EXPLORATION OF THE INFLUENCE OF RECOVERY SURFACE FOR THE DETERMINATION OF METHAMPHETAMINE THROUGH COLOUR TEST

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EXPLORATION OF THE INFLUENCE OF RECOVERY SURFACE FOR THE DETERMINATION OF METHAMPHETAMINE THROUGH COLOUR TEST

by

NG JIA QUAN

Thesis submitted in partial fulfilment of the requirements for the degree of Bachelor of Science in Forensic Science (Honours)

FEBRUARY 2025

CERTIFICATE

This is to certify that the dissertation entitled “EXPLORATION OF THE INFLUENCE OF RECOVERY SURFACE FOR THE DETERMINATION OF METHAMPHETAMINE THROUGH COLOUR TEST” is the bona fide record of research work done by Mr. “Ng Jia Quan”. Matric number “155872” during the period of October 2024 to February 2025 under my supervision. I have read this dissertation and that is my opinion in it conforms to acceptable standards of scholarly presentation and is gully adequate, in scope and quality, as a dissertation to be submitted in partial fulfilment for the degree of Bachelor of Science in Forensic Science (Honours).

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LIST OF SYMBOLS

mL	Milliliter
s	Second
μL	Microliter
μg	Microgram
%	Percentage
mg/mL	Milligram per milliliter
mg	Milligram
v/v	Volume per volume
cm	Centimeter
g/m^2	Grammage
μg/mL	Microgram per milliliter
:	Colon

LIST OF ABBREVIATIONS

AADK	National Anti-Drugs Agency
ADHD	Attention deficit hyperactivity disorder
ATS	Amphetamine Type Stimulants
CA	Cutting agent
CNS	Central Nervous System
CSA	Controlled Substances Act
DDA	Dangerous Drugs Act 1952
EMCDDA	European Monitoring Centre for Drugs and Drug Addiction
LC-MS/MS	Liquid chromatography-tandem mass spectrometry
MA	Methamphetamine
MDA	3,4-methylenedioxyamphetamine
MDEA	3,4-methylenedioxyethylamphetamine
MDMA	3,4-methylenedioxy-methamphetamine
NMA	N-nitrosomethamphetamine
P2P	phenyl-2-propanone
Red-P	Red Phosphorus
sec	Second
SWGDRUG	Scientific Working Group for the Analysis of Seized Drugs
USM	Universiti Sains Malaysia
UNODC	United Nations Office on Drugs and Crime
WWII	World War II

LIST OF APPENDICES

PENEROKAAN PENGARUH PERMUKAAN PEMULIHAN BAGI PENENTUAN METHAMPHETAMINE MELALUI UJIAN WARNA

ABSTRACK

Pelbagai permukaan pemulihan bermungkinan mempengaruhi pengesanan kualitatif methamphetamine menggunakan reagen Marquis dan Simon. Objektif utama bagi kajian ini adalah untuk menentukan jumlah minimum methamphetamine yang boleh dikesan dan menilai kesan pelbagai jenis kertas pada keterlihatan tindak balas warna dan kebolehpercayaan. Sampel methamphetamine dengan ketulenan 99.2% dicampur dengan agen pemotong pada nisbah 20:80 tetap untuk ujian kimia. Percubaan eksperimen dijalankan menggunakan pelbagai jenis kertas, termasuk kertas pelbagai guna, kertas mahjong, kertas lukisan, kertas turas, dan kertas berkilat. Reagen Marquis dan Simon telah digunakan pada setiap permukaan, dan tindak balas telah diperhatikan dan didokumenkan dari semasa ke semasa. Penemuan mendedahkan bahawa sensitiviti pengesanan berbeza dengan ketara pada jenis kertas. Pada kertas turas, penyerapan pantas reagen Simon, terutamanya terdiri daripada air ternyahion, menghalang pembentukan titisan penting untuk tindak balas. Penyerakan pantas ini berkemungkinan mengurangkan masa sentuhan, menghalang pembangunan warna yang betul untuk pengesanan methamphetamine. Sebaliknya, reagen Marquis memberikan hasil yang lebih konsisten di seluruh permukaan yang berbeza. Walau bagaimanapun, tindak balas antara asid sulfurik pekat dalam reagen Marquis dan selulosa dalam kertas menyebabkan pengkarbonan, membawa kepada perubahan warna coklat permukaan atau hangus. Fenomena ini seterusnya mempengaruhi keterlihatan tindak balas warna pada permukaan kertas. Kesimpulannya, penyelidikan ini menekankan kepentingan memahami bagaimana permukaan pemulihan dan

interaksi kimia mempengaruhi hasil pengesanan forensik dan menyerlahkan keperluan untuk aplikasi reagen yang disesuaikan untuk meningkatkan kebolehpercayaan pengesanan dalam makmal forensik.

EXPLORATION OF THE INFLUENCE OF RECOVERY SURFACE FOR THE DETERMINATION OF METHAMPHETAMINE THROUGH COLOUR TEST

ABSTRACT

The varying recovery surfaces could influence the qualitative detection of methamphetamine using Marquis and Simon's reagents, aiming to enhance forensic analysis techniques. The general objective of this study was to determine the minimum detectable amount of methamphetamine and assess the effects of various paper types on colour reaction visibility and reliability. In this study, methamphetamine samples with a purity of 99.2% were mixed with cutting agents at a constant 20:80 ratio for chemical testing. Experimental trials were conducted using different types of paper, including multipurpose paper, mahjong paper, drawing paper, filter paper, and glossy paper. Marquis and Simon's reagents were applied to each surface, and the reactions were observed and documented over time. The findings revealed that detection sensitivity varied significantly across paper types. On filter paper, the rapid absorption of Simon's reagent, primarily composed of deionised water, prevented droplet formation essential for reaction. This quick dispersion likely reduced contact time, hindering proper colour development for methamphetamine detection. Conversely, the Marquis reagent provided more consistent results across different surfaces. However, the reaction between concentrated sulfuric acid in Marquis reagent and the cellulose in paper caused carbonisation, leading to surface brown discoloration or charring. This phenomenon further influenced the visibility of colour reactions on paper surfaces. To conclude, this research underscores the importance of understanding how recovery surfaces and chemical interactions influence forensic detection outcomes highlighting

the need for tailored reagent applications to improve detection reliability in forensic laboratories.

