

Investigation on the Use of Chemical Dust Suppressants on Ash Emissions Due to Fort McMurray Wildfire

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ABSTRACT

A large-scale wildfire had broken out at Fort McMurray in Alberta, Canada during May 2016. Many oil sands mining activities were affected due to the wildfire and the associated ash emissions. In particular, ash emission generated from the fire outbreak is a huge problem during the post-fire cleanup. These emissions pose a severe health hazard to workers, environment and global climate. The ashes emitted into the atmosphere are caused by either human activities or climate conditions. The objective of this research is to assess the effect of three different ash dust suppressants, namely water, #1 surfactants, and #2 polymers at various volumetric concentrations on ashes samples to prevent propagation of fine solid emissions into the atmosphere. It is found that both #1 surfactants solution and #2 polymers solution are effective in retaining fugitive ash dust generated from the ashes. Volumetric concentration efficiency of 0.05% of #1 surfactant and 5% of #2 polymers in 500 ml of water have been proven to provide ash dust retention efficiency greater than 99% after the spraying of these suppressants. It is also found that both #1 surfactants solution and #2 polymers solution maintain an ash dust retention efficiency higher than that of the use of only water. This confirms the merit of using chemical dust suppressants on fugitive ash dust for a longer period, which is proven by the 72-hour data from this experiment. This study gives a general view of how effective chemical suppressants on fugitive ash emissions work.

1. Introduction

On May 1st, 2016, a large-scale wildfire gutted Fort McMurray, Alberta, Canada. Many oil sands mining activities were affected due to the wildfire and the associated ash emission. Due to the wildfire, some of the biggest oil sands companies in Fort McMurray such as Royal Dutch Shell and Suncor Energy shut down their oil production, at 255,000 and 350,000 barrels per day respectively [1]. Syncrude Canada Ltd scaled down its normal production capacity level of 350,000 barrels per day [1]. This generated an estimated loss of about 1.1 million barrels of oil production per day, constituting a 30% reduction in the Canadian daily oil production, crippling the economy [2]. This loss in production by the companies translated into 0.33 % of the Alberta GDP in 2016 constituting a loss of \$985 million and 0.06 % of the entire Canadian economy [3]. In 2017, it is estimated that the rebuilding and reclamation of the affected areas in Fort McMurray will add \$ 1.3 billion in GDP to the Alberta's economy [3].

A population of over 90,000 people was evacuated from the location and its surroundings for health and safety reasons [4]. The fire destroyed about 2,400 structures and over 500,000 hectares of forest vegetation in Fort McMurray, leaving an estimated 232,000 tonne of post-fire ashes [5,6].

As the fire got under control, one serious problem presented during the cleaning and reclaiming of the post-fire sites is the emission of the dust from the ashes into the environment, since wood ashes were produced as the byproduct of burnt forest vegetation and structures. According to Alberta Health Services, the produced ashes contain arsenic and other heavy metals, making the surrounding homes and environment unsafe for living. The release of the heavy metals into the environment can cause major health issues such as hematological disorder, chronic lungs disease, diabetes mellitus, low birth weight, cardiovascular diseases, and lungs and kidney problems [7]. The produced ashes were tested and shown high PH value, which can lead to skin burns and irritations [8–10].

Canada as one of the countries that signed the international treaty of conference of the parties (COP) at the 21st United Nations Climate Change Conference held in France has an obligation to combat climate change. The country under this treaty is currently committed to reduce the emissions of short-lived climate pollutants (e.g., fugitive ash dust) into the atmosphere, which is a significant contributor to global warming, by 30% on 2030 [11]. Therefore, it is of great significance to control the fugitive ash dust within its allowable borders in Fort McMurray [11,12].

According to the 2012 final report of the Canadian-wide standards for particulate matter and ozone's, the average daily value for the Alberta ambient air quality guideline of PM 2.5 μm per location is 30 $\mu\text{g}/\text{m}^3$ per day [13]. However, according to Alberta Health Services, Fort McMurray and its surrounding cities exceeded the concentration limit reported by Environment Canada over 20 times due to the fire ashes [8,9]. Hence, post-fires ashes must be controlled effectively to ensure a safe living and working environment in Fort McMurray.

Water over the years has been used as the traditional method for controlling the emission of normal fugitive dust (e.g., road dust and coal dust) into the atmosphere. However, water requires consistent re-application due to a high evaporation rate; this is not favored as more water needs to be consumed and the overall efficiency will be reduced [14–16]. Water over the years has been used as the preliminary method for controlling the emission of fugitive ash dust into the atmosphere. However, it has some limitations that make it less efficient. The molecules structure within water is separated from each other, which reduces the adhesive bond and creates a high surface tension. The high surface tension increases the evaporation rate of the water, which in terms reduces the fugitive ash dust retention efficiency [14–18].

