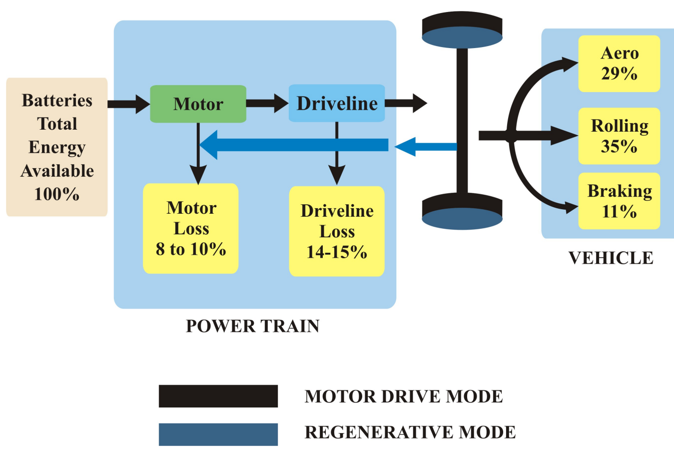

Fig. (2). Electric vehicle architecture.

EV disruptions that are going to be the tipping point are,

1) Big data for decisions (expected to be commonplace by 2023 - 2025);

2) Autonomous cars (by 2026 - 2027);

3) Artificial Intelligence and decision-making (also, by 2030);

4) Connected vehicles (by 2030).

Before delving into the challenges and opportunities in EVs, it is worthwhile to look into the advantages and disadvantages of EVs.

1.1. Advantages of Electric Vehicles Over ICE Vehicles

The total cost of ownership of an electric vehicle (EV) is lesser in comparison to a conventional fuel vehicle. Typical life of a battery is around 8 to 10 years, after which it will still find uses in storage and other less complex applications. Electric vehicles (EV) have relatively fewer moving parts, *i.e*., 75 to 80% less compared to the internal combustion engine vehicles. Due to the above characteristics, electric vehicles are easily adoptable for implementing autonomous technologies which results in autonomous driving. They also reduce emissions to help the environment (less pollution, renewable energy, eco-friendly materials). The battery cost is also expected to be half of the current price in the next 5 years.

1.2. Disadvantages of Electric Vehicles over ICE Vehicles

The affordability of electric vehicles will be of great concern at least for another decade till the prices of batteries become cheaper. In order to decide on the right technology for charging, numerous studies have been undertaken and many are still in progress in understanding the different modes of charging. Customers have options for night charging, home charging, public charging station, charging on the go, wireless charging, swappable solutions, opportunity charging, charging on malls and restaurants and charging at gas stations. The right technology needs are to be made standard. The investment for the charging stations is seen to be higher and subsidies are being provided for using the charging stations. Mergers and acquisitions of market leaders by sustaining business giants are slowly changing the scenario, but are time bound. The majority of the vehicle OEMs in the EV horizon are also in the process of establishing their standard chargers, taking into account customer requirements.

With countries going to end the non-renewable sources in respective years as given in Fig. (**3**), the e-mobility enablers are to be implemented on a holistic basis to have a seamless integration.

CHAPTER 4

A Review of the Current Challenges on the Issues of Scramjet Combustion Engines

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Abstract: Scramjet technology is one of the revolutionary technologies of the hypersonic industry. The scramjet engine uses air-breathing propulsion technology, which has been proven to be the most promising technology for high Mach number flights. The paper focuses on the status, key challenges and future scope of the scramjet engines. This paper presents an extensive literature review of the experimental and computational studies carried out by various researchers around the globe. In this paper, the current developments in scramjet technology and its future scope are precisely stated. It is concluded from the review that the flow inside the scramjet combustor is very complex and sensitive. The understanding of the turbulence, boundary layer formation and separation, physics of the flow, and the physiochemical processes involved in combustion still require extensive dedication of researchers in the near future to address the stated problems.

Keywords: Boundary layer interaction, Flame structure, Mach number, Supersonic combustion.

