CAER – University of Kentucky, Center for Applied Energy Research

Vol. 17, No. 5, 2006

Energeia

Development of the University of Kentucky – Toyota Research Partnership: Monozukuri: PART II

Kozo Saito
University of Kentucky

The first part of this article appeared in the last issue of *Energeia (v. 17 #4)* and can be found at: *http://www.caer.uky.edu/energeia/enerhome.shtml*

In the previous issue of *Energeia*, Dr. Saito explained the meaning of Monozukuri (a Japanese word consisting of 'mono' which means 'products' and 'zukuri' which means 'process of making or creating') and how this Eastern philosophy can be applied to technical problems to benefit all.

COMPUTATIONAL METHOD, GENCHI-GENBA CONCEPT, AND MONOZUKURI

Computational methods not only save time and energy, but also provide details in virtual-reality conditions under well-controlled initial and boundary conditions that may be difficult to achieve by experiments. However, all computer models include assumptions. Before computer models are applied to simulate the actual problems, they need to be validated against full-scale experiments, scale-model tests or plant-site observation. Validation by more than one of these methods helps researchers enhance their understanding of the problem.

Special emphasis should be given to the importance of plant site observation, known as "Genchi-Genba," an age-old Japanese philosophy in monozukuri. Genchi means exact location; Genba refers to function. The philosophy underlines the importance of interacting with things and problems directly, and in a specific context. It's a way to contextualize problem-solving in a very concrete way. Progress in high-speed computers made it possible for us to simulate and calculate many industrial problems and phenomena in a relatively short time. It should be noted, however, that the Genchi-Genga concept is the basic concept for all industry problem-solving processes and should be practiced before we conduct computation, analysis or experiments. Toyoda Saikichi reminds us of the value of on-site observation; he once described for an interviewer how he came up with the Toyota auto-activated loom. We should note the absence of advanced technology and computation in his description:

> *"In my village, every family farmed and each house had a hand-weaving machine. Influenced by my environment, I gradually began thinking about this hand-weaving machine. Sometimes I would spend all day watching the grandmother next door weaving. I came to understand the way the weaving machine worked."*

Figure 4 compares the plant site downward airflow measurement (left) with 2-D Computational Fluid Dynamics (CFD) laminar airflow model simulation (right).

