The problems CCS plants face and the solution for them

Hisao KOJIMA, Terutoshi SUZUKI

MU Company Ltd.

This paper is originally written in Japanese and included in a journal, Kagaku Sochi (Plant and Process), vol. 60, no. 2 (Feb. 2018), pp. 33-37., published by KOGYO TSUSHIN CO., Ltd.

The problems CCS plants face and the solution for them

Hisao KOJIMA[*1], Terutoshi SUZUKI[*2]

1. Introduction

A movement in CCS industry is accelerating. It's CCS-EOR. CCS, Carbon dioxide Capture and Storage, is the technique of capturing and compressing carbon dioxide and storing it in a stable condition. EOR, Enhanced Oil Recovery, is the method of recycling old oil field by injecting CO_2 and liquid and increasing 30 to 60 % productivity of residential crude oil. The combination of CCS and EOR techniques make oil production increase and CO_2 reduce. These advantages give an incentive for CCS, resulting in some plants capturing CO_2 one million tons per year in operation. The chemical absorption method has been used for CCS as an effective technique. This is the only way suitable for the large scale CO_2 capture process with its volume of one million tons per year.

In this paper, we describe the problem CCS plants face and solutions for them.

2. CCS plant

CCS plant captures low concentration CO_2 in exhaust gas given out from a chimney into the air, with the condition of high temperature and low pressure. A CCS plant of one million CO_2 capture is outlined below, as an example of CCS plant (Fig.1). The size of pretreatment unit and CO_2 absorption unit is relatively big due to the low concentration of CO_2 in an exhaust gas. The condition in Fig.1 needs packing column which can process gas flow with the volume of 0.6 million per hour. This means that the tower should be 15 meters in diameter. The tower with the diameter of 10m has been used before, unlike that of 15m diameter. Towers equivalent to the one with more than 15m diameter is now replaced as multiple towers in parallel or the concrete square tower. Both of the towers have a low efficiency of gas-liquid contact, which increases the construction cost of a scale-up plant.

The process configuration of units of general CCS plant is shown as Fig. 2.

Pretreatment unit: The unit consists of a counter current tower for removing SO_2 and dust in the exhaust gas and cooling the gas. Chemical substances are added into circulation liquid. Reactants and dust are removed from the bottom of a column.

CO_2 absorption unit: Exhaust gas is fed into the bottom of the absorption tower, and CO_2 absorption liquid is also provided from the top of the tower. Gas-liquid contact by countercurrent makes the solvent take in CO_2, and the rich solvent is moved to the next unit, CO_2 stripping unit, from the bottom of the tower. The CO_2 removal exhaust gas is vented from the top of the tower.

CO_2 stripping unit: A CO_2 stripping unit efficiently releases and captures CO_2 contained in solvent by heating and depressurizing. From the bottom of the tower, lean solvent, which has released CO_2, is returned to CO_2 absorption unit, after cooling down. Then, it is reused as an absorption solvent. From the top of the CO_2 tower, high-purity CO_2 gas is captured, pressurized by a compressor, and sealed into oil layer through long pipeline. We explain the problems and its solution of each unit in CCS plant as follows.

