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Estimation of nickel emission in the urban environment of an industrial city Bhilai, India

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Abstract

Air and rainwater samples were collected in Durg (Chhattisgarh) at sampling site Bhilai Institute of Technology and concentration of nickel was investigated. The obtained concentration was compared with the results which were obtained in 1998 by another study. The concentration of nickel was found higher than data of 1998. The obtained result represented that nickel was present in rain water as well as in air in considerable amount but did not exceeded their legislative limit. The concentration of nickel in air was found between the ranges of 0.87 ng/m^3 to 215.4 ng/m^3 and in rainwater the range of nickel was found between 312 ng/l to 584 ng/l. The objective of this paper is to estimation and regular monitoring of nickel in the ambient air and in rain water of industrial city during particular time period.

Keywords: Nickel, Air, Rainwater, Suspended particulate matter, Respirable particulate matter.

Introduction

Hazardous trace elements (HTEs) are coming under increasing scrutiny by regulators because of real or alleged effects on the environment and human health. Out of the HTEs, nickel has been identified as toxins and is widely studied because of the serious health problem concern associated with it. Nickel is a ubiquitous trace metal that is widely distributed in the soil, air, water and in the biosphere[1]. It is the 24th most abundant element in the Earth's crust, comprising about 3% of the composition of the earth. It is the 5th most abundant element by weight after iron, oxygen, magnesium and silicon. Nickel can combine with other elements including sulphur, chlorine and oxygen to form water soluble and insoluble nickel compounds.

The compounds of nickel occur in the environment only at very low level. Nickel compounds are continuously increasing in urban air due to various anthropogenic activities like combustion of fossil fuel and oil for heat or power generation, the incineration of waste and sewage sludge, nickel mining and primary production, steel manufacture, electroplating, and miscellaneous sources, such as cement manufacturing, coins, steel alloys, batteries, food processing and stainless steel. The burning of oil and coal resulted in widespread atmospheric deposition of nickel compounds like nickel sulphate and oxides of nickel[2]. Nickel in air exists in the form of particulate aerosol with particle sizes ranging from 0.1 to 2 μm. Nickel associated with these particles is mainly in the form of nickel sulphate, nickel chloride, nickel nitrate and nickel oxide. It is reported that nickel levels in the ambient air range from 1 ng^{m-3} to 10 ng^{m-3} in urban areas, while the concentration range is 110–180 ng^{m-3} in industrialized areas and large cities[3].

Nickel (in dissolved and particulate form) can enter in the aquatic environment through effluents and leachates, as well as through atmospheric deposition after release from anthropogenic sources. The mobility of nickel in the aquatic environment is controlled largely by the capability of various sorbents to scavenge it from solution. Nickel chloride is water soluble and would be expected to release divalent nickel into the water. The soil chemistry of nickel is based on the divalent cation (Ni^{+2}) with nickel ferrite the most probable solid phase that can precipitate in soils[2]. Above pH 8, the hydroxy complex $Ni(OH)^+$ is also a major species in soil solution, whilst in acid soils nickel sulphate and nickel hydrogen phosphate are important (depending on the levels of sulphate and phosphate)[2].

Some evidence suggests that nickel may be an essential trace element for mammals[4]. The toxicity of nickel is dependent on the route of exposure and the solubility of the nickel compound[5]. Probable routes of human exposure to nickel are inhalation, ingestion, and dermal contact[6]. There are many evidences which indicate that inhalation of airborne nickel aerosols or nickel containing compounds create respiratory problems. Dermatitis is the most frequent effect of exposure to nickel caused due to skin contact[7]. Soluble nickel species like nickel carbonyl are carcinogenic and severely damage reproductive health and can lead to infertility, miscarriage, birth defects and nervous system defects[8,9]. The TLV for occupational exposure of 1 ppb has been established. The increasing concern about nickel has resulted in a considerable number of studies around the world[10-14]. This paper presents a status and sources of nickel in different parts of the environment (air and rain water).

Materials and methods

Meteorological details of site: Bhilai features a typical version of the tropical monsoon climate. It receives much of its rainfall during the monsoon season which lasts from June to September. Summers are long and the weather is extremely hot from early April to mid-September, with the monsoon season in between. From March to May the weather is hot. The monsoon arrives at the first week of June, along with an increase in humidity. The brief, mild winter starts in late November, peaks in January and mild fog often occurs. Lower atmospheric pressures and consequently higher wind speed (>21-61 Km/h) have been observed in the summer-rainy season (May–September) whereas observed temperatures found range from 11.5^{o}C to 48.3^{o}C during study period.

