Experimental Apparatus and Test Variables for Evaluating Aging of TEDA Impregnated Activated Carbon

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ABSTRACT

The Air Cleaning Unit (ACU) as an Engineering Safety Features (ESF) in nuclear power plants (NPPs) is adopted to remove radioactive gaseous waste as well as toxic materials from operation and accidents. ACU is typically composed of a moisture separator, an electrical heater, pre-filter, pre-High Efficiency Particulate Air (HEPA), adsorber and a post-HEPA, and adsorber is filled with Tri-Ethylene-Di-Amine impregnated activated carbon (TEDA-AC). The removal performance and shelf-life of TEDA-AC are affected by the operating environment such as temperature, humidity and toxic materials. In order to verify the performance and shelf-life of TEDA-AC, the experimental apparatus were designed and test variables were investigated from air entering into ACU. Two types of experimental apparatus were designed and manufactured. One is a semi-plant scale test apparatus similar with ACU in NPPs and the other is lab-scale test apparatus. NPPs were investigated to obtain the parameters and values of test. These experimental apparatus, and analysis results of organic compounds and oxides in inlet air into ACU are expected to provide quantitative data that can be used for verifying aging characteristics of TEDA-AC and for confirming the validity of replacement period of the TEDA-AC under the plant operating conditions.

INTRODUCTION

The Air Cleaning Unit (ACU) is an Engineering Safety Features (ESF) which is devised to not only reduce the release of the radioactive material to the environment, but also assure that operators can have access to the Main Control Room (MCR) under a postulated accident. ACU is typically composed of a moisture separator, an electrical heater, pre-filter, pre-High Efficiency Particulate Air (HEPA), adsorber and a post-HEPA as shown in Figure 1.

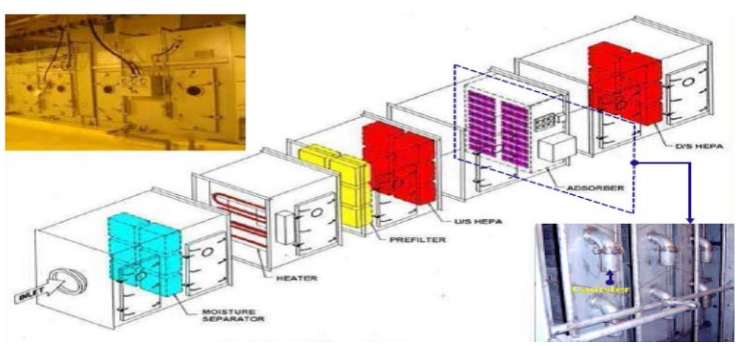

Figure 1. Schematic Diagram of Air Cleaning Unit

Adsorber is filled with Tri-Ethylene-Di-Amine impregnated activated carbon (TEDA-AC), and

TEDA-AC in ACU has been chosen as an absorbent to remove the radioiodine during normal and accident condition. As toxic chemicals including methyl iodide, nitrogen oxides, and sulfur oxides contained in the atmosphere are accumulated on the surface of TEDA-AC, its surface becomes oxidized and active sites for chemisorption decrease, leading to the aging of the TEDA-AC. Aging (or weathering) of a activated carbon is the gradual deterioration of “active sites” due to oxidation of its surfaces or to desorption or chemical reaction its impregnant with environmental poisons [1]. This deterioration results in decreases of capacity and efficiency with time, and thus affects the useful life of the carbon. Many researches have been conducted to investigate the aging of the impregnated activated carbon [2, 3, 4, 5]. However, a general mechanism for the aging has been unknown since the aging is accompanied by complicated chemical processes, and the type and concentration of the toxic chemicals differ according to the reactor types of NPPs as well. This paper deals with the design of the experimental apparatus and test variables to verify the aging of TEDA-AC.

DESIGN OF EXPERIMENTAL APPARATUS

In order to evaluate the aging of TEDA-AC in ACU, two types of experimental apparatus were designed and manufactured. One is a semi-plant scale test apparatus similar with ACU in NPPs and the other is lab-scale test apparatus. The former will be used to investigate the performance of TEDA-AC in adsorber under certain temperature, humidity and poisoning concentrations and the latter is to understand characteristics of TEDA-AC at various conditions, such as wide range of the temperature, humidity, and poisoning concentration.