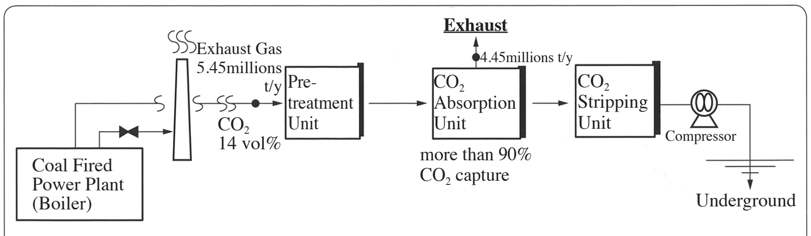


Fig.1 CCS Plant

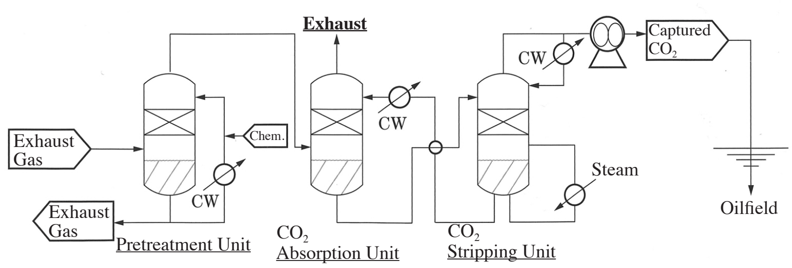


Fig.2 Unit of CCS Plant

*1 President of MU Company Ltd. Member of American Chemical Society

*2 General Manager of MU Company Ltd.

(MU Company Ltd.) Address: 18-8 Uenokouen, Taito-ku, 110-0007, Tokyo, Japan. Tel:+81-3-3828-7090 Fax:+81-3-3823-2890 Email: 01150324kojima@mu-company.com URL: mu-company.com

2-1. Pretreatment unit

This unit has an important role in the safe long-term operation of the CCS plant. The exhaust gas includes many impurities other than SO_2 gas.

Various companies have developed different solvents as carbon dioxide absorption liquid with excellent quality, which is introduced in CCS plant. To keep the solvent in such a high quality, impurities should be completely got rid of and solvent needs to be kept clean. Today, some chemicals are added into circulating liquid, and reacting it with SO_2 in counter-current tower, as well as removing dust. The velocity of gas in the tower is strictly limited so that countercurrent contact doesn't cause flooding (Fig. 3).

Now, there are three problems. The first is that the tower needs tons of circulation liquid due to the bigness. The second is that the efficiency is and cannot help being low so that the flow of dust avoid clogging. And, the biggest problem is that any pollution prevents the plant from the long-term non-stop operation.

Here, we propose MU-SSPW, MU Static Spiral Perforated Wings, as an alternative for the conventional packing in the column. This product successfully uses the concurrent flow, unlike conventional products with the countercurrent flow.

MU-SSPW is the only element which can use concurrent operation. Therefore, MU-SSPW can completely remove SO_2 and dust.

A track record of MU-SSPW operation shows that the product with the concurrent flow is best for removal of SO_2 with reaction, dust removal, and direct cleaning of gas. Now let me introduce MU-SSPW, an alternative element for the conventional tray and packing.

1. Philosophy of MU-SSPW

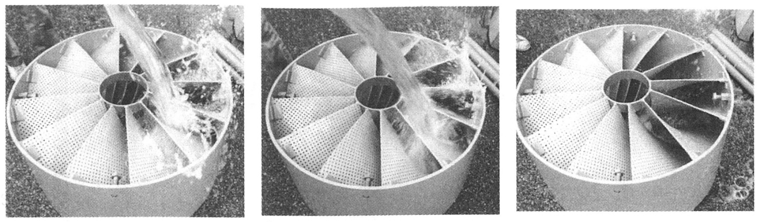


Photo 1 How MU Mixing Element generates bubbles

"Why do waterfalls and wild waves look so white?" The concept of MU-SSPW starts with this question. With the questioning, the idea of MU-SSPW is hit when water is fallen onto MU Mixing Element put on the ground and white bubbles are generated. The MU-SSPW is the result of observing nature and art. Photo 1 shows how the bubbles generate.

2. Principle of mixture of MU-SSPW

Each time fluid passes through the element, it is not only divided and stirred with the combination of spiral and axis flow continuously, but also churned and mixed without any movement of the element.

Each of scrubber unit, absorption unit, and stripping unit consists of MU Mixing Element, which contains spiral perforated wings in the clockwise or counterclockwise rotation. The elements of the clockwise or counterclockwise wing are alternately arranged with some distance in the unit. Fig 4 shows the structure of MU-SSPW.