The meteorological data also shows that the most predominant wind direction in south-west (17%) and west (14%) during the rainy season: northeast (12%) and north (9%) during the rest of the year. Percentage of calm has been noted on 32% days of the year[15].

Description of the study area: Durg district is one of the developed industrial districts among the total 27 districts of Chhattisgarh. Bhilai-Durg twin city is located at 81.2^{0}E longitudes, 21.3^{0}N latitudes, and lies in central India. According to the census of 2001, it had a population of 753,837. The population and a large volume of transport activities through and in the area and large number of industries are responsible for ever increasing pollution load on urban air in this city.

The sampling site, Bhilai Institute of Technology (BIT) was chosen at the threshold of Durg city besides NH-6 in Chhattisgarh state (India). The whole area covers 0.28 sq. km area. BIT is located in this premises and one of the buildings used as sampling location.

Collection and preparation of samples: Air samples: At selected site high volume sampler was placed on the roof top of the building at a height of about 10 m in order to the likelihood of larger particulate collection. Sampling of air was carried out through a weighed what man glass micro fiber filter paper 20.3 x 25.4 cm. The flow rate maintained was for a time period of 24 h. After loading, the filter papers were kept in desiccators and weighed by a digital electronic balance. The sampling of air was carried out during the month of November 2006 to October 2008, at least twice a month making about 96 samples (48 samples each for measuring respirable and suspended particulate matter). Further the pieces of filter paper was placed in a beaker and extracted by refluxing in a hot plate using mixture of analytical grade nitric acid and hydrochloric acid. The digestate was filtered to analyze the elemental concentration.

Rainwater samples: Rainwater on an episodic basis was collected during the study period June 2007 to June 2008 at Bhilai. 43 rainwater samples collected in polyethylene sampling bottles were filtered through filter paper in order to separate the solid suspended matter. All sampling bottles were washed dried and cleaned before sample collection and were kept closed, in the absence of light inside a cupboard.

Instrumental analyses: Air and rain water samples were analyzed in laboratory to evaluate the different element along with nickel by atomic absorption spectrophotometer (Varian AA240FS).

Results and discussion

The obtained results are discussed in the following headings.

Monthly variation of nickel in ambient air of Bhilai city: Maximum concentration of nickel was found in the month of March in both SPM and in RPM shown in Table-1. The concentration of nickel in SPM, and in RPM was found very low in the month of October because the precipitation helps in the removal of suspended particulates from the atmosphere and settles them in the soil. Maximum concentration of nickel was present in RPM as the highest nickel concentration in ambient air usually found in smallest particles.

Table-1: Monthly variation of nickel (ng/m^{3}) in ambient air of Bhilai.

Month	SPM	RPM	TSPM
January	4.42	19.84	24.26
February	16.81	27.13	43.94
March	76.3	139.11	215.4
April	3.43	1.27	4.7
May	1.37	0.6	1.97
June	1.51	1.19	2.7
July	2.46	1.67	4.13
October	0.34	0.53	0.87
November	2.09	11.43	13.51
December	0.87	3.27	4.14
Total	109.6	206.034	315.62

Monthly variation of nickel in air and in rainwater of Bhilai: The data of the analysis of rainwater indicates that the concentration of nickel was highest in the month of June. However, the concentration of nickel was very low in air in this month because the process of precipitation increases the

concentration of nickel in rainwater. Months of January, May, October and December were dry months presented in Table-2. The concentration of nickel was lowest in rainwater in the month of September. In the summer season, the concentration of nickel was high in RPM as well as in SPM shown in Table-3. The concentration of nickel in rainwater was found high in the samples those were collected in the summer season. It was also high in samples of winter season. Overall it was seen that the air and rainwater samples collected in summer season possess the higher concentration of nickel. The average atmospheric life time of nickel is estimated to be one week. Nickel particulate matter is removed from the atmosphere by either wet or dry deposition.

Table-2: Monthly variation of nickel in air and rainwater of Bhilai.

