CO_2 atomizing technology "CAT" for green coating process using high pressure micromixer

Shin-ichiro KAWASAKI[a]*, Kenji ISHIDA[a], Yuko SAKURAI[a], Tatsuya FUJII[a], Akira SUZUKI[b]
a: Research Center for Compact Chemical System,
National Institute of Advanced Industrial Science and Technology (AIST)
b: Tohoku University
* Nigatake 4-2-1, Miyagino, Sendai, Miyagi, 9838551, shin-ichiro-kawasaki@aist.go.jp,
TEL +81-22-237-3038, FAX +81-22237-5224

ABSTRACT

CO_2 atomizing technology "CAT" for green coating process has been developed. This technology can reduce discharge of VOC gas (Volatile Organic Compound) with constant high film performance. Feature of our approach in "CAT" is using high pressure micromixer for mixing of CO_2 and organic paint fluid. Micromixer is designed considering feed condition (Reynold's number and pressure drop), which enables CO_2 dissolve in organic paint fluid rapidly and homogeneously. If mixing performance was poor, polymer deposition caused by anti-solvent effect occurred at the inlet of mixer, frequently. On the other hand, when we apply a good performance micromixer we designed, the polymer deposition was not observed. Relationship between atomizing mechanism under operation condition and film performance are discussed here.

INTRODUCTION

In past times, "UNICARB®" for green coating process was developed by Union Carbide Corporation in 1980's [1]. It can replace organic diluting solvent with high pressure CO_2 in order to reduce viscosity of organic paint fluid. Therefore, it can reduce discharge amount of VOC gas (Volatile Organic Compound), which causes environmental pollution. In addition, it can decrease energy consumption of dry process because of low amount of organic solvent. Therefore, this technology can reduce not only discharge amount of VOC gas but also discharge amount of CO_2 (energy). However, this technology was not able to commercialize at that time.

We have focused its green concept and we started to re-consider from our standpoint since 2007. Furthermore, we have studied about applying high temperature and high pressure micromixer to continuous supercritical fluid process such as supercritical hydrothermal synthesis [2-4]. This combination realizes the maximum performance of supercritical fluid process. The most important difference of "CAT" with "UNICARB®" is performance of mixer. "CAT" uses high pressure micromixer with high performance of fluid mixing, while "UNICARB®" uses typical static mixer with poor mixing performance. Therefore, Our "CAT" did not have problem of polymer deposition caused by anti-solvent effect at mixing point. In case of using typical static mixer, polymer deposition occurred frequently. At inlet of the mixer, heterogeneous fluid region remained, and organic solvent in the paint fluid was selectively extracted by high pressure CO_2. As a result, polymer deposition occurred in the stream.

Our “CAT” for green coating process has been investigated focusing (1) viscosity reduction behaviour by CO_2 mixing and dissolving using high pressure micromixer, (2) atomizing condition (fluid temperature, pressure, CO_2 additive rate, nozzle hole diameter and configuration), (3) coating film performance (film thickness, roughness, image clarity) along with VOC reduction. Relationship between atomizing condition and film performance is discussed here.

PROCESS EQUIPMENT

Process comparison of conventional and “CAT” is shown in Fig. 1. In case of conventional spray process in Fig. 1 (a), organic paint fluid has high viscosity. Diluting solvent is added to reduce fluid viscosity. After that, diluted paint fluid is atomized to atmosphere from nozzle. The diluting solvent vaporizes and VOC gas is discharged.

