Solution for Estimating Generation Source of PM 2.5 with "Aerosol Analyzer"

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ABSTRACT

In recent years, air pollution has become a concern due to fine particles (PM 2.5) that have a diameter of 2.5 μm or less. In particular, pollution has become a serious problem in Asia, and in the future, it is expected that effective measures to reduce PM 2.5 will be sought and adopted in earnest. Fuji Electric's "Aerosol Analyzer" is capable of automatically analyzing the main components of PM 2.5. Since the measured component data includes information concerning the sources of origin of the PM 2.5, it is expected that the estimation of the main sources of origin through data analysis will contribute to creating effective measures of mitigation. Measurement examples in Kawasaki City and in China showed that it is possible to estimate the approximate location of the sources of origin.

1. Introduction

Aerosol (fine particles suspended in the air) has a significant impact on air pollution, and as a result, there has been an advance in countermeasures and analysis techniques for assessing the state of aerosol. The important parameters of aerosol include its particle size (diameter of the particle) and components. Aerosol has a particle size that ranges from several nm to 100 μm. Among the different sizes, aerosol with a particle size of 2.5 μm or less is referred to as PM 2.5. Since PM 2.5 is capable of penetrating deep inside the lungs, there are concerns about its health effects. Therefore, environmental standards*1 were announced regarding PM 2.5 in Japan in 2009.

There are various components of PM 2.5, but the main components include inorganic ion components such as sulfates (mainly sulfate ion: SO_4^{2-}) and nitrates (mainly nitrate ion: NO_3^-), organic matter and black carbon (elemental carbon). Black carbon and some organic matters are referred to as primary generated aerosols since they are contained in the exhaust gas of diesel engines and are directly emitted from the sources of origin. On the other hand, sulfates and nitrates are referred to as secondary generated aerosols since they are generated by the chemical reactions in the atmosphere caused by precursors such as the SO_2 and NO_x, which are emitted from the sources of origin. Since the components of PM 2.5 provide very important information that is useful in the elucidation of the sources of origin, local governments are being required to perform component analysis in addition to conventional PM 2.5 mass concentration measurement activities.

Component analysis of PM 2.5 is generally performed by a filter based method based on a standard measurement method. The filter based method is performed via manual analysis of PM 2.5 collected in a filter. As a result, this method requires a lot of time and cost, and it needs to be implemented often due to the limited time of measurement periods. It is against this backdrop that Fuji Electric has developed and released an "Aerosol Analyzer" as a device for measuring the main components of PM 2.5. It is capable of automatic operation at all stages of the analysis process from sampling to measurement. In this paper, we will describe the features of the aerosol analyzer and introduce its measurement principles, while also providing some measurement examples and describing its uses as a solution for estimating the generation source of PM 2.5.

*1: Environmental standard: A yearly average of 15 μg/m^3 or less, and a daily average of 35 μg/m^3 or less

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2. "Aerosol Analyzer"

2.1 Features

Figure 1 shows the external appearance of the aerosol analyzer. The aerosol analyzer is capable of implementing real-time quantitative analysis of the main components of PM 2.5.

(1) Three-component simultaneous measurement via compound analysis

The compound analysis combines light scattering, laser-induced incandescence (LII) and mass spectrometry to enable simultaneous measurement of sulfates, nitrates and black carbon.

(2) Real-time component analysis

The measurement period for component analysis

Fig.1 "Aerosol Analyzer"

that used to take more than 8 hours using the filter based method can now be done in 15 minutes.

(3) Quantitative analysis of the components

PM 2.5 is collected with high-efficiency using a particulate trap that adopts micro electro mechanical systems (MEMS) technology, thus making it possible to implement quantitative analysis, which is something that was difficult to do in the past.

(4) Display and operation via touch screen

Major operations can be performed using the touch screen that is mounted to the front surface of the aerosol analyzer. In addition to displaying measurement values, it is also possible to monitor the operation status, as well as display alarms.

2.2 Specifications

Table 1 shows the main specifications of the aerosol analyzer.

