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2014 November
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Combustion Science

from Keio's Faculty of Science and Technology

For perfect command of flames

Takeshi Yokomori

Associate Professor
Department of Mechanical Engineering

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

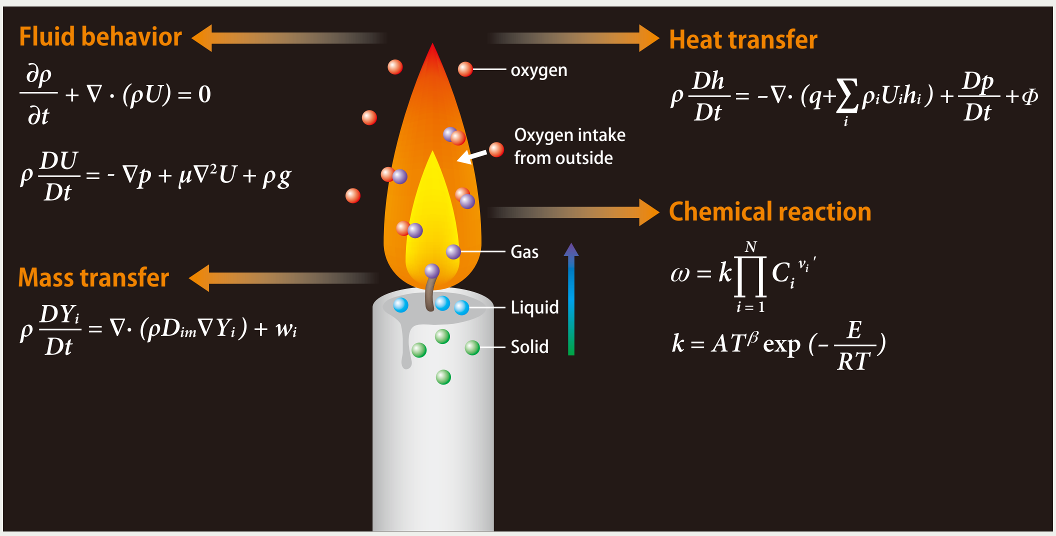
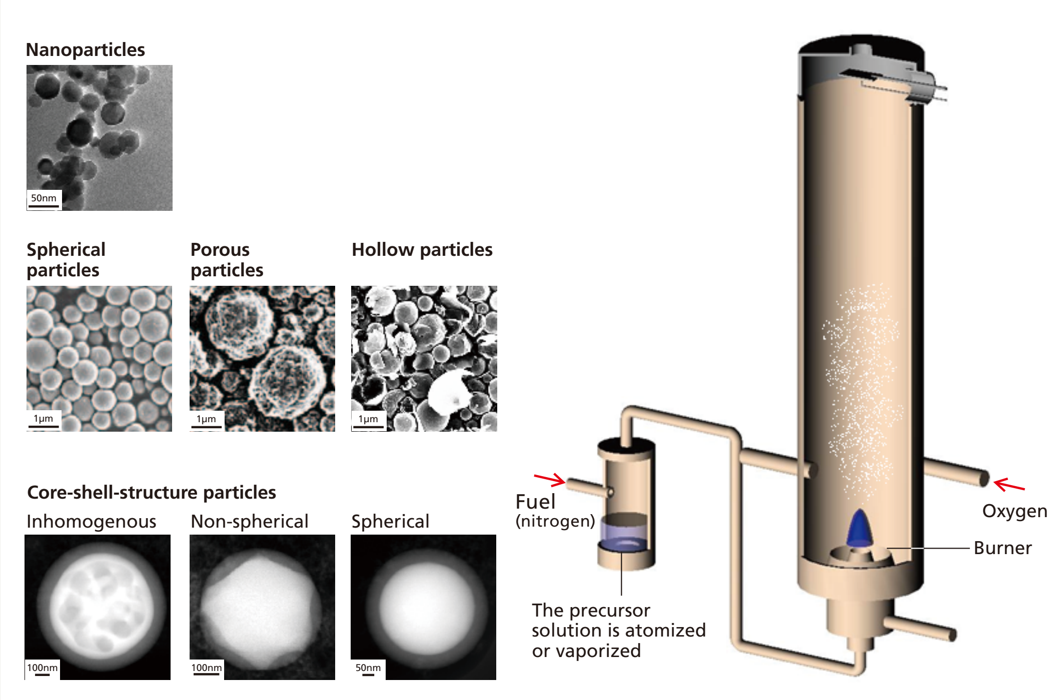


Fig. 1
Difficulties in understanding combustion
To elucidate combustion, we must address a number of element phenomena simultaneously, such as fluid behavior, heat transfer, mass transfer and chemical reactions. Indeed, there are still so many things to be clarified.

