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EXPERIMENTAL STUDY OF GREASE EMISSION FILTRATION FOR KITCHEN HOOD BY WATER MIST

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ABSTRACT

In this study, water mist spray operation are applied to control the emissions produces from cooking smoke and to reduce the temperature inside of the ductwork. A full scale of experiments was performed to investigate the effect of water mist spray on grease emission filtration in kitchen hood. Continuous measurement of temperature, pressure drop, and generations of TVOC at specific locations were made at average 8 hours and 15 minutes under grease load using grease generator designed based on UL 1046 Standard. For comparison, parameters were measured from3different types of test conditions which are without cold mist operation, with cold mist operation, and KSA filter exhaust plenum. The water mist activation have significant effects to filter the grease emissions contains particles size more than 10 μm and to decrease the temperature of the kitchen exhaust plenum and ducts 35 % and 2.5-6.2 % respectively.

Keywords: water mist, kitchen hood, grease emission, filtration, pressure drop, TVOC, temperature.

INTRODUCTION

Cooking activities from charcoal and char broilers produce high heat loads and large amount of grease emission that contains fats, oils, and grease (FOG). This high heat loads may increase the temperature inside the ductwork and potentially increase the fire risks. Generally, in heavy-duty cooking appliances grease deposits are combined with high heat temperatures and even spark that could lead to explosive cocktails inside the kitchen hood plenum and ductwork. Grease emission emitted from typical cooking process and enters the kitchen ventilation system consists the combination of particulate and vapour (Livchak *et al.*, 2003).

As been known cooking activities create high concentration of aerosol indoors. Emission generated lead to one major indoor particulate pollutant that significantly affect air quality and increase risk to human health. Typical asian, mediteranian, and western cuisine from cooking process creates high grease emission which in the form of particulate and vapour (Abdullahi, Delgado-Saborit, and Harrison, 2013; Zhao *et al*., 2014).

Water mist

Numerous of research studiedon the effectiveness of water mist spray for smoke control, suppress fire, and cooling system (Pan *et al*., 2011; Tianshui *et al*., 2014; Yamada *et al*., 2008). If several parameters are controlled with adequate water mist flow rate, nozzle type, and spray height and distance between nozzles, it would give better results in emission control, cooling effect and fire suppression.

Water mist spray system canwidely used to control emission from cooking smoke and for safety purpose. Fresh cold water was used as working fluid in cold mist system and work as mist curtain inside the exhaust plenum of the kitchen hood. The smoke produces from heavy duty cooking appliances which are contains the combination of high temperature, particulates, and vapor is forced to pass through the mist curtain at specified exhaust air flow rate and its depends on the hood length.

Theorically, water mist spray curtains will capture the airborne particles and reduce the smoke temperature inside the exhaust plenum of kitchen hood. The temperature drop of the smoke layer (contains particulate and vapor) will cause the grease particle to solidify and increase in size and finally separated from the smoke and drop to drainage located inside the exhaust plenum. Mist curtain from water mist spray also can work as spark arrester from entering the exhaust plenum to reduce the fire risk and decrease the temperature inside exhaust plenum and duct.

Grease emission

During cooking activities it's emitting numerous amounts of grease and water vapors, non-condensable gases (CO, CO_2, NO_X), various other gases, and particulate organic matter (POM). Grease vapor consist hydrocarbon compounds and can be turns into Volatile Organic Compounds (VOC), Very Volatile Organic Compounds (VVOC), Semi-Volatile Organic Compounds (SVOC) depending on its boiling point range(Gerstler *et al*., 1996; Shevchenko, 2012; Berglund *et al*., 1997). Grease particles size range produced during cooking activities can be categorized into three composition structure which are sub-micron (0.03 to 0.55 μm), steam (0.5 to 6.2 μm), and spatter (6.2 to 150 μm) (Shevchenko, 2012).