3. Gas bubble

Bubbles exist in the gas-liquid multiphase flow. The faster the flow of fluid is, the finer the bubbles in liquid is, generating sub-micron bubbles. The finer the bubbles is, the bigger surface area per volume is and,

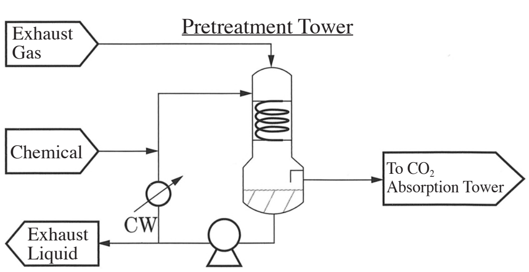
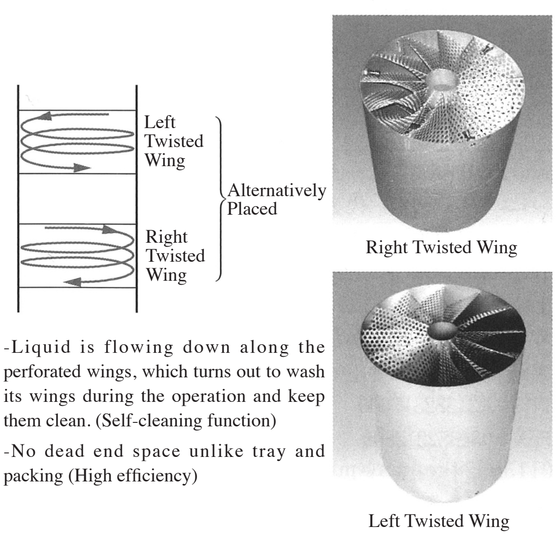


Fig.3 Pretreatment Tower



-Liquid is flowing down along the perforated wings, which turns out to wash its wings during the operation and keep them clean. (Self-cleaning function)

-No dead end space unlike tray and packing (High efficiency)