1. INTRODUCTION

Aerospace technology is advancing towards the possibility of supersonic or hypersonic technology in propulsion systems for space and military applications. The hypersonic industry is thriving with the success of the X-43A and X-51A, scramjet engines are considered the next generation of space vehicles [1]. Researchers are making a constant effort to find economical solutions to assess space by designing launch vehicles that can fly at hypersonic velocities. One such solution is air-breathing engines that use atmospheric oxygen for the combustion

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process. These engines have proved to be superior to any chemical propulsive device in terms of cycle efficiency. These vehicles do not carry any fuel-oxidizer, thus allowing a larger payload than any other conventional system [2]. The concept of Scramjet was first proposed by Antonio Ferri in 1950 [3]. The scramjets start their operation as the flight exceeds Mach number 5, and to escape aerodynamic losses, the combustion is maintained at supersonic speeds [4].

1.1. Principle of Scramjet

The scramjet engine comprises an inlet, an isolator, a fuel injection system, a combustion chamber and an exhaust nozzle [5]. When the vehicle moves forward, air enters the inlet. The air gets rammed, which leads to the formation of shock waves (*i.e*. oblique shock wave). Due to the formation of shock waves, there is an increase in the temperature and pressure. This high pressure and temperature air moves towards the combustion chamber and mixes with the fuel.

The fuel is injected through the fuel injection system and the combustion takes place. The combustion process occurs at supersonic speeds, thus completed within milliseconds. Due to the combustion process, flue gases are evolved which expand through the exhaust nozzle. Due to expansion, the engines get enough amount of thrust to overcome the drag forces of air. The scramjet engines work on the Brayton cycle. Under laboratory conditions, the concept of supersonic combustion was first described in the year 1960 [6]. As shown in Fig. **1**, the air flowing into the intake is compressed and decelerated by a series of shock waves known as oblique shock waves. There is an increase in pressure and temperature due to the compression of air. These high-pressure and high-temperature waves reach the combustion chamber at supersonic speeds. In the combustion chamber, fuel injectors inject fuel. Because the flow inside the combustion chamber is supersonic, there is extremely little time for the combustion process to take place. Flue gases are expelled from the exhaust nozzle after the combustion process, producing the push required for the vehicle to move ahead. The Brayton cycle governs the operation of the scramjet engine [8].

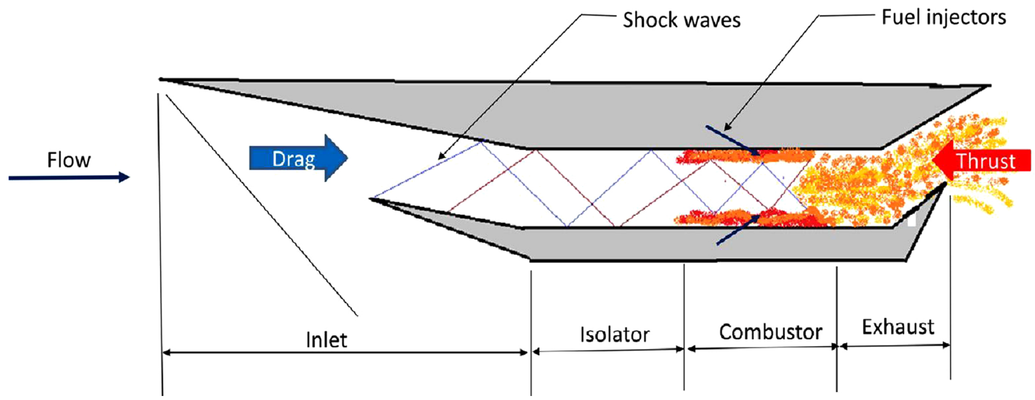

Fig. (1). Scramjet engine working principle (Schmetric Diagram).

Fig. **2** shows the dual Combustor Scramjet of Waltrup in 1997.A model with two combustors is used in this design: an initial subsonic combustor that runs on fuel, and a coaxial supersonic burner that finishes the combustion process. Various piloting approaches are used in other hydrocarbon-fuelled engine types. The wal pilot, split-inlet pilot and catalytic pilot are examples of such approaches [5].

