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An Integrated Approach to Initiate Preventive Strategies for Workers Exposed to Teflon Pyrolytic Gases in a Plastic Industry

Perng-Jy Tsai[1], Yue-Liang Guo[1]*, Jin-Luh Chen[2] and Hong-Yong Shieh[3]

[1]Department of Environmental and Occupational Health, Medical College, National Cheng Kung University,
[2]Tainan Science-based Industrial Park Development Office, National Science Council, Executive Yuan and
[3]Southern Labor Inspectory Bureau, Council of Labor Affairs, Executive Yuan

Abstract: An Integrated Approach to Initiate Preventive Strategies for Workers Exposed to Teflon Pyrolytic Gases in a Plastic Industry: Perng-Jy Tsai, *et al.* Department of Environmental and Occupational Health, Medical College, National Cheng Kung University—This study illustrates an integrated approach for industries to find possible hazardous factors, to identify the causes of an accident, and eventually to start preventive measures after a fatal accident occurred in a Teflon heating process. A team consisting of experts from several disciplinary areas was formed for the purpose. Through literature review and the examination of clinical reports, possible hazardous factors were proposed, and then examined and confirmed through a field study. The technique of fault tree analysis (FTA) was adopted to investigate the causes of the accident logistically. Investigation of the causes of the accident was not limited to those which were directly relevant to it, but all potential causes were included. A preventive strategy was proposed with prioritized measures which were determined based on their importance from the practical standpoint. This study demonstrates the benefits of integrating expertise from a number of disciplines for accident investigation, especially for those accidents in which the scenario cannot be reconstructed.
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Key words: Teflon, Pyrolytic gases, Accident investigation, Preventive strategy

On September 13, 1995, accidental exposure to toxic gas affected three Teflon workers in a plastic factory in southern Taiwan, resulting in one death and two hospitalized from severe pulmonary edema[1)]. The manufacturing processes involved the melting of Teflon resins and extruding of Teflon rods. Teflon, or Polytetrafluoroethylene (PTFE) resin, is an opaque material with a milk-white color, waxy and smooth, and widely used in the manufacture of bearings and gaskets, and coatings for chemical vessels and wires, due to its chemical stability, low friction, and resistance to heat and electricity[2)]. In its polymer form, Teflon is non-toxic and physiologically inert, but starting at a temperature greater than 260°C, PTFE resin generates polymer fumes in the heating process. At higher temperatures, for example more than 350°C, the fumes can cause polymer fume fever in exposed workers[3–7)]. Pyrolysis of Teflon has been found in the heating process at temperatures higher than 400°C[7)]. Pyrolytic gases are known to cause respiratory problems in Teflon workers, including irritative symptoms such as chest pain, shortness of breath, and cough. A relatively rare but severe condition is acute pulmonary edema due to inhalation of pyrolytic products of Teflon, although few cases have been reported in the literature[4, 9–11)], but no fatal case has been reported (except this one). In this special case, three questions were raised, including:

(1) Whether Teflon pyrolysis gases were responsible for the fatal event.
(2) The causes of the release of pyrolytic gases from the Teflon manufacturing process.
(3) How to start proper prevention strategies in the future for the Teflon industry?

Considering the fact that the fatal scenario cannot be reconstructed, this study demonstrates a possible approach to answering the above questions, which will provide important information to industrial hygienists for accident prevention in the future.

Methods

In this study, an integrated approach, by collaborating expertise from a number of disciplines, including industrial hygiene, occupational safety, occupational medicine and process engineering, is used to identify

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Correspondence to: P.-J. Tsai, Department of Environmental and Occupational Health, Medical College, National Cheng Kung University, 138, Sheng-Li Road, 70428, Tainan, Taiwan, R.O.C.

possible hazardous factors, the causes of the event, and eventually starts a comprehensive accident prevention program for the plastic industry. For hazard recognition, the first step involves the identification of possible hazardous factors through literature review and the examination of clinical findings conducted by the industrial hygienist and occupational physician. The proposed hazardous factors are then examined and confirmed through a field survey conducted by the industrial hygienist, safety engineer, and the process engineer. To find the causes of the event, one logistic accident investigation technique, the fault tree analysis (FTA)[12], is adopted and conducted by the safety engineer and industrial hygienist together. An effective preventive strategy with priority measures was first proposed by the industrial hygienist, then finalized after consultation with the safety engineer and process engineer from the practical standpoint.

