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Using Multiple-Phase Nozzles to Produce Water Droplets for Removing Smaller Dust Particles of Below MRT-BTS Saphan Khwai Station in Bangkok Thailand

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Abstract

The research is intentionally aimed to employ the multiple-phase nozzles to produce the 10-micrometer water droplets in gas form to remove less 100-micrometer smaller dust particles by agglomeration process inside street tunnel on heavy traffic point sources at sky train MRT-BTS Saphan Khwai station in Bangkok. The four sets of 100-m hoses with 52 multiple-phase nozzles (208 nozzles) were established on 100-m beams (four beams), which are 21-m wide (5-m apart) and 5.575-m high, and connecting with high pressure pump (1,000 lbs/min) to press clean water 0.076 liters/min through the 10-micrometer orifice nozzles. The spraying time was about every 10 minutes during collecting TSP and PM10 dust by Hi-Volume Air Sampler on five periods of 05:00-08:00, 08:00-11:00, 11:00-14:00, 14:00-17:00, and 17:00-20:00 for 5-consecutive days, 30 November to 4 December 2008. Also, the air temperature, actual vapor pressure, and speed-direction wind measured at 1.5 and 5.0 meters in height underneath of the ceiling and above the roof of MRT-BTS Saphan Khwai station. Results found that the multiple-phase nozzles showed effectiveness to remove the smaller 100-micrometer dust particles underneath of MRT-BTS Saphan Khwai station by spraying 10-micrometer water droplets through 10-micrometer orifice nozzles. The decreasing concentration of TSP northerly 30.25 %, southerly 26.21 %; and also for PM10 northerly 39.96 %, southerly 40.39 %. Moreover, the concentration between street tunnel and northerly were decreased in both TSP (30.38%) and PM10 (40.17 %), and southerly were decreased in both TSP (30.05%) and PM10 (40.88 %). In case, on the central line effects between street tunnel and northerly found the decreases of TSP (30.64%) and PM10 (37.65%), southerly decreases of TSP (33.71%) and PM10 (43.78%). An increase of the 10-micrometer water droplets spraying frequency through multiple-phase nozzles (208 nozzles) is expected to gain more decreasing concentration down to under standard values. In addition, an applying the concentration of smaller 100-micrometer dust particles is useful for setting the automatic pumping operation that would be acceptable to the public.

Keywords: multiple-phase nozzles, water droplets, outdoor particles control

1. Introduction

Air pollution in Bangkok has been accused more than standard since the year of 1970 due to extremely explode the population and inconsequently increasing vehicles that produce more concentration of hazardous gases such as carbon monoxide, oxides of nitrogen and sulfur, aerosols, and suspended dust. Also, the inflexibility of traffic volume, particularly shape, width, length, and surface roughness as well as the localization of disordered buildings on both roadsides around the city might be enhanced to decrease the speed of vehicles. In consequence, the slow movement of vehicles are not avoided to produce high polluting concentration of carbon monoxide, oxides of nitrogen and sulfur, hydrocarbon, aerosols and suspended dust which are harmful for human breathing, and also producing effects of another biotic, abiotic and social environment. Although, the air pollutant constituents seemed serious impacts on human health and another environments in Bangkok mega city, the real event was not shown in the same trend because the high actual water vapor as contained in the atmosphere and long-period rainy season could catch up with those pollutants falling down to the earth surface. It is remarkable of long-term records found that the most serious air quality problem usually occurs at stagnation period of each day during 17:00-19:00 pm and 6:30-7:30 am in which the vertical wind speed is terribly low and some day maybe zero that causing no vertical movement of polluted air but it is accumulated on road surface.

The aforesaid statement was pointed out that the highest concentration of toxic gases and suspended dust were indicated the most poison to human health and being harmful to another environments. In order to solve such problem, the Bangkok Metropolis has set long-term plan for mass rapid transit (MRT) for decreasing some numbers of vehicles on the traffic volume by constructing Bangkok Transportation System (BTS) skytrain above ground 12-m height with distance about 45 km from Moh Chit to Sukhumvit 77 and Sathorn. Since, the narrow roads and dense shophouses along both roadsides, it makes the MRT-BTS stations fitting-in that space between them causing to block off the buoying fly dust out to sky. Surely, fly dust and toxic gases not only removing from the underneath of MRT-BTS stations but they are also poisonous to shophouse dwellers as well as pedestrians, tourists, mass transit passengers, businessman, and school children. Concerning with the most seriousness of human health, the Office of Natural Resources and Environment Policy and Planning (ONEP), Ministry of Natural Resources and Environment, has made the strong requirement in the approved environmental impact statement (EIS) to mitigate suspended dust rather than toxic gases. The EIA study team recommended to suck up the contaminated air underneath of MRT-BTS stations to the upper levels of sky but it seems to take pollutants out from one place to another places in which it should not be ignored to follow such recommendation. In order to find the better means, the resolution from discussion between research team and MRT-BTS Operation manager found the atomizing water to dipolar molecules for catching up with PM10 suspended dust was the most probable means for mitigating measure to reduce the suspended dust underneath of MRT-BTS station. For serving research need and ONEP requirement, the Saphan Khwai MRT-BTS station was selected due to more amount of PM10 suspended dust than the other stations as recorded in approved EIA final report.

Normally, the fly dust (suspended dust) is surely one of the atmospheric component in the state of Brownian motion without direction according to the thermal forces of convectional process as one of heat transfer processes from vertically warmer earth surface to cooler adiabatically atmosphere, and also horizontally warmer to cooler points (Brabec, 2003; Carotenuto et al. 2010; Charinpanitkul & Tanthapanichkoon 2011; Hidy & Brock 1971; Gaunt et al. 2003a, 2003b; Jaworek et al. 2013). In paralleling of aforementioned statements, Sellers (1969); Linsley et al. (1988); Grim (1962); Grunding et al. (2006); Hidy and Brock (1971); Baver et al. (1972); Gaunt et al. (2003a, 2003b); Carotenuto et al. (2010); Botkin & Keller (2005); Balachandran et al. (2003) have done their research works and found that wind is identified as the supporting factors for fly dust moving, particularly turbulent wind and also dry season. Also, there are suspended dust particles in the atmosphere which is high concentration in the tropopause atmospheric layer, less in the stratosphere, and very less in the mesosphere. In other words, the more the closer the earth surface are more the concentration of suspended dust. In the same context, more suspended dust which are contained in the very close to the ground surface because they are very close to the point sources, such as wind erosion from fine texture of open soil surface, slash and burn farming activity, ploughing activity, forest fire, road construction, exhausting pipe of mobile vehicles, abrasion of vehicle tire, heavy equipment scouring, and cleaning on the streets. In general, suspended dust is a solid but some of them may be coating with water vapor, oils and grease or some wet chemicals, and hydrocarbon that make them adhering each other to form the bigger size, and then falling down to the ground.

