J. Condensed Matter Nucl. Sci. 19 (2021) 148–166

Research Article

# Development of weak Cold-fusion Engine Reactor (Fusine) Assisted by Molecular Chemical Reaction: Based on Focusing–compression of 1000 bar and 7000 K Due to Pulsed Supermulti-Jets Colliding

Tomotaka Kobayashi, Remi Konagaya, Ken Naitoh* and Yoshinari Wake

*Faculty of Science and Engineering, Waseda University, Tokyo, Japan*

**Abstract**

Some reports from ICCF22 (Takahashi et al., Iwamura et al., Parkhomov et al., Mizuno et al.) show that selected materials lead to higher power at higher temperatures, probably at temperatures below 2000 K, and pressures below 10 MPa. In the early part of this report, we show the theoretical extrapolation of data described in these recent reports which indicates that low energy nuclear reaction systems at temperatures over 7000 K may release energy at a rate comparable to combustion of fossil fuels, or perhaps even higher. It is also stressed that high pressure levels of 100 MPa physically will lead to less diffusion of $H_2$ (or $D_2$) gas from solid materials (e.g., powder of such as palladium or nickel) that have absorbed the gas. Less diffusion leads to higher power. In the present report, we propose a new reactor which may lead to power at the level of a chemical reaction such as combustion of fossil fuels. This reactor is based on two new basic technologies. Our first technology is a new device with a power source based on focusing compression due to pulsed supermulti-jets colliding around the reaction chamber center, which will have potential of the level of 7000 K and 100 MPa in chamber as maximum, leading to high power. It should be able to continuously produce power as an open system. The high compression potential at level of 100 MPa and 7000 K was confirmed by experiments and computational simulations without chemical and nuclear reactions. Our second technology is an injector of nanoparticles such as those of palladium or nickel, which remains durable for more than 30 hours, which may lead to continuous low energy nuclear reactions. These may make it possible to construct a heat source powered by a low energy nuclear reaction in nanoparticles such as palladium or nickel, which is triggered by a chemical reaction of $H_2$ (or $D_2$)-oxygen mixture, where the reactor is initially brought to a high temperature and high pressure.


*Keywords:* Computer simulation, Durability, Experiment, Focusing compression, Injector, Pulsed supermulti-jets colliding, Reaction, Theory

*Corresponding author. E-mail: k-naito@waseda.jp.

© 2020 ISCMNS. All rights reserved. ISSN 2227-3123

## 1. Introduction

The phenomenon called cold fusion (CF) or low energy nuclear reaction (LENR) reported over 20 years [1–4] may be very important for our future, as an ideal solution for baseline energy generation and environmental problems. Recently, it has been found that the use of nano-particles is an effective means of stabilizing the phenomenon [5]. Further, studies were conducted which also indicated stability of the reaction [6–8]. However, the production energy per unit time, i.e., power, or the reaction speed, is still small, whereas total energy integrated over a long time is fairly large.

In this report, we first show a theoretical analysis based on an extrapolation of experimental data reported in ICCF22 [26–28,33], which indicates that with systems with a reactor internal temperature over 7000 K at pressure less than 10 MPa, it may be possible to produce power at a rate similar to a chemical reaction such as the combustion of fossil fuels including gasoline. It is also stressed that high pressure level of 100 MPa physically will lead to less diffusion of $H_2$ (or $D_2$) gas from solid materials (e.g., powder of such as palladium or nickel) absorbed with the gas, i.e., higher power.

We next show two hardware technologies to implement a new power source with fast energy production.

The first technology we discuss is a new device with a power source based on focusing compression due to pulsed supermulti-jets colliding around the reaction chamber center, which has potential of 7000 K and 100 MPa in the chamber, leading to high power due to low energy nuclear reactions, that can continuously produce power as an open system.

The potential of high compression of 100 MPa and 7000 K due to the pulsed supermulti-jets colliding was basically confirmed by our experiments and computer simulations without nuclear reactions and also without accompanying chemical reactions. This approach based on focusing of supermulti-jets will also cause an insulation effect because of encasing high temperature region around the reaction chamber center, which will also result in keeping high temperature during reaction, because of less heat loss from the reactor walls. The insulation effect will also result in protection of the reactor walls from the high temperature of the reaction.

The second technology discussed here is an injector of nanoparticles, which remains durable for over 30 h, while nanoparticles such as those of palladium stabilizes low energy nuclear reaction. This is developed on the basis of durable liquid fuel injectors used in today's automobiles.

## 2. Level of Temperature and Pressure Necessary for Producing the Power of the Order of that of Combustion of Fossil Fuel

Recently, some independent experiments shown in the ICCF22 [26–28,33] indicate higher excess heat according to increasing temperature, at pressure less than 10 MPa. Based on the excess heat plotted against temperature shown by the experiments at temperatures less than 2000 K [26–28,33], we made an extrapolated graph up to 7000 K, which is shown in Fig. 1. The formula shown by Zheng [9] is used for the extrapolation. The extrapolated graph in Fig. 1 indicates that a chamber temperature of 7000 K may produce power comparable to those of chemical reactions such as combustion of fossil fuels including gasoline. This is because the power of a conventional internal combustion engine is on the order of 100 kW. Thus, we set the target temperature of 7000 K to obtain power for various uses.

We also believe that diffusion of $H_2$ (or $D_2$) gas outside from solid materials that have absorbed the gas may occur. Therefore, we also set the other target for encasing the gas inside solid materials, which is high pressure at the level of 100 MPa in the reaction chamber to push back the gas into solid materials. It is also stressed that the order of 100 MPa, i.e., compression at 1000 times atmospheric pressure, and also ten times the pressure (or more) for experiments shown in Fig. 1, may lead to the level of ten times the power of chemical reactions of fossil fuel. This is also because 10 times of the density of $H_2$ (or $D_2$) and the higher pressures will also make solid or liquid conditions for materials such as palladium and nickel, while very lower pressure will also lead to vapor.

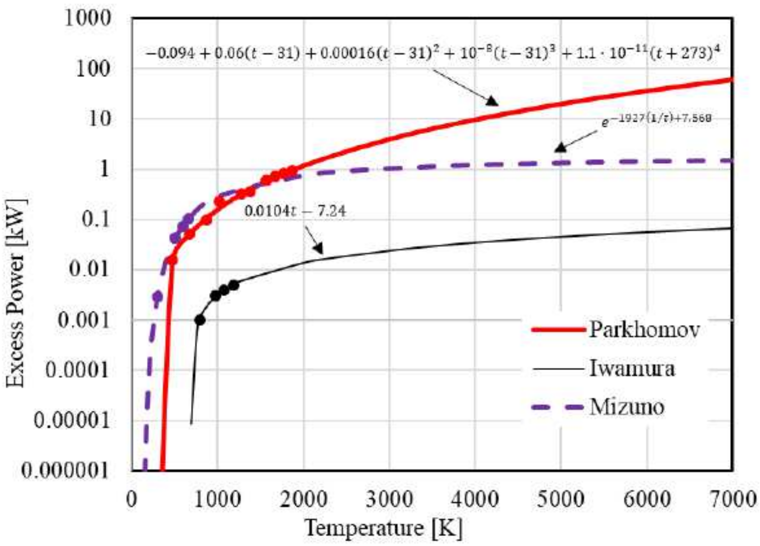



**Figure 1.** Extrapolation of temperature dependence of magnitude of excess heat in three independent experiments [26–28,33].

In Section 3, we will show the new technology that should allow us to reach the two targets of 7000 K and 100 MPa in the reaction chamber.