Table 1 Main specifications of "Aerosol Analyzer"

Item	Specification
Measurement target	○ Mass concentration of the PM 2.5 ○ Mass concentration of black carbon contained in the PM 2.5 ○ Mass concentration of the sulfates contained in the PM 2.5 ○ Mass concentration of the nitrates contained in the PM 2.5
Measurement method	○ Light scattering method: Mass concentration of the PM 2.5 ○ Laser-induced incandescence: Mass concentration of black carbon ○ Mass spectrometry: Mass concentration of sulfates and nitrates
Measurement range*	○ PM 2.5: 0 to 100 μg/m^3 or 0 to 1,000 μg/m^3 ○ Black carbon: 0 to 30 μg/m^3 or 0 to 300 μg/m^3 ○ Sulfates: 0 to 30 μg/m^3 or 0 to 300 μg/m^3 ○ Nitrates: 0 to 30 μg/m^3 or 0 to 300 μg/m^3
Sampling amount	Approx. 2.0 L/min
Power supply voltage*	100 V AC ±10%, 50 Hz/60 Hz ±5% or 220 V AC ±10%, 50 Hz ±5%
Power consumption	Approx. 1 kVA (Max. 1.5 kVA)
Dimensions	Main unit: W 640 × H 1,740 × D 828 (mm)
Mass	Main unit: Approx. 320 kg
Accessories	Scroll pump, UPS, chiller and others

* Measurement range, power supply voltage: Selected at time of purchase

2.3 Measurement principles

The aerosol analyzer consists of an LII component and mass spectrometry component. Figure 2 shows the measurement principles.

The LII component measures the mass concentration of PM 2.5 and black carbon. It detects the scattered light and incandescent light that comes from the aerosol contained in the air sample when the air sample is irradiated with a high powered infrared laser. The mass concentration of PM 2.5 is determined by measuring the particle size and number of particles from the intensity and frequency of the scattered light. At the same time, the mass concentration of black carbon contained in the PM 2.5 is determined from the intensity and frequency of the incandescent light.

The mass spectrometry component measures the mass concentration of the sulfates and nitrates of the ion components contained in PM 2.5. There are 2 methods available for implementing online mass spectrometry of the components of PM 2.5. These include a laser desorption/ionization mass spectrometry method that implements mass spectrometry via direct laser ionization, as well as a thermal desorption electron ionization mass spectrometry method that implements mass spectrometry via electron ionization after performing thermal vaporization using collected PM 2.5. Though the laser desorption/ionization mass spectrometry method is highly sensitive, quantitative analysis is difficult to be conducted due to the variation in ionization efficiency among components. On the

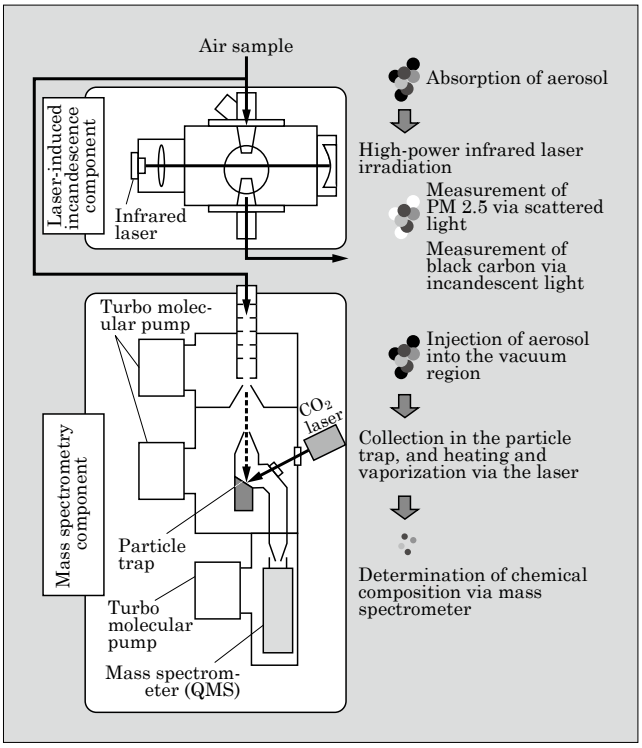

Fig.2 "Aerosol Analyzer" measurement principles

other hand, the thermal desorption electron ionization mass spectrometry method exhibits good quantitativeness regardless of selectivity in ionization. The aerosol analyzer adopts the thermal desorption electron ionization mass spectrometry method from the standpoint of quantitatively analyzing the PM 2.5 contained in the utilized air sample.