Theoretically, Linsley et al. (1988); Botkin and Keller (2005); Gardner (1955); Gaunt et al. (2003a, 2003b); Grim (1962); described that the suspended dust itself could have functioned as the negative charge particle, and readily to be absorbed by any positive-charged particles to form a bigger size with increasing weight and falling down if its weight is greater than gravitational forces. In addition, there are more 70 % of total fly dust in the atmosphere to be negative charge and hydrologically called as condensation nuclei that induces the occurrence of precipitation whenever the atmospheric moisture and cooling process are available. Following this hydrological principles for the occurrence of precipitation, the suspended dust with negative charges could hypothetically be caught up with dipolar water molecules in order to become neutral and gradually increasing in sizes until big enough to fall down by gravitational forces. In consequence, the dipolar water molecules as obtained from precipitation process are freed by Brownian diffusion to catch up with the negative-charge dust size more or less PM10 suspension, and increasingly forming in bigger size enough to drop from sky layers to the earth surface before distributing all directions. In case of more concentration of hazardous gases contaminating in the sky, the precipitated toxic solution might be affected to trees, cultivated crops, animals, buildings, stream water, and archeological objects one way or another.

Linsley et al. (1988); Grim (1962); Baver et al. (1972); Sellers (1969); Botkin and Keller (2005); Hidy and Brock (1971); Gaunt et al. (2003a, 2003b); Carotenuto et al. (2010); Dai et al. (2008); Hensley et al. (2008); Jaworek et al.

(2013) collected the research papers on the condensation nuclei (negative electron fly dust) from hydrological, meteorological, and air pollution points of view and explained that the condensation nuclei/fly dust was consisted of the products of combustion, oxides of some non-metals (such as nitrogen, carbon, and sulfur) and salt particles; ranging in size from about 0.1 to 10 micrometers in diameter but less than 3 micrometers are within the size range of aerosols and might remain airborne indefinitely were not precipitation fallout due to non-negative charge available to be caught by dielectric water molecules. However, most droplets in non-precipitating stratus cloud have diameters under 10 micrometers, and upward current of less than 0.5 cm/sec is sufficient to keep them from falling. For control practicing, the one-phase or two-phase nozzles can produce the water sprays for catching up with fine dust that automatically mobilizing in the air (Brabec 2003; Gaut et al. 2003a, 2003b; Charinpanitkul and Tanthapanichakoon 2011; Grunding et al. 2006; Linsley et al. 1988; Gardner 1955). Moreover, Plinke et al. (1991); Jaworek et al. (2013); Gardner (1955); Balachandran et al. (2003) have recommended to reduce the dust and bulk materials as well as smoke by moistening those particles for dropping down to the ground surface.

Employing research works of Balachandran et al. (2003); Brabec (2003); Gaunt et al. (2003a, 2003b); Grunding et al. (2006); Hensley et al. (2008); Hidy and Brock (1971) can creatively be the research title on using multiple-phase nozzle technique to produce the water droplets for removing the smaller dust particles underneath of MRT-BTS Saphan Khwai station as located on Saphan Khwai Square in Bangkok which is all-day traffic jam and plenty of dense buildings and all-day-long pedestrians.

2. Material and Methods

2.1 Study Area Attributes

Bangkok is the capital of Thailand with the coverage area about 1,520 sq.km. and legally population 6.52 million, approximately 9,600 persons/sq.km. (illegally about 5.0 million). There are 1.6 million vehicles on the traffic volume 6,400 km in length that providing the averaged speed less than 9 km/hr for traveling for work more 2.5 hours a day for public transportation. Accordance with the said problems, the governor of Bangkok Metropolis Administration Office initiated to construct skytrain for mass rapid transit (MRT) for transporting the passengers arriving destination in shorter time. To achieve such willingness, the MRT-BTS skytrain was initiated to place on along the most important traffic route, that was from the northern Bangkok at Mo Chit station on Paholyothin road, over passing Victory monument to Siam Square before dividing to Sukhumvit 77 (Soi Onnut) on Sukhumvit road (featuring 17 stations), and to the South at Sathorn road (featuring 7 stations) on the left hand side of Chao Phrya riverbank, totally distances 23.5 km. Nowadays, the MRT-BTS company has extended the MRT routes Silom station on Sathorn road coming cross Chao Phrya river to Wong Wien Yai and to the east from Soi Onnut on Sukhumvit road to Baring street.

It would be noted here that the construction of MAR-BTS skytrain was conducted on the narrow traffic routes of Bangkok city. In general, skytrain construction of MRT must be planned ahead at less 50 years before implementation for decreasing in unexpectedly environmental troubles from NGO protest, reinforcing construction, and extinguishing a fire. If not, the tracts of MRT skytrain at MRT-BTS-SPK (MRT-BTS-SPK) station has to be subjected to blockage on both sides by shophouses and some other buildings together with MRT-skytrain floor that cause the circulation of the accumulative-polluted gases and dust which impacted on dwellers as illustrated in Figure 1. Consequently, it cannot keep away from damaging to dwellers and their resources as the components of shophouses and blockage-constructed buildings one way or another.

Figure 1. Hypothetical street tunnel of MRT-BTS-SPK station by taking the shophouses, buildings and constructed materials as represented the vertical walls while the below BTS-MRT station ground floor as the ceiling wall

2.2 Zoning Measurement of Dust Concentration

The MRT-BTS-SPK station was purposively selected to study on removing smaller dust particulates by using multiple-phase nozzles to produce water droplets as induced the attraction process among dipolar water molecules and negative-charged small particulates to form the bigger size and falling down to the road surface and nearby areas. Actually, the area below MRT-BTS-SPK station has been identified as the worse point sources for producing more concentration of fine dust (the same manner as toxic gases) than the other stations of MRT-BTS routes exempt MRT-BTS SalaDaeng station. However, the MRT-BTS-SPK station is sized up 150 m in length, 22 m in width, and 5.5 m in height that makes this area as the street tunnel which is occupied on Paholyothin road 21.30-m width (including 6 lanes) plus street isle 3.80-m width as shown in Figure 1. In principles, the investigation was focused on the role of multiple-phase nozzle technique in producing water sprays for removing small particulates below MRT-BTS-SPK station in comparison with the outside nearby stations in north and south directions as shown in Figure 2.

