FINE NOZZLE CHARACTERISTICS FOR INCREASING FILTRATION EFFICIENCY IN COMMERCIAL KITCHEN HOOD VENTILATION SYSTEM

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ABSTRACT

Water mist sprays were used in wide range of application. It depends on the spray characteristic to suit a particular application. The modern commercial kitchen hood ventilation system was adopted with the water mist nozzle technology as an additional tool to increase the filtration efficiency. However, low level of filtration effectiveness and high water consumption were the major problems among the Commercial Kitchen Ventilation specialist. Therefore, this study aims to develop a new mist spray technology and investigate the flow characteristics in commercial kitchen hood system. At the same time, an appropriate recommended location to install the nozzle in kitchen hood system was suggested. An extensive simulation and experimental works were carried out to observe the flow pattern and spray characteristics, ANSYS (FLUENT) was used for simulation wise. Meanwhile, an experiment was conducted using Particles Image Velocimetry (PIV) to verify the spray simulation result. The boundary condition for kitchen hood simulations was set in the range of 0.235 m/s and 1.078 m/s for plumes and capture jet velocities respectively. In the case of nozzle studies, five nozzles were tested with various conditions; 1 bar (case A), 2 bar (case B) and 3 bar (case C). The results of the flow pattern in commercial kitchen hood system shows that, the highest velocity of plumes have more tendencies to flow pass through at the lower part of the filter. However, all the plumes remains covering the entire filter surface. Meanwhile for the nozzle studies, the novelty were each nozzle was able to produce water droplet size less than 2.5 micron and penetration length more than 750 mm under low pressure supply, which is in a range of 1 bar to 3 bar. Moreover, in comparison with conventional nozzles configuration, this new approach suggested nozzle configuration was reduce up to 50% of water consumption, which by adopted 3 numbers of nozzles instead of 6 numbers of nozzles in the commercial kitchen hood system. Therefore, this nozzle will be used in industry for their benefits of water consumption, filtration efficiency and reduced the safety limitations.
ABSTRAK

Semburan kabus air digunakan secara meluas dalam pelbagai aplikasi. Walau bagaimanapun, ia bergantung kepada ciri-ciri semburan yang sesuai untuk kegunaan tertentu. Sistem hud dapur masak yang moden telah mengadapertasikan teknologi semburan kabus air sebagai medium tambahan untuk meningkatkan kecekapan penapisan. Walau bagaimanapun, kecekapan yang rendah dan penggunaan air yang tinggi menjadi masalah utama yang sering dibincangkan oleh pakar sistem hud dapur. Oleh itu, kajian ini bertujuan untuk membangunkan teknologi semburan kabus dan mencadangkan lokasi yang sesuai untuk memasang sistem semburan tersebut.

