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ANALYSIS OF TIME-DEPENDENT MERCURY FLOWS THROUGH THE USE OF THERMOMETERS AND SPHYGMOMANOMETERS IN THAILAND

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ABSTRACT: Thermometers and sphygmomanometers pose a potentially large source of mercury emissions to the environment due to their high elemental mercury content. Many countries, e.g. most European countries, US have banned their uses already and many more strictly limited their use. However, in Thailand these mercury-based devices are still used, accumulating large stocks in the use phase as well as in landfills. To understand the development of mercury stocks and flows from thermometers and sphygmomanometers, a time-dependent mathematical material flow model is used in this study. The flows of mercury through these two products were calculated based on data between the years of 1962 and 2013. The simulation showed that the stock of mercury in thermometers is about 20 times smaller than the stock in sphygmomanometers. However the sum of waste flows and emissions to air and water from thermometers is 3 times larger than from sphygmomanometers. The reason is the lifetime of thermometers which is about 70 times shorter than the lifetime of sphygmomanometers. The calculated emission to air from mercury thermometers in hospitals can explain the higher mercury level measured in urine of health care staff. In order to reduce the mercury flows to the environment mercury thermometers should be replaced by alternative products as soon as possible.

Keywords: Mathematical Material Flow Analysis (MMFA), Mercury, Thermometer, Time-dependent, Sphygmomanometer

1. INTRODUCTION

Mercury (Hg) has been known as highly toxic for both environment and human health since 1956 when the so called Minamata disease was first discovered near the city of Minamata, Japan. It became widely known in 1968 when the company responsible for it stopped the production [1], [2]. Mercury affects the nervous, digestive, respiratory, immune system, kidneys, and lungs [3]. Several studies indicate that mercury emission is one of the most global concerns for hazardous air pollutants because once released into the air Hg may stay in the atmosphere for long periods, and can be transported across borders before being deposited and accumulated in the environment and living organisms [4], [5]. According to Health Care Without Harm (HCWH) report [6], the health care sector is a significant source of mercury demand and emission in the world. Mercury has been extensively used in health care products such as thermometers, sphygmomanometers (blood pressure measuring devices), dental amalgam, as disinfectant, as preservative in vaccines and eye drops, and in some traditional medicine for health care purposes [7]. The World Health Organization (WHO) is most concerned with thermometers and sphygmomanometers since both of them contain elementary mercury [8]. Sphygmomanometers in particular, build up a large stock since each of them contains up to 100 grams of metal mercury [8]. As long as they are used and mercury is not spilled from them, this is of minor concern, but as soon as they are either broken or become obsolete, they cause large waste flows of mercury. Waste containing mercury is hazardous waste and should never be mixed with municipal solid waste. It has to be treated separately, but unfortunately Thailand still lacks such treatment processes.

Pastore et al. [9] claim that the breakage of mercury-containing devices causes mercury spills to the environment, leading to mercury exposure of health care staff and patients. This is mainly due to unprofessional cleanup of mercury spills caused by broken thermometers which lead to mercury vapors slowly saturating the indoor air. Around 80% of inhaled mercury vapors from elementary mercury are absorbed in the blood through the lungs and cause harmful effects to human health [10]. So far, nothing indicates that mercury is a main cause of morbidity in Thailand [11] even though several studies show that health care staffs in Thailand always have high mercury level in their urine [12], [13]. These studies indicate that the mercury problem in the health care sector should be of concern in Thailand.

To prevent health effects from mercury exposure, WHO and United Nations Environmental Program (UNEP) have issued guidelines for mercury free health care in 2011 and 2013 [8], [14], aiming to phase out both Hg-thermometers and Hg-sphygmomanometers. In 2010, WHO in cooperation with Health Care Without Harm (HCWH) set to phase out 70% of Hg-thermometers and Hg-sphygmomanometers used in health sector by 2017 [15]. The "Minamata Convention on Mercury" by UNEP decided to phase out both devices by 2020 [14]. Currently, United State and European Union (EU) already banned mercury-based devices in their countries, while other countries such as Philippine, Argentina, and India are attempting to implement mercury-free health care in their countries [15], [16]. However, Thailand, which is promoted as a hub of health services in Asia, has neither signed the Minamata Convention on Mercury nor implemented mercury-free health care so far. Therefore, the understanding of mercury flows and stocks could be the first step to manage mercury in health care in Thailand.