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.

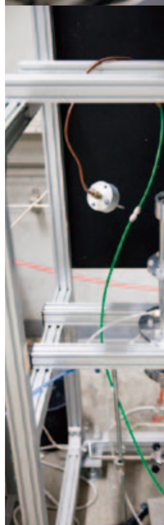
"On the other hand, in this materials synthesis process based on high-temperature combustion, chemical reactions and crystallization take place in a very short period of time – in a matter of several milliseconds. As such, it requires thorough understanding and control of its process and mechanism to 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)

What I have acquired by putting myself in an environment where I could devote myself to research, and through efforts day in and day out

A boy, who loved rockets, grew up and met the world of "combustion study." Blessed with diligent friends, excellent seniors at the lab, encounters with internationally-minded professors and through study abroad, he acquired a researcher's attitude of always making assiduous efforts. Dr. Yokomori puts it emphatically: "Work untiringly, and the way out will surely come into sight sooner or later" even when you are at a deadlock.



What was your childhood like?

As a young boy, I was extremely fond of space shuttles and other rockets. When a rocket is launched into the sky, you see blazing flames from its tail end, don't you? Fascinated by the powerfulness of the flames, I came to take an interest in rockets. As I recall, I may have been interested in combustion as early as those days (Laughter).

My father was running an electrical work company in Tokyo. He took me to work sites from time to time. As a junior high school student, I began to assist my family business in wiring work and equipment installation on site, which naturally awakened my interest in scientific studies.

On the other hand, as an elementary schoolboy I began to attend a tutorial class, where I was awakened to the excitement of solving mathematics problems. When I was an elementary school sixth grader, my mathematical ability reached the college level, for which I was awarded. This event motivated me to study mathematics more and more. Maybe I am a person who can grow when complimented by others (Laughter). My parents seem to have known my character well, so they never urged me to study hard.

It was at about the age of senior high school third year that I began to become conscious of my future. Perhaps because of my father's influence, I thought it would be nice if I could advance to electrical engineering department or mechanical engineering department. Although I was prepared to take a year off in the worst case, fortunately I was admitted to Keio University Faculty of Science and Technology to join the Department of Mechanical Engineering.

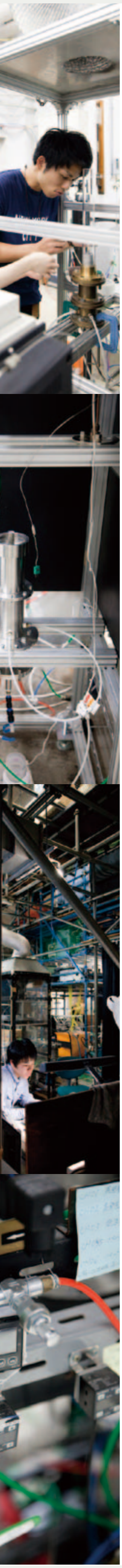
What was your university life like?

My life had been club activities-centered up to and through my high school days. After entering the university, however, my awareness of life turned around and I began to focus on study. Studying itself was not a headache because I was blessed with good friends, with whom I could compete in a friendly manner. All of my good friends were bright; in fact, three out of four including myself advanced to the doctor's course. Of course, our life was not limited to studying. We often played together and, after having come of age, we enjoyed drinking together almost every weekend, which is a good memory I still cherish.

Why did you take up the study of combustion?

When I visited Professor Masahiko Mizomoto's lab for inspection, seniors at the lab talked about combustion, which aroused my interest in this theme. After joining the Mizomoto lab, I was fascinated by combustion and soon found myself delving into this research theme with heart and soul.

The study of combustion is truly profound. For example, if you are going to simulate a certain combustion phenomenon, you must simultaneously solve problems related to elements such as fluids, heat, diffusion and chemical reactions of substances involved. Depending on the target, it can take more than a month even by using a supercomputer. Moreover, much still remains unsolved in fundamental theories, which makes fundamental research into combustion very exciting. I became increasingly



Creative ideas for research rarely come up all of a sudden. Any good idea can take shape only after making constant efforts.

