論文

自助加油站引發靜電放電危害之分析與防護探討

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摘要

2004年美國一位女性於自助加油時，因摩擦帶電而造成火花之意外影片，雖未造成嚴重的損失與傷害，但此畫面給予大眾極大的震撼，使看不見的靜電危害受到了矚目。現今在台灣設有247家以上之自助加油站，且因應時代的趨勢，其數量必然不斷上漲。自助加油站減少了人力之成本帶來方便，但消費者轉換為未受過訓練及規範之顧客，使其操作過程擁有一定之不確定性；且難以察覺之靜電，其在操作者無意之間即可能生成、累積並放電造成危害，故本研究目的為探討現今自助加油站之靜電預防措施之效用，並給予適當之建議。

本研究現場訪視15家自助加油站，蒐集其相關資訊並於現場量測設備之電導率，用以評估其導電性及效用。研究結果顯示：1.操作面板之金屬材質介面具有良好導電效果，其電荷散逸時間僅需0.3±0.12 秒；2.加油槍之把手部分通常使用塑膠套包覆，無法有效將消費者身體之電荷導掉（塑膠套電阻值：＞1,012 Ω；拆除膠套之電阻值：2 Ω）；3.加油機台本身即具有接地效果，具良好之導電性（18 Ω）；4.國人於油槍把手掛上抹布以保持清潔之動作，很可能增加電荷的累積引發靜電危害，故不建議使用抹布。

根據研究結果，分析出現有之自助加油站設備導電性不差，可惜的是未能確實定期作檢測與維修，若能藉由教育訓練等方式，提升國人之靜電放電危害及預防相關知識及嚴格遵守適當之操作流程，則靜電危害之風險即可有效降低。另外，製作標準作業流程讓消費者皆能正確操作，使靜電預防措施發揮效用，有效避免靜電放電危害之發生。

關鍵字：靜電放電、自助加油站、火災爆炸

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前言

台灣為海島型國家，根據中央氣象局網站於2011年更新之統計資料，台灣至2010年為止30年來的平均溼度介於74.1～89.7％之間[1]。由於氣候較為潮濕，加上靜電現象其看不見、不易察覺的特性，所以靜電危害時常被人們所忽略。然而，2004年美國一段於自助加油時，因摩擦帶電而造成火花之意外影片[2]，給予社會大眾極大的震撼，亦使看不見的靜電危害受到了矚目。

靜電之生成主要由於運作或動作之過程，經由摩擦、剝離、感應等作用而產生電荷。當物體無法將電荷導除，而不斷蓄積電荷至一定量時，若物體彼此間所帶有之電荷量差異大，或帶電物體之電荷不斷的累積，而使其週遭電場強度達3M V/M的時候[3]，則會發生放電現象造成人體觸電、電器短路或火災爆炸等危害。

現今社會講求快速與效率，且為求人力的精簡，設備設施自助化已成為流行的趨勢。現今在台灣設有247家以上之自助加油站[4,5]，且其數量勢必持續增加；然而當其操作者轉換為未受過訓練及規範之顧客，則於自助加油過程中其安全性有待更詳盡考量。根據石油設備工會之靜電造成加油站火災報告整理[6]，調查了美國176起產生靜電火花案例，而其中有87個案例為加油管仍在加油中，消費者在此期間會進出車內，因此消費者從車內出來要拔出加油槍時，其累積之電荷與加油槍產生電位差，因而造成靜電放電引發火災。為防止此類災害發生，除規定拆除自助加油站之油槍自動跳停功能之流速開關檔片外，靜電放電危害之預防有其重要性。

引起火災爆炸之三要素有：易燃物、助燃物及火源，當三者皆具備則會發生連鎖反應，造成火災爆炸之危害。在加油站之環境中，汽油本身即為易燃液體，且其極易揮發成油氣；而環境中之空氣則為良好的助燃物，兩者皆為無法避免之因素，故其火災爆炸的預防僅能從火源之要素著手。目前台灣加油站設置管理規則[7]中規定，加油站需設置「嚴禁煙火」、「熄火加油」、「禁止抽菸」等警告標示即為針對明火之設計。對於靜電火花之危害，則從減少靜電的產生、防止靜電積聚和防止產生高電場引起靜電火花放電方面著手。

現今加油站除設有禁用手機之標示外，亦裝設接地設備及靜電消除設備，避免放電作用產生火花而引發危害。靜電接地是指將儲存容器、管道及其他設備通過金屬導線和接地體與大地通聯而將電荷導於地表；而等電位跨接是指將設備及管道以導線相連，使彼此之電位相等，不致產生高電位差而放電。然而，環保局基於環境與健康危害之考量，倡導油氣回收之概念，除推動裝設油氣回收設備外，許多加油站於油槍口掛設抹布，避免油槍剩餘汽油滴落，然此動作可能造成靜電危害。因此，本研究目的為分析台灣自助加油站靜電放電危害與探討預防措施之效用。