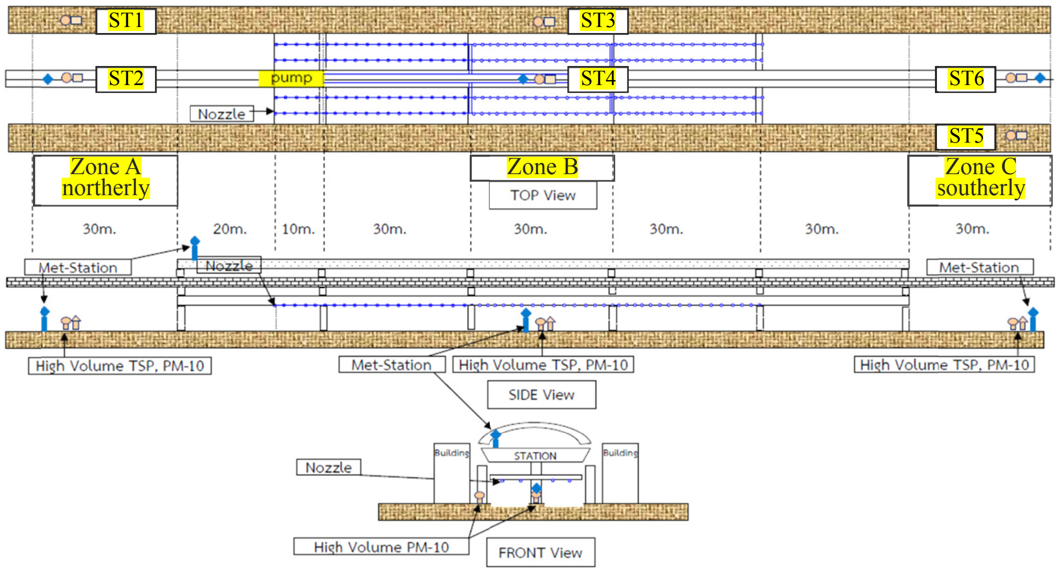

Figure 2. Zoning study areas for zone A (northerly), zone B (inside street tunnel) and zone C (southerly) for localizing multiple-phase nozzles to produce water droplets to remove the small particles from space below MRT-BTS-SPK station in order to enhance better air quality for surrounding areas

2.3 Pre-Experiment for Determining Nozzle Spacing

It was doubtful to make decision in using for space setting of nozzle orifice interval for high humid climate likewise Thailand, this would be the reason why the pre-experiment had to be conducted without any argument. To fulfill such objectives, the small-scale pre-experiment was randomly taken in account to collect the PM10 dust for 15 minutes during 3 periods (07:00-10:00, 10:30-13:30, and 14:00-17:00) for 3 days on each nozzle-spacing interval (1.0, 1.5, and 2.0 meters) by high volume samplers on street isle below MRT-BTS-SPK station. In fact, the pre-experiment was taken in 40-m length for establishing the 10-micrometer-orifice nozzles on 4 concrete beams in which the number of 10-micrometer-orifice nozzles were consisted of each beam with 37 nozzles (total 148 nozzles) for 1.0-m spacing, 25 nozzles (total 100 nozzles) for 1.5-m spacing, and 19 nozzles (total 76 nozzles) for 2.0-m spacing. As for high pressure pump, it was kept inside the shelter as placed on the isle of Paholyothin road and functioning to pump water through 10-micrometer orifice nozzle for making water droplets. After water droplets mechanizing bigger size of small particulates and falling down by gravitational forces to be blown by PM10 Hi-Volume Air Sampler before attaching to the road surface.

2.4 Multiple-Phase Nozzle Installation

Based on the theory of water-drop attracting and expected pre-experimental results, the 2-m spacing of nozzles with 10-micrometer orifice could be hypothesized to be employed for fully operation for removing small particulates (PM10 and TSP) below MRT-BTS-SPK station in the long run.

Actually, the exact length of the MRT-BTS-SPK station is 100 meters long, and 21 meter wide of both northerly and southerly rims, and 5.575 meters in high. To achieve the objectives, the research must be firstly conducted on pre-experiment in order to determine the most effective size of nozzle orifice to be applicable for producing the water droplet spray to remove the smaller particulates below MRT-BTS-SPK station. Thus, four 100-m hoses of the multiple-phase nozzle with 10 micrometers in diameter were established on ceiling of four concrete beams with 5 meters apart which located at below MRT-BTS-SPK station. At the same time, the high-pressure pumps of 1,000 lbs/min in order to press water flow rate of 0.076 liters per minute through 10-micrometer orifice for producing small water droplets as stated before that looked like drizzles. This high pressure pump was belonged to Master Kool Company and installed in a small shelter on isle at the middle of Paholyothin road. Together with those operation, the connection between the high pressure pumps and the 4-nozzle hoses were taken an account with stainless steel tubes as shown in Figure 2.

2.5 Determining TSP and PM_{10} Dust

Accordance with effectiveness of using multiple-nozzle technique could be indicated on removing small particulates below MRT-BTS-SPK station in which the high-volume sampler as the tool for air sampling were employed to measure the small dust (PM10) and total suspended particles (TSP) as well as the climatic measurement on two sampling points at both footpaths for pre-experiment and six sampling points for full operation as shown the sampling points in Figures 2. Accordance with multiple-phase nozzles were delicate at the 10-micrometer orifice that might be obstructed by some contaminants in spraying water. Therefore, the sampling times, on open-close valves, on every 10 minutes were taken in 5 periods during 05:00-08:00, 08:00-11:00, 11:00-14:00, 14:00-17:00, and 17:00-20:00 on purposively 5-consecutive days water was expected the worse cases due to more vehicles which produced higher concentrated small particulates than during 05:00-20:00 in every day, even working days.