Takeshi Yokomori

Dr. Yokomori was born in Saitama Prefecture, Japan. He graduated from the Mechanical Engineering Department of Keio University Faculty of Science and Technology in 1998, and then completed the doctor's course at the Graduate School of Science and Technology (School of Science for Open and Environmental Studies) without degree in 2003. In March 2004, he obtained a doctor's degree (Dr. Eng.). Then he successively served as postdoctoral fellow for the Institute of Fluid Science, Tohoku University; research fellow for the Japan Society for the Promotion of Science; and visiting researcher for the Department of Mechanical and Aerospace Engineering, Princeton University of the U.S. In April 2007, he joined Keio University Faculty of Science and Technology as assistant professor, and then assumed the current position as associate professor in April 2013.

inclined to study the basics. This is why I decided to advance to the doctor's course.

Later, from September 2003, I began to work in Tohoku University as a postdoctoral researcher. Experiences I acquired there marked a major turning point in my life. Professor Kaoru Maruta, the boss of our lab, was so internationally minded that renowned researchers frequently visited the lab from overseas to meet him. Encounters with these foreign researchers were truly valuable because I learned the importance of global communication and was able to broaden my perspective.

This motivated me to study abroad; I decided to study at Princeton University for one year from April 2005 as a research fellow for the Japan Society for the Promotion of Science.

How did you find your researcher life abroad?

Honestly speaking, really tough. At the beginning I couldn't find a fixed place to live in, so I had to move from one place to another, asking professors and other acquaintances for shelter for the first two weeks or so. To make the matter even worse, my English communication ability was extremely poor, which almost made me homesick after only two weeks or so (Laughter). I still remember that I had a hard time even opening a bank account.

I found Chinese students here and there on the campus where I learned, but very few Japanese. I could find only one Japanese person in another department. My mentor, Prof. Yiguang Ju, was also Chinese. He is a truly bright person. He is internationally minded as well as logical in thinking and acting. Not only that, he also has a very agreeable personality. I respect him very much as a researcher.

Was it necessary for you to study abroad after all?

Yes. Speaking for myself, I was lucky because I was able to experience a lifestyle that allowed me to have discussions and think together, at any time, with foreign researchers who were thinking only of research around the clock. Because of this valuable experience, my lab at Keio follows the Princeton University style.

I would like to advise those students, who wish to choose a researcher's career, to study abroad as early as possible, preferably by the age of 30 at the latest.

Do you have any creed that you value as a researcher?

Creative ideas for research rarely come up all of a sudden. Any good idea can take shape only after making constant efforts day after day, I believe. Of course, you may sometimes fail. But if you stick to it untiringly, I'm sure the exit will surely come into sight sooner or later. If you capture something exciting in this way, you can appreciate a sense of major achievement. That should be the zest for researchers.

In this connection, my overall impression of Keio students is that they are smart. In a negative sense, they are shrewd. So, if they learn to make constant efforts, there will be nothing to fear. I sincerely hope that they will acquire such abilities.

How are you spending your holidays?

I often go out to countryside onsen hot-spring resorts with my friends. I recently visited Dake Onsen in Fukushima Prefecture. Dake Onsen features hot waters of strong acidity. The open-air hot-spring bath I enjoyed there was really wonderful. Another diversion is drinking Japanese sake. I sometimes drink with my students to relieve accumulated stress.

◎ Some words from students . . . ◎

● Dr. Yokomori is an earnest, reliable teacher, who readily gives advice whenever we have a problem. What makes him great is his policy; he is kind but never spoils us, leading us to be independent. He is strict when it comes to research, but likes to go on a spree together with us at drinking parties – an unexpected aspect of his personality.

(Reporter & text writer : Madoka Tainaka)

For the full text of this interview
http://www.st.keio.ac.jp/kyurizukai

All-member group photo

This is a group photo with all Yokomori lab members. Prof. Ueda and his lab members are also shown here because the Yokomori lab is closely working with the Ueda lab.

Lab seminar (study session)

Our lab holds seminars (study sessions) twice a week. A student in charge of a particular seminar serves as an instructor, lecturing on other students' research subject matters related the session's theme. Thus, all participants develop active discussions.

Engaging in research

Upon setting about research into combustion, we conduct leading-edge experiments such as laser instrumentation and measurement. I work together with students daily, repeating trials and errors toward new discoveries.