CHAPTER 1

INTRODUCTION

1.1 Background of the study

Methamphetamine is one of the most widely abused synthetic drugs, posing significant public health and criminal justice challenges. Known for its strong stimulant effects, methamphetamine is often encountered in illicit drug markets in forms ranging from crystalline powder to tablets. Its abuse has driven the need for precise, efficient, and cost-effective forensic detection methods.

Methamphetamine use leads to a complex interaction between the brain, gut, and immune system, potentially contributing to neuropsychiatric disorders and offering therapeutic targets (Prakash et al., 2017).

Chronic methamphetamine use can be associated with neurotoxicity, cognitive impairment, and psychosocial issues, requiring treatment options including pharmacological, psychological, and combination therapies (Panenka et al., 2013).

Among the most used forensic tools for drug detection are presumptive colour tests, such as the Marquis and Simon's tests. These tests can provide a rapid and straightforward way to identify methamphetamine and other substances, particularly the amphetamine and 3,4-methylenedioxy-methamphetamine (MDMA). The Marquis reagent produces a characteristic orange to brown reaction with methamphetamine, while the Simon's reagent reacts specifically with secondary amines, yielding a blue reaction for methamphetamine. Despite their efficacy, the performance of these reagents may vary depending on factors such as sample preparation, environmental conditions, and critically, the surface on which the drug residue is recovered (Prunty et al., 2023).

Paper surfaces, being ubiquitous in forensic recovery scenarios, present unique challenges. Factors such as texture, absorbency, and chemical composition can potentially alter the visibility and reliability of colour reactions. Existing research focuses primarily on the reagents and the drugs themselves, leaving a critical knowledge gap regarding how recovery surfaces impact detection reliability.

1.2 Problem statement

The detection of methamphetamine in forensic investigations often involves materials on which the substance may have been stored, transported, or packaged, such as plastic or paper.

While colorimetric tests like the Marquis and Simon's reagents are widely used for initial screening due to their speed and simplicity, (Philp and Fu, 2018) the accuracy of these tests may be influenced by the characteristics of the recovery surface, including paper type.

Currently, there is limited understanding of how different types of paper affect the colorimetric responses of these reagents in detecting methamphetamine residues. This gap in knowledge poses a challenge for forensic analysts, as inconsistencies in detection reliability could lead to inaccurate presumptive results, especially when dealing with trace residues.

1.3 Aim and Objectives

The aim of this research is to explore the influence of paper materials as the recovery surfaces on the sensitivity and reliability of Marquis and Simon's colour tests for methamphetamine detection. To achieve this aim, the objectives were set as follows:

I. To determine the minimum amount of methamphetamine to be detected by Marquis and Simon's reagents.

II. To determine the effect of papers towards the positive detection of methamphetamine by Marquis and Simon's reagents.

1.4 Significance of the study

This study allows for improvement of the reliability of presumptive drug testing on different papers, reducing the risk of false positives or negatives in methamphetamine detection. The finding from this study also provides the clue if any residual methamphetamine on paper materials used to contain the illicit drug can be detected through the colour tests.

Results from this research will provide insights into best practices when conducting colorimetric tests on various paper types, helping forensic laboratories refine protocols and increase test validity.

1.5 Scope of the study

This study focuses on the preliminary screening test for methamphetamine detection on various recovery surfaces, specifically five types of commonly encountered papers with different physical properties. These papers are including multipurpose paper, mahjong paper, drawing paper, filter paper, and glossy paper. Each type possesses unique characteristics, such as porosity, thickness, and surface texture, which could influence the detection of methamphetamine through colour tests. The investigation is limited to a single drug, methamphetamine, a commonly abused stimulant. By focusing solely on this substance, the study provides a detailed and in-depth assessment of detection efficacy without the confounding effects of other drugs.

To achieve this, the Marquis and Simon's colour tests are employed, as they are widely used in forensic laboratories for the presumptive identification of methamphetamine. Samples are prepared with approximately 99.2% purity methamphetamine, mixed with a consistent ratio of 20% methamphetamine to 80% cutting agent. This standardized composition ensures reliable comparisons across different recovery surfaces. The primary objectives of the study are to determine the minimum detectable amount of methamphetamine, examine the influence of paper properties on reagent reactions, and assess the detection limits of the colour tests on each type of paper.

CHAPTER 2

LITERATURE REVIEW

2.1 Methamphetamine – amphetamine type stimulant

2.1.1 Background of methamphetamine

Methamphetamine, a synthetic stimulant from the amphetamine group, is a highly addictive drug with powerful, long-lasting effects on the central nervous system (CNS). Originally synthesised in 1893 by Japanese chemist Nagayoshi Nagai, methamphetamine was developed to replicate the effects of ephedrine and pseudoephedrine (precursor of methamphetamine), compounds found naturally in the Ephedra plant genus and used historically as an inhaler bronchodilator to ease respiratory issues (Celinda Franco, 2007). Ephedra is a botanic extract of Ephedra sinica and has been used in traditional Chinese medicine as Ma Huang for over 5000 years (Vearrier et al., 2012).

In fact, methamphetamine was synthesised to create a more potent and easily accessible stimulant compared to ephedrine (Martin et al., 1971). While ephedrine was used historically as a bronchodilator, methamphetamine is more powerful, crosses the blood-brain barrier more efficiently, and produces a stronger, quicker effect (Bondareva et al., 2002) Additionally, methamphetamine can be produced synthetically, making it cheaper and more accessible in illegal markets, with greater control over its concentration and purity (S. Cunningham and Finlay, 2016).

Between the 1930s to 1960s, the use of methamphetamine evolved significantly. Initially introduced in the 1930s by Desoxyn as a bronchial dilator and prescribed for conditions like narcolepsy, attention deficit disorder, obesity, and fatigue, its use expanded by the 1950s. During this time, it was widely available and used to enhance productivity, stay awake, and as a popular diet pill, especially among women.