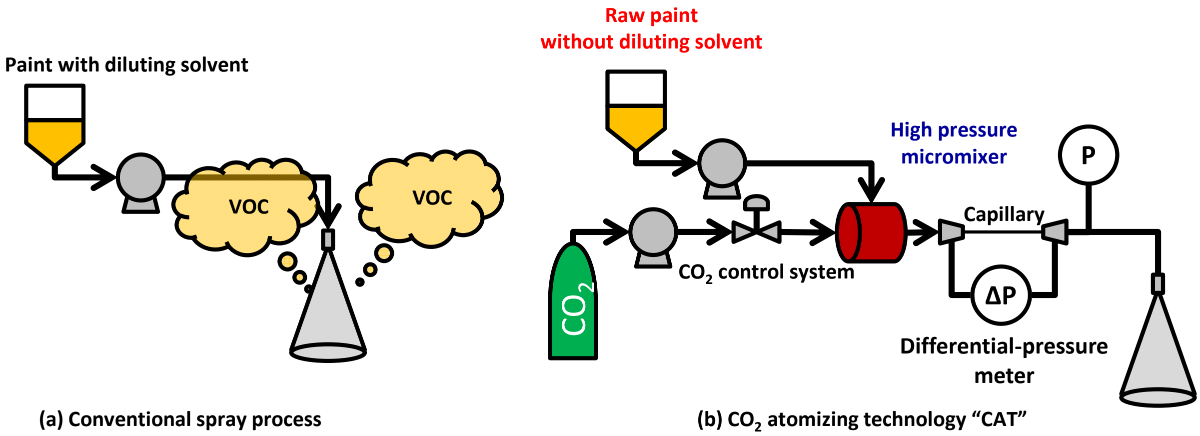

Fig. 1 Process comparison

In contrast, CO_2 atomizing technology “CAT” process is shown Fig. 1 (b). Raw Paint fluid without diluting solvent and high pressure CO_2 are supplied each other. CO_2 supplying control system is located in the CO_2 stream just before micromixer. High pressure micromixer designed based on feed condition (Reynold’s number and pressure drop consideration) is applied. The differential-pressure meter is used to calculate capillary viscosity by Hagen-Poiseuille equation. Thus, viscosity reduction behaviour is understood by on-line system. Paint fluid with CO_2 mixing is atomized to atmosphere from nozzle. CO_2 gas easily vaporizes compared with organic diluting solvent. Hence, it can decrease energy consumption of dry process by using high pressure CO_2 for diluting agent.

Our micromixer line-up designed based on fluid dynamics technology (CFD simulation) is shown in Fig. 2. In case of low viscosity fluid, turbulent mixing theory is applied. The channel diameter is designed based on Reynold’s number and pressure drop consideration. The feature of our turbulent type micromixer is to adopt swirl flow [2,4] and central collision flow (research collaboration with Mae et al., Kyoto University [5]).

In case of high viscosity fluid such as organic paint without diluting solvent, turbulent mixing cannot be applied, so we applied laminar mixing theory. In laminar mixing condition, it is not easy to achieve homogeneous and rapid mixing. Because laminar flow condition of organic paint fluid has low velocity, low vortex and high viscosity. Thus, fluid mixing depends on molecular diffusion at phase boundary. Our laminar type micromixer is designed based on multi-stage divided concept (MSD). A micromixer which has 85 mixing points is used, and organic paint fluid and CO_2 stream are divided many channels each other. . Turbulent micromixer has only one mixing point. In contrast, MSD has a lot of mixing point. Therefore, MSD increases phase boundary area; it realizes high mixing performance under laminar mixing condition.

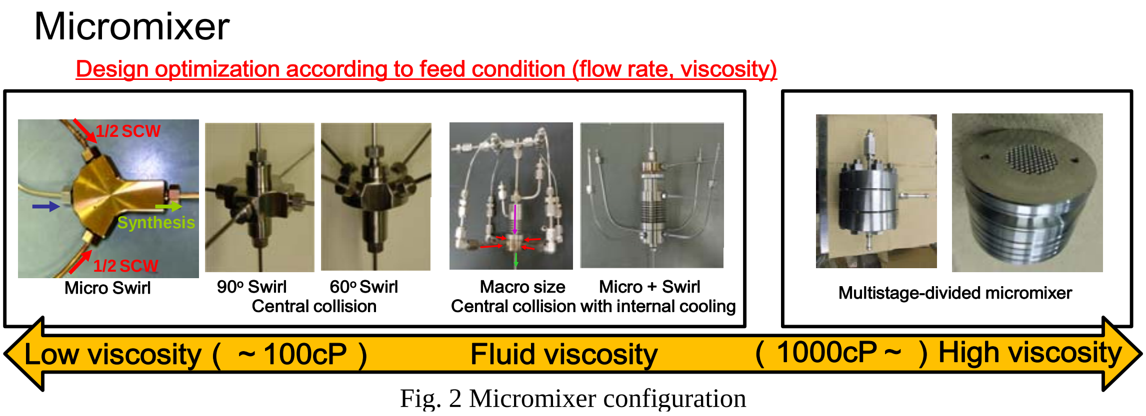

Fig. 2 Micromixer configuration

DROPLET SIZE MESUREMENT

3D spray structure and droplet size analyzer by laser CT technology system is shown in Fig. 3. This system can measure droplet size and size distribution by laser CT technology. The laser system is fixed. The nozzle can be moved on Y-axis from +500 mm to −500 mm, and rotated from 0 to 180° with a few degree intervals. The length from nozzle tip on Z-axis can be changed from 0 to 250 mm. Moving along Y-axis and rotating the nozzle, spray structural

