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EXTRACT AND CLEANING OF CONTAMINATED AIR IN COMMERCIAL KITCHENS

Ultraviolet Technology

Bachelor's thesis
Building Services Engineering Double Degree Program

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DESCRIPTION

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Abstract
The subject of the project was a research about cleaning of contaminated air in commercial kitchens. Kitchen hoods must be cleaned from heat, moisture, smoke, and vaporized grease all the time. Accumulations of grease on kitchen equipment can easily be the reason of fire.

The thesis presents literature review of various sources like books, reports, and Internet articles. Most of the articles and tests were maid by research institutes or big manufacture companies connected with ventilation equipment. Grease destroying ultraviolet technology is rather new for HVAC market. It is provided by some European companies like Halton or Purified Air. Materials from Halton company were used for my thesis work.

First step to avoid problems of commercial kitchens is use of powerful hoods in combination with various filters. Single stage filters are rather cheap, useful in work and cleaning and are able to prevent fire. Nevertheless they are not very effective in collecting of contaminants. Multi-stage filters are the next step of grease removal. Usually the aim of first filter is to collect large particles and next filters do more delicate work. There are several technologies used in multi-stage filters. My task was to explore information about Ultraviolet Treatment

UV oxidation process consists of two primary chemical reactions. The process when UV rays hit molecular chains and breaks them into smaller compounds is called Photolysis. Then grease and vapour are oxidized by ozone and hydroxyl radicals. This process of oxidation is called Ozonolysis. All parts of UV system should be covered or has special protective equipment to avoid of irradiation of people in the kitchen by ultraviolet light.

Use of ultraviolet light in exhaust air filtering is very efficient and convenient in many ways. It destroys grease in molecular level so systems don't need to be cleaned a lot.

Subject headings, (keywords)
Kitchen, Ventilation, UV light, Ultraviolet, Cleaning, Filters, Grease, Odours, Odors, Kitchen exhaust

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INTRODUCTION

No one will deny the role of foodservices in our life, but who knows what comes with it? Kitchen hoods must be cleaned from heat, moisture, smoke, and vaporized grease all the time. Accumulations of grease on kitchen equipment can easily be the reason of fire. Daily noise and odours irritate people who work or live nearby. Of course all this problems can be solved nowadays, but the question is how to solve them more efficiently and save the money?

Every type of commercial ventilation is a complex system with lots of requirements. Commercial kitchen ventilation is not an exception. The main task for it is to control discharges of heat, moisture, steam and gases, dust and grease. Concerning this there are well defined steps in design of commercial ventilation:

1) Find out right input of the system, which is enough to create certain conditions in premises
2) Right design of supply and exhaust air ducts to reach good efficiency of the system
3) Put in good air filters
4) Don’t forget about economy of the whole system. Choosing proper ducts, hoods, air outlets and other equipment can reduce air demand and it means reducing costs with same efficiency.

Commercial kitchens have a high fire risk because of grease discharges. Vapour and small grease particles go upwards above kitchen equipment and come to a hood. The problem is part of this grease don’t come to a filter but stays on a hood walls. Then this grease is accumulated on surfaces and can blaze up with even a small fire.

Furthermore the emission of cooking odours might cause environment problems which are very much discussed nowadays. To avoid such problems it is common to use powerful hoods in combination with various filters. These filters are renewed all the time to be more efficient and up-to date. I’m going to explore the most popular types of filters and give information about them. One of the last innovations in this field is using UV-light technology which I want to study during my thesis work.

Besides standard filtering systems I would like to say about UV-light. UV-light is not visible to the human eye. To define this technology briefly, it is measured in nanometers and has a wavelength between 100 and 400 nanometers in length. UV-C spectrum breaks the outer membrane of bacteria, moulds, and viruses due to the short wavelength. Then the light attacks DNA of the microorganism which makes up its structure, and destroys it.

Every thesis work starts with information and literature research. For my topic I found more journal and web articles than books. Most of the articles were written and tests made by research institutes or big manufacture companies connected with ventilation equipment. Role of ASHRAE (American Society of Heating, Refrigerating, and Air-Conditioning Engineers) also can’t be denied. Grease destroying ultraviolet technology is rather new for HVAC market. It is provided by some European companies like Halton or Purified Air. To investigate their work connected to UV-technology is a part of my work. I’m going to explore all the available information to find out the benefits of the method. It is important to know also drawbacks and problems which may occur while using UV-light, does it affect the people working in the kitchen or not. Is it reasonable to replace existent filters for UV-light technology? Let’s see.

1. PROBLEMS OF COMMERCIAL KITCHENS

1.1 Grease

Grease that is used in cooking comes out in the form of vapour and grease particulates. This particle's size can vary from 1µm to 12µm. Different cooking processes have different grease emissions. It was studied by ASHRAE journal /7/.

Figure 1 shows total emissions from different cooking processes and Figure 2 divides these emissions to vapour and grease particles.

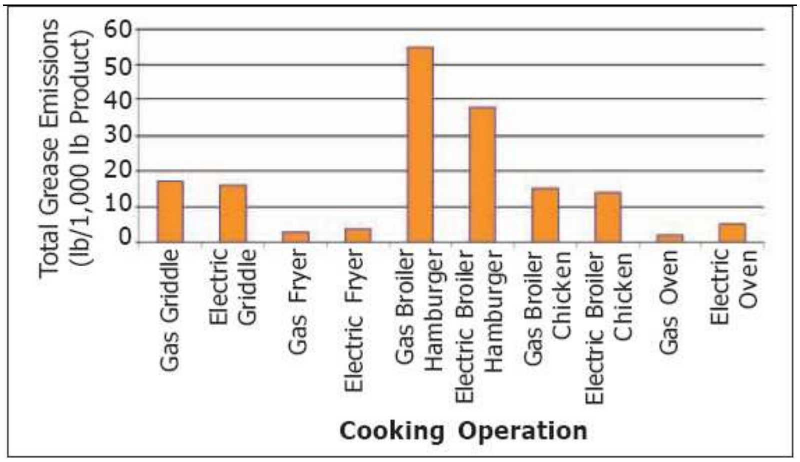


Figure 1 Total emissions of cooking processes /7/

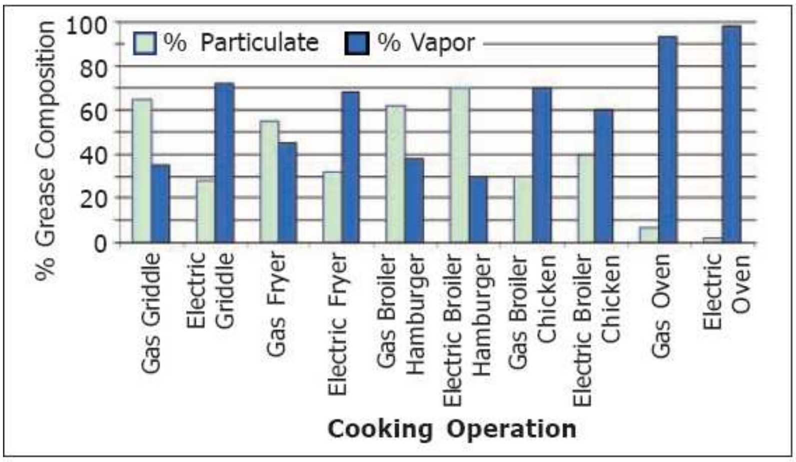


Figure 2 Vapour and particulate ratio in cooking emissions /7/

Mechanical grease filter can catch only grease particulates but no grease vapour. For collecting grease vapour and particulates smaller than 2µm there are HEPA-filters, electrostatic precipitators, and of course cleaning systems with UV-light technology.

1.2 Odours

Even if there is a low concentration of chemicals in the air our nose can catch it. All the smells are detected in our brain that is why some of them are irritating. Odours may cause nausea, headaches, difficulty breathing, frustration, annoyance, depression, stress, tearfulness and even reduced appetite /13/. There are always lots of odours with the cooking process.