In the 1960s, liquid methamphetamine was employed to treat heroin addiction, which led to patterns of abuse through injection, with black-market supplies often sourced from diverted pharmaceutical products (Celinda Franco, 2007).

Figure 2.1 Pervitin, an early form of Methamphetamine
(source: (Trenchies Traders, n.d.))

During World War II (WWII), methamphetamine was widely used by soldiers in Germany, Japan, and the United States to enhance endurance, sustain alertness, and reduce fatigue. In anticipation of the blitzkrieg invasion (lighting war) into France, German soldiers were given Pervitin as in Figure 2.1, a drug invented by Temmler Pharma during the war (Adam Borecky MD et al., 2021).

Taking the stimulants to enhance performance was a mark of patriotism (Michael S. Vaughn et al., 1995) on peasant the tablets been called hiropon or philopon (love of work) as a productivity-enhancement drug in pharmacies to the Japanese domestic market issued to military personnel as well as workers, students to ward off tiredness and mental problems (Celinda Franco, 2007).

In Japan, notorious kamikaze pilots were issued special tablets known as *totsugekijou* or *tokkoujou*, which translated to "the storming tablet" (Steven J. Zaloga, 2011). These tablets contained methamphetamine and green tea powder. Their main purpose was to act as an adrenaline boost, enhancing alertness and stamina, and helping the pilots stay focused and resist the urge to retreat from the battlefield during their final missions (Michael S. Vaughn et al., 1995).

Today, methamphetamine is classified as a Schedule II controlled substance under the United States Controlled Substances Act (CSA). The criteria for Schedule II substances include a high potential for abuse, accepted medical uses under strict regulations, and a severe risk of dependency. Other substances in this category include cocaine, fentanyl, oxycodone, and morphine (DEA, 2018).

In Malaysia, methamphetamine is regulated under the Dangerous Drugs Act 1952 (DDA) and is listed as a controlled substance under the First Schedule Part III. The penalties for possession and trafficking are severe. Under Section 15(b), possession of smaller quantities may result in a fine not exceeding five thousand ringgit or imprisonment for a term not exceeding two years. Possession of 50 grams or more, as defined under Section 37(xvi), is presumed to be for trafficking under Section 39B, which carries the mandatory death penalty under Section 39B(2) (Malaysia, 1980).

2.1.2 Chemical and physical properties of methamphetamine

Amphetamine-type stimulants (ATS) are phenethylamines that include principal members such as amphetamine, methamphetamine, MDMA, 3,4-methylenedioxyamphetamine (MDA), 3,4-methylenedioxyethylamphetamine (MDEA), methcathinone, fenethylline, ephedrine, pseudoephedrine, and methylphenidate. Figure 2.2 shows the chemical structure of methamphetamine (Cao et al., 2016).

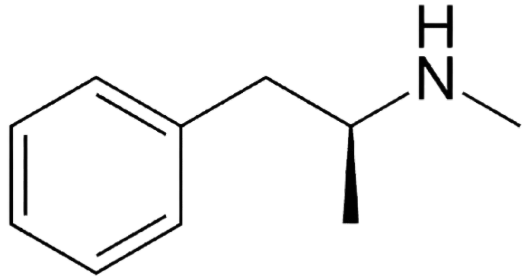

Figure 2.2 Structural formula of Methamphetamine

Methamphetamine, with an International Union of Pure and Applied Chemistry (IUPAC) name of (2S)-N-methyl-1-phenylpropan-2-amine, a methyl group is attached to the nitrogen atom in the structure, with a molecular formula $C_{10}H_{15}N$ and molecular weight 149.23 g/mol. Methamphetamine in its base form exhibits variable solubility depending on the solvent. It is only slightly soluble in water, indicating limited interaction with polar solvents. However, it dissolves well in organic solvents like methanol, ethanol, diethyl ether, and chloroform due to its non-polar characteristics. Methamphetamine hydrochloride, the salt form, shows different solubility behavior. It is highly soluble in water, methanol, ethanol, and chloroform due to its ionic nature, which interacts well with polar solvents. However, it is insoluble in diethyl ether, a non-polar solvent. (UNODC, 2006).

Structurally, methamphetamine is a chiral compound with a stereocentre, allowing it to exist as two enantiomers: D-(+)-methamphetamine (dextrorotatory methamphetamine) and L-(-)-methamphetamine (laevorotatory methamphetamine). D-(+)-methamphetamine also known as the s-methamphetamine, exhibits potent psychostimulant effects and is more frequently abused due to its stronger CNS stimulatory activity which is more effective dopamine releaser three to four times higher than L-(-)-methamphetamine (Maas et al., 2018)). In clinical view, d-methamphetamine is used to treat attention deficit hyperactivity disorder (ADHD), obesity, and narcolepsy, while L-(-)-methamphetamine is found in nasal decongestants and as a metabolite of (+)-selegiline, a drug for Parkinson's disease and depression (Jirovský et al., 1998)

Methamphetamines exists in three distinct forms; crystalline methamphetamine, referred to as ice, syabu and stone (batu); tablet methamphetamine known as Horse (Pil Kuda), Yaba, Yama, and Bomb pills; and liquid methamphetamine (National Anti-Drugs Agency, 2022). The crystalline form, which is the high-purity S-methamphetamine hydrochloride form, appears as white or translucent crystals. Its high purity makes it suitable for smoking (vapor inhalation) as it vapourises cleanly without undergoing pyrolysis or producing harmful byproducts. This elevated purity also enhances its potency and addictive potential, significantly increasing the risk of dependence among users (Cruickshank and Dyer, 2009).

Methamphetamine appears in the form of tablets or popularly known as "Nazi speed" or the "Yaba" (meaning "crazy medicine" in Thai). In Malaysia, it is called as "pil kuda" (National Anti-Drugs Agency, 2022). Yaba, usually a combination of methamphetamine (25-35 mg) and caffeine (45-65 mg). Yaba commonly sold as small, reddish-orange or green tablets. These tablets often have a candy-like flavour and can be consumed directly. Another common method of use is "chasing the dragon," where the tablet is placed on aluminium foil, heated from below, and the vapours are inhaled. Yaba tablets can also be crushed into powder for snorting or dissolved in a solvent for injection.

