Explosive-trace Detection System Using Mass Spectrometry

OVERVIEW: The terrorist attacks of September 11th, 2001 in the USA have radically changed the awareness of society towards both domestic and international security. These days, as a result of the destabilization of world affairs, terrorist attacks involving explosives or harmful chemical substances are happening all over the world, and the barbarity of such attacks has been worsening. In response to these circumstances, security inspection areas at airports and other important facilities are utilizing metal detectors and X-ray detection equipment to spot deadly weapons by revealing the presence of metal objects and the shape of baggage contents. However, it is difficult to detect the kind of explosives mentioned above by means of such detection equipment. To overcome this difficulty, new kinds of detection equipment, such as X-ray devices with tomography functions and detectors for identifying minute traces of explosive constituents left on target objects, are being installed. In addition, the terrorist threat posed by toxic chemical substances — which can be deadly in tiny amounts — is also on the rise. Accordingly, detection equipment that can meet this additional threat must also be deployed. Responding to the above-described security situation, Hitachi, Ltd. has developed and commercialized a mass-spectrometry detection system that utilizes the mass-spectrometry methods that we have acquired during the development of various analytical instruments.

INTRODUCTION

WITH the strengthening of security levels, there is a growing demand for explosive-trace detection systems that can detect traces of explosive ingredients adhered to the surfaces of hand luggage or postal matter in a short time.

After the terrorist attacks of September 11th, 2001 in the USA, measures to strengthen security around the world have been put into effect. Focused on important facilities, starting with airports, installation of sophisticated X-ray detection equipment and explosive-trace detection systems is thus continuing.

It is hoped that by supplementing conventional equipment and materials for inspecting hand baggage and checked-in luggage, an explosive-trace detection system will provide an effective means of realizing more dependable security. Accordingly, development and application of such a system is an urgent task.

In light of these circumstances, Hitachi Ltd. has developed a mass-spectrometry-type explosives detection system based on the measurement technologies we have acquired up till now. This paper describes the features, applications, and future developments of this system (see Fig. 1).

REQUIRED CAPABILITY OF EXPLOSIVE-TRACE DETECTION SYSTEM

Applications

The explosive constituent of a detection target has the characteristic that it is extremely stable at room temperature, so it is not given off as a gas easily. This means that explosive constituents can stick to the surface of objects and remain there until they pass through inspection areas.

At an inspection area, after passing through X-ray detectors, any suspicious objects are taken aside and their surfaces are “wiped” for explosive traces. The wiped sample is then placed in the developed detector, which establishes if explosive components are present or not and, if they are, determines their type.

Fig. 1—External Appearance of Explosive-trace Detection System and Display Image.
This system provides high-sensitivity, short-detection time, and high-selectivity by means of quadrupole mass spectrometry and atmospheric-pressure chemical ionization.

TABLE 1. Main Methods and Principles Applied to Trace-detection Device
The methods for detecting and identifying the target molecules are classified according to method and principle in this table.
The main methods used by conventional products are IMS or chemiluminescence.

No.	Method type	Principle
1	Atmospheric-pressure-chemical-ionization mass spectroscopy	Target object is ionized by an electric field under atmospheric pressure, and molecular mass of ions is determined in order to identify target object.
2	IMS	Mobility of ionized molecules of target object is measured under atmospheric pressure in order to identify constituents.
3	Chemiluminescence	Utilizing chemiluminescence of specific molecules in target object to identify explosive traces.
4	Antigen-antibody	Detector is set up so that as an antigen, a specific molecule of an explosive reacts with an antibody. Detecting this antigen-antibody reaction forms the basis of this detection method.

IMS: ion-mobility spectrometry

Type of Detection Method

As its name suggests, an explosive-trace detection system samples a trace of an explosive from the surface of an inspected object, and it then analyzes the trace to determine the presence (or absence) and type of explosive. The detection procedure follows the main steps listed below:
(1) Sample extraction
(2) Vaporization, separation, and selection
(3) Ionization
(4) Measurement
(5) Analysis
(6) Display analysis results

Several different methods for measuring the explosive constituents are being applied in practice. The fundamental principles and methods used by the main types of trace-detection systems are listed in Table 1.