When the air sample is injected into the vacuum chamber of the mass spectrometry component, the gas in the air sample is removed and only PM 2.5 is collected into the particle trap. The particle trap has a uniquely developed structure that was created using MEMS technology, and it achieves a high collection efficiency of at least 90%[1]. The external appearance of the particle trap is shown in Fig. 3. The collection portion of the particle trap is composed of a 100 μm square lattice-like structure. By superimposing multiple lattice-like plates, PM 2.5 moves quickly through a vacuum while repeatedly colliding against the inner wall of the particle trap, thus depriving the kinetic energy, while enabling collection. This PM 2.5 is irradiated with the high powered infrared laser (CO_2 laser) to create heat and vaporization, and after undergoing ionization via the electron-ion source, quantitative analysis is performed for the sulfates and nitrates utilizing a quadrupole mass spectrometer (QMS).

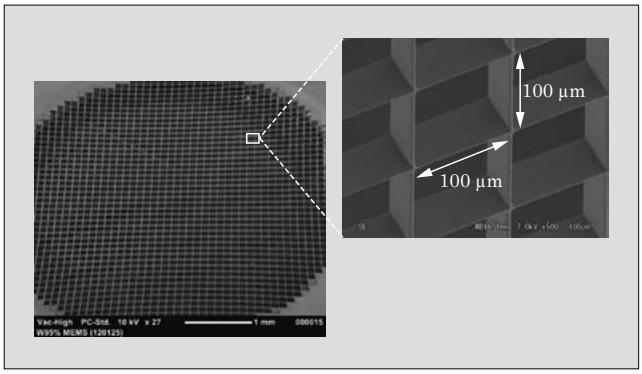

Fig.3 External appearance of particle trap

2.4 Measurement examples

We implemented a field evaluation with the help of local governments. We installed an aerosol analyzer at an ambient air pollution monitoring station as part of a joint research project (Kawasaki City Environmental Technology Industry-Academia-Public-Private Collaboration Research Pilot Project) implemented with Kawasaki City from FY2013 to FY2015. As a result, we were able to verify the measurement performance and maintainability of the analyzer. Figure 4 shows the results of carrying out a compara-

