Plasma

Not just a Fourth State of Matter

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WE normally hear of solid, liquid, and gas as the three states of matter; however, two other states also exist, viz. Plasma (4th state) and Bose-Einstein condensate (5th state). In this article, we will be studying and investigating some aspects of Plasma, which is the most abundantly present (99 %) in the visible universe. In other words, what we see at night in the form of glittering stars, the day lightning sun, auroras in the sky and nebulae, all glow as Plasma, which is basically a heating gas that consists of positively charged particles (ions) and negatively charged particles (electrons). Its applications vary from different fields like studying space science and astrophysics, microfluidics, electronic chips, biomedical engineering, etc.

Plasma can be generated in laboratories, too, by heating a gas to a very high temperature, leading to collisions between its atoms and molecules. Eventually, the electrons are ripped away, forming negatively charged electrons and positively charged ions. This process has a similarity to what happens in stars, a process called photoionisation. In this process, the photon from starlight gets absorbed by the gas, leading to electron emission and causing the star to shine in the form of ionised plasma. When the universe began to form because of the Big Bang explosion, all the matter was present in the form of plasma (which was at that time the 1st state of matter), and the fragmented parts of the explosion began to form stars. The process of solidification began as the gases changed their form to liquids and further to solids. Plasma thus became the 4th state of matter.

Now, how can it help with producing green fuels or other value-added chemicals? In the 20th century, a very important process to produce ammonia, known as the Haber-Bosch Process, came into existence, and it revolutionised the chemical industry. However, in 1903, scientists performed experiments using plasma to produce nitric acid by passing the air through charged copper electrodes and a strong magnetic field to generate plasma and eventually nitric acid. However, the efficiency of the nitric acid produced was very low.

Plasma can be created in two ways: thermal plasma and cold plasma. In thermal plasma, the source is like microwaves in which all species, like electrons, ions, and atoms, are at the same temperature, and these plasmas are likely to have temperatures about 10,000□C. In the case of cold plasmas, the temperatures are not high and are nearly ambient, as the energy is due to the reactive species and electrons, in contrast to heating the gas. Corona discharge is an example of this type.

Plasma has the capacity to activate molecules like carbon dioxide and nitrogen, enabling the conversion of these molecules to value-added products and chemicals in an energy-efficient manner. In the process of activating carbon dioxide or nitrogen using plasma, the electrical energy heats the electrons due to their smaller mass, which would then collide with the gas, like CO_2 or N_2, and this would cause excitation, ionisation, and dissociation. These excited species react and form newer molecules. Since non-equilibrium between energetic electrons and gas, there is a probability of allowing the non-feasible reactions to occur, like the splitting of nitrogen or carbon dioxide molecules, or dry reforming of methane.

As we know, carbon dioxide is a very stable molecule; its splitting is a challenge of the 21st century to produce fuels and value-added chemicals. There are various technologies, like thermochemical, photochemical, and Sonochemical, etc., to produce clean fuel by CO_2 splitting. However, plasma can be seen as an added and novel technology towards this approach. During the 1980s, several plasma reactors were used for splitting carbon dioxide into carbon monoxide and oxygen. There are various types of plasma reactors used as per the source, viz., DBD (Dielectric Barrier Discharges) Reactor, where the carbon dioxide conversion is early 30%, and energy efficiency up to 10%. In the Microwave Plasma Reactor, the energy efficiency is high; however, if operated at low pressure. In Gliding Arc discharges plasma, energy efficiencies are around 40%. There is also another concept that prevails over better energy-efficient processes, viz., rather than pure carbon dioxide splitting, combinations of carbon dioxide, methane, hydrogen, or water, where the source of hydrogen is present, a variety of products can be produced. Here, the main product is syngas; however, oxygenates and higher hydrocarbons are also produced. If the reaction is carried out catalytically, then there are higher chances of better product efficiency.

Today, hydrogen production is an important area where a cleaner source to produce it in an efficient manner becomes a challenge. Hydrogen produced through fossil fuels leaves a carbon footprint; therefore, newer ways of producing it become important. Plasma electrolysers have been paving the way towards a cleaner and more sustainable approach