Methamphetamine tablets often feature distinctive logos that provide insights into their origin and the groups involved in their production. A study Noor Azlina Awang et al. (2022) analysed 164 seized methamphetamine tablets revealed that the most common logo was "wY," appearing on 155 samples (94.5%). This logo was believed to be associated with the United Wa State Army, a known drug-producing organization. Variations in the size, positioning, and clarity of the "wY" logo were noted, likely due to the use of different tablet presses. Less commonly, the "WY" logo was found on 2 samples (1.2%), reportedly linked to the Myanmar National Democratic Alliance Army, while the "wy" logo appeared on 1 sample (0.6%), associated with the Shan United Army. Other logos, such as "Wy," "R," "OK," "888," and "Ã/99," were not observed in the samples analysed. These logo variations provide valuable forensic intelligence on the manufacturing sources and distribution networks of methamphetamine tablets.

Liquid methamphetamine refers to methamphetamine dissolved in a solvent, making it a solution rather than a solid form. This form is commonly used for smuggling and trafficking due to its ability to blend seamlessly with everyday liquids such as beverages, cleaning products, or other household items, making detection by law enforcement more difficult (ABF Media, 2024). Traffickers exploit the inconspicuous appearance of liquid methamphetamine to conceal it in everyday containers, making detection by authorities more difficult. For instance, in Australia, 132 litres of liquid methamphetamine were hidden in washing detergent bottles, blending seamlessly with household cleaning products to evade scrutiny during transit (ABF Media, 2024). Similarly, in Malaysia, authorities uncovered a case where 12 mineral water bottles containing liquid methamphetamine were used for smuggling, taking advantage of the ordinary appearance of the containers to avoid suspicion (Bernama, 2016). These cases highlight the adaptability of traffickers in using everyday packaging to transport illicit substances, posing significant challenges to law enforcement efforts. Once the liquid methamphetamine reaches its destination, the drug can be easily extracted and recrystallised for use or distribution, typically through simple chemical processes such as solvent evaporation.

2.1.3 Trends of methamphetamine

2.1.3(a) Global trends in methamphetamine seizures

According to metadata from the United Nations Office on Drugs and Crime (UNODC), global methamphetamine seizures reached an estimated 367,000 kilograms in 2022, making it the most seized drug within the ATS group, which totalled 536,000 kilograms overall (UNODC, n.d.-a). Malaysia accounted for 8,682.04 kilograms of methamphetamine seizures, highlighting its prominence in the country. On a global scale, Figure 2.3 shows that the methamphetamine quantities have demonstrated a consistent upward trend, underscoring its growing role in the global drug trade (UNODC, 2024).

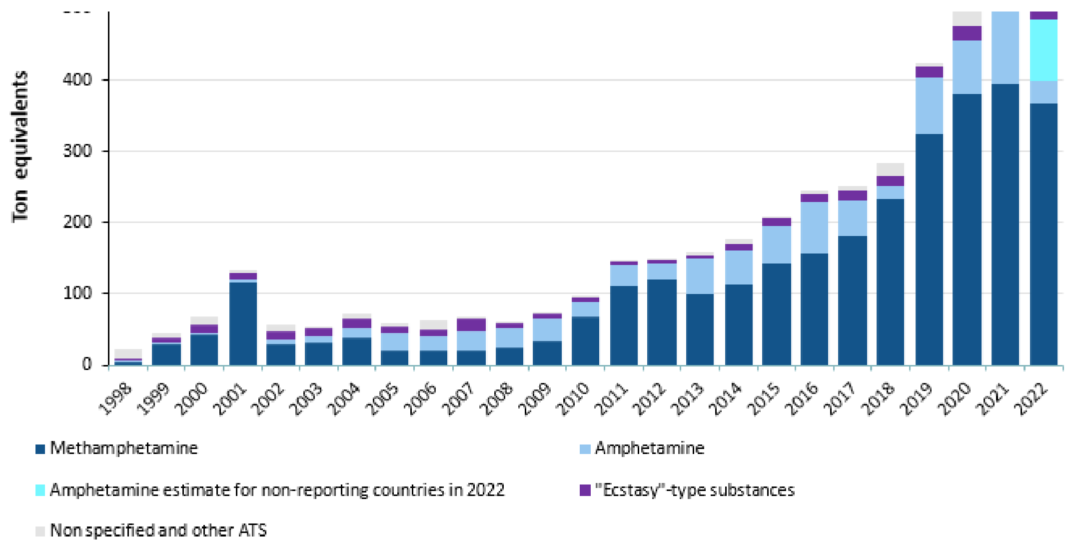

Figure 2.3 Global quantity of amphetamine-type stimulants seized, 1998-2022.
(Source: UNODC, 2024)

2.1.3(b) Comparison of drug seizures by type

According to the UNODC World Drug Report 2024, global drug seizures are predominantly dominated by cannabis, accounting for 59% of all cases and quantities seized between 2021–2022. Figure 2.4 illustrates global distribution of drug seizure case by drug types between 2021-2022. Cannabis herb alone constitutes the largest share of these seizures. The ATS group ranks second, representing 20% of the total seizures, with methamphetamine making up a staggering 78.66% of all ATS-related cases during the same period.

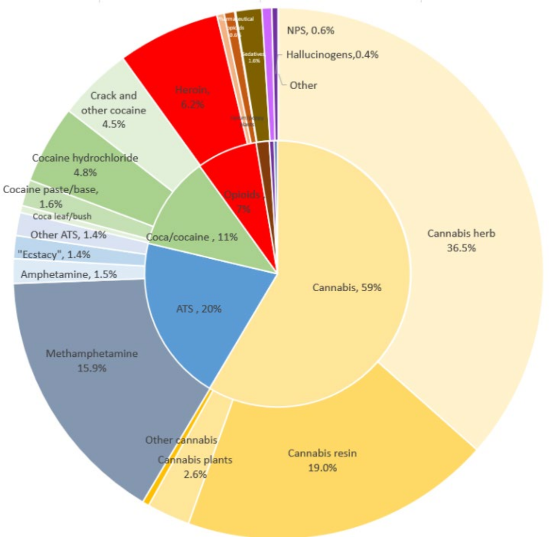

Figure 2.4 Global distribution of drug seizure case by drug types, 2021-2022
(Source: UNODC, 2024)

Over the last two decades, the quantity of ATS seized has shown the most significant increase compared to other drug categories, highlighting its growing prominence in the global drug market. Despite this rise, cannabis and cocaine continue to account for the largest overall quantities of drugs seized worldwide. This trend underscores the evolving dynamics of the global drug trade and the increasing focus on synthetic drugs like methamphetamine.

