Hitachi's Drug-trace Detection System

OVERVIEW: The increasing abuse of illicit drugs such as narcotics and stimulants has become a widespread social problem internationally. To stamp out such drug abuse, the supply of illicit drugs must be eradicated, and inspecting for drugs plays a key role in attaining this eradication goal. Responding to these social demands, Hitachi, Ltd. has developed a drug-trace detection system that provides convenient inspection with high reliability and high sensitivity. As a detection device, it applies a unique mass-spectroscopy technology that offers high reliability and sensitivity. Utilizing a method called APCI (atmospheric-pressure chemical ionization) — which applies corona discharge to ionize chemical substances in air — it eliminates the use of radioactive or poisonous substances often needed in conventional chemical-detection methods; it therefore provides safer and easier detection. It has been confirmed that the system can be applied to detection of many kinds of drugs; thus, it is expected to be a powerful weapon for interrupting the drug supply.

INTRODUCTION

ACCORDING to a report by the Ministry of Finance, the total amount of illicit drugs seized by customs authorities across Japan in 2003 — in excess of one ton — increased by 20% compared with the previous year[1]. Moreover, in regards to the so-called third-phase of stimulant abuse, vigilance of the police is becoming stronger. In recent years, it has become a serious social problem that not only specific groups such as violent gangs but also more general members of society such

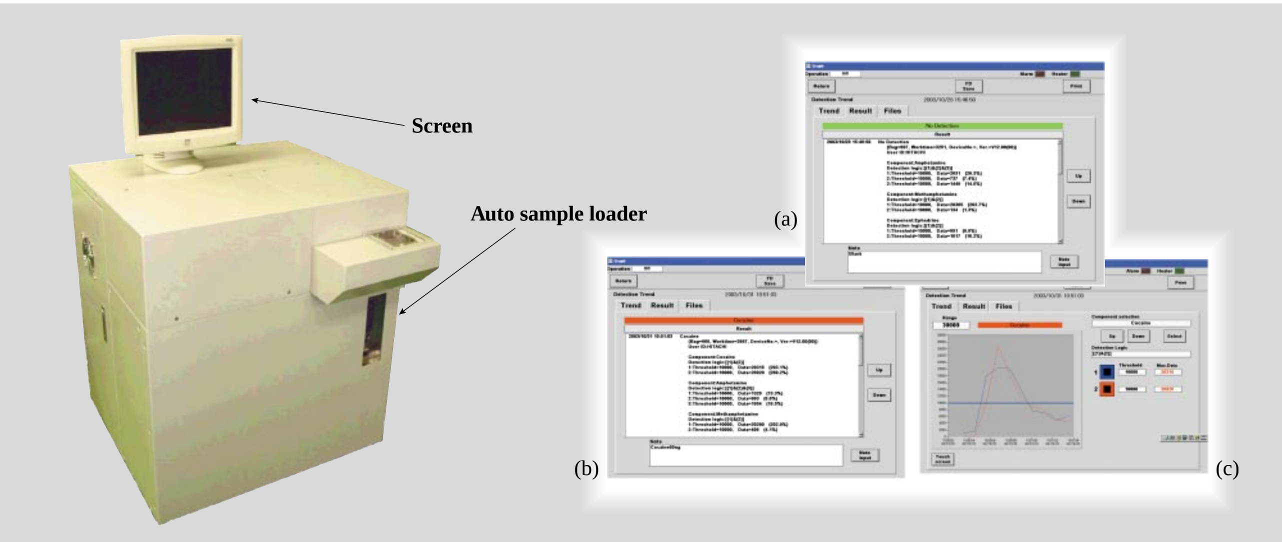

Fig. 1—External View of Drug-trace Detection Device (left); Examples of Detection Results Displayed on GUI (graphical user interface) (right).
The sample material placed on the device's auto sample loader is automatically taken into the detector, the presence (or absence) of illicit drugs is detected, and the detection results are immediately displayed on the screen. Example (a) shows the screen displayed when illicit drugs are not detected. Example (b) shows the screen displayed when the illicit drugs cocaine is detected; detected drugs are highlighted in red, and non-detected drugs are highlighted in green. Example (c) shows the change in the intensity of the detection signal in order that the details of the detection can be ascertained.

as high-school students are abusing drugs.