Odours can be characterized by: hedonic tone, quality, concentration and intensity. According to guidance on the control of odour and noise from commercial kitchen exhaust systems there are factors that influence the control of odour from commercial kitchens /13/:

- size of the cooking facility (influences the intensity of the odour and volume of ventilation air to be handled)
- type of food prepared (affects the chemical constituents within the ventilation air)
- type of cooking appliances used (dictates the level of fat, water droplets and temperature within the ventilation air)

1.3 Noise

Food preparing processes, kitchen equipment and kitchen ventilation system make noise which can disturb staff and other people.

There are several factors that influence noise in industrial kitchens /13/:

- size and shape of the exhaust duct

  in smaller duct velocity of air increase, so noise also increases

- heat release from kitchen

  if flow rate increases usually pressure gets higher and generate noise

- type of cooking appliances used

  different properties of equipment

- position of exhaust fan in the system

  fan can be situated closer to internal or external side of the building

- fitting and dimensions of the exhaust flow ducts

  every part should be designed carefully, using right materials and isolation

- fan type and speed

  fan should be chosen according to its efficiency, it is possible to take bigger fan with lower speed than small fan working too high.

1.4 Indoor climate conditions

There are big heat loads and vapour emissions inside the kitchens. There are two types of heat loads: thermal plumes and radiant heat. Thermal plumes consist of heat, water vapour and organic material released from the food. Radiant heat comes from the cooking equipment.

2. VENTILATION SYSTEM OF A KITCHEN

It was already mentioned that prevention of fire is one of the most important things in kitchen ventilation system. Other requirements are: hygiene, efficiency and comfort for people working in the kitchen.

There is a need of mechanical delivery of supply air to the kitchen. The main task is to not disturb the thermal plumes. Nowadays it is possible in two ways:

- mixing ventilation (with high velocity)
- displacement ventilation (with low velocity)

Exhaust ventilation system of the kitchen can be general and also can have local hoods above special equipment. There are at least 3 separated parts of exhaust ventilation system in the kitchen:

- exhaust from WC
- exhaust from dishwasher
- exhaust from kitchen stoves

2.1 Exhaust from WC

Exhaust system of toilets is important to keep air fresh and atmosphere around in hygiene. Usually it is separated part of the system which has good isolation. Speaking about restaurants toilets there are usually not situated near the kitchen.

2.2 Exhaust from dishwasher

This system is much more dangerous than it seems to be. The point is in chemicals which are used in dishwasher machines. Vapour and air which comes out the dishwasher is very saturated. When it comes to a place with low pressure or temperature condensation process starts. Because of condensation chemicals are setting down on the parts of the system and can damage it. Even such strong material as galvanized steel can be corroded.

There are two opportunities to avoid this problem. First possible solution is to avoid condensation of air. On the other hand it is possible to use materials that prevent corrosion. It was explored that steam condensate is accumulated on the first 5-7cm of the duct above dishwasher machine. For example aluminium is the cheapest material which can resist corrosion or stainless steel can also be used. Another way of solving this problem is prevention of condensation. In this case first part of the exhaust duct (about 5-7cm) is made with some angle to the dishwasher. What is more all the seams and joints must be hermetic.

2.3 Exhaust from kitchen stoves

This is the most studied part of the kitchen ventilation system. The main idea is to take away heat, moisture and grease.

High temperatures of cooking processes cause difficulties for people who work on the kitchen because of heat. Kitchen equipment creates radiant energy while its work, so that causes increasing of surface temperatures around and air also becomes warmer. This problem can be prevented with design of supply air flows going in special direction. On the other hand single hood above the stove can also help. Air that comes from the stove is warmed up so it goes upwards and is caught by the hood.

There are two types of systems: general ventilation and local hoods. General ventilation system is good enough to control heat emissions. But when there is a problem of other impurities like grease or dust it is common to add local hoods. Because of warm air all the impurities that weren't catch with local hoods come up to the ceiling. That's why in commercial kitchens the most contaminated air is at the top and exhaust hoods are there. Supply air usually comes to working zone.

It is necessary to remember that local hood must have right size and shape so that flow of exhaust contaminated air would not come through people's face. The simple example is showed on Figure 3.

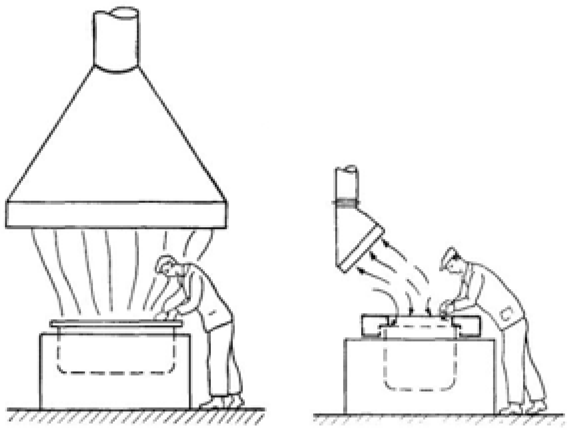


Figure 3 Scheme of the local hood place /15/

These local hoods can also remove excess of vapour. But it is also said that vapour which comes from cooking processes without any grease is not harmful and can be removed by general ventilation system without help of local hoods.

Grease removal is the most difficult process. It can't be removed without special filters or new technologies such as ultraviolet.

3. DIFFERENT TYPES OF CONTROL OF COMMERCIAL KITCHEN VENTILATION

Nowadays commercial kitchens need systems not just take away grease and other impurities but at the same time work with higher fan efficiency. Years ago kitchen hoods had manual control and could work all the time or be fully stopped. Some systems had several speed functions but weren't very effective either.

Today kitchen ventilation systems are based on automatic speed control of the fans using information of sensors. There are different types of speed control which have their benefits.

3.1 Benefits of speed regulation

In southern countries it is common that in day time there is not much cooking processes, but at the same time it is hot outside so ventilation system works hard. It causes the problem of over ventilating. What does it mean? It means that sometimes load from kitchen equipment is minimal but the system continues to work at the same level. It leads to unreasonable use of supply air, and system works more than it is needed.

There are several benefits of reducing ventilation speed while cooking process is stopped /10/:

- silence in the kitchen

  "If speed of fans is reduced to 80%, noise of air in filters is also reduced to more than 20%. And if fan speed is only 50% then noise from filters is almost disappear" /10/. This silence benefit is good not only for kitchen staff but also for people who live around

- air flow rate demand is controlled

  Specific Fan Power (SFP) is reduced. It saves both electricity and heating energy

- deterioration of ventilation system is reduced

Working time of compressors in air conditioning system is reduced, therefore it can work longer. Also strap’s service life becomes longer because of soft starting of fans. What is more reduced consumption of fresh air decreasing dirt accumulation on filters.

- prevention of fire is increasing

  Temperature sensors which are set to regulate speed of fans can also react to high temperature and make a signal to stop the system or even stop the system automatically.

- reducing of grease accumulation in ducts, fans and atmosphere

  In this case grease can stay in hoods and on its walls or in special grease collecting containers, because speed of fans would be rather small to blow it out. Cleaning this part of system is much easier and better than contamination of whole system.

- no contradiction in the air conditioning system

  Sometimes when sensors are not designed for combined work air conditioning system can do ineffective work. For example when outdoor air is first warmed and then cooled down by air conditioning system.

- decrease of construction costs

  Using regulation system speed of fans is usually reduced in the day time, after dinner. At the same time it is a period of the day when outside air temperature and humidity rises. So if we don’t need the system to work in day-hours with 100% efficiency we can build less efficient system and it will be less-cost.

- improvement in retaining of heat from kitchen equipment

With less speed of fans it is easier to take heat straight into the hoods because there is less air disturbance and draughts according to lower speed of supply air coming into the kitchen.

3.2 Control types

3.2.1 Control by energy inflow

This type of automatic regulation is based on energy inflow to the kitchen equipment. Sensors are set to gas or electric consumption lines to measure energy needed. The idea is that speed of fans is higher when equipment works hard.