研究方法

首先，本研究蒐集自助加油運作流程及法規等相關資訊，並針對靜電危害部分依據作業流程，分析出造成火災爆炸之失誤樹(Fault tree analysis, FTA)圖。經由FTA可幫助找出作業流程中易發生靜電放電引起火災爆炸危害之標的位置，進一步詳細探討其原因及預防方式，以利降低危害之發生。

藉由實地訪視15家自助加油站，量測機台設備之電導率、電荷散逸時間及評估其接地

效果以及其現有之靜電防護措施；另外亦針對92、95、98無鉛汽油，以及實際使用之抹布、油槍、油管等器具，探討其靜電特性，用以評估導電性及效用並充分瞭解其製程靜電危害與防護資訊。最後，整理量測數據並參考國內外資料，給予適當的建議。

研究設備主要以Metriso 2000-Test Kit 及三用電表作為電阻之量測工具，其檢測範圍分別為10^3−10^{12}Ω以及0.1−2×107Ω。搭配EN 61340-4-1 Ed. 2.0 / EN 61340-2-3所建議之Model 850探頭，以及828 M體積電阻量測設備，進行電阻值之測量與探討。

研究結果

從失誤樹分析圖中（圖1），我們將自助加油站引發靜電放電而造成火災爆炸之可能原因探討出，提供後續靜電預防及控制措施之探討與分析。此篇研究所要探討之標的為自助加油站之靜電放電危害，故僅針對有效火源之靜電部分進行分析。於正常操作流程下，自助加油步驟可能產生靜電放電危害之位點為：油槍與油箱口之間、操作者與油箱口之間、操作者與加油槍之間，以及油箱與液面之間。

根據分析結果發現，油槍、油箱、汽油以及作業人員為自助加油作業中靜電放電危害之主要探討對象。從燃燒三要素來說，於存有可燃性環境中，若此時提供有效的靜電放電能量，亦即放電能量大於易燃物之最低引爆能量(MIE)，則可能產生火災爆炸之危害。根據現有之知識，液體於油槍管中流動時會產生電荷，下料速度過快不只會增加電荷生成速度，亦使電荷來不及散逸，若溶液或油槍管之靜電特性為低導電性，則靜電荷累積的現象會更為嚴重。另外需特別要注意的是，人體活動過程

