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Determination of Heavy Metal Settling Velocities with Respect to Particle Size and Density

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Abstract: The aim of the study was to determine the settling velocities of heavy metal particles. The heavy metals in the rm of very fine dust particles originating from a variety of sources may settle onto the earth's surface. The heavy metals in the particulate form may re-suspend into the air and can move from place to place contributing to the atmospheric pollution. The settling velocities were found to be the function of the heavy metal particle size and density. The settling velocities of the six heavy metal particles were calculated. The size of the particles was varied to find out the settling velocity variations. It was observed that as the density as well as the particle size of a heavy metal was increased the settling velocities also increased correspondingly.

Key words: Settling velocities · Heavy metal · Particle size · Density

INTRODUCTION

The particulate matter (PM) is composed of very fine size solid particles as well as liquid in the atmosphere. These particles cannot be seen by naked eye and are present in the form of black soot, dust or haze [1]. The movement of gaseous effluent containing fine particles depends on their settling velocities [2]. The size of particle as well as its density is important in meteorological studies. The lateral dispersion of heavy particles is inversely related with the heavy metal particle size as well as density [3]. The heavy metal particles suspended in air may settle on the earth surface contributing to the heavy metal concentrations. The safe limits of the heavy metals concentrations present in soil, based on their negative effects, on the essential components of ecosystem including microorganism activity in soil, plant growth and food chain contamination are given in Table 1 [4].

Table 1: Heavy metals permissible levels.

Elements	Permissible level
Cd	0.33 mgkg-1
Cr	31 mgkg-1
Cu	179 mg kg-1
Ni	30.7 mgkg-1
Pb	81 mgkg-1
Zn	392 mgkg-1

Heavy Metals as Pollutants: The heavy metals in the particulate form are present in the atmosphere which are a source of pollution to the surrounding environment. These metals settle on different land type surfaces and are a cause of toxicity. Such metals also become part of various aquatic systems hence damaging the marine life [5]. Heavy metals sources and their impact on the living things is illustrated as under.

Cadmium: People living near the hazardous waste sites that release Cd into the air and those who live or work in metal refinery industries are heavily exposed to Cd. During respiration Cd is taken into the lungs where it damages the lungs severely. Cadmium is then transported into the liver and kidneys through blood damaging the filtering mechanism in the kidneys. Surface water and soil quality can be polluted when Cd is transported by sludge over greater distances. The strong adsorption of Cd by organic matter badly affects the plant as well as animal life. The soil as well as aquatic ecosystems can be badly affected by Cd concentrations.

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Chromium: People working in steel, leather and textile industry may be exposed to Cr. Chromium may cause allergy like skin rash, nose irritations and nosebleeds, upset stomachs and ulcers, respiratory problems, weakened immune systems, kidney and liver damage, alteration of genetic material, lung cancer and even death. According to National Toxicology Program (NTP), carcinogens are found in experimental animals in the form of hexavalent Cr compounds which include calcium chromate, chromium trioxide, Pb chromate, strontium chromate and Zn chromate [6]. Chromium in soils strongly attaches itself to the soil particles and is absorbed on sediments in dams and rivers. In animals Cr may cause a lower ability to fight against diseases, respiratory problems, birth defects and infertility.

Copper: Copper exposure may cause brain damage, head and stomach aches, vomiting and diarrhea, nose and eyes irritation and dizziness. High uptake of Cu results in liver and kidney failure and even death. In the soil, Cu strongly attaches itself to the organic matter and minerals. Copper negatively influences the activity of microorganisms and earthworms which as a result slow down the decomposition of organic matter in the soil. Also Cu does not break down in the environment and it is taken up as it is by the plants affecting the plant diversity badly especially near the Cu disposing factories.

Nickel: When Ni is up-taken in large quantities, it can result in lung cancer, respiratory failure, birth defects, asthma and chronic bronchitis, allergic reactions such as skin and heart disorders. Skin contact with Ni-contaminated dust may cause the development of a dermatitis known as “nickel itch” and skin ulceration in individuals with sensitive skins. Nickel sensitivity, once acquired, appears to persist indefinitely. Nickel and its certain compounds have been anticipated to be carcinogens as listed in the National Toxicology Program (NTP). The excess of Ni can also damage ecosystems, like Ni concentration in surface waters can affect the growth of algae and micro-organisms also suffer in the similar fashion. Human beings living near the Ni emitting sources may suffer from cancer.