In Japan these days, among drugs alone, there are over 100 different kinds of designated substances. To uncover chemical substances that are restricted by law, accurate chemical analysis by using any number of devices such as mass spectrometry is needed[2]. Such chemical analyses must be performed at test facility with specialists. Hitachi has pushed ahead with the development of highly reliable detection device that can get results quickly and easily. We have developed a system that can detect minute amounts of substances down to the so-called nanogram realm. This system represents a successful application of mass spectrometry in the field of highly sensitive chemical analysis. That is to say, it is easy to operate. The authors thus consider that we have created a high-sensitivity, high-reliability detection system that can meet the needs of places where specialist knowledge cannot be expected to be available at all times.

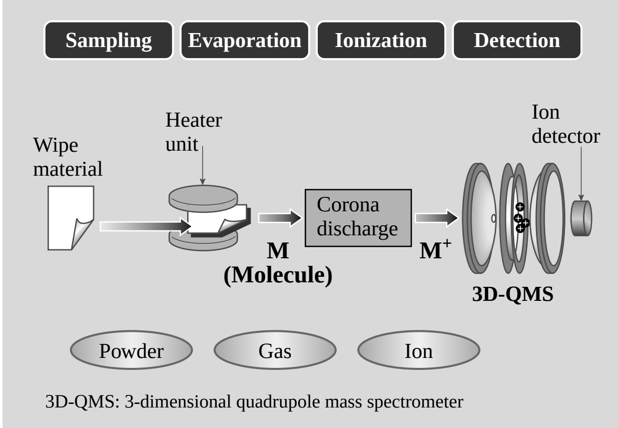

Fig. 2—Process Flow for Drug-trace Detection Using Newly Developed Device.
The drug-detection process is composed of four steps, sampling, evaporation, ionization, and detection.

REQUIREMENTS AND CHARACTERISTICS OF DRUG-TRACE DETECTION DEVICE

The required features of a drug-trace detection device are listed below:
(1) simplicity
(2) speed
(3) reliability
(4) safety
(5) high sensitivity

Fig. 1 shows an external view of the detection device and examples of detection results.

As shown in Fig. 2, in the process flow for the newly developed drug-trace detection device, a sample of powder or liquid is first transferred to the wipe material, which is then placed in the auto sample loader of the detector. Though this procedure is performed by hand, thereafter, the wipe materials for all samples are automatically loaded into the detector and the detection procedure starts. The detection results are automatically displayed on a screen after a few seconds, so there is no need for any complicated operations. And since the detection time is so short and the results are soon known, the system can function with no problems in places with heavy logistical flows, such as airports. The measured spectrum is compared with reference mass spectra stored in a database in order to determine the presence or absence of the substance of interest. This procedure is carried out automatically by software, so there is no need for specialist knowledge. In the case of analysis by special test facilities, even if harmful substances are used, since enough measures are taken, there should be no

TABLE 1. Comparison of Drug-trace Detection Devices
Compared with an instrumental analysis device, newly developed device has better handleability and does not require expertise; moreover, compared with a conventional detection device, its detection capability is superior, and it is safer to use.

Item	Conventional detection device	**Hitachi's newly developed device**	Instrumental analysis device
Detection time	5-10 s	**5 s**	Over several dozen minutes
Sensitivity	Several to several dozen nanograms	**Several to several dozen nanograms**	Several nanograms
Selectivity	Low	**High**	High
Detection errors	Many	**Few**	Low chance
Handleability	Non-expert OK	**Non-expert OK**	Expert knowledge required Expertise required
Harmful effects	Radioactivity or poisonous substances	**None**	Harmful reagents

problems. However, the same cannot be said of analysis on site. Accordingly, in the case of Hitachi's drug-trace detection device, use of dangerous chemicals or substances that have an adverse effect on the environment has been completely avoided. In particular, the operation of the detector only involves two chemical processes — evaporation by physical heating and ionization by corona discharge — both of which only consume electrical energy. This means that being extremely safe, the device can be used anywhere that electricity is used.