Mathematical Material Flow Analysis (MMFA) is an approach to study stocks and flows of goods and substances in anthropogenic systems. MMFA can be applied to (quasi) stationary as well as time-dependent models. The difference is that (quasi) stationary models cover a fixed time period, typically a one year period, for any kind of goods, in order to understand the system considered. Time-dependent models are used to investigate the development of the system including stocks and flows of goods over longer time spans in order to understand the development of stocks and flows over time and are often used for environmental management. Time-dependent models have been applied for different products and different scales such as country level for metals [17], [20], [21] and housing [18], on city level for durable goods [19], and on farm level for resources [22].

This study applies a time-dependent model to understand the mercury flows through the two health care products of concern, thermometers and sphygmomanometers in Thailand over time. The question below will be answered by this study:

1. How large is the demand, stock, and emissions of mercury through thermometers and sphygmomanometers used in health care facilities?
2. What are feasible scenarios to manage mercury from the health care sector in Thailand?

2. METHODOLOGY

Mathematical material flow analysis (MMFA) approach was used for this study. MMFA is the combination of conventional material flow analysis (MFA) with modeling concept developed by Baccini and Bader [23]. MMFA has been applied in many studies fields for environmental management: Zeltner et a. [17]; Binder et al. [19]; Sörme and Lagerkvist [20]; Bader et al. [24]; Huang et al. [25]; Kwonpongsagoon et al. [26]; Schaffner et al. [27]; Bader et al. [28]; Wongsoonthornchai et al. [29].

The procedure of MMFA consists of

1. System analysis: define both temporal and spatial boundaries; identify the products and processes related to mercury;
2. Time-dependent mathematical model: formulate time-dependent equations to describe the system and process in mathematical term;
3. Data acquisition and calibration: collect the input data set for the model;
4. Simulation: the model is used for simulating the past and current state and to investigate scenarios

The MMFA model for mercury flows in Thailand has been solved using the SIMBOX simulation program [30].

2.1 System Analysis

The geographic border of this study is Thailand and the time period selected is from 1960 to 2050. The system consists of the healthcare sector and includes only the products of thermometers and sphygmomanometers (blood pressure devices).

Fig. 1 shows the system analysis for mercury flows through thermometers and sphygmomanometers in the health care system in Thailand. Thailand has no production plants for thermometers and sphygmomanometers and therefore they are imported directly to the use process. Accordingly only mercury flows from import are considered and no domestic production processes are included. Mercury emissions were considered during the use phase of thermometers through breakage and wrong (or no) treatment of the waste afterwards and after use in the hazardous waste treatment. Sphygmomanometers were assumed to cause no or only little emissions during the use phase. Therefore no emissions in use phase were taken into account.

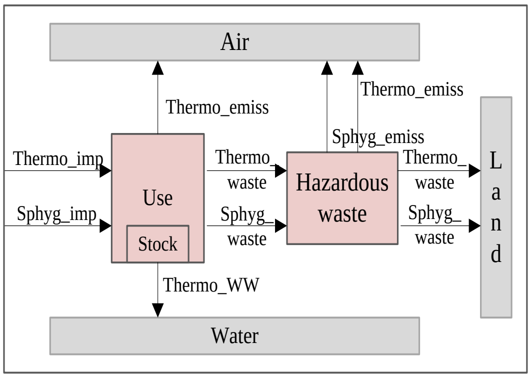

Fig. 1 System analysis for mercury flows through thermometers and sphygmomanometers in the healthcare system in Thailand

2.2 Model Approach

A time-dependent model is important because it allows understanding how stocks and flows evolve over time. The model used here is an adaption and generalization of the model developed for the simulation of the production, use and disposal including all emissions of flame retardants [31]. The approach is so called “stock-driven”, which means that the stocks in use in function of time are given together with the residence time distribution [31]. The emissions during the use phase are proportional by emission factors to a fraction of the stock. For a detailed description of the model see [32].

The 25 input parameters for each subsystem were needed for the simulation of the mercury flows though thermometers and sphygmomanometers in Thailand.

2.3 Data Acquisition and Calibration

Different types of data were collected for the estimation of mercury flows though thermometers and sphygmomanometers in Thailand between the year of 1962 and 2013. The data was retrieved from data sources such as the government sectors, surveys, interviews, company reports, and literatures.

Unfortunately no time series data were available for the number of thermometers and sphygmomanometers in Thailand.

