Strategies for Development of an Integrated Treatment System for Decontamination Wastewater generated during Nuclear Power Plant Dismantling

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1. Introduction

Radioactive CRUD adhered to the inner surface of large system such as reactor coolant system (RCS), spent fuel pool storage tank (SFP), nuclear refueling storage tank (RWST) water purification treatment, reactor coolant pump (RCP) and steam generator (SG) is desorbed and removed through chemical decontamination to protect workers from exposure to radiation before dismantling nuclear power plants. The radioactive wastewater generated from the decommissioning process generates the following three types from the radwaste.

First, low-concentration radioactive wastewater that is relatively easy to treat and close to pure water contained in reactor system water and various storage tanks

Second, high-level and high-concentration chemical decontamination wastewater generated during decontamination like the sticky radioactive CRUD attached to the inner surface of reactor coolant system, tank and storage tank,

Third, a large amount of slurry and sludge-like polluted wastewater containing fine concrete particles that are collected in the sump due to water used to prevent scattering during the NPP's dismantling process.

In the case of domestic nuclear power plants, there is no experience in treating non-decomposable liquid decontamination waste because decontamination has not been carried out so far.

Contaminated chemical wastewater contains chelating substances, so it cannot be brought into the disposal site unless it is converted into a stable form of inorganic substances using incineration and plasma. The advanced oxidation technology includes a high-temperature plasma technology developed by the Korea Electric Power Research Institute (KEPRI) for the treatment of non-decomposable Fe-EDTA wastewater generated during SG cleaning and a semi-pilot scale underwater plasma technology for the treatment of decontamination waste liquid. Underwater plasma technology has high applicability for decontamination wastewater treatment. This technology injects hydrogen peroxide into cleaning and decontamination wastewater with high electrical conductivity, and then thermally and chemically decomposes and treats organic matter in the plasma region formed between the surface of the immersed electrode and the solution by using a high-frequency alternating current of 60Hz or higher.

Fig. 1 shows the waste treatment technology to be developed in the future. The waste liquid is treated in two stages. For the treatment of system polluted water, coagulation, precipitation, and purification technologies using an electric ion separation membrane are applied, and for the treatment of decontamination waste liquid, a submergible underwater plasma technology is developed and applied.

In this paper, we tried to briefly introduce the technology for integrated treatment of two types of contaminated waste liquid and the development strategy for the improved submergible underwater plasma technology compared to the existing underwater plasma technology.

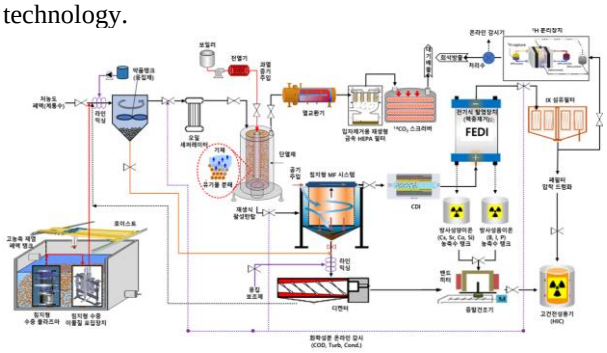

Fig. 1. Configuration diagram of integrated high/low concentration contaminated wastewater treatment

2. Development of Underwater Plasma System

2.1 Technical Overview of semi-pilot UWP

Fig. 2. View of UWP

Fig. 3. UWP reactor system

Underwater plasma is a technology that converts electrical energy into high-temperature thermal energy to instantaneously incinerate organic matter in water. When water reaches the boiling point on the surface of the applied electrode, the electrode is instantly surrounded by steam, which has a lower conductivity than water. Since the conductivity of the generated steam is lower than that of water, the amount of current flowing between the electrodes is reduced, and a phenomenon in which water does not reach the boiling point occurs on the surface of the electrodes. At this

time, arc plasma is generated between the water and the electrode, and the underwater plasma system (UWP) uses these phenomena to decompose dissolved organic matter. Since the arc plasma generated in the UWP system generally generates heat of 15,000 - 20,000℃ and strong ultraviolet rays, it is a very useful advantageous technology for decomposing dissolved organic matter present in water.

