Nuclear Fusion Reactor Applying Spherically Imploding Detonation Waves

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Abstract

In the center of spherically imploding detonation waves propagating in a stoichiometric propane-oxygen mixture in a detonation chamber having an outer-diameter of about *1 m*, a plasma having an ion temperature of about 10^8 K is observed. Considering the experimental results, fusion reaction velocity in *D+T* mixture and heat loss by radiation, the size of the detonation chamber in which a nuclear fusion can be initiated is estimated. A nuclear fusion reactor for a power plant applying the detonation chamber and H_2O as coolant and turbine driver gas is proposed.

1. Introduction

The experimental results obtained from our investigation of spherically imploding gaseous detonation waves suggest that a temperature near 10^8 *K* and an ion density higher than $10^{20}/cm^3$ were observed within the implosion focus of *0.5 mm* in diameter in a convergent space having a diameter of *500 mm*. The energy state in the implosion focus is beyond the so-called Lawson's limit for the nuclear fusion in a tritium and deuterium mixture, in which a nuclear fusion reaction can start. In this paper a nuclear fusion reactor having a larger detonation chamber for a steady fusion reaction is proposed, considering the theoretically calculated results of reaction velocity and heat loss.

2. Experimental results of imploding detonation waves

The experiments of spherically imploding detonation waves propagating in a stoichiometric propane-oxygen mixture having an initial pressure of *40 kPa* and a room temperature of *20 ℃* were carried out using first the detonation chamber-***a*** [1] schematically illustrated left in Fig. 1 and then that ***b*** [2] illustrated right in Fig. 1. Both the detonation chambers made of chrome-molybdenum are composed of a detonation tube, a flat cylindrical space, *96* connecting holes and a convergent space surrounded with a ring having a spherical surface or a divergent-convergent space. The detonation chamber-***a*** has a hemispherical convergent space of *800 mm* in diameter below the connecting holes, while ***b*** has a hemispherical divergent-convergent space having a radial section of rhomboidal form with an external diameter of *940 mm* and a convergent space of *500 mm* in diameter.

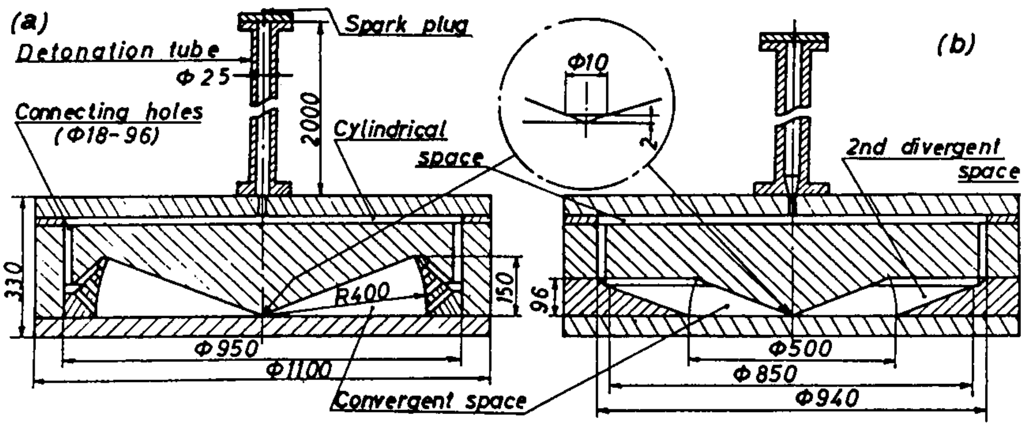

Fig. 1. Apparatus for spherically imploding detonation. Left (***a***): Goettingen type, right (***b***): two-step divergent-implosion type.

Detonation waves initiated by a spark plug set at the end of the detonation tube propagate through the detonation tube into the center of the flat cylindrical space, are reflected there and propagate towards the circumference, forming a cylindrical detonation wave, which is stagnated at the cylindrical wall at the circumference. From the stagnated detonation shock waves propagate through 96 connecting holes and the holes of the ring into the convergent space in the detonation chamber-***a*** or into the external corner of the divergent-convergent space of ***b*** having a rhomboidal radial section, where ignitions and consequently detonations take place almost simultaneously. The detonation waves thus implode into the center of the convergent space.