Each method is designed to efficiently separate and measure explosive constituents. However, regarding security inspection from now on, greater performance in terms of speed and accuracy in inspecting physical objects is required.

To meet these requirements — with detection expressed by the key factors “sensitivity, selectivity, and speed” as our goal — Hitachi, Ltd. has applied measurement technologies developed from our conventional analytical techniques in order to develop, commercialize, and implement an easy-control, simple-maintenance detection system.

FEATURES AND STRUCTURE OF DEVELOPED DETECTION SYSTEM

Features

The developed explosives detection system — which can detect the main constituents of high-power plastic explosives in a few seconds — has attained an industry-leading false-detection rate of 0.1% or less. In addition, adoption of atmospheric pressure chemical ionization and use of a mass spectrometer give this system the following features compared to the other systems presented earlier.
(1) No need for radiation management

No radiation is used making device management

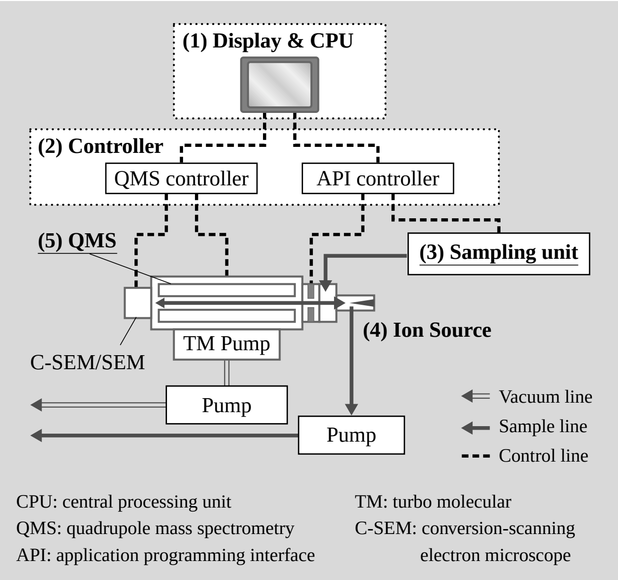

Fig. 2—Configuration of Explosive-trace Detection System.
The detection system is composed of (1) a display/touch panel, (2) a controller, (3) a sampling unit, (4) an ion source, and (5) QMS.

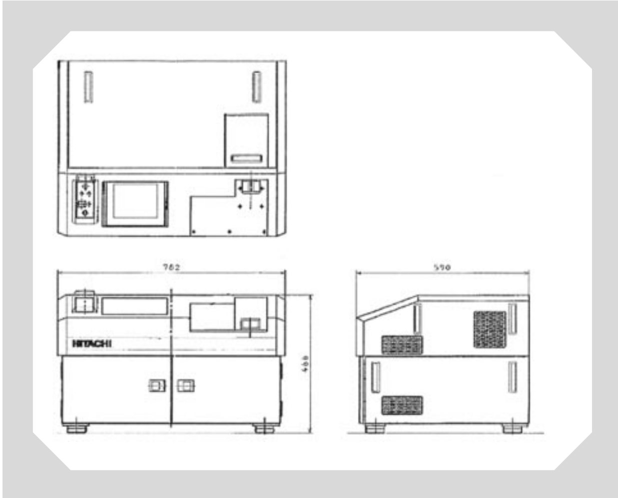

Fig. 3—Outline of Explosive-trace Detection System.
Each part of the system — sampling unit, spectrometer, and analyzer — are housed in a compact, desk-top-type steel casing.

after deployment simple.

(2) Enhanced operability

No additives or water are used during normal operation enabling the system to be operated by simple procedures.

(3) Database extendibility

Use of a mass spectrometer enables the database to be expanded based on mass number of target material.

Device Structure

The configuration of the developed explosives detection system is shown in Fig. 2, and its outline is shown in Fig. 3. The main features of the system [labeled (1) to (5) in Fig. 2] are briefly described as follows:

(1) Display and touch panel: A touch-panel-type, high-definition LCD (liquid crystal display) panel is used for operating the detector and displaying the detection results. Along with its high visibility at the inspection site, which contributes to the smoothness and reliability of the inspection process, the panel is highly flexible, which makes for excellent system handleability. The system is equipped with a function that allows previous detection results and measurement details to be displayed, so a flexible, easy-to-handle system that suits the skill of the operator can be set up.