Chemical suppressants on the other hand can improve the efficiency of fugitive ash dust retention and reduce the need of re-application [14,15]. The addition of chemical suppressants to water will help improve molecule bonding by increasing the cohesive force. This will decrease the surface tension of the solution and the evaporation rate [14–16].

Post-fire ash is different from normal fugitive dust since it contains more toxic and hazardous compounds (e.g., arsenic, benzene) and a high PH value, and may also have heavy carbon contents [7,8]. At present, the use of chemical dust suppression agent on post-fire ash dust is rarely investigated.

Hence, the objective of the study is to assess the effect of three different ash dust suppressants to control the emission of fugitive ash dust generated from post-fire ashes due to the recent Fort McMurray wildfire.

2. Experimental Detail

2.1. Material

A sample of ashes from the Fort McMurray fire outbreak was received on May 9th, 2016 from a local company. A total of 20 kg of the ash samples were received in a sealed bag. As shown in Fig 1, the ash samples were composed of coarse and fine solid particles, including large wood chunks, coal, and fine ashes.



Fig 1. A photo of fire Ash from Fort McMurray

2.2. Ash Dust Suppressants

Two chemical suppressants provided by a local company and water were tested as the control means for controlling the emission of fugitive ash dust into the atmosphere. Suppressants such as water, #1 surfactants, and #2 polymers were examined. Fig 2 shows the dust suppressant agents considered for this research.

Fig 2 (1) presents the tap water used in the research. The used water meets the acceptable concentration limit of 80 $\mu\text{g/L}$, as the running annual average of water for all chemicals, physical and radiological parameters set by Health Canada [19]. This makes the tap water free from impurities and safe for experimental purposes.

Fig 2 (2) shows the #1 Surfactants solution. The #1 surfactant is a non-flammable yellowish liquid with potential of hydrogen (PH) value ranging from 8-9; the boiling point is 100 °C and the specific gravity is 1.0. This chemical has the capability of binding widely space molecules of water together to form a stronger bond by decreasing surface tension [14,16,20].

Fig 2 (3) shows the #2 Polymers solution. The #2 polymers solution is non-flammable white liquid with a PH value ranging from 8-9, and has a boiling point of 100 °C and a specific gravity of 1.03. This suppressant can keep the separated water molecules closer to form an adhesive bond and reduces the evaporation rate of the solution [14,16,20].

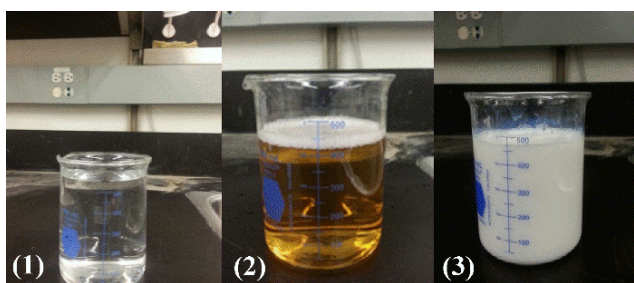


Fig 2. Dust suppressant agents used in the study; (1) Water, (2) #1 Surfactants solution, and (3) #2 Polymers solution

2.3. Test Methods

The ash sample was dried in an oven at a controlled hot climate of 60 °C for 72 hours. These parameters were selected as the optimum temperature and time for the drying out all the moisture content present within the ash sample based on the material size of the ash sample. At a temperature of 60 °C the sample will be fully dry after 72 hours. Through this process, all the moisture content present in the sample was taken out. Because the samples tested were composed of chunks of burnt woods, coal, and fine ash particles, screening process is used for separating the coarse particles from the fine particles by performing a sieve analysis test with mesh opening ranging from 3.35 mm to 750 µm. This mesh size was chosen to obtain ashes with smaller particle sizes, which are the main source of fugitive ash dust flying that stays in the atmosphere. Climate conditions such as wind velocity, temperature, and humidity play a significant impact on the amount of ash particles emitted into the atmosphere and the efficiency of a suppression agent in controlling the ash dust emission [15,18,21,22]. According to the weather statistics of Fort McMurray from Environment Canada, the maximum average wind speed and temperature at Fort McMurray for the past five years in the second quarter (April- June) are 55 km/h and 33 °C respectively [23].

These parameters were selected as the base conditions for this experiment because they had been shown over the last five years to be the highest temperature and wind condition, which is considered as the extreme weather condition for the location of the fire outbreak. Stipulated time intervals of 3 hours, 6 hours, 24 hours, 48 hours and 72 hours were considered to be the time bases for the experiment. Three series of ash samples are tested for each suppressant per stipulated period, with the average taken as the reported value of the series. Fig 3 is a schematic diagram showing the principles behind the experimental procedure. Likewise, Fig 4 shows the actual experimental set-up.