2.6 Multiple-Phase Nozzles for Water Droplet Sprays

The removal of small particulates below MRT-BTS-SPK station started up by operating the high-pressure pump for spraying the water droplets through the 10-micrometer orifice as the outlet of multiple-nozzle pumps. The flat fan sprays would be identified from 10-micrometer orifice of the multiple-phase nozzles which was shown in Figure 2. Such water droplets were expected to become more or less gas mobilizing with Brownian movement under the support of buoyancy forces due to heat transfer by radiation and convection processes from road surface under the MRT-BTS-SPK station. With chemically ionic attracting forces between negative-charged small particulates and dipolar-ionic charges of water molecules, the bigger sizes of moistened particulates which were collected by filter paper.

3. Results and Discussion

Accordance with TSP and PM10 dust were measured at two level on the Paholyothin road surface, at 1.5 and 5.0 meters, at zone A (northerly), zone B (100-m street tunnel, Saphan Khwai), and zone C (southerly) for 24-hour measuring between 05:00 am of the 30 November 2008 to 20:00 pm of 4 December 2008. Although the measuring time was rather short, it implied the vital breakthrough on how TSP (less 100-micrometer particles) and PM10 dust moving inside and vehicle entrance-exit street tunnel which could be a lesson learnt for solving urban air problem of at least 5 MRT routes in Bangkok, Thailand. Even if shorter collection time of them, the result is presumably stopped public conflict of sky-train MRT construction in narrow street town. However, the results found can be presented in details as following sections.

3.1 Vehicle Tallying and Surveying

The numbers of move-in and move-out vehicles which are comprised of car, pick-up car, bus, truck, and motorcycles were tallied every hour from 05:00 to 20:00 for 5-day period (November 30-December 4, 2008). The peak load of both moving-in and moving-out vehicles occurred in the morning between 06:00-09:00, and fluctuation from 09:00 to 20:00, particularly 11:00-14:00 in every day. Cars seemed dominate all numbers of vehicles while trucks were somewhat constant in the whole day, details as shown in Table 1. However, there were a lot of vehicles on both sides, moving-in and moving-out transportation, that implied as the effective point sources as well as trouble makers for inducing the small particulates below the MRT-BTS-SPK station. Fortunately, there was less number of vehicles which had been count at night time, especially from 08:00-05:00 that coming along with very low quantity of TSP and PM_{10} as falling on glass fiber paper in the Hi-Volume Air Sampler. It was observed that there were so many motorcycles when it compared with the other types of transportation (Table 1).

In contrary, the low velocity was indicated at time 05:00-09:00 and tending to climb up high velocity 09:00-12:00. Then after, the vehicles seemed uncertain velocity but gradually decreasing down to be low speed at time

16:00-18:00 before going up high velocity during 18:00 to 05:00 am of the next day. In other words, the total solid particles and polluted gases could be emitted during 06:00-09:00 and 16:00-19:00 inside MRT-BTS-SPK station rather than 19:00-24:00, 00:00-06:00 but higher noise pollution to replacing occurrence. As driving a line motor vehicles, there are some days of the year that may be uncertainly predictable to exist just said situation, such as holidays, Thai and international new years, and Thai traditional days, and school closed periods, which might be varied inversely from weekdays.

Saphan Khwai square is called as the north gate of Bangkok downtown which is localized on the intersection between Padipat and Paholyothin road that the vehicles traveling through more than 10,000 cars plus motor cycles and small trucks. It is also named a place of dense-populated area and plenty of shophouses, super markets, department stores, hotels, clinics, and schools that should be the grassroots of air pollution distribution over Saphan Khwai areas, especially inside the tunnel of MRT-BTS-SPK station. Understandable issues are relied on the three main factors, that is, air temperature, actual vapor pressure, and wind both speed and direction in which are supposed to be effectively point sources for air pollution, gases and dust emission. (Botkin & Keller 2005; Carotenuto et al. 2010; Gaunt et al. 2003a, 2003b; Grunding et al. 2006; Hensley et al. 2008; Gehlin et al. 2003).

Table 1. Numbers of vehicles (cars, motorcycles, buses, pick-up cars, and trucks) as moving-in and moving-out through the street tunnel (MRT-BTS-SPK Station) at Saphan Khwai, in Bangkok

Time	30 Nov 2008		1 Dec 2008		2 Dec 2008		3 Dec 2008		4 Dec 2008	
	No. of vehicles	Velocity (km/hr)	No. of vehicles	Velocity (km/hr)	No. of vehicles	Velocity (km/hr)	No. of vehicles	Velocity (km/hr)	No. of vehicles	Velocity (km/hr)
05:00 – 06:00	4074	40	1932	40	1932	40	2130	45	2226	35
06:00 – 07:00	4482	45	2886	25	2886	35	3408	30	3936	30
07:00 – 08:00	6444	40	5268	15	5268	20	5964	15	5904	25
08:00 – 09:00	4704	35	4998	25	4998	15	5310	20	4584	25
09:00 – 10:00	5088	40	4836	35	4836	35	5052	35	4956	35
10:00 – 11:00	5748	45	5748	40	5748	45	5640	45	5340	40
11:00 – 12:00	4932	40	5592	50	5592	35	5412	50	5130	35
12:00 – 13:00	4548	35	5928	40	5928	30	5880	35	4860	30
13:00 – 14:00	5418	40	5400	45	5400	35	5106	40	5034	45
14:00 – 15:00	6144	35	5214	45	5214	40	5592	45	5064	40
15:00 - 16:00	3960	40	5100	50	5100	45	5292	50	7104	35
16:00 – 17:00	4344	35	4860	35	4860	30	4233	35	4527	35
17:00 – 18:00	3852	40	3927	40	4110	25	3603	40	3660	40
18:00 – 19:00	4032	50	3861	50	4191	35	3807	50	3804	45
19:00 – 20:00	3858	50	3534	45	3729	45	3819	45	3645	50

Note. motorcycle 31.15%, car 50.89%, bus 7.31%, pick up 10.26%, truck 0.39%.

3.2 Climatic Condition and Mobilization

As mentioned before, the below MRT-BTS-SPK station was functioned as the street tunnel by opening in the northerly and in the southerly directions and surrounding with shophouses in the east and west. The climatic instruments which included thermometers and hygrometers were installed together with high-volume air samplers at the middle, and another two outsides, the northerly and southerly rims of the station. The results found that the differences among sampling points were somewhat not shown in high ranges on both the temperature and relative humidity as well as actual water vapor (see Tables 2 and Figure 3).