Results and Discussion

1. Hazard recognition

(1) Identification of possible hazardous factors

Detailed clinical reports have been published elsewhere[1]. In summary, three workers were involved in the accident given in this study, resulted in one dead and two hospitalized. The deceased worker suffered from severe pulmonary edema, with total opacity of both lungs on chest radiography, severe dehydration, with shock and hemoconcentration. Both survivors had diffuse infiltrates in bilateral lung fields on chest radiographs, and their pulmonary function tests during hospitalization showed mild restrictive ventilatory defects and mild impairment of diffusing capacity.

Based on the literature reviews, it is known that Teflon is a non-toxic and even physiologically-inert substance at low temperature. At temperature of 260°C or above, Teflon fumes may be generated, which are believed to be responsible for polymer fume fever, but polymer fume fever is not adequate to explain the clinical diagnosis of pulmonary edema found in the three workers involved. It therefore seems necessary to identify other toxicants that are associated with the development of pulmonary edema, and even the death of the exposed workers.

Several workers have reported that some toxic pyrolytic products may be produced by Teflon heating processes at high temperature[11, 13]. The possible pyrolytic products evolved from Teflon heating process are summarized in Table 1. The toxicity of these pyrolytic products varies widely, from the moderately toxic (such as tetrafluoroethylene monomer, $CF_2=CF_2$, with a median lethal concentration (LC_{50}) of 40,000 ppm for 4 h exposure in rats) to the highly toxic compounds (such as octafluoroisobutylene ($(CF_3)_2C=CF_2$), with a TLV-ceiling of 0.01 ppm; hydrogen fluoride (HF), with a TLV-ceiling of 2.0 ppm; and carbonyl fluoride (COF_2), with a TLV-ceiling of 5.0 ppm)[14, 15]. Animal studies have shown that there are no observed symptoms changes in the lungs of rats exposed to polymer fumes or pyrolytic products of Teflon at temperature below 425°C, but at 450°C, rats develop severe respiratory difficulty, and were found to have pulmonary edema, hemorrhage and necrosis of the tracheobronchial epithelium[15, 16]. These findings are comparable to the clinical conditions diagnosed in the three workers involved. Therefore, exposure to pyrolytic products during the Teflon heating process at high temperature is thought to have been responsible for this accident.

(2) Examination and confirmation of hazardous factors

A field survey was conducted collaboratively by one industrial hygienist, one safety engineer and one process

Table 1. The pyrolytic products of Teflon resin resulting from the heating process conducted at different temperatures under oxygen-present or oxygen-absent conditions

Heating temperature (°C)	Under oxygen-absent condition	Under oxygen-present condition
400	$CF_2=CF_2$	$CF_2=CF_2$
450	$CF_2=CF_2$, CF_3-$CF=CF_2$	$CF_2=CF_2$, CF_3-$CF=CF_2$, COF_2, HF
500	$CF_2=CF_2$, CF_3-$CF=CF_2$, cyclic C_4F_8, $(CF_3)_2C=CF_2$	$CF_2=CF_2$, CF_3-$CF=CF_2$, COF_2, cyclic C_4F_8, CF_4, HF
550	$CF_2=CF_2$, CF_3-$CF=CF_2$, cyclic C_4F_8	C F_3-C F_3, CF_3-$CF=CF_2$, COF_2, cyclic C_4F_8, CF_4, HF
600	$CF_2=CF_2$, CF_3-$CF=CF_2$, cyclic C_4F_8, $(CF_3)_2C=CF_2$	$CF_2=CF_2$, CF_3COF, COF_2, CF_3-CF_2-CF_3, C F_3-$(CF_2)_2$-CF_3, cyclic C_4F_8, CF_2, HF, CF_3COOH
650	$CF_2=CF_2$, CF_3-$CF=CF_2$, cyclic C_4F_8	$CF_2=CF_2$, CF_3COF, COF_2, CF_4, HF, CF_3COOH