Semi-plant scale test apparatus

Figure 2 is shown the semi-plant scale test apparatus [6]. As shown in Figure 2, this test apparatus is similar with the actual ACU in NPPs except for the moisture separator and post-HEPA. The distances between each component in this apparatus were determined in accordance with ASHRAE [7] to simulate the air flow in the actual ACU.

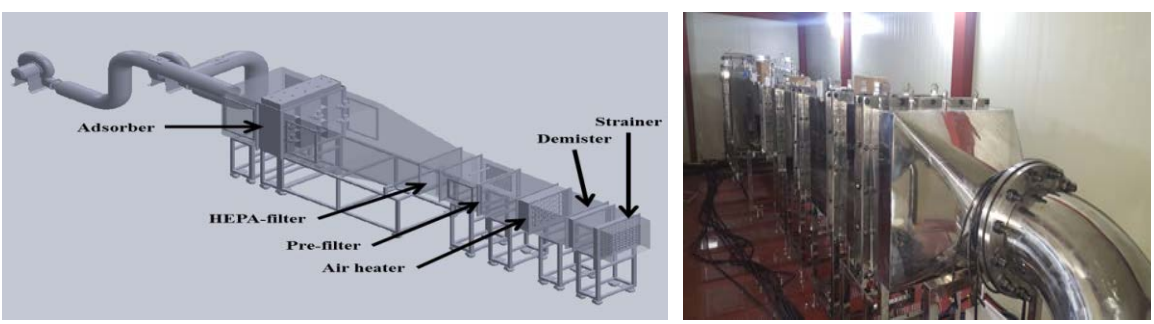

Figure 2. Schematic diagram of semi-plant scale test apparatus

The type of adsorber in this apparatus uses the same TYPE III adsorber as NPPs. TYPE III adsorber is characterized as consisting of multiple beds of AC, fixed in place, and sized to process a given volume of air or gas. The bed is fabricated using perforated sheet and structural pieces, into a welded assembly. Figure 3 illustrates a schematic drawing for a TYPE III adsorber that is equipped with total 12 canisters. 6 canisters are installed in the upstream side and the remaining 6 canisters are attached on the downstream side of this adsorber

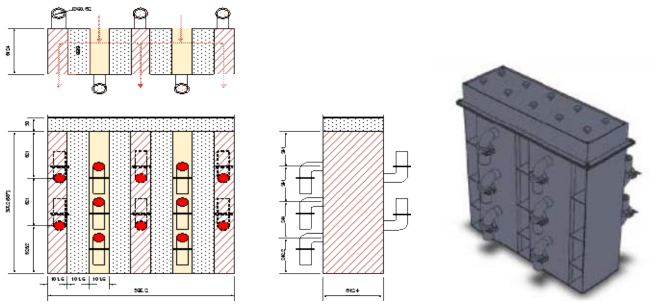

Figure 3. Schematic drawing for TYPE III adsorber

Design requirements of the test apparatus are as follows: 0.5 sec residence time corresponding to 0.2 m/s face velocity, 4 inch bed thickness, and 160 CFM air flow. In order to determine the size of adsorber, its size has to be calculated by using residence time defined in code [8]. The size of adsorber is $965.2(W) \times 965.2(H) \times 312.4(L)$ mm^3. The flow analysis in designed adsorber is conducted to investigate the flow field prior to verify the design suitability of the test apparatus by the certification body. As shown in Figure 4, velocity of canister and bed is converged to 0.65 m/s. This indicates that the flow can be uniformly distributed to the canister and bed, and the sampling with canister can be representative of the bed.

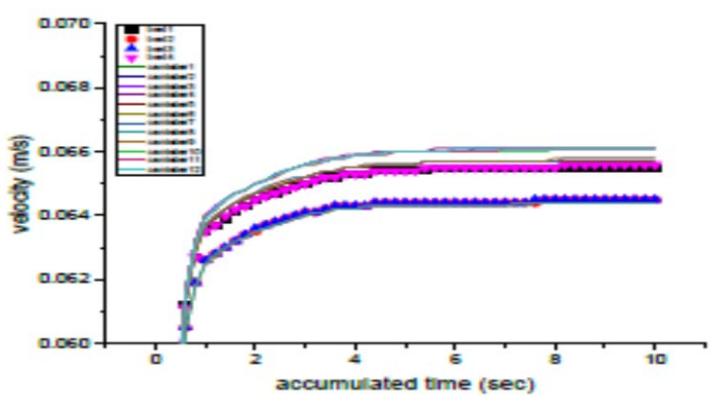

Figure 4. Velocity profile in each canister and beds

Based on the verification results, the test apparatus secured the design suitability from the certification body according to relevant requirements [8, 9]. The verification items and its results are shown in Table 1.

