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Feasibility Study of Using Condensation in Increasing Diameter of Airborne Particulate Matter to Enhance Control Efficiency

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ABSTRACT- Particles with aerodynamic diameter of less than 10 µm can effectively pass through respiratory system and deposit on pulmonary areas wich cause adverse health effects. These particles are divided in to coarse particles (diameter: 2.5 to 10 µm) and fine particles (diameter < 2.5 µm). Fine particles can be more harmful for human's health and harder to remove by air pollution control machines compare to coarse particle so it is crucial to find methods to enlarge the size of these particles. In this regards common methods such as utilizing electricity are costly and not efficient enough. Hence other economical and efficient methods such as using condensation are eamined. In this study the growth of particles has investigated experimentally via heterogeneous condensation as a preliminary technic to be implemented before control devices. The effect of four parameters was investigated: The condenser temperature, the saturator's temperature, the temperature difference of condenser and saturator, and the length of the condenser. The saturator's and condenser's temperatures did not considerably affect, however but as the temperature difference increased, an increscent was seen in the particle's growth a certain length. As the condenser length increased, the particle's growth enhanced however after a certain length increase it didn't considerably changed. The results also indicated that the high density of particles could adversely affect the nucleation rate and sudden nucleation for all particles was not possible. The results indicate that, in temperature difference of 80oc, this method was able to decrease the up to 80% of particles smaller than 2.5 µm. The result of this study showed the significant potential of this method in increasing the efficiency of the air pollution control devices.

***Key words**: Condensation, Particulate matter, particle growth, Air pollutants control, Air pollution*

One or several pollutants or a combination of them in external or internal atmosphere in the amount and time interval that might cause damage to life of human, animal and herbs or properties, and also cause intervention in enjoying convenience in life or properties, are called air pollution. Such pollution is the product of construction in cities, remnant of activities like manufacturing goods, transport, generation of thermal energy and light at residential areas, entertainment and workplace. The leading factor which results in air pollution is combustion, and as known, combustion is still required for life. If combustion occurs in complete or in part, hydrogen and carbon existing in fuel will be combined in air oxygen, whereby heat, light, Carbon dioxide and water vapor will be produced.

However, impurities in the fuel, poor ratio of fuel to air and extremely high or low temperature of combustion have caused developing byproducts including Carbon monoxide, sulfur oxides, nitrogen oxides, volatile ash and Unburned hydrocarbons, that all are air pollutants[2].

Problem statement and research importance

A way to purify particles is submerging them at natural area with presence of rain drops. Tiny particles with Brownian Diffusion Collide rain drops. Brownian Diffusion reduced by increasing particles in diameter.

Effect from this mechanism can be reported for particles smaller than 0.1 micron. By increasing diameter of particles, Inertial Impaction has been removed from the prevailing process. This process is for particles greater than 1 micron. As shown, for particles ranging from 0.1 to 1 micron, a gap has been created that recognized with Greenfield Gap [8].

Separation of tiny particles or particles in Greenfield Gap in common devices for controlling air pollution like Cyclone, scrubber, Electrostatic Predicator (ESP) is with very little efficiency as compared to larger particles, and also correcting these devices to have better control over tiny particles is highly expensive and difficult[9-11].

For instance, Mhor has shown that even in Electrostatic precipitator that are the best choices to remove Small suspended particles, where the more size of particles reduces, the more efficiency for removal reduces that the highest decrease is at interval 0.2 to 0.4 micron. For precipitator with efficiency (99.7%) for all the particles, the efficiency for particles ranging from 0.1 to 1 micrometer has been reported 85%[12]. As stated, the studies have shown that tiny particles compared to coarser particles will bring about more damages, that further Mhor has shown that efficiency of pollution control devices for tiny particles severely decreases. It should be noted that the severe decline in efficiency is not particularly for Electrostatic precipitator, that further includes other devices like Cyclone and scrubber, and this has been clearly clarified in table 1. Oversizing particles and shifting particles distribution can help to avoid such problem, and then efficiency of pollution control devices can be largely increased. For this, a variety of methods like use of acoustic waves, Electrical charge and condensation can be used. In method of acoustic waves using acoustic waves, impacts increase leading to increasing particles in diameter and Retention time reduces. This method can be used in open spaces and in exposure to accidental disasters. Yet, to particles with different diameters, different waves are required[13]. Studies on increase size focused at using electrical charge have been conducted. In the method of Electrical charge, closed particles fluctuate depending on size and load with a specific speed and amplitude. This difference has caused Kinematics of particles stick together, and then Efficiency of Electrostatic precipitators to increase[14].This method in addition to imposing high cost due to electricity force, will not have a high efficiency for particles like cement that have little loading capability. Problems in using these methods even in economic perspective or considering lack of their efficiency have been observed for all particles, that all made the research in order to find a method without the problems. A method proposed in this context is the use of Condensation of particles.