Lead: High concentrations of Pb may cause kidney damage, disruption of nervous system, rise in blood pressure and anaemia. In children, Pb may cause behavioural disruptions like aggression and hyperactivity. Lead uptake results not only in miscarriages and subtle abortions in females but also damage the nervous system of the unborn child. Various ecosystems in soil, fresh water and marine environment also suffer badly from Pb concentrations.

Zinc: High concentrations of Zn badly affect the fertility of the farmland. The activity of micro organisms and earthworms is negatively influenced and the process of breakdown of organic matter becomes slow. Zinc enters in the environment through vehicle tyres, industrial plants and factories.

Settling Velocities of the Heavy Element Particles: The heavy particles moving in a fluid when stop accelerating and fall under the action of gravity at a constant velocity such a velocity is known as terminal velocity or settling velocity. The settling velocities of the heavy particles are computed using the following relation [7].

$$V_s = \frac{(\rho - \rho_{air}) g d_p^2 C_2 S_{CF}}{18\mu}$$

Where

ρ = *The particle density*

ρ_{air} = *The air density*

d_p = *The particle diameter*

μ = *Air viscosity*

C_2 = *Air units conversion constant*

S_{CF} = *Slip correction factor*

g = *Acceleration due to gravity*

The slip correction factor is computed as follows

$$S_{CF} = 1 + \frac{2X_2(a_1 + a_2 \exp^{(\frac{a_3 d_p}{X_2})})}{10^{-4} d_p}$$

Where , , and are constants with values 6.5 x 10^{-6}, 0.4 and 0.55 x , respectively.

RESULTS AND DISCUSSIONS

The settling velocity of the particles has a pronounced impact on the deposition of heavy particles in the form of dust over a surface. The dust suspended

Table 2: The settling velocities of a number of heavy element particles calculated with respect to the particle sizes and density.

S. No	Name and Symbol of the heavy element	Density of the heavy element (g/cm)	Size of the heavy element particle (µm)	Settling velocity of the particle (m/s)
1	Cadmium (Cd)	8.650	10	0.026
			20	0.104
			30	0.234
			40	0.416
			50	0.650
			60	0.936
			70	1.270
			80	1.660
			90	2.100
			100	2.600
2	Chromium (Cr)	7.190	10	0.021
			20	0.086
			30	0.194
			40	0.346
			50	0.540
			60	0.778
			70	1.060
			80	1.380
			90	1.750
			100	2.160
3	Copper (Cu)	8.960	10	0.027
			20	0.108
			30	0.242
			40	0.431
			50	0.673
			60	0.970
			70	1.320
			80	1.720
			90	2.180
			100	2.690
4	Nickel (Ni)	8.900	10	0.0267
			20	0.107
			30	0.240
			40	0.428
			50	0.669
			60	0.963
			70	1.310
			80	1.710
			90	2.160
			100	2.680
5	Lead (Pb)	11.350	10	0.034
			20	0.136
			30	0.307
			40	0.546
			50	0.853
			60	1.220
			70	1.670
			80	2.180
			90	2.760
			100	3.410

Table 2: Continue

S. No	Name and Symbol of the heavy element	Density of the heavy element (g/cm)	Size of the heavy element particle (µm)	Settling velocity of the particle (m/s)
6	Zinc (Zn)	7.130	10	0.021
			20	0.086
			30	0.192
			40	0.343
			50	0.536
			60	0.771
			70	1.050
			80	1.370
			90	1.730
			100	2.140