The pressure variation behind the imploding detonation was measured by a piezoelectric pressure transducer in different positions of the convergent space, while the temperature was measured by observation of the light emission from argon present in the mixture to an extent of *5 %*. The ratios of the peak pressure and temperature P, T at the detonation front and behind the shock waves reflected in the implosion center to the initial mixture pressure P_0 and temperature T_0 with respect to the distance r from the implosion center are shown in Fig 2

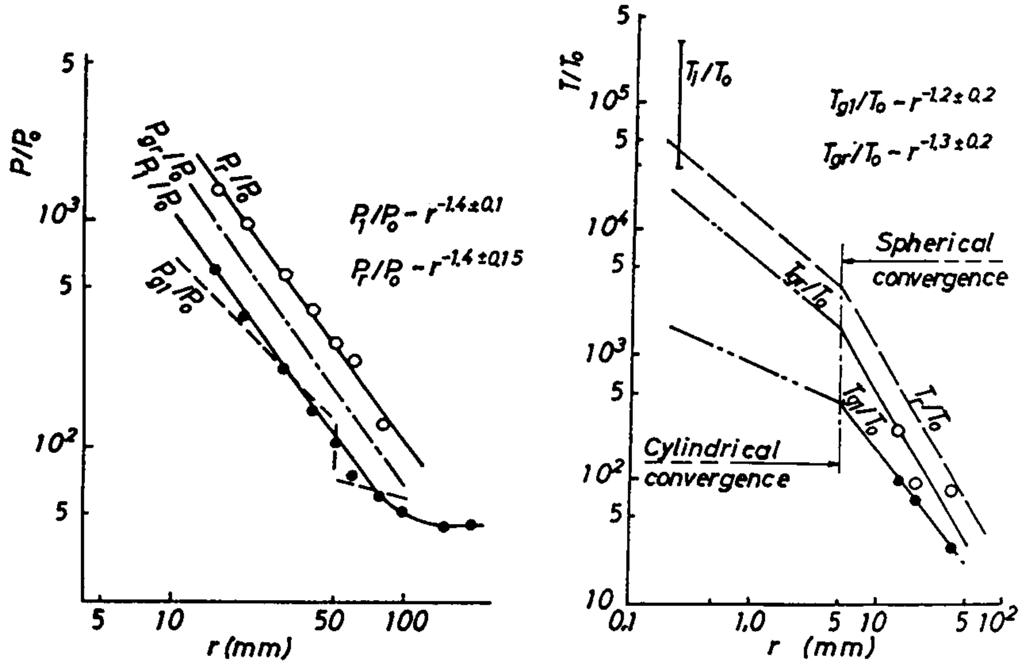

Fig. 2. Ratios of peak pressure P_1, temperature T_1 at the detonation front and those P_r, T_r at the reflected shock front to the initial mixture pressure P_0 and temperature T_0 with respect to the radial distance r. Subscript g means in the apparatus ***a*** and others in ***b***. T_r is estimated from the measured pressure P_r. T_i is the ion temperature measured by a laser light scattering method.