Yokomori Lab's Four Seasons ON and OFF time

Here I'd like to introduce Yokomori lab ON time activities as well as OFF time as viewed through major seasonal events.

Summer: Study camp

Every summer we visit the seaside or mountains for an overnight stay, where we enjoy sports, barbecue, camping, etc. This event serves as a good opportunity for the lab members to further solidify mutual bonds.

Spring: Cherry blossom viewing

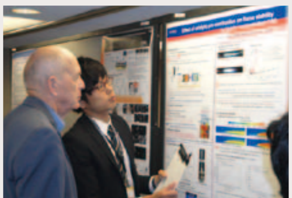
In early April when lovely cherry blossoms are in full bloom, all of us go out to enjoy cherry blossom viewing. Seniors, who have become new lab members, also participate in this event, marking the start of a new year for the campus.

Winter: Hot-pot party

For the cold winter season, nothing could be better than hot pots! Lab members are divided into several teams, who prepare their own hot pots – seasoned with soy sauce, miso (bean paste) or salt – and vie for tastiness. Could your team cook a tasty hot pot? Some say victory depends on the leadership of your "pot magistrate".

Autumn: Seasonal taste party

Autumn brings a wide variety of delicious treats to the table. We have a lively party to chat over tasty dishes while refreshing ourselves to prepare for research work toward the busy Year End season.



Presentation at international conventions

Our lab encourages its members to participate in international conventions as venues for presenting their research results. Our participants also accumulate international exchange experiences through active discussions with front-line researchers from around the world.

Open lab

On the Open Campus day and other occasions, we open our lab to interested visitors. Some appear surprised at an experiment demonstration using a large blazing flame, which is a rarity.

Graduation

March is when some of our undergraduate and graduate students graduate. Some advance to higher education while others find employment with businesses. Whichever the future course, they fly away toward their bright futures.

Japanese *sake*

Japanese *sake*, in a sense, serves as a vital fuel for our lab activities. We like to enjoy famous-brand *sake* from around Japan. Naturally our students gradually become familiar with brand names and other *sake*-related information.

私の本棚

My favorite books

Midnight Express

Authored by Kotaro Sawaki, this book is a travelogue of his own experiences as a backpacker. It vividly conveys excitement, difficulties and local situations experienced by Sawaki in foreign countries as he wandered from one country to another. It surely makes the reader feel like setting out on a journey. I was no exception. In fact, I carried a backpack and visited Egypt and other countries during the spring holiday season of my undergraduate days.

Combustion Theory – Second Edition -

This book provides detailed explanation of combustion phenomena theoretically and mathematically, which makes it a "classic" in this field. It approaches combustion from a perspective of reactive fluid dynamics and make effective use of numerical formulas to describe specific phenomena. While this book may be a bit difficult for some readers, it is safe to say that its descriptive style is beautiful. It's the most important reference book for the theoretical understanding of combustion.

Combustion Physics

This volume was published in 2006 based on a textbook that Prof. C. L. Law, Ex-Chair of the International Combustion Society, had prepared and used for his own lectures at Princeton University. It explains combustion thoroughly and in an easy-to-understand way, the contents ranging widely from chemical reactions and other basic aspects to the latest combustion theories. At present, it is one of the world's most widely used textbooks on combustion.

H-II Rocket Skyward!

Backed by a variety of data, this book is a detailed account of the path to the successful launch of Japan's domestic H-II Rocket. It became a reality after engineers and researchers involved in the rocket development overcame many difficulties and failures. I decided to become a researcher partly because this book motivated me and I found being a researcher would be cool.

Combustion, Flames and Explosions of Gases – Third Edition -

Using a phenomenological approach, this reference book introduces combustion phenomena in a systematized, easy-to-understand way based on a variety of experimental data. As such, the book is a "Bible" among researchers specializing in combustion experiments. Even today, 30 years after the book was first published, its contents and data remain fresh and useful, allowing it to be used in a wide range of research fields.

Fundamentals of Combustion Phenomena

A number of renowned Japanese researchers coauthored this introductory book on combustion engineering for the development of combustion studies in Japan. While its primary aim is to promote the understanding of fundamentals of combustion phenomena, the book also introduces the latest topics. As such, I strongly recommend all those, who are involved in combustion research, to begin by reading it.

