Title	Elucidating the mechanism of combustion and making use of it to create solutions for environmental problems and advanced manufacturing : Research into combustion without CO2 emissions and combustion-based materials synthesis
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Associate Professor Takeshi Yokomori is featured in this issue, whose field of research focuses on combustion-based manufacturing by elucidating the highly efficient mechanism of combustion that minimizes waste.

Elucidating the mechanism of combustion and making use of it to create solutions for environmental problems and advanced manufacturing

Research into combustion without CO_2 emissions and combustion-based materials synthesis

The phenomenon called "combustion" is indispensable to internal combustion engines, such as automobile and aircraft engines and gas turbines that constitute the core of power generation plants, among others. Although it is a long-standing field of research, piles of challenges are yet to be overcome to burn things with high efficiency and minimizing the environmental load. Associate Professor Takeshi Yokomori is an up-and-coming researcher engaging in both fundamental research into the mechanism of combustion and applied research focused on combustion-based materials synthesis.

Improving efficiency and environmental load by developing better methods of combustion

Dr. Takeshi Yokomori pursues "combustion" as his main research theme. The study of combustion itself has a long history. It saw phenomenal development especially after the era of Industrial Revolution from the mid-18th century to the 19th century, when a variety of systems such as steam locomotives, automobiles, aircraft and power generators, which are driven by internal combustion engines, were invented and widely used as vital infrastructure supporting our modern lifestyle.

"Most of the energy sources for combustion are fossil fuels and it is said that oil will be depleted in about 50 years and coal in about a century. This rather pessimistic outlook makes it an urgent issue for humankind to develop highly efficient ways to utilize these limited resources," remarks Dr. Yokomori.

For example, even T. Corporation's hybrid vehicle, which has a reputation for good fuel efficiency, still remains at a thermal efficiency of 38%. This means much of the energy available from fuel is thrown away in the form of exhaust gas and the like. As such, improvement of fuel's thermal efficiency continues to be a great challenge.

At the same time, CO_2 emissions responsible for global warming are another issue of serious concern relating to combustion. Furthermore, air pollution, which was once a great social issue in Japan, and the ever-aggravating problem of PM2.5 currently facing China and neighboring countries, can be attributed to improper combustion. So history sees the scope of combustion studies now expanding to include environmental measures in addition to pursuit of efficiency.

Dr. Yokomori continues, "However, phenomena related to combustion are so complicated that many things about combustion remain unknown even today." "To elucidate combustion, we need to know the flow and diffusion of air and particular substances as well as the state of heat that changes with a lapse of time. We must also identify chemical reactions occurring there. A number of intertwined elements develop simultaneously, which makes combustion phenomena difficult to understand." (See Fig. 1)

As you know, a specialized field is established for each field of study – whether it is about fluids, chemical reactions or whatever else. This means scientific elucidation of any subject is not an easy attempt. Despite such difficulty, Dr. Yokomori dares to bring combustion problems to light not by the conventional rule of thumb but through theoretical approach and by making the most of simulations.

Investigating methods of combustion that do not generate CO_2 or NOx

Of the many research themes Dr. Yokomori deals with, the major one is to develop a combustion method that minimizes CO_2 emissions.

"The burning of fossil fuels necessarily emits CO_2. I'm now involved in an attempt to develop a method that allows the produced CO_2 not to be emitted into the atmosphere. Specifically speaking, I'm