Measurement of air temperature and actual (water) vapor pressure were taken in zone A (northerly), zone B (inside street tunnel), and zone C (southerly) on the levels of 1.5 and 5 meters inside street tunnel ceiling and over the roof top (see Table 2 and Figure 3) of the MRT-BTS-SPK station as shown in Table 2. The results were shown that the amount of actual water aqua vapor were somewhat less variation than air temperature but only the case of increasing volume when the air temperature increased, especially during 10:00-14:00 and gradually decreased until 17:00 o'clock. Surprisingly, the performance of actual water vapor, as stated before, was not seriously changed even if temperature was highly increased in wide range. In other words, actual water vapor might not be concerned with temperature increasing or decreasing. However, the differences of temperature, actual water vapor, and relative humidity were somewhat narrow due to the street tunnel would be four reasons: firstly, the street tunnel was only 100 meters in length which is identified as the small microclimatic area within micro-topographic range rather in relation to altitude, slope an aspect that making the very less differences of atmospheric pressure. Secondly, the surroundings of shophouses on both sides in east and west directions would be covered by the MRT-BTS-SPK tunnel roof that generated the going-to-be homogeneous temperature of circulated air-mass according to all-form heat transfers (conduction, convection, and radiation). Thirdly, there might be some air-mass by vertical flow through the upper open-space between the shophouses (as street tunnel wall on eastern and western sides) and the MRT-BTS-SPK station to the upper sky, especially during vehicles moving on the road that makes the air-mass to escape and being replaced by horizontal flow from the opening northern and southern sides. Lastly, the heated road due to hot weather on daytime could be the another cause of vertically moving-up of the moist air-mass through the said open spaces for some period of time after rain falling (Gaunt et al. 2003a, 2003b; Ameth & Stichlmair 2001; Gehlin et al. 2003; Grunding et al. 2006; Hensley et al. 2008; Hidy & Brock 1971; Jaworek et al. 2013; Plinke et al. 1991; Saranagapani & Wexler 2000; Sellers 1969).

Table 2. Air temperature, actual water vapor and relative humidity as measured during 30 November to 4 December 2008 at the middle and outside of both northerly and southerly rims in the beneath of MRT-BTS-SPK station (street tunnel) at Saphan Khwai in Bangkok

Date/ Time	Out Northerly		Out southerly		Under SaphanKhwai					Top SaphanKhwai		
	Temp (c)	Actual Vapor (mmb)	Temp (c)	Actual Vapor (mmb)	Temp 1.5 (c)	RH 1.5 (%)	RH 5.0 (%)	Actual Vapor 1.5 (mmb)	Actual Vapor 5.0 (mmb)	Temp (c)	RH (%)	Actual Vapor (mmb)
30Nov2008												
05:00-08:00	23.0	18.5	22.7	18.2	23.1	53.9	60.0	15.2	15.3	21.9	66.0	17.3
08:00-11:00	26.6	19.8	26.0	19.1	25.0	46.0	62.6	14.5	19.8	23.9	56.8	16.9
11:00-14:00	29.3	19.3	28.9	18.9	27.6	37.5	56.7	13.8	20.9	27.1	47.4	17.0
14:00-17:00	31.0	18.8	30.9	18.7	27.7	29.3	51.3	12.0	19.8	28.3	41.8	16.1
17:00-20:00	27.2	17.2	27.0	17.0	26.9	36.7	55.5	13.0	19.7	26.1	47.7	16.1
1Dec2008												
05:00-08:00	22.6	16.8	22.3	16.5	23.0	49.8	64.7	13.9	18.1	21.5	61.4	15.7
08:00-11:00	26.4	17.7	26.1	17.4	25.8	40.6	59.1	13.5	19.6	24.8	51.4	15.6
11:00-14:00	29.5	18.5	29.2	18.2	28.3	33.9	54.3	13.0	20.9	27.6	44.9	16.5
14:00-17:00	30.7	18.8	31.0	19.1	29.6	31.4	51.8	13.0	21.5	28.6	42.6	16.6
17:00-20:00	27.9	17.0	27.6	16.7	28.0	31.9	53.0	12.6	20.4	27.0	45.3	16.2
2Dec2008												
05:00-08:00	22.8	16.9	22.4	16.5	23.0	49.1	64.4	13.8	18.1	21.5	61.1	15.6
08:00-11:00	26.7	19.7	26.0	18.9	25.6	44.4	62.4	14.6	20.5	24.3	56.3	16.1
11:00-14:00	29.8	19.4	29.3	18.8	28.2	36.2	55.9	13.8	21.4	27.9	46.2	17.3
14:00-17:00	30.7	18.6	31.3	19.3	29.1	30.5	52.0	12.9	21.3	29.0	42.1	16.8
17:00-20:00	27.6	18.2	27.6	18.2	27.7	38.2	56.8	14.2	21.1	26.8	49.2	17.3
3Dec2008												
05:00-08:00	22.8	20.6	22.2	19.9	22.4	64.5	76.3	17.2	20.4	21.6	74.2	19.1
08:00-11:00	27.6	21.0	26.1	19.2	25.6	48.0	64.9	15.6	21.2	25.5	56.8	18.4
11:00-14:00	31.1	19.7	30.6	19.2	29.5	34.2	54.7	14.1	22.5	29.5	43.7	18.0
14:00-17:00	31.7	20.3	32.2	20.9	30.5	33.4	53.9	14.6	23.6	30.1	43.5	18.6
17:00-20:00	28.6	19.6	28.7	19.7	27.9	38.7	58.3	15.2	22.3	28.1	50.1	19.0
4Dec2008												
05:00-08:00	25.0	21.7	24.4	20.9	24.8	58.7	72.1	18.3	22.5	24.2	68.4	20.6
08:00-11:00	29.4	23.7	28.8	22.9	28.9	45.7	64.2	18.1	25.6	27.7	57.7	21.3
11:00-14:00	32.8	23.9	32.6	23.7	32.1	35.5	56.6	17.0	27.1	30.8	48.1	21.3
14:00-17:00	33.6	24.4	33.7	24.5	32.5	35.3	55.8	17.3	27.4	31.6	46.8	21.8
17:00-20:00	29.9	24.0	30.1	24.2	30.0	46.9	63.6	19.8	26.9	29.5	56.8	23.4