Perisian ANSYS (FLUENT) digunakan untuk proses simulasi manakala Particle Images Velocimetry (PIV) digunakan untuk menentukan keputusan simulasi di dalam kajian ini. Halaju wap masakan di laraskan pada kelajuan 0.235 m/s dan halaju Capture Jet di laraskan pada kelajuan 1.078 m/s. Di dalam kes kajian semburan halus, terdapat lima jenis Nozzles telah diuji di dalam tiga keadan iaitu 1 bar (Case A), 2 bar (Case B) dan 3 bar (Case C). Berdasarkan kajian, jelas kelihatan wap masakan yang mempunyai halaju yang tinggi cenderung untuk melalui bahagian bawah sistem penapis KSA. Walau bagaimanapun wap masakan masih lagi kekal meliputi keseluruhan permukaan penapis. Sementara itu, bagi kajian semburan halus, terdapat kelebihan yang didapati di dalam kajian ini, iaitu setiap Nozzles berkebolehan dalam menghasilkan saiz titisan air kurang dari 2.5 mikron dan jarak semburan melebihi 750 mm, yang mana ia dihasilkan pada tekanan rendah pada julat 1 bar hingga 3 bar. Selain itu, dalam membuat perbandingan terhadap kongurafi susunan Nozzles sediada, dengan menggunakan Nozzles baru ini dan penyusunan konfigurasi baru, ianya berkebolehan mengurangkan penggunaan air sehingga 50%, yang mana dapat dicapai dengan menggunakan hanya 3 unit Nozzles berbanding 6 unit Nozzles seperti pada sistem hud dapur sediada. Oleh itu, pendekatan ini berdaya maju untuk digunakan di dalam sektor industri untuk faedah penjmatan air, kecekapan penapisan dan mengurangkan batas keselamatan.
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<td>--------</td>
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<td>m</td>
<td>Metre</td>
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<tr>
<td>s</td>
<td>Seconds</td>
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<td>K</td>
<td>Kelvin</td>
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<tr>
<td>°C</td>
<td>Celsius</td>
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<td>µm</td>
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<td>ms</td>
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<td>m/s</td>
<td>Metre per seconds</td>
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<tr>
<td>bar</td>
<td>Pressure Bar</td>
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<td>kg/liter</td>
<td>Kilogram per litre</td>
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<td>kg/s</td>
<td>Kilogram per seconds</td>
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<tr>
<td>kg/m³</td>
<td>Kilogram per cubic metres</td>
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<td>g/cm³</td>
<td>Gram per cubic centimetres</td>
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<tr>
<td>Ø</td>
<td>Diameter</td>
</tr>
<tr>
<td>D</td>
<td>Diameter</td>
</tr>
<tr>
<td>L</td>
<td>Length</td>
</tr>
<tr>
<td>P</td>
<td>Density</td>
</tr>
<tr>
<td>V</td>
<td>Normalised volume flux</td>
</tr>
<tr>
<td>A</td>
<td>Area</td>
</tr>
<tr>
<td>Q</td>
<td>Volume flow rate</td>
</tr>
<tr>
<td>K</td>
<td>Orifice coefficient</td>
</tr>
<tr>
<td>m</td>
<td>Mass flow rate</td>
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mL - Milliliter
Re - Reynolds Number
We - Weber number
$V_{exit}$ - Averaged flow velocity of nozzle exit
$D_{32}$ - Symbol represent Sauter mean diameter
$D_p$ - Normalised droplet density
$i$ - Size range considered
$N_i$ - Number of drops in size range $i$
$D_i$ - Middle diameter of size range $i$
$\sigma$ - Surface tension
$k – \varepsilon$ - K-epsilon
CKV - Commercial kitchen hood ventilation
Vol - Volume
CTM - Continuous Thermodynamics
CFD - Computational Fluid Dynamics
DNS - Direct Numerical Simulation
SST - Shear Stress Transport
LES - Large-eddy-simulation
PIV - Particle image velocimetry
RANS - Reynolds-Averaged Navier-Stokes
DSLR - Digital Single Lens Reflex
VOF - Volume of fluid
TKE - Turbulence kinetic energy
SMD - Sauter mean diameter
TAB - Taylor Analogy Breakup
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CHAPTER 1

INTRODUCTION

1.1 Research background

The use of kitchen hood has been widely used especially in hotels and restaurants. In general, commercial kitchen hood was initially served only to filter out the plumes during cooking activities. It is the consequences of cooking activities that generate heat and effluent which are very dangerous to human health. Thus, both heat and effluent must be captured and exhausted from cooking area in order to control odour and thermal comfort in cooking space. Therefore, commercial kitchen hood function improves from day by day, due to the addition of new technologies to the kitchen hood designs that resulted in a more efficient system. The global environmental changes and global warming effects have become a serious and major interest in research society. In order to face the new challenges in the new century, reduction of harmful gases and improvement of burner system needs to prioritize [1]. The burner system is a unique, patented and high-efficiency system that works with a specially designed oil burner to create ultra-efficient combustion which consequently will reduce oil usage and greenhouse gases as well as other harmful emissions.

A Professional Commercial Kitchen Ventilation is a very challenging and demanding environment. Ventilation plays an important role in providing comfortable and productive working conditions as well as in securing contaminant removal [1]. This can be described as the exhaust hoods and make-up air system is the “lungs” of the kitchen. Exhaust hoods exhale contaminated air from the cooking area while simultaneously inhaling a fresh supply of outdoor air back into the kitchen. Unfortunately, when the exhaust hood fails to remove the heat and smoke generated by the appliances and the plumes all at once, or when the replacement of air inside the kitchen area is not adequately supplied, the kitchen area becomes
suffocated. To benefit from a profitable and successful operation, the ventilation system first needs to be considered more globally than the simple fact of exhausting and renewing the air of the kitchen space. This will systematically interact with other spaces or systems. The best example of this interaction is the basic kitchen concept. There are 4 cornerstones that have to work all together:

i. Energy Efficiency
ii. Indoor Environment Quality (IEQ)
iii. Safety Air
iv. Purification.

