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# Development of a Model Instrument of Thermal Power Plant for Understanding of Air Pollutant Generation

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## ABSTRACT

In order to deal with current environmental issues and their backgrounds, further development of current teaching methods and tools are essential. The result of questionnaire performed in this study indicates that the effect and the change of the perception of power generation in Japan after the great disaster of East Japan have caused many students (both high school and college students) to become interested in the energy situation. In the present study, we made an attempt to develop a model instrument of a thermal power plant that can be applied as a teaching tool for understanding of air pollutant forming as well as power generation. Our novel model tool consists of a body (30 cm width, 21 cm depth, and 41 cm height), a combustion chamber, two motors, a boiler, a voltmeter, and a chimney for measurement of exhaust gas. Using our novel hand-made power plant, we carried out some model experiments with learners (i.e. high school and college students). Through model experiments, students can be experienced not only about power generation but also about generation of air pollutants. In order to estimate the applicability of our novel instrument as an educational tool, we carried out the questionnaires before and after model experiments. More than 80% of educatees reported that it was very useful as a teaching tool for energy and environmental education. The results of questionnaires indicated that learners achieved a very deep understanding of the principles of power generation and the forming of air pollutants.

**Key words:** Thermal power generation, Air pollutant, Teaching material, Model experiment, Environmental education

## 1. INTRODUCTION

The energy and environmental issues of global scale are mainly caused by the consumption of fossil fuels and can threaten the continuation of mankind. In order to improve these problems, it is necessary not to use energy wastefully (Joseph *et al*., 2010; Peter, 1987). It is also essential to develop a deeper understanding of environmental issues and responsible decisions to address and prevent them. Individuals, especially children and students, need more interest and active understanding about environmental issues. There is a rapidly increasing of student's interest in the energy and environmental issues and a growing demand to develop sustainable energy systems (David *et al*., 2015; Youyi, 2015; Chacko *et al*., 2008). However, in order to bring the change of people's behavior, the improvement of educational methods is essentially needed (Ohgaki, 2013).

Under this circumstance, it is necessary to develop new experimental tools that are applicable to the education of energy and environment. Recently, numerous studies have been carried out for resolving the above problems, and text development for education to realize the systematical curriculum for environmental education. However, comparing the progression of global environmental issues with the situation in which it needs urgent action, the practice of environmental education is not always thoroughly established.

Nakamura *et al*. (2009) tried to develop a digital movie archive by forest monitoring for several days. The benefit of their teaching material was time and space expansion of environmental recognition, grasp of major pattern of nature, and efficacy which attracts children's interest. Kawamura (1993) developed an experimental teaching tool that demonstrates how global warming and cooling are caused by aerosols for environmental education. Furthermore, he discussed not only global warming by greenhouse gas but also global warming and cooling by aerosols.

In order to truly demonstrate the effects of energy related environmental problems (e.g., air pollution, global warming, and acid rain), more practical and engaging teaching tools are strongly needed.

The aim of this study was to develop a model instrument as a teaching tool to create a simulation for generating by fossil fuels, how power generation affects environment and a mechanism of generation air pollutant, and estimating its applicability.

## 2. PRELIMINARY QUESTIONNAIRE AND ITS RESULT

In order to assess the environmental awareness of students, we conducted a survey for 167 Japanese high school and college students. The high school students surveyed were the second year of the natural sciences track and they were receiving the environmental education once a week. Meanwhile, most college students who participated in our survey were the liberal arts students and they have not yet undergone any environmental class.

The question was "How much interest do you have in environmental problems?". The result of the survey shows that "interested", "neither", "not much interested", "well interested", and "not interested" accounted for 52%, 20%, 13%, 11%, and 4%, respectively. More than half of those who answered the survey question reacted positively (i.e., both "interested" and "well interested"). This suggests that a large portion of Japanese students have an active interest in environmental issues.

