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Nuclear Fusion Reactor- A Review

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Abstract

Nuclear Fusion Reaction what actually happens in it , The history of Nuclear fusion reactors, contrasting nuclear fusion reactor power with other currently available energy resources, the advantages of using Nuclear fusion reactors to generate energy, what is a "tokamak" and how a tokamak works, Conclusion and Referred articles.

***Keywords:** Fusion, plasma, nuclei, stellarator, tokamak, torus*

INTRODUCTION

Reactions in which two or more atomic nuclei come close enough so that the nuclear force pulling them together is greater than the electrostatic repulsive force between them is called nuclear fusion. Here the nuclei combine to form a heavier nucleus which is exothermic if nuclei combining is lighter than iron 56, otherwise it is endothermic The nuclear force acts only for short distances but the electrostatic repulsive force acts for longer distances. In order for fusion reaction to take place, the participating nuclei need to be given enough kinetic energy to overcome repulsive force and come close enough for nuclear force to be effective. The ways to achieve this are by either accelerating nuclei using a particle accelerator or by heating atoms to a sufficient temperature so as to strip them of their electrons, leaving behind just the bare nucleus (ion) in form of plasma.

Because the charges here are separated, plasma are electrically conducive and magnetically controllable .Since plasma can be easily controlled, many fusion devices use the latter method of heating atoms to high temperature to form plasma as basis for fusion reaction Fusion reaction does take place in the sun where hydrogen nuclei combine to form helium nuclei.

One important point to be gathered here is that while high temperature and pressure as found inside the sun is not a theoretical prerequisite for nuclear fusion(as accelerating a particle can also be done),it is nevertheless the most commonly used method for nuclear fusion reactions as it is more viable than accelerating particles

NUCLEAR FUSION REACTOR-HISTORY

The field of fusion reactor research started from the late 1920s.R Atkinson and F.G Houtermans suggested that star's energy source is due to some sort of a nuclear reaction taking place inside the star. Quantitative evaluation of nuclear fusion was first revealed in the late 1930s, thus spiking interest in the field as nuclear fusion reactor was promised to be the ultimate solution for energy crisis. In 1950 L Spitzer,a reputed astronomical scientist came up with the idea of a "stellarator",a device which confines hot plasma by applying a magnetic field twisted so as to contain the plasma. Currently "tokamak",a type of plasma confinement system, which twists magnetic field by producing current inside of plasma has become a main trend in fusion research and development, which has continued till now. As time passes by over the decades with both research in the field and improvement in technology, the plasma confinement and its temperature have been improving.

Currently the ITER project, which is the world's largest fusion project, is now in progress. ITER (International Thermonuclear Experimental Reactor) is an international collaboration on research of nuclear fusion and its engineering applications which is funded and run by 7 member entities-the European Union, India, China, Russia, Japan, the United States and South Korea. ITER is an experimental tokamak nuclear fusion reactor being built in the south of France

LITERATURE SURVEY

T. Hamacher et al (1) have concluded that fusion reactor research has matured over the last 3 decades, with the joint European experiment JET already having produced more than 16 MW of fusion power at a Q value of 0.65 and that technology for the next step in form of ITER have already been improved in construction of prototypes and by intense R&D in engineering. Fusion if ever made commercially viable, would fit into a sustainable energy system and be able to supply clean energy for millennia at economically acceptable costs.

Yoneda et al (2) have concluded that towards ITER project and by default nuclear fusion reactor technology in general, the R&D activities have been extensively conducted by ITER members. Since nuclear fusion reactor is not yet commercialized, official government intervention is required to support the development of this technology.it can also be said that R&D activities and development in nuclear fusion reactors greatly depends on progress in large device experiments. The design trend and analysis show that tokamak has become the preferred method and in commercialization, compactness of reactor has been gathering attention .Overall there has been steady progress in international R&D towards fusion power plants.

Ankit Gupta et al (3) have concluded that the process of nuclear fusion for power generation is applicable on a large scale. Nuclear fusion power generation is clean in the sense that it does not produce any greenhouse effect or other eco-harmful effects which are normally associated with fossil fuels. In a nuclear fusion reactor (once physically realized),the reactor can convert nearly 90 percent of energy generated into electrical energy as compared to 40 percent in the case of a traditional coal fired plant(This is due to greater efficiency of the conversion process of energy liberated into electrical energy, in case of fusion reactor). The fusion reactor would cost half as much as a traditional coal power plant to run annually since the fuel used here is extremely cheap and readily available. Moreover as there is no radioactivity here, extreme safety measures are unnecessary. As the amount of fuel in the nuclear fusion reactor at any given time is very small, nuclear fusion reactors are also very safe to use.