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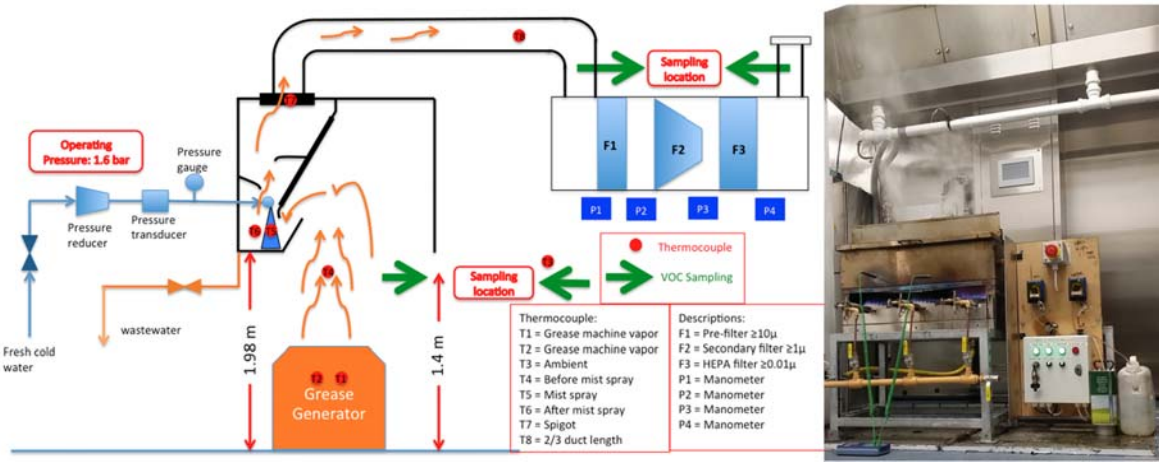

Figure-1. Sketch of the test setup kitchen facilities.

Grease emission produced from cooking activities can be mixin vapor and particulate. In ASHRAE 1375 final report studied the grease emission produced from various type of cooking appliances conducted with full scale of experiment. The results shows that the grease emission are dominated by vapor 60 - 90% followed by 10 - 40% particulate in the exhaust duct and its depends on the cooking operations. The highest grease emissions in the exhaust duct are from solid fuel broiler test with 70% grease emissions are in vapour and 30% in particulate has been reported(Kuehn et al., 2008).From previous research (Livchak *et al.*, 2003), the emissions of grease particulate composition for gas broiler hamburger was 70% dominated and 30% are in vapor.

Water mist versus mechanical grease filters

The mechanical grease filters are installed to the exhaust plenum to capture particulate grease emission produced during cooking activities. There several types of mechanical grease filters with different design and efficiency can be found in the market such as cyclonic filter and baffle filter. Mechanical grease filters are closely to 100% efficient to capture particles size more than 10 µm but unable to extract vapor grease emissions (Livchak et al., 2003).

Cooking activities produced heat that definitely will increase kitchen ventilation temperature as well as to surroundings. This mechanical grease filters are only effective to capture particulate but not to cooling down or to prevent spark generated from heavy-duty cooking to entering exhaust duct. For heavy-duty cooking such as chabroiler, the water mist activation will not only to filter the grease emissions, but functions as spark arrester and to cool down the kitchen ventilation system due to mist curtain and from the temperature drop.

During grease loading test, three different types of filters were used and installed in the ducting system to study the effectiveness of water mist spray. These three filters were efficiently capture at difference particles size range which are greater than 10 µm, greater than 1µm, and greater than 0.01µm. Finally a comparison were made base from without water mist and with water mist test conditions.

EXPERIMENTS

Experimental setup

The full scale test kitchen hood with water mist exhaust plenum was carried out and the dimension of the hood and ducting system is similar with the ASTM F2519-05. A schematic diagram of the test setup is shown in **Error! Reference source not found.**. The water mist kitchen hood exhaust plenum used was manufactured by Halton Foodservice.

The type of water mist nozzles was used during this test is 1/8 KJSB 0.5 and was manufactured by John Brooks Company. Thereare 6 numbers of nozzles was installed horizontally along 1219 mm kitchen hood length with integration of 170 mm distance between nozzles as shown in **Error! Reference source not found.**.

Figure-2. Water mist spray (mist curtain) operated.

The pressure of the working fluid was set to 1.60 bar at water mist spray flow rate 0.29 l/min for each nozzle. The K-type thermocouples and VOC sensors were installed and labelled as in **Error! Reference source not found.** for temperature measurements and gas sampling. Continuous measurement of temperature, TVOC contamination, and filters pressure drop were recorded using Pico Log recorder, KONTAR-Konsole, and Lrc Tester LHC1-MainUnit Filter System.

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Three types of filters were used in this test to mass concentration of the particles and vapor pass through the exhaust ducts. The pre-filter, secondary filter, HEPA filter, vegetable oil (grease machine), and water (grease machine) were weighing before start and at the end of the test. The air was supplied to the test room and the exhaust airflow was set at actual pressure 72 Pa at actual airflow rate range from 3000 to 3490 m^3/hour.

Grease loading test

Grease machine was used as the grease loading test to create grease emissions. The grease machine and test hood design and specifications is similar and comply with UL 1046, ASTM 2519-05 and NFPA 96 requirements and standards.