1.2 Problem statement

High level of emission emitted from the cooking activities is very dangerous to the human health. Nowadays, production of kitchen exhaust ventilation focused mostly on environmental comfort, contamination, waste treatment and emissions reduction in an exclusive kitchen environment. Due to demands from the clients and strict regulations, the manufacturer was keen to implement sustainable and integrated green technology, to the existing products and client solutions. Among the issues associated with the proposal were listed as follows:

i. Significant challenge faced by commercial restaurants on labour shortage. The low popularity of kitchen workers was mainly due to the unsatisfactory thermal conditions.

ii. Strict requirements set for indoor air quality, the comfort of customers and the health of personnel.

iii. Significant amount of smoke generated in a very short time when heavy cooking equipment was installed (grills, char broilers, Teppanyaki table etc).

iv. Thermal comfort is a state where a person is satisfied with the thermal conditions. The International Organisation for Standardisation (ISO) specifies such a concept as the predicted percentage of unsatisfied occupants (PPD) and the predicted mean vote (PMV) of occupants. PMV represents a scale from -3 to 3, increasing from cold to hot, with 0 being neutral as shown in Figure 1.1. PPD tells what percentage of occupants
was likely to be dissatisfied with the thermal environment. These two concepts take into account four factors affecting thermal comfort.

![Figure 1.1: PPD as a function of PMV][2]

Due to the rising issues listed above, manufacturer implemented a water mist spray nozzle as an additional tool which used nontoxicity fluids (water) to be used in the kitchen area. Since the nozzle is utilised in a premise, thus the nozzles which produces a fine mist spray in low pressure condition is a major factor in consideration. Halton Company has selected a nozzle which complies the concept of deflector atomizer. This nozzle functioned as the first stage filtration system to trap the plumes before it passes through the second stage filtration system. However, there are still some weaknesses on the spray characteristic which affects the filtration efficiency. The conventional nozzle generated course water droplets, which resulted in the reduction of collision between water droplets and plumes. This will eventually leads to the reduction of filtration efficiency. Since the filtering system fails to capture the contaminant below the size of 2.5 micron, the targeted mist droplets size to be produced must be in the range of 1 micron to 3 micron.

Moreover, the angle and spray penetration also plays an important role in improving the filtration efficiency of the system. As a conventional nozzle adheres to the concept of deflector wall, it’s usually sprayed pointing downwards, causing the restricted in limitation of nozzle configuration. For this commercial kitchen hood ventilation case, 6 units of nozzle is required to ensure that entire surface of filter is fully covered. This configuration limitation will lead to water consumption issues. Therefore, it is required to discover an appropriate nozzle design and it’s
characteristic (water droplets size, water droplets velocity, spray angle and spray penetration) for new development of new mist spray.

1.3 Objective

The objectives of the study carried out were as follows:

To develop a new liquid/gas-spray filtration system for Halton hoods system with low water/energy consumption (maintenance costs) and higher grease filtration efficiency. Whereas, the capability of the new development of nozzle is measured based on the ability to produce good spray characteristic; fine water droplets size, spray penetration, spray angle to increase the filtration and reducing water consumption by using a fewer number of nozzle compared to current design.

Summarised main targets were:

i. To develop a mist nozzle under low pressure condition.
ii. To study the capability of the spray to cover filter surface.
iii. To produce fine mist spray to increased filtration efficiency.
iv. Effectively to decrease water consumption.

1.4 Scope

This thesis was divided into two simulation sections. The first part was a simulation of commercial kitchen hood system, while the second part was a simulation of the nozzle model. Five nozzles were tested in order to identify the effects of the blockage ratio to the water droplet velocity, water droplet diameter and angle of penetration. The commercial kitchen hood system was simulated in order to understand the flow characteristic of the air and to observe the critical location. Air and water were used as working fluids in the nozzle simulation. Meanwhile, for commercial kitchen hood system, the only air was used as working fluids. The outcomes generated by each nozzle and commercial kitchen hood simulations were analysed by using ANSYS software. The Particle Image Velocimetry (PIV) was used in the experimental section to observe the velocity of the water droplet. At the end, experimental data were validated using simulation data on the nozzle spray. Summarised list of scope involved was as follows:
a) Commercial kitchen hood ventilation system
   - 2D simulation on commercial kitchen hood system.
   - Water wash/Water mist kitchen hood system.
   - Air was used as a working fluid.
   - Three different air velocities were tested which were 1.071 m/s, 0.871 m/s and 0.671 m/s.

b) Mist nozzle system
   - 3D simulation of mist nozzle.
   - 5 nozzles tested namely nozzle A, nozzle B, nozzle C, nozzle D and nozzle E, each with blockage ratio of 0.316, 0.237, 0.158, 0.079 and 1.
   - Water and air were used as working fluids.

c) Experimental model
   - 2D analysis using Particle Image Velocimetry (PIV) to observe the particles’ velocity and trend of the water droplet.