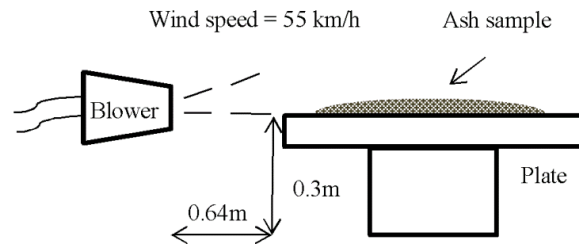


Fig 3. Schematic representation of experimental procedure

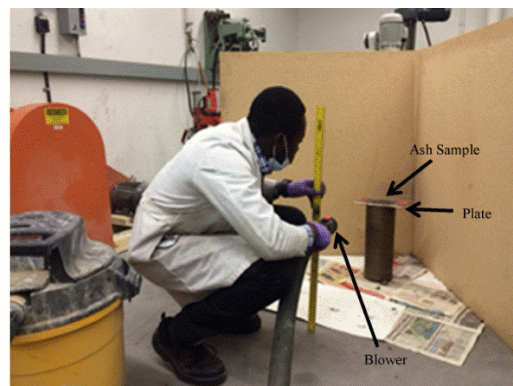


Fig 4. Photo showing the experimental set up

In proving the efficiency of each tested suppression agent in controlling the fugitive ash dust emission, a control baseline of no suppressant applied to the ash sample is tested. An ash sample weighting 15 g is placed in an oven at a temperature of 33 °C per stipulated duration. The sample is then with a wind speed of 55 km/h. After blowing this wind weighed on a scale before being blown

at to the sample, no ash sample remained on the plate. This base process showed 0% ash retention efficiency on the plate after the wind effect, which prompt the testing of ash dust suppressant to reduce fugitive ash dust.

Water is the first suppression agent tested on the ash sample for the control of the emission of fine particles in the atmosphere. Water as an ash suppressant needs no dilution with any surfactant at the initial stage of its usage since it is regarded on its own as an ash suppression agent. 15 g of ash sample is measured on a laboratory scale. 30 ml of water is applied to the sample using a sprinkler. The sample is then placed in a controlled hot temperate oven of 33 °C for 3 hours. After the required duration is reached, the sample is weighed on a scale to know its weight before being blown with wind speed of 55 km/h to the sample (ω_1). The sample is measured again as (ω_2) after the application of the wind speed.

The weight of material loss during the process is determined from Equation 1. The mass of loss material serves as the basis for measuring the ash retention efficiency of the sample (Equations 2 and 3). Three series of test is conducted for each stipulated period to eliminate as many anomalies as possible. The same method of calculations and procedure is followed for all the considered ash dust suppressants and their volumetric concentration in this experiment. A stipulated time periods of 6 hours, 24 hours, 48 hours, and 72 hours were also considered for the experiment. This process helps to determine the ash retention efficiency per period and will serve as a determinant for the efficiency of the ash dust suppression agent when applied over time.

Chemical suppressant such as #1 surfactants and #2 polymers were added to water to form a solution, to help improve the efficiency of water as an ash dust suppression agent. This addition holds the water molecules together to enhance the bond between them making it more adhesive against external forces. For a productive solution of dust suppression agent, water and each of the surfactant needs to be mixed at a certain volumetric concentration of dilution for a perfect mixture in controlling the emission of fugitive ash dust. Different concentration of #1 surfactant was tested with water to form a solution of 500 ml. The effectiveness of each dilution was tested, and the optimum value is selected as the volumetric concentration of the #1 surfactants solution for the experimental work. Volumetric concentrations of 0.05%, 1%, 2%, 3% and 4% of #1 surfactants were tested.

#2 polymers are the second surfactant considered for this experiment. This surfactant is mixed with water at a certain dilution of volumetric concentration to form a solution. This solution helps improve the efficiency of water to help form a better suppressant on the ash sample. Different concentrations of the #2 polymers were tested with water to form a solution of 500 ml. The effectiveness of each concentration is tested, and the optimum value is selected as the volumetric concentration of the #2 polymers for the experimental work. Volumetric concentrations of 2%, 3%, 5%, 10%, and 15% of the suppressant were created with water.

2.4. Calculation Methods

The parameters used in the equations for the experimental research is shown below.

t	Duration of sample under hot climate (hours)
d	Dilution rate for surfactants (%)
ω_p	Weight of plate (g)
ω_1	Weight of sample before blowing (g)
ω_2	Weight of sample after blowing (g)
$\Delta\omega$	Weight of sample loss (g)
r	Ash retention efficiency (%)
R	Average ash retention efficiency (%)

The weight loss ($\Delta\omega$) by an ash sample before and after the application of a wind speed of 55 km/h is calculated by Equation (1):

$$\Delta\omega (g) = \omega_1 (g) - \omega_2 (g) \quad (1)$$

Where $\omega_1(g)$ is the weight of the ash sample with the application of ash suppression agent under a temperature season of 33 oC before applying a wind speed of 55 km/h and $\omega_2(g)$ is the weight of the ash samples remaining on the plate after the application of the wind velocity. Once the weight loss of the material is calculated, the ash retention efficiency can be calculated.