The loading pan of grease machine was preheated to 385 °C (±14°C) and the thermocouple were placed inside the vapor box to monitor and maintain contionuously the heating temperature. Then, followed by activation of dripping the oil and water at flow rate of 10± 0.5 ml/minute and 124.5 ± 0.5 ml/minute respectively. To test closely in physical and chemical properties of the compounds emitted during cooking, the representative of vegetable oil (0.92 g/ml) were used as the loading material.

The grease loading test was conducted with three test conditions. The first condition is without activation of water mist spray and followed by the second test condition with water mist (mist curtain) activation and the final condition using KSA mechanical grease filter plenum without water mist activation. The test was run continuously with same amount of vegetable oil and water for each test condition.

RESULTS AND DISCUSSIONS

The mass concentration for a grease emission sample in the exhaust ducts were calculated as:

$$C = (Wf - Wi)/V \qquad (1)$$

Where C is the mass concentration in µg/m^3. Wf and Wi are the final and initial weights of the filter used to collect the particles and vapor sample and measured in µg and V is the total air volume sampled through the filter in m^3 along duration of 8.25 hours.

Figure-3 shows the results for mass concentration from 3 different type's offilters during activation water mist system and without water mist activation under grease load along 8.25 hours. The filter was installed to determine how much the portion of particles and vaporpass through to the exhaust ducts. The pre-filter, secondary filter, and HEPA filter grade were used in this test are 98% - 99.9% efficient to capture particles size greater than 10µm, 3 µm, and 0.3 µm.

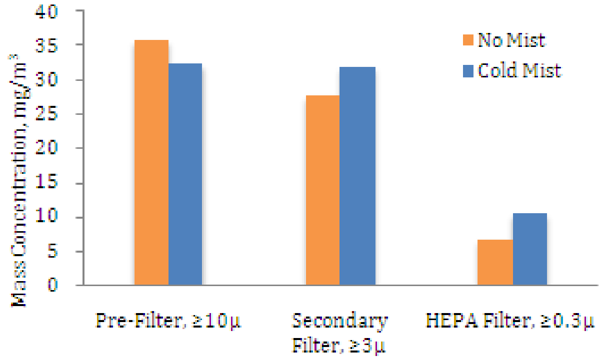

Figure-3. Mass concentration from different 3 types of filters for two test conditions at durations of 8.25 hours.

Test condition without water mist activation show the highest mass concentration on the pre-filter. The results from both test conditions, it shows that the grease loading test was dominated by 86.1 - 90.5 % particles size greater than 3 µm. From the observation during water mist activation, some amount of water pass through into the exhaust duct and the filters captured the mixture of grease and water particles and vapor. From visual observation on the pre-filter after reached its maximum final resistance, it shows that the grease deposited more on the pre-filter used for test condition without water mist as in **Error! Reference source not found.**.

Figure-4. Pre-filter after reached maximum final resistance (pressure drop).

Exhaust duct temperature

The average temperature of grease emissions smoke layer before activation of mist spray at location T4 and T6 were 55.62 °C and 42.71 °C respectively. For test condition with water mist activation, the average temperature at location T6was 27.76 °C. The mist spray activation test, the average temperature inside the exhaust plenum dropped to 35 % and the temperature at location T8 (2/3 hood length) decreased 2.5 - 6.2 % as shown in Figure-5. Base on 3 test conditions, the small temperature drop occurred at location T8 due to the exhaust airflow temperature effects.

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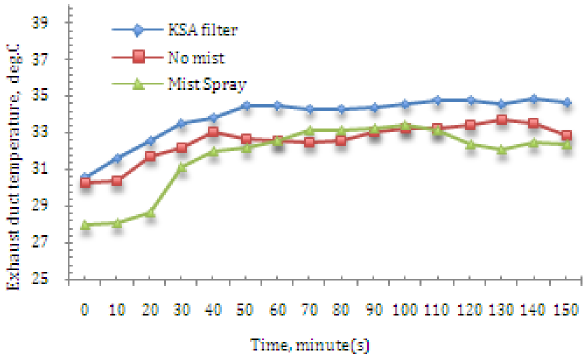

Figure-5. Temperature variations for 3 test conditions at location 2/3 hood length.

The continuous measurement on temperature variations for each test condition was conducted separately. The water mist activation along durations of 150 minutes shows us that the grease emissions smoke layer at location 2/3 hood length decreased compared to others 2 test conditions. When the water mist activated, the cooling effects inside the exhaust duct was great at duration less than 50 minutes and almost no significant effects at durations over than 50 minutes.