1.5 Significance of study

The purpose of installing kitchen exhaust ventilation at the workplace is to provide better air quality by capturing moisture and airborne contaminants created during cooking activities. Although it helps to produce good air quality in a kitchen space, but indirectly, it also contributes to the environment pollution. These phenomena happened because of the low level of filtration efficiency, thus small contaminants which fail to be filtered were directly discharged out through the hood. The filtration efficiency was measured based on the capability of the water mist spray generated by the nozzle to cover the entire surface area of the filter. Therefore, this thesis aims to develop a new mist spray technology along with good spray performance such as length of spray penetration, droplets size and spray angle. The best spray performance selected was then proposed for appropriate installation location of the nozzle particularly to increase the filtration efficiency while reducing water consumption and at the same time, overcome the environmental pollution created during cooking activities. Providing water mist spray technology helps to trap small contaminants before being vented out to the atmosphere.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Particles such as dust, mists, gases, vapour, and fumes are the most common organics which humans heavily exposed to due to extensive use of the kitchen. Exposure to such particles mentioned above can cause health effects [3]. An effective way to this problem was by the installation of Kitchen Exhaust Ventilation (KEV) at the kitchen area. KEV captured airborne particles close to the source of emission. It was generally achieved by means of an exhaust hood, ducting, air cleaner, fan and discharge which remove particles before they had a chance to escape in the kitchen. KEV was used in the industries in order protect workers from exposure to particles at their workstations. The principle of KEV system is the adoption from Local Exhaust Ventilation system which known as LEV system. With LEV system the general worker will need to use respiratory protection factor 5 and 10. However, without the LEV system, the workers need to use respiratory that has a protection factor more than 10, resulted in an overall exposure reduction of 92% [4].

Previous studies had shown that pressure swirl atomiser was vastly used in high viscosity liquid spray which was able to convert pressure energy of the liquid into kinetic energy by increasing liquid velocity. The design on swirl atomiser was created by using tangential cylinder or disc compartment in the atomiser. The tangential velocity component such as liquid velocity provided the possibility of pumping pulsating energy into the turbulent flow. Pressure swirl atomiser with 21 bar pressure and bigger exit orifice provided solid cone spray using water [5]. The pressure swirl atomiser was accepted as the most efficient method for producing fine spray using pressurized liquid for a given flow rate. This method requires the minimal supply pressure to provide a given drop size with full cone spray.
Symmetrical spray pattern was an important variable in industries such as painting, coating and rescaling. There were three types of spray patterns that were commonly used in the industry namely hollow cone, full cone and flat spray pattern. These spray patterns mainly depended on the internal geometry and flow within the atomiser. Figure 2.1 shows some applications which depended on sprays pattern.

<table>
<thead>
<tr>
<th>TYPE</th>
<th>DESCRIPTION</th>
<th>DROP SIZE</th>
<th>COMMON USES</th>
<th>TYPICAL APPLICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydraulic</td>
<td>Circular ring of</td>
<td>Small</td>
<td>Used in areas where dust is widely dispersed</td>
<td>Transfer points, Transport roads, Jaw crushers</td>
</tr>
<tr>
<td>hollow cone</td>
<td>water</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydraulic</td>
<td>Tapered edge,</td>
<td>Small to</td>
<td>Used in narrow or enclosed spaces</td>
<td>Stockpiles</td>
</tr>
<tr>
<td>flat fan</td>
<td>rectangular or even</td>
<td>medium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydraulic</td>
<td>Round pattern</td>
<td>Medium to</td>
<td>Used in areas where nozzles must be located a good distance from the dust source</td>
<td>Stackers, reclaimers, Transfer points</td>
</tr>
<tr>
<td>full cone</td>
<td>spray</td>
<td>large</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Air atomizing</td>
<td>Round, full or flat</td>
<td>Very small</td>
<td>Used in enclosed areas to minimize drift</td>
<td>Jaw crushers, Loading terminals, Dump hopper, Transfer points</td>
</tr>
<tr>
<td>Hydraulic</td>
<td>Round pattern or</td>
<td>Very small</td>
<td>Used in enclosed areas to minimize drift and when a light fog is required</td>
<td>Stackers, reclaimers, Stockpiles, Jaw crushers, Loading terminals, Dump hopper</td>
</tr>
<tr>
<td>fine spray</td>
<td>circular ring</td>
<td></td>
<td></td>
<td></td>
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</table>

Figure 2.1: Application of spray pattern [6]