2.2 UWP system configuration and test operation

Since this technology oxidizes organic matter in water, it is an eco-friendly technology that generates almost no harmful gas and generates less CO_2. In addition, since AC power is used, power consumption is low and it is a suitable technology for large-capacity wastewater treatment. This system consists of a multi-stage underwater plasma reactor capable of decomposing and evaporating waste liquid at 80L/hr, centrifugal drying system that can separate and dry the concentrated sludge, and a catalytic reactor that can treat toxic gases below the air emission limit. By adopting a tubular multi-stage underwater reactor, the waste liquid treatment efficiency and throughput were increased, and the developed Pt/Fe/TiO_2 catalyst was used to completely oxidize volatile organic matter in exhaust gas accompanied by wet steam (Fig. 4). In particular, the evaporation concentrate generated as a final by-product was dried using a centrifuge and a dryer, and then put in a drum immediately and classified and treated as mixed waste.

2.3 Underwater Plasma System operation

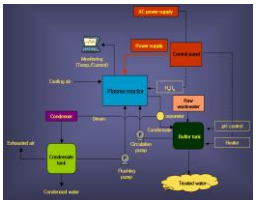

Fig. 4. Process chart of UWP

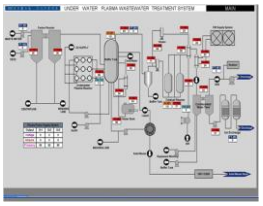

Fig. 5. Automatic control drawing

The UWP system consists of three reactors. The wastewater flows into a buffer tank and adjusts the pH and temperature of the wastewater in advance to increase the organic matter treatment efficiency before being introduced into the plasma reactor. The pH and temperature-adjusted wastewater flows into the plasma reactor and decomposes organic matter by the arc plasma generated as shown in Fig. 4 below.

At this time, the input of an appropriate amount of H_2O_2 contributes to the supply of an oxygen source necessary for the removal of organic matter by thermal decomposition and the formation of a large amount of OH radicals. Due to the nature of the UWP system using high-temperature plasma, the temperature of the wastewater treated in the plasma reactor is about 100°C. Part of the steam generated at this time is condensed through the separator and goes to the buffer tank, and the remaining steam is collected in the condensate tank. Due to the high-temperature thermal plasma, the plasma reactor causes an increase in conductivity due to evaporation of moisture and accumulation of salts. At this time, condensate is supplied from the condensate tank to the plasma reactor to prevent deterioration in operation efficiency.

2.4 Cleaning wastewater decomposition efficiency and test

The performance evaluation of the underwater plasma waste treatment system was performed using 1 ton of experimental wastewater having a composition of EDTA 20.13%, TOC 114,260 ppm, COD 76,000 mg/L, and Fe 51.5 mg/L (Table 1.).

Table 1: Composition of simulated wastewater solution

Analysis substance	Concentration	Analysis method
pH	5.96	Thermo, USA Model: 250+
Cond. (mS/cm)	47.80	
TS(%)	31.20	Gravimetric method
VS(%)	22.50	
FS(%)	8.70	
TOC(ppm)	114,260	Shimadzu TOC-V(CPH/CPN)
EDTA(%)	20.13	Titration
COD_{Mn}(mg/L)	176,000	Water Pollution Process test method (in Korea)
TKN(mg/L)	17,536.14	
Fe(mg/L)	51,537.50	ICP-MS

2.5 Results of performance
2.5.1 Wastewater input

The waste liquid having the composition shown in Table 1 was first supplied to the Fenton reactor at an average rate of 1.37 L/min for EDTA decomposition, and at this time, the introduced H_2O_2 (purity: 25%) was 0.27 L/hr, which is about the amount of the waste liquid input. It was 20v/v%. The injected wastewater and hydrogen peroxide water are evaporated and concentrated in the neutralization tank.

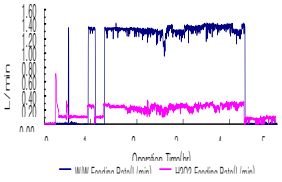

Fig. 6. H_2O_2 and wastewater injection amount

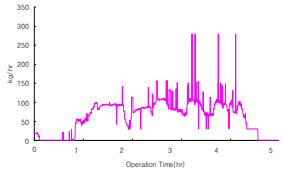

Fig. 7. Tank inlet steam volume

At this time, the amount of steam generated is 90kg/hr on average, which is 10% lower than the amount of wastewater and hydrogen peroxide, and is due to the organic matter and solids contained in the wastewater (Fig. 7).

