FUSION AND FUTURE

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ABSTRACT

Fusion energy has the potential to provide a sustainable solution to global energy needs on Earth. The fuel for fusion reactors will be two isotopes of hydrogen gas: deuterium and tritium. Deuterium is abundant and Tritium is radioactive and is extremely scarce in nature. Lithium is the next promising material. Simple nuclear reactions can convert lithium into the tritium needed to fuse with deuterium. Lithium is more abundant in seawater. Fusion fuels offer the irresistible combination of abundant supply with minimum environmental consequences. Energy from fusion alone can produce a carbon free, very safe, free from radioactive waste, and environment friendly sustainable energy source for the world. The objective of the present paper is to present the current status of fusion research and to describe the engineering challenges of designing fusion reactors.

Keywords: fusion; radioactive waste; sustainable energy source;

Introduction:

Global energy demand may double over the next 50 years. Today's society desires for access to an abundant and reliable supply of energy. Every source that is being currently used is significant sources of greenhouse gas emissions and is going to be exhausted. Renewable energies like wind and solar are excellent sources , but they do not provide the necessary power needed for large industrial or population centres and are more expensive. So, we need to develop new energy sources that can deliver continuous, large-scale power for the long term without harming the environment.

Recent advances in high energy plasma physics show that nuclear fusion, the energy source of the sun and the stars [1] may become a future sustainable energy system. Such power plants would be safe and environmentally friendly. A possible uncontrollable nuclear reaction of fission reactors and the problem of radiotoxic waste force us to look for safe alternatives. Fusion reactors would have almost limitless supplies of fuel and could be positioned anywhere in the world. Fusion is, however, still in the development stage and it is not expected that commercial power plants will start operation before the middle of this century.

Everything is made of matter. Every matter is bundled with energy. Matter is made of atoms [2]. Their constituents are positively charged nuclei surrounded by negatively charged electrons. Two light nuclei, when they approach each other, with a certain probability depending on their separation, undergo a fusion reaction. The isotopes of hydrogen Deuterium and Tritium react, to give helium and a sub-atomic particle, the neutron. The mass lost is transformed into energy related by Einstein's famous equation, $E=mc^2$ and is carried away as kinetic energy by the helium atom and the neutron. Numerous nuclei could be used as fuel in a fusion power plant. The advantage of deuterium and tritium is their high reaction probability.

Oceans could meet the world's current energy needs for literally billions of years. Deuterium is a relatively uncommon form of hydrogen. But, water which is a source of deuterium is abundant enough to make deuterium supplies essentially unlimited. There are around 33 milligrammes of deuterium in every litre of water. Tritium, on the other hand, is radioactive and is extremely scarce in nature. So, the next lighter nuclei lithium atom can be considered for this role. Simple nuclear reactions can convert lithium into the tritium needed to fuse with deuterium. Lithium is more abundant and is available from seawater. A 1,000 megawatt fusion-powered generating station would require only a few metric tons of lithium per year.

Lithium is found in nature in two different isotopes 6Li (7.4 %) and 7Li (92.6 %). The two nuclear reactions

6Li + n -> T + 4He + 4.8 MeV

7Li + n -> T + 4He + n - 2.5 MeV

Since the second reaction is endothermic only neutrons with energy higher than the threshold can initiate this process [3]. In most blanket concepts the reaction with 6Li dominates, but in order to reach a breeding ratio exceeding unity the 7Li content might be essential.

Lithium can be found in:

- salt brines, in concentrations ranging from 0.015 % to 0.2 %
- minerals: spodumene, petalite, eucrypotite, amblygonite, lepidolite.; the concentration varies between 0.6 % and 2.1 %.

- sea water; the concentration in sea water is 0.173 mg/l (Li+). As the oceans contain trillions of metric tons of lithium, supply would not be a problem for millions of years [3].

Fusion is one of the alternative energy sources that will challenge engineers in the future. Human-engineered fusion has already been demonstrated on a small scale. The challenges facing the engineering community are to find ways to scale up the fusion process to commercial proportions, in an efficient, economical, and environmentally benign way [4]. A major demonstration of fusion's potential will soon be built in southern France called ITER (International Thermonuclear Experimental Reactor). The test facility is a joint research project of the United States, the European Union, Japan, Russia, China, South Korea, and India. It will be designed to reach a power level of 500 megawatts. ITER will be the first fusion experiment to produce long pulse of energy release on a significant scale.

The most advanced fusion involves magnetic forces to hold the fusion ingredients together. ITER will use this magnetic confinement method in a device known as a tokamak, where the fuels are injected into and confined in a vacuum chamber and heated to temperatures exceeding 100 million degrees. Under those conditions the fusion fuels become a gas-like form of electrically charge matter known as plasma. Even in plasma, however, the nuclei do not come close enough to react because of mutually repulsive forces. By heating the plasma to an even higher temperature, the ions acquire an even higher velocity, or kinetic energy, and can then overcome the repulsive force. The number of fusion reactions that take place will depend on the plasma temperature and plasma density. The production of the plasma and its subsequent heating require of course energy.