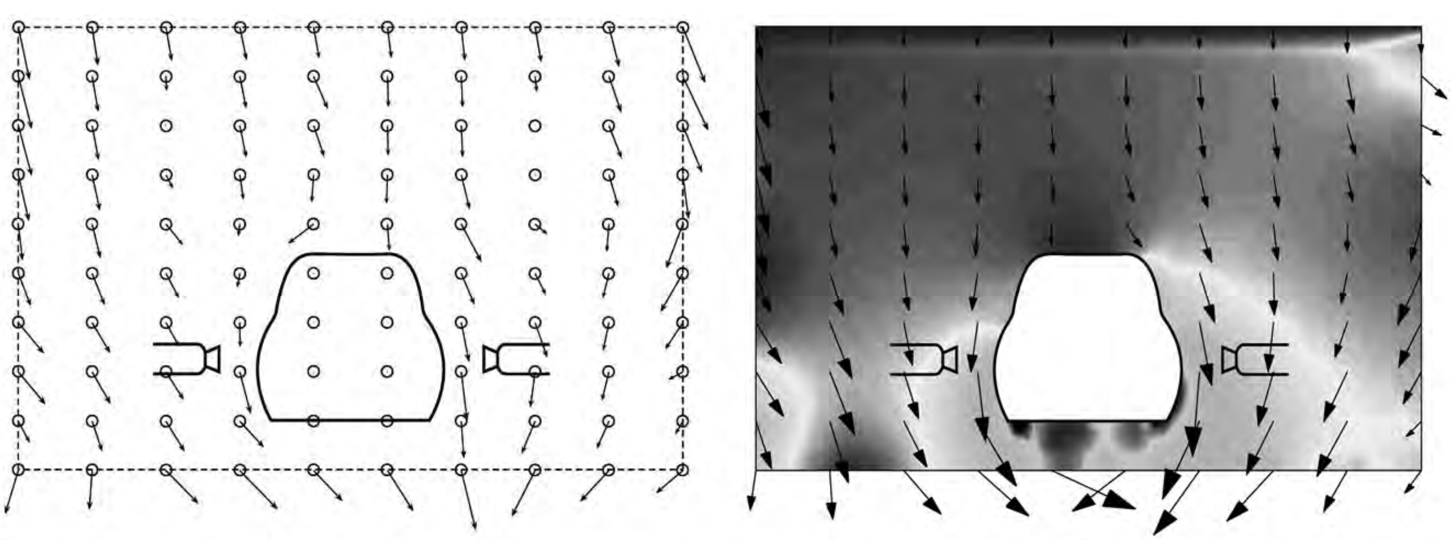


Figure 4. Comparison of a prototype airflow measurement (left) and 2-D laminar. Computational Fluid Dynamics (CFD) simulation (right), from A. Salazar, Ph.D. thesis, University of Kentucky, 1998. Color indicates pressure difference inside the booth.

(continued, page 2)

The plant site airflow measurement was conducted by the former members of PE7 team at Toyota Motor Corporation, Motomachi plant (then the general managers, Mr. N. Tanaka and Mr. Y. Tamura kindly provided us with this very useful data) and we conducted the CFD model simulation at IAES. It was very fortunate to have this plant site measurement data to validate our model.

Our simple CFD model simulated the booth airflow profiles with approximately 80 % accuracy. Then, this CFD model was applied to assess an entire airflow structure inside the booth during an actual operation. To assess how accurately our CFD model predicted the actual airflow, we visited a company's paint booth to practice Genchi-Genba. We confirmed qualitative agreement, but also found several miss-matches that required modifications on the CFD model. Taking this step-by-step process of improvement over the past seven years, our CFD model has been upgraded to the transient three-dimensional capability model including the effects of water mist, electric static, and evaporation with better than 95 % accuracy.

VORTECONE INVENTION AS AN EXAMPLE OF TEAMWORK MONOZUKURI

Here I present an example of how scientific and engineering methods worked side by side to develop a new type of wet scrubber that can effectively capture over-spray paint particles. Seven years ago, there was a need to develop a new type of device to capture over-spray paint particles, which have higher capturing efficiency and less energy consumption than products that were already available. All of the wet scrubbers were then designed based on craftsmanship-type experience and categorized as one of three different types: venture type, high-impact type and other type. All of these scrubbers, regardless of type, created high unrecoverable energy loss due to their poor design of fluid dynamics.

Using the above CFD model validated against experiments, we carefully analyzed the wet scrubber that performed best in capturing particles. Prior to our model simulation, we asked the company's engineers why their product worked better than other companies' products, and what mechanism they used to capture fine paint particles of 20 micron diameter. Their explanation was that when air flow carrying the over-spray paint particles hit a water pool, paint particles penetrated into the water, mixed with water, and were captured by water, but air escaped.