Use of Condensation of particles by means of a high cost has been utilized as a method to measure and Condense particles. Use of Condensation of particles to increase diameter so as to increase efficiency of device has been examined in terms of effect of condensation on particles and determining the effect by different parameters, where its use has not been examined as an economic system for control of particles. As stated, use of Condensation in normal condition due to essential energy for the processes of heating and cooling required for Condensation, is not economically effective. Yet, in most of factories like electric arc furnace, the air must be cooled before entering to devices for pollution control, as shown in figure 3, that use of this process can be beneficial to have economically effective use of Condensation. For this, it can saturate air by putting the water tank in the direction of exhaust air before cooling system with water, so that by passing through cooling part, necessary conditions will be built for Condensation, and efficiency of pollution control will increase by increasing diameter of particles.

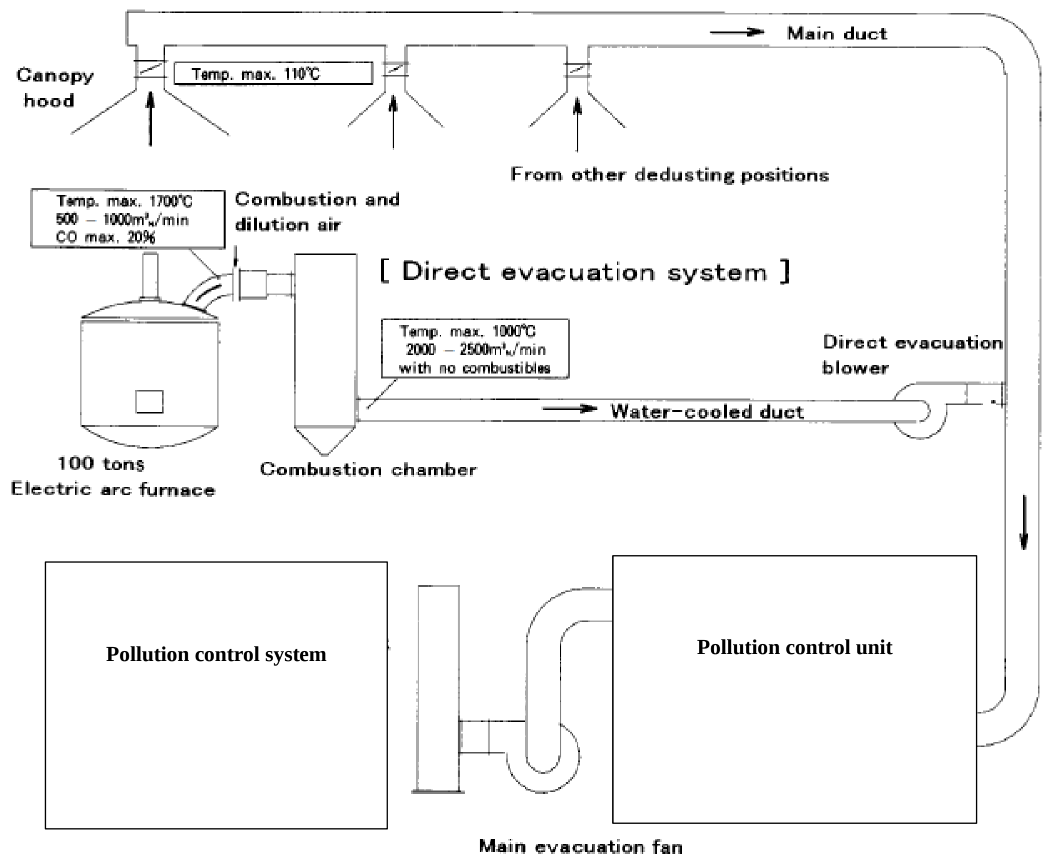

Figure1- a common pollution control system for 100 ton EAF

Table1- reduce suspended particles from gas

Device	Size (μm) (Efficiency)	Advantages	Disadvantages
Electrostatic Precipitators (dry and wet)	1-2 (95-98%) 0.5 (91%) 0.1 (95%)	• High efficiency even for small particles. • Suitable for wide temperature, pressure and gas flow ranges. • Low pressure drop, hence the energy required tends to be low.	• Explosion risk with dry ESP. • The separation capacity depends on the resistivity of dust particles. • Dry ESP not recommended to remove sticky or moist particles.
Wet scrubber (Spray Towers)	1-2 (70-85%) 0.5 (60%) 0.1 (93%)	• Flammable and explosive dusts can be handled with little risk. • Simultaneous removal of dust and inorganic compounds.	• Relatively low mass-transfer efficiencies. • Relatively inefficient at removing fine PM.
Fabric Filter	1-2 (99.7-99.8%) 0.5 (99.1%) 0.1 (99.8%)	• High collection efficiencies for coarse and fine particles. • Residual emissions are virtually independent of the intake concentration.	• No wet or sticky dusts allowed as input. • There is an explosion risk.
High Efficiency Cyclone	1-2 (20-40%) 0.5 (8%) 0.1(-)	Simple plant and low cost.	For lower diameter it needs to be enhanced by another method.