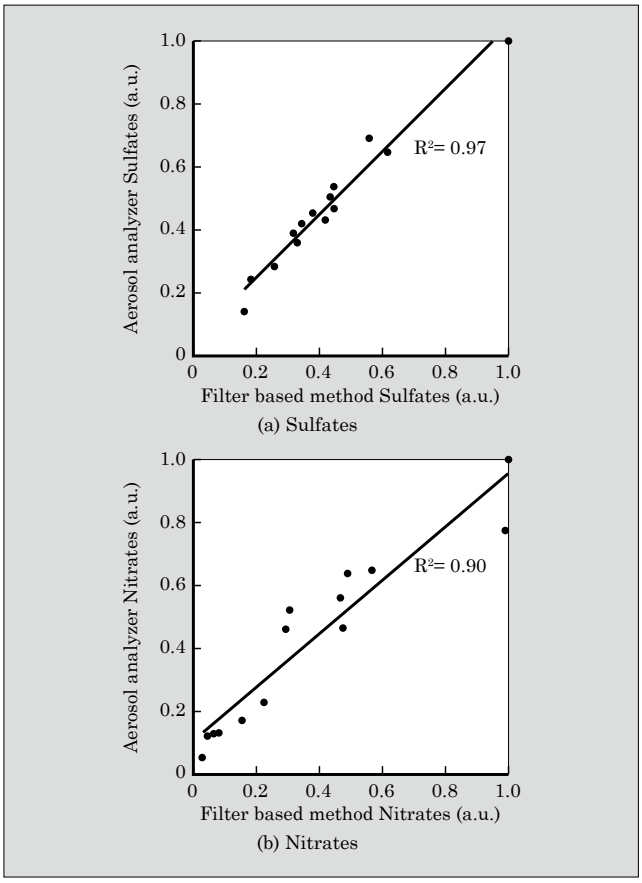

Fig.4 Results of comparative evaluation with filter based method

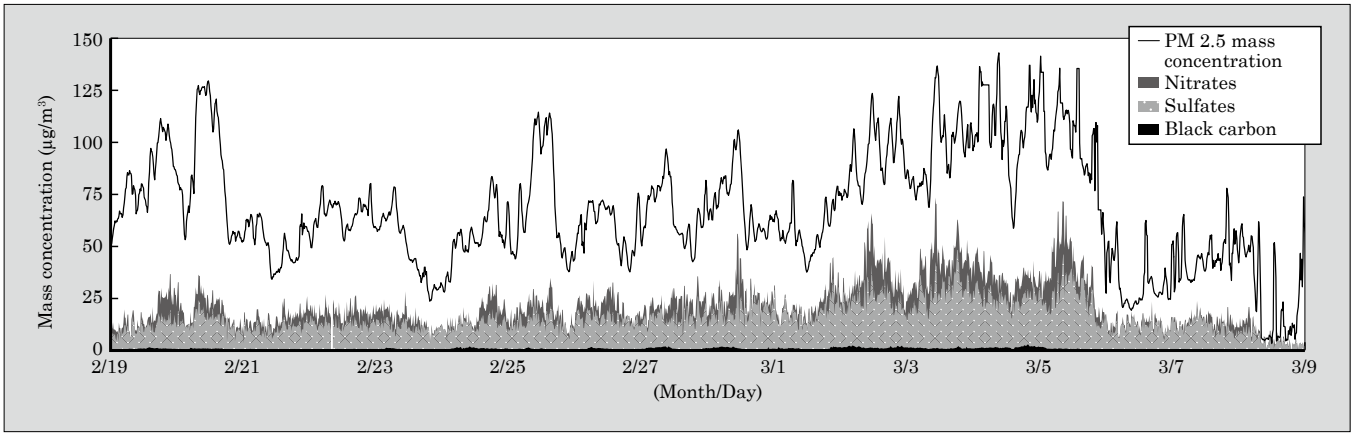

Fig.5 Measurement example in China

tive evaluation with the filter based method in regard to sulfates and nitrates. The determination coefficient R^2 in the analysis of the aerosol analyzer and the filter based method demonstrated a high correlation of 0.9 or higher for each.

Furthermore, the field evaluation was not only carried out in Japan, but also overseas. Figure 5 shows an example of continuous measurement being implemented in China. We confirmed that continuous real-time measurement can be implemented smoothly even in high concentration environments where the mass concentration of PM 2.5 exceeds 100 μg/m^3.

3. Solution for Estimating Generation Source of PM 2.5

3.1 Need for estimating generation source

In China, pollution has become a serious problem, and as a result, measures are being taken in earnest to reduce PM 2.5. The Air Pollution Prevention Action Plan (announced by China's State Council in September 2013) has set a goal of reducing the yearly average PM 2.5 concentration by approximately 15% to 25% when compared with the year 2012. The goal is intended to be achieved by the year 2017 for the regions of Beijing, Tianjin and Hebei, as well as the various regions around the Yangtze River Delta and Pearl River Delta. According to the PM 2.5 source apportionment for Beijing (announced in April 2014) conducted by the Beijing Municipal Environmental Protection Bureau, the main occurrence factors for PM 2.5 include automobiles (31%), coal combustion (22%), industrial production (18%), dust (14%) and others (14%). Furthermore, air pollution has been shown to improve significantly when traffic restrictions and factory shutdowns are imposed at the time of hosting important international conferences and sporting events. However, these types of restrictions cannot be imposed long term because of their impact on economic activities.

In order to strike a balance between solving environmental problems and achieving sustainable economic growth, it is important to understand the conditions of occurrence and to take effective measures against the sources of occurrence. As a result, there has been rapidly increasing demand for instrumentation equipment that not only supports measurement of PM 2.5, but also facilitates reduction measures through analysis of generation sources. Therefore, we have been working on the development of a system for estimating the generation sources of PM 2.5. The system estimates generation sources by analyzing various data in combination, which includes the measurement data from the aerosol analyzer, data on precursors and meteorological data. Figure 6 shows the configuration of the system.

