# Annual report: Measurement of radiocarbon using AMS in Gyeongju region

Seung-Won Lee [a], Sae-Hoon Park [a], Yu-Seok Kim [a*]
[a]*Department of Nuclear & Energy System Engineering, Dongguk University, 123, Dongdae-ro, Gyeongju-si 38066*
**E-mail: unison@dongguk.ac.kr*

## 1. Introduction

Human activities such as deforestation and use of fossil fuels have affected the global carbon cycle. Carbon dioxide ($CO_2$) emissions from fossil fuel combustion is increasing continuously due to human activities. Global $CO_2$ emissions reached an all-time high of 36.3 Gt in 2021 [1]. The measurement of $CO_2$ emissions using the radiocarbon dating method was developed by Willard Libby at the University of Chicago in the late 1940s. The method is based on the production of a certain quantity of radiocarbon ($^{14}C$) throughout the Earth's atmosphere by the interaction of cosmic radiation and nitrogen; $^{14}C$ combines with oxygen to form $CO_2$, which is absorbed by plants through photosynthesis. Then, plants absorb not only $^{14}CO_2$ but also $^{12}CO_2$ and $^{13}CO_2$ [2]. The isotopic proportion of carbon that plants absorb will be characteristic of the region. $CO_2$ emissions in each region can be compared using a proportion of radioactive carbon. Herein, leaves of the cherry tree were collected from six places in Gyeongju and measured using accelerator mass spectrometry (AMS) at the Dongguk University.

## 2. Methods and Results

### *2.1. Regional characteristics*

The population density of Gyeongju is 188.40 persons/km$^2$. To clearly compare regional characteristics, the standard area representing population density was set as the housing site and the resident population of each region was identified. In addition, we compared and analyzed forest and farmland areas of each region. Table I contains information about each region. Among the sampling areas, Leaf 5 has a factory site, which accounts for 14.28%.

### *2.2. Sample preparation method*

Precaution was taken during the sampling of leaves to avoid contamination by carbon-containing substances. Samples were washed with distilled water, and then washed again according to the acid–alkali–acid method [3]. Pure iron was obtained via a preheating process and was used as a catalyst for the reaction with the sample.

$$Fe + (\text{C-contents}) + nO_2 \rightarrow FeO \text{ or } Fe_2O_3 + n'CO_2 \quad (1)$$

$$FeO \text{ or } Fe_2O_3 + H_2 \rightarrow Fe + H_2O \quad (2)$$

The sample was combusted through an Element Analyzer(FlashSmart™) to form $CO_2$. The generated $CO_2$ reacted with the catalyst through a reduction process to graphitize. The graphitized sample was ground and put in the cathode. The cathode was analyzed using AMS. Standard samples (phthalic acid, C4, C5, C8, and OX-II) were also investigated to verify the accuracy of measurements.

### *2.3. Results*

In this experiment, AMS (MICADAS, Mini Carbon Dating System, 200keV model, Ionplus) of Dongguk University's WISE campus was used. The results are displayed in Tables II and III. Table III confirms that the experiment was successful and that sample data are relatively reliable.

Table I. Sampling region and regional characteristics

| | Sampling region | Regional characteristics | Population density (persons/km$^2$) | Housing site (%) | Forest area (%) | Farmland area (%) |
|---|---|---|---|---|---|---|
| Leaf 1 | Sannae-myeon | Rural | 2,955.88 | 3.07 | 67.93 | 11.51 |
| Leaf 2 | Bomon-dong | Tourist spot | 10,041.67 | 3.63 | 44.90 | 40.59 |
| Leaf 3 | Hwango-dong | Residential area | 20,092.72 | 44.01 | 0.25 | 5.96 |
| Leaf 4 | Hwangridangil | Tourist spot | 21,054.19 | 24.57 | 6.12 | 22.49 |
| Leaf 5 | Hwangseong-dong | Residential area | 30,857.30 | 23.15 | 8.30 | 14.62 |
| Leaf 6 | Dongcheon-dong | Residential area | 21,002.88 | 19.82 | 40.27 | 13.14 |

Table II. Sample data

| Sample | $F^{14}C$ | **$\Delta^{14}C$** (‰) |
|---|---|---|
| Leaf 1 | 0.9889 | −19.7 |
| Leaf 2 | 0.9874 | −20.3 |
| Leaf 3 | 0.9806 | −27.0 |
| Leaf 4 | 0.9852 | −23.3 |
| Leaf 5 | 0.9762 | −32.3 |
| Leaf 6 | 0.9849 | −23.6 |

Table III. Standard sample data

| Sample | Eigen value $F^{14}C$ | Measured value $F^{14}C$ |
|---|---|---|
| Phthalic acid | 0 | 0.0037 |
| IAEA C4 | 0.0020–0.0044 | 0.0032 |
| IAEA C5 | 0.2305 (± 0.0002) | 0.2244 |
| IAEA C8 | 0.1503 (±0.0017) | 0.1515 |
| Ox-II | 1.3408 | 1.3406 |

To analyze the sample data, we used $\Delta^{14}C$, which can be calculated using $F^{14}C$. The smaller the value of $\Delta^{14}C$, the higher the $CO_2$ emissions.

$$F^{14}C = A_{SN}/A_{ON} \quad (3)$$

$$\Delta^{14}C = (A_{SN}/A_{abs} - 1) \times 1000 \quad (4)$$

$$A_{abs} = A_{ON}e^{\lambda(year - 1950)} \quad (5)$$

$$(F^{14}C / e^{\lambda c(year - 1950)} - 1) \times 1000 = \Delta^{14}C \text{ (‰)} \quad (6)$$

In equation 6, the applied λc was 1/8267 $yr^{-1}$ along with considering the year in which the sample was collected. [4].

*2.4 Discussion*

Sample data in Table II show that regional characteristics are related to $\Delta^{14}C$. Rural areas represent the highest $\Delta^{14}C$, followed by tourist spots and residential areas. Leaf 6 has the characteristics of a residential area; however, its $\Delta^{14}C$ is relatively high, indicating that it most likely corresponds to the large forest area and small housing site. Leaf 5 shows the lowest $\Delta^{14}C$ in Gyeongju, probably because of the influence of the highest population density in Gyeongju and a factory site.

## 3. Conclusions

Samples were collected in six regions in Gyeongju, and their $\Delta^{14}C$ amounts were calculated. An analysis of the difference in the emitted $CO_2$ according to regional characteristics confirmed that $CO_2$ emissions increased based on traffic volume. In addition, $CO_2$ emissions were higher in the factory area. We propose to measure CO2 emissions in industrial park areas and analyze the relationship with the number of adjacent factories in the future.

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