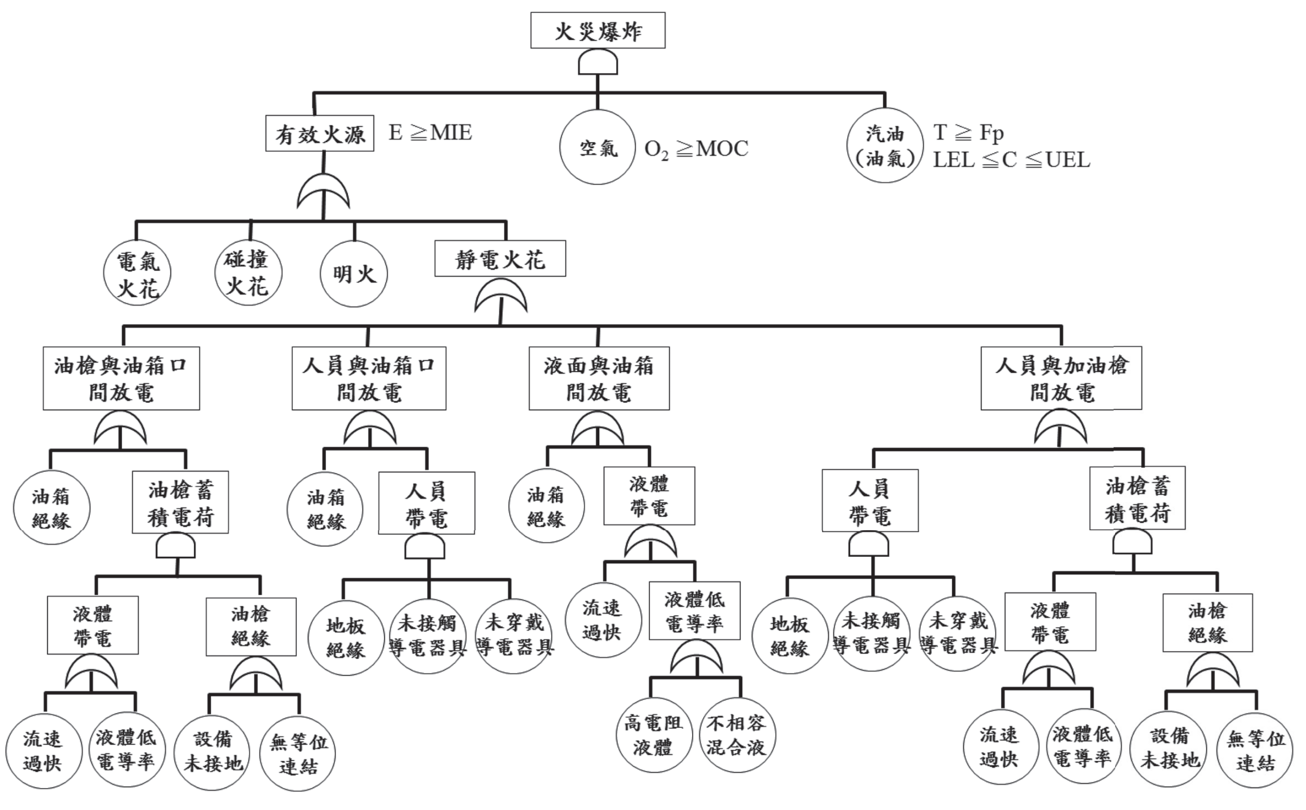

圖1　自助加油站火災爆炸之失誤樹分析圖

中難免會產生電荷，因此人員其穿戴之衣物或配戴之器具是否可有效將電荷導除，以及接觸之地板導電性亦為重要探討之標的。因此，以上影響物體電荷累積量之各個因素皆為本研究中主要探討的因子。

經由現場訪視，實地量測自助加油站之接地設備及加油機台，探討其靜電特性與接地效果，其量測結果如表1所示。量測到設備之接地電阻值皆小於10 Ω，僅配電盤處之接地電阻為18 Ω。

表1　接地設備及機台之電阻值

檢測點	電阻（Ω）
配電盤接地電阻	18
空氣壓縮機	2.8
避雷設備	2.3
卸油口	7.4

分別量測於現場採樣之92、95、98無鉛汽油，導電率介於1-10^{-2} pS/m之間，平均為1.07±1.34 pS/m。根據NFPA77之標準，溶液小於50 pS/m則為絕緣性之液體，故三種汽油皆屬於絕緣性溶液（如表2所示）。液體於運輸流動過程中，會經由摩擦等作用而生成電荷，若溶液為低導電性液體，則不論其是否接地、或儲槽的導電性良好與否，皆無法使溶液內的電荷有效散逸。

表2　無鉛汽油之電導率

油品	電導率(pS/m)
92	1.53×10^{-1}
95	2.77
98	2.80×10^{-1}

塑膠為絕緣性物質，故當加油槍、油管以塑膠套包覆時，其會導致原本具良好導電性的金屬材質之油槍與油管被絕緣。經量測後，利用塑膠等絕緣物質包覆之油管及油槍之電阻分別為1.51×10^{8}、5.74×10^{11}（如表3所示）。

表3　油槍、油管之電阻量測與電荷散逸時間整理

檢測點	電阻（Ω）	散逸時間(s)
油管塑膠包覆	1.51×10^{8}	3.4
油槍握把	5.74×10^{11}	15.1

實地訪查後，從加油站帶回三種實際使用的抹布樣本，量測其電阻後發現，三種抹布樣本皆屬於絕緣物質（如表4所示），因此其於使用過程中可能累積電荷，造成潛在的靜電危害。

表4　抹布之電阻

名稱	電阻(Ω)
抹布A	＞1.00×10^{12}
抹布B	9.01×10^{11}
抹布C	3.11×10^{9}

自助加油站按鍵控制面板之導電力，會影響是否能讓消費者於操作過程中將其身體累積之電荷導於機台及地面，使人體不帶有靜電荷，避免靜電放電的危險。

本研究利用儀器將電壓板充電至1,100 V以上，隨即接觸靜電消除專用面板或一般自助加油操作面板，計算從1,000 V降至0 V所需時間，即為電荷散逸時間，測試後發現靜電消除專用面板具有良好導電效果，電荷散逸時間皆在3秒內，但一般自助加油操作面板之導電效果差異甚大。面板A、B、C為不同家加油站不同機台之面板。如表5所示，除面板C電荷散逸時間僅需0.3秒，具有導掉加油者身體電荷效能外，面板A及面板B效能並不好，尤其面板A的數字鍵似乎有問題，應進一步評估檢討。

表5　一般自助加油操作面板之按鍵電荷散逸時間

檢測點	電荷逸散時間(s)
面板A-數字鍵	33.3
面板A -空白鍵	2.7
面板B-數字鍵	2.9
面板B -空白鍵	1.8
面板C-數字鍵	0.3
面板C-確認鍵	0.3

討論

自助加油之過程中，最容易累積電荷的地方除接地失效的機台本身外，即是人體，故為避免靜電放電危害，我們應從降低電荷生成量、防止電荷累積以至於產生高電場引起靜電火花放電方面著手。加油站設置管理規則[7]中規定，加油站除設置「熄火加油」、「嚴禁煙火」之警戒標誌外，加油機應接地，並經製造國安全檢驗合格，且距離地界線應在二公尺以上。

接地之目的為將設備之電荷導入地面，使設備不會累積電荷至一定量而產生放電現象。低壓用電設備接地則規定為100Ω以下[8]。而加油站的加油機、加油槍均應作靜電接地，接地電阻亦不大於25 Ω。於實際量測自助加油站加油機台設備之接地電阻，其結果皆小於標準，能正常發揮作用。根據失誤樹分析結果，當確認機台設備不帶有電荷後，靜電放電現象之產生僅可能為與人體或物體產生電位差而造成。