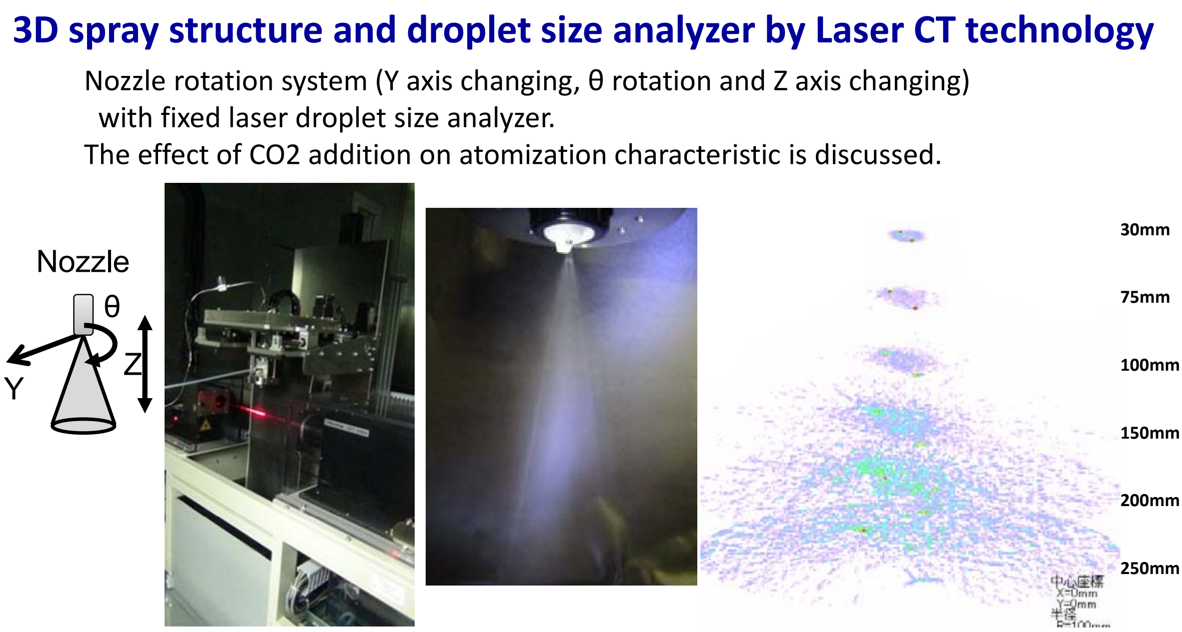

Fig. 3 3D spray structure and droplet size analyzer by laser CT technology analysis on a plane was performed. Other planes were analysed by changing the length from nozzle tip on Z-axis like CT scan as shown in Fig. 3 (right image).

CONCLUSION

Relationship between atomizing condition and film performance is discussed.

(1) Fluid condition before atomization (temperature, pressure, CO_2 additive rate, viscosity) is very important factor on atomization and film performance.

(2) When temperature of fluid before atomization is room temperature, Joule-Thompson effect of CO_2 spray is large, and droplet temperature decreased. Because of the temperature decrease, droplet viscosity increased, and atomization was inhibited. Film performance was also poor caused by increasing droplet viscosity. Residual marks of CO_2 bubble were remained in the film.

(3) When temperature of fluid before atomization is too high, the atomization occurred too much, and droplet size decreased excessively. Vaporization of solvent in the droplet was enhanced because of high droplet temperature and small droplet size (large surface area). Film performance was also poor because of large droplet viscosity.

In case of (2) and (3), results are similar, although each mechanism is considered to be different.

(4) In intermediate temperature condition, we obtained better film performance. Both negative effects observed (2) and (3) were diminished.

Currently, the commercial equipment for coating process of small plastic component for interior automotive trim was constructed. Pilot equipment for coating process of constructing machine's body was also constructed. In addition, modifying "CAT" process, organic small powder production technology can be realized with a process similar to CAT with high pressure and high temperature micromixer. "CAT" is expected to be applied to broader application fields by adding adequate modification.

REFERENCES

[1] Bok, H.F., Hoy, K.L., Nielsen, K.A., Patent US 5 057 342, **1989**

[2] Wakashima, Y., Suzuki, A., Kawasaki, S.-I., Matsui, K., Hakuta, Y., J. Chem. Eng. JPN., Vol. 40, **2007**, p. 622-629.

[3] Kawasaki, S.-I., Sue, K., Ookawara, R., Wakashima, Y., Suzuki, A., Hakuta, Y. Arai, K., J. Supercrit. Fluids, Vol. 54, **2010**, p.96-102.

[4] Kawasaki, S.-I., Sue, K., Ookawara, R., Wakashima, Y., Suzuki, A., J. Oleo Sci., Vol. 59, **2010**, p. 557-562.

[5] Mae, K., Suzuki, A., Maki, T., Hakuta, Y., Sato, H., Arai, K., J. Chem. Eng. JPN., Vol. 40, **2007**, p. 1101-1107.