## 3. Principle and Basic Evaluation of Focusing Compression based on the Supermulti-jets of Gas Colliding with Pulsation at Condition without any Reaction: Bringing about High Temperature and High Pressure

### 3.1. Principle

The key point of the new technology to achieve 7000 K and 100 MPa in reaction chamber is based on the supermulti-jets of gases such as deuterium (or hydrogen) with a pulse, in which the gas jets entering from reaction chamber wall collide around the center of reaction chamber through a focusing process (Fig. 2). Although we employ a mixture of oxygen and hydrogen (or hydrocarbon fuel) for use of molecular chemical reactions [10,14], gas of deuterium (or hydrogen) is mainly used as gas jets for low energy nuclear reactions, while gas of nitrogen can be added for ensuring safety. (We think that a trial of low energy nuclear reaction based on the focusing compression and nanoparticles such as palladium should be started with lots of nitrogen gas. After that, we will gradually decrease nitrogen gas, which should trigger the reaction.)

The ideal spherical displacement of jets is shown in Fig. 3. Semispherical sixteen jets show stable point compression due to the supermulti-jets. Then, the experimental visualizations for a different collision system of supermulti-jets [29] show nearly axial symmetry after the supermulti-jets collide on the center axis, while large disturbances due to asymmetrically placed jets also show nearly symmetric pattern of density distribution. Thus, spherical distribution of jets will be more stable.

We can control or increase the levels of pressure and temperature by varying the geometries and distributions of nozzles, while varying also pressure differences before suction and initial temperatures at upstream and in the reaction chamber [10,14].

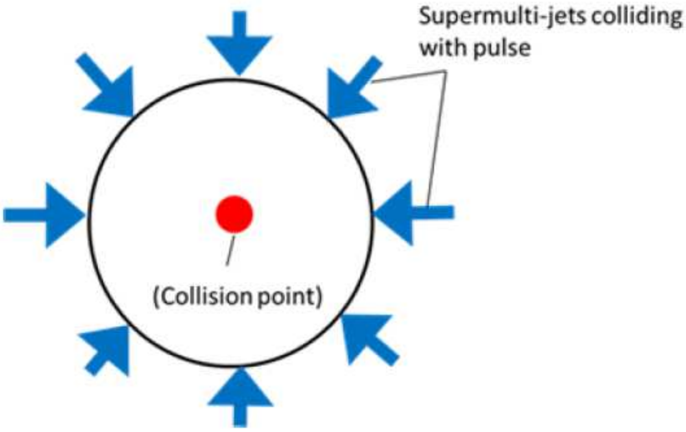



**Figure 2.** Principle of the point compression due to supermulti-jets colliding with pulse.

It is also stressed that this self-contractive flow due to supermulti-jets results in confinement of burned (or reacted) hot gas only around the cylinder center, which reduces contact between the hot gas and the cylinder walls and leads to less heat loss [10–14]. Computational results indicate that the heat loss to the cylinder walls is extremely small. Consequently, these computations and theoretical considerations show that a new engine based on the collision of pulsed supermulti-jets and turbo-/super-charging over 0.3 MPa for fossil fuels including gasoline may achieve indicated thermal efficiency of about 60% at low and medium loads, when the conditions of geometry and operation close to those in the cycle theory are set [10,14–16]. By using the absolute minimum and maximum temperatures computed for the new engine (the exhaust temperature TC 600 K and burned temperature TH 2400 K) [10,14,17], the efficiency of the Carnot cycle is calculated to be about 75%. Therefore, our computational thermal efficiencies of about 60% maximum [10] should be possible because the level is less than that of the Carnot cycle.

Then, this effect of strong insulation is also important for heat resistance on chamber wall during a large heat release due to low energy nuclear reaction.

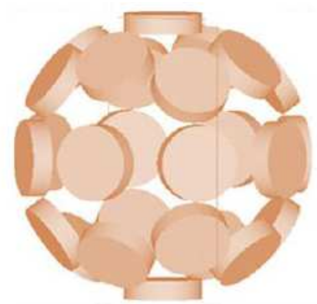


**Figure 3.** Focusing compression device due to 26-pulsed jets colliding with spherical distribution. (Interspaces between 26 nozzles can also be used for exhaust process. One among 26 nozzles can be removed to allow the exhaust process.)

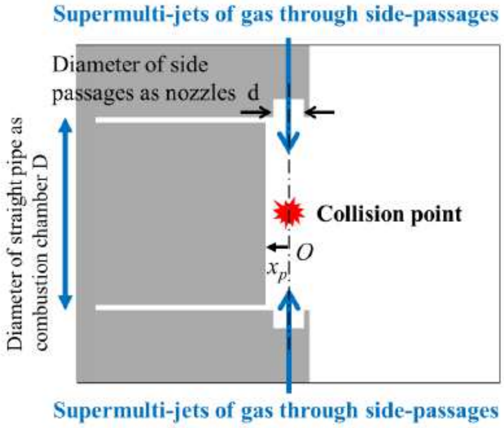



**Figure 4.** Focusing compression device due to pulsed jets colliding in a plane surface.

### 3.2. Focusing compression device as reaction chamber shown mainly in the present study

In this study, we consider the focusing compression device as a reaction chamber shown in Fig. 4, which is configured with 14-pulsed jets colliding in a plane surface, and also a solid side-wall on the left-hand side of the collision point to increase the compression level by reflecting pressure waves. The solid wall is also used for the installation of a pressure transducer.

(*Technique* I) It is stressed that the solid side-wall on the left-hand side has an important role, which also stabilizes collision of jets by reflecting pressure waves, while the flow is driven only on the right-hand side of the chamber for generating thrust and power.

We also show two other techniques, which stabilize the focusing process of jets:

(*Technique* II) Collision of jets in laminar flow due to small size ratio $D/d$ of jet nozzle $(d)$ and reaction chamber diameter $(D)$.

Let us examine the transition from laminar to turbulent flows due to shear stress in the single high-speed jet in Fig. 5 [30]. Figure 5 indicates that there is a certain laminar jet length $(L)$, i.e., a region where the jet is straight. Thus, we set up the device so that jets collide in the laminar flow, i.e., in the size ratio of $D/d$ <4.0 ($L/d$<2.0). Thus, the condition of nearly laminar straight jets will also lead to stable point compression around the chamber center.

(*Technique* III) Potential flow generated by pulse.

The pulsed flow shows potential flow without fluctuations such as turbulence at the early intake process, as is well known from fluid dynamics textbooks [31], which will lead to stable collisions. In the engine described in Section 4, pulse jets are injected for 5 ms, while following that the jet nozzles are closed for 2.5 ms.

### 3.3. Stability of compression

A physical (dynamical) explanation can answer the question of why symmetric flow pattern due to collision of jets is stable for three (or more) jets. Where the center jet among three is inclined, a pressure difference along the upper-lower direction around the collision point of three jets is generated, which induces a flow that returns the jets to the geometrical collision point (see Fig. 6).

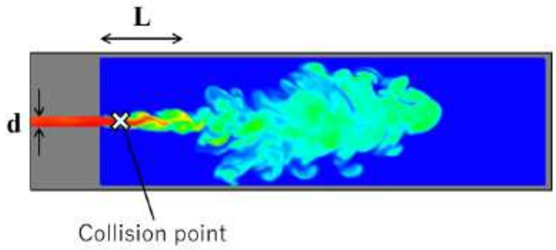



**Figure 5.** Example of a single jet computed by the present numerical code based on the CIP method (spatial distribution of the volume ratio of hydrogen, which is injected into a chamber initially filled with air) [30].