人體若穿著人造纖維、橡膠等絕緣衣服及鞋子，則當此人有所動作時（如：走路、拿取物品）則會產生電荷並累積在身上，不易散逸。為避免人體帶電而與機械設備產生電位差，造成靜電火花而引發火災，故最好之方法即為於加油前消除人體靜電。台灣一龍頭石油公司即設置靜電消除棒，並於操作步驟中導引消費者於加油前觸摸靜電消除棒，以降低靜電放電危害。除設置靜電消除裝置外，若操作面板具有良好之電導性，則消費者於按鍵輸入時即可達到靜電消除之功用，量測自助加油站面板按鍵電荷散逸所需時間，結果顯示當機台接地系統正常發揮作用的時候，則按鍵鈕僅需1～2秒即可將人體電荷消除，故業者將操作步驟設為先按鍵輸入號碼始可加油，即能有效消除人體電荷。然而要注意的是定期檢測及維修的重要性，若其接地設備等之裝設有問題，則量測按鍵面板的電荷消散時間高達33秒，失去其效用。

當兩個不同物質彼此有正負電子流動，產生摩擦、攪拌等接觸後就會產生靜電，故當汽油經由油管從油槍中流出時亦可能產生靜電。加油站之油槍為防止碰撞產生火花，故使用鋁合金材質，其具良好導電性並設備接地。然而經實驗量測後，不論92、95或98無鉛汽油皆為絕緣性液體，故汽油從加油槍噴出之狀態有產生靜電放電的可能性。值得慶幸的是，以正常操作步驟來看，加油槍置入汽機車之充滿油氣的油箱內，由於箱內缺乏空氣等助燃物，故即使有靜電火花之產生也不會有火災爆炸的危險。

值得注意的是抹布擦拭油槍口之動作。基於環境保護與人體健康之觀念，為避免殘留於油槍內之汽油滴落，而使揮發之油氣散布於空氣中造成安全與健康上的危害，許多加油站於油槍上掛上一條抹布，讓消費者從油箱抽出油槍時可以抹布吸收剩餘之油滴。然而經檢測現場訪視加油站所帶回之抹布，抹布A及B皆為絕緣性物質，易累積電荷於其中。而擦拭之動作已使油槍管口帶電，當其與油箱口產生電位差。然而，從油箱中揮發出來的油氣以及大氣中之空氣，於油箱口混合成良好之易燃環境，故此時若產生靜電火花即可能造成火災爆炸之危害。因此，我們建議改用抗靜電材質之抹布，或設置回收裝置，即可降低靜電火花之危害。

油槍握柄裝設膠套之用意為讓消費者抓握感到舒適，然而塑膠套會造成鋁合金材質之油槍無法讓消費者抓握時將其身上之電荷導除，

故基於靜電防電危害問題之考量，建議拆除塑膠套。雖然人體累積之電荷可經由面板或靜電消除棒導除，但要注意的是於加油過程中，人體亦可能有摩擦等動作造成電荷生成，因此亦建議配合流速開關檔片的拆除，使消費者需於加油過程中持續握著油槍，人體生成之電荷可經由握柄導除。

根據研究結果，現有之自助加油站設備皆已作接地措施，預防靜電危害。然而最重要的是定期檢查與維修需確實實施，以及員工及維修人員對於靜電放電危害之教育訓練，方能確保其有效性。另外，製作標準作業流程，且經由教育宣導民眾正確安全觀念並確實遵守自助加油操作指示之步驟，則可使靜電預防措施發揮效用，有效避免靜電放電危害之發生。

結論

1. 應定期檢查及維修接地措施，訂定合適之管理辦法。
2. 建立操作流程（SOP）並運用易懂之圖示或標示，張貼操作者顯明易見之處。
3. 加油前除應熄火之外，應先利用操作指南或設計導引消費者接觸按鍵面板或靜電消除棒。
4. 油槍之塑膠套建議予以拆除。
5. 拆除流速開關檔片，避免操作者固定使油槍自動加油，而做出其餘易產生靜電荷的動作。
6. 應使用抗靜電材質抹布，並時常更換。
7. 維修人員、勞工及主管應針對靜電危害與預防作教育訓練。

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Research Articles

Analysis and Protection Discussion of Self-service Gas Stations' Hazards Caused by Electrostatic Discharge

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Abstract

In 2004, there was a famous self-refueling accident caused by electrostatic discharge (ESD) in America, California, and it reminds people the potential risk of self service gas station. Taiwan has more than 247 self service systems and it will continue increasing, so we should take care about this issue. Therefore, to explore the ESD hazard and its related prevention measures on self-refueling operation will be the key issue in Taiwan, and this is also the purpose of this study.

We cooperated with 15 gas stations to collect some information, and to explore the most common methods used for electrostatic hazard prevention in self service gas station in Taiwan, then to measure the electrostatic condition on necessary area when refueling.

