REMOVAL OF ARSENIC FROM WATER VIA SOLAR ENERGY HARVESTING TECHNIQUE WITH INTEGRATED SYSTEM OF ACTIVATED ALUMINA ABSORBENT BED AND DOUBLE SLOPE SOLAR STILL

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ABSTRACT

The present research article reports an experimental study on solar energy harvesting for the removal of arsenic (As) from water by using an integrated system of activated alumina absorbent bed along with double slope solar still complemented with numerical approaches of arsenic adsorption. During the investigation, arsenic contamination level was found between 90.23 ppb to 477.89 ppb which are exceeded the maximum acceptable limit of 10 ppb for drinking water as recommended by the Environmental Protection Agency. Results show that the mean arsenic concentrations in water samples were found in the order: Dubagga (90.23 ppb) < Gaughat (127.60 ppb) < Hanuman Setu (283.75 ppb) < Barrage (341.60 ppb) < Kukrail (322.54 ppb) < Mohan Meakin (477.89 ppb). It was found that the quantity of adsorbed arsenic was more for a higher initial concentration of arsenic. On the other side, the temperature (20°C) and maximum adsorption (≈100 percent) obtained at a pH value of 8.4. The equilibrium condition has been achieved in 3 hr after conducting several experimental runs. The obtained experimental data have been analyzed and verified with suitable adsorption isotherms (Langmuir and Freundlich) which are also confirmed by the best-fit curve of experimental data.

Keywords: Arsenic, Adsorption, Activated Alumina, Solar Distillation, Solar Energy Harvesting.

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INTRODUCTION

Arsenic compounds are found naturally on earth in small concentrations but these are very poisonous elements. It may be present in water, soil, and minerals with various forms. Arsenic also comes in the atmosphere by biomethylation, has the chemical formula $(CH_3)_nAsH_{3-n}$, where n varies from 1 to 3.^{1,2} The volcanoes release about 3k tonnes per year and some of the microorganisms such as bacteria, fungi, and yeasts, and many animals are now considered as biomethylate arsenic, forming volatile (e.g., methylarsenics) as well as non-volatile (e.g., methylarsenic acid and dimethyl arsenic acid) compounds which release up to the extent of 20k tonnes/year, but human activities enhanced the amount of arsenic contamination (about 80k tonnes) which is released in water and other environmental bodies by combustion of various conventional fuels every year. Arsenic is extremely hard to convert in water-soluble bodies or the form of volatile components. Normally, arsenic is also found in various mobile components that means the possibility of high concentrations which are not likely to present on one specific site.^{3,4}

Water is the lifeline of the living bodies of nature. Some of the heavy metals, like chromium (Cr), fluoride (F), lead (Pb) and arsenic (As) are toxic for humans as well as other living bodies. Arsenic is the major hazardous contamination in drinking water in the area of eastern Uttar Pradesh⁵. Although not only natural sources of arsenic contamination but human activities and industrialization are creating a

hazardous level of arsenic contamination. Especially, ceramic and electronic industries are contributing significantly to this carcinogenic contamination⁶.

In ancient times, arsenic was used as a weapon of murder. Its traces are even sufficient to assassinate the living body⁷. Arsenic almost affects many organs of our body along with the disbalances in the enzymatic secretion in the body and it has other major effects on human health as mental retardation, neurological, cardiovascular, gastrointestinal and different types of cancers related with various parts of the body like lung, prostate, skin, liver, and kidney. Both types of trivalent and pentavalent forms of arsenic are hazardous but the trivalent form of arsenic has been found highly toxic. It can be found in various forms like powder, crystalline, amorphous and vitreous⁸. In anaerobic conditions, a high concentration of arsenic contamination especially As(III) is found in groundwater as well as river water. While in aerobic conditions, surface water is considered as the main source of As(V). In some cases, both forms have been found in the groundwater, due to leaching activity within the soil.⁹