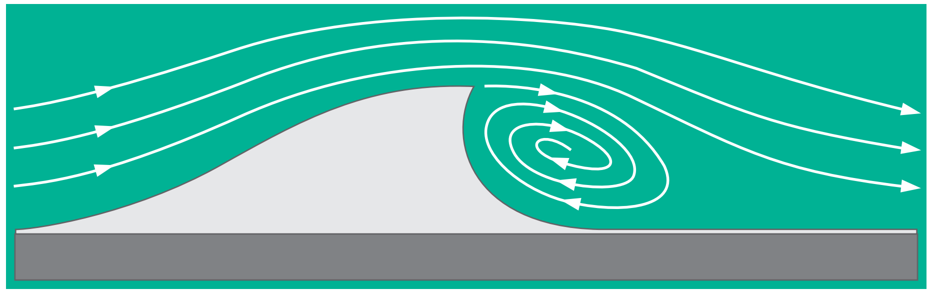
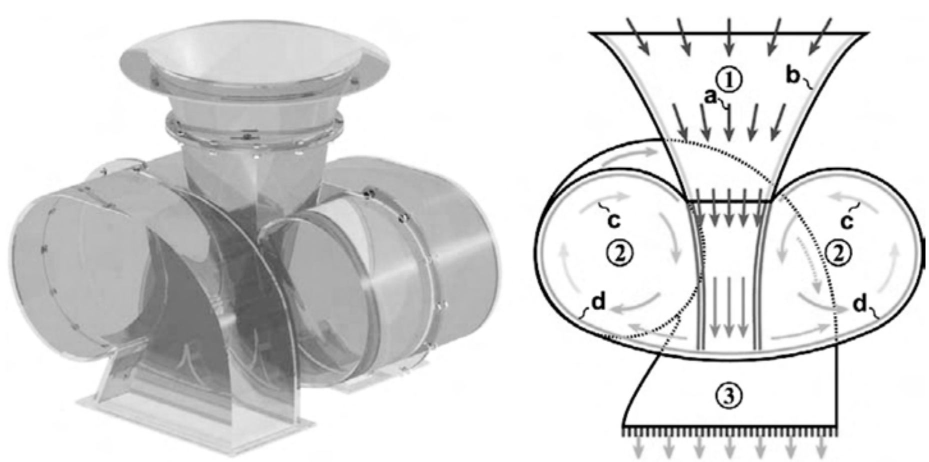


Figure 5. Cross section of a sand dune displaying the flow pattern generated over desert sand.

We used our model to simulate the capturing efficiency by the company's suggested mechanism, but failed. During that process, our computer model showed a very interesting vortex flow where particles circulated along the circulation at a least expected location. We carefully analyzed this motion and conducted further calculations that confirmed a newly found vortex mechanism to be very effective in capturing fine paint particles.

Next we considered what might be the best geometry and shape to enhance the vortex while minimizing energy to operate the system. Engineers' creative minds played an important role in this process. We paid attention to a desert where an interaction of wind and fine sand particles creates a special 3-D shape, known as a sand dune. This 3-D crescent shape structure can easily stand against desert storm winds of over 30 m/s. Since sand particles are not bonded, sand particles would be blown away under a strong wind. Why can the sand dune shape stand against a strong wind? **Figure 5** shows a cross section of the sand dune where the wind blows from left to right. Behind the crescent shape dune, there is a strong circulation which traps the otherwise blown away sand particles, protecting the dune from erosion and also significantly reducing the drag force of air that flows over the dune because the circulation acts as a bearing. The sand dune shape would be most ideal for capturing small particles with lowest energy consumption.

Based on the sand-dune shape, we wanted to build a new type of wet scrubber. As a result, Vortecone over-spray paint scrubber, shown in **Figure 6**, was jointly designed with Toyota and the University of Kentucky. The first prototype was manufactured and tested by Trinity Industrial Corp. in Japan in 1998. The first prototype of Vortecone showed 30 % less energy consumption compared to a traditional type A scrubber, and 37 % less compared to a traditional type B scrubber, while Vortecone's capturing of paint



- 2 U.S. Patents: US6024796 and US6093250
- 2 Japanese Patents: JP2004042044 AND JP2005007395
- 2 European Patents: EP1007219 and EP1258294

Figure 6. Vortecone wet scrubber jointly invented by UK, Toyota and Trinity.

 (continued, page 3)

mass increased 21 times. Based on these test results, Toyota Motomachi was the first plant to adopt Vortecone scrubbers in the fall of 1998, followed by three other Toyota plants within three years: Takaoka, Tahara, and Indiana. As an additional benefit, the maintenance cycle of three months required for the traditional type scrubbers was extended to one year compared to the type B scrubber.