According our research, we found the electric resistance of gasoline is very high, the average value is 0.04 pS/m (0.04 ± 0.05 pS/m). We also test some electrostatic prevention methods, such as: 1. removed the billet from gasoline pump nozzle, and customers would not jam the pump nozzle and touch other area when they refueling; 2. ESD eliminating bottom, or conductive operation keyboard (discharge time：0.30 ± 0.12 second), keep them could conducting the charge which stay on person; 3. gasoline pump nozzle and operation relative pipe with metal materials, and we test grounding

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resistance of gasoline dispenser, periodically; 4. removed the plastic sheath from handle, to increase the conductivity (plastic sheath resistance：＞1012 Ω; removed plastic resistance：2 Ω). Those methods also exhibited a good effect of ESD prevention at the good maintenance condition. Besides, the method of hang a piece of cloth on nozzle may produce more electrostatic charge, and make a potential risk.

Base on the study results, we give some suggestion to self-refueling operation. We hope the suggestion can effectively minimize the risk of ESD hazard on gas station.

Keywords: Electrostatic discharge, Self service gas station, Fire and explosion

Introduction

Taiwan is an island country, and according to updated statistics on the website of the Central Weather Bureau in 2011, the average humidity of Taiwan during the past 30 years leading up to 2010 is between 74.1～89.7 %[1]. Since the climate is fairly humid and carries invisible and inconspicuous static, electrostatic hazards have often been overlooked by people. However, the video of an accident caused by friction sparks during self-refueling in the United States in 2004[2] has greatly shocked the public, but also has brought attention to the invisible electrostatic hazards.

Static electricity is mainly generated through friction, peeling, and induction effects during the processes of operation or movement, giving rise to an electrical charge. When an object cannot discharge and continues to accumulate until it reaches a certain amount of charge, if the difference in charges between the two objects is great, or the object with the charge has been continuously accumulating a charge, resulting in its surrounding electrical field intensity reaching 3M V/M [3], it would create a discharge phenomenon, causing hazards such as electrification of the human body, the short circuiting of electronic devices, or fire explosions.

Nowadays, society emphasizes speed and efficiency. In order to reduce manpower, equipment, and facilities, self-service has become a popular trend. There are more than 247 self-service gas stations now in Taiwan [4,5], and the number is bound to continuously increase; however, when its operators have been converted to untrained, normal customers, then it is necessary to give more exhaustive consideration to the process of self-refueling. According to the summary report made by the Oil Equipment Union [6], it has investigated 176 cases of fires ignited by static sparks in the United States, of which there were 87 cases of consumers going into the vehicle while the refueling gun was still pumping fuel, so when consumer came out of the vehicle and pulled out the refueling gun, the consumer's cumulative charge created a difference in the electrical potential of the refueling gun, resulting in a fire caused by electrostatic discharge. In order to prevent such disasters from happening, other than regulating the removal of the flow velocity switch stopper of the refueling gun's automatic jump stop function, the prevention for electrostatic discharge hazards itself has its own importance.

Three elements of fire and explosions are: combustibles, combustion-supporting materials, and ignition sources. When all three of these are present a chain reaction could result, causing fire and explosion hazards. In the environment of a gas station, gasoline itself is a flammable liquid and can easily evaporate into gasoline vapors; meanwhile the air around it is a highly combustible-supporting material. These two are unavoidable factors, therefore, the prevention of fire and explosions can only proceed from controlling ignition sources. Current Taiwanese gas station installation management rules [7] stipulate that gas stations should install signs such as "Open Flames Strictly Prohibited", "Turn Off Engine Before Refueling", and "No Smoking", warning against open flames. As for the danger of static sparks, we must start from such static spark discharge aspects as reducing the generation of static electricity, avoiding static electricity building up, and preventing static spark discharge caused by strong electrical fields.

Nowadays, gas stations not only display labels to prohibit the use of mobile phones, they also install grounding equipment and static elimination equipment to avoid hazards caused by the discharge of sparks. Static grounding refers to the connection of storage vessels, piping and other equipment through metal wires and grounding objects with the earth to lead the charge onto the surface of the ground; while equipotential bonding refers to wires connecting equipment and pipes so that their potential would be equal to each other and would not generate discharges due to high potential differences. However, the Environmental Protection Agency, in consideration of environmental and health hazards, advocates the concept of gasoline vapor recovery. Besides promoting the installation of gasoline vapor recovery equipment, many gas stations have placed rags on refueling guns' muzzles to avoid excess gasoline from dripping, however, this action may cause static electricity hazards. Therefore, this study aimed to analyze the static discharge hazards of Taiwan's self-service gas stations and to discuss the effectiveness of preventive measures.

Research Methods

First of all, this study collected information on self-refueling operation processes and regulations. It looked into the process that is the basis of static hazards, and it analyzed the Fault Tree (Fault tree analysis, FTA) chart that results in fire and explosions. The FTA can help to identify the subjects underlying the operational process for creating electrostatic discharge that causes fire and explosion hazards, to further discuss its causes and prevention methods in more detail, and to reduce the occurrence of hazards.