3.2 Overview of generation source analysis technology

In the analysis of generation sources, emphasis is placed on the generation process of secondary generated aerosols (sulfates and nitrates), and estimation of generation sources is performed based on the differences in the lifetime and diffusion process of secondary generated aerosols and their precursors in the atmosphere. Gaseous precursors spread via atmospheric circulation immediately after being emitted regardless of the location of their generation sources, but the concentration of these substances decreases gradually as they are mixed in with the surrounding air. On the other hand, PM 2.5 is mainly removed from the atmosphere via precipitation such as rain or snow, and as a result, it can remain in the atmosphere and travel long distances for periods of over one week depending on environmental conditions, such as when it does not rain.

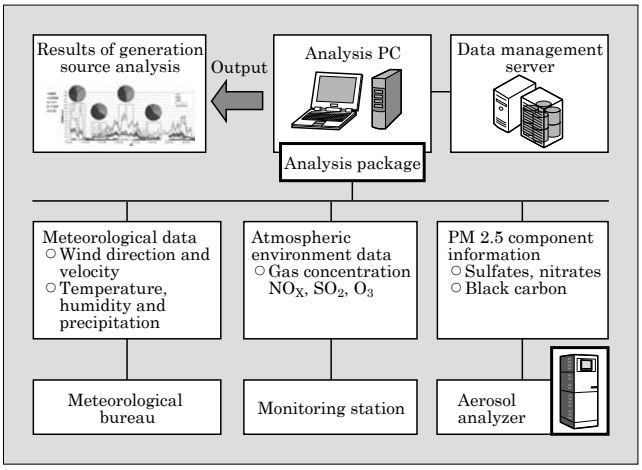

Fig.6 Configuration of system for estimating generation sources of PM 2.5

Therefore, the correlation between the secondary generated aerosol concentration and precursor gas concentration is analyzed, and if there is high correlation in these concentration changes, it is estimated that the generation source is in the vicinity of the place of measurement (approximately less than 100 km). If the correlation is low, this means that the generation source is located at a remote distance from the place of measurement (approximately 100 km or more), and in such a case, it is estimated that advection will likely occur from outside of the region. As mentioned above, since the influence of the weather is large, analysis needs to be done in consideration of meteorological data.

3.3 Analysis case examples

An analysis case example of sulfate and its precursor SO_2 is shown in Fig. 7. Figure 7(a) and Figure 7(b) show data measured in different regions. The aerosol analyzer was used to obtain the measurement data for the sulfate, but a separate gas analyzer was used to obtain the measurement data for the SO_2.

Figure 7(a) shows the correlation in the concentration changes of the sulfates and SO_2 cannot be seen. In such a case as this, it can be estimated that the