Second, it is also stressed that the supermulti-jets analyzed in this report have less shear stress between the jets, because there is only a very small stagnant region between neighboring jets. Let us think about the case of only one jet, whereas Fig. 6 shows three jets. With only one jet, i.e., only the central horizontal jet after eliminating two upper and lower jets in Fig. 6, the jet is surrounded by a motionless (static) chamber region. Thus, the flow speed largely varies between the one jet and motionless static chamber region, whereas flow speed does not vary much between two neighboring jets among the three in Fig. 6, because the upper or lower jet has the flow speed identical to that of the center jet. This results in very less shear stress (very less flow speed variation in space) in Fig. 6 leading to longer laminar flow, because shear stress brings turbulence. As a result, the length L of laminar flow for one jet in Fig. 5 is longer for the supermulti-jets shown in Fig. 6. Therefore, the supermulti-jets can collide in a laminar flow at the collision point.

The computation of a single high-speed jet injected into ambient air, done by the present numerical method based on the CIP and CUP method shown in Fig. 5 and validated by agreement with various experimental data, has a relatively strong shear stress around the contact surface between the jet and ambient air, which results in turbulence at the area far from the nozzle [30].

### 3.4. Energy loss inside jet nozzles

Let us consider the energy loss due to viscosity in the jet nozzles. We should discuss this point by classifying the jet speed into two categories: subsonic and supersonic ones.

First, let us recall that piston engines for automobiles and also turbojet systems for aircraft and for rockets employ subsonic flows. Energy loss due to the viscous jet-flows in nozzles in the subsonic regime, i.e., a few percent of

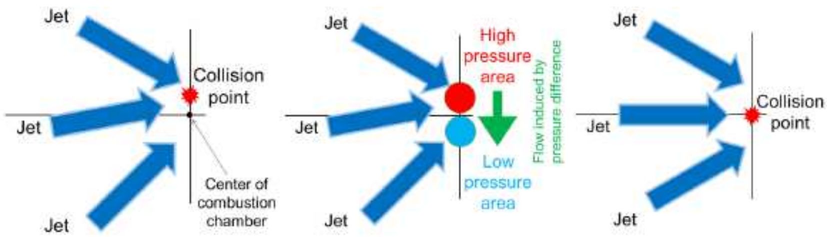



**Figure 6.** Mechanism of how slightly inclined jets generate force that returns jets to the geometrical collision point, which leads to stability of collision [29].

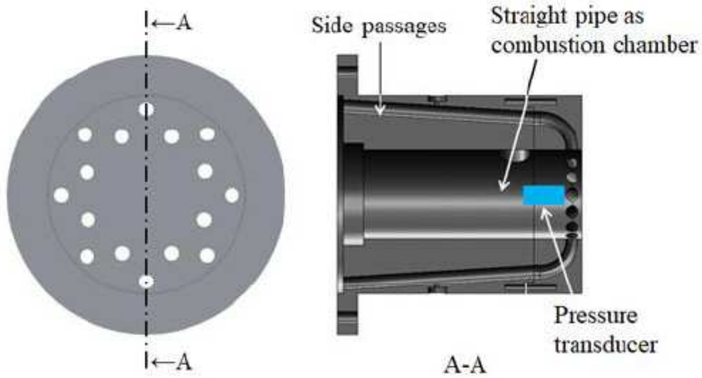



**Figure 7.** Focusing compression device with fourteen pulse-jets placed on a geometrical plane.

input energy, is negligible, because the supermulti-jets colliding with pulse through focusing process leads to a large reduction of energy loss due to heat transfer from the chamber wall and exhaust heat loss (reduction of energy loss on the order of 20–30%) are much larger than that of the viscous jet-flow loss. Actually, as we show later, we use the present focusing compression due to the pulsed supermulti-jets colliding in the subsonic regime in most cases.

Second, let us think about the case in which the supersonic jets colliding generates a low energy nuclear reaction, i.e., about ten times of power of chemical reaction. Then, the viscous energy loss for the supersonic regime at Mach number between 1.0 and 2.0 will be of the order of 20–80%. However, the present loss is relatively trivial in comparison with the large power due to low energy nuclear reaction caused by jets colliding

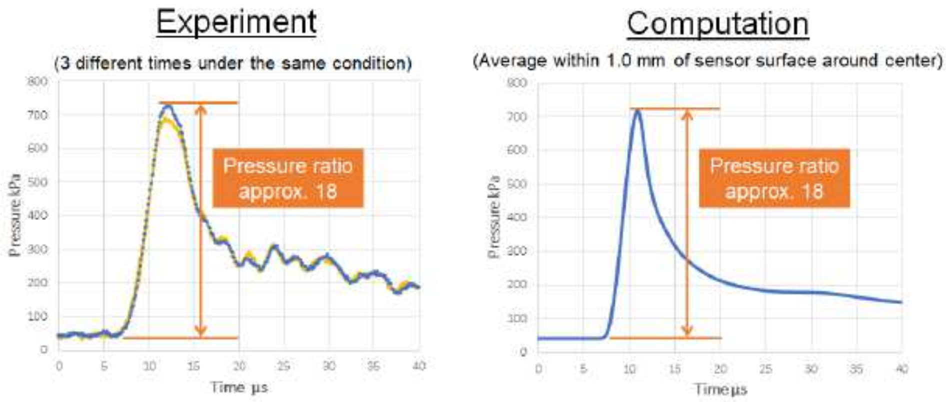
### 3.5. Pressure–temperature level of the focusing compression due to the pulsed supermulti-jets colliding at condition without chemical and nuclear reactions

Pressure around the collision point of fourteen pulse-jets placed on a geometrical plane in an engine developed originally (Figs. 4 and 7) is first measured in a long shock-tube facility by varying the pressure transducer position (Kistler Instruments Ltd.), without chemical and nuclear reactions. A high pressure ratio over 18:1 is reliable and stable with variation of about 3% for peak pressure, and variation of intake pressure less than 1%, while cases with stronger disturbance of intake pressure also indicate stable and high compression (Fig. 8a). Computation results obtained by numerically solving the compressible Navier–Stokes equation and averaged in the 2 mm diameter of the pressure transducer is similar to experimental pressure increase (Fig. 8b). (Averaging in the 2 mm diameter of the pressure transducer must be done because it is well known that pressure distribution in space cannot be resolved [32].)

These shown in Fig. 8 also implies, while computations show the maximum temperature over 1000 K at the chamber center, a temperature of about 700 K averaged in the 2 mm diameter on pressure transducer at collision timing, which is similar or more to that in traditional Diesel and jets engines.

Moreover, we added a glow plug (a torch system) to stabilize startup of combustion due to the 14-jets injected with a little high upstream pressure of about 0.3 MPa corresponding to turbo- or super- charging. (At startup, this glow plug brings burned gas of high temperature kept in reaction chamber, corresponding to the hot EGR gas [19], leading to stable and continual chemical reaction after startup.)

Thus, the single focusing collision of 14-pulsed jets injected with initial pressure increased by conventional turbo- or super-charging system (or high-pressure tank) brings the level over 1000 K, which may be enough to generate a low energy nuclear reaction of the order of 1 kW, as shown in Fig. 1.




(a) Experiment (b) Computation

**Figure 8.** Pressure at geometrical collision point plotted against time.

It is also emphasized that agreement of computations and experiments in Fig. 8 indicates the usefulness of the present computational code. Therefore, we also try to compute various geometries and conditions. Figure 9 demonstrates time-histories of pressure for focusing compression using 26 pulsed jets colliding with atmospheric temperature and pressure as initial conditions in the chamber, which brings about 3000 K and 250 MPa after collision of the 26 jets for both of air and hydrogen gas. Another important point is that computations for collision due to the supermulti-jets of hydrogen gas show a pressure increase similar to that for atmospheric air, at identical upstream pressure condition, because lighter gas results in a higher speed of the jet.