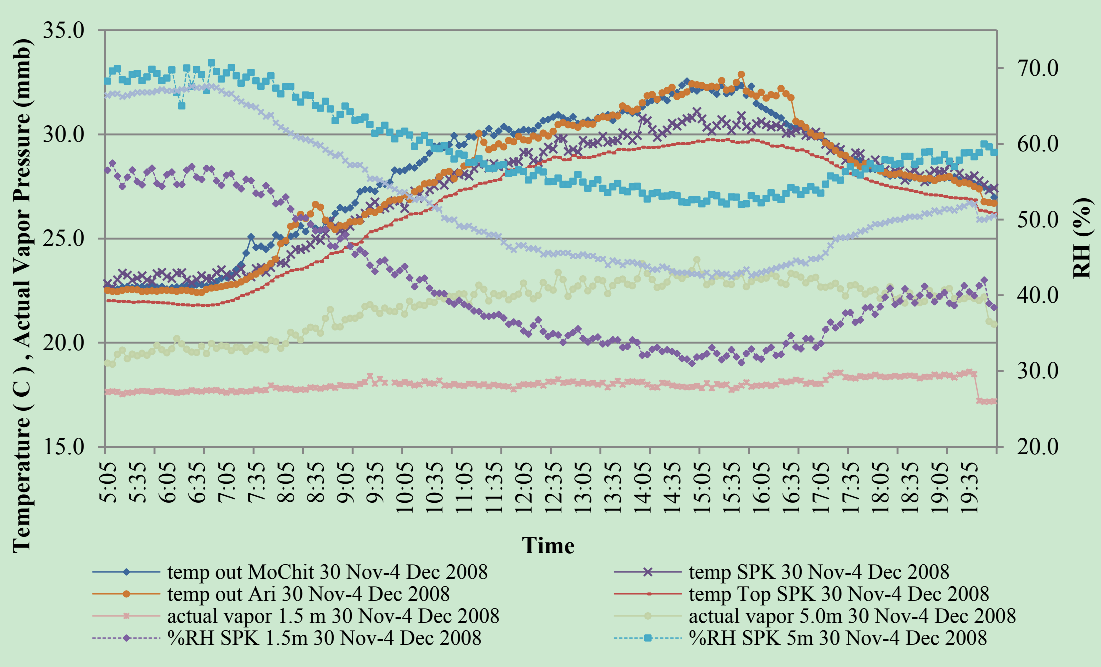

Figure 3. Variation of air temperature and relative humidity as measured at the middle and both southern and northern outside rims below the MRT-BTS-SPK station (street tunnel) at Saphan Khwai in Bangkok

Interpretation could be stated that the warm air mass naturally moves away and replacing by cool air mass (Ameth and Stichlmair 2001; Gehlin et al. 2003) that allocated on the spaces between shophouses as well as buildings and MRT-BTS-SPK station which might be the open spaces for warmer air escaping away to the sky. In reality, the weather condition under the MRT-BTS-SPK station (called as street tunnel), the air is usually warmer than the outer parts due to reradiated heat storage from running vehicles and MRT-BTS-SPK buildings, and also continuously consecutive heat conduction from asphalt road and soils underneath (Mirmov and Belyakava 1982).

3.3 Coagulation between Water Droplets and Dust Particles

It would be informed that Baver et al. (1972) summarized the previous researches in textbook on Soil Physics and described on agglomeration or flocculation that attraction between negative charges of clay particles and positive charges of water molecules by adhesive forces, and then the negative charges of soil-water film again attracting another water molecules by cohesive forces. Such phenomena will be proceeded until the last water film equivalent to gravitational forces, the next drop of liquid water becoming a gravitation water and flow out from soil particles. The same manner, Clair (1994) brought the Smoluchowski's theory which stated that "the reciprocal of the number of particles per unit volume varies as a linear function of time". The said theory is applicable to employ the agglomeration of TSP and PM10 dust after spaying 10-micrometer water drop from 10-micrometer diameters of multiple-phase nozzle orifices on its horizontal and vertical distribution in order to increase the gravitational forces the water-drop-attracted smaller dust particles finally accumulating on the ground floor (Brabec 2003; Charinpanitkul & Tanthapanichakoon 2011; Gardner, 1955; Gaunt et al. 2003a, 2003b; Hidy & Brock 1971; Jaworek et al. 2013).

In reality, the attractive forces among dipolar water molecules as produced by multiple-phase nozzles with 10-micrometer orifices and small particulates (fly dust, smoke, mist, and others) were formed the bigger sizes that falling down to the ground floor due to its weight greater than gravitational forces. Naturally, there are so many kinds of small particulates in the street tunnel below the MRT-BTS-SPK station which should be composed of solids, liquids, and gases in individuals and chemical compound forms. The matter of fact, the warmer air is mostly found at the level close to the ground floor because of re-radiation from road that making warmer air moving upwards and another direction pertained cooler air. This phenomena might be supported some wet dust away which should be the main factor causing less TSP and PM10 collection (Plinke et al. 1991; Sellers, 1969; Saranagapani & Wexler 2000).

The said principles made clearly understandable that the mobilization of the 10-micrometer-nozzle water molecules under the Brownian movement principles was occurred around smaller buoyant dust particles with normal distribution on higher elevation, close to the ceiling. After water droplets attracting to dust particles and it was caught by cohesive forces more and more, the gravitational forces were dominated to make dust particles, as adhered with more water molecules, falling down to the ground floor in terms of TSP and PM10 (Balachandran et al. 2003). The said process caused high concentration of adhering water droplets on closer ground floor rather than on higher elevation and gradually decreasing concentration at the ceiling of the MRT-BTS Saphan Khwai station.

3.4 Quantitative Determination of TSP and PM10 Dust

Field experiences could be pointed out that over-roof wind direction seemed to have more influences on decreasing the coagulated dust particles as felt by gravitational forces on the floor. To accomplishing such statement, three climatic stations were installed at over-roof Saphan Khwai station (zone B) as street tunnel, northerly Mo Chit (zone A), and southerly MRT-BTS Saphan Khwai station (zone C) in which the wind direction and speed of zones A, B, and C were recorded as shown in Table 3.

An analysis of collected data of TSP and PM10 dust was conducted on measuring stations (ST1, ST2, ST3, ST4, ST5, and ST6) in relation to wind directions (NE, N, NW, S, SSE and WSW) during 30 November 2008 through 4 December 2008. It was found that WSW wind direction (Zone C in Table 3), there was none particulate sources to interfere the dust concentration. So, this research has to take WSW wind direction (Zone C) in Tables 3 and Table 4) for evaluating the decreases of TSP and PM10 dust after spraying the 10-micrometer water droplets by employing multiple-phase nozzles.