2.1.3(c) Long-term drug seizure trends

Figure 2.5 shown the long-term trends in quantities of drug seized between 1988-2022. In recent years, seizures of ATS have stabilised, while cocaine seizures have seen the most significant increase, reflecting a growing global supply and demand for cocaine. In contrast, opiate seizures experienced a decline in 2022, coinciding with the announcement of an opium ban in Afghanistan, a major global producer of opium (UNODC, 2024).

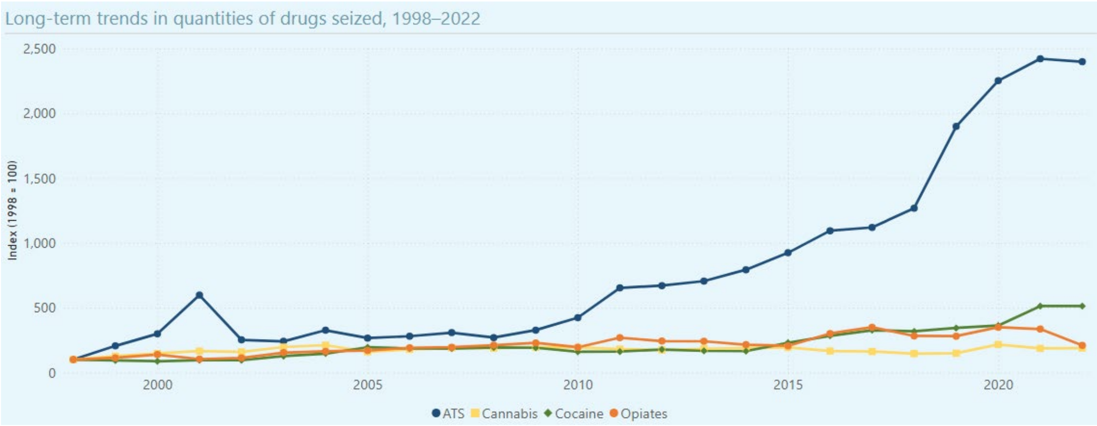

Figure 2.5: Long-term trends in quantities of drugs seized, 1988-2022
(Source: (UNODC, 2024)

2.1.3(d) Methamphetamine trends in Malaysia

According to the National Anti-Drugs Agency (AADK), as of 2023, the retail price for methamphetamine powder in Malaysia is RM32,721 per kilogram, while methamphetamine tablets are priced at RM11 each. Methamphetamine tablets in Malaysia typically have an average purity of 16% in 2021 and 14% in 2022 acc druording to the UNODC purity data.

In Malaysia, ATS have emerged as the primary drug of use among treated clients, surpassing opioids in recent years. The number of patients treated for ATS-related issues increased significantly, rising from 8,109 cases in 2019 to 56,306 cases in 2021, Figure 2.6. This dramatic shift underscores the growing dominance of ATS in Malaysia's drug landscape (UNODC, 2024).

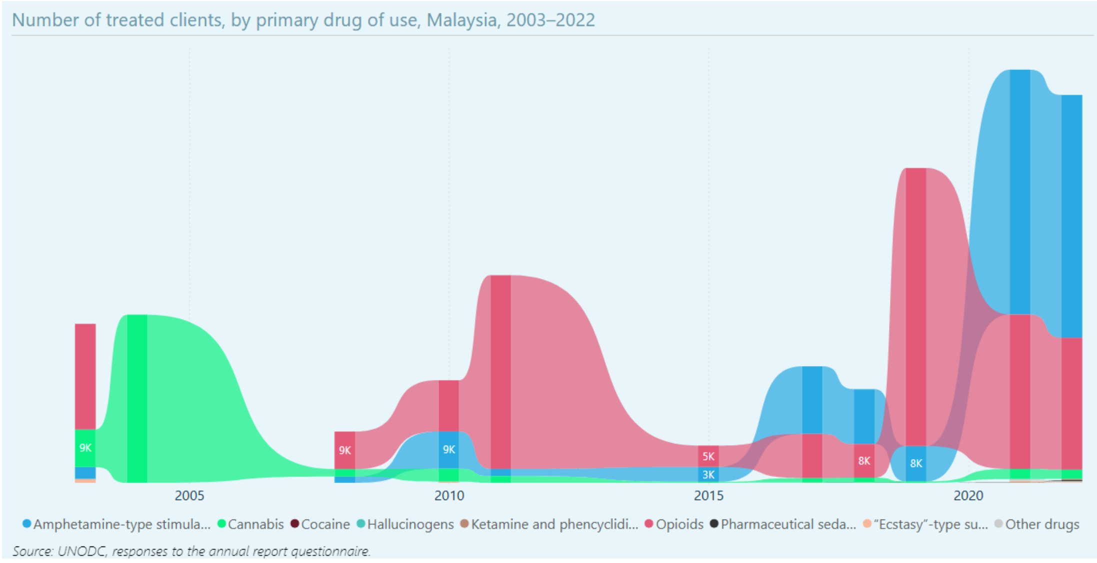

Figure 2.6 Number of treated clients, by primary drug of use, Malaysia, 2003-2022. (Source: (UNODC, 2024)

A study Du et al. (2020) analysed wastewater from wastewater treatment plants in Kuala Lumpur in the summer of 2017 showed that fourteen drug residues were detected. Among these, MDMA and methamphetamine, both belonging to the ATS group, ranked as the top two substances with the highest estimated per capita consumption. In contrast, opioids such as codeine and heroin were found at moderate levels, placing them in the middle of the list. These findings align with Figure 2.6, which shows a significant increase in treated clients for ATS-related abuse, while treatment cases for opioids have declined. This indicates a shift in the prevalence of drug abuse in Malaysia, moving from opiates toward ATS substances.