Through field visits to 15 self-service gas stations, we have measured the equipments' conductivity and charge dissipation times and assessed their grounding effectiveness, as well as their existing static protection measures; we also looked into 92, 95, and 98 unleaded gasoline, as well as their actual usage of rags, refueling guns, pipelines and other equipment to investigate their electrostatic characteristics for evaluating their electrical conductivity and effectiveness, and to fully understand information on their electrostatic hazards and protection processes. Finally, summarizing the measured data and referring to domestic and foreign information, we gave appropriate recommendations.

Research equipment mainly consisted of the Metrison 2000-Test Kit and the Volt-Ohm-Milliammeter as tools for measuring resistance, with individual detection ranges of 10^3–$10^{12}\,\Omega$ and $0.1\text{-}2\times10^7\,\Omega$, along with the recommended Model 850 EN 61340-4-1 Ed. 2.0/EN 61340-2-3 probe detector and 828 M volume resistance measurement equipment for undertaking resistance value measurements and exploration.

Research Results

From the Fault Tree Analysis (FTA) chart (Figure 1), we have investigated the potential causes of fire and explosions caused by static discharge in self-service gas stations, and have provided subsequent discussion and analysis on electrostatic prevention control measures.

This study has aimed to explore the electrostatic discharge hazards of self-service gas stations, so we have only analyzed the static part of effective ignition sources. Under normal operating procedures, locations that may generate electrostatic discharge hazards during self-refueling steps include: between refueling gun and gas tank port, between operator and gas tank port, between operator and refueling gun, and between gas tank and liquid surface.

According to the analysis results, we find that the refueling guns, gas tanks, gasoline and operators are primary focuses for electrostatic discharge hazards during the self-refueling process. As for the three combustible elements, while existing in a flammable atmosphere, if provided with effective electrostatic discharge energy which is greater than the minimum discharge energy (MIE), it may cause fire and explosion hazards. According to existing knowledge, liquid flowing inside the refueling gun will produce an electric charge. If the delivery speed is too fast, not only will it increase the electric charge generating rate, it will also leave the electric charge no time for dissipation. If the fluid or refueling gun have low electrostatic conductivity, then the electrostatic charge accumulation phenomenon will be even more serious. Moreover, what especially requires attention is the electric charge inevitably created during the process of human activity. Thus, whether clothing or devices worn by personnel effectively conduct an electric charge, as well as the conductivity of the ground they are in contact with are also important subjects to explore. Therefore,