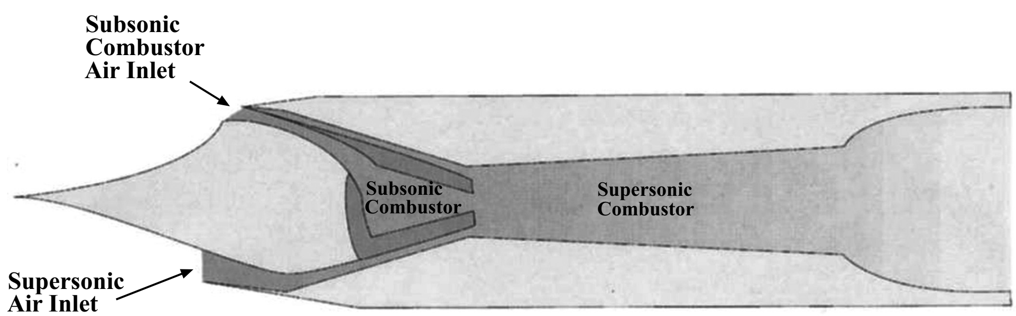

Fig. (2). Dual Combustor Scramjet.

Scramjet research in the United States began in the 1940s. By the end of 1950, the NASA and the US Navy were developing scramjet engines. The first major project on the scramjet engine, named the Hypersonic Research Engine (HRE) was started in the United States [7]. Other nations have also contributed greatly to the evolution of scramjets.

CHAPTER 5

Review of the Role of Geometrical Modification of Scramjet Combustor on Performance Characteristics

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Abstract: The current scenario in the field of aviation is focused on hypersonic-speed vehicles. To achieve the required performance, engines have to be designed in such a way that their outcome should be maximum. Nowadays high-speed performance engines have utilized a type of air-breathing engine amongst which, the scramjet is found appropriate. However, the engine can only perform under atmospheric area because the supersonic combustion ramjet engine utilizes the atmospheric air as an oxidizer. Nonetheless, engines do not comprise any rotating or moving parts. So, to complete the mixing and chemical kinetics, engine geometry has special dimensions. The present chapter is focused on a rigorous review of the geometrical modification of the combustor and fuel injector. The impact of mixed fuel, different types of working fuels, and variable inflow conditions have been explored to uncover the beneficial effects on scramjet combustion performance. Since numerous authors have explored different aspects of the ongoing challenges in scramjet hence a summary has been drawn to acquire a suitable model for future work.

Keywords: Combustion Characteristics, Fuel Injection Strategy, Geometrical Modification, Inflow Conditions, Supplementary Fuels.

1. INTRODUCTION

A supersonic combustion ramjet engine is a type of air-breathing engine, which performs all the thermodynamic processes at the supersonic speed level. Any kind of air-breathing engine utilizes the incoming free stream atmospheric air to participate inside the combustor for the completion of chemical kinetics. As shown in Fig. (**1**), the Scramjet engine comprises three major sections *i.e.*, a converging inlet, a combustor, and a diverging nozzle. The respective four

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processes of every engine are compression, combustion, expansion, and exhaust. However, the behavioral impact will change by changing the working conditions of the engine and also its applications [1 - 3]. The specialty of scramjet can be identified by looking at its geometrical configuration *i.e.*, no moving or rotating parts are utilized for completion of the all the processes. So, to create a desirable environment inside the respective section of the scramjet, several approaches are used. Fuel injection strategy and mixing approach in the supersonic combustor can be considered as a leading parameter for achieving higher combustion efficiency and stability [4 - 6]. Through various experimental and numerical investigations of a supersonic combustor, different aspects of ongoing challenges have been performed by many authors, few major considerations have been categorized as follows:

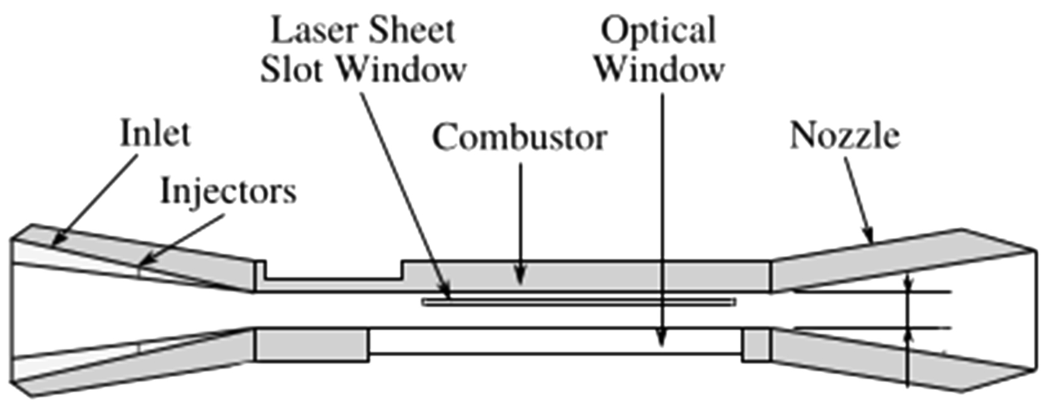

Fig. (1). Scramjet Engine Model.

2. SCRAMJET GEOMETRICAL MODIFICATION

The scramjet engine comprises an isolator, a fuel injection system, a combustion chamber, and an exhaust nozzle. Since all the thermodynamic processes of the scramjet engine are completed in the restricted length of the scramjet. Hence the modifications in the combustor geometry and fuel injection implication have a major influence on the desirable outcome.

2.1. Combustor Geometry

The supersonic combustion ramjet engine does not involve any moving parts. Therefore, Combustor geometry should be designed in such a way that a beneficial environment arises to complete the mixing between incoming fuel and air. During the combustion process, chemical kinetics should evolve rapidly to create a stable flame entirely. To keep in mind the above phenomena, the below-mentioned subsections are drawn:

2.1.1. Combustor Wall Transverse Fuel Injection

A numerical investigation of a two-strut scramjet combustor was performed by Gautam Choubey and K. M. Pandey [7, 8] to explore the effect of a wall transverse fuel injector. Four different cases were compared and among them, two struts with lower wall transverse fuel injectors at two subsequent locations were found appropriate in regards to mixing performance because fuel penetration was identified deeper in the same case so it leads to better combustion. The same author has also examined the double cavity scramjet combustor [9] by numerical investigation. Eight different sets of the investigation were performed by changing incoming fuel and air boundary conditions. The author concluded that the high-pressure regimes near the cavity could help to create a favorable environment for mixing and stable combustion. An experimental investigation has been performed in the supersonic flow field with a cavity present at the combustor wall. Since the presence of a wall cavity has been identified as a flame holder in the supersonic flow regimes. Yueming Yuan *et al.* [10] approached a similar investigation by changing incoming boundary conditions. To uncover the flame behavior near the cavity, temperature and equivalence ratio were scrutinized. The author identified four different locations at which flame was seen stabilized *i.e.* inside the cavity domain, shear layer around the wall cavity, near jet wake, and also in the oscillation region generated between jet wake and cavity. A strong correlation was recognized that the flame balance in the turbulence regions could be affected by temperature and the global equivalence ratio.

O. R. Kummitha *et al.* [11] optimized the cavity geometry and wall fuel injection position to explore the flow field characteristics. The author concluded that the geometry design is responsible to increase the thickness of the recirculation region and also shear mixing layer growth. Nonetheless, an additional upper wall cavity was found helpful toward combustion stability. The computational investigation was performed by Wei Huang *et al.* [12] to explore mixing augmentation by utilizing a novel step at the lower combustor wall. The combined effect of oblique shock wave and the influence of jet location and jet pressure ratio were examined. A conclusion has been drawn by the author that to lengthen the residence time, oblique shock waves were found suitable nonetheless larger jet pressure ratio was responsible to create a recirculation region near the novel wall step. Hence the above combination can be further promoted for mixing enhancement. K. M. Pandey *et al.* [13, 14] numerically investigated wall cavity scramjet combustors at higher air Mach numbers. A further performance was also done by utilizing

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