Needs of ventilation in the kitchen are not always connected with work of equipment. Due to this and other problems this method is not very popular.

3.2.2 Control by energy outflow

The other way of regulation is based on outflow of energy and waste water from kitchen equipment. That means when more heat comes out system runs faster.

This method works well and is rather popular because of its simplicity and low price. Various sensors can be used. For example temperature sensor or optic sensor which can detect smoke and steam.

System starts working with minimal speed until cooking processes start. Then it gets higher speed according to information of sensors and works hard up to the moment when grease and vapour disappear. After that speed of fans starts slowly decreasing depend on the temperature of exhaust air. Furthermore this system imply an opportunity of manual switching on the system to it's high speed if needed and change it to automatic mode in time.

3.2.3 Control by supposed cooking time

This type of system works depend on time of the day. It should be mentioned that this regulation type is more suitable in kitchens with regular timetable of food serving. For example needs of ventilation are known in certain part of the day. Usually this method is used with first or second regulation type of kitchen ventilation.

3.2.4 Control by the staff

This method is good for certain and known types of kitchen equipment so it is rather restricted in use. Cooks should turn the system on and off by themselves or it can be switched on after opening of the cooking oven. For example it can be used for hoods above grill equipment in different fast-food restaurants. It can be efficient only with good cooperation between hoods and kitchen equipment.

4. GREASE FILTERS FOR KITCHEN HOODS

The topic of grease removal is widely discussed and popular nowadays. It concerns towards to every type o commercial kitchen, such as kitchens in schools, hospitals, cruise ships or other. Nevertheless restaurant kitchens have the first place in grease emissions because of its never ending quantity.

It has also been said that "restaurants consume more energy per square foot than any other commercial use, and eight times as much as office space. Kitchen ventilation is a major contributor to a restaurant's high energy use." To save electricity it is important to design the system very carefully. /3/

4.1 Role of standards

Kitchen equipment and ventilation systems are developing all the time and role of different standards and building codes can not be denied. Year by year they restrict opportunities to use old or inefficient equipment and raise requirements.

USA is one of the leading countries in grease emissions research. When we think of this grease problem we have in mind fire hazards. It is no wonder that already in 1961 National Fire Protection Association (NFPA) of USA printed the first edition of *Standard 96, Ventilation Control and Fire Protection of Commercial Cooking Operations.* It was updated in 2004, but there is another document connected with fire concern which is used now. It is UL Standard 1046, *Grease Filters for Exhaust Ducts.*

Except fire norms there are also building and sanitation codes which control commercial kitchen ventilation. First time people didn't care about air emissions from cooking processes. For example in USA lots of research work started after publishing *The Clean Air Act* in 1970. It caused rising of attention paid to understanding and reducing the sources of air pollution. In different counties people started to study what are the emissions of different types of cooking. In Europe there are research institutes in various countries which develop their own standards for commercial kitchens. In USA lots of research is done by ASHRAE who still do a lot of work concerning grease emissions and kitchen ventilation systems as well. It must be said that role of ASHRAE is high not only in USA but all over the world.

4.2 Single-stage filters

It is common to use fiber media in filters in the overall ventilation market, but it is not suitable for commercial kitchens at all. There are serious reasons:

- no fire prevention
- not good in grease capture
- disposable after a single use period

We should always remember 3 base things about good filter (Figure 4).

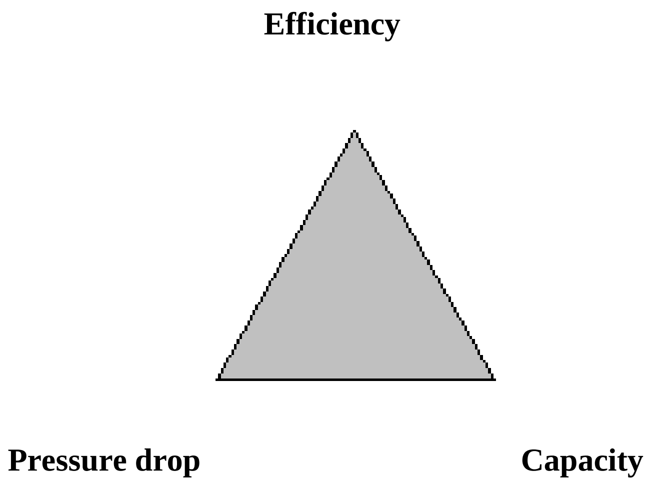


Figure 4 Filtration design components /4/

Efficiency in case of filter means how much particles are captured. Capacity is connected to cleaning interval. Pressure drop have an influence on initial and operating costs. Single stage filters are suitable for almost every commercial kitchen because of their properties. They are rather cheap, useful in work and cleaning, able to prevent fire. Moreover they have a low pressure drop, which means low initial and operating costs.

The most popular single-stage filters are baffle filter, water wash filter, and dry-cartridge filter. All of them have simple scheme of work: vanes are united to redirect exhaust flow and throw grease droplets against a surface to collect them.

Baffle and dry-cartridge filters are similar. Unfortunately baffle filter has lots of deficiencies. It is so that the capture efficiency of many conventional baffle filters is relatively low. It can be said also about flame retarding capability of baffle filter. Low

Figure 5 Baffle filter /8/

capture efficiency leads to the problem when filter catch only large particles of grease and all the impurities come to the system. In this case ducts often are in need of cleaning to work well, so costs of maintenance become higher. New baffle filters are able to improve their efficiency because of some innovations. Most of them have larger surface area so centrifugal separation is increased.

Water wash filters have same base principles of work as baffle filters except cleaning. Water wash filters are automatically cleaned with hot soapy water. Usually washing cycle starts by the end of the day, when equipment doesn't work. Wasted water is then drained to the sewer. Water wash filter is more expensive because of its automatic cleaning system.

4.3 Two-stage filters

Multi-stage air filters are the next step in the development of grease removal. In spite of their high price, they work much better than one-stage filters because they combine advantages of baffle filter with new abilities. Since two-stage filters were designed with standard width it is possible to use them not only in new systems but also renovate old ones without any difficulties.

First stage of multi-stage filter works a lot like simple one stage filter. Its main purpose is collecting large grease droplets and fire prevention. This first stage is important because it protects the second stage.

The second stage is usually a packed-bed device which collects smaller grease droplets coming from the first stage. "The captured grease wets the media's surface and is drawn into its pores by capillary action, thereby extending run time."/4/

It is obvious that efficiency of the first stage has an influence on work of the second stage. Most part of the kitchen emissions rises above in large particles. Every bed-filter will quickly reach its capacity if pre-filtering is weak because of accumulation of the mass contained in large particles of grease. Using computational fluid dynamics method it is possible to compare the flow simulations through a primary stage. This kind of test was made by ASHRAE. /4/ Particles were taken with different size from 1μm to 7μm.

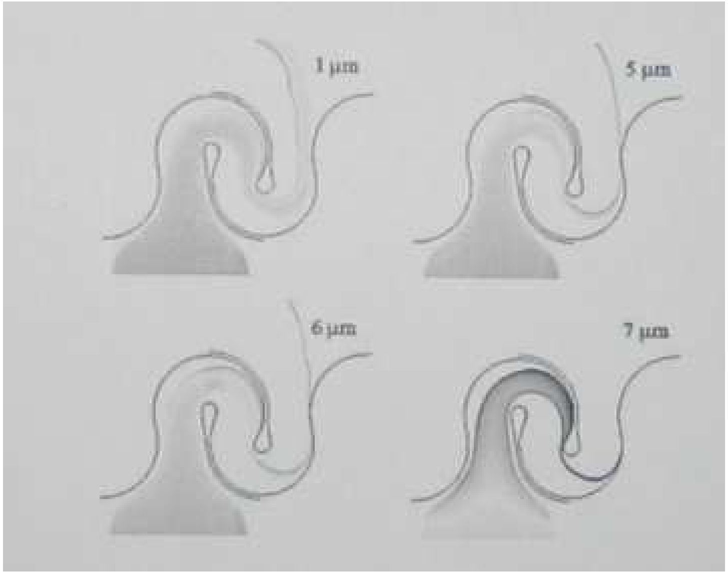


Figure 6 CFD flow simulations showing capture of larger particles in the primary stage /4/

It shows that droplets with 1µm size go through primary stage rather easy. But the main idea of the test is to show that almost all 7µm particles are captured, because they are dangerous for bed-filters.