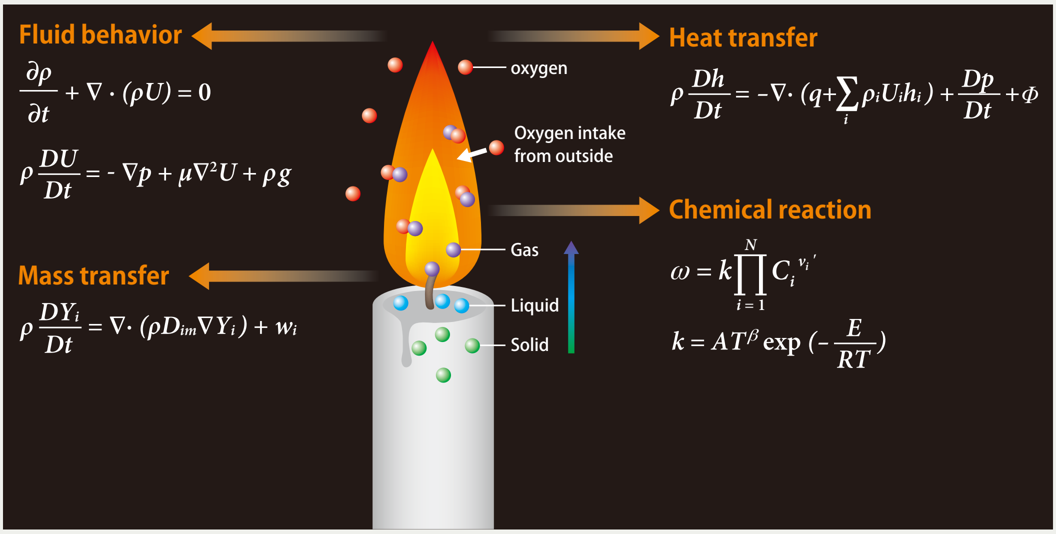
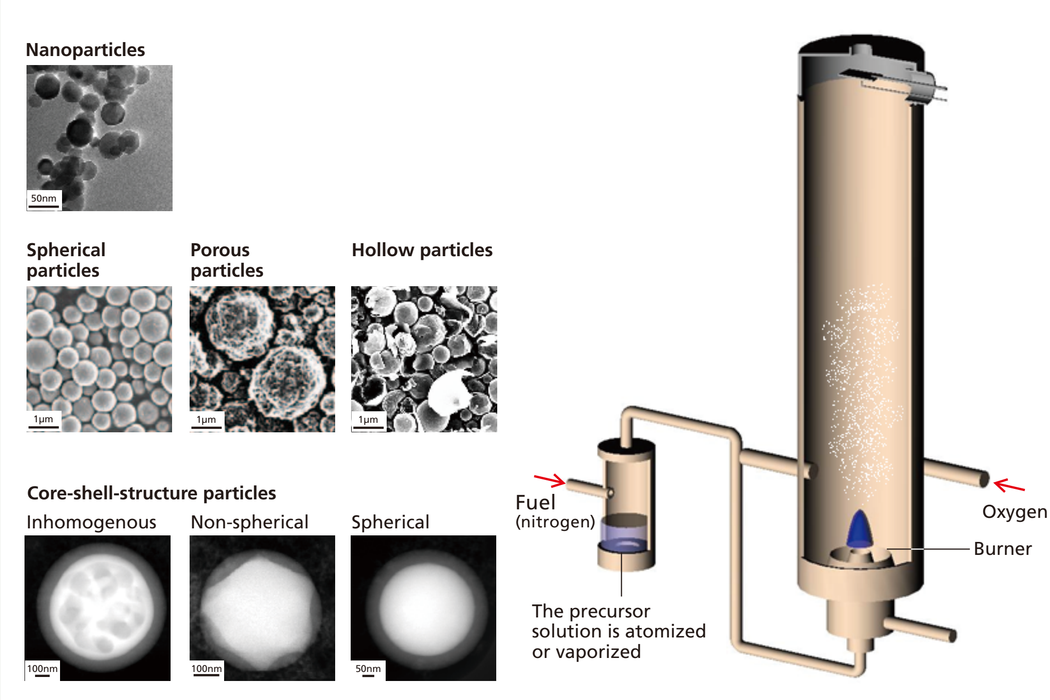


Fig. 1 Difficulties in understanding combustion
To elucidate combustion, we must address a number of element phenomena simultaneously, such as fluid behavior, heat transfer, mass transfer and chemical reactions. Indeed, there are still so many things to be clarified.

