CHEMICAL ENGINEERING TRANSACTIONS

VOL. 62, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Fei Song, Haibo Wang, Fang He

ISBN 978-88-95608- 60-0; **ISSN** 2283-9216

DOI: 10.3303/CET1762073

Numerical Simulation of Solute Migration of Groundwater Remediation under a Chromium Contaminated Site

Zhenyu Ding[a], Kunpeng Zhou*[b], Wenhui Zhu[a], Tianwei Sun[a], Xin Zhou[a], Yankun Zhang[a]

[a] Chinese Academy of Environmental Planning, Beijing 100012, China
[b] Baohang Environment Co., Ltd., Beijing 100012, China
imzkp@outlook.com

Groundwater remediation technology of Pump-Treat and Vertical anti-Seepage is an effective treatment to retard the migration and diffusion of pollutants. It is widely used to prevent and retard the long-term leakage of pollutants in landfills. Based on the groundwater infiltration, dispersion and source-sink interaction, this research work has established a three-dimensional coupled model of hydrologic and contaminant transport was constructed with Modelflow groundwater modelling. It ultimately provides a scientific basis for the prevention and control treatment of groundwater pollution in the actual construction of the site. According to the data of borehole sampling, stratigraphic section and pumping test, the site is vertically divided into three layers, namely the upper weak aquifer, the sandy pebble aquifer and the mudstone weak aquifer. The groundwater system in the assessment area is generalized as non-homogeneous anisotropy, spatial three-dimensional structure, unsteady groundwater flow system. It takes convection and dispersion of contaminant into consideration when transport characteristics of hexavalent chromium (Cr^{6+}) contaminant with pump-treat and vertical curtain in groundwater environment were numerically analysed. The retention effects of curtain grouting were researched and predicted. The results showed that the Cr^{6+} concentration of groundwater was decreasing from 317 mg/L to 180 mg/L under the condition of continuous pumping without curtain grouting with removal efficiency of 43%; and the Cr^{6+} concentration of groundwater was decreasing from 317 mg/L to 80 mg/L under the condition of continuous pumping with curtain grouting with removal efficiency of 75%.

1. Introduction

Physical and chemical properties of soil and groundwater in contaminated sites, pollution distribution and conservation characteristics, as well as the risk assessment are the keys to the design of rehabilitation scheme (Chen, 2005). At present, most of the field remediation projects in China mainly study the migration equations, principles and laws of pollutants by means of experiments and simulations. There are relatively few cases of applying theories and techniques of soil-groundwater systems and pollutant migration to practical projects, Practical application of engineering basis. How will the remediation theory and technology research and development fall into the engineering application to really meet the state's demand for soil pollution remediation in the future are the keys to promote the entire site remediation industry. Based on the current extraction-treatment and vertical barrier seepage control technology, the current research on groundwater remediation is based on the simulation of migration and diffusion of contaminants in a chromium-contaminated site under the blockage condition. Modelflow is used to establish the groundwater seepage and pollutant transport Coupled model (with emphasis on infiltration, dispersion and source-sink interaction of groundwater, without considering the biodegradation and chemical reaction of pollutants), the combination of extraction-treatment and vertical barrier seepage barrier in the field flow field of the research site Pollutants block effect and law, and provide a scientific basis for the prevention and treatment of groundwater pollution in the actual site of site remediation.

Please cite this article as: Zhenyu Ding, Kunpeng Zhou, Wenhui Zhu, Tianwei Sun, Xin Zhou, Yankun Zhang, 2017, Numerical simulation of solute migration of groundwater remediation under a chromium contaminated site, Chemical Engineering Transactions, 62, 433-438 DOI:10.3303/CET1762073

2. Materials and methods

2.1 Site background

One historical predecessor of the department of chromate plant of chromium contaminated site in the northwest area, founded in 1955 for trial operation, and formally put into production in 1958, is one of the earliest manufacturers of sodium dichromate in china. In 1997, due to old equipment and poor management, bankruptcy and legacy 472,400 tons of chromium residue, distributed in the region three chromium slag field, the original factory area also have heavy pollution, become the country's typical legacy of chromium contamination sites. The plant has a long history of production. In the early years, its awareness of environmental protection was weak and the environmental protection and technological facilities were backward. Any disposal of chromium slag and indiscriminate disposal of the reactor caused the heavy metal chromium to penetrate underground and spread to the surrounding areas, causing soil and groundwater pollution. Three large-scale chrome slag in the open storage process of particulate matter, but also caused the surrounding soil and groundwater, and even the ambient atmosphere of heavy metal chromium content exceeded.