Because As can produce a complex compound with specific coenzymes, As(III) has been found more toxic in comparison to As(V). Sometimes, seafood is also found contaminated with arsenic but these are pentavalent and these are not so efficient and carcinogenic to make complex compounds with enzymes. On the other hand, the trivalent form (inorganic form) of arsenic contamination has been found 10 times more toxic¹⁰. For the purification of this arsenic-contaminated water, the trivalent arsenic must be converted in pentavalent arsenic because it is quite easy to remove the As(V) in comparison to As(III). In adsorption bed, activated alumina has been considered as an effective adsorbent for the removal of various water impurities, hazardous materials, and heavy metals from contaminated water¹¹. Due to this behavior of activated alumina, we are using adsorption for the removal of arsenic from contaminated water samples found in groundwater. Pore volume and surface area play an important role in the adsorption technique. Activated alumina shows porous behavior having a surface area (200 m²/g) with fine micropores which is responsible for the adsorption of arsenic contamination¹². Although this method is quite effective to remove organic compounds having high molecular weights it is also used for metallic ions. Removal of arsenic in inorganic form, water normally found in anionic form. The adsorption process is affected by various parameters like adsorption capacity, adsorption rate, contact time, pH value, and initial concentration of adsorbate and dosage of the adsorbent. In this article, we have connected these environmental parameters to understand the mechanism of adsorption of toxic arsenic compounds, on the surface of activated alumina.¹³

Different technologies and methods are available in the literature for the removal of arsenic from contaminated water such as ion-exchange, adsorption with activated alumina, activated charcoal and activated bauxite. Moreover, some other methods are also found, e.g. various biological treatment, solvent extraction (SE), reverse osmosis (RO), precipitation and adsorption using metal hydroxide and solar distillation.¹⁴ In these available techniques, adsorption through activated alumina combined with MDSSS, has been found as an effective, simple in nature, and optimal cost technology for the removal of arsenic in the production of drinking water.¹⁵ Evaporation and condensation is the principle of working of such solar distillation units. This method works on the principle of adsorption of any charged particles or ions on the active site of any solid adsorbent. Such porous adsorbent like activated alumina has also worked efficiently on the same principle.¹⁶ Every system in nature always tries to minimize its energy to get stability. Due to thermodynamic imbalances or uneven energy levels of surface molecules on the active surface of the activated alumina, ions are adsorbed or deposited easily to get stabilized.¹⁷ Dehydroxillation of aluminum hydroxide results in the production of activated alumina. Along with the adsorption of arsenic contamination from drinking water, this compound is also used for the desiccation purpose, to keep things moisture less.¹⁸ Aluminium oxide (γ -Al₂O₃) is used as activated alumina while aluminium oxide (α -Al₂O₃) is found stable and it has a negligible number of active sites, so, it cannot be used for the adsorption process of arsenic contamination.¹⁹

It is a challenge to our technologists and scientists to develop such type of technology which can be useful to treat this contaminated water as well as it should not consume a huge amount of energy.²⁰ Therefore, for this purpose, solar energy harvesting is a technically sound method in which we can purify the contaminated water in arid regions. Here, we are using the sample of river water having organic and

inorganic impurities. The beauty of solar distillation technology is that it removes all types of contamination up to extremely low levels.²¹ In the experimental section, the production capacity of fabricated double slope solar distillation unit having volume $4.68 \times 10^5 \text{ cm}^3$ was found to be 7.5 liters per day in the shiny days.^{22,23} Therefore, present experimental work aims to construct a unit that must be the same as an integrated process adsorption bed (activated alumina) with modified double slope solar still by employing solar energy harvesting because of its low cost, availability and eco-friendly. This process is one of the solutions to provide fresh and drinking water. The estimation of the affecting variables like temperature, initial concentration, contact time, and pH value with various parameters like adsorption isotherms, reaction kinetics and thermodynamic behavior in this process has been done.^{24,25}

EXPERIMENTAL

Study Area and Experimental Setup

Gomti River is a lifeline for the capital of Uttar Pradesh. It originated near Pilibhit and terminates in the Ganges River near Ghazipur after moving from different cities like Lucknow, Sultanpur, Jaunpur, and Varanasi. About 15 to 20 percent of the total flow is contributed by the Gomti River. This river flows in the range of 1.5×10^3 to 5.5×10^4 millions of liters per day during different seasons. The effective area of the Gomti River has been estimated at around $2.6 \times 10^{10} \text{ m}^2$. The Gomti River is the main source of supplying water to a large number of industries. Untreated effluents of these industries, huge amounts of sewage are draining in the river. From Pilibhit to Lucknow, this river passes a distance of $2.5 \times 10^2 \text{ km}$ and it faces so many drainages.