For the 26 jets, a chemical reaction will be stable without the glow plug and EGR. Moreover, an initial chamber temperature of 1500 K due to pre-heating, which can be done by using another energy source such as a glow plug or electric heater, leads to 7000 K at collision timing (over 100 MPa), which may increase the probability of a low energy nuclear reaction at the level of ten times the power of chemical reaction of fossil fuels and hydrogen, as shown in Section 2.

## 4. Combustion Experiments Obtained for the First Prototype Engine with Focusing Compression due to the Pulsed 14 Jets of Gas Colliding

### 4.1. Engine geometry

Figures 10a and b show an outline view of the first prototype engine for chemical reaction added with a rotary plate valve generating repeated pulse jets, a torch system having a glow-plug, and fuel injectors, while including the chamber for focusing compression due to the pulsed 14 jets of gas colliding and its cross-section shown in Figs. 4 and 7. Then, Fig. 10c shows a small wall at a position downstream from the geometrical collision point of jets, which increases pressure around the collision point and makes the collision more stable. The total period of each cycle is 7.5 ms, where the rotary valve is open for 5 ms to admit the pulse jet-flows into the chamber, and then closed for the 2.5 ms remaining.

A small wall is set at a downstream position. This is because the pressure wave reflected at the small wall brings stronger compression. Burned gas does not hit the small wall, because of reflection of pressure wave [10,16]. More-

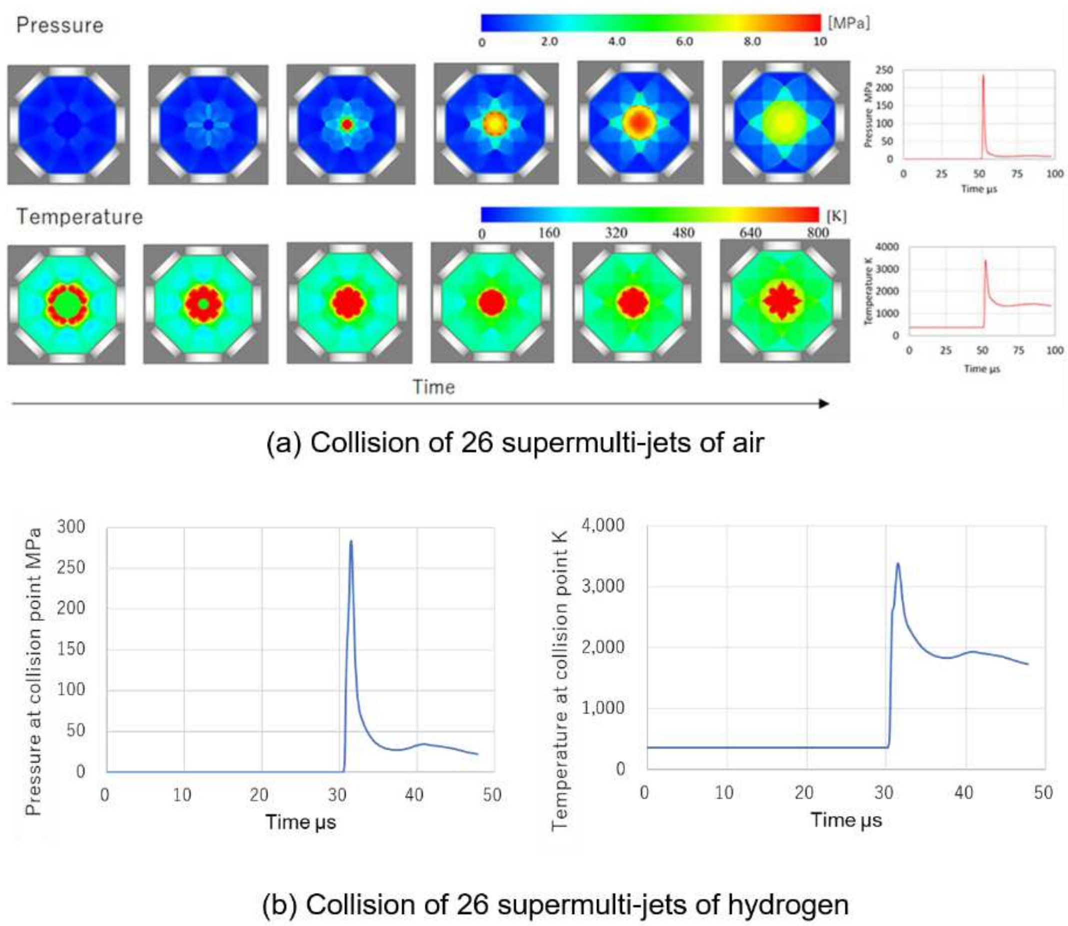
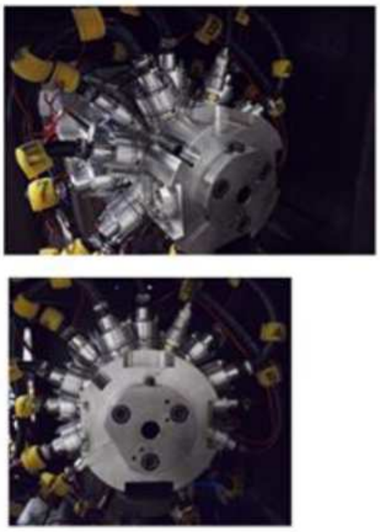



**Figure 9.** Pressure and temperature history computed for supermulti-jets colliding with pulse. (a) Air [34] and (b) Hydrogen.

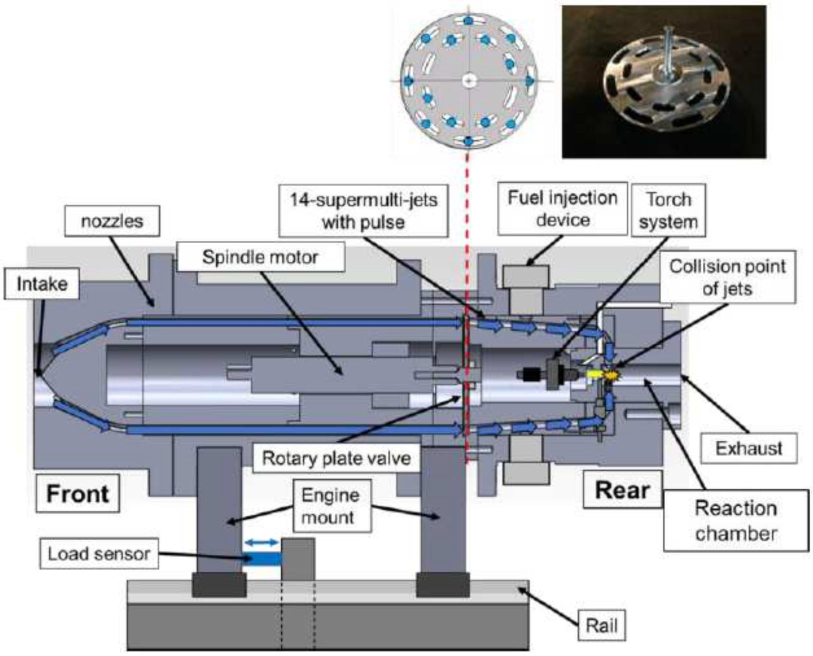
over, the small wall downstream also has the other effect of maintaining burned gas around the collision point of jets until the next cycle.