The IRSN institute (4) have concluded that those who are designing nuclear fusion reactors should focus on these subjects as a priority-

a. Residual heat removal, considering the tokamak cooling systems and those for blanket sectors.
b. identification of the preferred waste management and containment system based on the general policy of the country which is hosting the nuclear fusion reactor
c. possibilities of minimizing and limiting the overall quantity of tritium present in the facility and also

considering the usage of tritium breeding blankets

S. Chiocchio et al (5) have concluded by saying that the ITER project is the current pinnacle of technology of nuclear fusion reactor design and engineering and is also the culmination of 50 years of research in fusion and has currently finally entered into the building and construction phase of the project. The management and proper coordination of a project of this vast magnitude, with unprecedented new technology and R&D is itself a complex challenge, but the sharing of a common goal towards achievement of commercialization of fusion reactor among the member countries, with personal commitment among the constituent individuals will focus the ITER ethos and keep the whole team highly motivated and efficient and will be the key to achieving success in this project.

Shutaro Takeda et al (6) have concluded by saying that even though nuclear fusion energy has faced widespread criticism and a quip of it always being 30 years ahead (due to fusion scientists since the 1970s continuously predicting commercialization of fusion reactor to take 30 years), it appears that this time it will be true and a commercial, working fusion reactor can indeed be achieved in the next 3 decades. Current plans to realize a commercially viable fusion power plant are being continuously updated but they should still be treated with caution as they are subjected to uncertainties, unknown barriers to technological progression and limitation of resources. At the current timeframe, it can be said that a commercial fusion reactor can be achieved in the next 3 decades. Every effort to realize this timescale (and to possibly advance it) should be done so that fusion can fulfil its vast potential and make a much needed difference in the field of global energy.

Silvano Tosti et al (7) have concluded that successful exploitation of nuclear fusion via magnetic confined devices such as tokamak relies on the development of a reliable and efficient fuel cycle. In tokamaks of the future, tritium will be produced in a Lithium based breeding blanket, hence to sustain fusion reaction with deuterium it has to be extracted and purified before being sent to plasma chamber. Finally, an innovative Membrane gas Liquid Contactor (MGLC) has been researched for extraction of tritium from liquid LiPb, proposed for future tokamaks as a candidate blanket material

A.Cardinali et al have concluded that there is a undoubted need of actively shaping the current profile at large radii of plasma column so as to exploit the self-produced current and thus save the huge costs of the heating systems. The natural profiles usually produced by the plasma are usually matched by lower hybrid current drive, which is successfully extrapolated to higher densities and currently, with larger flexibility to higher temperatures envisaged for a fusion nuclear reactor, thus enabling its economic viability and prospects for commercialization.

NUCLEAR FUSION REACTOR-CONTRAST WITH OTHER ENERGY SOURCES AND ITS ADVANTAGES

For any country and its development the 3E formula-Energy security, Environmental protection and economic efficiency and sustainable economic growth is paramount. For this the country needs access to precious energy resources, vital for development in nearly all sectors of the economy, however many countries today either do lack access to the level of energy resources needed for sustained growth, especially as the population keeps on increasing, adding more strain on the economy of certain countries like India and China.

Huge consumption of energy resources in the world today has led to depleting energy reserves of fossil fuels like coal and petroleum. Thus development in many countries gets retarded due to lack of energy resources. In addition to this while fossil fuels do offer constant energy, they do cause severe environmental problems such as toxic and noxious smoke, drastic degradation in air and water quality and respiratory diseases.

Renewable energy resources, although unlimited in nature do have their own drawbacks of varying supply of energy which is not uniform. In addition to this, some renewable energy sources such as solar can only be used during certain time limits such as in daylight Nuclear fission reactors have unlimited supply of energy and have continuous availability of power but do produce a lot of highly toxic radioactive waste, which proves difficult to dispose. In addition, they must be constantly monitored, so as to prevent reactor meltdown, which can cause dangerous consequences as in the example of Chernobyl. In short a unstable nuclear fission reactor is an atomic bomb.

Nuclear fusion reactors like their fission reactor counterparts do have unlimited and continuous supply of energy but unlike their fission counterparts do not produce highly radioactive wastes. In addition to this they can produce more net energy than any other energy source. Also unlike in case of a nuclear fission reactor, In fusion reactor if the reaction were to spiral out of control, the reaction would stop and would not produce a meltdown comparable with those seen in fission reactors.

Thus the advantages of Nuclear Fusion Reactor over other energy sources are

- Fusion reaction generates the most energy possible in any power plant, generating up to 4 million times the energy in any chemical reaction.
- Fusion reactors are clean and do not cause emission of any greenhouse gases, thus not leading to global warming
- Fuel required for fusion reactors are widely available and are nearly inexhaustible. Deuterium can be distilled from nearly all forms of water, including seawater
- There is no creation of any radioactive waste in the entire process, and thus the problem of radioactive waste management and radioactive emission is eliminated.
- Since no enriched radioactive fuel is used here, there is limited list of proliferation
- Unlike a traditional nuclear fission reactor, in a fusion reactor if there is any disturbance in the reaction the plasma cools immediately and the reaction stops. Here there is no risk of a chain reaction and thus there is no risk of a meltdown of the reactor

WORKING AND DESIGN OF A NUCLEAR FUSION REACTOR IN TOKAMAK FORM

For any fusion reaction to take place in a laboratory, three necessary conditions are required-

- very high temperature- to excite nuclei and cause high energy collisions,
- sufficient plasma density- to increase the probability of having collisions
- Sufficient confinement time- to confine the plasma which has a tendency to expand, within a given volume

The tokamak is an experimental device in the form of a torus designed to harness the power of nuclear fusion reaction, most commonly the fusion of deuterium or tritium isotope to form helium nuclei.