engineer (from the plastic plant) on the day one week after the accident. After briefing with the plant managers, a walk-through inspection was done at the plant. Attention was paid to the Teflon workroom, including the layout, workplace ventilation, and the functioning of the extruder, particularly the function of the resin charging hopper, thermocouples, control panels, cooling system, and its water supply. From the field survey, we found that the workplace involved was a completely closed room, with the exception of a general exhaust fan installed on the opposite wall next to the door (Fig. 1). The dimensions of the workplace are approximately 8.5 m × 4.2 m × 4.0 m (L × W × H). Two horizontal Teflon extruders (HT_1 and HT_2) and two vertical Teflon extruders (VT_1 and VT_2) were installed in the workplace. Each extruder contains four main parts, including one Teflon feeding hopper equipped with a water cooling system, one heating tube with a screw-type plunger inside and covered by five consecutive heating sleeves outside, one compressor and one thermal control panel. The manufacturing process involved continuously charging dry granulated Teflon resins from the hopper into the heating tube, then the screw-type plunger, driven by the compressor, transporting Teflon through five consecutive heating sections, and finally the melted Teflon was extruded to form a Teflon rod. The temperature in each heating sleeve was preset on the control panel by the foreman before the work shift started. The preset temperatures for the five consecutive heating sleeves were 350°C, 380°C, 370°C, 360°C and 350°C, respectively. Temperatures at each of five consecutive heating sections were monitored by five thermocouples seeded in each of the five heating sleeves and controlled by the control panel based on monitored temperatures to automatically disconnect or connect the circuit when the temperature changed to 10% above or below the preset temperature. As reported by the plant manager, only one horizontal extruder (i.e., HT_2) was used to produce Teflon rods on the day of the accident. The Teflon powder charging rate for the HT_2 extruder was about 3 kg/h, which was significantly lower than the normal charging rate of 10 kg/h. The resultant Teflon rod (10 cm in diameter) production speed was about 15 cm/h, which was also significantly lower than the normal production speed of 50 cm/h. As to the Teflon workroom, the door was closed, but the general ventilation fan was functioning normally.

Three workers were involved in this accident, including two day-shift workers (molder A and the foreman) and one night-shift worker (molder B). Molder A was assigned to feed in the Teflon powder and therefore usually stayed near the feeding hopper approximately for 7 h as estimated by the foreman. The foreman was not limited to work in the Teflon room, because his duties included not only the cutting and packaging of Teflon rods, but also monitoring other workplaces. As the foreman recalled, he stayed approximately 1 h in the Teflon workroom during the work shift. Night-shift molder B, although usually near the feeding hopper, was also responsible for other jobs, such as cutting and packing outside the Teflon room. Molder B recalled that he was near the feed hopper for approximately 5 h, and outside the Teflon workroom for about 3 h during the work shift. Each of the three workers sought medical care separately due to chest pain, general weakness, shortness of breath, and fever with a chill right after finishing his work shift. Molder A was admitted to the intensive care unit and died 5 h after admission. The foreman and molder B were hospitalized and discharged 7 d and 9 d after admission, respectively.

Based on the clinical reports, all three workers were found to have pulmonary edema, and it was therefore suspected that all these workers might have been exposed