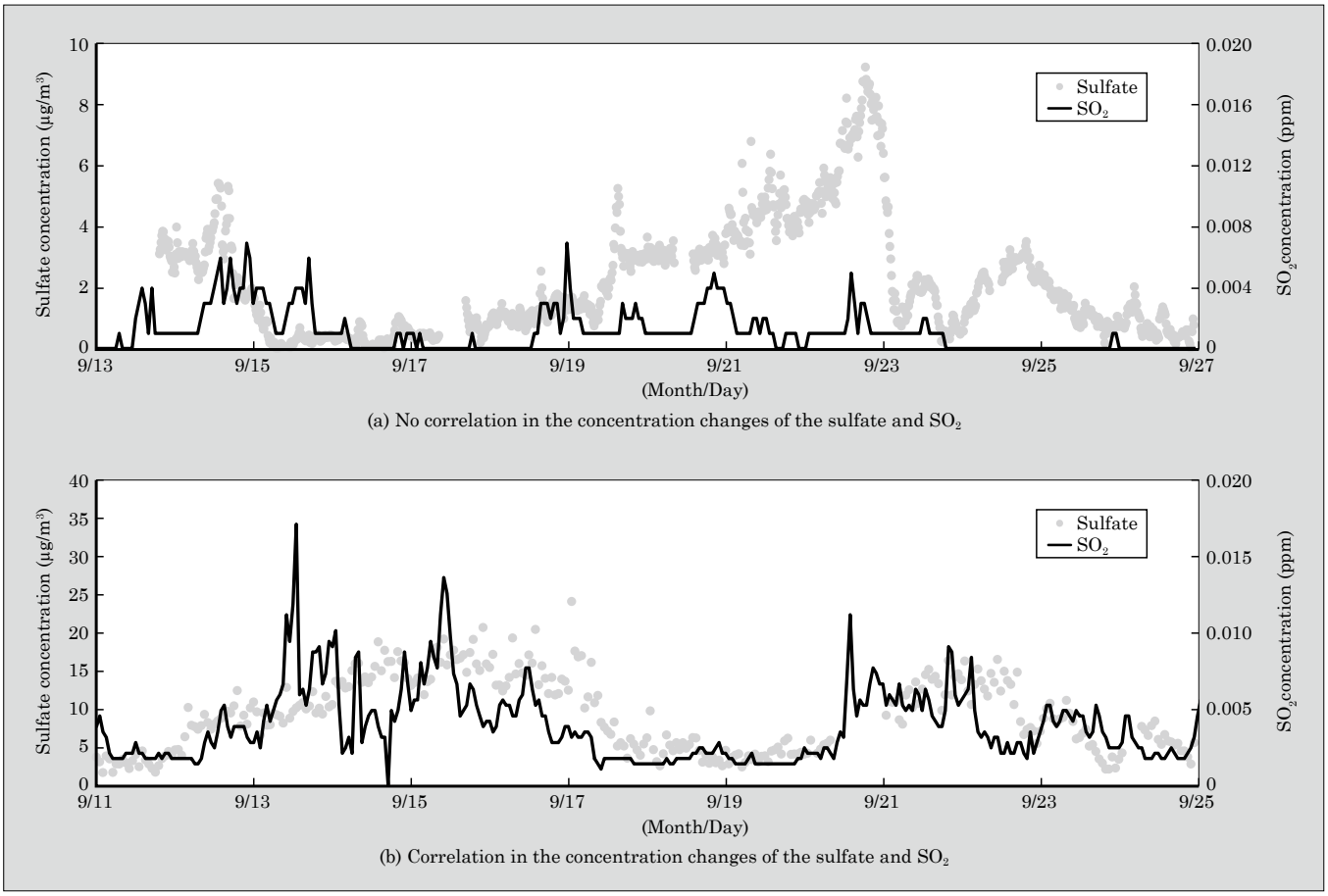

Fig.7 Analysis case example of sulfates and SO_2

generation source of the sulfates is located at a remote distance from the place of measurement. The weather during this period was mostly sunny, and the weather map showed a migratory anticyclone moving from west to east, and as a result, it could be estimated that much of the aerosol would be carried via advection from the west due to westerlies.

Figure 7(b) shows the motion that the concentration of the sulfates followed in contrast to the concentration of the SO_2, and the correlation in the concentration changes of the sulfates and SO_2 is also observable. In such a case as this, it can be estimated that the generation source of the sulfates exists in the vicinity of the place of measurement. The weather during this period was sunny or cloudy, and since the wind was nearly always blowing from the north-west, it could be estimated that the main generation source was a coal-fired power plant located several tens of kilometers north-west of the place of measurement.

3.4 Future developments

As described above, it is possible to estimate generation sources by analyzing the correlation between secondary generated aerosols and precursors. The current state of the analysis is limited to rough estimation, but by increasing the number of places of measurement by installing multiple aerosol analyzers in the applicable regions, analysis can be performed in combination with various data such as the operation data of major factories and power plants, traffic data and topographical information. By doing this, we believe that we will be able to estimate generation sources in detail. Furthermore, we are planning to implement a demonstration project of the system for estimating the generation sources of PM 2.5 in cooperation with local governments.

4. Postscript

In this paper, we have described our "aerosol analyzer," which is capable of implementing real-time quantitative analysis of the main components of PM 2.5, as well as introduced our solution for estimating the generation sources of PM 2.5 with the aerosol analyzer. PM 2.5 not only influences air pollution, but also greatly impacts climate change such as global warming, and as a result, it needs to be dealt with on a worldwide scale. In the future, we plan to provide an instrumentation solution based on a foundational technology for accurately measuring fine particles, and we believe this solution will contribute to the conservation of the world's environment and the sustainable development of society.

References

(1) Takegawa, N. et al. “Evaluation of a New Particle Trap in a Laser Desorption Mass Spectrometer for Online Measurement of Aerosol Composition.” Aerosol Science and Technology, 46.4 (2012) : p.428-443.

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