Furthermore, we carried out another survey about "What environmental issues are you most interested in?". Fig. 1 shows the results of this questionnaire. "energy problem" accounted for 37%, followed by "global warming" (33%), "depletion of the ozone layer" (9%), "air pollution" (7%), "waste problem" (6%), "acid rain" (4%), deforestation" (3%), and "water pollution" (1%). This result indicates that both of "energy problem" and "global warming" became a hot topic related to energy and environment for Japanese students. Therefore, it is suggested that something needs to be done about energy and its impact on the environment in the chalk face.

Before Fukushima, the Great East Japan Earthquake on March 11, 2011, the Japanese government planned an increase in zero-emission energy (i.e., renewable energy) rising from 6% in 2007 to 13% in 2030 and nuclear power rising from 10% in 2007 to 24% in 2030 (2010 edition Japanese White Paper on Energy, 2010). However, because of energy instability after Fukushima, it has to launch a new energy policy (Richard, 2013). As the result, fossil fuels play an important role in Japan after the Fukushima. Simultaneously, it has to promote energy efficiency and protect the environment because fossil fuels easily cause various environmental issues.

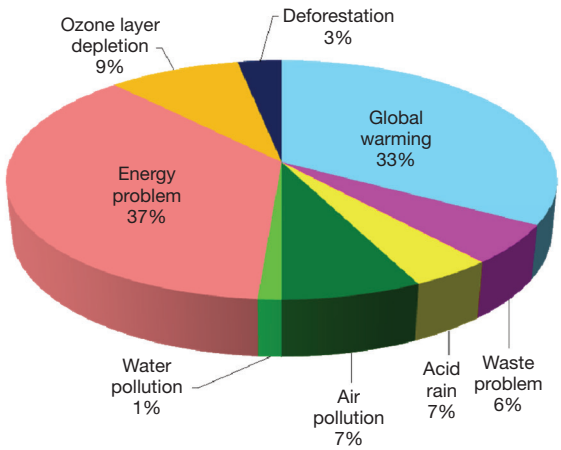


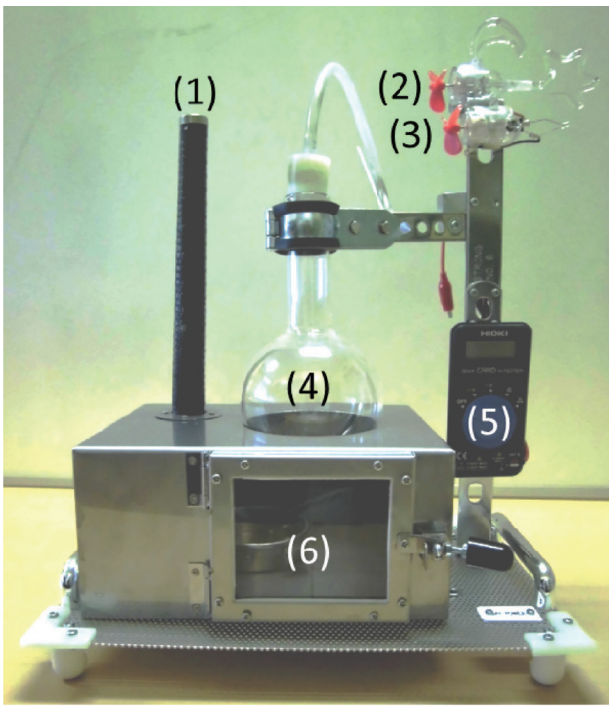

**Fig. 1.** Result of a questionnaire about "What environmental issues are you most interested in?" for high school and college students (n = 167).

## 3. DEVELOPMENT OF SELF-MAKABEL MODEL INSTURMENT FOR THERMAL POWER GENERATION

In this study, we suggested a self-making model instrument for thermal power generation as a teaching tool for energy and environmental education. Our model instrument was designed for students, for example, high school and college students, village learners, people related to education or the environment and so on. It was designed to visually confirm power generation and to really measure exhaust gas from a chimney of model instrument. It mainly consists of a body (30 cm width, 21 cm depth, and 41 cm height), a combustion chamber, two motors, a boiler, a voltmeter, and a chimney for measurement of exhaust gas (see Fig. 2).