Table 1. Verification items and results of the semi-plant scale test apparatus

Item	Results
Visual Inspection	Passed
Duct and Housing Leak Test	Passed
Airflow Capacity Test	Passed
Air-Aerosol Mixing Uniformity Test	Passed
HEPA Filter Bank In-Service Leak Test	Passed

Adsorber Bank In-Service Leak Test	Passed*

* This is proved by applying a separate method because this verification item is different from the methods of NPPs

Lab-scale test apparatus

As is shown in Figure 5, lab-scale test apparatus is composed of test section and systems for injection of poisoning gases.

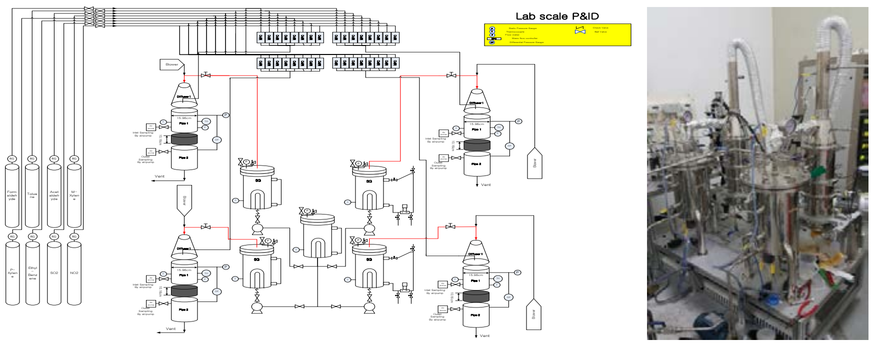

Figure 5. Schematic diagram of lab-scale test apparatus

The test section is installed vertical downward to prevent channeling as settling the AC by gravity. It includes an adsorber bed for performance of TEDA-AC at various combined conditions, such as temperature, humidity, and high concentration of poisoning gases. The design requirements applied to this apparatus are only the thickness of adsorber bed and residence time among the requirements applied to semi-plant scale test apparatus. Figure 6 is shown the startup results of this apparatus and indicates that this apparatus is suitable to test performance of this apparatus at various combined conditions.

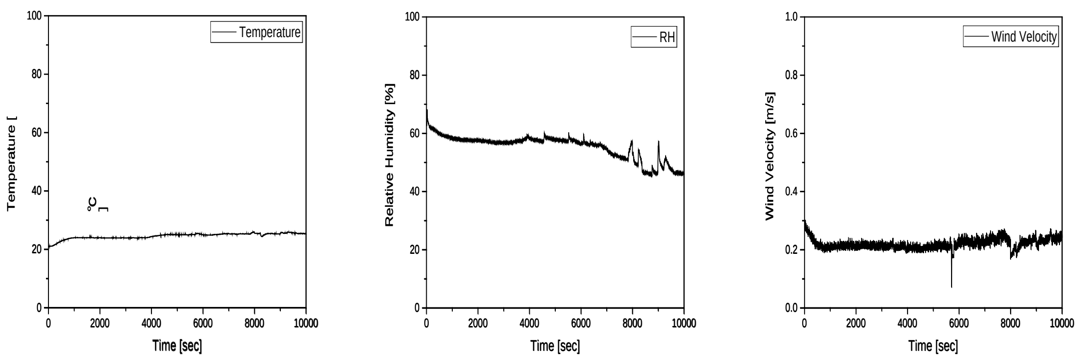

Figure 6. Startup results of lab-scale test apparatus at 25℃ and RH 50%

TEST VARIABLES TO EVALUATE THE AGING

The standards or guides are needed to evaluate the shelf life of AC but there are currently no valid standards or guides. According to the report of Oak Ridge National Laboratory [1], the shelf life of AC indicated 18~24 months in a continuously on-line system, 3 years in s standby system, and 5 years for carbon kept in sealed container. The test methods to evaluate the shelf life of AC were set for the semi-plant and lab-scale test apparatus as follows, respectively.