According to the demand for land planning and construction, it is proposed to use this chromium to pollute the historic sites for the construction of new urban sewage treatment plants. Due to the serious pollution of chromium in the soil and groundwater in the plant, effective remediation and treatment must be carried out before the new planned land is constructed.

Based on the investigation and analysis of a historical chromium residue in northwestern China, this paper puts forward the ideas of soil and groundwater pollution control in chromium-contaminated sites, which not only provides detailed and reliable evidences for the investigation, evaluation and treatment of chromium contaminated sites in China, but also provides other types of pollutants Survey evaluation and remediation programs for reference and reference.

2.2 Regional geological environment condition

The site stratum is respectively plain filling soil, silty soil, silty clay, sand and gravel layer and Paleogene mudstone under the NST. According to the data of geological exploration holes, water is visible in shallow holes (usually less than 6m). This layer of water is filled with filling silt, accepting the recharge on the interface (Most of the plant hardened and in Non Hardened areas, recharge of atmospheric precipitation and recharge of wastewater from the plant can be accepted). The lower sandy gravel and the aquifer covered with silty clay, having a stable impermeable layer, therefore, from the site scale, the aquifer becomes a deep, slightly confined aquifer. The aquifer thickness is 0.7-6.0 m. The depth of penetration ranges from 0.1 to 3.45 m. According to site pumping test data, pebble permeability coefficient is 25.6-49.1 m/d, with radius of influence 13.2-67.3m. Groundwater flows from south to north, recharged by precipitation and groundwater, and runoff underground recharge downstream, eventually excreted in the surface water. The seasonal variation is obvious, and the annual water level varies about 0.5-1.0 m.

2.3 Pollution status and investigation

Groundwater survey results show that the shallow super-standard multiples of the largest in the plant site and the northeast side. Among them, the concentration of Cr^{6+} in the groundwater of shallow groundwater at the leaching plant in the middle of the plant area was the highest, which was 5640 mg/L. According to the groundwater quality standard (GB/T 14848-93), concentrations of Cr^{6+} higher than 0.1 mg/L are exceeded. Then it exceeded 56,400 times. Followed by chromium slag field (northeast), two monitoring period concentrations were 6.99 and 24.4mg/L. Concentrations in the east and west of the plant varied widely, exceeding the first monitoring period (dry season) and the supplementary investigation (wet season) at concentrations less than 0.01 mg/L. South shallow super standard is also more serious.

Compared with shallow, deep underground water to the East, West and South three boundaries, generally has low concentration, but there is also super punctuation. The maximum concentration of groundwater in the deep water is in the center of the plant (581 mg/L) and the Northeast chrome slag yard (312 mg/L) similar to the shallow distribution. But in the lower reaches of the plant, deep groundwater is seriously exceeding standard, with a maximum value of 256 mg/L. It is shown that the Cr^{6+} infiltration in the plant has passed through the silty clay with relatively water retention as the groundwater moves, with pollution to deep sand, gravel, groundwater, and it may contaminate the river on the north side of the plant.

2.4 Groundwater remediation design

At present, impervious technique of pump-treatment and vertical anti-seepage barrier is an effective means to prevent the migration and diffusion of pollutants in Site Groundwater Remediation(Zhan et al., 2011; Zeng et al., 2013)., which was used in prevention and block of long term leakage for landfill pollution. In order to ensure the safety of surface water near the river, while considering the maturity of the groundwater remediation technology, the combination technology of "pump-treatment & In-situ vertical anti-seepage barrier "as the main remediation technology of groundwater in the contaminated site.