This shift was further supported by an observational study Muhamad et al. (2024) conducted between 2018 to 2021, which examined substance abuse among 9,606 new patients attending major government hospitals in Malaysia. The study revealed a notable increase in substance abuse during the COVID-19 pandemic, with the most abused substances being the tobacco (61.8%), ATS (43.1%), alcohol (39.7%), cannabis (17.2%), opioids (13.0%), and kratom (8.8%).

The age range between 15-39 years old is the largest group contributing to the country's economic development and social progress. However, the group dominated the percentage of drug & substance abusers and addicts by 64.3 per cent in 2022 and recorded an increase of 6.2 per cent over the previous year (National Anti-Drugs Agency, 2022).

Additionally, between 2019 and 2022, Malaysian authorities arrested a total of 153,259 drug offenders and dismantled 15 clandestine laboratories with the arrest of 50 individuals, ranging from small-scale to medium and industrial-scale operations (National Anti-Drugs Agency, 2022; UNODC, n.d.-b).

2.1.3(e) The new drug phenomenon

The new drug phenomenon, particularly with methamphetamine, illustrates how manufacturers alter chemical properties to evade legal restrictions. This practice exploits the delay in legislative responses, allowing them to profit significantly before regulations adapt (Brandt et al., 2014). Precursor regulations have shown mixed results, with some reducing methamphetamine supply and use by up to 77% (McKetin et al., 2011), while others have been undermined by alternative precursor sources or imports. Manufacturers also adapt quickly by developing new synthesis methods, perpetuating the cycle of illicit drug innovation (Callaghan et al., 2009; Nonnemaker et al., 2011). Furthermore, enforcement targeting large-scale producers has led to shifts in methamphetamine purity and hospital admissions, demonstrating the complex and dynamic challenges in regulating this phenomenon (Callaghan et al., 2009; J. K. Cunningham et al., 2009).

2.1.3(f) Methamphetamine manufacturing

Methamphetamine synthesis has evolved over time, adapting to increasing regulatory restrictions on precursor chemicals. The presence or absence of specific impurities and precursors can be useful in determining the synthetic route employed (UNODC, 2006). Early production methods relied on phenyl-2-propanone (P2P) combined with alcohol and aluminium amalgam, followed by hydrochloric acid extraction to isolate the drug. Later, the Leuckart reaction emerged, using P2P mixed with N-methylformamide and formic acid, with hydrochloric acid reflux for final conversion into methamphetamine. In February 1980, P2P was designated as a Schedule II controlled substance, leading to restricted availability (Ralph Weisheit, 2008). As a result, by the late 1980s, the reduction of ephedrine and pseudoephedrine, synthetic compounds such as Ephedra commonly found in over-the-counter cold medications, became the preferred method for methamphetamine production due to their easier accessibility and availability (Frank, 1983; UNODC, 2006).

Two primary synthesis techniques using these precursors gained popularity, namely the "Red Phosphorus" (Red-P) method and the "Nazi" or "Birch" method. The Red-P method involves combining ephedrine or pseudoephedrine with hypophosphorous acid or Red-P, often sourced from matchbook striking pads or road flares, along with iodine or hydriodic acid (Ralph Weisheit, 2008). This reduction process works through a cyclic oxidation mechanism where the iodide anion is oxidised to iodine and subsequently reduced back to the anion by red phosphorus. The red phosphorus is then converted into phosphorus or phosphoric acids as a byproduct, yielding relatively high-quality methamphetamine. This reaction eliminates one chiral centre in the ephedrine molecule, which preserving the structural integrity of the methamphetamine molecule (National Drug Intelligence Center, 2005; Ralph Weisheit, 2008; Skinner, 1990)

The Nazi/Birch method, also known as the lithium-ammonia reduction method, involves the use of ephedrine or pseudoephedrine as the precursor, combined with anhydrous ammonia and lithium metal, often sourced from lithium batteries or raw lithium metal (UNODC, 2006). Anhydrous ammonia acts as a solvent and reducing agent, while lithium facilitates the removal of the hydroxyl group from the ephedrine/pseudoephedrine structure, converting it into methamphetamine (Allen and Cantrell, 1989). This process, named either after its rumoured historical use by German soldiers during WWII or a methamphetamine cook who used Nazi symbols on recipe letterheads (Ralph Weisheit, 2008; Vearrier et al., 2012).

2.4 Cutting agent

Cutting agents are substances mixed with illicit drugs to dilute or modify their effects, primarily to increase profit margins by expanding the product's volume. They can be categorized into diluents and adulterants based on their properties and effects. Diluents are inactive substances that serve mainly as fillers, increasing the drug's bulk without altering its pharmacological effects. Common examples include sugars, starch, and carbonates. These substances are typically inexpensive and widely available. Adulterants, on the other hand, are active compounds that can alter or enhance the drug's effects, often mimicking or intensifying the substance's psychoactive properties. Examples include caffeine, lidocaine, and phenacetin. Adulterants can pose greater health risks due to their effects on the central nervous system and their potential toxicity (Fiorentin et al., 2019).

A study by Fiorentin et al. (2019) analysed 103 unweighted methamphetamine samples and identified several substances commonly used as adulterants and diluents. The findings revealed the presence of diphenhydramine (3.9%), levamisole (3.9%), caffeine (2.9%), quinine/quinidine (1.9%), acetaminophen (1.9%), lidocaine (1.0%), and xylazine (1.0%).

Żubrycka et al. (2022) analysed 49 methamphetamine samples using GC-MS and identified various cutting agents commonly present. The study found that amphetamine was the most frequently detected substance (51.0%), followed by caffeine (42.9%). Other cutting agents, such as pseudoephedrine, a-methylaminohexanophenone, and dipentylone, were each detected in 2.0% of the samples.

Quinn Cate et al. (2008) reported that adulterants typically present in methamphetamine in Victoria, Australia included sugars (glucose, lactose, sucrose, mannitol), caffeine, dimethyl sulphone (MSM) and a variety of other pharmaceuticals, including paracetamol and ephedrine.