The ash retention efficiency (r) of each sample tested in the laboratory is dependent on the mass of the loss sample (Equation 2):

$$r (\%) = 1 - \Delta\omega / (\omega_1 - \omega_p) \quad (2)$$

With the Ash retention efficiency of the sample, the average ash retention efficiency for three series of test, R is calculated as follows (Equation 3):

$$R (\%) = (r_1 + r_2 + r_3) / 3 \quad (3)$$

Where r_1 , r_2 and r_3 are the ash retention efficiency for each experiment conducted for the ash sample within a series.

3. Results and Discussions

The results of the experiment demonstrate the use of suppressants as one of the effective ways of controlling the emission of fine solid particulate matter from ashes into the atmosphere. Water, #1 surfactants solution, and #2 polymers solution were tested during the research study. The baseline suppression agent considered for the control of fugitive ash dust into the air for this study was water.

The average ash retention efficiency for the ash sample with water as an ash dust suppression agent is shown in Table 1. The effect of water as an ash dust suppression agent over time in controlling the emission of fugitive dust is shown in Fig 5.

From the results provided the effectiveness of water decreases in accordance with time. The efficiency of water during the first 3 hours was effective and started reducing during 6 hours to 72 hours as the suppression agent gets more exposure to the hot climatic conditions. This process means that water dries up quickly under hot climate conditions, returning the ash sample back to the original state where no application of a control measure of a suppressant was implemented for the control of fugitive dust. Water as a suppressant contains molecules that are mostly separated from each other, reducing the bond of togetherness between the molecules.

Therefore, water is less efficient under hot climate and lacks the ability to retain its moisture content in the sample for longer duration when applied as an ash dust suppression agent, making the constant re-application of water as dust suppressing agent a requirement to control the fugitive ash dust from ashes. In improving upon the deficiency of water as an ash dust suppression agent, chemical suppressants are required.

Table 1. Average ash retention efficiency using water as an ash dust suppression agent

Trial (Water as a suppression agent)	$\omega_p(g)$	$\omega_1 (g)$	$\omega_2 (g)$	$\Delta\omega (g)$	$r (\%)$	$R (\%)$
W 01	429.10	450.51	449.47	1.04	95.14	
W 02	433.52	453.58	452.52	1.06	94.72	94.86
W 03	423.17	443.25	442.19	1.06	94.72	

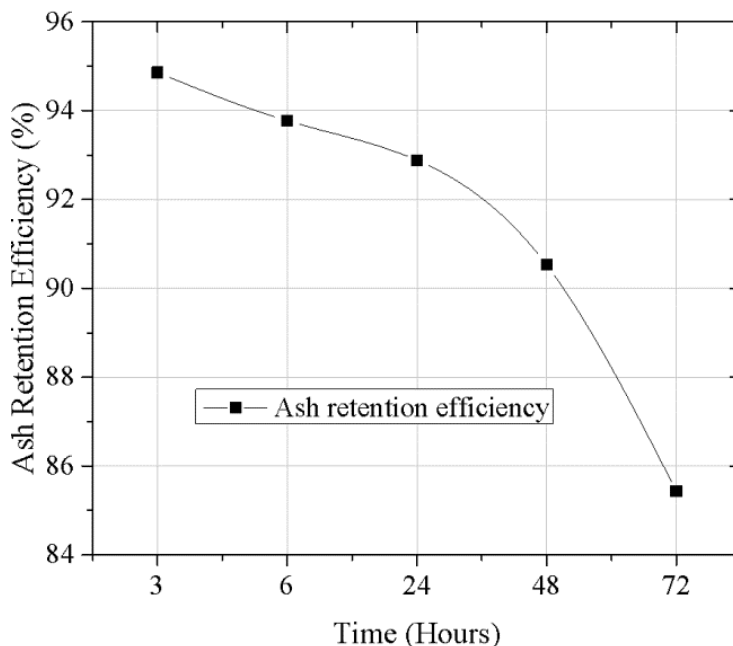


Fig 5. Effect of water as an ash dust suppression agent

Volumetric dilutions of each chemical suppressant were tested per the mixture with water through a preparatory process to form a solution. The optimum value of all the results is selected as the final dilution for the solution as shown in in

Table 2 and Table 3 . The corresponding ash sample retained per the volumetric concentration of each tested dilution is graphically shown in Figs 6 and 7.

#1 surfactants solution of 0.05% dilution was selected as the optimum solution. At this dilution, the solution will be efficient and economical during its application in controlling ashes emissions into the atmosphere. A 5% dilution concentration was selected as the optimum solution for #2 polymers solution. At this dilution, the solution will be efficient and economical during its application in controlling ashes emissions into the atmosphere.