Okuyama in 1977 conducted a study entitled “Particle loss of aerosols with particle diameters between 6 and 2000 nm in stirred tank”, where deposition loss of aerosol particles in a stirred tank has been studied experimentally by observing the time-dependent changes in particle number concentration for various intensities of stirring. The stirred tank used in this study is a standard baffled tank with six-bladed turbine impeller or three-bladed propeller, and the aerosol particles used are mono disperse uncharged NaCl, DEHS (diethylhexyl sebacate), and polystyrene latex particles. The experimental results have shown the clear dependence of the deposition rate on particle size and turbulent intensity of stirring, and also shown that for a given intensity there exists the particle size at which the deposition rate constant becomes minimum[24].

S. Heidenreich, F. Ebert in 1995 conducted a study entitled "Condensational droplet growth as a preconditioning technique for the separation of submicron particles from gases", that Droplet growth by heterogeneous condensation of water vapor as a preconditioning technique for the separation of submicron particles from gases has been investigated both theoretically and experimentally[25]. Heidenreich to continue his study in 1999 conducted a study entitled "A novel process to separate submicron particles from gases - a cascade of packed columns", where A novel process using a cascade of packed columns to separate submicron particles from gases with high efficiency is presented. The process is based on the enlargement of the submicron particles by heterogeneous condensation. The particle enlargement as well as the collection of the droplets is achieved in the packed columns. Each column of the cascade is trickled with water which is alternately colder or warmer than the gas. The temperature difference between the gas and the water is required to achieve super saturation of the vapor and correspondingly droplet growth by condensation in each column. The performance of the process is evaluated by experimental investigations. The collection efficiency of a two-stage cascade is determined using different submicron particles, such as residual particles, quartz particles, and paraffin oil droplets. It is shown that high collection efficiencies can be obtained by this separation process, also at high particle number concentrations. Since a new super saturation is achieved in each column, large droplets are formed which are collected at the packing material of the columns with high efficiency. Correspondingly, submicron particles are separated with high performance by cascading packed columns [9].