Contaminated Water Sampling

Samples were collected in containers from six different locations of the Gomti River (Mohan Meakins, Hanuman Setu, Dubagga, Gaughat, Kukrail and Barrage) in rainy, winter as well as summer seasons, over the period of 10 months in the difference of two months. A 20 liter PVC container was used to collect each sample. Three samples of contaminated water have been collected from each location within the gap period of 15 days.

Fig.-1: Sample Site Locations of Gomti River, Lucknow (U.P.)

Table-1: Arsenic Contaminated Water Samples Taken From Gomti River

Sample No.	Sample Location	Sample Number	Arsenic Concentration in ppb			Average Conc ⁿ in ppb	Mean Arsenic Conc ⁿ in ppb
1	Dubagga	CWS-1	71.00	104.00	87.44	87.41	90.23
		CWS-2	92.18	95.21	129.65	105.68	
		CWS-3	56.18	95.25	96.34	82.59	
		CWS-4	78.29	102.26	115.25	98.60	
		CWS-5	70.88	60.28	99.45	76.87	
2	Gaughat	CWS-6	127.10	99.24	108.20	111.50	127.60
		CWS-7	137.75	133.06	84.34	163.16	
		CWS-8	65.30	77.32	101.88	81.50	
		CWS-9	180.21	192.10	208.25	193.52	
		CWS-10	69.71	74.50	63.04	88.32	
3	Mohan Meakins	CWS-11	467.50	493.27	486.13	482.30	477.89
		CWS-12	570.47	520.70	492.08	527.75	
		CWS-13	406.60	401.70	428.88	403.42	
		CWS-14	437.53	468.50	449.50	451.99	
		CWS-15	518.90	514.62	508.45	513.99	
4	Hanuman Setu	CWS-16	302.41	296.47	305.92	301.60	283.75
		CWS-17	224.76	271.60	276.74	257.70	
		CWS-18	303.23	293.05	305.22	300.50	
		CWS-19	297.40	278.70	256.10	277.40	
		CWS-20	291.80	298.13	254.72	281.55	
5	Kukrail	CWS-21	351.30	348.20	341.86	347.12	341.60
		CWS-22	357.10	350.41	347.59	351.70	
		CWS-23	350.20	317.50	317.05	328.25	
		CWS-24	377.30	355.70	375.20	369.40	
		CWS-25	318.30	320.25	296.04	311.53	
6	Gomti Barrage	CWS-26	407.22	400.01	408.07	405.10	322.54
		CWS-27	310.50	319.08	304.32	311.30	
		CWS-28	302.00	300.80	323.51	308.77	
		CWS-29	286.71	297.21	311.58	298.50	
		CWS-30	291.30	297.50	278.29	289.03	

This research article is the experimental study of arsenic contamination in Gomti River water samples of Lucknow city (Uttar Pradesh). Our study also highlights the seriousness of present arsenic contamination in Gomti river water collections along with the purification of drinking water through the harvesting of solar energy with the help of fabricated double slope solar still.

Activated Alumina Filter Bed Preparation

Activated alumina filtration bed was prepared according to Fig.-2, 0.5 kg of activated alumina was used. We used the PVC bucket having a height of 18 inches and variable-width 8" to 14" (from bottom to top). A double layer of cotton was used at the bottom of the bed²³. The bucket was filled in the steps of 5 liters. PVC tube of 0.5 inches was used to drain this filtered water it to double slope solar distillation unit for further treatment and purification process. We have preferred this technique because Al_2O_3 adsorption has strong selectivity to arsenite and arsenate ions, is non-hazardous and less expensive than other treatment processes (e.g., membrane separation and ion exchange) for the arsenic removal and also it can be safe disposal on landfills. Its main drawbacks are its pH very sensitive and low regeneration range of about 60-70% (must be recharged after 4 to 5 regeneration cycles)^{26, 27}. The pH value of 7.4 for the effluent is maintained by adding a buffer solution of either H_2SO_4 or NaOH at 0.1 M and it is maintained during the entire sampling period for all treatment processes. The surface of activated alumina is +ve charged until the pH than the point of zero charges. According to the result, the optimum pH values of oxyanions

adsorption onto activated alumina is in the range of 6.0 - 8.4, where it is predominantly positively charged and with the increase of pH, the +ve charge of Al_2O_3 increases, decreasing the adsorption of arsenic oxyanions²⁵.