Instead, such data were estimated as follows:

$$Thermo = (B * TB) + (D * TD) \quad (1)$$

Where:

Thermo = Number of thermometers in use [pieces]
B = Number of bed [beds]
TB = Number of thermometers per bed [pieces/bed]
D = Number of doctors in Thailand [persons]
TD = Number of thermometers per doctor [pieces/doctor]

$$Sphygmo = [(B / BW) * BP] + (D * BD) \quad (2)$$

Where:

Sphygmo = Number of sphygmomanometers in use [pieces]
BW = Number of bed per ward [beds/ward]
BP = Number of sphygmomanometers per ward [piece/ward]
BD = Number of sphygmomanometers per doctor [pieces/doctor]

The basic assumption for Eq. (1) and (2) is that both thermometers and sphygmomanometers are assigned to beds in hospitals and to the doctors since only hospitals and doctors own such equipment.

Fig. 2 shows the estimated time series extrapolated from 2015 to 2050 assuming a linear growth of hospital beds and number of doctors due to population growth and improvement of health care.

2.3.1 Estimation of average lifetime:

The results for lifetime gained through interviews with nurses and doctors are about 1.5 month for thermometers and about 9 years for sphygmomanometers. Therefore we assumed as lifetimes 1.5±0.7 month and 9±5 years for thermometers and sphygmomanometers, respectively.

2.3.2 Ratio of mercury thermometers to mercury free thermometers:

This ratio is 1 up to 2001 since Thailand used only mercury thermometers before then. From 2001 to 2050 it is assumed that the ratio decreases exponentially, stabilizing at 0.3 in 2030. This assumption is very conservative, but faster phasing out of mercury thermometers are discussed in the scenario section. A similar assumption was made for sphygmomanometers.

2.3.3 Emission factors:

For thermometers it is assumed that they are broken after their lifetime and 50% of mercury is emitted to air, 40% to the water phase and the rest to soil.

It was assumed that no emissions occurred during the use phase of sphygmomanometers because they are well covered and the staff handles them carefully during use.

2.3.4 Calibration:

Using this data set and the model the flows in Fig. 1, except the emissions from the hazardous waste were calculated. Fig. 2 shows the results for the stocks, and inputs for thermometers and sphygmomanometers, as well as the statistical data for import of mercury thermometers. A recalibration of the lifetime for thermometers was necessary since the number of calculated imported thermometers between 1960 and 2000 was too high. Therefore the lifetime for this time period was assumed to be 4.5 month since 1950, decreasing gradually to 1.5 month in 2000. This assumption can be justified by the fact, that the equipment was handled more carefully in the past.

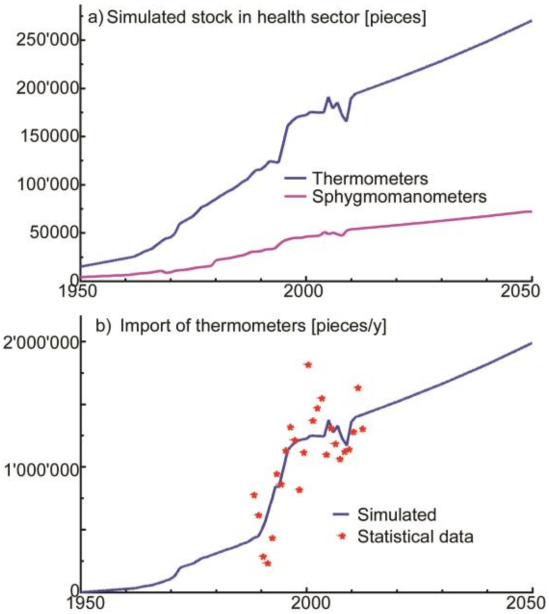

Fig. 2 a) Stock of thermometers and sphygmomanometers in Thailand between 1950 and 2050, b) Import of thermometers between 1950 and 2050

3. RESULTS AND DISCUSSION

3.1 Stock of Mercury

Fig. 3 shows the stock of mercury in thermometers and sphygmomanometers in use. The double peak of the joint stock is roughly 3,700 kg and occurs around 2000-2010. Compared to the amalgam stock in dental fillings which is about 10,080 kg according to [29], this is roughly 37% of that stock. The assumption that mercury free thermometers and sphygmomanometers replace continually the mercury containing equipment in the 21st century leads to the decrease of the mercury stock after 2010 shown in Fig. 3.