The advantages of tokamak over other fusion reactor designs is that the tokamak can currently produce the world's highest plasma temperature, plasma densities and confinement durations of any confinement device In the case of a tokamak, there are two superimposed magnetic fields which enclose the plasma and there is an toroidal field generated by external coils on the one hand and field of flow of the plasma in the other hand. Thus when the magnetic fields are combined, the field lines run helicoidally around the torus center. Thus the necessary twisting of field lines and structure of magnetic areas is done. Apart from these fields, the tokamak requires a third vertical field (poloidal field), which is used for fixing the position of flow in the plasma container. The flow in the plasma is mainly used to create the enclosing magnetic field, in addition to which it also provides effective initial heating of the plasma. A transformer coil is normally used to induce flow in the plasma. Owing to the transformer the tokamak does not run continuously but in pulses. However, since a power plant cannot be run in pulses for technical reasons, methods are being evaluated to run the fusion reactor in continuous flow- for example by high frequency waves.

In the tokamak the actual energy is got by creation of a large amount of high energy neutrons from plasma. Since these neutrons are not charged, they are no longer held in the plasma stream by the magnetic fields and thus not being confined, move on until they collide with the inner walls of the fusion reactor. The heat from these neutrons in converted into energy by generating steam and running turbines and generators, however a lot of energy is lost in the process due to cooling.

To protect the fusion reactor from breakdown due to excessive heat ,a complex cryogenic cooling system consisting of a mixture liquid helium and liquid hydrogen combined with ceramic plates are required to protect the superconductors and reactor walls.

Some additional sources of heating the plasma to the required temperature are

- Neutral beam injector
- Radiofrequency heating

CONCLUSION

Nuclear fusion reactor is still a work in progress. The technology of effectively containing the plasma and maintaining high plasma temperatures and densities is not yet satisfactorily developed as well as the cryogenic cooling processes. However as the technology required for these develops, both the ease and the cost of building the fusion reactor would come down, which given its vast potential, means that this option soon becomes the optimal one.

Currently the biggest problem in nuclear fusion technology is physically realizing it and making it commercially viable. In 1997 JET (Joint European Torus) was able to set the then world record for fusion output at 16 MW from 24MW heating input and 700-800MW total input of electric power, a record which still stands to this day. This is also the current world record for the value of Q, which was 0.67 in this experiment. It can be observed here that even at the maximum value obtained till date for fusion power generation and Q value the reactor was unable to break even, that is the reactor still consumed more energy than it generated, resulting in a net negative energy realized or generated form the reactor. This is one of the main drawbacks preventing Nuclear fusion reactor technology from being commercialised.

Given the advantages of the fusion reactor and its unmatched ability to produce energy, it would be prudent to say that it would be the best solution to the energy crisis. Nuclear fusion reactor is widely touted to be the ultimate solution to the world’s energy crisis.

This is because it is clean (no pollution) has no risk of meltdown, produces no toxic radioactive wastes. In addition up to 90 per cent of the energy liberated in a fusion power plant is converted into electricity, compared to 40% in case of a coal fired plant. this is due to greater efficiency in conversion of fusion energy into electrical energy in fusion reactor, compared to conversion of thermal energy into electrical energy in case of a coal plant. Since at any instant, only a small amount of fuel is present in the reactor, the fusion reactor is extremely safe compared to other power plants, and nothing serious might occur even in case of a minor failure in some of its components. In addition since it is not radioactive and extremely safe, unlike fission reactors and coal plants, fusion plants can be located near or even in middle of a city. Thus large amounts of wiring required to transmit power ,which adds to cost of utilization of power plant as well as causing large amounts of energy to be lost while transmitting in the form of heat which are essential for fission and coal power plants can altogether be avoided for fusion power plants, thus saving on energy and net cost(since there is minimum power loss) Most importantly, fuel required for it can be easily and widely obtained from nearly any water sources such as seawater in abundant quantities. Nuclear fusion reactor has an annual running cost nearly half of that of other power plants like coal fired power plants, due to its fuel being extremely cheap and readily available. Thus many developing countries with no access to other energy resources can easily obtain precious energy to satisfy their needs through fusion reactors, thus bringing out development in the world.

Thus nuclear fusion reactors are valuable for sustainable and eco-friendly development of the world.

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