Though the sensitivity of the detector changes according to the target substance, minute traces can be detected in the range of a few to several hundred nanograms. This means that it is possible to detect even a minuscule amount of a substance adhered to the surface of a bag concealing illicit drugs. Table 1 compares the detection results by the newly developed device with those by a simple, conventional detection device and those by a chemical analyzer operated by a specialist. As regards the conventional detection device, on top of the fact that many of its parts utilize radioactivity — use of which is governed by strict regulations — problems are often caused by detection errors. In contrast, having no such problems, the newly developed detection system is not only a compromise between the conventional detection device and the specialized chemical analyzer in terms of detection performance, but it is also easy to use by a non-specialist.

DETECTION MECHANISM

The scientific mechanism behind the detection method is explained simply in the following section.

Generation of Drug-trace Ions

The newly developed detection device applies the fundamental principles of mass spectrometry to detect traces of drugs. Mass spectrometry is a method that investigates the behavior of charged ions under vacuum in order to determine the mass of individual ions.

To detect traces of drugs, first, ions of the drug in question must be generated. The device uses APCI (atmospheric-pressure chemical ionization)[3] — an ionization method that selectively generates chemical elements by heating in air. In regards to APCI, H_3O^+ ions are generated by corona discharge from components in the air. These ions then combine with the chemical molecule of interest and produce ions of that molecule according to the following chemical reaction.

$$H_3O^+ + M \rightarrow H_2O + (M+H)^+$$

In this reaction, H_3O^+ comes from the water vapor in air, while M represents the chemical molecule of interest (i.e. the drug trace). The energy required for the water molecule H_2O to become H_3O^+ (i.e. proton affinity) is 697 kJ/mol. Therefore, if the proton affinity of M is higher than that value, the chemical reaction given above will take place; namely, a proton will attach to M, thereby forming the ion $(M+H)^+$. In this way, positive ions of drug molecules are generated.

The ions generated in this way are then injected into a vacuum chamber for mass-spectroscopy analysis. The analysis determines the molecular mass of the ions, which is then checked against previously registered test results (held in a database) on various kinds of narcotic substances. In this way, the presence or absence of drugs can be established.

Identification of Drug-trace Ions

In the drug-identification step, the generated ions are introduced through a small hole into a vacuum containing a special-purpose mass spectrometer composed of three electrodes (called a 3D-QMS). In the 3D-QMS, the ions are contained in the magnetic field produced by the three electrodes and decomposed by helium bombardment[4]. When the narcotic ions decompose, they break up in a unique spectral pattern that depends on their molecular structure. Accordingly, the drug ions can be precisely identified from the data on their molecular mass combined with the unique

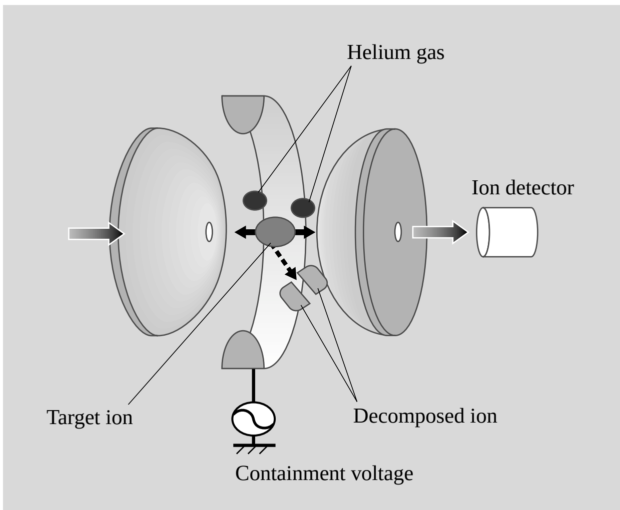

Fig. 3—Outline of 3D-QMS.
The target ions are confined in an electric field created by three electrodes, where they are bombarded with helium gas and decomposed.

decomposition pattern.

An schematic outline of the 3D-QMS mass spectrometer is shown in Fig. 3. While containing ions in a single device, the 3D-QMS performs analysis in three steps:
(1) selection of target ion,
(2) decomposition of target ion, and
(3) identification of the mass of the decomposition products.