The set up procedure of the model instrument shown in Fig. 3 is as follows:

(1) Fix four legs on a basal plane made from incombustible metal.
(2) Set the glass door to the combustion chamber so you can check inside.
(3) Set a boiler on the combustion chamber and fix a pole to prevent it from falling down.
(4) Set a chimney (2 cm diameter, 30 cm height) as a measurement point for exhaust gas on the combustion chamber.
(5) Fix two small motors with LED bulbs (a voltage input about 2 V) on a pole.




(1) Chimney (2) Motor-1 (3) Motor-2 (4) Boiler
(5) Voltmeter (6) Combustion chamber

**Fig. 2.** Real view of model instrument for thermal power generation.

(6) Connect an LED to a voltmeter for measurement of the generation amount and another that can confirm the generation of electricity visually.

## 4. MODEL EXPERIMENT FOR THERMAL GENERATION AND MEASUREMENT OF EXHAUST GAS

The procedures adopted in this study for the experiment of thermal generations and measures of exhaust gas were summed up in Fig. 4 and details are as follows;

(1) Prepare mixed fuel. This mixed fuel is composed of 9 mL ethanol and 3 mL of kerosene.
(2) Burn fuel and boil water to create steam.
(3) Check generating from LED lighting by visual identification and from the amount of electric power generation of a voltmeter.
(4) Measure the exhaust gas from the stack of model instrument.

It is possible to directly measure exhaust gas from the stack. However, a gas measurement set is useful when a large number of educatees attend a model experiment. This gas measurement set (see the right bottom of Fig. 5) consists of a gas collecting bag, a syringe, a gas-detecting tube, and a gas inhalator.
(4-1) Collect exhaust gas with a syringe (see the left of