### 4.2. Nearly complete gas-insulation effect and high thrust obtained for focusing engine having the pulsed 14 jets of gas colliding

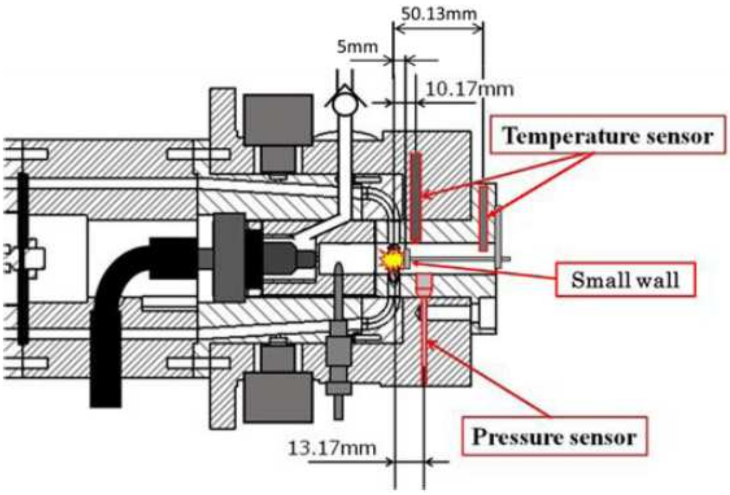
Engine specifications and conditions are depicted in Table 1. As fuel, we use gasoline, which is one of the fuels that are difficult to ignite. However, combustion reliably occurs, which is evidence of focusing compression (Fig. 11). Then, we qualitatively get a nearly complete air-insulation effect (Fig. 12). Figure 13 indicates high thrust over 100 N, although this engine is very small, with an 18 mm chamber diameter and injection pressure at the level of only 3



(a) Outline view




(b) Cross-section




(c) Small wall set at a downstream position

**Figure 10.** First prototype engine having 14-jets collided with rotary valve for generating a pulse.

bar. (Analysis based on these combustion experiments and computations indicate power and thermal efficiency higher than those in traditional combustion engines for air-breathing vehicles and rockets, because of relatively silent higher compression and nearly complete air-insulation [10].)

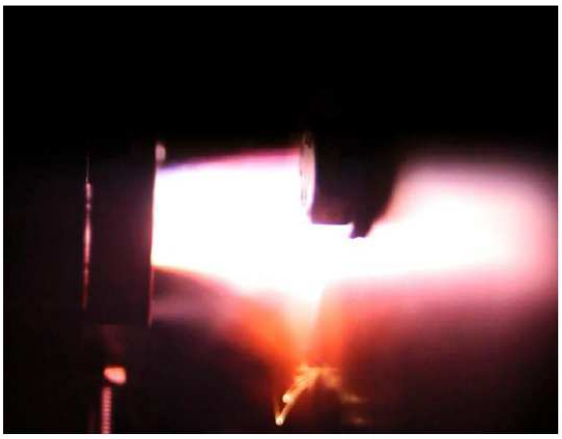


**Figure 11.** Photographs of combustion occurrence for first focusing compression engine with14-jets. [35].

**Table 1.** Engine specifications and conditions.

| | |
|---|---|
| **Reaction chamber diameter** | **18 mm** |
| Diameter of nozzles for supermulti-jets | 6.5 mm |
| Number of colliding supermulti-jets | 14 |
| Mach number of supermulti-jet speed | Subsonic (about 0.6) |
| **Fuel for 14 main injectors** | **Regular gasoline** (injection pressure=0.35 MPa) |
| Number of main injectors | 14 |
| Fuel flow rate | About 1450 mL/min |
| Fuel injection period | 0.1 sec. |
| **Oxygen concentration in the air supply** | **47%** |
| Flow rate of the air supply | About 13000 L/min |
| Air/fuel ratio | 50.7 (Lean) |
| **Inlet pressure just before intake of the engine** | **0.29 Mpa** |
| Rotating speed of rotary plate valve | 1000 rpm |

## 5. Development of the Second Prototype Engine for Achieving Low Energy Nuclear Reaction: with Focusing Compression due to the Pulsed 26 Jets of Gas Colliding

We developed the second prototype engine to achieve a low energy nuclear reaction, with focusing compression due to the pulsed 26 jets of gas colliding, displaced with spherical distribution, although the first prototype engine has only

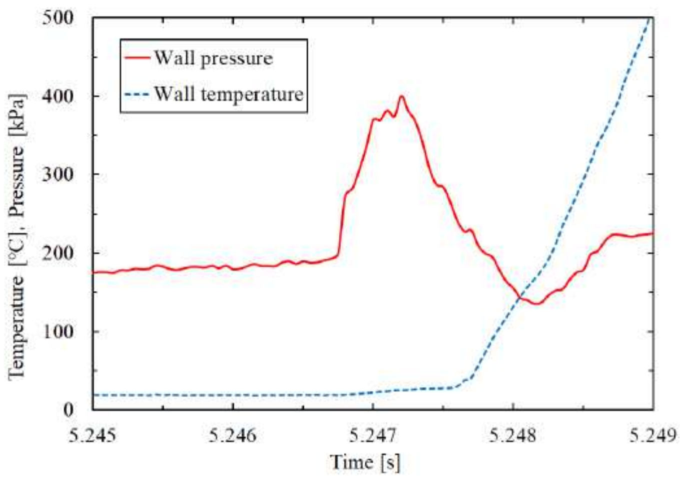



**Figure 12.** Wall pressure and temperature of a combustion experiment done with a prototype piston-less engine, which qualitatively proves the nearly-complete air insulation effect. During pressure increase due to combustion, the wall temperature does not increase. This kind of data is reliably obtained [36,37].

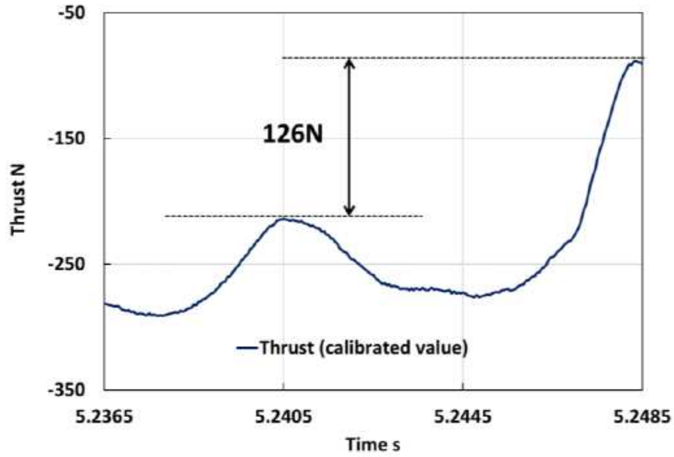
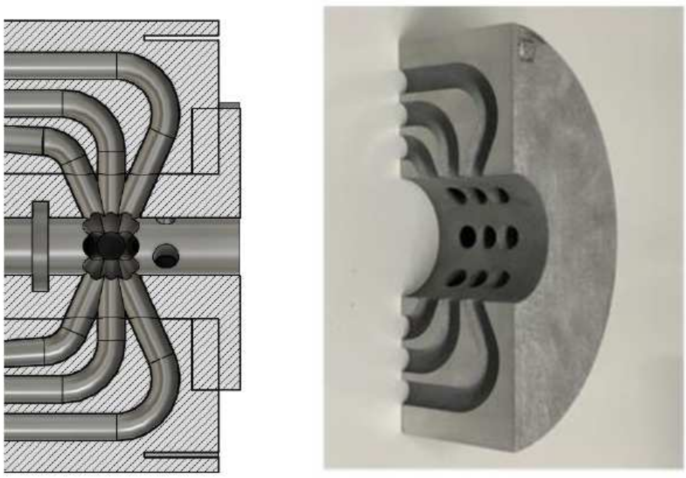



**Figure 13.** Thrust obtained for first focusing compression engine with 14 jets pulsed [35,36].

14 jets displaced non-spherically. This will lead to more stable and strong compression around chamber center. Three stages of eight jet nozzles are distributed (Fig. 14).