Pressure drop

Each filter has its own resistance limits. The maximum resistance limits and particles arrestance efficiency for each filter depends on the filter grades. The continuous measurement was made where the manometer tube was placed at before and after airflow direction for each filter to measure static pressure different. The measurement was made continuously until one of the filter reached its resistance limits. At this time, the grease loading and exhaust airflow were stopped and the filter was replaced. Then, the test was continue immediately with brand new filter (weighted) and activation of the grease loading and exhaust airflow.

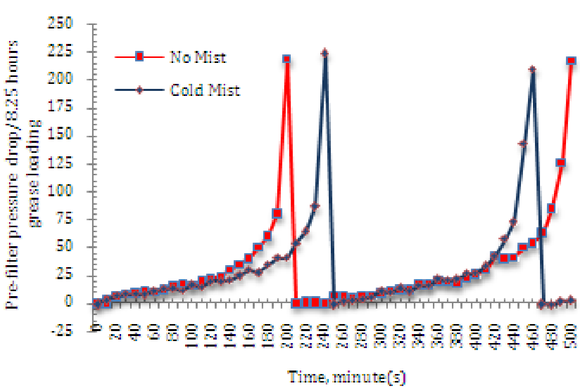

Figure-6. Variation of pre-filter resistance.

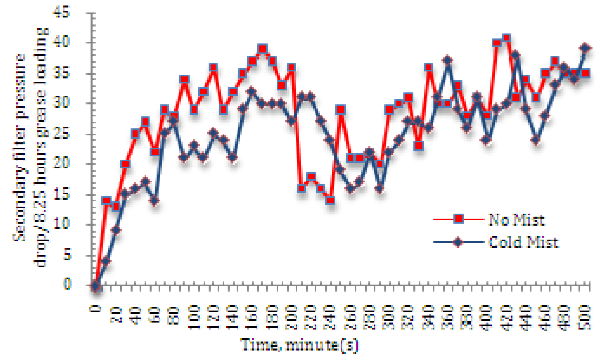

Figure-7. variation of secondary filter resistance.

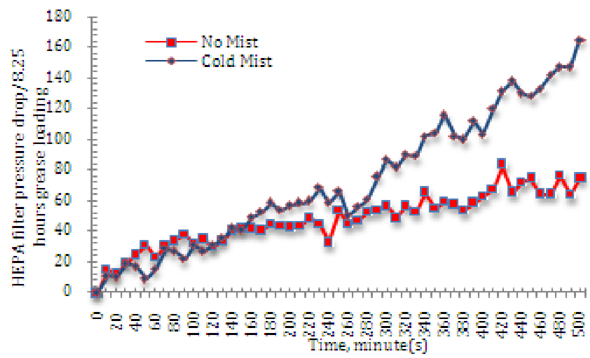

Figure-8. Variation of HEPA filter resistance.

The pre-filter tested shows that the activation of water mist spray slow down the build up of the pressure drop. The maximum resistance reached for the pre-filter decreased to 16.7 % and its shows the significant effects of water mist activation to capture grease emissions particles size greater than 10 µm as in Figure-6. The results from Figure-7 and Figure-8 shows that the resistance from the pre-filter affected the resistance of the secondary and HEPA filter. There was some drop can be observed in filter resistance on secondary and HEPA filter right after the pre-filter was replaced. The secondary filter shows that it slow down the build up of the pressure drop by 25 % at 200 minutes sampling time.

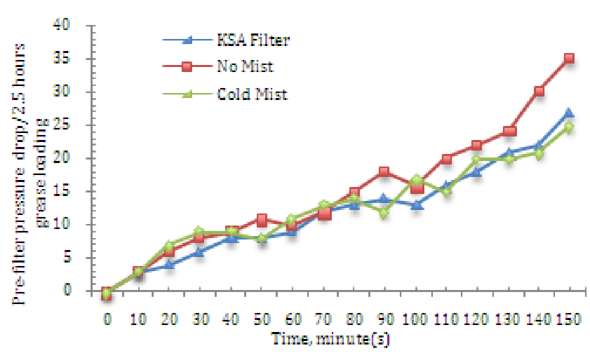

Figure-9. Variation of pre-filter resistance for 3 test conditions.

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Water mist activation increased the water contents (moisture) in the grease emissions smoke layer since the final weighing results show that the total filters weight increased by 6.1 %. The amount of particles size smaller than 3 μm contains in the smoke layer in the exhaust ductsincreased23.5 % during activation of water mist system at 8.25 hours grease loading.Base on Figure-9 it shows that the water mist activation and mechanical grease filter shows similarity in pre-filter resistance between 150 minutes grease loading. As results, water mist gives significant effect with mechanical grease filter to capture efficiently particles size greater than 10 μm.