Fig. 2
Examples of particles synthesized in the lab
Based on knowledge obtained through combustion studies, the Yokomori lab is creating a variety of ultrafine (nm or μm in size) substances that can be used for a wide range of applications. Various substances shown on the left could be created using the device shown on the right.



thinking of using pure oxygen, not air, for combustion," he explains.

Air contains nitrogen. So if you use oxygen in place of nitrogen, combustion will produce only CO_2 and water (H_2O). Then it will become possible to collect CO_2 only by cooling the combustion gas and taking out the condensed water. In Japan, methods for preventing collected CO_2 from being emitted into the atmosphere – by compressing it into liquid and storing it on deep-sea bed, for example – are being examined. Naturally, Dr. Yokomori's research is attracting attention from interested circles.

"Yet, my attempt is not without problems. Use of oxygen for combustion raises temperatures as high as 3000℃. Combustion systems currently available cannot stand such high temperatures. To reduce the oxygen content, therefore, We're racking our brain to keep the current combustion temperature range of 1500 to 2000℃ by returning the emitted CO_2 to a furnace and circulating it there. This is a breakthrough approach and its possibility is being examined by members of a study group within the Combustion Society of Japan."

Then, at what levels should oxygen and CO_2 content be maintained to realize optimal combustion? He says he is seeking the answer through experiments and simulations.

"The key point of optimal combustion lies in the base of the flame. Its control holds the key because the flame itself will go out and vanish unless a proper amount of oxygen is supplied to that part of the flame. This is one of the most critical problems for large plants like thermal power plants, where combustion should never be suspended to maintain operation."

He is also involved in research into methods to prevent nitrogen oxides (NOx) from being generated in the process of combustion. This technology is particularly required by systems like aircraft in which post-processing equipment cannot be installed due to weight and/or space limitations.

"NOx is prone to be generated during combustion especially when nitrogen content is high and the flame temperatures reach as high as 1800℃. So it is necessary to control the amounts of air and fuel always in a balanced condition. To be specific, we control temperatures and combustion by adopting a two-step system. With this system, we put in a relatively large amount of fuel to keep temperatures within a certain level, then blow a large amount of air into the remaining fuel to burn it again."

Under normal circumstances, you can achieve efficient combustion if you burn the fuel at high temperatures. So the major challenge here is how to increase efficiency while minimizing the load on the environment, he points out.

Creating a variety of oxides by combustion-based materials synthesis

Yet another research theme Dr. Yokomori is addressing is the synthesis of "oxides" such as ceramic materials used as structures, titanium oxide mainly used as photocatalyst, and fluorescent substances used in diverse applications such as LED and biomarkers.

"Oxide crystals can be created relatively easily by means of oxidation reaction, for which knowledge obtained through combustion studies can be useful. Accordingly, we are creating ultrafine substances of nm or μm in size that could be used for a variety of applications. What makes our technology unique is the use of pure oxygen; by heating a particular substance at high temperatures of between 2000 and 3000 ℃, it is possible to create excellent crystalline structure. Another great advantage is that we can easily create a variety of substances simply by changing ratios of materials." (Fig. 2)

Though it is not yet a widely known approach, much is expected of combustion-based materials synthesis as a method for creating functional materials that have good crystal structures. Because of this advantage, the method is attracting business inquiries from a number of industrial companies, he mentions.

"On the other hand, in this materials synthesis process based on high-temperature combustion, chemical reactions and crystallization take place in a very short period of time – in a matter of several milliseconds. As such, it requires thorough understanding and control of its process and mechanism to create an exactly targeted material. As far as this problem is concerned, much still remains unsolved, which is very intriguing and challenging as a theme of research."

"I would like to develop new technologies useful for society by expanding into materials synthesis and other applied fields while continuing to pursue combustion theory construction as the base of my research activity," concludes Dr. Yokomori with a bright, motivated look.

(Reporter & text writer : Madoka Tainaka)