## 6. Injection System of Nanoparticles such as Palladium and its Durability

To produce cold fusion (a low energy nuclear reaction) in a future cold fusion engine (a "Fusine"), a device for injecting solid particles such as palladium must be added to the focusing compression device due to pulsed supermulti-jets colliding. Figure 15 shows the injector system of nanoparticles such as palladium, which we add.



(a) Cross section of the engine (b) Cutaway made by 3D printer

**Figure 14.** Second prototype engine for achieving low energy nuclear reaction, with focusing compression due to the pulsed 26 jets of gas colliding, displaced with spherical distribution.

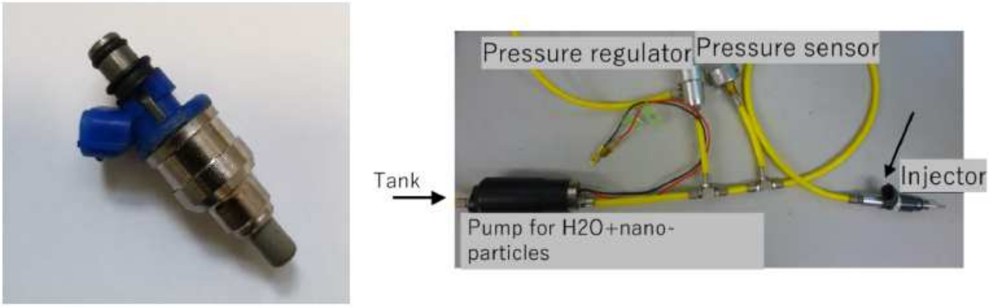



**Figure 15.** Injector system of nanoparticles including water.

In this report, we use diamond particles of diameter less than micrometer as test nano-particles in liquid water as test liquid (Carbodeon Ltd. Oy). The weight ratio of nano diamond particles is 2.0%, while volumetric ratio is 0.57%.

This injection system of solid particles showed a constant level of injection amount of liquid water including nano-particles over 30 h, i.e., durability, while focusing collision of jets is absent. i.e., as a unit test of the injector (Fig. 16).

## 7. Concept of a Double Focusing Compression Engine

In Section 3.5, we show a way of pre-heating to over 1500 K to increase the initial chamber temperature in order to reach 7000 K after collision timing of 26-jets pulsed through focusing process, i.e., just before the nuclear reaction occurs. However, for the present way, a large energy source system will be necessary for this pre-heating.

Thus, we propose another way to reach 7000 K by using only the focusing compression due to 26 pulsed jets colliding. The other way shown below is inspired by the fact that traditional combustion engines, including piston engines and jets engines, use the high temperature gas burned in the previous cycle as an ignitor to assist the stable combustion

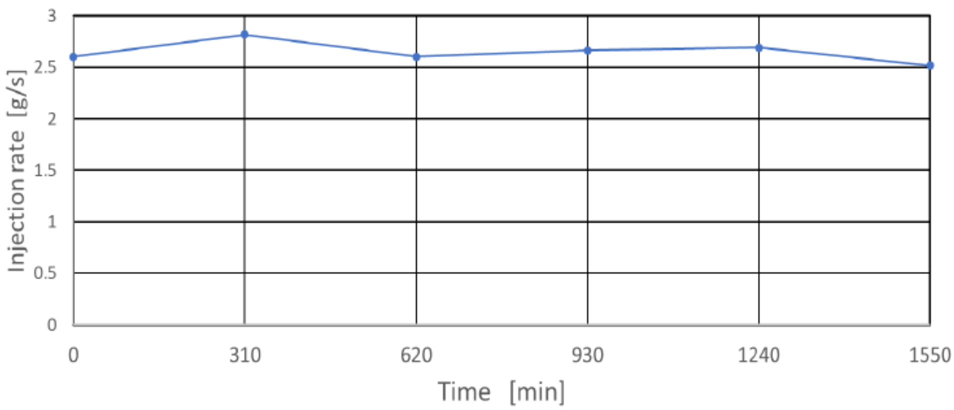



**Figure 16.** Injection rate plotted against time.

in the next cycle. The high-temperature gas in the previous cycle is known as EGR or burned gas maintaining in recirculating area employed for the next cycle [19].

The method developed using the burned gas in the previous cycle for the next cycle, i.e., double-focusing compression, is explained as follows. In the first focusing compression cycle, a chemical reaction of hydrogen and oxygen occurs, which results in high temperature water vapor of over 2500 K at the end of the first cycle. A portion of the burned gas water vapor is exhausted. After that, the burned gas of water vapor remaining in the reaction chamber is used as high temperature source for assisting the initial stage of second focusing compression cycle with only hydrogen gas (or $D_2$) and palladium injected. This leads to a higher temperature than 7000 K just before a low energy nuclear reaction occurs. This is a combination of a chemical reaction and a nuclear reaction weaker than that of uranium.

This will be possible if a second focusing–compression cycle with nanoparticles such as palladium is achieved, after a chemical reaction of $H_2$ (or $D_2$)+oxygen occurs in the first cycle of focusing compression. This compression level will be larger than that in a traditional internal combustion engine and traditional cold fusion systems, whereas it will be much less than for high temperature fusion systems. This may bring about more stable and frequent cold fusion reactions. This approach due to supermulti-jets will also cause an insulation effect because of encasing, which will result in less heat loss from the reactor walls and protecting the reaction chamber walls from the high temperature of the reacted gas. In short, this method ensures safety, durability, and low cost.

## 8. Conclusion

Most of the studies on low energy nuclear reactions (cold fusion) have been done with closed reactors until now. Thus, the open reactor systems shown in Figs. 4, 7, 10 and 14 will be important for the actual implementation of low energy nuclear reactions. We have started to make a reactor system including an injector of nanoparticles, and we have also started fundamental experiments in a small constant volume reaction chamber for low energy nuclear reactions, in order to find optimized conditions of nano-particles and gas around the nano-particles. A suitable laboratory to perform this experiment should be found, because it will be difficult to do at our university in Tokyo, and also because nobody has tested this type of engine which continually generates high energy by focusing jets entering from outside.

## Acknowledgements

This paper is part of the outcome of research performed under the JSPS grant for research projects (25630072) and also under the grant of the Thermal & Electric Energy Technology Foundation (TEET). Sincere thanks are also due the other members of the Naitoh Laboratory for their help.

## References

[1] Fleischmann M and Stanley P, Journal of Electroanalytical Chemistry and Interfacial Electrochemistry. Volume 261, Issue 2, Part 1, (1989): 301-308
[2] Fleischmann M, Stanley P, Anderson MW, Li LJ, Hawkins M. Journal of Electroanalytical Chemistry and Interfacial Electrochemistry. Volume 287, Issue 2, 25 (1990): 293-348
[3] Miley GH and Patterson JA, J. New. Energy, Vol.1-3 (1996): 5-30.
[4] http://newenergytimes.com/v2/conferences/LENRConferenceProceedings.pdf
[5] Arata Y and Zhang Y. Journal of High Temperature Society, Vol.34-2, (2008):85-93.
[6] Kitamura A, Nohmi T, Sasaki Y, Taniike A, Takahashi A, Seto R, Fujita Y. Physics Letters. Vo. A373, pp.3109-3112. (2009).
[7] Hioki T, Sugimoto N, Nishi T, Itoh A, Motohiro T. J, of Condensed Matter Nuclear Science. Vol.13, pp.223-233. (2014).
[8] Kitamura A, Takahashi A, Seto R, Fujita Y, Taniike A, Furuyama Y. Current Science. Vol.108, no.4, pp.589-593, (2015).
[9] Zheng SX, Huang GS, Dong ZM, Liang CL, et al., 22nd International Conference on Condensed Matter Nuclear Science (ICCF22) Book of Abstracts, p.60, (2019).