According to the European Monitoring Centre for Drugs and Drug Addiction EMCDDA and Europol methamphetamine is typically adulterated with a variety of other substances, including caffeine, sugars, and less frequently, ephedrine and ketamine.

Cutting agents, including caffeine, lactose, fructose, mannitol, paracetamol (PCM), and starch, were incorporated into the study to simulate real-world conditions. These substances are commonly used as adulterants and diluents in drug formulations, reflecting the complexities often encountered in forensic drug analysis. According to reports from the UNODC (n.d.-a) and AADK (2022), the average purity of methamphetamine in seized samples is approximately 14%. To replicate these realistic scenarios, the experiments were designed using a mixture ratio of 20% methamphetamine to 80% cutting agents. This ratio closely mirrors the typical composition of illicit drug samples and ensures that the study findings are relevant for forensic investigations involving adulterated drugs.

2.5 Colorimetric methamphetamine detection

Colorimetric presumptive tests are widely used for field drug testing and serve as an initial screening method in laboratory settings (Alonzo et al., 2022). While colorimetric tests are typically qualitative, studies have explored methods to quantify these results. For example, the Simon test can be coupled with an iPhone 4 and the ColorAssist app to analyse colour changes. This approach involves comparing the red, green, and blue (RGB) values from the colour changes with calibration graphs based on average intensities, as demonstrated in Choodum et al.(2014). This approach allows for real-time data analysis and reduces the subjectivity associated with visual interpretation.

Generally, in colorimetric test, chemical reagents are added to a small sample of the drug material, and the resulting colour changes are observed with the naked eye, often comparing them to a reference colour chart, Table 2.1 (UNODC, 2006). The chemistry behind colorimetric tests varies depending on the reagents used, as the drug of interest reacts with the test chemicals to form coloured metal complexes or charged organic species (Alonzo et al., 2022). The Scientific Working Group for the Analysis of Seized Drugs (SWGDRUG) recommendations classified colour testing as a technique with low discriminating power, similar to ultraviolet spectroscopy and immunoassays.

Table 2.1 Marquis and Simon's tests results on methamphetamine

Compound	Marquis Test	Simon's Test
Methamphetamine	Orange, slowly turning brown	Deep blue

A manual created by UNODC (1994) Rapid Testing Methods of Drugs of Abuse, recommends the use of the Marquis and Simon presumptive chemical tests for detecting methamphetamine. These reagents are commonly used because they produce distinct colour changes when methamphetamine or related compounds are present (Philp and Fu, 2018). The Marquis test results in an orange-brown reaction, while the Simon test yields a blue reaction. The Simon test is particularly useful for differentiating methamphetamine from amphetamine, as it selectively reacts with the secondary amine group in methamphetamine.

2.5.1 Marquis test

The Marquis reagent is widely used for initial screening in drug analysis, especially for synthetic drugs (Philp and Fu, 2018). The Marquis test serves as a general screening method, targeting compounds such as alkaloids, opiates, amphetamines, and phenethylamines. The Marquis test is especially effective in distinguishing amphetamine from its ring-substituted analogues. When methamphetamine is present, an orange colour gradually develops, shifting to brown, indicating its presence. This colour change occurs due to a complex reaction that produces a carbonium ion, formed when formaldehyde reacts with methamphetamine in an acidic medium, illustrate in Figure 2.7. The resulting orange-brown product is the carbonium ion, created through the reaction of formaldehyde with the aromatic compound in the acidic environment (Choodum and NicDaeid, 2016).

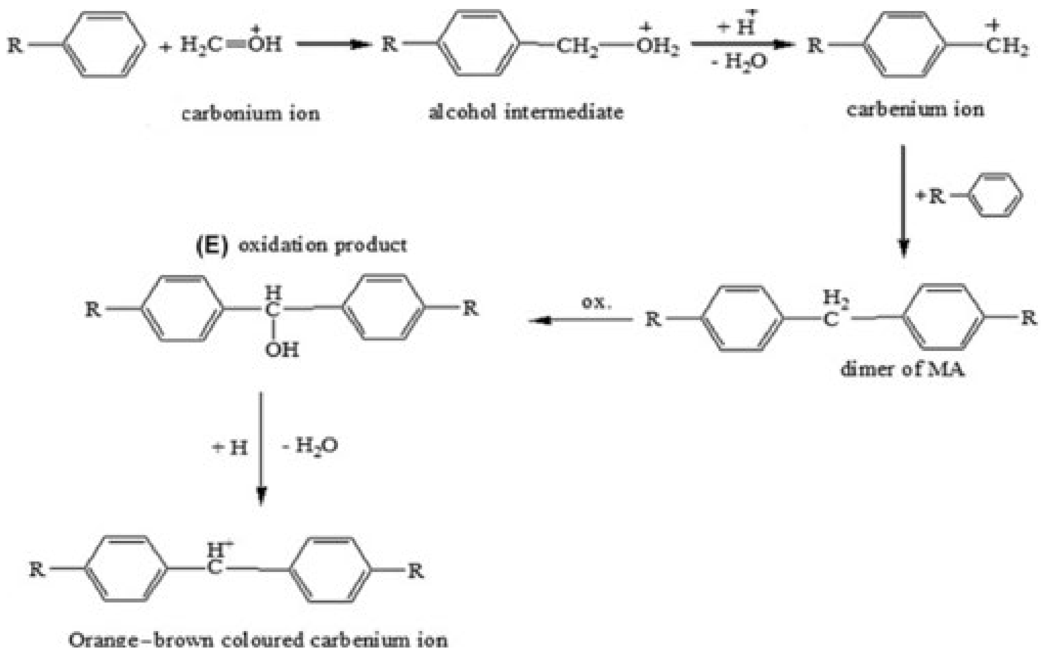

Figure 2.7 Mechanism of Marquis Test for methamphetamine
(Source: Choodum & NicDaeid 2016)

2.5.2 Simon’s test

Simon's test is another chemical method for detecting methamphetamine, often used in conjunction with the Marquis test. The Simon test specifically reacts with the secondary amine group in methamphetamine, producing a blue colour observation (Choodum et al., 2014). This test is selective for secondary amines, like methamphetamine, and forms a deep blue compound known as the Simon awe complex, illustrate in Figure 2.8. The reaction occurs when methamphetamine interacts with acetaldehyde, forming an enamine, which then reacts with sodium nitroprusside. This produces an immonium salt intermediate, which, upon reacting with water, results in the characteristic blue colour observation (Choodum and NicDaeid, 2016).