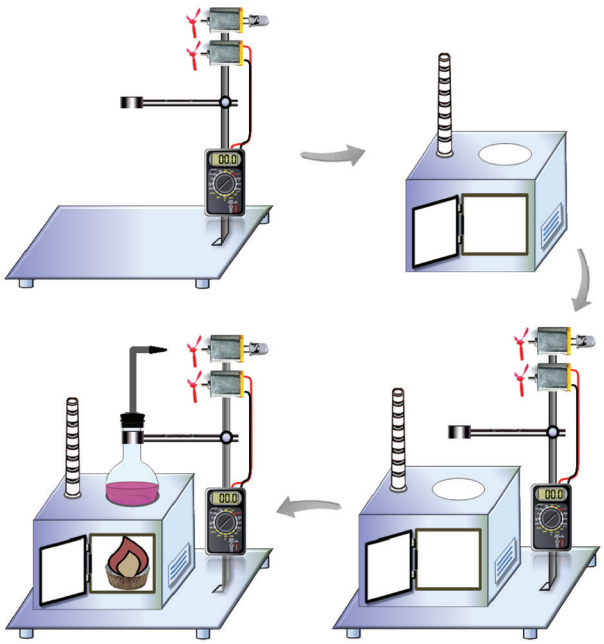


**Fig. 3.** The set up procedure of the model instrument.

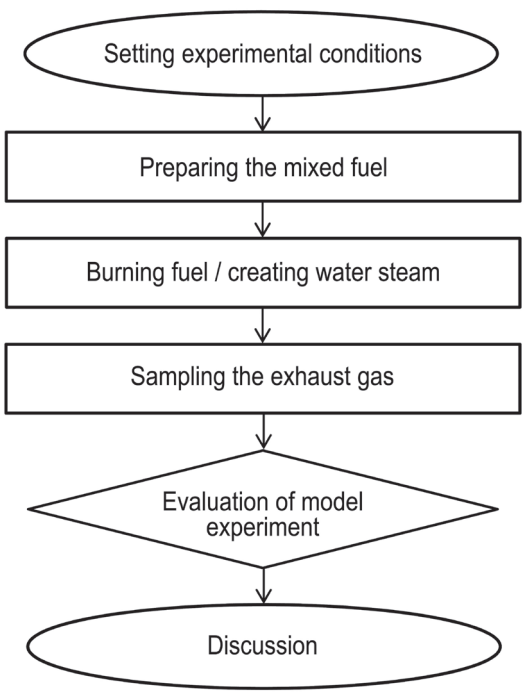



**Fig. 4.** Flow of the model experiment.

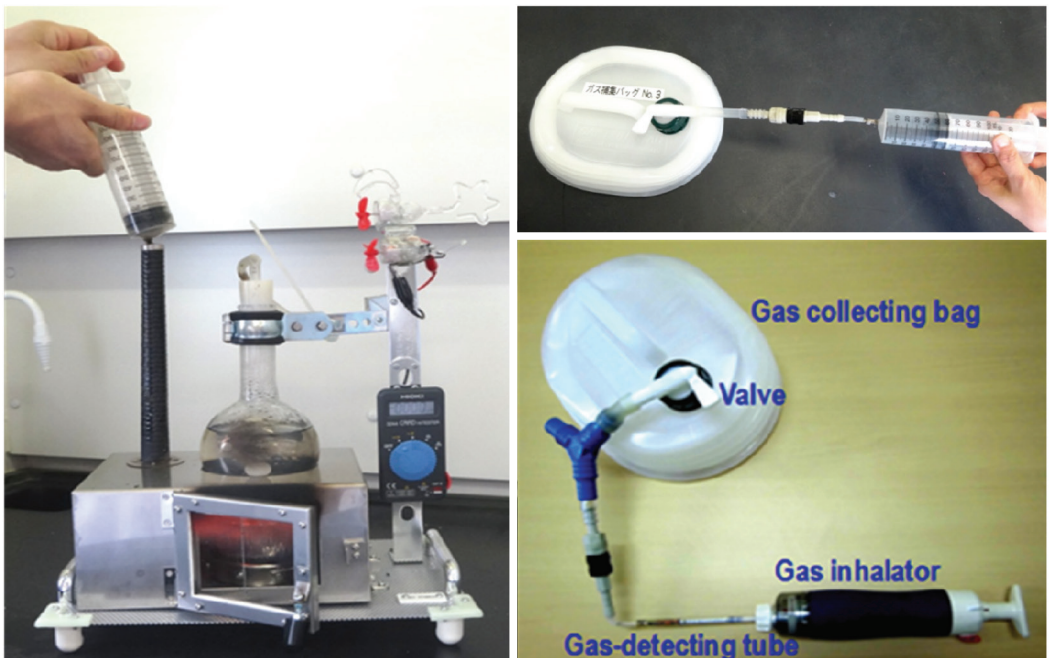



**Fig. 5.** Collection of exhaust gas from the stack of model instrument with a syringe (left), transferring collected exhaust gas into a silicone bag (right top), and a gas-detect set composed of a silicone bag, a detecting tube, and a gas inhalator (right bottom).

Fig. 5).

(4-2) Transfer collected exhaust gas into a silicone bag (see the right top of Fig. 5).

(4-3) Measure the concentration of CO, $CO_2$, and $NO_x$ from the exhaust gas by each gas-detecting tube.

A caution is needed to avoid the inhalation of exhaust gases during the model experiment. Therefore, the place with a well-designed ventilation system is appropriate.