Table 3. Relationships between main wind direction occurrences and measurement of zone A (ST1 and ST3), zone B (ST2 and ST4), and zone C (ST5 and ST6) as measured during experimental period on 30 November 2008 throughout 4 December 2008

Zone / Main Wind Direction	TSP (μg/m^3)						PM10 (μg/m^3)					
	ST1	ST2	ST3	ST4	ST5	ST6	ST1	ST2	ST3	ST4	ST5	ST6
B/NE	407	395	389	359	461	409	219	220	200	182	260	239
B/N	641	629	623	512	587	509	328	348	306	270	317	265
B/NW	409	417	325	363	413	478	215	211	155	156	195	266
A/N	497	477	527	437	532	459	252	268	265	223	279	243
A/S	461	466	363	374	424	486	244	247	178	178	245	262
C/SSE	413	410	400	359	459	408	207	211	196	179	254	209
C/ WSW	527	523	368	363	498	547	297	288	178	172	286	306

Table 4. Averaged concentration of TSP and PM10 dust in relation to wind directions as measured for at MRT-BTS Saphan Khwai station in main WSW wind directions on 30 November 2008 throughout 4 December 2008

No.	TSP (μg/m^3)						PM10 (μg/m^3)					
	ST1	ST2	ST3	ST4	ST5	ST6	ST1	ST2	ST3	ST4	ST5	ST6
1	675	582	495	295	651	469	392	320	248	175	372	310
2	355	544	244	357	341	561	185	205	93	121	214	253
3	617	534	434	445	581	591	356	372	205	242	316	383
4	315	450	204	374	301	580	174	160	119	111	171	254
5	673	504	461	342	617	534	377	384	226	210	356	328
average	527	523	368	363	498	547	297	288	178	172	286	306

The quantitative determining values of TSP from WSW wind direction (WSW in Tables 3) at measuring stations for ST1, ST2, ST3, ST4, ST5, and ST6 equivalent to 527, 523, 368, 363, 498 and 547 μg/m^3; while PM10 from northerly wind direction found ST1 (297 μg/ m^3), ST2 (288 μg/ m^3), ST3 (178 μg/ m^3), ST4 (172 μg/ m^3), ST5 (286 μg/ m^3) and ST6 (306 μg/ m^3), respectively, as shown in Table 4. All determined-quantities values of TSP and PM10 dust seemed higher than standards due to not only the coverage of MRT-BTS Saphan Khwai station but also the contaminant emission from buses, trucks, heavy trucks, cars, motorcycles, and out sources. This would be very necessary to decrease them which was chosen the multiple-phase nozzles by using 10-micrometer orifice to spray water droplets in order to coagulate smaller dust particles with them.

3.5 TSP and PM10 Dust Decreasing Concentration

As stated before, WSW wind direction (in Tables 3) played a significant role in decreasing concentration of TSP and PM10 dust in the street tunnel of MRT-BYS Saphan Khwai station. Beforehand, it has to understand that the decreasing concentration of TSP and PM10 dust are differentiated between measuring stations on isle of the road (ST2, ST4, and ST6) and on footpaths (ST1, ST3, and ST5) which showed in Figures 2. In other words, the measuring stations represented as the street tunnel (particularly ST4), the stations on footpaths as contaminant outflow.

Following the above assumption, the isle measuring points at ST1 (527 μg/m^3) and ST3 (368 μg/m^3) was caused the decrease of 159 μg/m^3 (30.25 % in Table 5), ST5 (498 μg/m^3) and ST3 (368 μg/m^3) equivalent to the difference of 130 μg/m^3 (26.21 % in Table 5), ST2 (523 μg/m^3) and ST4 (363 μg/m^3) equivalent to the difference of 160 μg/m^3 (30.64 % in Table 5), and ST6 (547 μg/m^3) and ST4 (363 μg/m^3) equivalent to the difference of 184 μg/m^3 (33.71 % in Table 5). In the same manner, the PM10 dust can calculate the decreasing concentration at ST1-ST3 equivalent to 39.96 %, ST5-ST3 equivalent to 40.39 %, ST2-ST4 equivalent to 37.65 %, and ST6-ST4 equivalent to 43.78 % as shown in Table 5. The calculating findings resulted that the higher decreases of TSP and PM10 dust were occurred inside the street tunnel according to 10-micrometer water droplets spraying, while another wind direction found the minimum decrease because of some parts from zone B and northerly was placed on the middle due to carry some parts from zone C.

Table 5. Decreased concentration of TSP and PM10 dust in relation to wind directions in zone B (ST3 and ST4), as the street-tunnel representative, to compare with northerly zone A (ST1 and ST2) and southerly zone C (ST5 and ST6)

No.	position	Decreased concentration) %(	
		TSP	PM10
1	Footpath Zone A-B (ST1-ST3)	30.25	39.96
2	Footpath Zone C-B (ST5-ST3)	26.21	40.39
3	Street isle Zone A-B (ST2-ST4)	30.64	37.65
4	Street isle Zone C-B (ST6-ST4)	33.71	43.78
5	Zone A-B (northerly)	30.38	40.17
6	Zone C-B (southerly)	30.05	40.88

In case of zone effects on TSP stand point of view, the results found about 1,050 μg/m^3 for zone A, 731 μg/m^3 for zone B, and about 1,045 μg/m^3 for zone C. The decrease was found at zone A - zone B for 319 μg/m^3 (30.38 %) and zone C - zone B for 314 μg/m^3 (30.05 %). For PM10 dust, it was found 585 μg/m^3 for zone A, 350 μg/m^3 for zone B, and 592 μg/m^3 for zone C in which the decreases were indicated at zone A and zone B 235 μg/m^3 (40.17 %), zone C and zone B 242 μg/m^3 (40.88 %).

In case of on the central line effects, the results found the averaged values of TSP equivalent to 363 μg/m^3 at ST4, 523 μg/m^3 at northerly ST2, and 547 μg/m^3 at southerly ST6. The increases between ST2 and ST4 found 160 μg/m^3 (30.64 %), and ST4 and ST6 equivalent to 184 μg/m^3 (33.71 %). For PM10 dust, the results found 288 μg/m^3 at northerly ST2, 172 μg/m^3 at ST4, and 306 μg/m^3 at ST6. The decreases between ST2 and ST4 were shown as 166 μg/m^3 (37.65 %) and ST4 and ST6 about 134 μg/m^3 (43.78 %).