Fig.-2: Schematic of the Activated Alumina Filter Bed

Fabrication of Solar Distillation Unit

Solar still was constructed by using a fiber-reinforced plastic sheet (FRP) as shown in Fig.-4B. The cumulative inside volume of fabricated solar distillation unit is $4.68 \times 10^5 \text{ cm}^3$ and black paint was used for better absorption. Other materials were used like acrylic sheets, transparent glasses, and plastic pipes. The direction of the fabricated solar distillation unit was kept in East-West, by which we can harvest the maximum amount of solar radiation within the distillation unit. In Fig.-4: A the treatment of arsenic-contaminated water (S_0), activated alumina was used as an adsorption bed and filtered water (S_1) was directly sent to the solar distillation unit for further distillation using solar energy. The output water (solar distilled) was found through the channels of the distillation unit and it was collected in a container (S_2). To measure the temperatures at different locations of our fabricated solar distillation unit, thermocouples were used. The mass flow rate of water has been maintained in the solar still. For getting experimental data, the fabricated solar distillation unit was kept on the top floor of the I.E.T. Lucknow, Sitapur Road, Uttar Pradesh, INDIA.

Pathway for the Removal of Arsenic Contamination

Fig.-3: Schematic Diagram for Removal of Arsenic with Various Combinations (S_0 = Initial Arsenic Concentration Level, S_1 = Arsenic Concentration Level after Activated Alumina Bed, S_2 and S_3 = Final Arsenic Concentration Level)

Fig.-4: Conventional Treatment Units- (A) Analytical Method for the Removal of Arsenic with Activated Alumina bed, (B) Solar Still System Integrated with Activated Alumina Adsorption Bed for the Removal of Arsenic

Analysis of Contaminated Samples

During the analysis of pentavalent arsenic As(V), 1.0 gram of sodium arsenate ($\text{Na}_2 \text{HAsO}_4 \cdot 7\text{H}_2\text{O}$) was dissolved in 25 liters of distilled water, results from the stock solution having concentration level of 0.1 g/L. Similarly, for the determination of trivalent arsenic contamination As(III), 4.3 gram of sodium arsenite (NaAsO_2) was dissolved in 25 liters of distilled water, results in the stock solution having concentration level of 0.1 g/L. The arsenic-contaminated water sample was analyzed by using a 7500-CE spectrometer (ICP-MS) integrated with octopole system. 1.0mg/L stock solution (standard) was kept between 0.005 mg/L to 0.100 gm/L used for the calibration with standards values like 2, 4, 20, 40, 80 and 100 $\mu\text{g/L}$ concentration range was used to estimate the arsenic contamination level. The experimental data measurements were accepted as reasonable data in cases of less than 5% relative standard deviation (RSD).²⁸⁻³⁰

Adsorption Isotherms (Adsorption Equilibria)

The adsorption phenomena can be described by various adsorption isotherm models such as Brunauer-Emmet and Teller (BET), Langmuir, Freundlich, Polanyi, and Dubinin and Raduskevich. Among all of these, Freundlich and Langmuir isotherm models are very well known isotherms for single solute adsorption. The empirical correlation of Freundlich isotherm is given below:

$$q_e = K C_e^{1/n} \quad (1)$$

Its linear form is as follows:

$$\log q_e = \log K + \frac{1}{n} \log C_e \quad (2)$$

Where, q_e is mass of adsorbate per mass of adsorbent at equilibrium, C_e is the solution concentration (mass per unit volume), K (determined by the units of q_e and C_e) and $1/n$ (unit less) are constant parameters. If the values of C_e and $1/n$ is fixed, then the value of K is larger which increases the capacity q_e . If the values of K and C_e are fixed then the value of $1/n$ is smaller which is responsible for stronger adsorption bond. As $1/n$ becomes very small, the capacity tends to be independent of C_e .