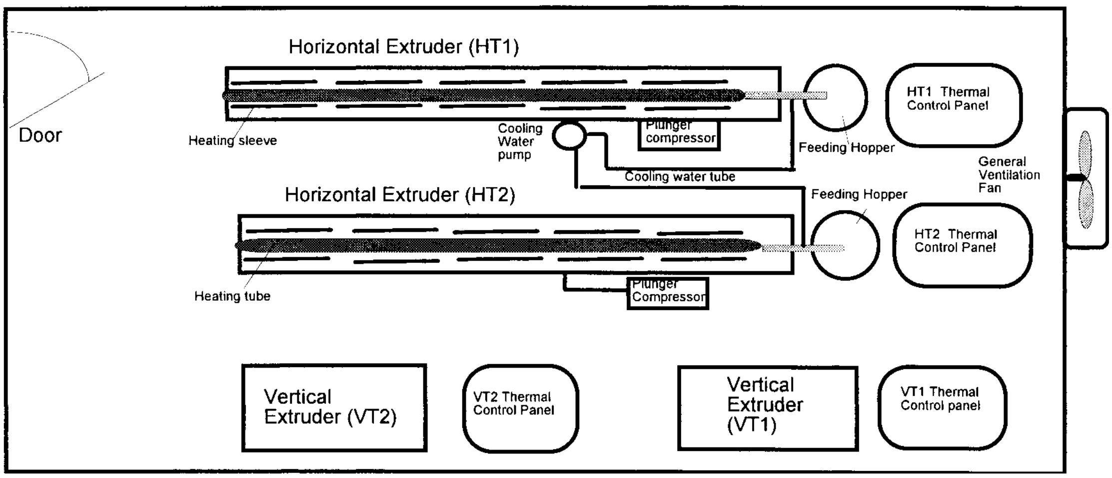

Fig. 1. The layout of the Teflon room.

to Teflon pyrolytic products. Since the preset temperatures for the Teflon rod manufacturing process (ranging from 350°C to 380°C, as mentioned above) were lower than the temperature required for the pyrolysis of Teflon resins, the temperatures involved in the heating process required further investigation. As we re-examined the HT_2 extruder during our field survey, it was found that the thermal control panel was malfunctioning. Within 2 h the surface temperatures on the five heating sleeves had been increased to 410°C, 430°C, 430°C, 510°C, and 430°C, respectively, as measured by an infrared thermometer (Raytek PM40, able to measure temperatures from −18°C to 870°C). Considering there was no sign that the rise in temperature on the surface of the heating sleeves had ceased, the test was stopped at 2 h after the HT_2 extruder had been restarted due to safety considerations. Nevertheless, considering that the HT_2 extruder had been continuously operating about 8 h for each work shift on the accident day, it can be expected that the heating sleeves might have reached even higher temperatures than those measured in our field survey.

In principle, if Teflon resin had been continuously driven by the screw-type plunger through the heating tube, the temperature inside the heating tube could be lower than the surface temperature of the heating sleeve due to the short contact time between the Teflon resin and the heating sleeve, but if the plunger had been stopped, prolonged heating of the Teflon resin might occur, and toxic pyrolytic products could be generated. To clarify this, the team consulted both survivors (the foreman and molder B) who stated that some of the charged resin was stuck in the throat of the feeding hopper during the heating process. Therefore, they used a wooden rod to assist feeding the Teflon resin from the hopper into the heating tube intermittently. While using the wooden rod, the plunger was stopped to prevent breakage, resulting in prolonged heating of the charged resin.

Furthermore, as we re-examined the HT_2 extruder, we found that the water cooling system of the feeding hopper did not work properly. After rechecking, we found that the water supply was accidentally (not deliberately) reduced, resulting in sending insufficient cooling water into the cooling tube. One water tube had scarcely any water flowing through it, and the other three tubes were empty. Although precise retrospective estimation of the time span and frequency of the prolonged heating, and the rise in temperature inside the heating tube was difficult, the above findings provide a basis on which to expect that the generation of pyrolytic products on the day of the accident was possible.

In addition to the above findings, approximately 10 cm of Teflon rod was found to have been extruded at the end of the heating tube, and it was suspected that the end of the heating tube was blocked. Therefore, the Teflon pyrolytic products in the workplace atmosphere might not be released from the end of heating tube, but could be generated in the heating tube, and delivered via the throat to the feeding hopper, and then finally released into the workplace atmosphere. Since a general exhaust fan was installed on the wall near the hopper of the HT_2 extruder (see Fig. 1), it was expected that workers working around the hopper might be exposed to higher concentrations than workers who worked elsewhere. It is therefore not surprising that molder A who worked near the hopper would be most exposed and died after the event, whereas molder B and the foreman who were not restricted to being near the hopper were hospitalized but recovered.