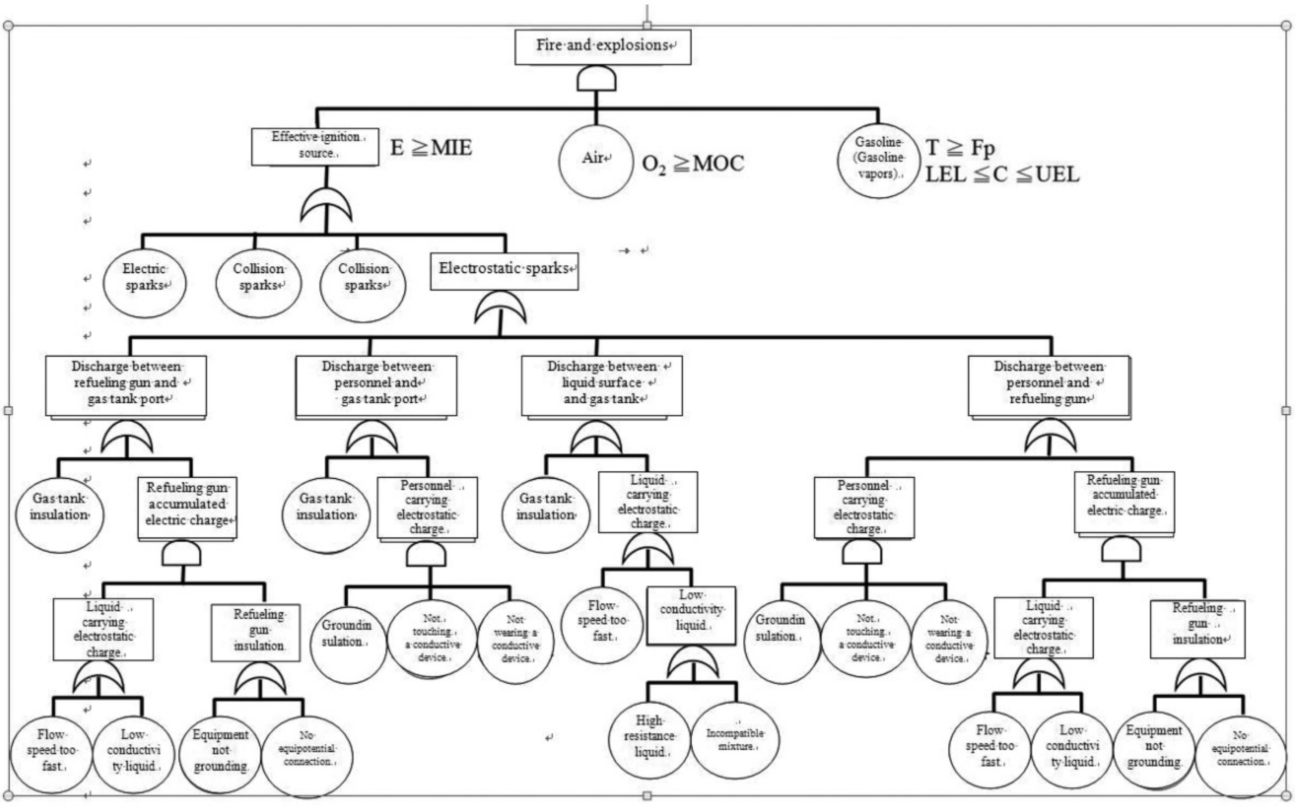

Figure 1 Self-service Fire and Explosion Fault Tree Analysis Chart

the above factors that would affect the amount of objects' electric charge accumulation are the factors primarily discussed in this study.

Through on-site visits, we have taken field measurements of grounding equipment and refueling machines of self-service gas stations to investigate their electrostatic characteristics and grounding effects. The measurement results are shown in Table 1. The measured values of the equipments' grounding resistances were all less than 10 Ω, except for the distribution panel's grounding resistance, which was 18 Ω.

Table 1 Resistance Values of Grounding Equipment and Machines

Inspection point	Resistance（Ω）
Grounding resistance of distribution panel	18
Air compressor	2.8
Surge protection equipment	2.3
Unloading port	7.4

Individual conductivity measurements for on-site sampling of 92, 95, and 98 unleaded gasoline were between 1-10^{-2} pS/m, with an average of 1.07 ± 1.34 pS/m. According to NFPA77 standard, liquid lower than 50 pS/m would be insulation liquid, so all these three kinds of gasoline are considered to be insulation liquids. Liquid flowing in in the transport process would generate electric charge through friction. If the liquid has low conductivity, irrespective of whether it was grounded, or whether the reservoir's conductivity was good or not, they won't be able to make the electric charge of the liquid to effectively dissipate.

Table 2 Conductivity of Unleaded Gasoline

Oil	Conductivity (pS/m)
92	1.53×10^{-1}
95	2.77
98	2.80×10^{-1}

Plastic is an insulation material, so when refueling guns and pipelines are wrapped in plastic sleeves, it will result in insulating the original metal refueling guns and pipelines with good electrical conductivity. After the measurement, the resistances for pipelines and refueling guns wrapped with an insulating material such as plastic were 1.51×10^{8} and 5.74×10^{11}, respectively.

Table 3 Summary of Resistance Measurements and Charge Dissipation

Inspection point	Resistance（Ω）	Dissipation time(s)
Pipeline wrapped in plastic	1.51×10^{8}	3.4
Refueling gun handle	5.74×10^{11}	15.1

Through field visits, three rag samples actually used by gas stations were brought back, and resistance measurements indicated these three rag samples all to be insulation materials, therefore they may accumulate electric charge in the process and result in potential electrostatic hazards.

Table 4 Resistances of Rags

Item	Resistance (Ω)
Rag A	$>1.00\times10^{12}$
Rag B	9.01×10^{11}
Rag C	3.11×10^{9}

Conductivity of the push button control panels in self-refueling gas stations will affect whether electric charge accumulated by the body can be guided to the machine and the ground during operation process, so that the body will not carry a static electric charge, so as to to avoid the risk of electrostatic discharge.

This project uses instruments to charge the voltage board to over 1,100 V, then immediately touch the electrostatic eliminator panel or average refueling operational panel of a self-service gas station to calculate the time needed to drop from 1,000 V down to zero V, which would be the electric charge dissipation time. After testing, we found that the electrostatic eliminator panels had great conductivity results. Their dissipation times were all within 3 seconds, however, average operational panels of self-service gas station have very different conductivity results. Panels A, B, and C are all from different gas station machines. As indicated in Table 5, only panel C has a dissipation time of 0.3 second that can effectively eliminate electric charge from the customer, while panels A and B were not effective – especially panel A, which seemed to have some problems with the number keys that should be further evaluated and examined.

Table 5 Regular self-service refueling operational panel push button charge dissipation time

Inspection point	Dissipation time(s)
Panel A - Number button	33.3
Panel A - Space button	2.7
Panel B - Number button	2.9
Panel B - Space button	1.8
Panel C - Number button	0.3
Panel C – Confirmation button	0.3

The Discussion

During self-refueling process, the most likely places for accumulating electric charge would be machines with grounding failure and the human body, so to avoid static discharge hazards, we should start by reducing the amount of charge generated to prevent charge accumulation that generates a high electrical field and causes the discharge of static sparks. Gas Station Installation and Management Rules [7] stipulates that gas stations should set up “Turn Off Engine Before Refueling” and “Open Flames Strictly Prohibited” warning signs. In addition, the gas pump should be grounded and be safety inspected by the country of manufacture, and the distance to the boundary should be two meters or more.