The empirical correlation for Freundlich adsorption isotherm is with the assumption that the adsorbent has a heterogeneous surface which composed of various sections of adsorption sites is given below:

$$q_e = \frac{q_{\max} \cdot bC_e}{1 + bC_e} \quad (3)$$

The linear form of the Langmuir isotherm model can be written as:

$$\frac{1}{q_e} = \frac{1}{q_{\max} \cdot bC_e} + \frac{1}{q_{\max}} \quad (4)$$

Where, b and $q_{\max}$ are constants. The value of $q_{\max}$ is the maximum value of surface concentration q_e at which monolayer is formed. The constant b corresponds to the amount of energy adsorbed which increases with the increase in strength of adsorption bond³¹.

Adsorption Kinetics and Mechanisms

The adsorption rate is the most affecting factor to evaluate the efficiency of the adsorption process and which also helps to determine the quantity of removal of arsenic contamination for water purification purposes. The adsorption rate can be explained by the pseudo-second-order kinetics. This equation employs the adsorption of solid particles from the solution. This rate expression is used to discuss the various types of reactions, e.g., adsorption of heavy metal ions from solutions and also the designing of multistage as well as batch adsorption systems. This equation can be applied to explain the kinetics of adsorption of arsenic. The pseudo-second-order expression is given below:

$$\frac{1}{q_t} = \frac{1}{k_2 q_e^2} + \frac{1}{q_e} t \quad (5)$$

Where, k_2 is the rate constant of adsorption (g/kg min) and his initial adsorption rate (mg/g min). As time approaches zero ($t \rightarrow 0$), then the cab is written as: $q_e \sim h$

$$h = k_2 q_e^2 \quad (6)$$

Where h is the initial adsorption rate, q_e is the equilibrium adsorption capacity, and k_2 is the pseudo-second-order rate constant which was evaluated with the help of slope and intercept values in the plot between t/q and t .

Arsenic Chemistry and Ecotoxicity

The river water has arsenic complex chemistry. For the removal of arsenic by various technologies, firstly should know the chemical behavior of arsenic with oxidant, coagulant and activated adsorbent, etc. Depending on the pH and Eh (redox potential) conditions, arsenic contamination is present mainly in two oxidation states in the aquatic system, one is As_2O_3 which is known as form arsenite and another is As_2O_5 known as a form of arsenate. The trivalent form of arsenic As(III) is sixty times highly toxic than the pentavalent form of arsenic As(V) which means an organic form of arsenic is less or non-toxic while the inorganic form of arsenic is highly toxic. The dissociation of As(III) and As(V) acids is quite different can be quantified the equilibrium constants of dissociation (pka_i) as given: H_3AsO_4 : pka_1 is 2.19; pka_2 is 6.94; pka_3 is 11.5 and H_3AsO_3 : pka_1 is 9.20³².

The LD_{50} is processed to measure the short-term poisoning potential (acute toxicity) of harmful material. A lower LD_{50} is an indication of increased toxicity. The limit of LD_{50} is dependent on the effects of projected health in lifetime arsenic exposure. Bond energy which is required to dissociate into different chemical bonds is usually measured in units of kJ/mol at ambient temperature value of 25°C. Therefore, the bond energy of a C-H, C-O, etc. single bond is not the same in all organic compounds. Thus, the bond energy values given from chemical data books are average values and also given in Table-2³³.

$$\Delta H = \sum \Delta H_{(\text{bonds broken})} - \sum \Delta H_{(\text{bonds formed})} \quad (7)$$

Effect on Human Health of Arsenic Exposure

The consumption of water and seafood affected by arsenic-contamination are the biggest sources of the exposure of the human body. Some As(V) contaminated seafood is not much toxic, but As(III) contaminated seafood is quite hazardous for human health. Both the forms of arsenic may enter the chain of food plants obtained from agricultural materials or irrigation of soil with arsenic-contaminated water²⁸. The effects of long-term exposure of arsenic in human health are (a) Preclinical stages: In this case, the withdrawal of arsenic-contaminated water/food intake leads to no detection of arsenic metabolites in urine. (b) Clinical stages: In this case, confirmed detection of arsenic toxicity based on analyzing external (hair, nails & skin scales) and other body parts. (c) Internal complications stages: In this case, affected body organs such as eyes, lungs, liver, fatigue, and muscles. (d) Malignancy stages: In this case, affecting skin pigmentation, lungs, bladder, uterus, hypertension, and other body organs³⁴.