2. Identification of the causes of the accident

To find the causes of the accident, the logistic accident investigation technique of fault tree analysis (FTA) was adopted in this study. The technique involves first the identification of all possible cause elements (as seen at the bottom of the fault tree in Fig. 2), then grouping relevant cause elements to investigate intermidiate cause elements via the logistic determination process, then repeating the above process until it reaches the occurrence of the accident scenario. The detailed FTA result for the given event is shown in Fig. 2. In this study, it should be noted here that the analysis of the causes of the event are not limited to those which are directly relevant to this special event. Instead, potential causes that might lead to the occurrence of similar exposure scenarios are taken into account. It is concluded that three basic causes (the cause elements with the hatched area) are found directly relevant to the event, including:

(1) Improper design of the ventilation system.
(2) Inadequate water supply for the cooling water system during the resin charging process.
(3) Malfunction of the thermal control panel.

In addition, four potential causes (the cause elements with no hatched area), though not directly relevant to the event, might result in similar exposure scenarios, were found in this study, including:

(1) Malfunction of the ventilation system.
(2) Failure to start the cooling water system during the resin charging process.
(3) Inaccurate temperature detection by the thermal detecting system.
(4) Incorrect preset temperature for the heating process.

3. Initiation of prevention strategies

For practical reason, preventive strategies for those causes directly relevant to this fatal event are rated as first priority measures for the purpose of recommending the employer to take immediate action to prevent such an accident from happening again. Preventive strategies that are not directly relevant to the causes of the given event, but are relevant to the intrinsic safety of either the manufacturing process or facilities are rated as secondary