Month	Rainwater (ng/l)	Air (ng/m^3)
January	--	24.26
February	400	43.93
March	410	215.4
April	425	3.43
May	---	1.37
June	584	2.7
July	365	3.87
August	312	--
September	200	--
October	--	0.871
November	400	13.51
December		4.14

Table-3: Distribution of nickel in air and rainwater in Bhilai.

Type of medium	Winter (ng/m^3)		Summer (ng/m^3)	
	Max.	Min.	Max.	Min.
SPM	4.43	0.34	126.3	0.77
RPM	19.84	0.53	189.11	0.60
TSPM	13.51	4.14	215.4	2.7
Rainwater	400	-	584	-

Typical average level of airborne nickel are 0.00001-0.003 µg/m^3 in remote areas ; 0.003-0.03 µg/m^3 in urban areas having no metallurgical industry; 0.07 0.77 µg/m^3 in nickel processing areas[16-18] and in the present study the range of nickel was found between 0.00087 µg/m^3 - 0.215 µg/m^3 .

Sources of nickel in sampling site at Bhilai: Nickel is common in coals, oil sample and residual oils. The primary stationary sources that have reported emissions of nickel in Bhilai are crude oil, fuel oil [{high speed diesel oil (HSDO)}, {low speed diesel oil) (LSDO)}, petrol, kerosene] metallurgical process from steel plant, and gas extraction[15]. In the average it is present in crude oils as a result of the refining and distillation process[19]. The estimation of nickel emission from various operations at Bhilai has shown in Table-4. The Table showed that Steel Melting Shop (SMS), Blast Furnace (BF), coal consumption (from steel plant), were the main source of nickel in the environment of Bhilai, whereas coke oven, petro fuel and liquid fuel consumption found the second ranking among of them.

Table-4: Estimation of nickel emission from various operations at Bhilai.

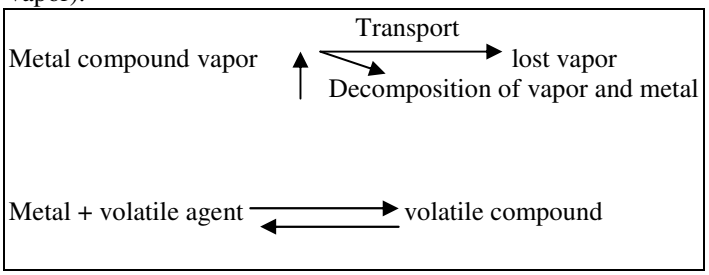
Units	Production (million ton)/year	Rate/ Factor[6] (EPA, 1984)	Compound of nickel	Estimated emission in (kg/hour)
Coke oven	3.3	0.008 kg/mg	nickel carbonyl, metal	3.014
BF	4.71	0.014 kg/mg	oxides of nickel[20]	7.52
SMS	5.35	0.014 kg/mg	nickel-containing particulate emissions[21]	8.55
Coal	4	15.25 ppm/kg	nickel sulfate, and nickel oxide	6.96
Transportation and miscellaneous	10.86	0.003 kg/mg	-	3.72
Petro Fuel	12748 (kilolitre)	25.18 ppm/kg	-	0.037
Liquid fuel consumption	70236 (kilolitre)	25.18 ppm/kg	nickel sulfate in fly ash particles[22,23]	0.202
Total				30.003

The sequence of the sources was found SMS > BF > Coal > Coke oven > Liquid fuel. From this analysis total calculated nickel was that found 30.003 kg/hour.

The condensation mechanism theory (VCM) (EPA, 1984)[6] clearly explained the emission of nickel from the combustion of coal or oil. As per the theory, the peak temperature in the firebox of a boiler or furnace is approximately 1650°C which is sufficient to volatilize the fuel elements (as M.P. and B.P. of nickel is 1555 and 2837°C respectively).

General mechanism (formation and decomposition of metal vapor): Extractive metallurgical and smelting processes are highly polluting activities. Metals may be released as fine particles or with volatile compounds from different such operations.

General mechanism (formation and decomposition of metal vapor).



General Kinetics: i. Rate of volatile compounds formation = rate of formation - rate of decomposition, ii. Rate of loss = rate of vaporization - rate of vapor decomposition.

Concentration of nickel in different matrices of Bhilai: The higher concentration of nickel was found in soil and rainwater as compared to air, sediments and surface water presented in Table-5. The larger proportions of total nickel compounds that are released to the environment are absorbed by sediments or soil particles thus have high concentration of nickel in soil.