Table-2: Different Species of Arsenic Present in the Water/Environment.

S. No.	Arsenic Species	Chemical Structure	Bond Energy ΔH (MJ/mol) at 298 K	LD ₅₀ (Median dose)
1	Arsenite		2.162±0.023	8 mg/kg (Mouse, injected)
2	Arsenate		3.207±0.033	21 mg/kg (mouse, injected)
3	Methylarsenite		2.840±0.028	2 mg/kg (mouse, oral)
4	Methylearsenate		3.677±0.034	916 mg/kg (mouse, oral)
5	Dimethylarsenite		3.310±0.030	21 mg/kg (mouse, oral)
6	Dimethylarsenate		4.148±0.035	648 mg/kg (mouse, oral)

Fig.-5: A and B show the Arsenic Infection on Human Health

RESULTS AND DISCUSSION

For getting better purification of contaminated water through this technique, we have integrated adsorption bed with solar still. The outcome of these types of combinations in Fig.-3 was compared. It was found that the integrated system has performed best in the arsenic removal from contaminated water. Various affecting environmental parameters have also been estimated and correlated with the performance of these various integrated different methods.

Effect of Weather Conditions and Season

Figure-6 represents the hourly distinction of ambient temperature and global radiation during summer and winter seasons. It was observed that the solar intensity in the summer season was higher than the winter season in the geographical location ($26^{\circ}84'N$, $80^{\circ}94' E$) of Lucknow city (Uttar Pradesh). In the northern hemisphere during the summer season, the higher amounts of direct solar radiation as well as higher ambient temperature were monitored in comparison to winter. The maximum solar radiation measured was 950 W/m^2 at 14:00 hr on 15 June, 2017 in summer, while 716 W/m^2 at 13:00 hr on 9 December, 2017 in winter. The ambient temperature also rises from morning hours and reaches a maximum value and then declines in the evening hours. During the winter season, the sun rays are far more tilted and the sun's position in the sky is lower in comparison to the summer season. During the winter season in the northern part of India, where Lucknow is situated, the days are hazy and the amount of diffuse radiation in the environment is higher due to foggy weather. The maximum observed temperature (ambient) was found 48.3°C at 14:00 pm on 15 June, 2017. On the other hand, it was found at 28.3°C at 13:00 pm on 9 December, 2017 during the winter season.

Fig.-6: Variation (Hourly) of Global Radiation and Ambient Temperature *versus* Solar Time in Summer and Winter

Effect of pH

The rate of adsorption for arsenic removal from contaminated raw water and its purification by using activated alumina was found to be dependent on the pH of a given solution. According to the experimental result, the behavior of the adsorption process of As(III) and As(V) ions were found concentrations dependent, like 0.1 gm, 0.25 gm and 1.0 gm of activated alumina which are shown as Fig.-7. It was found that As (III) adsorption increases with an increase in pH up to 8.5 and maximum adsorption were found as 92%. The reason for different trends of As(III) & As(V) adsorption are due to pH 9 but all subsequent tests were conducted at pH 7.

Concentration Effect of Adsorbate

Figure-8 shows the effect of contact time and As(III) concentration on adsorption. The extent of adsorption increases with an increase in contact time and decreases with As(III) initial concentration. Equilibrium adsorption has been activated filter 3 hr of operation and after that, it has been saturated and looks like a straight line. It also shows that the adsorption rate is quite higher for a higher initial concentration of As(III). It has been observed that adsorption was found fast up to initial 1 hr operation

but, at saturation level, approximately 95 percent adsorption has been completed. The saturation may be due to the decrease in the efficiency of the activated alumina bed. Similarly, Fig.-9 shows the effect of contact time and As(V) concentration on adsorption. The extent of adsorption increases with an increase in contact time and decreases with As(V) initial concentration. Equilibrium adsorption has been activated filter 3 hrs of operation and after that, it has been saturated and seems like a straight line. It is also shown that the adsorption rate is quite higher for a higher initial concentration of As(V). It has been observed that adsorption was found fast up to initial 1 hr operation but, at saturation level, approximate 99.8 percent adsorption has been completed. The saturation may be due to the decrease in the efficiency of the activated alumina bed.

