Using Stable Isotopes of Carbon to Monitor Biodegradation of Pollutant Compounds

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INTRODUCTION

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PURPOSE OF CARBON ISOTOPE MONITORING AT PORT HUENEME

Carbon isotope monitoring is being conducted on contaminated petroleum soil and groundwater and in remediation demonstrations at the Construction Battalion Center (CBC) in Port Hueneme to indicate if bioremediation of petroleum compounds is occurring.

ADVANTAGES

By comparing the carbon isotope ratios of the different carbon containing compounds, this will indicate that the bacteria are indeed consuming the pollutant compounds and are converting them into harmless ¹²CO₂ and ¹³CO₂.

TECHNICAL DESCRIPTION

Many elements exist as two or more isotopes. Isotopes of an element have the same number of protons in their nuclei but different numbers of neutrons. For example, ¹²C has six protons and six neutrons, and ¹³C has six protons and seven neutrons. Both ¹²C and ¹³C are stable, i.e., they are not radioactive like their ¹⁴C counterpart. The ¹²C isotope is the most abundant isotope, making up about 98.89% of all carbon, whereas ¹³C constitutes approximately 1.11% of all carbon (¹⁴C makes up less than 0.00001% of all naturally occurring carbon).

The additional neutron in ¹³C element makes it slightly heavier than ¹²C. Because of this weight difference, the two isotopes tend to react at slightly different rates in biological and chemical reactions. The most significant reaction where this occurs is during photosynthesis, in which CO₂ in the air is incorporated into plant tissue. Once the carbon isotope ratio has been established in the plant, further transformations of carbon compounds do not change the isotope ratio to a large degree. Throughout millions of years, animal, plant, and tiny marine organism residues have been subjected to geological conditions, which have converted them into a complex mixture of organic substances called petroleum. There are hundreds of individual carbon containing compounds in every crude oil. The composition of ¹²C and ¹³C elements in each crude oil varies with its origin. Crude oil is refined by fractional distillation into commercially usable petroleum products. Petroleum products are a complicated mixture composed primarily of molecule chains containing 5 to 10 carbon atoms for gasoline, 11 to 18 carbon atoms for jet fuel, and 15 to 40 carbon atoms for lubricating oils.
Biological processes are varied and depend on the fuel hydrocarbon contaminant chemistry and soil and water conditions. The microorganisms act to transform contaminants from relatively toxic forms to relatively nontoxic forms (CO₂, methane) of carbon. Stable carbon isotope ratios are being measured as indicators of the bioremediation of petroleum products, such as diesel and gasoline, as shown in Figure 1.

![Figure 1. Measuring stable carbon isotope ratios.](image)

It has been found that bacteria take on the carbon isotope ratios of their food; furthermore, the CO₂ that they release during the breakdown of the diesel and gasoline has the same carbon isotope ratio as their food. The implication of this is that when bacteria consume pollutant compounds in diesel and gasoline, their tissues and the carbon dioxide waste product that they respire have $^{13}\text{C}/^{12}\text{C}$ ratios that are the same as the pollutants that they are degrading.

At contaminated sites, scientists hope to use carbon isotope ratios to indicate whether or not bioremediation of pollutant compounds is occurring. They will measure the carbon isotope ratios for the pollutant compounds (in Port Hueneme this will consist of gasoline and diesel) as well as non-pollutant organic matter. Scientists will then measure the carbon isotope ratios of bacteria collected from the polluted ground waters and soils, and will measure the isotope ratios of CO₂ collected from soil gas samples.

For more information about this monitoring system, contact Mr. Jeff Heath, Manager, Technology Application Branch, Code ESC414, at (805) 982-1657 or DSN: 551-1657, or call our 24-hour number: (805) 982-4070 or DSN: 982-4070.

![Figure 2. Gas chromatograph/isotope ratio mass spectrometer.](image)