Marco Tammaro, Francesco Di Natale, Antonio Salluzzo, Amedeo Lancia in a study entitled "Heterogeneous condensation of submicron particles in a growth tube", reported that This study reports a study on the enlargement of particles, produced by a model ethylene/air flame, by heterogeneous condensation of water vapor. This was carried out in an instrumented lab-scale facility based on the use of a growth tube. Tests were performed by varying the temperature of the condensing vapor and the gas residence time in the growth tube. Particle enlargement was favored by increasing the vapor temperature and the residence time. Experiments can be proficiently described using consolidated models for heterogeneous condensation, provided that the contact angle between the liquid embryo of condensing vapor and the particle surface is considered as an adjustable parameter, variable with temperature. Studies in this context have not limited to condensation in particular. Large studies in the context of using Heterogeneous condensation I scrubbers to increase their efficiency against tiny particles have been conducted. Large body of studies about these processes and use of them in controlling particles has been conducted.

Messerer(2007) in a study "Combined particle emission reduction and heat recovery from combustion exhaust—A novel approach for small wood-fired appliances", examined Replacing fossil fuels by renewable sources of energy is one approach to address the problem of global warming due to anthropogenic emissions of greenhouse gases. Wood combustion can help to replace fuel oil or gas. It is advisable, however, to use modern technology for combustion and exhaust gas after-treatment in order to achieve best efficiency and avoid air quality problems due to high emission levels often related to small scale wood combustion. In this study, simultaneous combustion particle deposition and heat recovery from the exhaust of two commercially available wood-fired appliances has been investigated. The experiments were performed with a miniature pipe bundle heat exchanger operating in the exhaust gas lines of a fully automated pellet burner or a closed fireplace. Deposition was dominated by thermophoresis and diffusion and increased with the average temperature difference and retention time in the heat exchanger. The aerosols from the two different appliances exhibited different deposition characteristics, which can be attributed to enhanced deposition of the nucleation mode particles generated in the closed fire place. The measured deposition efficiencies can be described by simple linear parameterizations derived from laboratory studies. The results of this study demonstrate the feasibility of thermophoretic particle removal from biomass burning flue gas and support the development of modified heat exchanger systems with enhanced capability for simultaneous heat recovery and particle deposition. Gröhn et al (2009) Reduction of Fine Particle Emissions from Wood Combustion with Optimized Condensing Heat Exchangers, provided their study in this way , designed and built a condensing heat exchanger capable of simultaneous fine particle emission reduction and waste heat recovery. The deposition mechanisms inside the heat exchanger prototype were maximized using a computer model which was later compared to actual measurements. The main deposition mechanisms were diffusion and thermophoresis which have previously been examined in similar conditions only separately. The obtained removal efficiency in the experiments was measured in the total number concentration and ranged between 26 and 40% for the given pellet stove and the heat exchanger.

Aim of study

This study aims to produce and evaluate condenser device in enlarging particle size under different circumstances so as to increase efficiency in removing particles. Using the results below can help to understand the use of this method in industrial environments. In general, aims of study are as follows:

- Feasibility Study of device and examine functioning by device in enlarging particles
-examine effect of condenser length on functioning by device
-examine effect of condenser temperature on functioning by device
- examine effect of saturating temperature on functioning by device
- examine effect of condenser temperature difference of on condenser and saturating temperature on functioning by device

Materials and methods

To examine to what extent condenser affects by means of processes like Brownian diffusion for the case saturator removed from system, 15 other cases are added to experiments. An experiment was also conducted to measure the amount of early particles. To sum, 61 experiments were conducted.

A general view of experiment:

This study aims to determine a mechanism to address enlarging particles size and shifting particles distribution by means of condensation. Meanwhile, functioning by condensation is also taken into account in this mechanism. In this system, pollution produced by pollution source has been gathered by means of a hud, and then polluted air has been entered into a closed area. In this area, pollution in air is uniformed, and pollution fluctuations deriving from fluctuations by producing have been reported.

Pollution source

There are a variety methods and devices to produce Suspended particles. An ideal producer produces Stable and spherical particles without charge by an ability for uniform producing that size and distribution of its particles have been easily controlled. To produce particles, different methods including Atomization of Liquids, Ultrasonic Nebulizer, Metered Dose Inhaler, Vibrating Orifice Aerosol Generator, Spinning Disc Aerosol Generator, Fluidized Bed Aerosol Generator and Electrospray Aerosol Generator have been used.