A voltage is applied to the three electrodes of the mass spectrometer, thereby producing an electric field within which the ions are retained. Then by controlling the trajectories of the many retained ions, certain ions are eliminated so that only the drug ions and ions with the same molecular mass remain [step (1) above]. The remaining (i.e. target) ions are given energy and decomposed by means of bombardment with diluted helium gas [step (2) above]. Finally [step (3)], a mass spectrum of the decomposed ions is produced, and checking this spectral data against the spectral decomposition pattern for registered drugs can distinguish whether the detected target ion comes from a controlled drug or not. Although it is known that mass spectrometry is an excellent method for identifying chemical compounds, it is possible that other chemical substances with the same mass as the target substance are accidentally included in the spectral results. In regards to the analysis method described here, however, by utilizing the spectral pattern of the decomposition products (in addition to the molecular-mass values themselves), it is possible to attain higher detection reliability.

PRACTICAL APPLICATION OF DRUG-TRACE DETECTION

Fig. 4 shows an example of the device being used for drug-trace detection. The following three operations only are performed by hand.
(1) Sampling a specimen by transferring it onto the wipe material
(2) Setting the wipe material in the holder
(3) Placing the holder on the auto loader

Once these steps are completed, the sample is automatically taken into the detector and analysis begins. After detection is completed, the sample and holder are automatically ejected from the detector. And while the detection procedure is going on for one sample, the next sample can be prepared and loaded. This means that consecutive detections can be performed, resulting in a highly efficient detection procedure.

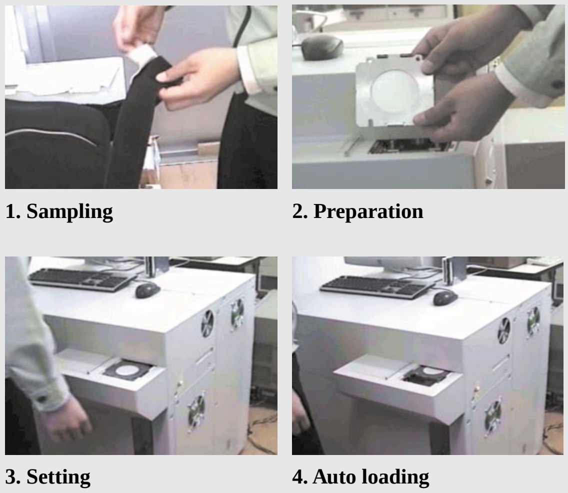

Fig. 4—Operation Procedure for Drug-trace Detection.
Once the wipe material is set in the predetermined place, measurement is performed automatically.

TABLE 2. List of Detectable Substances
Standard registered chemicals are in bold letters; others are optional.

Category	Chemicals
Stimulant	**Amohetamine**
	Methylamphetamine
	Ephedrin
	Methylephedrin
Narcotics	**Heroin**
	Cocaine
	Morphine
	Codeine
	Dihydrocodeine
	LSD
	MDMA
	MDA
Hemp	Marijuana
	THC
	Cannabinol
Opium	**Opium**
Psychotropic drug	Phentermine
	Triazolam (Halcion)
	Methylphenidate
	Chlordiazepoxide
	Quazepam
	Clorazepic acid
	Nitrazepam
	g-Hydroxybutyric acid
	Diazepam
	Amfepramone
	Alprazolam
	Cathine
	Phenobarbittal
	Barbital
	Butalbital

Drug detection and identification are carried out automatically by means of a computer program. This program determines whether the obtained mass-spectrum pattern of the target ion agrees with patterns previously recorded in a database, and when a candidate mass is confirmed against the background spectrum, the detected drug corresponding to that mass is shown on the screen. Several database-registered chemical substances can be detected at the same time. Table 2 lists in bold letters the 12 kinds of chemicals that are registered. Added to these twelve, the optional chemical substances bring the total of drug data already prepared to over 30 substances.

CONCLUSIONS

A newly developed, easy-to-use and high-reliability detection device — which uses mass spectrometry to detect drug traces —was outlined in this paper. The authors expect that since the device does not need expertise on mass spectrometry, it will be utilized in a variety of locations. In future work, the database range will be expanded in order to cover a wider range of drugs. Moreover, aiming at expanding the range of applications of the detection device, we plan to expand the detection range to cover chemical substances other than illegal drugs.