Separate stages of a filter give better opportunities for cleaning. Apart from this there are more benefits of using multi-stage filters /4/:

- reduced fire hazard
- reduced frequency of duct cleaning
- elimination of grease accumulation on roofs and adjacent surfaces, preventing need for expansive repairs
- enhanced performance and reduced operational costs of more elaborate downstream pollution and odour control equipment were required

Moreover the development of air cleaning technologies has created possibilities to raise grease removal efficiency of multi-stage filters. Different particulate removal units can be applied next to primal stage filters:

1) water cleaning units
2) electrostatic precipitator

o Electrostatic precipitators are particulate removal devises used for air cleaning. They can collect particles with very small size ranging from 0,1μm to 10μm. Operation of this devises is based on using high voltage and opposite charged electrodes. A discharged electrode is usually a metal wire with rather small diameter. The collection electrode is usually a flat plate with the opposite charge. Work principle is not complicated. Firstly exhaust air flows through row of wires which are discharged electrodes. Because of high voltage applied, an electric discharge ionizes the gas around electrodes. This ionized gas then charges the particles. When these charged particles come to a next part of precipitator they pass plates with the opposite charge. Then particles move to this plates, stay there and soon create a layer. This layer of dust is not collapsed because of electrostatic pressure.

When there is too much dust in the precipitator it should be cleaned. It is possible in two ways and depends on the type of precipitator. If particles collected in dry form with hammers that impact electrodes then it is dry precipitator. Otherwise particles can be dissolved in the liquid then it is wet precipitator. Figure 7 shows a principal design of a section of a dry electrostatic precipitator.

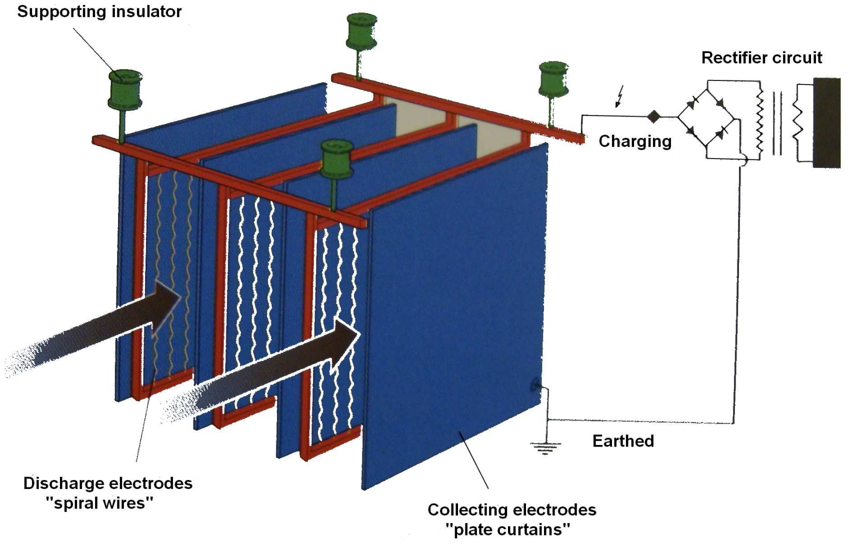


Figure 7 Section of a dry ESP /12/

Dust layer which is collected on the surface of the plates has a certain resistivity. Sometimes this layer gets too high resistivity which creates so-called back-corona effect. It is illustrated in Figure 8.

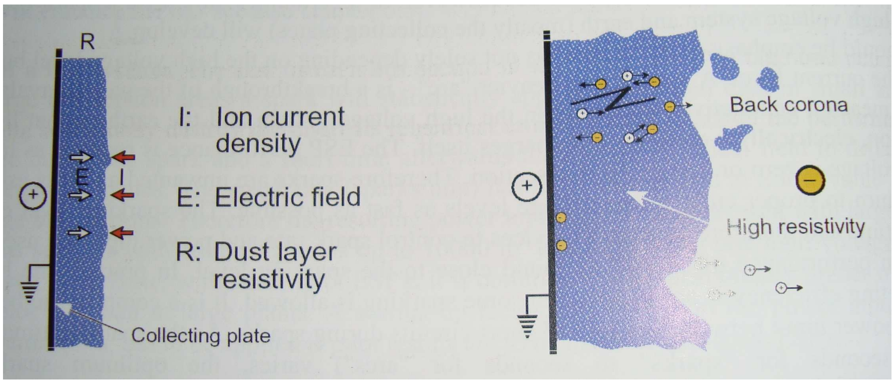


Figure 8 Back-corona effect /12/

This affect seriously impacts dust collection efficiency and increases power consumption. There are several methods to solve this problem. The main thing is to modify resistivity of the dust.

3) disposable pleated or bag filters

- Bag filters are widely used in industrial ventilation for dust collecting. They consist of several components:

  - bag filter housing
  - filter bags
  - bag cages
  - venturi assembly
  - pulse jet air cleaning assembly
  - air bleeding assembly

The key elements are filter bags which determine the dust collecting efficiency and working temperature. Lifetime of a bag filter is usually 2-6 years and its renewal is the most costly part of maintaining bag filters.

It is important to choose proper material for filter bags. It depends on temperature, humidity, chemical properties of dust and size of particles. Knowing characteristics of dust it is possible to choose filter media by different physical and chemical methods of treatment. Filter bag can be made of:

- polypropylene (PO)
- polyester (PE)
- nylon monofilament (NO)

Depending on the application of filter bag the particles can be captured on the internal or external side of the filter surface. It depends on the direction of the flow. Normally the flow goes from the inside to outside and particles are collected on the internal surface. Besides replacement some of the bag filters can be cleaned. It is suitable for filters collecting dust from gases. Methods of cleaning are for example backwashing with compressed air or mechanical shaking of the filter.

4) activated carbon filters

- Activated carbon air filters have a great ability to catch pollutants and hold them. The reason of such efficiency is millions of tiny pores on the surface of carbon. These pores are highly adsorbing after "opening" by reaction with oxygen. That is why before using in filters carbon should be activated by heating it with high temperatures and pressure. Then tiny pores between the carbon atoms can form a strong chemical attraction to odours, gaseous and liquid contaminants. This process is shown on Figure 9.

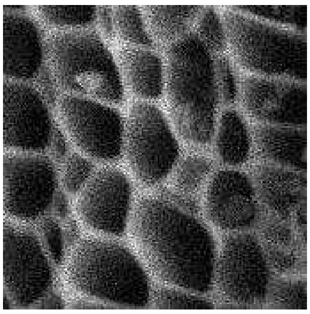


Figure 9 Pores of activated carbon /1/

Efficiency of the activated carbon filter depends on carbon type, carbon weight and width of the chosen unit. More surface area of carbon collects more particles. Granular activated carbon has much more surface area than saturated pad so it is more efficient.

5) oxidizing pellet bags

- Photocatalytic oxidation air filter is rather new technology on the HVAC market. It is usually combined with other filtering methods. Nevertheless oxidation systems are able to completely oxidize and degrade organic contaminants.

6) incineration

- Rather simple method of air purifying. It is based on heating the air with high temperature until it becomes sterilized. While the air is passing through the chambers, contaminants are destroyed by burning with temperatures up to 400°C. This method is more appropriate for removing viruses and bacteria, but it can also remove general odours from cooking processes, VOCs and tobacco smoke as well.

7) UV treatment

- UV treatment method will be described in the following parts of the work.