- Semi-plant scale test apparatus
  - CH_3I penetration and physical characteristics of impregnated activated carbon [10.11]
- Lab-scale test apparatus
  - CH_3I penetration and physical characteristics of impregnated activated carbon [10.11]
  - TEDA Loss and BET (Brunauer Emmett Teller)

The environmental conditions and ingredients (or poisons) in air entering into ACU were investigated to evaluate the shelf life of TEDA-AC. Table 2 shows NPPs investigated to obtain the parameters and values of test.

Table 2. NPP investigated to obtain the parameters and values of test

Plants (Designer)	Sampling Time (Operation Mode)	Sampling Location
KHNP-1 (WH) KHNP-2 (OPR1000) KHNP-3 (Framatom) KHNP-4 (CANDU)	Full Power (Mode 1) Sychronizing (Mode 2) De-Sychronizing (Mode 3) Overhaul (Mode 6)	Containment Bldg. Fuel Bldg. Auxiliary Bldg.

The typical environment conditions of ACU are temperature and relative humidity and the investigation results show that the temperature is between 18℃and 30℃, and relative humidity is less than 70% and always keeps about 50%. In order to obtain the variables and values of test, the representative sampling was carried out at the inlet of ACU. The analysis items of air samples were determined by type and concentration of volatile organic compounds, oxides and aldehydes based on the related studies and organic solvents used in NPPs. The analysis results of type and concentration of organic compounds are shown in Table 3 and Figure 7. The total concentrations of organic compounds with NPPs are shown in Figure 8.

Table 3. Type and concentration of organic compounds

Organic compounds	**Molecular Formula**	**Concentration (㎍/㎥)**
Formaldehyde	CH_2O	95.91
Accetaldehyde	C_2H_4O	52.62
Benzene	C_6H_6	10.26
Toluene	C_6H_6-CH_3	101.30
Ethylbenzene	C_8H_{10}	86.19
M, p-Xylene	C_8H_{10}	145.00
Stylene	C_8H_8	3.04
o-Xylene	C_8H_{10}	70.82

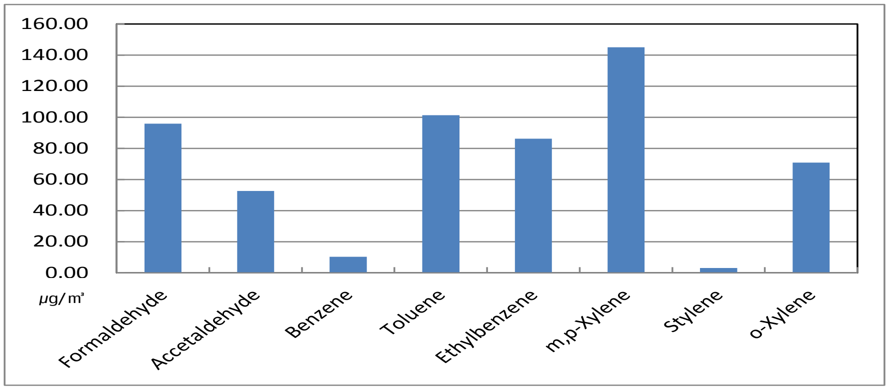

Figure 7. Distribution of organic compounds in inlet air (Unit: ppm)

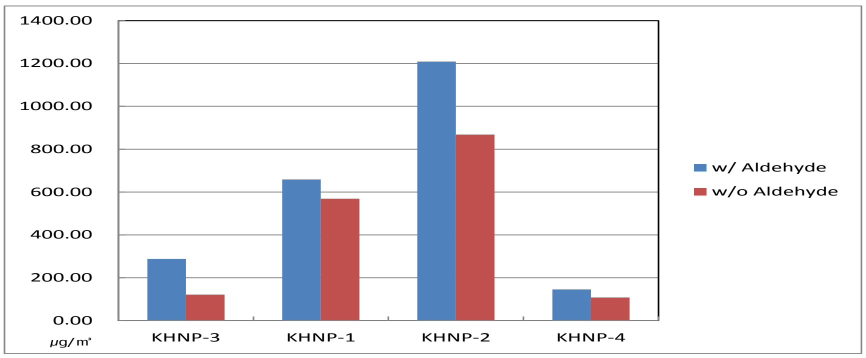

Figure 8. Total concentrations of organic compounds with NPPs

The type and concentration of oxides with NPPs are shown in Table 4 and Figure 9, and Figure 10 shows the distribution of oxides, SO_2 and NO_2, in inlet air with NPPs [12].