For the above heterogeneous, isotropic, spatial three-dimensional structures, the unsteady groundwater flow system is considered, it can be described by the continuity equation of groundwater flow and its definite solution condition (Gao et al., 2012). The advanced groundwater model Visual Modflow software is chosen to solve the problem of determining the solution (Wei, 2011), so as to establish the groundwater numerical simulation model of the study area. According to the simulation results of hydrogeological model, groundwater flow field simulated by model, the movement of pollutants in groundwater is dominated by diffusion and convection. In the groundwater pollution simulation and prediction process, the adsorption, volatilization, and biochemical reactions of pollutants in aquifers are not considered, the parameters in the model are conserved(Chen et al, 2008; Geelhoed et al, 2001). The simulated longitudinal dispersion parameter values are 10m, and the transverse dispersion parameter values are 1m.

3. Numerical simulation and results

3.1 Generalization of model in study area

In order to ensure the safety of groundwater utilization in the surrounding areas of the site, it is necessary to take strict principle where environmental sensitivity is pretty high (Zhang et al., 2010). The model focuses on the hydrogeological conditions of the site, with the boundary of groundwater and the sensitive points of groundwater environment (surface water on the northern boundary). The simulation range is from the south side to the groundwater inflow boundary (Figure 1). The groundwater simulation range is 0.36 km^2, the bottom boundary of the model is the Paleogene mudstone which is poor in water abundance.

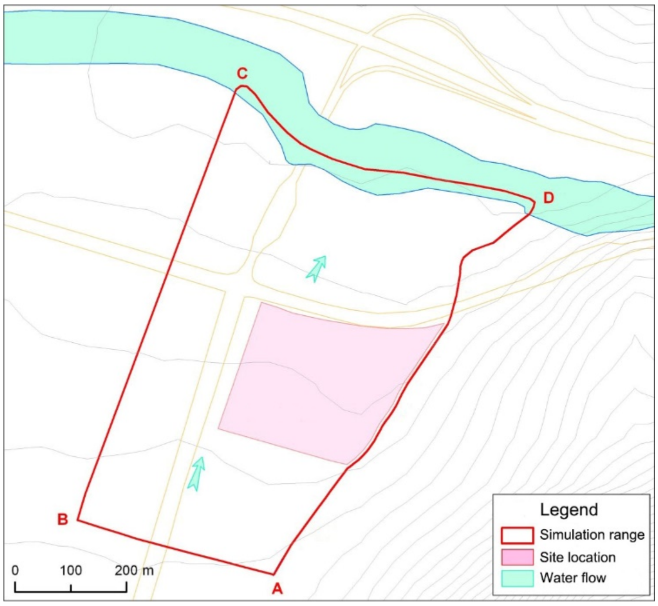

Figure 1: The groundwater simulation range

According to the characteristics of groundwater system in the study area, rectangular mesh is used, and the mesh size is 2 × 2 m. The simulation area is divided into 76940 grids, and the 3 layers are divided into 230820 grids. The main targets of this simulation are lower sand gravel aquifer that is silty and the lower part is mudstone. Therefore, the amount of precipitation recharge and evapotranspiration can be neglected. The main source of recharge is the southern lateral supply, which is discharged into the river without artificial extraction during the simulation period.

This work is mainly based on the existing hydrogeological parameters obtained by pumping tests, and the empirical coefficients of hydrogeological parameters of specific lithology. According to field pumping test data, the permeability coefficient of pebbles is between 25.6 and 49.1 m/d.

3.2 Scenario Design

There are 40 pumping wells in the study area, and the pumping capacity of the single well is 5 m^3/h. It takes 5 days for continuous withdrawal and 5 days；This cycle is implemented with a duration of 3 months. According to the pumping scheme, the total water extraction capacity can reach 216 thousand m^3. According to preliminary investigation, the groundwater pollution amount is 67 thousand and 800 m^3. Groundwater pumping capacity is 3 times of the amount of pollution, which can satisfy the purpose of cleaning contaminated groundwater. In the prediction model, pumping water is drawn according to the parameters of the well.