[10] Konagaya R, Naitoh K, Kobayashi T, Isshiki Y, et al., SAE Technical Paper 2020-01-0837, doi:10.4271/2020-01-0837. (2020).

[11] Naitoh K, Tsuchiya J, Ayukawa K, Oyanagi S, et al., J. Condenced Matter Nucl. Sci. 24, 236-243, (2017).

[12] Naitoh K, Okamoto T, Kubota T, Yamagishi K, et al., SAE Technical Paper 2014-32-0100, doi:10.4271/2014-32-0100. (2014)

[13] Naitoh K, Yamagishi K, Nonaka S, Okamoto T, et al., SAE Technical Paper 2014-01-2641, doi:10.4271/2014-01-2641. (2014)

[14] Naitoh K, Tanaka Y, Tamura T, Okamoto T, et al., AIAA Paper 2015-2968, (2015).

[15] Yamagishi K, Onuma Y, Ohara S, Naitoh K, et al., SAE Technical Paper 2016-01-2334, doi:10.4271/2016-01-2334. (2016)

[16] Konagaya R, Oyanagi S, Kanase T, Tsuchiya J, et al., SAE Technical Paper 2017-01-1030, doi: 10.4271/2017-01-1030. (2017)

[17] Naitoh K and Shimiya H, Japan Journal of Industrial and Applied Mathematics 28, 3-14, doi: 10.1007/s13160-011-0033-1. (2011)

[18] Kobayashi T, Naitoh K, Wake Y, Naridomi Y, Takahashi A, Seto R, Ido H, Hachisuka J, JCF20 ABSTRACTS, JCF20-13, (2019).

[19] Naitoh K, Advanced and Ultimate Engines, Asakura Publishing Co.,Ltd., (2019).

[20] Naitoh K, Cyto-fluid dynamic theory, Japan J. of Industrial and Applied Mathematics, 18-1, (2001): 75-105.

[21] Naitoh K, Quasi-stability theory: revealing various atomic breakups and cold fusion. Proc. of ICCF17, Korea, (2012).

[22] Naitoh K, A spatiotemporal structure: common to subatomic systems, biological processes, and economic cycles. J of Physics, CS, 344. (2012): 1-18.

[23] Naitoh K, Artificial Life and Robotics 18, 133-143, 2013.

[24] Kobayashi T, Naitoh K, J. Adv. Simulat. Sci. Eng., 6, 80-93, 2019.

[25] Kobayashi T, Naitoh K, Transaction of the Japan Society for Simulation Technology, Volume 12, Issue 2, 54-58, 2020.

[26] Parkhomov AG, Zhigalov VA, Zabavin SN, Sobolev AG, Timerbulatov TR, "Nickel-hydrogen heat generator continuously working for 7 months", 22nd International Conference on Condensed Matter Nuclear Science (ICCF22) Book of Abstracts, p.77, (2019).

[27] Takahashi A, Yokose T, Mori Y, Taniike A, Furuyama Y, Ido H, Hattori A, Seto R, Kamei A, Hachisuka J, "Latest Progress in Research on AHE and Circumstantial Nuclear Evidence by Interaction of Nano-Metal and H(D)-Gas", 22nd International Conference on Condensed Matter Nuclear Science (ICCF22) Book of Abstracts, p.9, (2019).

[28] Iwamura Y, Itoh T, Murakami S, Saito M, Kasagi J, "Excess Energy Generation using a Nano-sized Multilayer Metal Composite and Hydrogen Gas", 22nd International Conference on Condensed Matter Nuclear Science (ICCF22) Book of Abstracts, p.54, (2019).

[29] K. Tsuru, R. Konagaya, S. Kawaguchi and K. Naitoh, "Unsteady three-dimensional computations and experiments of compression flow formed by collision of supermulti-jets," JSME Journal of Thermal Science and Technology, vol. 13, no. 1, pp. 1-23, 2018.

[30] R. Konagaya, K. Naitoh, K. Tsuru, Y. Takagi and Y. Mihara, "Unsteady three-dimensional computations of the penetration length and mixing process of various single high-speed gas jets for engines," SAE Technical Paper, 2017-01-0817, pp. 1-18, 2017.

[31] Tatsumi, T., Fluid mechanics, Bifukan, 1982.

[32] S. Sembian, M. Liverts, N. Tillmark and N. Apazidis, "Plane shock wave interaction with a cylindrical water column," Physics of Fluids, vol. 28, no. 5, 2016.

[33] Mizuno T, Rothwell J "Increased Excess Heat from Palladium Deposited on Nickel", 22nd International Conference on Condensed Matter Nuclear Science (ICCF22) Book of Abstracts, p.47, (2019).

[34] Konagaya R, Naitoh K, "Supercomputer simulation and experiment clarifying the maximum level of focusing compression due to pulsed supermulti-jets colliding: in weak cold-fusion engine (Fusine)", 22nd International Conference on Condensed Matter Nuclear Science (ICCF22) Book of Abstracts, p.14, (2019).

[35] Konagaya R, Naitoh K, Kobayashi T, Kobayashi Y, Makimoto H, Naridomi Y, Wake Y, "Development of weak cold-fusion engine (Fusine) assisted by molecular chemical reaction: based on double focusing-compression over 1,000 bar and 7,000 K due to pulsed supermulti-jets colliding", 22nd International Conference on Condensed Matter Nuclear Science (ICCF22)

Book of Abstracts, p.15, (2019).
[36] Ashikawa K, Tsuchiya J, Ayukawa K, Mikoda J, et al., AIAA Paper 2018-4631, (2018).
[37] Konagaya R, Kawaguchi S, Mikoda J, Kinoshita K, et al., AIAA Paper 2019-4312, (2019).

## Appendix A. Trial of the Low Energy Nuclear Reaction in a Small Constant Volume Chamber: without Focusing Compression due to the Supermulti-Jets of Gas Colliding Shown in Section 5 and also without Injector of Nano-Palladium Explained in Section 6

We also started another basic experiment, in order to find optimized conditions of nano-particles used for the low energy nuclear reaction based on the supermulti-jets colliding. Fundamental experiments of low energy nuclear reaction using hydrogen (or deuterium) and nano-particles such as palladium is performed in a simple reaction chamber with constant volume, by varying some conditions such as amount of palladium and nitrogen. This is also important to confirm and check the previous data done by the other research groups [5–9]. For two different gases of hydrogen and nitrogen, we have gotten some fundamental experimental data in a constant-volume chamber shown in Fig. 17. In the experiment using $H_2$ gas and PNZ10r at about 45°, temperature increase of about 3 K temperature due to palladium is observed [18]. We will get experimental data at higher temperatures soon.

### Appendix A.1. Quasi-stability theory

We think that three approaches: three sacred imperial treasures of experiments, computer simulations, and also theoretical consideration, for accelerating the study. Although the two approaches of experiments and computations are depicted above, a theory (quasi-stability theory) for clarifying physical mechanism underlying phenomena [20–23] may be useful to know mechanism underlying the nuclear transformation, which is related to power.