Uniform tank

In this experiment, a tank similar to the tank used in study by Okuyama(1986) has been used, with the difference that the tank is made of aluminum in which Glass and foam fibers were used to develop Insulation conditions. To measure the amount of pollutant in the beginning of experiment, another output has been also embedded within it[60]. To be well-informed of the early temperature, a Thermometer has been embedded within tank. As shown in figure 25, reducing particles for retention time used in this experiment is 30 seconds, that is negligible, and it can say particles maintain their early status.

Water bath (saturator):

To simulate conditions, Okuyama has proposed two other methods including Steam injection and air contact with heated water. air contact with heated water in addition to be an easier way can be adapted with real status in terms of functioning[24]. To design water bath, retention time for saturating air is a deterministic factor. Kim has proposed this time 3 seconds at 30 ° C, and Sivas has proposed this time 10 seconds at 50° C[27,30].

Condenser:

Condenser used in this experiment has been developed from a Copper pipe that placed inside a plastic pipe with one inch diameter. The warm air passes through pipe and cold water passes between the plastic tube and copper tube. At the end of two Condensers, silicone adhesives have been used for Sealing.

Cold water tank

To have cold water flow, an insulated tank has been used that the required cold water at given temperatures equal to 0, 10 and 20 ° C, prepared with a mix of water and ice.

Measurement Machine for Suspended particles

All the measurements have been measured via Aerocet-531 Mass Particle Counter/Dust Monitor device, that have the ability for online measurement, and can go on the measurement per one or two minutes in terms of type of required measurement. Aerocet is a type of Optical particle counter. Measurement in Optical particle counter is based on Nephlometry measure (Cloud Detector) regarding light scattering. In such devices, sample enters to device via pipe. In case of light particles produced via Scattered light source, the scattered light can be measured via sensors. Measured signals are equivalent to size and number of particles. Such devices in case of being under calibration, accuracy in use and correct measurement are reliable and totally ture. Kim in 2001 used a type of Optical particle counter and other devices to evaluate VACES.

Measurement device for gas pollutants

To examine other gas pollutants and effect of device on them, VRAE device has been used in this experiment. Measure this device can be regulated for each data that is considered 10 seconds in this experiment.

Measurement tank:

This tank is a cylindrical tank of Polyethylene that is put alongside the path to use it in case of turning off pipe during measurement for measurements. Tank is taken having 32 liter volume, to have fewer problems.

Dehumidifiers:

To avoid effect of air particles on pipe, Dehumidifiers have been embedded. In this part, air entered to a glass chamber that caused trapping moisture in chamber and conserving vacuum pipe. In figure 27, a schematic view of Dehumidifier has been proposed.

Flow measurement:

Flow measurement in suspended particles experiments have been conducted using a variety of instruments including Pitot tube, Hot wire Anemometer, Venturi meter, Orifice meter, Laminar flow meter, Rotameter and etc.

Vacuum pipe:

In this experiment, to build necessary Propulsion to move air in different parts of experiment, a vacuum pipe has been used that worked with electricity available at city and has the power of 018/0 km. this pipe by means of tap above it can regulate flow.

Pipes and taps:

Pipes used to transmit air alongside experiment as well as inside Condenser are of cooper. Why cooper chosen lies on a fact that due to sever warmness, the possibility to use plastic pipes was not provided, and cooper pipes rather than aluminum pipes were a better choice as found available all the time.

How to measure:

To measure the early flow after joining measurements tank and starting device for 20 minutes, better to wait for replacing existing air in tank with polluted air. Then the pipe must be turned off, addressing measuring mass concentrations with AEROCET device for 2 minutes and measuring gases with VRAE for 10 seconds.

The results from effect of Condenser on suspended particles:

Results in different intervals of condenser

In figure below, the concentration of particles after condenser for particles smaller than 2.5 and 10 micron has been proposed. as shown, data are so close to each other.