Table-5: Concentration of nickel in different matrices at Bhilai.

Matrices	Concentration of nickel
Air	315.49 ng/m^3 [a]
Rain water	387 ng/L [a]
Surface water	0.01 mg/L [24]
Sediment	34.90 mg/kg [24]
Soil	435 mg/kg [24]

[a]Present study.

Comparison of the results: Comparison of the results of this year long study with some reported results of India and other parts of the world has been presented in Table-6. On comparison between present studies with the result of 1998 it was found that the concentration of nickel has increased 13 times in last 12 years shown in Table-7.

Table-6: Comparison of present result with other reported result of nickel.

Type of Matrices nickel from present study		Nickel from other study
Air	315.49 ng/m^3 [a]	0.025µg/m^3 (Poland)[25]
		0.198 µg/m^3 (Australia)[26]
Rain water	387ng/L [a]	300ng/dm^3 (uncontaminated water)[27]
Surface water	0.01mg/L[24]	0.012-0.0375 mg/L (West Bengal)[28]
Sediment	34.90mg/Kg[24] Toplayer– 28.16 mg/Kg 0.15meter- 31.51 mg/Kg 0.3meter– 45.04 mg/Kg	21 m- 27-40.2 mg/kg 27 m- 32.6 -40.2 mg/kg (submarine pit) Dragon ear[29]
		42–100 mg/kg River Krka area-sediment (Prohic´ and Juracˇic´ 1989)[30]
Ground water	--	14ppb (Nazirabad Bhopal)[31] 30ppb (Balrampur ghati, Bhopal)[32]
Soil	435 mg/Kg[24]	28.5mg/Kg (UK)[33]
		26,000 mg kg"1 (Canada)[33]
		250 mg kg-1 (Poland)[33]

[a]Present study.

Table-7: Comparison of the results (ng/m^3) with previous study.

Type of particulate	Presence in air
TSPM[34] (1998)	24.04
TSPM[a] (2006-08)	315.49
RPM[a] (2006-08)	189.11
SPM[a] (2006-08)	126.3

[a]Present study 2006-2008.

Species of nickel in percentage: After liberation of nickel from various sources, it is scattered and spreads in various segments of the atmosphere in various forms as discussed before. Nickel is found maximum in the form of insoluble salt (NiO and NiS_2) approximate 52% [35].

Enrichment factor: Enrichment factors have been calculated by using given formula.

$$Enrichment\ factor = \frac{Background\ concentration\ X\ 100}{High\ exposure\ area}$$

[Back ground concentration = Results of present study], [High exposure area concentration = Result found in 1998]

Obtained enrichment factors are shown in the Table-8. The elements are showing the concentration in the order nickel > cadmium > flouride. High concentration of nickel was found according to high EFs the enrichment of nickel was increased.

Table-8: Enrichment of the nickel at the present location.

Metals	Enrichment (2008)
Cd	430.19
Cu	30.15
Zn	33.98
Cr	73.91
Mn	7.36
As	3.44
Fe	10.36
Pb	2.21
SO_4^{-2}	8.88
F^-	337.56
Ni	1312.35

Conclusion

In last few decades, ever-increasing use of nickel in industrial sector and has adversely effected our environment. This element is most responsible for their toxicity in the environment of sampling area. The presence of nickel contaminants in ambient air is due to the combustion of coal, diesel oil and fuel oil, the incineration of waste, sewage and miscellaneous sources. The main conclusions from this analysis are the following. i. Presence of nickel is found in high concentration in rain water than air. ii. On comparison between present studies with the result of 1998 it was found that the concentration of nickel has increased 13 times in last 12years. iii. Estimated nickel is found highest from Steel Melting Shop and followed by Blast furnace > Coal > Coke oven > Liquid fuel. From this analysis total calculated nickel was found 30.003 kg/hour. iv. The presence of nickel was found in rain water was 0.312 µg/l – 0.584 µg/l. Bhilai as a nickel processing area and having steel plant, the range of nickel found between 0.00087 µg/m^3-0.215 µg/m^3 does not exceed legislative limits in air but can be dangerous in future. v. In the final analysis, however, their action is dependent on many factors; the discovery of which has become an immediate need. Although nickel is not emitted extensively in the environment but may constitute a major health hazard.

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