Behaviors around breaking up for two connected particles, which are assumed with flexible spheroids (or other shapes) and forces working between particles existing in various natural phenomena from subatomic particles to bio-

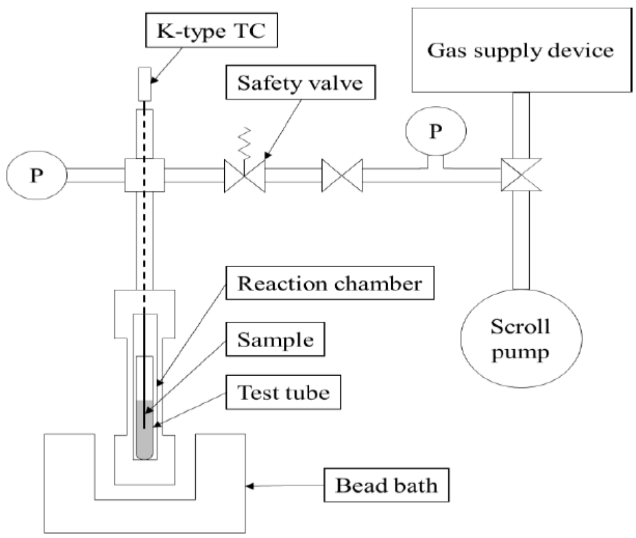
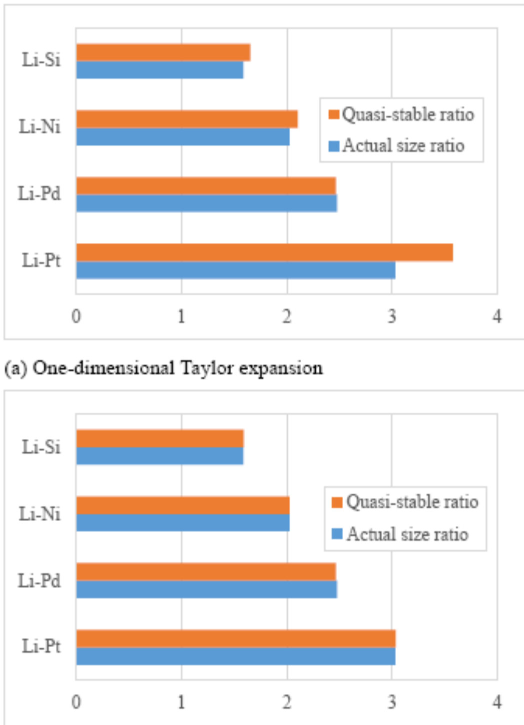



**Figure 17.** Constant-volume reaction chamber [18].




(b) Multi-dimensional Taylor expansion

**Figure 18.** Prediction of size ratios of atoms produced in cold fusion. (a) One-dimensional Taylor expansion. (b) Multi-dimensional Taylor expansion.

logical cells in the living beings, are described by momentum equation (Eq. (1)) having stochastic term $\delta_{st}$, while $\varepsilon$, $\gamma_k$, and $\bar{t}_k$ denote size ratio of connected two particles and deformation rate of particle $k$ and dimensionless time of particle $k$ (=1, 2), with the other constants $m$ and $\Delta m$ of order of surface force and degree of indeterminacy of contact position of connected particles [20–23].

$$\frac{d^2}{dt_i^2}\gamma_i = \frac{1}{Det}\left\{\begin{array}{l} \left[\left(-\varepsilon-\varepsilon^4+\frac{2}{3}\varepsilon E_{0j}\gamma_j^{-\frac{1}{3}}\right)B_{0i}+\frac{2}{9}\varepsilon^{4-2\Delta m}E_{0i}\gamma_i^{-\frac{4}{3}}\right]\left(\frac{d}{dt_i}\gamma_i\right)^2 \\ +\left(-\varepsilon-\varepsilon^4+\frac{2}{3}\varepsilon E_{0j}\gamma_j^{-\frac{1}{3}}\right)C_{0i}\gamma_i^{\frac{5}{3}-\frac{2}{3}m} \\ +\left[\frac{2}{3}\varepsilon^{2+m-\Delta m}E_{0i}\gamma_j^{-\frac{1}{3}}B_{0j}-\frac{2}{9}\varepsilon^{2+m-\Delta m}E_{0i}\gamma_j^{-\frac{4}{3}}\right]\left(\frac{d}{dt_j}\gamma_j\right)^2 \\ +\frac{2}{3}\varepsilon^{2+m-\Delta m}E_{0i}\gamma_j^{-\frac{1}{3}}C_{0j}\gamma_j^{\frac{5}{3}-\frac{2}{3}m} \end{array}\right\}+\delta_{st} \qquad \text{(A.1)}$$

$$[\text{for (i, j)} = (1,2),\ (2,1)]$$

$$Det = -\varepsilon-\varepsilon^4+\frac{2}{3}\varepsilon^4 E_{0i}\gamma_j^{-\frac{1}{3}}, \quad B_{0k}=\frac{1}{3\gamma_k}\frac{\gamma_k^2-2}{\gamma_k^2-1/2}, \quad C_{0k}=\frac{3}{8}\frac{2\gamma_k^{2m}-\frac{1}{\gamma_k^m}-\gamma_k^m}{\gamma_k^2-1/2}, \quad E_{0k}=3\frac{\gamma_k^{7/3}}{\gamma_k^2-1/2}$$

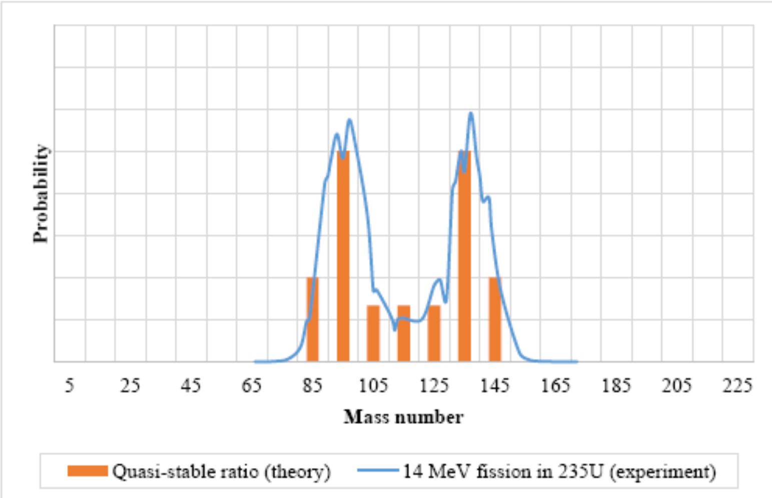



**Figure 19.** Prediction of mass distribution of atoms produced in nuclear fission of $^{235}$U [25].

Quasi-stability is defined as condition that one term in the right-hand side of Eq. (A.1) approximated by Taylor expansion becomes zero, which is weaker than the neutral stability [20–23]. By using this quasi-stability after performing one-dimensional Taylor expansion for Eq. (A.1), the bi-modal size ratios of 1:1 and about 2:3 for atoms produced in fission of uranium 235 is qualitatively revealed [20–23].

In our previous report using multi-dimensional Taylor expansion [24], size distributions for biological molecules in DNA and protein are quantitatively explained. Thus, in this report, we apply multi-dimensional Taylor expansion to predict size ratios of atoms produced in cold fusion, which results in quantitative predictions, especially for Li–Pt (Fig. 18).

In addition, we proposed a method to estimate the mass distribution of atoms generated by nuclear fission, by classifying the terms of multi-dimensional Taylor approximation equation of Eq. (A.1) (Fig. 19) [25].