## 5. RESULTS OF MODEL EXPERIMENT

Fig. 6 shows the blackish smoke emitted from the chimney (left), the rotating propellers by the successfully generated steam (right top), and the LED lighting (right bottom). As shown in Fig. 6, it was possible to visualize both air pollutant and the power generation. This visual effect can maximize the energy environmental education for the educatees, especially the lower grade students of elementary school. The voltage displayed by a voltage meter was around 350 mV and current marked about 0.25 A for each model experiment.

Moreover, it was possible to measure the concentration of gas emitted from the stack of our model instrument. The concentrations of three-kind gases (CO, $CO_2$, and $NO_x$) were measured by the gas-detect set shown in the right bottom of Fig. 5. The measured values of CO, $CO_2$, and $NO_x$ from 15 times model experiments were summarized in Table 1. Although the gas-detecting tube employed on this study was one of simplified methods, the measured data show a good reproducibility.

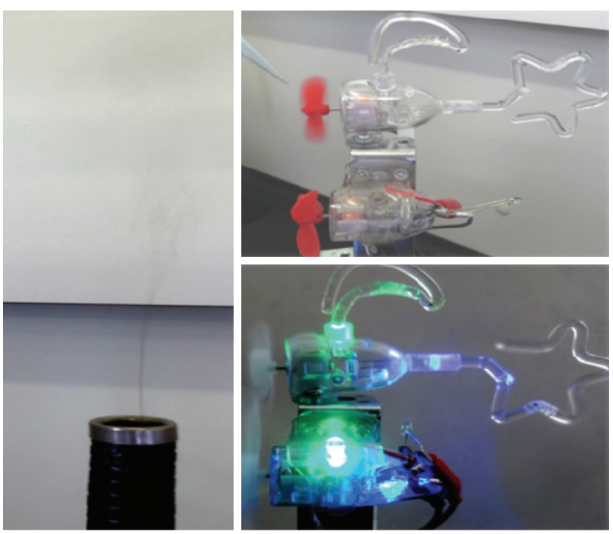


**Fig. 6.** The blackish smoke emitted from the chimney (left), the rotating propeller by the successfully generated steam (right top), and the LED lighting (right bottom).

The environmental quality standards of CO and $NO_x$ in Japan are following;

**Table 1.** The measured values of CO, $CO_2$, and $NO_x$ from 15 times model experiments.

| | CO (%) | $CO_2$ (%) | $NO_x$ (ppm) |
|---|---|---|---|
| Mean | 0.55 | 2.0 | 0.55 |
| S.D.* | 0.05 | 0.1 | 0.05 |

*standard deviation

The daily average for hourly values of CO shall not exceed 10 ppm, and average of hourly values for any consecutive eight-hour period shall not exceed 20 ppm. Meanwhile, the daily average for hourly values of $NO_2$ shall be within the 0.04-0.06 ppm zone or below that zone (The Japanese Air Pollution Control Law last amended by Rule No. 32, 1996). The concentration of CO measured in this study is overwhelmingly higher than that of Japanese ambient environmental criteria. On the other hand, in the case of $NO_x$, the measured value (0.5-0.6 ppm) in the present study shows the lower concentration than that of measured from the flue gas from coal thermal power generator in Sendai, Japan (The report of environmental effect assessment at the Sendai thermal coal power generator, 2015).

## 6. APPLICABILITY OF OUR MODEL INSTRUMENT AS A TEACHING TOOL

In order to assess the effect on energy and environmental education after the experiment with our model instrument developed in this study, we carried out a questionnaire survey of participants in experiments. The targets were high school and college students (sociology and science courses). We adapted partial questions to targets with differences in age and lifestyle. The questionnaires asking "Do you understand the principle of power generation?", "Do you think this model instrument has a novelty value as a teaching tool?", and "Do you want to do such this model experimental lesson at the school and society in the future?" were conducted before and after the model experiments.