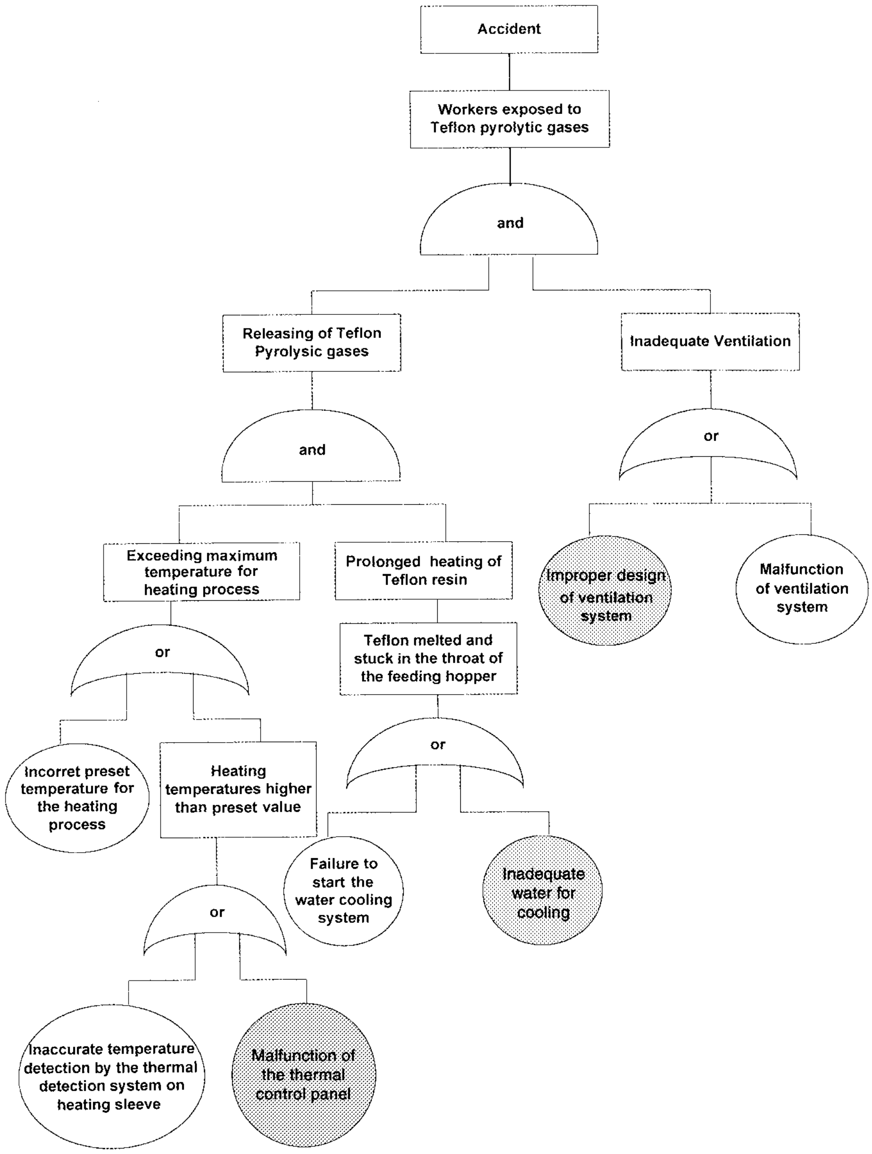

Fig. 2. The result of fault tree analysis (FTA) for the accident reported in this study. Circles and rectangles shown in the fault tree represent the possible cause elements, and the intermidiate cause element, respectively. The possible cause elements with a hatched area represent those causes which are directly relevant to the event, the possible cause elements with no hatched area are regarded as potential causes which might result in the occurrence of a similar accident.

priority measures. Preventive strategies that are relevant to administrative control are rated as third priority measures. Detailed preventive strategies recommended by this study are shown in Table 2, including:

(1) First priority measures

a. Installing a local exhaust ventilation system in addition to the general exhaust ventilation system that is currently used in the Teflon room.
b. Checking the flow rate of the cooling water system at the beginning of each work shift.
c. Periodically examining the function of the thermal control panel.

(2) Second priority measures

a. Installing an interlock system to ensure that both the ventilation system and the heating process will be simultaneously started.
b. Installing an interlock system to ensure that both the cooling water system and the Teflon resin charging process will be simultaneously started.

Table 2. The causes, prevention strategies, and recommended priorities for the accident reported in this study

Scenarios	Causes	Preventive strategies	Priority
1. Inadequate ventilation	a. Improper design of the ventilation system	• Replace the existing general ventilation system with local exhaust ventilation systems	1
		• Install an interlock system for automatically starting the ventilation system during the heating process	2
	b. Malfunctioning of the ventilation system	• Periodical examination of the ventilation system	3
2. Releasing the Teflon pyrolytic gases			
A. Exceeding the temperature normally involved in the heating process	a. Malfunctioning of the thermal control panel	• Periodically examine the function of the thermal control panel	1
	b. Inaccurate temperature detection by the thermal detection system on the heating sleeve	• Periodically examine the function of the thermal detection system	3
	c. Incorrect preset temperature for the heating process	• Establish a standard operation procedure (SOP) for the heating process	3
		• Establish and conduct a worker-training program	3
B. Prolonged heating of Teflon	a. Inadequate water flow rate in cooling water tubes	• Periodical examination of water flow rate	1
	b. Failure to start the water cooling system	• Establish a standard operation procedure (SOP) for the heating process	3
		• Establish and conduct a worker-training program	3
		• Install an interlock system for automatically starting the cooling water system during the heating process	2

(3) Third priority measures

a. Periodical examination of the function of the ventilation system.
b. Periodical examination of the function of the thermal monitoring system.
c. Establishing a standard operation procedure (SOP) for the heating process.
d. Conducting a worker-training program to train workers to strictly follow the SOP and educate workers to be aware of the toxic properties of Teflon pyrolytic products.

Conclusions

This study illustrates a useful approach for industries and occupational health workers to find potential hazardous factors, to identify the causes of the event, and eventually to start preventive strategies for the kind of fatal accident that happened in a Teflon heating process. The approach demonstrates the benefits of integrating expertise from a number of disciplines for accident investigation and prevention. Most importantly, the approach could be valuable especially for those accidents in which the accident scenario cannot be reconstructed.

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