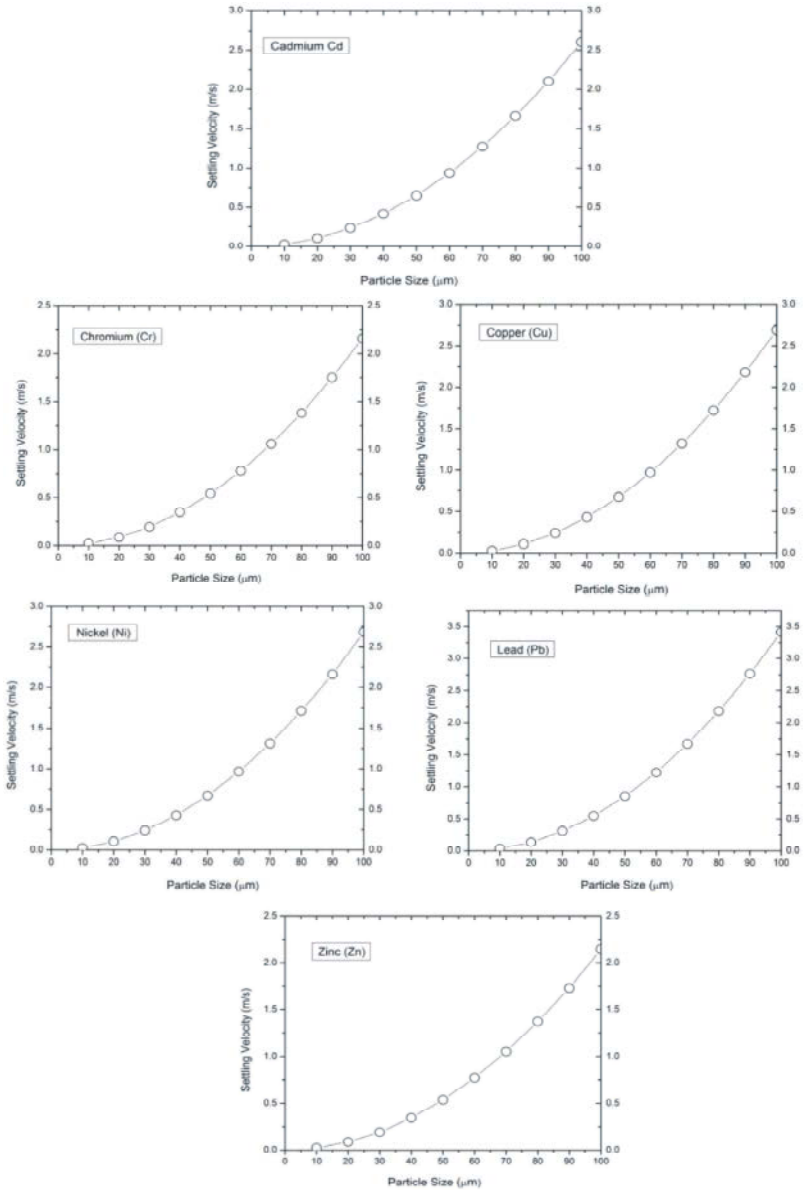

Fig 1: The settling velocities curves against various particle sizes for the heavy elements of Cd, Cr, Cu, Ni, Pb and Zn.

in air along the roads is enriched with the heavy particles. The settling velocities of various heavy particles have been calculated with respect to the particle size and density. It can be concluded that the settling velocity of a heavy particle is a function of particle size as well as density of the particle of particular heavy element as shown in Table 2 and Fig 1.

The increasing order of the densities of the heavy particles results in the increase of settling velocities of the heavy particles.

$$\rho_{Pb} > \rho_{Cu} > \rho_{Ni} > \rho_{Cd} > \rho_{Cr} > \rho_{Zn}$$

$$S.vel_{Pb} > S.vel_{Cu} > S.vel_{Ni} > S.vel_{Cd} > S.vel_{Cr} > S.vel_{Zn}$$

Also the increase in the particle size increases the settling velocities

$$S.vel_{100\mu m} > S.vel_{90\mu m} > S.vel_{80\mu m} > S.vel_{70\mu m} > S.vel_{60\mu m} > S.vel_{50\mu m} > S.vel_{40\mu m} > S.vel_{30\mu m} > S.vel_{20\mu m} > S.vel_{10\mu m}$$

where 'ρ' is the density of an element and 'S.vel' is the settling velocity.

CONCLUSIONS

In this paper the settling velocities of the heavy metals in the form of particles have been estimated. It was found that the settling velocities of the heavy metals are the function of the element density as well as the particle size. It was found that as the density of the heavy metal increases the settling velocity of the heavy metal also increases. Also as the particle size of the heavy metal particle increases the settling velocity increases correspondingly.

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