Fig.4 Structure of MU-SSPW

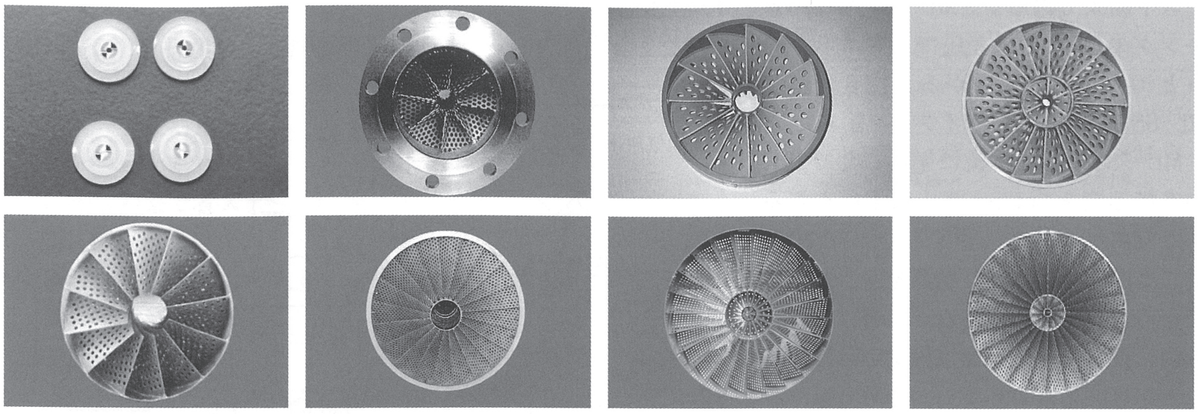


Photo2 Various MU Mixing Element for various application

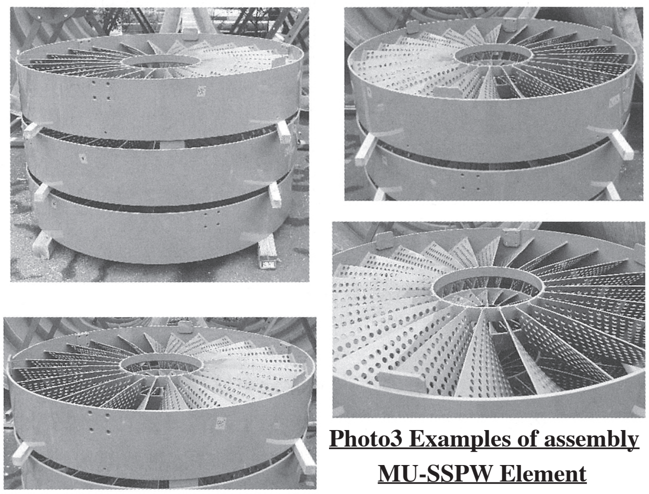


Photo3 Examples of assembly MU-SSPW Element

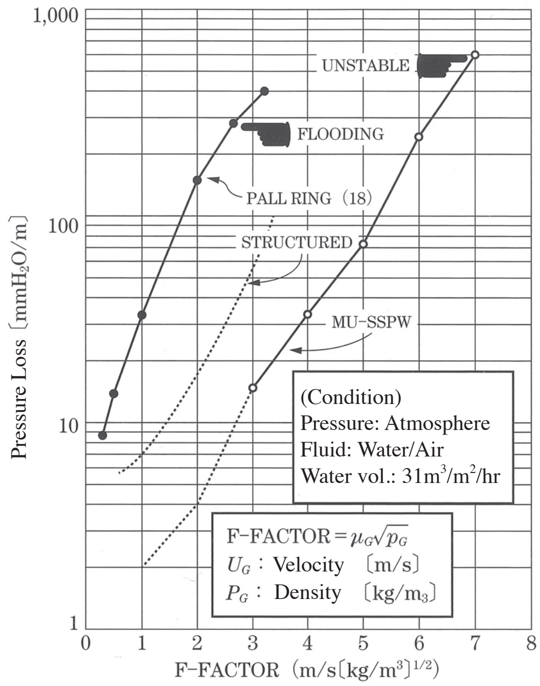


Fig.5 Comparison of Pressure Loss (Counter current)

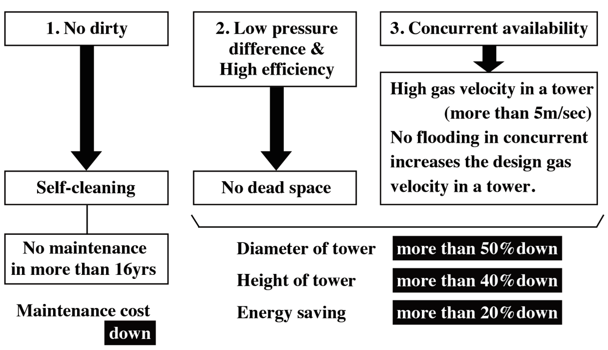


Fig.6 Advantages of MU-SSPW

therefore, the higher the pressure inside the bubble is. Such high-pressure bubbles tend to be divided continuously, which is renewing surface area of the bubbles. The renewal interface urges gas-liquid/liquid-gas mass transfer, which improves the function of dust removal, absorption, and stripping.

The efficiency of dust removal, absorption, and stripping is proportional to the contact time of gas-liquid and the contact area of gas-liquid. The efficiency is enhanced by heightening the tower, or arranging multiple towers in series. Bubbles can also decrease the power of friction and have ionic quality. Photo 2 shows the various kind of MU Mixing Element. Photo 3 is the assembly of MU-SSPW element. In Figure 5, an experimental result shows the relationship between pressure loss and F-FACTOR.

The result shows that MU-SSPW is helpful for energy-saving and dirt prevention due to the 1/10 lower pressure gap than packing method. The advantages of MU-SSPW is summed up in Fig.6.