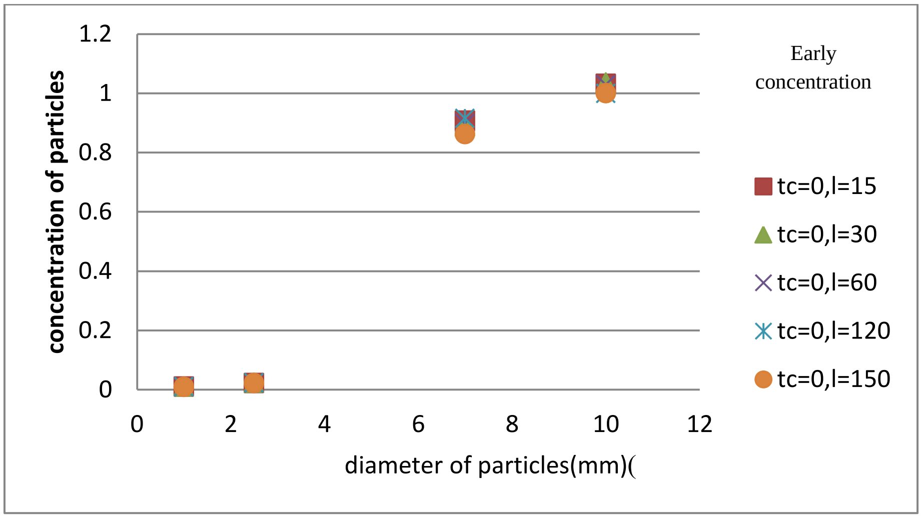

Figure2. Results from effect of Condenser on suspended particles for different intervals of condenser

Results at different temperatures of condenser:

In figure below, the concentration of particles after condenser for particles smaller than 2.5 and 10 micron has been proposed. as shown, data are so close to each other.

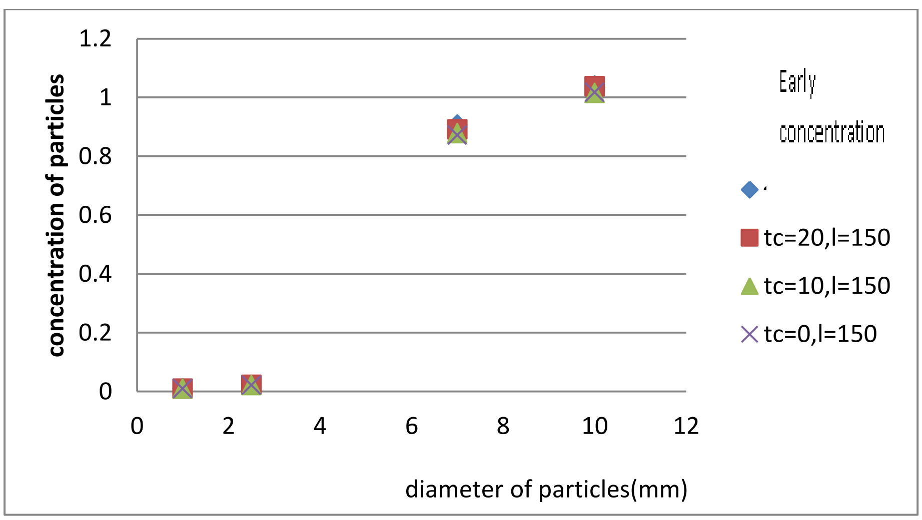

Figure3. Results from effect of processes inside Condenser on suspended particles for different temperatures of condenser for particles smaller than 10 micrometer

As the results indicate, in general decreasing the amount of suspended particles can be seen, yet it cannot judge on the effect by condenser's temperature on suspended particles. Yet, as this amount is just little, so the measurements might reach to about 10% of measurements value. This way cannot be seen in experiments.