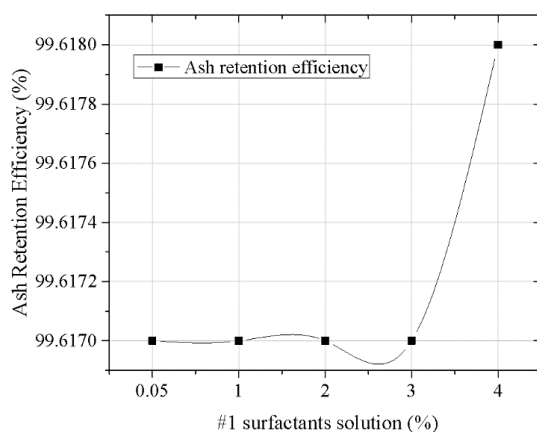


Fig 6. The relationship between of #1 surfactants solution and their ash retention efficiency

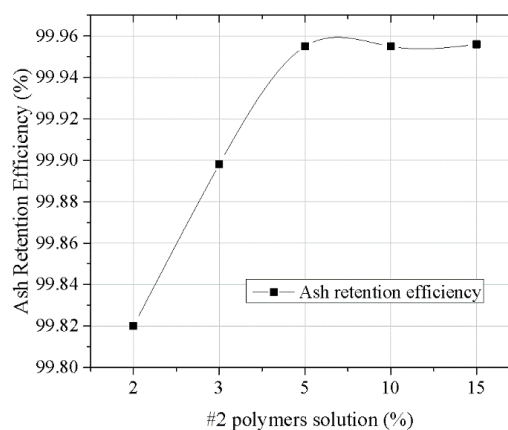


Fig 7. The relationship between #2 polymers solution and their ash retention efficiency

Table 4 and Table 5 show the results of the average ash sample retained after 3 hours of application of #1 surfactants solution and #2 polymers solution in controlling fugitive ash dust.

Table 2: Dilution concentration of #1 surfactants solution

Average Volumetric Concentration for #1 Surfactants Solution (%)	Average Ash Retention Efficiency (%)
0.05	99.62
1	99.62
2	99.62
3	99.62
4	99.62

Table 3: Dilution concentration of #2 polymers solution

Average Volumetric Concentration for #2 Surfactants Solution (%)	Average Ash Retention Efficiency (%)
2	99.82
3	99.90
5	99.95
10	99.95
15	99.96

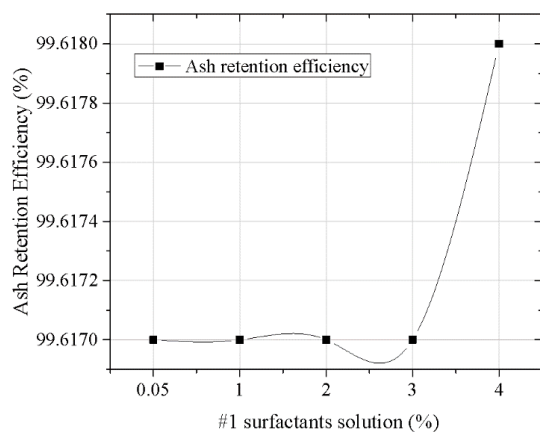


Fig 6. The relationship between of #1 surfactants solution and their ash retention efficiency

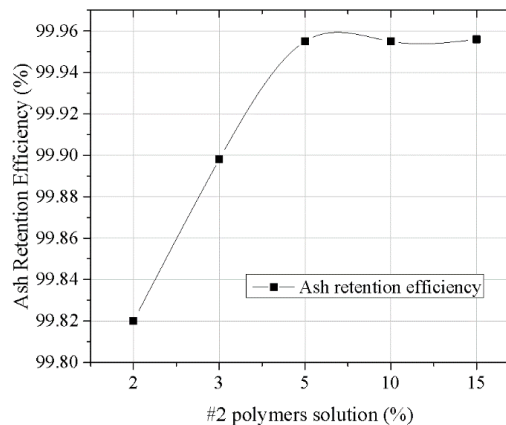


Fig 7. The relationship between #2 polymers solution and their ash retention efficiency

Table 4: Average ash retention efficiency for #1 surfactants solution

Trial (#1 surfactants solution for test)	ω_p (g)	d (%)	ω_1 (g)	ω_2 (g)	$\Delta\omega$ (g)	r (%)	R (%)
S 01	415.81	0.05	437.65	437.58	0.07	99.68	
S 02	430.45	0.05	451.21	451.12	0.09	99.57	99.63
S 03	456.86	0.05	476.93	476.86	0.07	99.65	

Table 5: Average ash retention efficiency for #2 polymers solution

Trial (#2 polymers solution for test)	ω_p (g)	d (%)	ω_1 (g)	ω_2 (g)	$\Delta\omega$ (g)	r (%)	R (%)
P 01	429.50	5.00	450.60	450.59	0.01	99.95	
P 02	425.10	5.00	447.60	447.57	0.03	99.87	99.92
P 03	434.70	5.00	456.30	456.29	0.01	99.95	