These additions to the system reduce pollution of the environment and allow heat recovery because of their high efficiency. At the same time heat recovery reduces energy demand of the system. In general the only drawback of these units is a high price of installation and maintaining.

4.4 Testing of some filters

The quality of filter in exhaust hood can affect to efficiency of the whole system. The amount of collected grease particles characterizes filter quality. As it was said all cooking processes emit grease particles with different size and amount. Different filters can be more or less efficient with different cooking processes. It can de proved only through tests in real conditions.

For example German standard VDI 2052 helps to find out the efficiency of a filter concerning to size of the particles. Nowadays in USA analogous standard has been already developed and now is in confirmation stage. Russian scientific project “ABOK” is going to edit the standard for commercial kitchens ventilation also, where minimal efficiency of the air filters can be found.

The test described below was carried out by ASHRAE using VDI 2052 method /7/. Proving was held in independent state research organization in Finland. Its name is VTT (Technical Research Center of Finland). Proportional flow of particles from 1µm to 10µm size was made by two spinning top aerosol generators. First generator made a flow with particles from 1µm to 5µm size, the other one made particles from 4µm to 10µm size. The amount of particles was measured by aerodynamic particle sizer (APS).

The fractional efficiency **$E_f(d_p)$** can be calculated by following formula /7/ for each particle size **(d_p)**:

$$E_f(d_p)=100\left(1-\frac{c_a(d_p)}{c_b(d_p)}\right),$$

where $E_f(d_p)$ – fractional efficiency for particle size (d_p);

$c_a(d_p)$ – amount of particles before the filter;

$c_b(d_p)$ – amount of particles after the filter.

Three most popular filters were choused for this experiment. Two of them are baffle filters and one is multicyclone filter. Photos of the filters which were used in a test are shown below on Figure 10.

Figure 10 Photos of the filters used in a test /8/

Filter “A” is a multicyclone filter produced by Halton. Filters “B” and “C” are commonly used baffle filters. These filters have some difference in work principle.

In multicyclone filter grease particles of the polluted air stay in because of the centrifugal force. Structure of the multicyclone filter is shown on Figure 11.

Figure 11 Structure of a multicyclone filter /8/

In baffle filter polluted air stream is drawn inside the filter through the slots on the exterior surface. Then air is several times turned on 180 degrees and come out through slots on the back side of the filter. Grease particles stay in the filter because of collision with baffles during quick change of air flow direction. Structure of the baffle filter and its work scheme is shown on Figure 12.

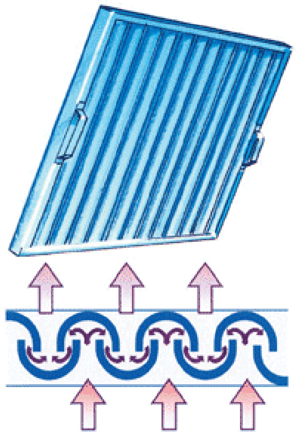


Figure 12 Structure of a baffle filter /8/

Filters were tested with 3 different loads of specific air flow per linear length of the filter:

- light load – 220 l/(s·m)
- medium load – 300 l/(s·m)
- heavy load – 400 l/(s·m)

The results of the test are presented on figures 13, 14 and 15. Filters were compared to each other with same air flow per linear length.