Fig.-7: Effect of pH on Adsorption of As(III) and As(V)

Fig.-8: Effect of Contact Time and Adsorption Capacity by Activated Alumina for Different Concentrations of As(III)

Fig.-9: Effect of Contact Time and Adsorption Capacity by Activated Alumina for Different Concentrations of As(V)

Fig.-10: Mean Values of Arsenic Concentration in the Water Sample at Various Locations of the affected Area

Fig.-11: Average Values of Arsenic Concentration of Water Samples of Various Sample Locations of Gomti River

Figure-10 shows the mean values of arsenic contamination in various wastewater samples at various locations of the affected area. Similarly, Fig.-11 is a representation of the average arsenic concentration of all 30 contaminated water samples.

Concentration Effect of Adsorbate with Adsorption Isotherms

The adsorption process is based on the distribution ratio of the solute between the liquid phase and the solid phase. It is a measurement of the equilibrium condition. This distribution can be represented with the quantity q_e as a function of C_e at given fixed temperature, where, q_e is the quantity of adsorbed arsenic per unit weight of the activated alumina, and C_e is the equilibrium concentration value of arsenic remained in the solution. Adsorption isotherm for As(III) was calculated at this equilibrium test by using the optimum value of contact time as 3 hr with pH value of 8.5 for better adsorption.

Fig.-12: Langmuir Isotherm for Arsenic Adsorption onto Activated Alumina

Fig.-13: Freundlich Isotherm for Arsenic Adsorption onto Activated Alumina

Figure-12 shows the plot of Eq. (3), which is a linear form of the Langmuir adsorption isotherm model. It reflects the correlation between the adsorbed amount and the remaining amount of arsenic. On the other hand, Fig.-13 shows the plot of Eq. (2), which is also the reflection of adsorbed amount and the remaining amount of arsenic as a linear form of Freundlich adsorption isotherm. Various constants were found for Langmuir as well as Freundlich in Table-3. The adsorption capacity has been found higher for As(V) as compared to As(III) with activated alumina adsorbent. Thus, activated alumina is a potentially preferred adsorbent for the removal of arsenic contaminations from the river as well as groundwater.

Table-3: Langmuir and Freundlich Isotherm were Constant.

Langmuir Isotherm Constant		Freundlich Isotherm Constant	
q _{max}	B	K	1/n
0.775	5.785	1.062	0.578

Percent removal of Treated Water

The percent removal efficiency of produced water has been calculated before and after using an integrated approach adsorption with activated alumina bed and solar distillation is shown in Table-4. We found that the pH of water often adsorption-solar distillation increased from mean value 6.53 to 8.5; it means that produced water is mostly higher pH than that of wastewater due to the presence of contaminations in water and sorption of anions on activated alumina surface. Similarly, the conductivity of produced water also increased due to the separation of contaminations and therefore, it also depends on the number of contaminations present in water. The percent removal efficiency of COD shows that 16.23 percent decreases due to the higher initial value of COD and complex composition for purification of water. In the case of arsenic, 100 percent removal efficiency has been found from produced water with the adsorption-solar distillation method. Therefore, this method can be widely used for the efficient removal of other heavy metals present in wastewater.

Table -4: Percent Removal Efficiencies Obtained Before and After the Distillation Process.

Major Parameter	Before Treatment	After Treatment	Percent Removal
pH	6.53 ± 0.01	8.47 ± 0.19	-
Conductivity (µs/cm)	88530 ± 36	8762 ± 176	-2.64
TSS (ppm)	23.57 ± 4.05	4.00 ± 1.05	96.56
BOD (ppm)	3.23 ± 1.6	2.15 ± 1.02	51.43
COD (ppm)	43.05 ± 16.2	37.04 ± 15.2	16.23
Arsenic (ppb)	273.06 ± 25.04	≤0.01	Approx. 100

Economic Analysis

It is essential to check whether this integrated approach is economically viable or not. Therefore, we have analyzed for the estimation of the economic study of this integrated adsorption-solar distillation unit.