Spray cleaning systems were often thought of in terms of grease extraction efficiency. In fact, this type of system has little or no impact on the grease extraction efficiency of the hood. It is a system that facilitates cleaning of the filters. The basic premise of a spray cleaning hood was the ability to “wash down” the exhaust plenum within the hood as well as technical grease extraction device as shown in Figure 2.2. A secondary benefit was said to be an aid to fire suppression. Spray cleaning hoods exist in a variety of configurations, as far as hood geometry goes. In order to improve the existing design of KEV in ensuring high efficiency, performance and verification, the new KEV system employing spray cleaning technique was suggested. The effectiveness of the system was evaluated with the aid of Computational Fluid Dynamics (CFD) simulation and later on through experimental validation.
2.2 Commercial kitchen hood

Cooking process emitted ultra-fine particles that were very dangerous to human health. It was mainly because of the size of the particle ranging from 0.006-20 μm [8] that was too small. Thus, in order to assess health risk due to exposure from the particulate air pollution, engineers has introduced kitchen hood ventilation.

The objective of the kitchen hood was to capture moisture and airborne contaminants known as a plume which was created during cooking activities [9]. Exposure to particles emitted by cooking activities may be the sources of variety repertory health effects [8]. Hence, providing kitchen hood ventilation system at kitchen area helped to capture the plumes and further on vent out from the building [10]. If convective heat was not removed directly from the cooking equipment, the impurities will spread throughout the kitchen and will cause discoloured ceiling tiles as well as greasy countertops and floor [9]. Ventilation was the most important factor in the design of kitchen hood. An effective commercial kitchen ventilation (CKV) system requires balance air which was called "Balancing Act" [11]. The balancing act is a phenomenon occurred when air existed in the building must be replaced with outside air that enters the building. If the replacement air did not occur, there is a strong likelihood that the kitchen hood had a problem [11].
2.3 The Hood Factor-Capture and Containment.

Commercial kitchen hood is the device used to capture heat plumes that were emitted from the cooking equipment through cooking activities. In this system, the most important part was the exhaust part. To allow the exhaust air flow for fully captured and containment the cooking effluent depended on the hood style and its construction features. There are various types of hood canopies such as island (single or double) canopy hood, wall mounted canopy hood and proximity hood. Each hood had different captured areas and mounted at different heights and horizontal position relative to cooking equipment [12].

![Figure 2.3: Type of kitchen hood style [13]](image)

2.4 Cleaning System

In Commercial Kitchen Hood system, there were a few methods applied as additional tools to increase the filtration efficiency. KSA filter, Ultra violet (UV) light technology and mist nozzle technology were parts of the cleaning system.
2.4.1 Grease extraction through KSA filter

According to the University of Minnesota, grease is comprised of a variety of compounds including solid and/or liquid grease particle, grease and water vapours, as well as a variety of non-condensable gasses including nitrogen oxides, carbon dioxide, and carbon monoxide [2]. Cooking activities produced variety types and sizes of particulate air pollution depended on the types of food and appliances being used. The particles’ sizes vary from 0.006-20 μm [8]. The entire plume arises and was then trapped in the filter.

Nowadays, the installation of grease filter at commercial kitchen hood is the best solution with the purpose to extract greases emitted through cooking activities. The purpose of mechanical grease filter was to provide fire protection by preventing flames from entering the exhaust hood and ductwork. At the same time, it acts a mean of removing large grease particles from the exhaust stream. The more greases that were extracted, the longer the exhaust duct and fan remain clean, resulting in better fire safety. There were two standard types of grease filter in the market which were, baffle filter and multi cyclic filter [13]. From a practical standpoint, grease filters should be easily clean and non-cloggable. This is to avoid the increasing of pressure drop across the filter and the decreasing of exhaust airflow which will affect the system efficiency. Figure 2.4 shows the graph of total grease emissions versus different types of cooking appliances. Figure 2.5 shows the graph of grease composition versus different types of cooking appliances [14].

The topic of grease removal has been widely discussed among engineers; it was still under research to produce better grease removal technique. The filter in kitchen hood ventilation system was developing from time to time and the role was different between standards and building codes. The USA has been one of the leading countries in grease emissions research, hence lots of research work started after publishing the Clean Air Act in 1970. This causes the rising of attention paid to understanding and reducing the sources of air pollution [15].
The filtration system was divided into two categories, namely single-stage filter and two-stage filter. Single-stage filter normally uses fibre media as the filters in the overall ventilation market. However, this fibre media was not suitable for commercial kitchens. Fibre media was not suitable for the commercial kitchen because of poor fire prevention, relatively poor in grease capture and disposable after a single used period. These were the benchmark of a good filter as shown in Figure 2.6 [16].
The 3 most popular single stage filters used in industry were baffle filter, water wash filter and dry cartridge filter. Each type has simple work principle. For example, vanes in baffle filter were united to redirect the exhaust flow and throw grease droplets against a surface to collect them. On the other hand, baffle filter and dry cartridge filter has the same function. However, baffle filter has slight deficiency compared to dry cartridge filter.