The result from Fig 8 shows that the application of #1 surfactants solution as an ash dust suppression agent performs better than water. This addition will help improve the efficiency of water to prevent the generation of fine solid particulate matter from the ash samples into the atmosphere for a longer duration when applied as a control mechanism for fugitive dust. The #1 surfactants solution at the initial stage of its application acts effectively by holding smaller particle sizes of the ashes together with the large particles, which helps prevent the emission of particles into the atmosphere when disturbed. After getting to the premium ash dust suppression ability, its efficiency on the sample starts to decrease. It has better ability in binding water molecules together cohesively and does not form a crusty surface above the sample when applied, making it easier to sweep and clean when disturbed by humans.

#2 polymers solution was also considered as a suppressant for the control of ash emissions into the atmosphere. Fig 9 shows the effect of #2 polymers and water as a suppression agent over time. The results show that the #2 polymers solution of dust suppression agent has the capability of holding fine solid particles of the ashes together after its application and until the third day.

This application shows how #2 polymers solution can bind water molecules together by help strengthening the bond by reducing the tension on the surface of the water. This property reduces the rate of evaporation under hot climate condition with time. The closer the molecule to molecule reaction, the lower the evaporation rate of the suppressant and the more effective the solution reacts with the fine and coarse ash samples by holding the two components together. The #2 polymers solution does not form crispy surfaces above the samples, which makes it easier to sweep when disturbed by waste management companies.

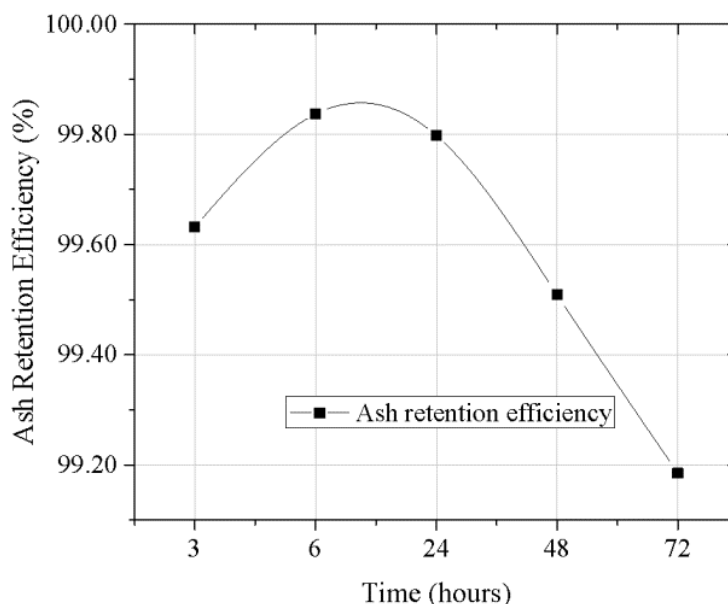


Fig 8. Effect of #1 surfactants solution as an ash dust suppression agent

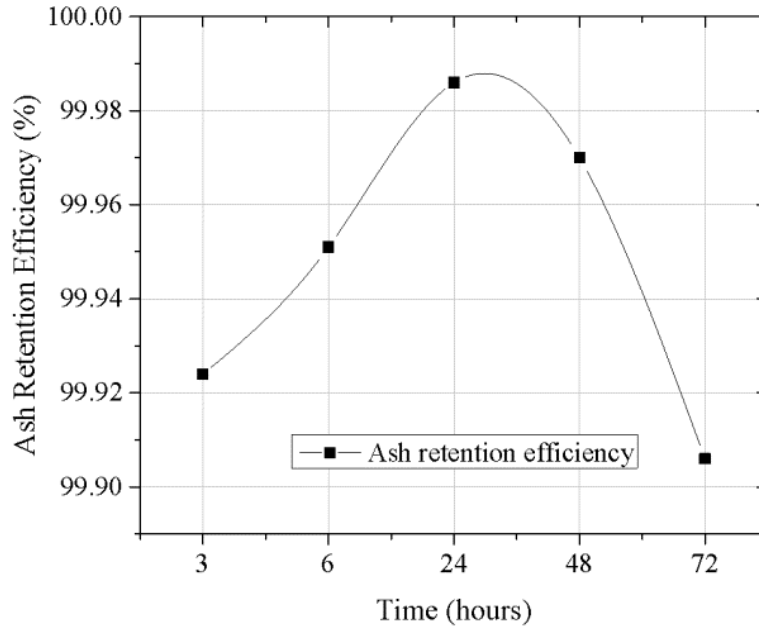


Fig 9. Effect of #2 polymers solution as an ash dust suppression agent

Ash retention efficiencies of all the tested suppressants are considered in selecting the most efficient ash dust suppression agent under a controlled hot climate condition. Fig 10 summarize the effect of all the considered dust suppression agents in this research. The result shows that #2 polymers solution is the most efficient ash dust suppression agent on fugitive ash dust emission from ash samples into the atmosphere compare to the others. #2 polymers solution has a high capacity of binding most of the water molecules together in forming an active suppressant for a longer duration against hot climate conditions as compared to the use of #1 surfactants solution and water as an ash dust suppression agent, based on their performance in terms efficiency.