Due to pumping and in-situ barrier, the in-situ reaction zone construction is basically synchronous and the application cycle is about 2 months. According to pumping and in-situ barrier, the in-situ reaction zone construction is basically synchronous and the application cycle is about 2 months. On the South and west sides of the site, the total length of the wall is 498.6 m, The south boundary of the continuous wall is located at the south side of the factory boundary at 2 m, the south boundary of the continuous wall is located at 1.5m outside the factory. The project adopts the slot type plastic concrete material cutoff wall. The wall thickness of the diaphragm wall is 600mm, the wall height is 10m, the steel cage length is 10m, and the pile is made of C30 ordinary concrete. In the model, the bottom boundary is connected with mudstone, and the permeability coefficient is taken as 1×10-4 m/d (1.16×10-7cm/s).

The project contains two in-situ reaction zones with a total length of 704 m, with the in-situ reaction zone adjacent to the northern boundary of the plant（343.0 m）. It is located at 1.5 m north of the factory area. The west side extends to the in situ resistance wall, extending to the East plant drain out of bounds；The in-situ reaction zone on the north side of Bayi Road (361.7 m) is located at 2 m on the north side of Bayi road, 1m to the edge of the road. In the model, the removal rate of reaction wall is set to 90%.

The concentration of groundwater pollutant was measured in December 2015. According to the distribution of feild site and hydrogeological conditions, the initial value of pollutant concentration in the simulated area is obtained.

3.3 Modeling predictions

(1) Simulation of pumping-treat only

According to the prediction results, the groundwater level is basically stable for 1 months after the pump-treat, with water level drop in plant 5-7m (Figure 2). According to the change of Cr concentration in the plant area, the result shows that, the concentration of Cr in the plant showed a downward trend. But after pump-treat, the concentration of Cr in the plant is still in the state of exceeding standard. The highest concentration of pollutants falls from 300mg/L to 180mg/L.

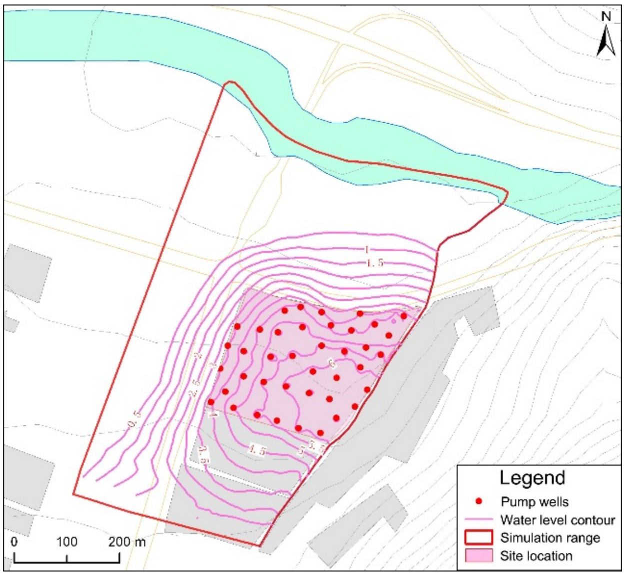

Figure 2: The predicted contour map of water level after 30 days pump-treat

(2) Simulation of the combination technology of "pump-treatment & In-situ vertical anti-seepage barrier "

In order to make the scope of control of the pollution plume no longer expanding, and the protection of the lower reaches of the Huangshui River and other sensitive areas, combined extraction and disposal system, s barrier belt and reaction belt are arranged around the plant area. Taking into account the overall groundwater flow from southwest to northeast, therefore, providing with an in-situ barrier wall on the west side of the factory area, the south side and the east side, obstructing upstream groundwater continues to flow into the plant area. Combined with the actual geological survey data and the actual situation of the project site, it is recommended to use the ground wall barrier scheme. The total length of the diaphragm wall is 840 m, ①The south boundary of the earth wall: The south boundary is located 2 m south of the factory boundary; ②The East and west sides of the earth wall: Considering the plant west adjacent to the Kunlun Road, the western boundary in a factory at 1.5 m.