The concurrent flow brought by MU-SSPW can increase gas velocity in the tower at more than 5m/s. This means that the diameter of the tower can be reduced less than half that of countercurrent tower designed with the condition of the gas velocity of 1m/s. A tower with the large diameter needs excessive circulation liquid. But with the use of MU-SSPW, the volume of circulation liquid can be reduced.

On this condition, MU-SSPW can maintain the difference of pressure inside the tower at the level of less than $150mmH_2O$. The merits of concurrent flow tower and MU-SSPW for pretreatment tower are summarized as follows:

1. The diameter of the pretreatment tower can be scaled down by less than half. The downsizing of a tower, pump and other equipment leads to the reduction of equipment cost.

2. Self-cleaning behavior of MU-SSPW causes no dirty and clogging, bringing successive long-term operation.

3. Solvent can be kept clean so that any dirty and foaming can be avoided at the next process, which contributes to the long-term stable operation.

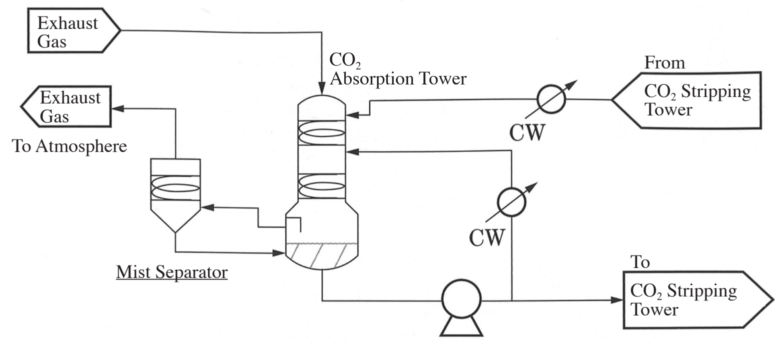


Fig.7 CO_2 Absorption Unit

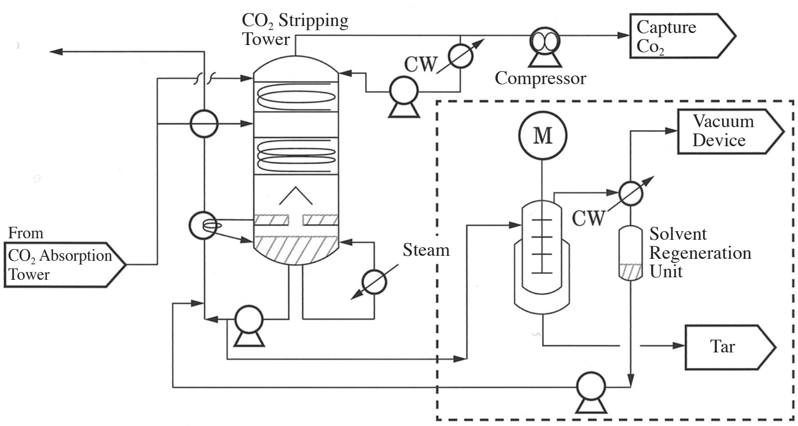


Fig.8 CO_2 Stripping Unit

2-2. CO_2 absorption unit (Fig.7)

This unit contains internal cooler for removing absorption heat and a cleansing part for preventing entrainment of CO_2 absorption liquid with the top part of the tower. The point is whether CO_2 can be efficiently absorbed in CO_2 absorption liquid. The absorption of CO_2 into the solvent is basically the outcome of the chemical reaction under aqueous electrolyte solution. So, we recommend that MU-SSPW is installed in CO_2 absorption tower and the conventional countercurrent flow is changed into the concurrent one.

The advantages of the application of MU-SSPW to the unit are:

1. The diameter of the absorption tower can be less than half, bringing the reduction of equipment cost.
2. No foaming and flooding occurred in the tower, which leads to stable operation of the tower.

2-3. CO_2 stripping unit (Fig. 8)

Three major improvements are made in CO_2 stripping unit.