Fig. 7 shows the summary about "Do you understand the principle of power generation?", namely, the variation of degree of understanding for the principle of power generation before and after the model experiments. Before the experiment, 25 to 50% of learners replied positively. However, 69 to 100% of learners gave a positive answer after the experiment. This result suggests that the participative experiment with our novel model instrument was readily intelligible to almost the all of learners who joined. An unusual feature of our results, namely, the reversal in the degree of understanding between high school students and college students, was found. It is clear that the high school students who took the environmental class scored higher degree of understanding compared to the college students who were inexperienced the environmental class.

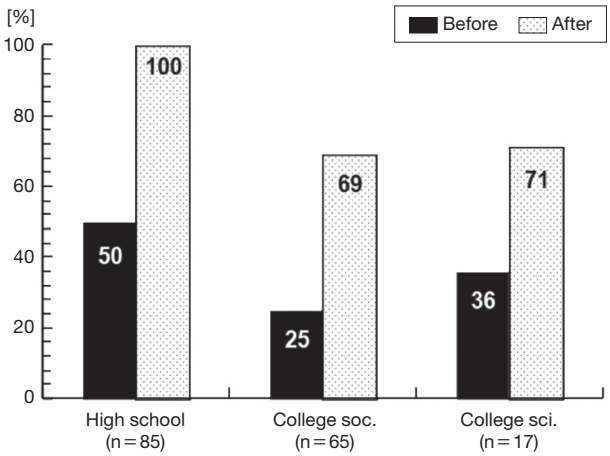



**Fig. 7.** Variation of degree of understanding for the principle of power generation between before and after model experiment.

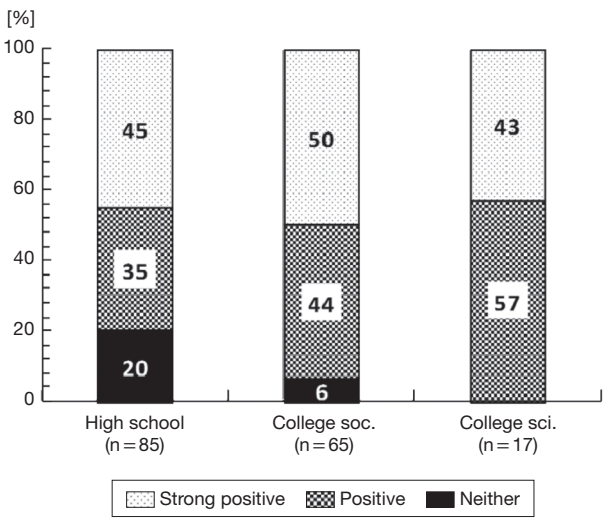



**Fig. 8.** The result of the question about "Do you think this model instrument has a novelty value as a teaching tool?" after the model experiment.

Fig. 8 shows the result of the question about "Do you think this model instrument has a novelty value as a teaching tool?" after the model experiment. According to Fig. 8, all of students of the college of science estimated our model instrument as the perfect teaching tool. The 80% of high school students and the 94% of

the college students of sociology cource replied positively. Therefore, it can be said that our novel model insturment has the high applicability as an effective teaching tool for energy and environment sbjects.

## 7. SUMMARY

Throughout the world, rapid increasingly consumption of energy source, especially fossil fuels, creates serious energy and environmental problems. Our daily attitudes and motivation are required to improve environmental quality. Whereas an even more advanced environmental education is needed strongly. A lot of high school and college students and adults in Japan are more interested in energy problems after the great disasters of East Japan in March of 2011. Under these circumstances, we made an attempt to develop a model instrument of thermal power generation as a teaching tool. Our model instrument provides a realistic experience of power generation based on the participative model experiment to students as well as citizens. Moreover, it was designed to really measure exhaust gas from a chimney of model instrument. The result of the questionnaire after model experiments demonstrates that our model instrument is useful as a practical learning tool that helps educatees and instructors make a visual connection between energy use and its effect on the environment. As a result, through the model experiments, it was also possible to help educatees have a direct sense of connection between energy use in their everyday lives and environmental quality.

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