According to the forecast results, because of the continuous wall barrier, groundwater supplies are scarce, after pump-treat, the southern part of the plant is in a dry state. According to the change of Cr concentration in the plant area, the result shows that, the concentration of Cr in the plant showed a downward trend, but after pump-treat, the concentration of Cr in the plant is still in the state of exceeding standard, under continuous pumping and continuous wall pumping conditions, the concentration of pollutants in the plant continued to decline, and the maximum concentration of pollutants Cr in groundwater decreased from 317mg/L to 80mg/L, and the removal rate was close to 75% (Figure 3). However, after pumping, the concentration of Cr in the plant is still in excess. Therefore, it is necessary to repair the site with in-situ chemical reduction.

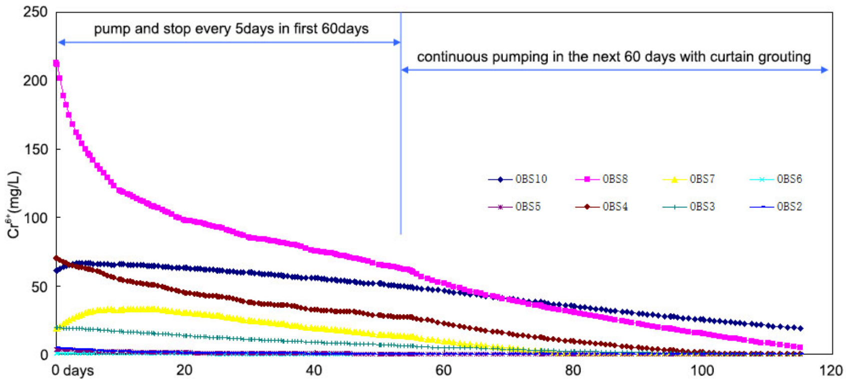

Figure 3: The Cr^{6+} concentration curves under the condition of continuous pumping with curtain grouting

4. Conclusions

The model of solute transport in groundwater contaminated by chromium is established based on Modelflow. After the identification and verification of the model, the model simulation results are good. Using solute transport model, the application of extraction treatment and vertical barrier restoration technique are discussed. The change of pollution degree of chromium pollution component to ground water showed that, There is a large amount of water in this area, and the overall trend of pollutant diffusion is obvious, which will affect the sensitive point of northern surface water easily, Therefore, it is necessary to strengthen the in-situ rehabilitation of the inland water in the original plant area so as to prevent the expansion of the scope of groundwater pollution. At the same time, the model results also put forward higher requirements for the scientific design of the rehabilitation target and the engineering scheme, which must be based on a full and detailed site survey and risk assessment.

In addition, comprehensive consideration is given to the subsequent site construction function and the human health risk of peripheral sensitive receptors, as well as 200 m outside the Huangshui River surface water security on the north side, In this project, the construction waste and the treated soil are required to meet the highest allowable discharge concentration of GB 8978, with soil remediation objectives for shallow, ectopic and deep in situ soils meet the risk assessment limitCr^{6+}≤70mg/kg. Taking into account the site environment, local economic and technical conditions, such as the implementation of comprehensive rehabilitation (Zhao et al, 2015) the overall repair targets are set up to meet the relevant national standards. At the same time, it meets the requirements of ensuring environmental safety and preventing further migration and diffusion of pollutants.

The pollution of chromium residue not only seriously affects the soil and groundwater quality of the contaminated sites and surrounding areas, but also has a great influence on the quality of the chromium residue, also leads to a decrease in water quality and atmospheric environment, What is more serious is the direct harm to the health of the people living nearby and the ecological security of the surrounding environment. There are higher risks in the construction of the following sewage treatment plants (Kantar et al., 2015; Gu et al., 2008). The implementation of Cr^{6+} in chromium slag contaminated site restoration project, in order to prevent and control large area in contaminated soil chromium released into the environment (Wang et al, 2016) To avoid further pollution of the surrounding soil and underground water by chromium, so that a major source of pollution in the urban areas has been effectively controlled, reduce pollution and damage to surrounding water bodies, and restore the ecological function and function of the soil in the restoration area (Guo et al, 2013; Dong et al., 2013) to meet the needs of land construction, ensure the health of the surrounding residents, and comprehensively enhance the value of land use.