Table 4. Type and concentration of oxides with NPPs

NPPs	CO_2	SO_2	CO	NO	NO_2
KHNP-3	460.51	0.08	0.33	ND	0.03
KHNP-1	436.88	0.10	0.04	ND	0.01
KHNP-2	480.25	0.04	0.42	ND	0.01
KHNP-4	468.79	0.01	0.22	0.0036	0.03

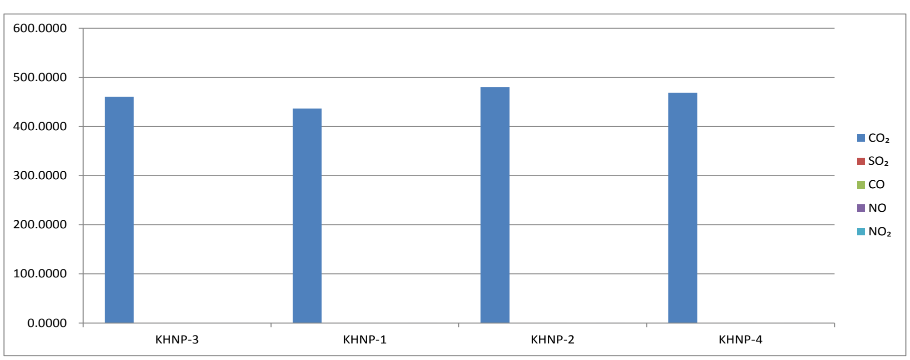

Figure 9. Distribution of oxides in inlet air (unit: ppm)

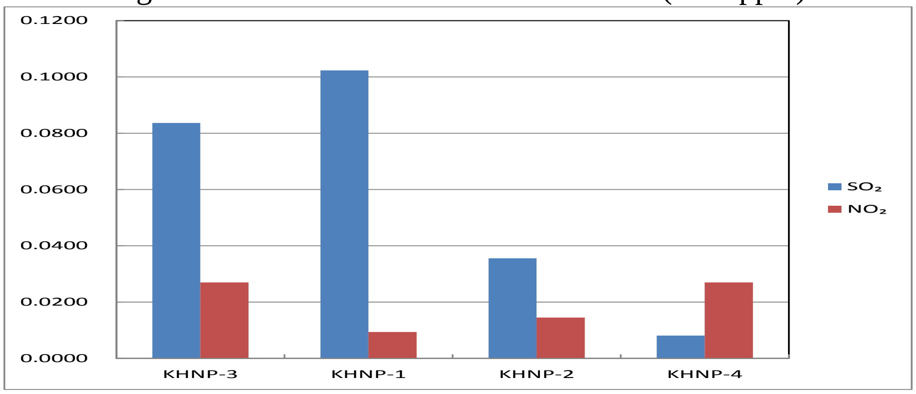

Figure 10. Concentration of oxides, SO_2 and NO_2 (unit: ppm)

CONCLUSIONS

Two experimental apparatus are designed and prepared for understanding the TEDA-AC aging in NPP condition. One is the semi-plant scale test apparatus to verify the performance of TEDA-AC with plant operating conditions. The other is lab-scale test apparatus to understand the characteristics of TEDA-AC and this is designed to perform the test at various combined conditions. The environmental conditions and ingredients (or poisons) in air entering into ACU were investigated to evaluate the shelf life of TEDA-AC. The types and concentrations of organic compounds and oxides in inlet air into ACU were analyzed for representative NPPs. The representative organic compounds were identified as formaldehyde, acetaldehyde, benzene, toluene, ethylbenzene, m,p-xylene, stylene and o-xylene, and the concentrations of formaldehyde, toluene and m,p-xylene are relatively higher than that of other organic compounds. In addition, it was confirmed that NO2 and SO2 exist as oxides in inlet air and their concentrations were analyzed as 0.1 ppm. These experimental apparatus, and analysis results of organic compounds and oxides in inlet air into ACU are expected to provide quantitative data that can be used for verifying aging characteristics of TEDA-AC and for confirming the validity of replacement period of the TEDT-AC under the plant operating conditions.

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