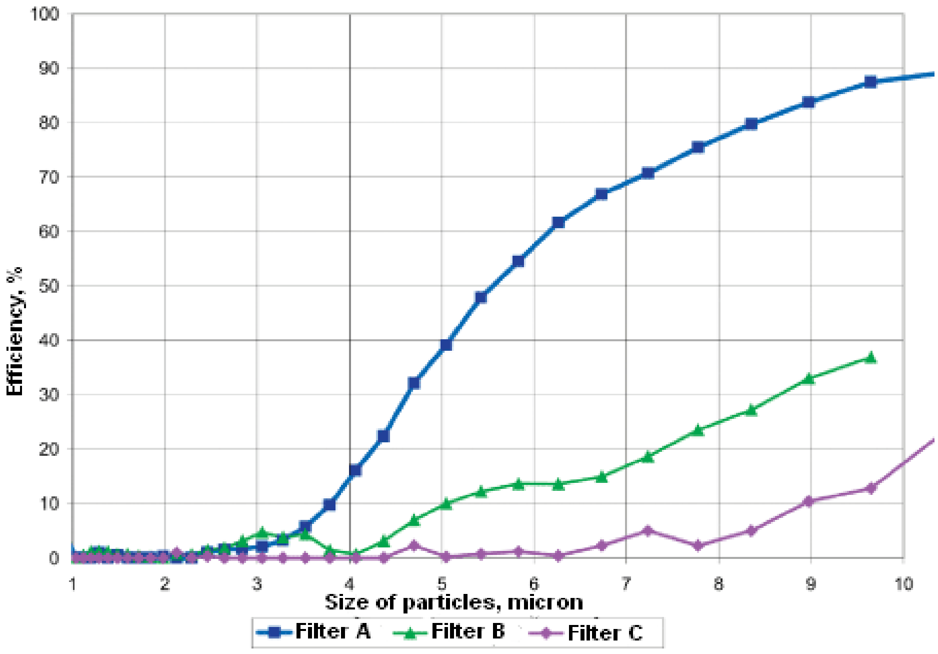


Figure 13 Filter efficiency with 220 l/(s·m) load /8/

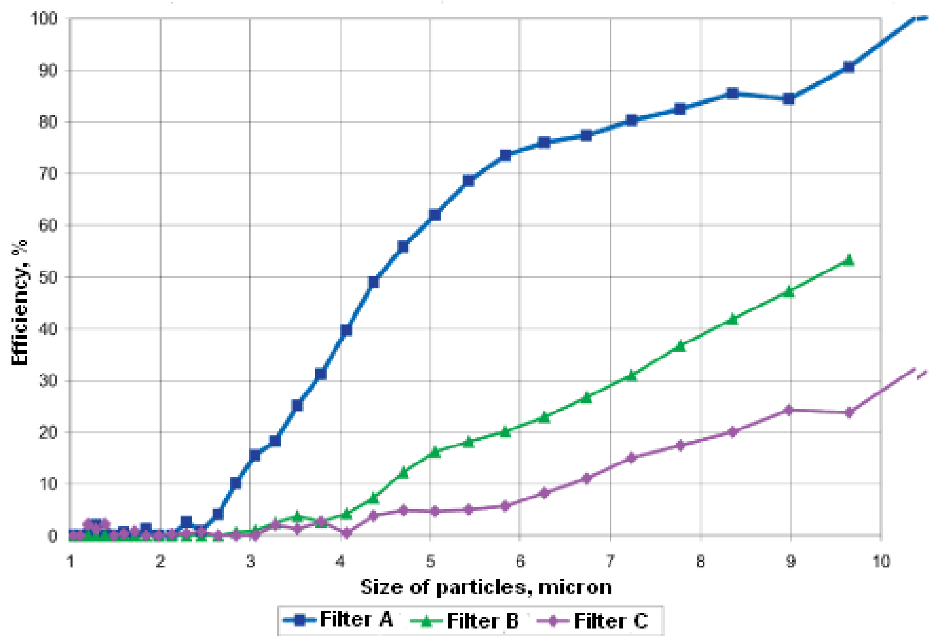


Figure 14 Filter efficiency with 300 l/(s·m) load /8/

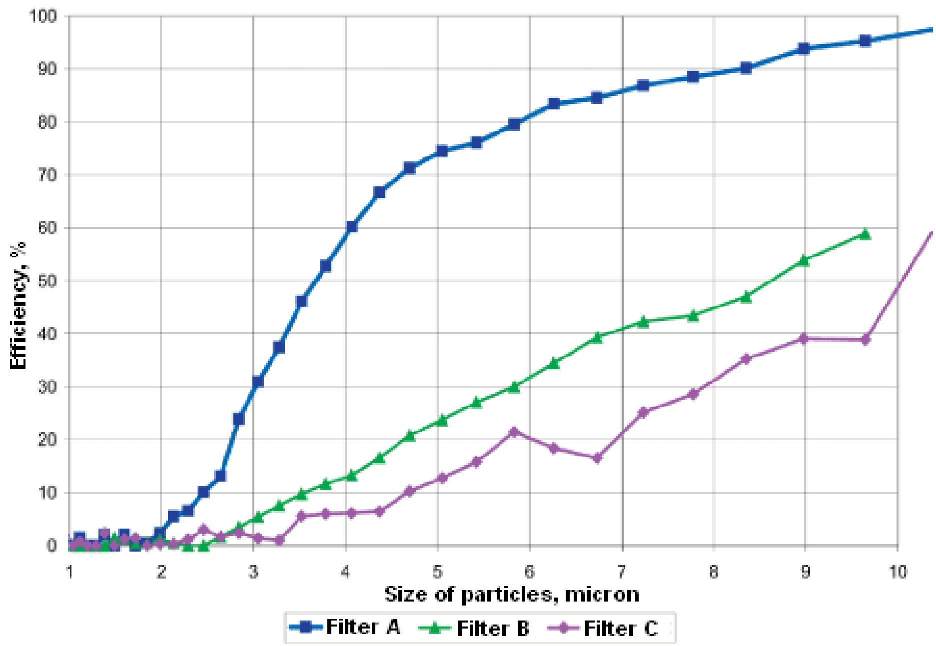


Figure 15 Filter efficiency with 420 l/(s·m) load /8/

It was detected that all of the tested filters were inefficient in collecting particles smaller than 2,5µm. For the bigger particles the efficiency depends much on the filter type and manufacturer. For example multicyclone filter can catch two times more particles than the better one of baffle filters (for specific air flow of 420 l/(s·m). Moreover this difference in efficiency is increasing during decrease of the air flow.

There is a dependence of efficiency increasing with increasing of exhaust air flow, because when contaminated air passes the filter there is a higher pressure drop. When air passes through filters A and B pressure losses are approximately same, but in filter C pressure losses are two times smaller with same specific air flow /8/.

4.5 Filter efficiency in certain cooking operations

As it was said it is possible to measure not only the quantity of cooking emissions but its exact compound and size, corresponded with amount of vapour and grease particles. Also it is possible to measure efficiency of filters for different range of particle size. Due to this we can find out efficiency of different filters in certain cooking operations.

This work consists of three stages /7/:

Find out amount of vapour and particulate emissions for a cooking process → Determine filter efficiency due to size of particles and various airflows through the filter. → Compare particle distribution curve and filter efficiency curve for certain cooking process at the designed airflow

Results of testing this method on our mentioned above filters A, B and C are shown in table 1 below.

Table 1 Efficiency of filters A, B and C for certain cooking operations /7/

Cooking operation	Emissions		Total filter efficiency, %			Filter efficiency for particulate only,%			Grease particulate extracted kg/1000kg		
	Total kg/1000 kg	% Vapour	A	B	C	A	B	C	A	B	C
Gas griddle	17	35	60	22	30	92	33	47	10,17	3,68	5,15
Electric griddle	16	72	26	9	13	92	33	46	4,10	1,49	2,08
Gas fryer	3	45	51	19	26	93	35	48	1,53	0,58	0,79
Electric fryer	4	68	28	8	13	87	26	41	1,11	0,34	0,52
Gas broiler hamburger	55	38	55	28	33	88	46	54	30,07	15,67	18,28

Electric broiler hamburger	38	30	60	31	36	85	44	52	22,64	11,73	13,75
Gas broiler chicken	15	70	20	10	12	68	34	40	3,05	1,52	1,80
Electric broiler chicken	14	60	28	14	17	71	35	42	3,97	1,97	2,35
Gas oven	2	93	6	1	3	85	21	37	0,12	0,03	0,05
Electric oven	5	98	2	0	1	81	19	34	0,08	0,02	0,03

In Table 1 there are values of total emissions and efficiency of used three filters. Total filter efficiency means a percentage of grease cached by to filter per total grease emissions. Particulate filter efficiency means a percentage of grease captured by the filter to particulate emissions of cooking processes. In Table 1 there is also information about mass of grease captured by every tested filter for 1000 kg of product cooked. For example multicyclone filter A will collect about two times more grease comparing to other tested filters when hamburgers are cooked with gas broiler. It means that using kitchen hood with multicyclone filters can reduce amount of contaminants settled down on surface of hood or ducts up to 12 kg of grease after cooking 1000 kg of hamburgers.

Cooking emissions depend not only on their composition, but product being cooked, cooking processes and cooking appliance. Moreover location of the sampling probe and method of measuring influence a lot. Condensation of grease vapor depends on exhaust airflow volume and also temperature of exhaust air. There are some benefits of using higher exhaust flow. For example higher exhaust flow decrease its temperature and balance of vapour/particles changes. Mechanical grease extraction efficiency increase when number of particles becomes higher comparing to amount of vapour. But these benefits are not so significant comparing to high energy costs when using systems with higher exhaust flow.

Number of conclusions can be made after test results /7/:

- Mechanical grease filter efficiency depends on cooking operation and pressure drop across the filter

- Filter design affects the efficiency of grease removal. Test with particles from 2μm to 10μm shows that multicyclone filter is twice more efficient comparing to baffle filter

- Single database about emissions from different cooking processes should be created and contain data on total emissions, percentage of particulates and particulate distribution

- The VDI 2052 standard should be developed to a new single test protocol to set filter efficiency depending on size of emission particles and exhaust airflow

5. ULTRAVIOLET TECHNOLOGIES IN AIR CLEANING SYSTEMS

Even the best of multicyclone filters can’t collect small grease particles and vapour. More complicated filters which were described above have their drawbacks. For example water wash filters should be connected to water-supply so it is rather complicated construction. What is more such systems need lots of water and can easily be littered up in case of hard water. Multi-stage filters are expensive in maintenance because of need to change complicated filters. Electrostatic precipitators are quite big and usually installed on the roof of a building. They are mostly designed not to prevent grease accumulation inside the hood and ducts but to clean exhaust emissions to atmosphere. Electrostatic precipitators need to be cleaned often. Electrodes become polluted with grease and efficiency of filter decrease.

Nowadays systems with ultraviolet air cleaning technology become more and more popular. Ultraviolet units for cleaning and disinfection of water are well known, but using this technology for commercial kitchens is new and developing. Special cartridges with UV-lamps are installed to the exhaust hood next to the mechanical filter. Lamps should radiate rays of UV-C spectrum with wave length smaller than 280 nanometers.

5.1 Operation principle of systems with UV-light

Rays of UV-C spectrum have high energy. UV oxidation process consists of two primary chemical reactions. If wave length is 265 nanometers radiation has got disinfection effect and kills bacteria. Rays with wave length of 185 nanometers destroy diatomic ties in oxygen molecules. Ozone is created when monatomic oxygen reacts with oxygen molecules and water vapour. During the process of Ozone creation it is also possible to get hydroxyl radicals OH. When ultraviolet rays react with grease coming with kitchen emissions they destroy diatomic ties, it is similar like reaction with other molecules of organic substances. The process when UV-C hits molecular chains and breaks them into smaller compounds is called Photolysis. Photolysis is shown on Figure 16.