1. CO_2 stripping tower is in a condition of countercurrent flow, and MU-SSPW can be used as an element.
2. Internal reboiler can be installed at the bottom part of the tower.

In CO_2 stripping tower, the temperature on the upper part of the tower is low, and, in utter contrast to the upper part, the temperature of the bottom part is drastically high. The difference of temperature between the upper and the lower part is more than 10 degree Celsius. Taking advantage of the difference, internal reboiler is installed on this part for efficient heat recovery in order to reduce the steam consumption in the reboiler.

The conventional heat exchange system of liquid at the bottom of the tower and feed in CO_2 stripping tower has a weak point: due to much entrainment of solvent to the top of the tower, reflux shall increase. This is contrary with energy saving.

3. A part of liquid at the bottom of CO_2 stripping tower is fed into a solvent regeneration unit.

Because of some variation in operation, it is inevitable to mix impurities in the pretreatment unit into the absorption one. Solvent is constantly polluted by some polymers made of pyrolyzed additives and impurities. The polymers are attaching in layers on the surface of heat transfer wall of reboiler, which is hottest in the unit. The fouling film deteriorates the function of heat transfer. The fouling substances are made of microfine impurities and dissoluble polymeric substance which cannot be physically removed by the conventional filter. To remove these substances under the condition of low temperature and low pressure, a small unit is added for recycling solvent. The capacity of this added unit can be considered as less than 5% of the volume of total solvent flow rate.

Table 1 Improvement of CCS equipment of one million t/y CO_2 capture

	Pre-process Tower	CO_2 absorption Tower	CO_2 stripping Tower
Volume of gas in a tower	460 thousands Nm3/hr (600 thousands m3/hr at 80 degree Celsius)	460 thousands Nm3/hr (540 thousands m3/hr at 50 degree Celsius)	58 thousands Nm3/hr (80 thousands m3/hr at 100 degree Celsius)
present Packing	φ 15m x 20mH Counter current	φ 14m x 20mH Counter current	φ 7.5m x 20mH Counter current
MU-SSPW	φ 5.5m x 12mH Concurrent	φ 5.2m x 12mH Concurrent	φ 3.0m x 10mH Counter current
Reduction ratio	63%	63%	60%

The merits of MU-SSPW application in the unit are as follows:

1. MU-SSPW application decreases the degree of a pressure difference, lowers the temperature of the bottom part, and lessen the dirty so that the unit can successively operate in the long term.
2. MU-SSPW and installment of internal reboiler can save the steam consumption.
3. Impurities can constantly be removed in solvent regeneration unit, which boosts the No.1.

Table 1 shows the advantage of its downsizing due to the application of MU-SSPW. In the table, the reduction of equipment cost can be expected.

3. Conclusion

Today, coal industry faces the challenging period since coal emits a large volume of CO_2 and the fuel is thought to be a major factor for greenhouse warming. Our company has been researching and developing products for saving the environment since its establishment 35 years ago. By applying our product, MU-SSPW, with pretreatment unit, CO_2 absorption unit, and CO_2 stripping unit, as well as using the product in CCS system, nearly zero CO_2 emission might be achieved. A track record of our product applied with process system proves that the concentration of dust with its size of sub-micron level can be less than 0.1 mg/Nm^3, and that the concentration of acid gas is less than 0.1 ppm. This level cannot be achieved by bag filter or electric precipitator. So, we believe that our technique is innovative and will steadily move forward step by step for "Wuji", nonpolarity, spirally with the notion of serving the Earth and with the help of others. The idea of MU-SSPW is come from a following work of Haiku by Basho Matsuo, describing a myriad of stars in the grand galaxy flowing into the wild "Sea of Japan".

Rough sea:
lying toward Sado Island
the River of Heaven[*1]

Basho Matsuo

*1: Matsuo Basho, Hiroaki Sato (1996) *Basho's Narrow Road: Spring and Autumn Passages*: Stone Bridge Pr