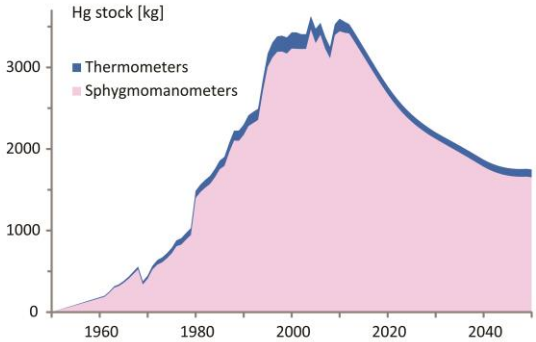

Fig. 3 Mercury stock in Thailand through thermometers and sphygmomanometers

3.2 Mercury Emissions and Flow to Hazardous Waste

The short lifetime of thermometers of about 1.5 month is due to breakage during use. About 70% of mercury from broken thermometers is collected as hazardous waste, 23% is emitted to air and 7% to water. Fig. 4 shows the mercury flows of import, hazardous waste and emissions to air and water for thermometers.

The flows in Fig. 4 in function of time show a similar behavior as the stocks in Fig. 3. The reason is the same as for the stocks.

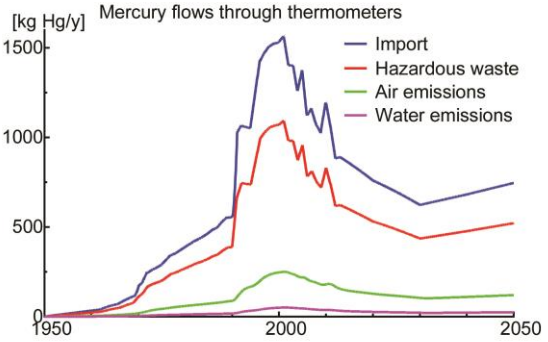

Fig. 4 Mercury through thermometers in flows from import, to hazardous waste, emissions to air and water

The peak values of the residual flows are about 1,000 kg, 250 kg and 51 kg to hazardous waste, air and water, respectively. A comparison with Wongsoonthornchai et al. [29] shows that the residual flows from the thermometers are about 20%, 14% and 5% of the flows from intentional use to waste, air and water, respectively.

The maximum of emissions to air is about 250 kg/y in the year 2001. According to the number of beds in hospitals of 136,000 in 2001 this gives an emission of 1.84 g Hg per bed and year. The maximum tolerable workplace exposure limit of mercury is 0.05 mg Hg / m^3 [33]. To be below the limit the emission per bed would have to be diluted in more than 36,700 m^3 air per bed and year. Assuming a space column of about 15 m^3 per bed, this means that the air would have to be exchanged completely almost 7 times per day in each hospital room in order to be below the limit. This could explain the high mercury level in urine of health care staff.

From the simulations follows that until 2010, about 24,000 kg of mercury from thermometers ended in hazardous waste, 5,400 kg and 1,100 kg were emitted to air and water, respectively.

3.3 Scenario Analysis

As suggested by WHO and HCWH [15], thermometers and sphygmomanometers are interesting health products to reduce mercury on the global scale. Therefore, the following scenario is considered to reduce mercury emission in Thailand.

3.3.1 Scenario: Replace all Hg-thermometers and Hg-sphygmomanometers with alternative products by 2020

Since the lifetimes of thermometers are very short, the residual flows to hazardous waste, and the emissions to air and water would be zero after 2020. The simulation shows that the reduction would be in average 540 kg/y, 122 kg/y and 25kg/y for the flows to hazardous waste, emissions to air and water after 2020. For sphygmomanometers, because of their lifetime of about 9 years the flows to hazardous waste would be reduced to zero in about 2030.

In total this scenario would reduce the residual flows by 25,730 kg between 2020 and 2050. This is quite a large amount, even compared with the already deposited and emitted amount of 38,900 kg up to 2010.

4. CONCLUSION

This paper analyzed the time-dependence of mercury flow and stock through thermometers and sphygmomanometers using MMFA approach. The simulation showed that the stock of mercury in thermometers is only about 5% of the stock of mercury in sphygmomanometers. However with thermometers 3 times more mercury is imported than in sphygmomanometers. The reason is the short lifetime of thermometers of about 1.5 month, which is about 70 times shorter than for sphygmomanometers. Therefore also the residual flows of mercury from thermometers to hazardous waste, air and water are about 3 times larger than those for sphygmomanometers.

The calculated emission to air from mercury thermometers in hospitals can explain the higher level mercury measured in urine of health care staff.

To reduce the emissions to air and water mercury thermometers should be replaced as soon as possible by alternative products.

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