Acknowledgments

This work was supported by the 2016 MEP Plan Grant from “Project of Technical Support and Evaluation of Soil Pollution Prevention and Control Action Plan”. Moreover, this study was funded by the National Soil Special Foundation of Qinghai Province.

Reference

Chen L.G., 2005, Study on Health Risk Analysis System of Soil and Groundwater Pollution Control, Tsinghua University, Beijing, China.

Chen M.J., Keller A. A., Lu Z.M., 2008, Stochastic Analysis of Transient Three-phase Flow in Heterogeneous Porous Media, Stochastic Environmental Research and Risk Assessment, 1, 5-19.

Dong G.X., Li L.N., Tang G.G., Jing L.X., 2013, The Characteristic of Chromium Waste of Industry and Regional Distribution and Suggestions, Environmental Monitoring in China, 29,196-199.

Gao H.Q., Yang M.M., Hei L., Ye W.C., 2012, MODFLOW & FEFLOW Application of Domestic Groundwater Value Simulation, Groundwater, 4, 1-5.

Geelhoed J.S., 2001, Modelling of Chromium Behaviour and Transport at Sites Contaminated with Chromite ore Processing Residue: Implications For Remediation Methods, Environmental Geochemistry and Health, 3, 24-39.

Gu Q.B., Guo G.L., Zhou Y.Y., Yan Z.G., Li F.S., 2008, Classification, Application and Selection of Contaminated Site Remediation Technology: An Overview, Research of Environmental Sciences, 21,197-202.

Guo N., Tian Y.W., 2013, Practice Obstacles and Improvement Measures of Environmental Public Interest Litigation in China-Talking about the Chromium Pollution Incident in Yunnan, Qujing, Environmental Pollution and Control, 35, 96-99.

Kantar, C., 2015, Comparison of Different Chelating Agents to Enhance Reductive Cr(VI) Removal by Pyrite Treatment Procedure, Water Research, 76:66-75

Wang X., Xiong H.L., Ma J., Xia F.Y., Pei Y., 2016, Study on the Occurrence Characteristics and Feasibility of Ectopic Leaching Remediation of Chromium in the Soil of the Abandoned Chromate Plant, Journal of Environmental Engineering, 10, 6744-6752.

Wei P.X., 2011, Application of Visual Modflow to Simulation of Groundwater Contamination Migration, Water Resources Protection, 4, 211-216.

Zeng X., Zhan L.T., Chen Y.M., 2013, One Dimensional Diffusion Analytical Solution of Organic Pollutants in HDPE Membrane Bentonite Composite Antifouling Curtain. Journal of Environmental Science, 33, 2786-2794.

Zhan L.T., Liu W., Chen Y.M., 2011, Simulation and Long-Term Prediction of Natural Soil Transfer at the Bottom of a Landfill Leachate, Journal of Environmental Science, 31, 1714-1723 (in Chinese)

Zhao W.Y., Yang Y., 2015, Analysis on Remediation Technology of Soil Heavy Metal Pollution, High Technology and Industrialization, 11, 64-69.

Zhang H J, Wang X R, Chen C Y, et al., 2010, The Health Risk Assessment and Remediation Guide Limit Value of Typical Chromium Slag Contaminated Sites, Acta Scientiae Circumstantiate, 30, 1445 -1450(in Chinese)

Zhang H.J., Wang X.G., Chen C.Y., Wang Q., Yang Y., Yong S.Q., 2010, Study on the polluting property of chrome residue contaminated sites in plateau section, Chinese Journal of Environmental Engineering, 4, 119-227.