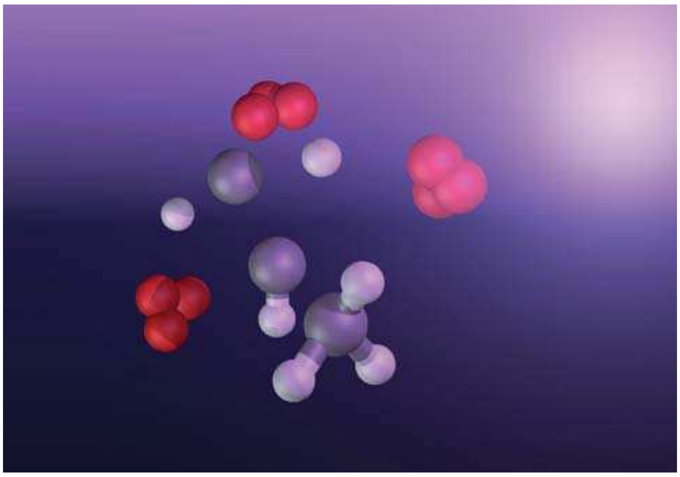


Figure 16 Photolysis which is chemical breakdown of the grease molecules by photons /6/

In kitchen hoods equipped with UV-system process of photolysis occurs in cartridges with ultraviolet lamps. These cartridges are situated next to the mechanical filters. Process of photolysis stops when air leaves UV-cartridge and comes to the exhaust duct. In exhaust duct the ozone, created from the reaction of the UV-light with oxygen molecules, continues to react with the grease molecules which move through the duct to the outside. So grease and vapour are oxidized by ozone and hydroxyl radicals. This process of oxidation is called Ozonolysis. Ozonolysis is shown on Figure 17.

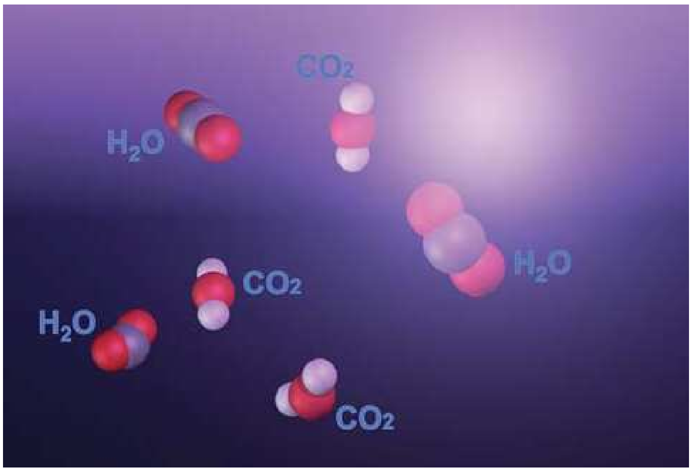


Figure 17 Ozonolysis which is the oxidation of VOC and part of the odours by the ozone generated by the UV-C lamps /6/

Combined process of photolysis and ozonolisys is called Ultraviolet oxidation. If UV-oxidation process was 100% efficient, all of the organic substances of kitchen emissions could be oxidized to the carbon dioxide (CO_2) and water (H_2O). Unfortunately it is not rational system due to its cost and sizes of the units.

Despite the fact that UV-systems are not 100% efficient they help to keep exhaust ducts, surfaces and roofs of restaurants clean. For example Halton company used UV-technology for the exhaust hoods on the kitchen of cruise ship “Queen Mary II” /8/. It was an experiment so they used UV-systems only for the part of exhaust ducts. After one year of exploitation they checked conditions of the exhaust ducts. The photos of that ducts are shown on Figure 18. The difference is clearly seen. Left photo shows a duct without ultraviolet units and the right one is the duct after using UV-light.

Figure 18 The result of using exhaust ducts without UV-technology (on the left) and with UV-technology (on the right) on a cruise ship “Queen Mary II” /8/

Halton company is actively provides UV-technology. Their last innovation for commercial kitchens is UVF – Capture Jet Canopy with grease removal technology and low velocity supply.

5.2 The Capture Jet Technology

The Capture Jet canopy produced by Halton is based on the use of ultraviolet lamps which neutralize grease particles and vapour. It is highly efficient kitchen ventilation canopy with new generation of peripheral and horizontal Capture Jet technology. It removes contaminated air and takes away heat from cooking equipment with delivering supply air at low velocity. The goal of the system is lower amount of energy needed. Capture Jet canopy needs about 30-40% less exhaust air volume than traditional canopies to remove the same heat load /6/.

Efficiency of Capture Jet Technology is reached because of the innovations in operation of the hood. This technology is based on two sets of nozzles, one vertical and one horizontal:

- horizontal nozzles push vapour back towards the filters
- vertical nozzles increase the volume capacity and prevent vapour escaping from cooking areas

The scheme of Capture Jet technology and operation of nozzles is shown on Figure 19. Left part of the picture shows a hood without Capture Jet heat spilling and the right part of the picture shows a hood with Capture Jet technology.

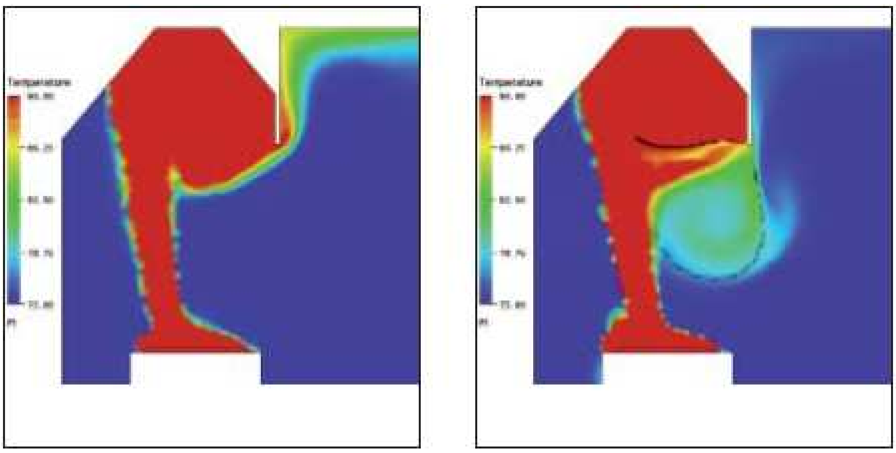


Figure 19 Result of using two sets of nozzles with Capture Jet technology /6/

The bottom part of the exhaust volume is designed not to disturb thermal streams which rise up from the cooking equipment.

5.3 Operation and description of Capture Jets

Figure 20 shows a simple simulation of a cooking process in kitchen made by Halton. Lots of steam, heat, vapours and grease particles come upwards from kitchen equipment (1, Figure 20). Then these emissions meet Capture Jets with its technology of peripheral, horizontal and vertical nozzles (2, Figure 20). In point 3 (Figure 20) comes a supply air with low velocity which helps convective flows to rise freely. Then they are removed by the extraction plenum (4, Figure 20) as quickly as possible.

Besides low velocity supply and new Capture Jet technology that both increase the efficiency of the system there is a special internal shape of the canopy. It raises the contaminant collecting capacity and reduces exhaust airflow up to 30-40% /6/.