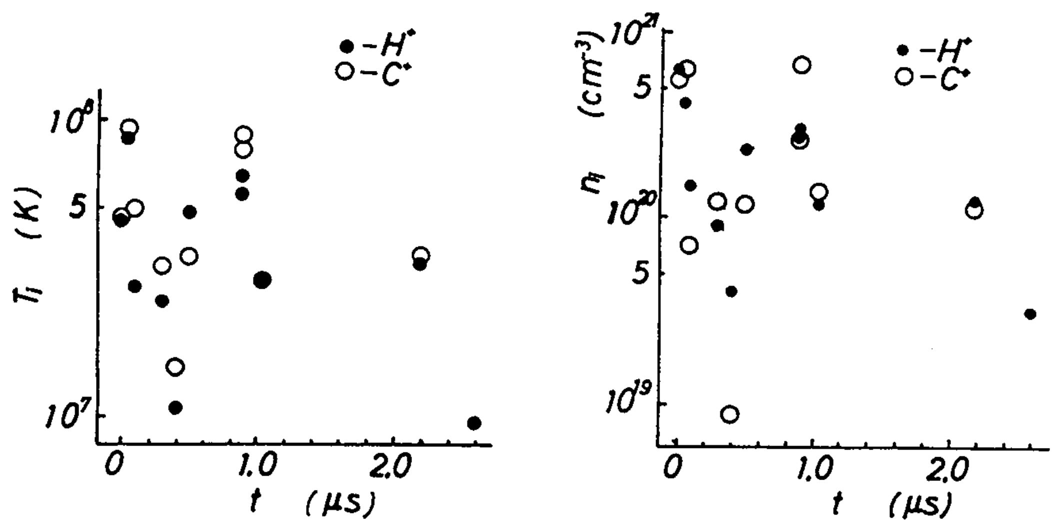

Fig. 3. Ion temperature T_i (left) and density n_i (right) in the implosion focus measured by a laser light scattering method with respect to the time t after the implosion.

The results in the hemispherical convergent space suggest [1,2] :

$$P / P_0 \sim (r / R_0)^{-1.4 \pm 1.5} \quad (1)$$

$$T / T_0 \sim (r / R_0)^{-1.3 \pm 0.2} \quad (2)$$

The temperature as well as the density of the ions in the implosion center of the chamber-***b*** were measured by a laser light scattering method [2]. The results shown in Fig. 3 suggest that the ion temperature is 10^7 K to 10^8 K and the ion density $10^{19}/cm^3$ to $10^{21}/cm^3$ during *1 μs* to *2 μs* after the focusing in the implosion center. The energy state in the implosion center having a temperature of 10^8 *K* and density of $10^{21}/cm^3$ is beyond the so-called Lawson's limit for a nuclear fusion reaction in a $T+D$ mixture and can initiate a fusion reaction.

3. Size of detonation chamber for steady fusion reaction

As eq. 2 suggests, the larger the size of the convergent space of a detonation chamber, the higher the ion temperature in the implosion center. In a mixture of $T+D$, the following fusion reaction takes place [3]:

$$D + T = {}^4He + n + 17.6\ MeV_i \quad (3)$$

in which only *3.52 MeV* of the reaction heat can be used to heat the mixture, while the other *14.08 MeV* is transported by neutrons. On the other hand, the heat W_f per second released by the fusion depends on the following equation [3]:

$$W_f = 1/4 \cdot n_i^2 < \sigma v > Q \quad (4)$$

and heat loss W_r per second caused mainly by Bremsstrahlung is expressed by [3]:

$$W_r = 4/3 \cdot \pi^3 Z^2 e^6 / (m_e c^3 h) \cdot n_e v_e = 1.71 \times 10^{-27} Z^2 n_e T_e^{1/2}, \quad (5)$$

where n_i is the density of particles T or D, σ the collision cross section of the particles, v_e the free velocity of the particles and Q the reaction heat, Z the charge of the ions, e the elementary electron charge, m_e the electron mass, c the light velocity, h Planck's constant, n_e the electron density and T_e the electron temperature.

The mixture $T+D$ in a capsule put in the implosion focus is thus heated by the heat $\Delta Q = W_f - W_r$.. From the theoretically calculated results of ΔQ, spherically imploding detonation waves having a temperature higher than 3.6×10^8 K in the implosion center under an initial pressure higher than atmospheric is necessary to initiate a steady nuclear fusion in a mixture of $T+D$. According to eq. 2 the detonation chamber shown in Fig. 1-***b*** should be enlarged its size to more than three times.

4. A proposal for a nuclear fusion reactor applying spherically imploding detonation

According to the conclusions described above, a reactor for a power plant of *1000 MW* having a thermal efficiency of *20 %*, for example, is proposed as schematically illustrated in Fig. 4. The fusion reactor is composed of a two-step divergent-implosion chamber having a convergent space of *850 mm* in radius, a reaction guide tube of stainless steel having a length about *2 m* and an inner-diameter of *5 mm* below the implosion center, several fuel nozzles of mixtures $D+9\ He$ and $T+9\ He$ in a reaction chamber at the guide tube end, first wall, blanket and others necessary for a fusion reactor around the reaction zone [4]. The detonation chamber is filled with $C_3H_8 + 5\ O_2$, while a capsule of about *10 mm* in diameter filled with a $T+D$ mixture under atmospheric pressure is put in the implosion center.