The efficiency of filtration system was measured based on how much the particles captured by the filter. Low captured efficiency leads to problems in the ducting system. For example, when the filter captured only large particles of plumes while small impurities flow through the ducting and stick to the ducting wall, the ducting system requires cleaning services. In fact, these phenomena will disturb the performance of the whole system where the cost for the maintenance of the hood increases. Another approach to increase the filtration system was by conducting some modification to the baffle filter itself. Figure 2.7 shows an example of baffle filter.
The multi-stage air filters system was the new development approaches for the filter, towards a better result for grease removal system. Two stages filters work much better compared to single stage filters. The combination of two baffle filters formed new abilities, hence increases the efficiency of the filtration system [15]. Since two-stage filters were designed using standard width, it was possible to apply them not only to new systems but also at the existing single-stage filters without any difficulties. In a two-stage filter, the first stage works simply as one stage filter, where the main purpose of was to collect large grease and acted as fire prevention [15]. Second stage filter was used to collect small grease droplets missed from the first stage. Wet grease was captured by media’s surface and was drawn into its pores by capillary action, thereby extending run-time [16].

Figure 2.8 shows the particles flowing through a baffle filter, where the particles were trapped at the filter depended on the range of size from 1 μm to 7 μm. Computational fluid dynamics methods were used to compare the flow simulations through a primary stage. This method was made by ASHRAE [16]. From Figure 2.8, the droplets with 1 μm size passed the filter easily compared to particle with the droplets size 5 μm, 6 μm and 7μm, concluding that at this stage, almost all particles with 7 μm will be trapped easily [18].

A study on filter efficiency was conducted by Halton on a variety of filters. The three difference types of filter selected were Halton KSA filter, generic baffle filter I and lastly baffle filter II [14] as shown in Figure 2.9.
By comparing the performance of all filters at the same airflow, the result in Figure 2.10 below shows that none of the mechanical filters were effective in capturing particles less than 2.5 μm in size. From the graph, it shows that Halton’ KSA filter trapped at least twice the amount of grease compared to the top rated baffle in a particle size ranging from 2.5 μm to 10 μm at the exhaust airflow of 200 cfm/ft. The efficiency of grease removal devices varies with the filter design [14].
2.4.2 Ultraviolet (UV) Light Technology

Ultraviolet (UV) was the most common form of electromagnetic radiation (EMR) that average person was exposed to. UV technology has been known since 1800's, where it has been utilised in hospital, waste water treatment plants and various industry applications [2]. Halton has been the leading company in commercial kitchen ventilation technology which has developed a new technology to harness the power of ultraviolet technology in kitchen hood system. UV light was divided into 3 categories which were [2]:

i. UVA - ultraviolet A radiation (closest to the wavelengths of visible light)

ii. UVB - ultraviolet B radiations (shorter and more energetic wave)

iii. UVC - ultraviolet C radiations (shortest of the three ultraviolet bands and was used for sterilisation and germicide applications)

In commercial kitchen ventilation systems, UV light has been added to the system as an agent to react to the plumes and reduce or eliminate the grease emissions on the exhaust ductwork, exhaust fan as well as on the roof of a building. UV light was not grease extractor but rather as grease conversion device. This section provided an overview of what UV technology does and how it interacts with the mechanical extraction system [14]. A general overview of how Halton’s UV technology was implemented is shown in Figure 2.11.
2.4.2.1 UV Chemical Reactions

Ultraviolet light reacted to small particulate and volatile organic compounds (VOC) generated during cooking activities in two ways, either by exposing the effluent to the light or by the generation of ozone (UVC) [2]. Ozone was created when monatomic oxygen reacted with oxygen molecules and water vapour [15]. Normally, cooking activities generate fatty substance consists of double bonds, which were more reactive than any single bonds. Thus, to break the bonds, light and ozone were used to attack these double bonds and consequently break them [2]. The chemical processes which took place when UVC directly hits molecular chains and breaks them into smaller compounds was called Photolysis as shown in Figure 2.12 [14].
Figure 2.12: Photolysis which was chemical breakdown of the grease molecules by photons [19].

The photolysis reactions were most effective on small grease particles (especially vapor) since the light can only break the chemical bonds on the outer surface of large grease particles. The second chemical process that took place was when the ozone, created from the interaction of the UV light with the oxygen molecules in the air, continues to react with grease molecules as they move through the exhaust duct and released to the atmosphere. This process was called Ozonolysis. The ozonolysis reactions continue until either all of the ozone has reacted or exits the exhaust duct work.