TVOC Contamination

The TVOC sample was collected inside the exhaust ducts for 2 test conditions (with and without water mist activation) at 8.25 hours sampling time. The TVOC sample for KSA filters exhaust plenum also was carried out for 150 minutes (maximum pre-filter resistance) for comparison as in Figure-12.

The results as in Figure-10 shows the TVOC contamination for both test at location before pre-filter in the exhaust ducts. For test condition without water mist activation, the TVOC contamination rose sharply 29.8 % and achieved the peak values at average 711 ppm after 10 minutes of sampling time. During water mist activation, the TVOC contamination rose 24.3 % and achieved the peak values at average 707 ppm after 40 minutes of sampling time. As results, it shows the water mist activation has significant effects on TVOC contamination for less than 40 minutes sampling time.

Figure-11 shows the TVOC contamination at location after HEPA filters in the exhaust ducts. The results show the similar effects at the sampling location before pre-filters. The TVOC contamination decreased at average 17.1 % for test condition without water mist activation and 18.6 % during water mist activation.

The average total TVOC contamination at 150 minutes sampling time for KSA exhaust plenum, without water mist activation, and water mist activation was 656 ppm, 621 ppm, and 627 ppm respectively as in Figure-12. As results, the highest TVOC contamination occurred from KSA exhaust plenum. However, base on Figure-10, Figure-11, and Figure-12 there is not much differents in TVOC contamination for all test.

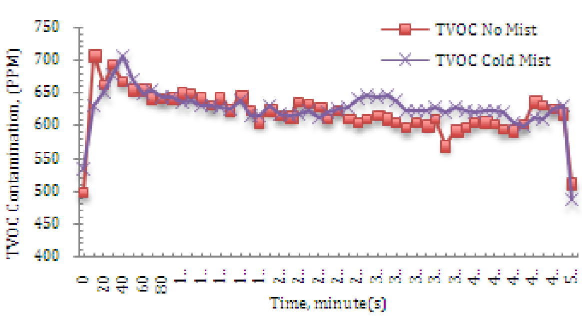

Figure-10. TVOC contamination at location before 3 filters in the exhaust ducts.

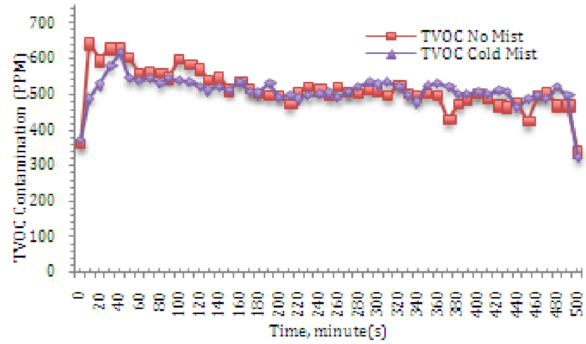

Figure-11. TVOC contamination at location after 3 filters in the exhaust ducts.

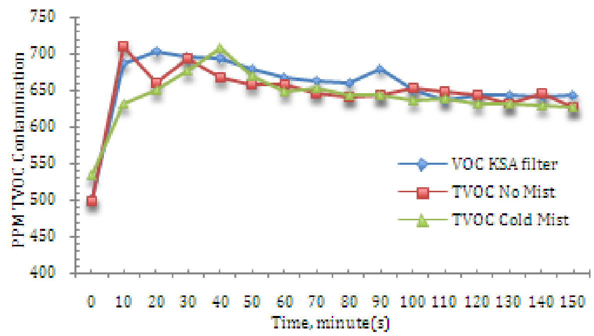

Figure-12. variation of TVOC contamination for 3 test conditions.

CONCLUSIONS

The tests via experiments conducted have shown that the water mist system for commercial kitchen hood has significant effects to filter the grease emissions and to reduce the temperature inside the exhaust plenum and ducts.

- Base on the mass concentration on the filters that have examined, water mist activation reduced the amount of particles size greater than 10 μm in the smoke layer to enter the exhaust plenum.
- The maximum resistance of the pre-filter extended by 16.7 % which mean the water mist activation have significant effects as well as cyclone mechanical grease filter (KSA filter) where can capture 100% efficiently particles size more than 10 μm.
- The smoke temperature inside the exhaust ductreduced due to the temperature drop occurred on the smoke layer during penetrating water mist curtains.
- The average TVOC contamination from 3 different conditions test have shown similar results. But, the water mist activation have shown great result at sampling time less than 40 minutes.

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