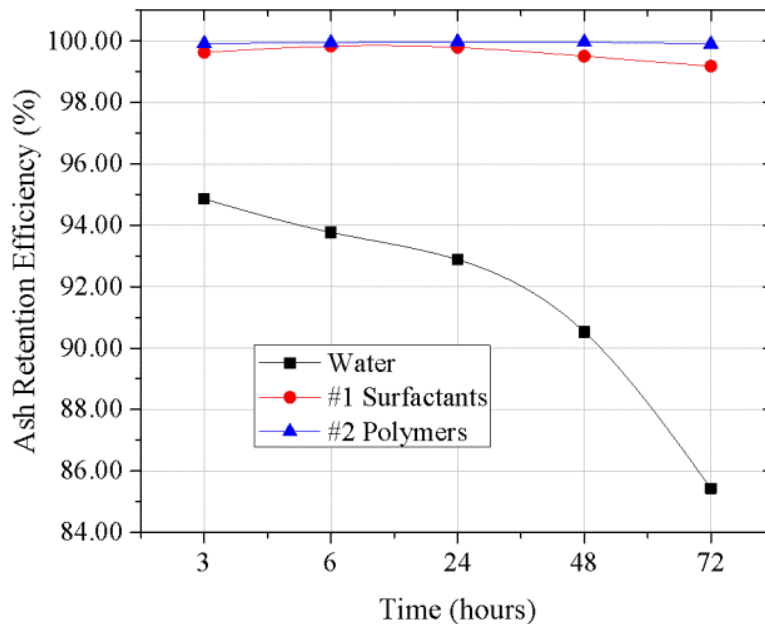


Fig 10. Effect of all ash dust suppressants on ash samples

4. Conclusions and Recommendations

The conclusive findings from the application of all the tested ash dust suppressants show:

1. Water at the initial stage of its application as an ash dust suppression agent worked fairly good on fugitive ash dust by showing an efficiency of 94.86 % of retained ash sample, but it decreased constantly with time and after 72 hours the efficiency drops to 85.44 %. This problem of depreciation of the ash retention efficiency with time shows that water works at the first; however it does not last long when applied as an ash dust suppressant.
2. #1 surfactants solution as an ash dust suppressant worked effectively at the initial stage of its application, retaining 99.63 % of the ash sample and maintained a fairly consistency retention efficiency even after 72 hours at 99.19 %. This solution works effectively for the control of fugitive ash dust on ash sample.
3. #2 polymers solution at the initial stage of its application as an ash dust suppression agent retained 99.92 % of ash samples on the plate and maintained this consistent retention even after 72 hours of its application at 99.90 %. This solution as an ash dust suppressant is highly effective in controlling the emission of fugitive ash dust into the atmosphere.
4. The inference of volumetric concentration of a chemical suppressant in a solution plays an important role on ash retention efficiency. Fig 6 shows that at an optimal concentration level, an increase in the concentration of a chemical suppressant have little or no impact on the ash retention efficiency. This implies that for each chemical suppressant an optimum concentration could be set up to avoid excessive suppressant addition to save cost.
5. The combined results from all the tested ash dust suppressants prove #2 polymers solution as the most efficient of all the three suppressants tested, followed by #1 surfactants solution, and water as the least efficient.
6. The use of chemical ash dust suppressants on ash emissions has been preliminary investigated. The results show how much more effective chemical suppressant prevents the emission of ash dust into the atmosphere compared to water. Hence, it is recommended to use chemical ash dust suppressants for the control of the fugitive ash dust in Fort McMurray.

It is recommended that conditions of climate factors such as humidity, precipitation, and others environmental parameters needs to be taken into consideration for future works.

5. Acknowledgment

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6. References

- [1] The Globe and Mail. Major oil sands producers scale back output, shut down as wildfire rages. The Globe and Mail [Internet]. 2016 Oct 22 [cited 2016 Jan 1]; Available from: <http://www.theglobeandmail.com/report-on-business/industry-news/energy-and-resources/oil-sands-firms-cut-production-as-fort-mcmurray-wildfire-rages/article29850997/>
- [2] CBC news. Tallying Alberta's oil revenue losses from Fort McMurray wildfires [Internet]. CBC news. 2016 [cited 2016 Jan 1]. Available from: <http://www.cbc.ca/news/canada/calgary/wildfire-alberta-fortmcmurray-royalties-1.3622811>
- [3] The Conference Board of Canada. Economic Impacts of the Fort McMurray Wildfires [Internet]. The Conference Board of Canada. 2016 [cited 2016 Jan 1]. Available from: http://www.conferenceboard.ca/press/newsrelease/16-05-17/economic_impacts_of_the_fort_mcmurray_wildfires.aspx
- [4] Woo A, Tait C. Up to 90,000 evacuated from Fort McMurray; some ordered to move again as fire spreads. The Globe and Mail [Internet]. Edmonton; 2016 May 4; Available from:

- <http://www.theglobeandmail.com/news/alberta/fort-mcmurray-burns-this-is-a-nasty-dirty-fire/article29862009/>
- [5] The Globe and Mail Inc. The Fort McMurray fire: What's happening now, and what you've missed. Globe staff and The Canadian Press [Internet]. 2016 Jun 10; Available from: <http://www.theglobeandmail.com/news/alberta/the-fort-mcmurray-disaster-read-the-latest-weekend/article29930041/>
- [6] CTV NEWS. Taking out the trash: Massive amount of garbage after Fort McMurray's wildfire [Internet]. CTV NEWS. 2016 [cited 2016 Jan 1]. Available from: <http://www.ctvnews.ca/canada/taking-out-the-trash-massive-amount-of-garbage-after-fort-mcmurray-s-wildfire-1.2980811>
- [7] Squibb KS, Fowler BA. The toxicity of arsenic and its compounds. *Biol Environ Eff Arsen.* 1983;233.
- [8] CBC news. Hundreds of undamaged Fort McMurray homes declared unsafe due to toxic ash. CBC news report. 2016 May 31;
- [9] The Globe and Mail. Tests reveal toxic levels of contaminants in Fort Mac soil and ash. The Globe and Mail [Internet]. Fort McMurray; 2016 Jun 7; Available from: <http://www.theglobeandmail.com/news/alberta/tests-reveal-toxic-levels-of-contaminants-in-fort-mac-soil-and-ash/article30346538/>
- [10] Alberta Government. Fort McMurray Ash and Air Results [Internet]. 2016. Available from: <http://www.alberta.ca/documents/FtMcMurray-AshMonitoringDataMemo.pdf>
- [11] CBC news. COP21: Canada's new goal for limiting global warming "perhaps a dream" [Internet]. CBC news. 2015 [cited 2016 Jan 1]. Available from: <http://www.cbc.ca/news/technology/climate-change-talks-canada-emissions-goal-1.3357770>
- [12] Environment and Climate Change Canada. Canada pledges \$35 million to combat short-lived climate pollutants. In: Environment and Climate Change Canada, editor. Canada pledges \$35 million to combat short-lived climate pollutants [Internet]. Paris, France: Government of Canada; 2015. Available from: <http://news.gc.ca/web/article-en.do?nid=1024009>
- [13] Canadian Council of Ministers of the Environment. Canada-wide standards for particulate matter and ozone 2012 final report. 2014.
- [14] Foley G, Cropley S, Giummarra G. Road dust control techniques: evaluation of chemical dust suppressants' performance. 1996.
- [15] Kavouras IG, Etyemezian V, Nikolich G, Gillies J, Sweeney M, Young M, et al. A new technique for characterizing the efficacy of fugitive dust suppressants. *J Air Waste Manage Assoc.* 2009;59(5):603–12.
- [16] Thompson RJ, Visser AT. Selection, performance and economic evaluation of dust palliatives on surface mine haul roads. *Journal-South African Inst Min Metall.* 2007;107(7):435.
- [17] Swanson J-G, Langefeld O. Fundamental research in water spray systems for dust control. *Min Technol.* 2015;124(2):78–82.
- [18] Chakradhar B. Fugitive dust emissions from mining areas. *J Environ Syst* [Internet]. 2005;31(3):279–88. Available from: <http://dx.doi.org/10.2190/ES.31.3.e>
- [19] EPCOR Canada. Raising the standard 2014 enviroVista Champion Report [Internet]. 2014. Available from: <http://www.epcor.com/water/water-quality/reports-edmonton/Documents/EnviroVistaChampionReport2014.pdf>
- [20] RaodTech Industries. Products [Internet]. RaodTech Industries. 2016 [cited 2016 Oct 15]. Available from: <http://www.rtindustries.ca/>
- [21] Mohapatra R, Rao JR. Some aspects of characterisation, utilisation and environmental effects of fly ash. *J Chem Technol Biotechnol.* 2001;76(1):9–26.
- [22] Tsai C-J, Chiou S-F. Measurement of emission factor of road dust in a wind tunnel. *J Aerosol Sci.* 1999;30:S227–8.
- [23] Environment and Climate Change Canada. Fort McMurray Historical Temperature [Internet]. Environment and Climate Change Canada,. 2016 [cited 2016 Jan 1]. Available from: <http://fortmcmurray.weatherstats.ca/>