Even though UV light technology is the best method to demised the cooking plumes contaminant, this method leads to cost issue among the clients. Thus, to overcome this problem, commercial kitchen hood manufacturer introduced the water mist technique to the commercial kitchen hood system.
Figure 2.13: Ozonolysis which was the oxidation of VOC and part of odours by the ozone generated using UVC lamps [19].

2.4.3 Mist Spray

The term "water mist" was referred to a very fine particle of water sprays in which 99% of the volume of the spray was in drops with diameters less than 1000 microns and remain suspended in the air for an extended period of time [20]. Typically, the droplets were much smaller, with diameters in the range of 20 micron to 500 micron, in which depended on the water pressure and the method used to generate the droplets [21].

In the commercial kitchen hood system, water mist nozzle was used to produce water mist droplets and formed a layer just in front of the filter. The water droplets will trap the plumes contaminant by colliding with each other before drained. Another advantage of using water mist nozzle was that it works as a cooling agent in the kitchen area and nontoxicity liquid.

However, there was still an issue to implement this method which was related to water consumption. Nowadays, the used of water mist system was still under research in order to understand and find the ideal condition to implement with the particular application.
2.5 Water Mist

The first finding of the application on the water mist was during 1950's and 1960's about water mist fire protection system [22]. The water mist system was rather cheap and effective system compared to the available system such as conventional sprinklers and halon gaseous agent water [23]. The principle of this system was by applying high pressure to the water to generate very fine droplets of water and delivered them to the fire zone. In fact, due to its high specific heat and heat of evaporation, with the increases of surface area will allow faster heat absorption [24]. Technically, the mist system raised concerns due to the high pressures required to produce a fine spray, where there is a potential for blocking of the small orifice nozzles and doubts the long-term ability to maintain the equipment [20]. Moreover, this system have both advantages and disadvantages which were listed as below [25].

The advantages are:

i. Replacement for halon and CO$_2$ system in many applications.

ii. Safer than CO$_2$

iii. Cools the fire area drastically.

iv. Used less water than conventional sprinklers.

v. Prevent reignition.

vi. Has some smoke scrubbing qualities.

vii. Can be used to suppress explosions.

The disadvantages are:

i. More expensive.

ii. Less effective against small fire.

iii. Required greater water pressure than conventional sprinkler systems and required the use of compressed gas with high-pressure pumps.

iv. New technology with uncertainty existed as to how to evaluate such systems

v. Fire and component testing was required to verify that water mist was effective for a particular hazard.

vi. Slower to extinguish fires than gas system.
By comparing sprinkler spray with fine water mist spray, water mist spray installed with several of the following fire suppression mechanisms depended on the nozzle design to determine the operating pressure and flow [24].

i. heat extraction.

ii. oxygen level reduction.

iii. radiation blocking.

2.5.1 Heat Extraction

Water have high specific heat and heat of vaporization, which acts as an excellent heat extraction. Figure 2.14, shows that the energy absorbed by the water during heating occurs during liquid to gas phase change [26]. Moreover, in comparison to other extinguishing agents, water has higher effective value as heat absorption agent followed by CO₂, IG-541, HCFC Blend A, Nitrogen, Argon, Halon 1211, HFC-227ea and lastly Halon 1301. The absorption area was divide into three areas which were hot gases and flame, fuel and the surrounding object and surfaces [20]. According to the previous study, it is not necessary to extract all of the heat from the reaction. Absorption between 30% to 60% may be enough to reduce the risk of burning [27].

Figure 2.14: Heat absorption during heating and phase change of water [26]
2.5.2 Oxygen Displacement

An important mechanism for fire suppression was oxygen displacement in the compartment, which was needed to reduce the amount of oxygen. Typically, 7 to 13% oxygen was reduced in the compartment. Thus, the fire can be easily extinguished [20].

2.5.3 Radiant Blocking

The presence of fine water droplets effectively absorbs and disperse the heat produced by the fire. At the same time, this mechanism assisted in suppressing the fire by reducing the feedback to the fuel surface and hence reducing the pyrolysis rate [23].

2.5.4 Droplet Size

Water droplets size was the interest in dealing with the mist spray. This was because of the water droplet size being produced greatly affects the spray behavior. The water droplets show that the spray will interact with the fire and which of the extinguishment mechanisms such a heat extraction, oxygen displacement and radiant blocking [23]. Figure 2.15 below shows the spectrum of drop sizes from 0.1micron to 1000micron in relation to everyday occurrences.