3.6 Effectiveness of Multiple-Phase-Nozzle Techniques

According to the significant role of 10-micrometer water droplets spraying inside zone B by employing the multiple-phase nozzles (totally 208 nozzles) of four sets (four rows) on the 100-m long beam with 2-m spacing, the results were found the decrease of TSP (less 100 micrometers in diameter) 30.08 % on northerly zone A and 30.05 % on southerly zone C. In addition, the role of 10-micrometer multiple-phase nozzle spraying in decreasing of PM10 dust (less 10 micrometers in diameter) also found the decrease of 40.17 % on northerly zone A, and decrease 40.88 % on southerly zone C. In other words, employing 10-micrometer orifice of nozzles as installed on 4 beams (100 meters each) on ceiling and 52 nozzles each beam with 2-m spacing, all together 208 nozzles to spray the 10-micrometer water droplets were appreciated not only underneath of street tunnel at MRT-BTS Saphan Khwai station but also it supported to northerly and southerly mouth of street tunnel as shown in Figure 2.

Weather condition, especially air temperature and actual vapor pressure played important role in decreasing TSP and PM10 dust in terms of agglomeration or flocculation which occurred mostly in zone B (underneath of MRT-BTS Saphan Khwai station) rather than exist-entrance street tunnel in northerly and southerly directions. The existing characteristics might surely be influenced in wind direction and speed from directing the way to Bangkok downtown (southerly) and to Mo Chit bus terminal (northerly). Sometime, the occurrence of strong wind speed together with high pressure over roof of MRT-BTS-SPK station could be forcefully pressed down throughout the Saphan Khwai station building and shophouse space that causing smaller solid particles traveling someway into shophouses and splitting to northerly and/or southerly street tunnel exist as illustrated in Figure 2. If wind speed was very, the condition might be opposite direction in which the water droplets as gas form can be taken an armful of some smaller solid particles passing shophouse-station building spaces up to sky, particularly in the condition of daily ground floor heating.

As stated before, air temperature and actual vapor pressure were paid more attention in flocculation between less 100-micrometer small solid particles with negative charge and dipolar-water molecules with 10-micrometer water droplets in form of gases but it depended on air temperature like wind speed and direction as shown their influences in Figure 2 (Gardner 1955; Gaunt et al. 2003a, 2003b; Sellers 1969; Baver et al. 1972). It is observed that the decreases of water vapor pressure due to the increases of TSP and PM10 dust collection but the fluctuation of them and moving direction was depended on severances of wind speed and direction.

3.7 Multiple-Phase Nozzle Pumping Operation

The research results as described above can be convinced that the numbers and velocity of vehicles as well ad weather condition inside and outside MRT-BTS Saphan Khwai station were unsteady in every period of the day. In consequence, the pumping machine has to run without stopping, then the budgeting operation is going up that causing unnecessary payment. Actually, the existence of TSP and PM10 dust is usually found out above the ground surface up to the ceiling of MRT-BTS Saphan Khwai station floor but their concentration is depended on time of the day, mostly 06:00-09:00 and 16:00-19:00 because of high numbers of vehicles and period of air stagnation. However, the better way to do thing like this should automatically install by set up the starting time on whenever the amount of smaller solid particles at harmful healthy level. If possible, the alteration operation between in-town and out-town management should be taken in the future operation.

4. Conclusion

The street tunnel at MRT-BTS Saphan Khwai station was assigned to solve the air pollution problem in part of smaller solid particles, TSP and PM10 dust, in order to find means how to make the stakeholders satisfied. The pre-experiment was studied for finding the numbers and establishing space of 10-micrometer-orifice nozzles to spray 10-micrometer water droplet size, which is presumable as gas form, to catch the less 100-micrometer small solid particles by agglomeration process to make the agglomerated solid particles falling down on the ground floor. The pre-research result found the 2-m spacing for this research to establish the 208 nozzles on four of 100-m beams (52 nozzles each) on ceiling of 5.575-m height, and 21-m width (5-m apart). The four sets of 100-m hoses with 52 multiple-phase nozzles were connected with high-pressure pump (1,000 lbs/min) that being able to press clean water 0.076 liters/min through the 10-micrometer orifice to produce the small water droplets in gas form. In reality, the high-pressure pump which is belonged to Master Kool Company, has been installed in a small shelter on isle at the middle of Paholyothin road. The spraying time was about every 10 minutes in each of 5 periods for collecting TSP and PM10 dust by Hi-Volume Air Sampler, that is, 05:00-08:00, 08:00-11:00, 11:00-14:00, 14:00-17:00, and 17:00-20:00 for 5-consecutive days, 30 November to 4 December 2008. At the same time, the measurement of air temperature, actual vapor pressure, and speed-direction wind at the levels of 1.5 and 5.0 meters in height under the MRT-BTS Saphan Khwai station and also on its roof. The results were presented as follows:-

1) The street tunnel were shown high density of vehicles during 06:00-09:00 and 16:00-19:00 in everyday, and high concentration of less 100-micrometer diameter of total suspended particles (TSP and PM10 dust) which higher standard values.

2) Among air temperature, actual vapor pressure, and speed-direction wind were important factors for coagulation between water droplets and smaller dust particles, but wind direction found the most suitable for decreasing)concentration of TSP and PM10 dust.

3) Employing the multiple-phase nozzles (208 nozzles) with 10-micrometer orifice was brought to get the success for decreasing concentration of TSP and PM10 dust inside the street tunnel from three cases of following studies:

3.1) Out-Road Decreasing: for TSP, northerly 30.25 %, southerly 26.21 %; for PM10, northerly 39.96 %, southerly 40.39 %.

3.2) Zone Decreasing: for TSP, zone A-B 30.38 %, zone C-B 30.05 %; for PM10, zone A-B 40.17 %, zone C-B 40.88 %.

3.3) On the Central Line Decreasing: for TSP, on the Central Line A-B 30.64 %, on the Central Line C-B 33.71 % (measuring street isle); for PM10 dust, on the Central Line A-B 37.65 %, on the Central Line C-B 43.78 %.

4) Psychologically and economically speaking, the automatic pumping operation for spraying 10-micrometer water droplets related to concentration of less 100-micrometer dust would be satisfied the public in terms of environmental pollution protection.

5) From research point of view, the pumping time should be taken in longer period in order to decrease the smaller dust particles under the standards. If not, the pumping time might be more frequent than the experimental period.

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