A successful fusion power plant requires that the power produced by the fusion reaction exceed the power required to produce and heat the plasma. The ratio of the power generated to that consumed (the fusion power amplification factor) is called the Q value. Initially, the plasma will be heated by various external sources, e.g. microwaves. With increasing temperature, however, the number of fusion reactions also increases and the fusion reaction itself heats the plasma due to the production of the energetic helium atoms actually ions, or α particles. The kinetic energy of the helium nuclei exceeds the average kinetic energy of the nuclei of the fuel (deuterium and tritium) by orders of magnitudes. The energy is distributed to the fuel nuclei via collisions. A point can be reached termed ignition point when external heating is no longer necessary and the value of Q goes to infinity. In practice, however, power plant operation would probably correspond to a Q value of 20-40. The state of very hot plasma and its nearness to the ignition condition can be characterised by the product of temperature, density and the so-called energy confinement time. The latter value describes the ability of the plasma to maintain its high temperature. In other words, it is a measure for the degree of insulation of the plasma. Ignition can only be achieved if this “fusion triple product” exceeds a certain value [4].

The temperatures necessary to ignite plasma are between 100-200 million degrees. Obviously no solid material is able to confine a medium with such a high temperature. This dilemma is solved by the fact that in the plasma, all the particles carry an electrical charge and can thus be confined by a magnetic field. The charged particles spin around the magnetic field lines. The magnetic field lines have to be doughnut-shaped, and need to have a helical twist. This scheme is referred to as magnetic confinement. Major improvements are expected from active measures to shape the plasma by special control mechanisms.

The first promising results were achieved in the Russian tokamak T3, following which tokamaks were constructed in many countries at the beginning of the seventies. Construction of the Joint European Torus (JET) started the end of the seventies. It went into operation in 1983 and remains the largest fusion device in the world. At JET, experiments with deuterium and tritium have led to considerable power production.

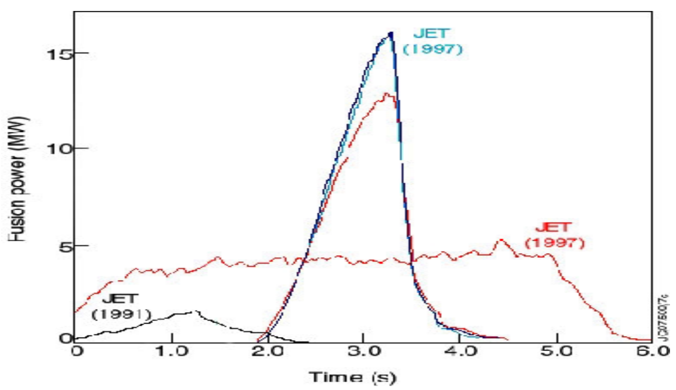

Figure 1: Fusion energy production in the Joint European Torus (JET) **[5].**

The major physics issues in the world-wide fusion program centres are: improvement of the energy confinement time, plasma stability, particle and power exhaust, and α particle (helium nuclei) heating. ITER will test the ability of magnetic confinement to hold the plasma in place at high-enough temperatures and density for a long-enough time for the fusion reaction to take place. Construction of ITER is scheduled to start by 2009, with plasma to be first produced in 2016, and generation of 500 megawatts of thermal energy by 2025. It will not convert this heat to electricity, however. Among ITER's prime purposes will be identifying strategies for addressing various technical and safety issues that engineers will have to overcome to make fusion viable as a large-scale energy provider.

Deuterium-fusion reactions produce helium, which can provide some of the energy to keep the plasma heated. But the main source of energy to be extracted from the reaction comes from neutrons, which are also produced in the fusion reaction. The fast-flying neutrons will strike through the reactor chamber wall into a blanket of material surrounding the reactor, depositing their energy as heat that can then be used to produce power. Neutrons impact will convert atoms in the wall and blanket into radioactive forms. In advanced reactor designs, the neutrons would also be used to initiate reactions converting lithium to tritium.

Materials will be needed that can extract heat effectively while surviving the neutron-induced structural weakening for extended periods of time. Methods also will be needed for confining the radioactivity induced by neutrons as well as preventing releases of the radioactive tritium fuel. In addition, interaction of the plasma with reactor materials will produce radioactive dust that needs to be removed. Building full-scale fusion-generating facilities will require engineering advances to meet all of these challenges, including better superconducting magnets and advanced vacuum systems. Robotic methods for maintenance and repair will also have to be developed.

Inadequate materials could mean an unacceptably high level of probability of massive failure in the surrounding envelope structures. Further, materials like ceramics become more attractive technically to consider than high-Z metals for reducing the masses of neutron-activated materials such as used at or just behind the first wall that would have to be handled, treated and disposed of as nuclear waste. So, problems with materials can be the main challenge as well as problems with the plasma and nuclear physics.

Conclusion

Though these engineering challenges are considerable, fusion provides many advantages beyond the prospect of its almost limitless supply of fuel. Fusion research has made considerable progress in the last three decades. Technologies for the next step in the international fusion programme (ITER) have already been improved by intense engineering R&D and the construction and test of prototypes. From a safety standpoint, it poses no risk of a runaway nuclear reaction. It is so difficult to start the fusion reaction initially but can be quickly stopped by eliminating the injection of fuel. The fusion reactor's success as an energy provider will depend on whether the challenges in building generating plants and operating them safely and reliably can be met in a way that makes the cost of fusion electricity economically competitive, with minimum environmental consequences. Fusion, if fully developed in 2050, will fit into a sustainable energy system and be able to supply electricity for millennia to come at economically acceptable costs.

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