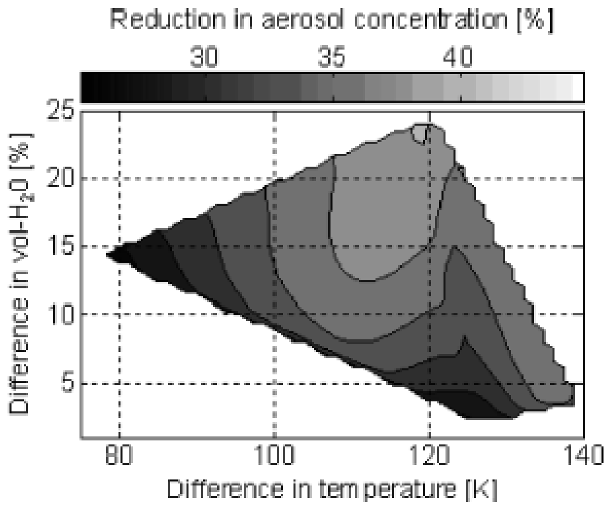

Figure4-decreasing suspended particles regarding temperature difference and the early vapor concentration [41]

As observation on results has shown, processes within condenser have just negligent effects on the early concentration of particles. To study this experiment, it has to take into account that the early temperature of particles in unfirming tanks reported equal to 40° C. According to the obtained results from the study by Grohen that shown in figure above, and given the temperature difference in the experiments, and regarding the fact that pipe with more diameter in this study compared to study by Grohen has been used, thereby decreasing effect of processes including Brownian Diffusion will be seen. Obtained results indicating little effect by such process are reasonable.

Effect of device on other pollutants:

To observe effect of other pollutants, the results from gas measurements device were examined, that indicate changing pollutant SO_2 ranging from 1.2 to 1.6 ppm, and from 40 to 50 ppm for pollutant CO. other pollutants found with an amount equal to zero, these results are in accordance with the results of study by Pakbin[33,56].

Conclusion

This study aims to propose Feasibility Study of Using Condensation in Increasing Diameter of Airborne Particulate Matter to enhance efficiency of pollution control devices and examine to what extent parameters including temperature of condenser, temperature of saturator, temperature difference of condense and saturator can affect the process. The results indicate feasibility of using heterogonous condensation to shift particles distribution towards larger particles and increase efficiency of air pollution control devices, which enjoys the ability to reduce concentration of smaller particles from 2.5 micron to 80% at proper conditions.

The results observed in the study do not indicate a relationship between temperature of condenser and saturator, and the changes of these two parameters without a change on temperature difference will not have any effect on shifting particles distribution. Indeed, it can say these two parameters do not affect or affect just a little, thereby the little effect can be ignored in case of having other parameters.

The results of experiment indicate increasing temperature leads to increasing efficiency of device. Yet, it must take into account that exceptions are observed in tis context yet the general process indicates increasing shift by particles to larger particles. Study impacts of condenser that can represent time on function of device indicate increasing efficiency of device by increasing length of condenser. Yet, it should be noted that in the early lengths rather than ending lengths, increasing particles found rapider. Results indicate that decreasing relative concentration decreases from 17% to 48% for temperature difference of 40° C by increasing length from 15 to 150 cm. According to the high early concentration used in this experiment and given positive functioning by device, it can conclude this method can be used effectively in high concentrations. It can also say by decreasing pollution concentration, more efficiency can be than expected. This efficiency can be increased even till 100% for proper concentrations.

Having a percent of remnant particles smaller than 1 micron and as the result of previous studies for length of condenser and temperature difference above 1 micron, it can say that high concentration has caused this.

Suggestions

As stated, this is aimed to use condensation to increase efficiency of pollution control devices. For this, it is suggested to use this method as a technique together with a pollution control device like scrubber so as to observe to what extent device affects efficiency of pollution control device. As observed, larger particles have negative effect on device's function. The larger particles can be reduced before entering to device, using a silcon. Then, it can address to device's function under a variety of parameters. As stated, high concentration of particles has caused decreasing efficiency of device. It can use a real source like wooden heater, outlet of an automotive's engine with high temperature in the experiment, and examines effect of dilution through weather of area on device. Further, in case of using a thermal source with high temperature, it can carry out air saturation by passing warm weather through water at normal temperature, and then investigate efficiency of device for different retention time of air in saturator. Use of a real source has caused better distribution of particles be close to 2.5 micron. In this sense, it can investigate device's function. As observed in results, ignoring moisture at condensation process on particles in mass transmission and temperature inside condenser is not suggested. In upcoming studies, modeling can be provided.

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