The purpose of grounding is to guide the electric charge of equipment to the ground, so that the devices do not accumulate electric charge to the amount necessary to generate a discharge phenomenon. Low-voltage electrical equipment grounding is defined as 100 Ω or less [8]. All refueling machines and guns should be grounded, and grounding resistance should not be greater than 25 Ω. After field testing the grounding resistances of self-service gas stations’ refueling machine equipment, the results were all less than the standards, and can work properly. According to Fault Tree Analysis results, after confirming that the device did not carry electric charge, then the electrostatic discharge phenomena could only be caused by potential difference between the human body and objects.

If the human body is wearing rayon or rubber insulated clothing and shoes, then when this person starts to perform an action (such as walking or pick up items), it will generate electric charge that accumulates in the body, and would not easily dissipate. In order to avoid the human body carrying an electric charge and creating potential differences with machines and equipment, resulting in static sparks and causing a fire, the best way would be to eliminate human body static before refueling. One of the leading gasoline companies in Taiwan has set up static elimination bars and guides the consumer to touch a static elimination bar before refueling in order to reduce static discharge hazards. In addition to setting up static elimination devices, if the operational panel has good electrical conductivity, then when the consumer pushes the keypad buttons, a static elimination result is achieved. When measuring the charge dissipation time needed when using the keypad of self-service gas stations, the results showed that when the machine grounding system was functioning properly, it would only take 1-2 seconds to eliminate body charge by pushing the buttons, thus the gas station owner has set operational steps for pushing buttons to input numbers before refueling so as to effectively eliminate electric charge of the body. However, what needs to be paid attention to is the importance of regular inspection and maintenance. If the grounding equipment has problems, then the measured charge dissipation time of the button panel could be up to 33 seconds and lose its effectiveness.

When two different substances have mutual electron-positron flow, they would be creating friction and agitation that would produce static electricity after contact, thus when gasoline flows through the pipeline of the refueling gun, it could also create static. In order to prevent sparks from collisions, gas stations' refueling guns are made of aluminum alloy, which has good conductivity and equipment grounding. However, after measurement, 92, 95 and 98 unleaded gasoline are all insulated liquids, so when gasoline ejected from the refueling gun there would be potential electrostatic discharge. Thankfully, in the scope of normal procedures, when placing the refueling gun into a gas tank filled with gas vapors, due to the lack of combustion-supporting air inside the tank, even if there were static sparks, there would be no danger of fire and explosion.

Worthy of notice is the wiping of the refueling gun port with a rag. Based on the concept of environmental protection and human health, in order to avoid residual gasoline on the refueling gun from dripping off and letting its volatile oil gas spread in the air and cause safety and health hazards, many gas stations place a rag on the refueling gun so that consumer can use the rag to absorb remaining gasoline droplets when extracting the refueling gun from the gas tank. However, after testing rags brought back from field visits to gas stations, rags A and B were both insulating materials and would easily accumulate electric charge. Moreover, the wiping action would make the refueling gun port carry static, and creating a difference of electric potential with the gas tank port. However, volatile oil gas from the gas tank and the air in the atmosphere would be mixed into a flammable environment in the gas tank port, so if there would be static sparks generated, it could cause fire and explosion hazards. Therefore, we recommend instead using rags with anti-static materials, or to install recovery devices, so as to reduce the hazard of static sparks.

The reason for installing a plastic cover on refueling gun grips was to make the consumer feel comfortable when gripping it. However, the plastic cover of aluminum alloy refueling guns cannot guide electric charge eliminated from the body while the consumer grabs the handle, so based on the consideration of anti-static hazards, we propose removal of the plastic cover. Although the accumulated electric charge of the human body can be eliminated via a panel or an electrostatic elimination bar, what needs to be paid attention to is that during the refueling process, the motions of the human body could also cause electric charge due to friction. Therefore, it is also recommended that the flow rate switch stopper be removed so that the consumer needs to continuously hold the refueling gun, as electric charge generated by human body can be eliminated through the grip.

According to study results, existing self-service gas stations have all taken grounding measures to prevent electrostatic hazards. However, the most important things are for regular inspections and maintenance to be reliably executed, as well as the training of staff and maintenance personnel on static discharge hazards, so as to ensure its effectiveness; and in addition, by establishing standard operating procedures by using public education to promote compliance with correct safety concepts and following proper steps for self-refueling, we can make electrostatic precaution measures become functional and effectively prevent hazards of electrostatic discharge from arising.

Conclusion

1. Regularly inspect and maintain grounding measures, and formulate appropriate management procedures.
2. Establish standard operating procedures (SOP) and use easily understandable signs or labels, and post them places where the operator can plainly and visibly see them.
3. In addition to stopping the engine before refueling, operating guidelines or design should guide customers to touch the key panel or electrostatic elimination bar.
4. It is recommended that the plastic cover of the refueling gun be removed.
5. Remove the flow rate switch stopper to avoid the operator from using automatic refueling and making motions that generate electrostatic charge.
6. Use rags with anti-static materials, and frequently replace them.
7. Maintenance personnel, workers and executives should take training for electrostatic hazards prevention.

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