2.5.2 System performance evaluation

As a result of test operation with one reactor, the organic matter decomposition rate was 67.2% and the EDTA decomposition efficiency was 96.2%. The conductivity of the waste liquid increased to 32.8 mS/cm (approximately 2 times concentrated) by moisture evaporation in the buffer tank, and the reactor was designed and manufactured with 3 trains to improve the treatment efficiency. A centrifugal separation method was adopted for efficient separation and removal of concentrated sludge. As a result of the final treatment using the full-scale device, the removal efficiency of TOC was 70% and EDTA was 99.8%.

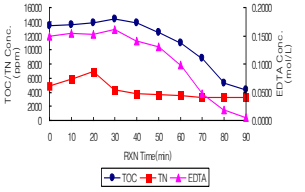

Fig. 8. Decomposition concentration of Fe-EDTA solution

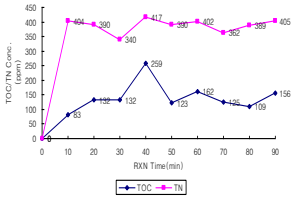

Fig. 9. TOC/TN effluent concentration of buffer tank

The steam generated from the neutralization tank contains CO, NOx, and other THC (Total Hydro Carbon) gaseous substances discharged from the underwater plasma reactor. These gaseous substances are finally purified while passing through the catalyst furnace, and the above figure shows the change in the concentration of NOx and CO substances before and after the catalyst. The concentration of CO in front of the catalyst was 500-2,000 ppm and the concentration of NOx was 100-120 ppm, and it was shown that 150 ppm of CO and 80 ppm of NOx were treated through the catalyst furnace. The wet steam treated through the catalyst furnace was condensed and collected in the condensate tank after passing through the heat exchanger, and the water quality of the final treated water was shown in Fig. 8.

3. Submergible Underwater Plasma System Developed in the Future

The submergible UWP device to be developed has the advantage of being able to reduce the hassle of installation because it decomposes and treats the waste liquid in the water by inserting the main body into the water. there is. In a solution with sufficient conductivity, a plasma region is formed between the surface of the immersion electrode and the solution by high-frequency alternating current, and UV radiation and plasma are thermally and chemically decomposed at a very high temperature. When an appropriate oxidizing agent is added, the decomposition of organic matter is better achieved by an oxidizing environment.

3.1 Technical requirements of the system

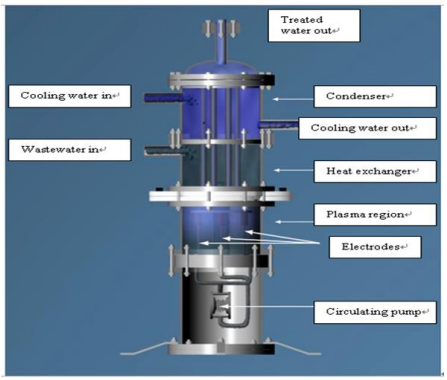

Fig. 10. Submergible UWP system conceptual diagram

- Treatment capacity: 600 kg/8 hr
- Main component of wastewater: 0.2 mol/L Fe-EDTA
- pH=7, adjusted to NH_3
- EDTA decomposition efficiency: min. 97%
- Separation of treatment wastewater and sludge

4. Conclusions

As a result of experiments using high-concentration Fe-EDTA waste liquid, Fe-EDTA was decomposed by more than 99.8%. NOx, CO, and organic substances such as Acetaldehyde and Pyridine, which are contained in the exhaust gas accompanied by wet steam, which were the most concerns during plasma treatment, were treated within the atmospheric environment standards while passing through the high-efficiency catalyst tower ($Pt/Fe/TiO_2$). No organic components were detected in the condensate, and it was confirmed that all of them were oxidized. The submergible UWP system to be developed for the treatment of decontamination waste generated during the dismantling of nuclear power plants is planned to be developed based on the experience of semi-pilot device development.

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