Based on this success, the University of Kentucky is studying the application of Vortecone to capture fly ash and other combustion by-products from coal-fired power plants. Currently, Kentucky coal-fired power plants use electrostatic precipitators to recover fly ash particles from coal combustion gases. The installed cost of these precipitators varies depending on the fraction of fly ash removed, as dictated by environmental regulations when the plant was granted a permit. New green technology that could either reduce the recovery cost, improve the percent recovered, or both, would improve the market position of coal as a boiler fuel and also help Kentucky's coal-fired utilities update their facilities. This environmentally friendly new green technology for coal-fired power plants, created as spin-off from long-term research collaboration between Toyota and the University of Kentucky, would help enable continued use of coal for power generation in Kentucky and all over the United States.

CONCLUSION

A series of discussions began in the late 1980's through the early 1990's in order to initiate and further develop mutually beneficial research collaboration between the Toyota Georgetown plant and the University of Kentucky. Then Toyota Georgetown plant president was Mr. Fujio Cho, Senior VP was Mr. Alex Warren, VP was Mr. Naoji Tanaka, and the special assistant to President was Mr. Hiro Adachi. All four distinguished Toyota executives shared a common vision to create a win-win-win relationship among industry, university and the state of Kentucky by working together for a common good. This Toyota–UK research collaboration served this purpose and Vortecone can be seen as a product of this effort. The Toyota-UK research collaboration also has grown over the past 13 years, involving more than 10 UK faculty and researchers, and more than 20 UK graduate students. For the year 2004-2005 alone, four Toyota offices (TMC, TMMNA, TMMK, and TTC) funded a total of 12 projects with a total budget of $1.2M. Toyota's commitment for long term and sustainable research funding attracted other companies (Nippon Steel, Mitsui Bussan, Ford, Nissan, Honda, Trinity, Admatechs, etc.), Federal agencies (NASA, National Science Foundation, Department of Energy), and the state of Kentucky Economic Development Cabinet to join in investing in UK's research. This group of well-diversified sponsors created a dynamic research environment for faculty, researchers, and students to study a variety of research topics. Some research outcomes are ready to create a spin-off company which will bring in high tech jobs for UK graduates and Kentuckians.

ACKNOWLEDGEMENTS

I owe many individuals who helped shape the Toyota-UK research collaboration. It is possible to only acknowledge a few here. Special thanks go to the following individuals for their special help, encouragement, and guidance: Mr. Yukio Tamura, Mr. Yasuo Tanigawa, Mr. Ken Kreafle, Mr. Mark Boire, Mr. Richard Alloo, distinguished members of former TMC PE7, UK Dean Dr. Tom Lester, and Dr. John Walker.

Kozo Saito is the Tennessee Valley Authority Professor in Mechanical Engineering at he University of Kentucky. His research interests are in Combustion, Fire Research, Painting Technology, Thermal Sensing and Control, Scale Modeling and Lean Manufacturing. He is also the Director of IAES – The Industrial Applications and Engineering Science Laboratory. Dr. Saito may be contacted at: saito@engr.uky.edu.

Short Course on the Science of Coal Product Utilization

Monday, May 7th, 2007
8:00 am - 5:00 pm

This short course is being taught in conjunction with the **2007 World of Coal Ash (WOCA)** conference, co-hosted by the University of Kentucky Center for Applied Energy Research and the American Coal Ash Association. It will cover basic information about the science and technology of coal combustion by-products and will be taught by experts from academia and industry. The course that was taught at the 2005 WOCA meeting has been expanded to include two parallel tracks, offering more choices for students, whose knowledge ranges from novice to expert. This course offers Professional Development Credits.

For more information on content, cost, and associated details, go to: *http://www.worldofcoalash.org/registration/shortcourse.html.*