The fusion reaction initiated in the capsule propagates accompanied by detonation waves through the guide tube to the reaction chamber at the tube end, where a steady fusion reaction is hold by supplying the fuels, the mixtures $D+9\ He$ and $T+9\ He$, both together by *0.12 mol/s.*

In order to gain the mechanical power, a system of steam turbine driven by water vapor heated by the fusion is proposed, as water can decelerate the fast neutrons and absorb their energy occupying *80 %* of the whole reaction heat. The water used to cool the turbine case, the reaction chamber and blanket under a pressure of *10*

MPa is injected into the reactor vessel and evaporated around the reaction chamber. The vapor is heated there to a temperature of about *900 K* under a pressure of *5 MPa* and drives the turbine, expanding to the atmospheric pressure. The water to be supplied into the steam turbine is estimated to be about *1400 kg/s*.

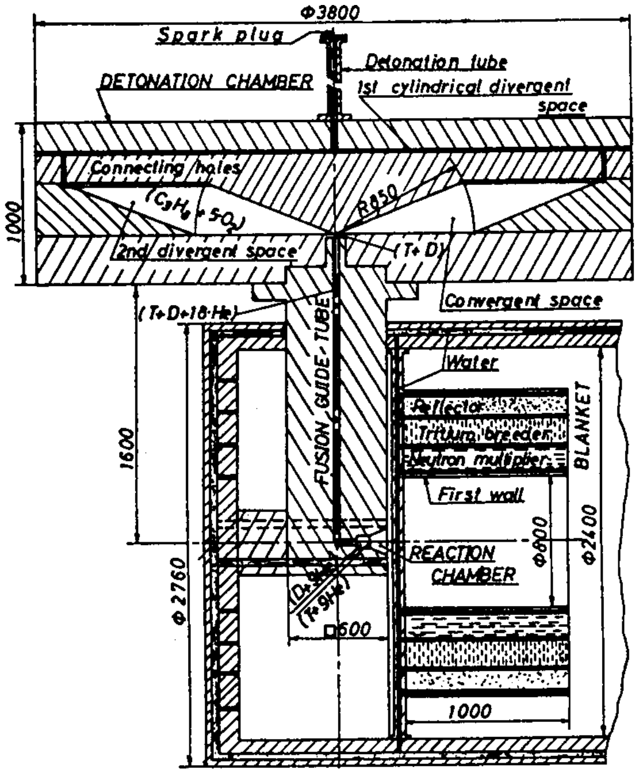

Fig.4. Sketch of proposed nuclear fusion reactor

5. Conclusions

Using a detonation implosion apparatus having a convergent space of *1.7 m* in diameter and an outer-diameter of about *4 m*, a mixture of deuterium and tritium in a small capsule put in the implosion center can be heated to a state having an ion temperature higher than 3.6×10^8 *K* and ion density higher than $10^{20}/cm^3$ by spherically imploding detonation waves propagating in a stoichiometric propane-oxygen mixture. In a *T+D* mixture in a capsule set in the implosion center a fusion reaction can take place which can be further introduced through a guide tube filled with a mixture of *T+D* and *He* gas to a reaction chamber at an arbitrary position where a steady fusion reaction is kept by supplying *T+ 9He* and *D+ 9He* mixtures as fuel. Applying a steam turbine in which a high pressure water supplied as coolant for the case of the turbine, reaction chamber and blanket is injected into the reaction zone and heated by the fusion reaction, some mechanical power can be obtained.

Even if we have still many problems to be solved and difficulties to be overcome, we can realize a practical fusion reactor, applying a spherically imploding detonation chamber.

References

[1] K. Terao and H. G. Wagner, Experimental Study on Spherically Imploding Detonation Waves, Shock Waves 1:27-34,1991.

[2] K. Terao, H. Akaba and H. Shiraishi, Spherically Imploding Detonation Waves by Two-step Divergent Detonation, Shock Waves 4:187-103, 1995.

[3] J.G. Linhart, *Plasma Physics*, North-Holland Publ. Co. Amsterdam, 1960.

[4] R.E. Conn, The Engineering of Magnetic Fusion Reactor, Scientific American, October 1983, 44--55.