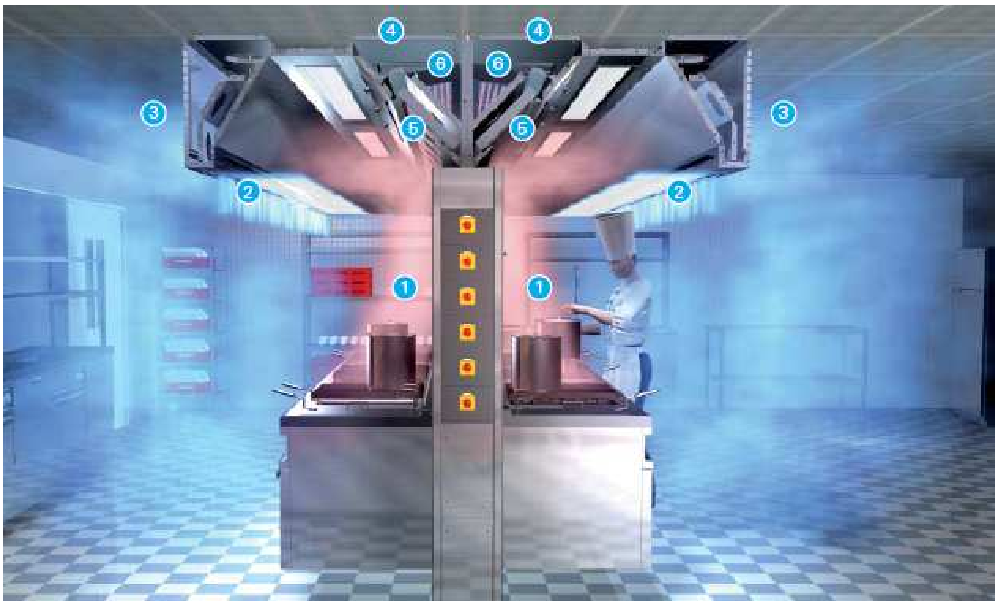
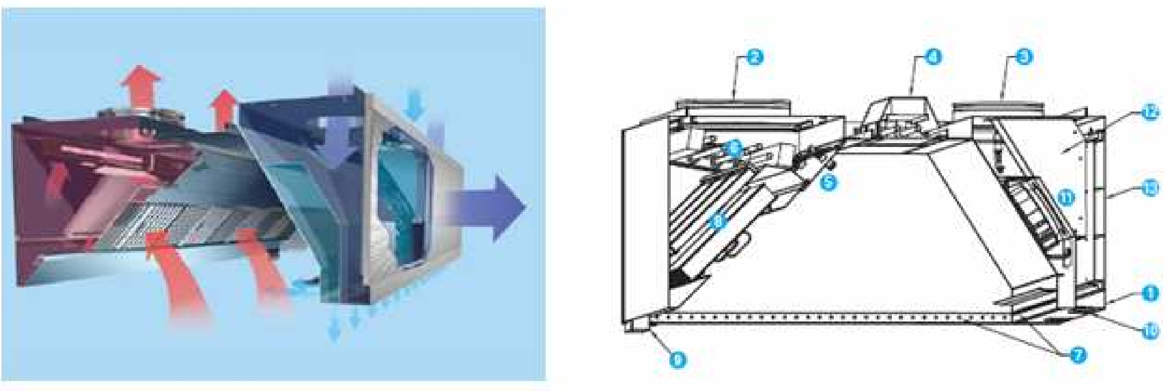


Figure 20 Simulation of a cooking process /6/

Double stage filtration is a next step of the system. Convective stream cached by the hood goes through two multicyclone filters (5, Figure 20). At this step most of the large grease particles are removed. After multicyclone filters comes a section with UV-C lamps (6, Figure 20). Here lamps generate UV-light and ozone which neutralize smaller grease particles and vapours of the exhaust stream. Efficiency of this step depends much on size of grease particles which should not be large. That is why efficient work of fist stage with mechanical filters is very important. Multicyclone filters are therefore most likely used with Capture Jet technology.

Capture Jet canopies are manufactured in modular sections. They can be joined together in a row because of the design properties. Some units are opened from the both sides and can be put in the middle; some are closed from one or both ends. More exact description of a unit is shown on Figure 21.



CODE DESCRIPTION
1 Outer casing – visible parts in stainless steel AISI 304
2 Exhaust air connection and adjustment damper
3 Supply air connection and adjustment damper (type MSM)
4 Light fixture with electrical junction box
5 Access hatch
6 UV lamps rack
7 Capture Jet™ nozzles
8 KSA double stage filtration
9 Grease collection tray or drain tap
10 Personal supply air nozzles
11 Capture Jet™ fan
12 Capture Jet™ fan air inlet plenum
13 Perforated front face

Figure 21 Description of a Capture Jet unit /6/

Besides reducing of energy demand and exhaust airflow this technology reduces odours in exhaust air. It increases opportunities to use heat recovery units. Moreover ducts stay clean longer than with other systems so maintenance costs are reduced.

5.4 Integration of UV-lamps and UV control system

The system can be controlled by special integrated Capture Ray Ultraviolet cassette which has complete controls and safety features. The main idea of this cassette is useless maintenance controlled by the computers. There are maintenance free magnetic proximity switches which control the access door to the cassette and individual filters. It means that even accidental open of the doors would not be dangerous because UV-lamps will turn off immediately. It prevents any exposure to direct UV radiation in any case.

There is also a control panel. All the informing messages come to a display in case of any faults. For example there can be any of these warning messages:

- UV access door is open
- filter removed
- UV-lamps life time is exceeded
- ballast fault
- low pressure
- low air flow
- communication error between units

There are other opportunities to control the system using new technologies. For example SMS/GSM modem for remote maintenance communication or BMS (Building Management System) connectivity. Another way of improved maintenance is connection of the UV system to the PDA (Palmtop computer) or mobile phone. Assessable information includes:

- all the time renewed data about air volume and pressure
- actual working hours of the UV-lamps
- access to reset working hours for those lamps which were replaced

5.5 Recommendations for using and maintenance of systems with UV-C technology

There are some main points which should be always known and remembered using UV-C systems:

1) Mechanical filters

- It is necessary to use efficient mechanical filters before UV-C system. It is all about chemical reactions that happen in a molecular stage. If the first-stage grease filters are not enough efficient to take away grease particles bigger than 3μm to 5μm, the grease molecules inside of this particles would not be oxidized by UV-light. Moreover these non-oxidized particles will stay on the surfaces of ultraviolet lamps making them less efficient.

2) Protection against UV-radiation

- All parts of UV system should be isolated. They should be covered or has special protective equipment to avoid of irradiation of people in the kitchen by ultraviolet light. Irradiation by this light can cause different problems including burns of skin and mucous membrane of the eye. It is rather dangerous because of using rays with high intensity in UV-lamps of exhaust cleaning systems.

3) Protection against ozone

- Outputs of UV systems used in kitchen can contain ozone. Ozone in high concentrations can cause an irritation of upper respiratory tracks. So there is a need to disconnect the whole system automatically in case of malfunction or stop of exhaust fan. High-quality UV-C equipment usually have this kind of protective system. The concentration of ozone in exhaust air is usually not more than 1 particle of ozone to 1 million particles of air. It brings no harm if output of exhaust air is above the roof so that exhaust air is mixing with fresh air without delays. In some difficult cases it is possible to use special filters to clean exhaust air from ozone.

CONCLUSION

There are many complaints about kitchen emissions. Mostly they are from people who work in commercial kitchens or live around. Inside problems are caused by heat, grease emissions, smoke, vapour, odours and noise. Outside complaints are connected to odours and noise as well.

After the research work that I've done it is obvious that all these problems are solvable. There are simple decisions as one-stage filters. They are more suitable for smaller kitchens. To get more efficient filtration there are multi-stage filters supplemented with new technologies like HEPA-filters, activated carbon filters, electrostatic precipitators or UV treatment. All of these technologies are rather efficient, but they are expensive as well.

Use of ultraviolet light in exhaust air filtering is very efficient and convenient in many ways. It destroys grease in molecular level so systems don't need to be cleaned a lot. The main maintenance costs come from a need of changing UV-lamps. To sum up the research done by ASHRAE there are several well-defined benefits of UV-technology:

- UV-light changes the chemical structure of cooking emissions
- The concentration of volatile organic compounds is reduced after using of UV treatment
- The concentration of carbon dioxide is increased
- The inner surfaces of exhaust air ducts and UV chamber stay dry and rather clean, except of appearance thin layer of white powder on duct surfaces in time
- Amount of odours is reduced
- Treatment of air using UV-light is noiseless.

Efficient work of UV system needs some requirements as well. First of all it is efficient filtration in the first stage of exhaust ventilation. Tests with comparing efficiency of different filters were made by Technical Research Center of Finland. Multicyclone filters have shown the best performance in tests with grease collecting comparing to other common first-stage filters. Other thing is limitation of output of

UV lamps depending on size of a kitchen and whole exhaust system ventilation. It is important because of dangerous influence of UV-light and ozone on human health.

To my mind UV treatment of exhaust air is a good solution for commercial kitchens. This technology should become more popular in time. Different cooking processes create various emissions so needs of filtering and their types depend on situation. I suppose it is a question of time and investment to make UV systems widely distributed and convenient for every type of commercial kitchens.

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