Cost Estimation

The economic analysis of the integrated approach adsorption-solar distillation unit has been enumerated based on simple techno-economic calculation. During experimental work, we have been observed that solar based distillation system is operated for two hundred and fifty days (excluding rainy days) in the eastern part of Uttar Pradesh in a year and generates 1875 liter distilled water. Also, in comparison to electric operated distillation system, it consumes not less than 1218.75 electric units (4.875×250) to produce 1875 liter distilled water for which a person has to pay Rs/- 6.5 per electric unit (KWh) for domestic usage. The gross cost to operate this electric based distillation system for producing 1875 liter distilled water is Rs/- 7921.87 (Rs/- 6.5×1218.75). Hence, we could save Rs/- (29,615) per year by utilizing this system of solar distillation for the production of freshwater which can reduce power consumption.

Pay-back Time

The payback time is the minimum time required to recover investment costs. Payback can be used to determine the minimum time a system must last to recover the investment costs. The payback time for a system saving energy is calculated as the total investment cost divided by the annual revenues from energy saved, displaced, or produced. In this study, solar distillation important is given to distilled water produced annually rather than saving energy. In payback analysis, the unit of measurement is the number of years to “payback” the investment cost. It indicates the length of time between cumulative net cash outflow recovered in the form of yearly net cash inflows. Pay-back time (yrs) = Capital investment / (Annual profit + Depreciation). The payback time for this system was calculated to be 18 months.

CONCLUSION

The purpose to carry out this study for the production of water for drinking purpose and treatment of wastewater by using an integrated adsorption-solar distillation process uses activated alumina as adsorbent and solar energy harvesting for evaporation-condensation which is easy in operation for the supply of water and sanitation of arsenic (As), especially in rural areas. This technology is based on renewable energy, therefore, there is no need for energy requirement from conventional sources such as thermal electric power. It produces nonhazardous by-products with negligible cum less operational cost. Adsorption kinetics was found well fitted by using empirical correlations of the pseudo-second-order model. In adsorption isotherms, Langmuir model was best fitted with experimental data, resulting in the maximum adsorbed amount of 3.2 mg/g for As(III) and 6.3 mg/g for As(V) at pH of 7.2 and 20 °C temperature.

Treated water quality (through conducting many experiments) meets the requirement of drinking water within the permissible limit of WHO drinking water standards. This technique is also effective for the removal of microbial pathogens in water. This experimental set up can be installed on the rooftop of each house so that it can provide many benefits such as health improvement of the community, hygiene, public welfare, and removal of arsenic from water. The obtained results after all specified analysis, it is concluded that the combination of these technologies (activated alumina absorbent bed integrated with double slope solar still) can be a better option in comparison to previous techniques as the successful implementation of an efficient and economically viable solution for minimizing arsenic contamination levels in raw water with excellent chemical and microbiological qualities.

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ABBREVIATIONS

As	Arsenic
ppb	Parts per billion
ICP-MS	Inductively coupled plasma mass spectrometry
MDSSS	Modified double slope solar still
FRP	Fiber-reinforced plastics
S ₀	Input arsenic concentration
S ₁ , S ₂ & S ₃	Output arsenic concentrations
AA	Activated alumina
C _e	Equilibrium concentration of As(III) and As (V) solution (mg/L)
MLD	Millions of liters per day
EPA	Environmental protection agency
CWS	Contaminated water sample
q _e	equilibrium surface (mass of adsorbate/mass of adsorbent)
C _e	solution concentrations (mg/L)
K & 1/n	Freundlich model constants
b & q _{max}	Langmuir constants.
k ₂	Rate constant of adsorption (g/kg min)
h	Initial adsorption rate (mg/g min)
q _e	Equilibrium adsorption capacity
BOD	Biochemical oxygen demand (ppm)
COD	Chemical oxygen demand (ppm)
TSS	Total suspended solids (ppm)

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