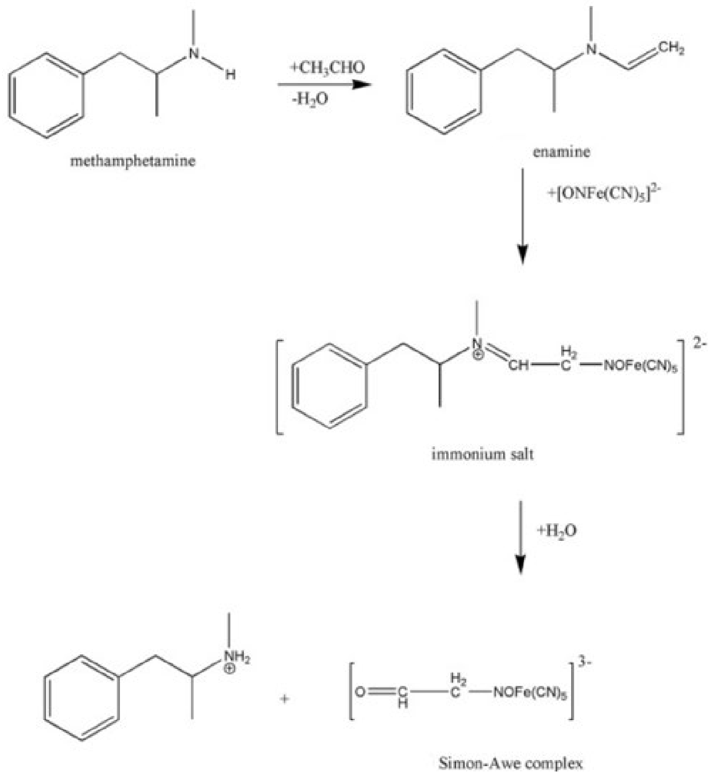

Figure 2.8 Mechanism of Simon's Test for MA
(Source: Choodum & NicDaeid, 2016)

2.5.3 Detection limits of colorimetric test

According to a study by O'Neal et al. (2000), the detection limit for Simon's test is approximately 10 µg. The research evaluated 12 different colorimetric tests, including Cobalt thiocyanate, Dille–Koppanyi, Duquenois–Levine, Mandelin, Marquis, nitric acid, para-dimethylaminobenzaldehyde (p-DMAB), ferric chloride, Froehde, Mecke, Zwikker, and Simon. These chemical spot tests were found to be highly sensitive, with detection limits ranging from 1 to 50 µg. While Simon's reagent had a detection limit of 10 µg for methamphetamine, the study did not specify the detection limit of the Marquis test for methamphetamine.

2.5.4 Methamphetamine residue on surfaces

Clandestine methamphetamine laboratories are often heavily contaminated with residues, with high levels of hazardous chemicals such as phosphine, iodine, ammonia, and hydrogen chloride present during the "cooking" process. As a result, protective clothing and breathing apparatuses are required for individuals entering these environments (Martyny et al., 2007). Methamphetamine residues on household surfaces and materials can persist for years and may also adhere to the clothing of individuals who enter such premises (Wright et al., 2016, 2019)

A study by Mayer et al. (2022) investigated the carcinogenic N-nitrosomethamphetamine (NMA) and suggested that the “cooking” process of methamphetamine, similar to cigarette smoking. Such procedure could lead to the formation of the carcinogen. The study also found that methamphetamine reacts with nitrous acid, a common indoor air pollutant, to produce NMA. A steady-state concentration of 0.87 µg/100 cm^2 was detected during the sampling period. While the study presents a lower limit for NMA formation, it raises concerns about the passive formation of this nitrosamine in methamphetamine-contaminated properties. Given the methamphetamine’s ability to penetrate various materials, NMA could form in the structural components of contaminated buildings, highlighting potential risks in current health assessments of such properties.

A case from Mayer et al. (2022), report a family living in former methamphetamine drug laboratory in Australia. In 2015, the family in unknowingly moved into a former methamphetamine drug laboratory and was exposed to residues, leading to health issues like asthma-like symptoms, sleep problems, and behavioural changes. The property, seized by police in 2013, was sold without proper cleanup or disclosure. Environmental testing in 2014 revealed that the methamphetamine levels on the housing far exceeding safe limits. Hair samples from the family, collected after they left, showed also the methamphetamine contamination, particularly in the two youngest children. Follow-up testing in 2015 showed most members cleared the drug, but traces remained in one child's hair. The case underscored the methamphetamine residues in homes can persist for years and pose health risks.

Law enforcement personnel investigating clandestine drug laboratories face increased health risks. Studies have shown that responding to active laboratories raises the risk of illness by 7 to 15 times (Burgess et al., 1996). Furthermore, research by Witter et al. (2007) found that more than 70% of law enforcement officers involved in methamphetamine laboratory investigations reported experienced symptoms such as headaches, respiratory issues, central nervous system symptoms, and sore throats.

In the case of children removed from law enforcement-certified clandestine methamphetamine labs, an observational study by Grant et al. (2010) found that 46% of these children tested positive for methamphetamine shortly after removal, although no immediate medical intervention was necessary.

An interesting development in detecting clandestine methamphetamine production involves the use of a membrane inlet mass spectrometer mounted on a hybrid vehicle, as described in a study by Mach et al. (2015). This portable system allows for atmospheric sampling while the vehicle is in motion, effectively detecting and localising clandestine methamphetamine manufacturing by identifying the unique chemical signatures in the air.

2.6 Effective surfaces for methamphetamine recovery

Previous studies have demonstrated varying recovery rates for methamphetamine from different surfaces. The mentioned recovery surface included, stainless steel, glass, plastic, varnished wood or painted wood, soapstone, and quartz, showing high recovery rates for methamphetamine.