Work assiduously – this is the key to success

Takeshi Yokomori

As you may know, combustion – my field of research – is the most familiar technology that we humans have been using since the earliest times.

Some of you may have had this experience before: For example, if we are going to make fire without using modern tools just as ancient people did, it will require an enormous amount of labor – like forcibly rotating a wooden rod on straws to generate frictional heat sufficient enough to make fire. Today, however, you can cause this phenomenon very easily using a home-use gas stove. Furthermore, this phenomenon is used in various aspects of our modern life, such as for making gigantic flames that can generate thousands of tons of thrust for a space rocket, and for causing combustion inside an automobile engine that rotates thousands of times per minute. We must remember that our modern lifestyle has behind it heaps of knowledge and technologies we humans have accumulated untiringly through countless years.

I first became involved in combustion research as an undergraduate senior when I was about to be assigned to one of the many labs at Keio's Faculty of Science and Technology. I knocked on the door of Prof. Masahiko Mizomoto's combustion lab. I already had a strong interest in research from the beginning of assignment to the lab. Judging from my experience of lecture and experiment classes, at the beginning I underestimated the workload at the lab, thinking that I'd be somehow able to deal with it. But once I actually became involved in research activity, I suddenly found the reality much, much harder than I expected.

The study of combustion that I target not only involves diverse academic elements (fluid dynamics, thermal dynamics, chemical reactions, etc.) but it is also supported by a long historical background and accumulation of knowledge and technologies developed by our predecessors over the years. This means that we need to develop truly creative ideas in research. Furthermore, we need, as the base, an enormous amount of knowledge sufficient enough to persuade others. Once I realized the almost endless ways to go, I'm making steady, strenuous efforts from day to day.

Whatever the field may be – not limited to research and technological development – anyone (athletes, businesspersons, etc.) who is active at the front line has achieved their success through untiring effort, as you know.

I believe making assiduous efforts from day to day is requisite to achieve anything valuable – large or small. I know I'm still immature as a researcher, but I'm determined to continue striving steadily.

Science and Technology **Information**

Introducing Keio's "Program for Leading Graduate Schools"

The "Program for Leading Graduate Schools" is a project initiated by the Ministry of Education, Culture, Sports, Science and Technology, aiming to produce outstanding graduates capable of serving as internationally active leaders with a wide range of expertise and creativity.

Science for Developing a Super-Mature Society

~ To nurture and produce outstanding talented persons of the future with doctoral degrees ~

This ideal form of science aims to nurture and produce outstanding talents of the future with doctoral degrees who can lead the sustained development of the coming super-mature society. It will be pursued in an innovative educational environment that seeks integration of arts and sciences as well as collaboration with the business and administrative sectors.

Features:

① Chooses and employs research assistants (RAs) from Keio's 13 graduate schools as early as the master's course stage (aim: publicizing the appeal of their future professional careers at an early stage).

② RAs will learn in a genuine environment that seeks integration of arts and sciences ("Joint Degree System" established).

③ Guidance will be provided by mentors (division-manager class) from leading Japanese businesses, etc.

④ "Watering Hole" effect expected (various people come to a designated venue every week to mutually inspire).

GESL

Global Environmental System Leader Program

~ To nurture global environmental system leaders with abilities to develop new environmental science and technology and to propose desirable social rules ~

This program aims to nurture "global environmental system leaders" of the future with the awareness, knowledge and expertise to sustain and improve the global environment. They are expected to be able to design and structure technological and social systems targeting the global environment.

① International Academia-Industry-NPO collaborative advisory group (an international team consisting of 3 or more teachers and/or specialists).

② International training system (overseas field work and internship).

③ Remote collaboration system (use of a system capable of intuitively manipulating/editing 3D data on the Web, a teleconference system, and a system for multimedia sharing/analysis and visualization).

Editor's postscript

While interviewing him, I was very impressed with Dr. Yokomori's eyes twinkling like a boy. At the start, he appeared a little tense, but became fueled as he explained about his research work. Toward the end of the interview, he became relaxed with smiles and enthusiastically talked about the importance of students turning their eyes to overseas activities.

The lab exuded a nostalgic atmosphere because of an old experiment space still intact that Dr. Yokomori made using single pipes when he was a student. The photographer clicked the shutter excitedly, saying "What an impressive atmosphere!" We were also impressed with flames in the furnace emerging fantastically against darkness. We used this shot for the front cover. (Manami Matsubayashi)

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