Figure 2.15: The spectrum of drop sizes from 0.1micron to 1000micron [28]
The most common single figure identifiers describing the size of single particle used were as listed below [29]:

i. Arithmetic mean: A simple weighted average based on the diameter of all individual drops in the spray.

ii. Surface mean: The diameter of a drop whose surface area, if multiplied by the total number of drops, will equal to surface area of all the drops in the spray sample.

iii. Volume mean (Dv50): The diameter of a drop whose volume, if multiplied by the total number of drops will be equal to the total volume of the spray.

iv. Sauter Mean Diameter (SMD): Also known as the volume surface mean. The diameter of a drop whose ratio of volume to surface area was equal to that of the entire spray sample.

2.5.5 Water Mist Applications

The water mist technology was still under research over the last decade. Few applications of water mist have been divided into different categories of different types of fire. Class A was fire ignited in residential occupancies, marine accommodations, public spaces, heritage buildings and libraries. The fire ignited pool fires in machinery spaces, gas turbine enclosures, combat vehicles and flammable liquid storage room was categorized in Class B whereas for Class C fires in electronic equipment, computer room, aircraft onboard cabin and cargo compartment. The last class was Class K where the fire ignited in commercial cooking rooms [30].

Water mist applications in many areas still continued to expand in research. New findings of applications of a water mist fire suppression system were for the protection of commercial cooking areas. It was found by a group of researcher from The National Research Council of Canada with collaboration with fountain fire protection inc [31]. They found that the cooking oil in cooking areas were the most difficult fires to be extinguished because they burnt at a high temperature and reignite easily. This type of case cannot be effectively extinguished by form powder or carbon dioxide. Normally wet chemical agent was used in cooking areas [30].
The National Research Council had evaluated the extinguishing performance of water mist against the cooking oil fires in the cooking area. The water mist can effectively extinguish and cool cooking oil fires [30]. In term of cost, water mist was the lowest cost compared to other agents. Moreover, it is effectively cooling, nontoxicity, less water requirement, less water damage and less clean up time [30]. The primary challenge in restaurant cooking area was fat or cooking oil fires [31], which were hard to extinguish and easy to reignite [32].

The application of water sprays as an alternative method for fire control was discussed intensely. For more effective heat extraction, rapid evaporation of water droplets occurred when smaller size of water mist droplets were used. Larger surface area of the droplets contributes to this phenomenon. At the same time, combustion can be slowed down by diluting the concentration of oxygen using mist vapor. Pyrolysis of fuel vapor can also arrest combustion from spreading. Furthermore, water mist acted as thermal radiation blocker which pre-wet the combustibles at the surrounding to delay the ignition and lowers the temperature [33].

Currently, a wet chemical agent was the primary tools used to extinguish grease fires in the cooking area. However, this chemical caused irritation to the skin and eyes [31], as well as required high cost. The used of a LA water mist system for extinguishing cooking oil fires was studied [34]. There were requirements for water mist characteristic such as discharge pressure, flowrate, spray coverage area and nozzle location in order to extinguish a cooking oil fired [35]. A very fine spray sprays with low momentum and the low mass flow rate was ineffective to extinguish small fires occuring in the electronic equipment [35].

Not only in the kitchen space, water mist spray was used in the industry that dealing with dust problems. The dealing with dust was no longer optional in most regions of the world but when it comes to dust control systems, options abound. The water mist wet spray systems offer significant advantages over ventilation/exhaust systems or structural enclosures. The advantages of the wet spray were [36]:

i. Highly effective
ii. More economical to operate
iii. Quickly installed and offer straightforward operation
iv. More durable
v. Reliable and offer consistent performance with routine maintenance.
It was important to understand the principle of dust prevention and dust suppression technique, even both systems used moisture as agents to react with the dust. Dust prevention increased the humidity/moisture in a material to prevent dust from becoming airborne as shown in Figure 2.16. Dust suppression humidity/moisture was added to the air to capture dust particles that were already become airborne [37].

![Dust Prevention and Dust Suppression Diagram](image)

**Figure 2.16:** Moisture was added directly to the material and airborne dust particles were also captured by sprays [36]

This technique can be very effective to control the dust because of the collision concept between water droplets with dust particles. It can be seen in Figure 2.17, if the drop diameter was larger than the dust particle diameter, the dust particle will follow the air stream around the drop without any collision (left) but if the drop diameter was smaller compared the dust particle, the drop will follow the air stream and collide while evaporate quickly and release the captured particles [36]. However, the greatest chance for suppression occurs when the diameter of the drop size and dust particles were comparable. Moreover, dust suppression was most effective in areas where there was little air turbulence [36]. After understanding the principle of the water mist droplets, it is important to know the concept on how to produce water mist droplet which also known as spray.
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