(2) Controller: The controller regulates the main structural components of the system, namely, the sampling unit and the spectrometer. Having a compact on-board computer incorporating a Hitachi SH-series microprocessor in its CPU, the controller helps to minimize the size and power consumption of the detection system.

(3) Sampling unit: In line with our "simple and easy" concept, a sample is collected on a special "wipe sheet" and inserted into the unit, where it is heated so that gases are given off. When the wipe sheet is inserted into the unit's tray, the detection process starts automatically, and after detection is complete, it is ejected back into the tray.

(4) Ion source: The constituents of the sample are efficiently ionized by corona discharge under atmospheric pressure by means of atmospheric-pressure chemical ionization.

(5) QMS: The molecular masses of the ionized target constituents are measured accurately by QMS.

Detection Principle

A flow diagram of the detection process is shown in Fig. 4. Since explosive molecules do not readily vaporize at room temperature, the sampled explosive constituents must be vaporized. To meet this requirement, the wiped sample is heated to the appropriate temperature in the sampling unit so that when the detection process starts, the explosive constituents are vaporized efficiently.

After vaporization, the sample gas travels along the induction route to the ion source, where carrier-ion molecules (such as oxygen ions) generated by corona discharge ionize the gas into negative ions. The

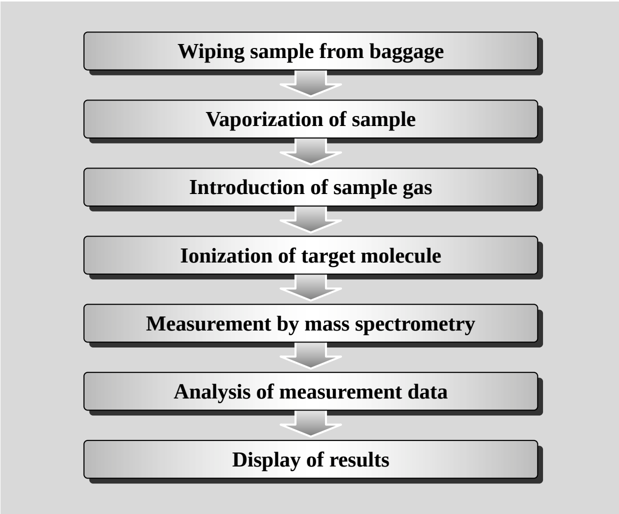

Fig. 4—Flow Diagram of Detection Process.
The detection process is split into three main steps: sample wiping, vaporization, and analysis. Analysis is completed in about 10 seconds.

developed detector is configured so that any impurity components that inhibit the ionization process are immediately removed. This means that the explosive constituents in the sample gas can be ionized more efficiently. Moreover, atmospheric-pressure chemical ionization is different to the electron-bombardment ionization often used in a gas-chromatography mass spectrometer in that it has the unique feature that the molecular structure of the target constituents is kept in tact during ionization.

Because of this feature, detection focused on the chemical properties of the detected constituents is possible. At the same time, the constituents can be distinguished without the need for complicated preprocessing procedures such as separation and selection.

Application to Detection of Harmful Chemical Substances

The developed detection system has been described in terms of its application to the detection of explosive materials. However, over recent years, in addition to the threat from explosive materials, the threat from harmful chemical substances has also been growing. The need to detect such harmful chemicals in real time is thus becoming more urgent. To meet this need, Hitachi is pushing forward with the application of the developed detector in the field of harmful-chemicals detection and aiming to commercialize products in the near future.

CONCLUSIONS

An explosive-trace detection system for application to security inspection and monitoring of harmful substances was developed and outlined in this paper. With the cooperation of both domestic and international companies in the Hitachi group, Hitachi, Ltd. is helping to meet the threats to the safety and security of our society through the development and commercialization of physical-security devices and systems.