Berkeley pit and its impact on the environment

A S Kuznetsova, A V Ivanov
Saint-Petersburg Mining University, 2, 21st Line, St Petersburg 199106, Russia
E-mail: kuznetsovaanna@hotmail.com

Abstract. The article tells about the Berkeley Pit and its environmental impact. The main chemical characteristics of mine water and water treatment systems are outlined. Possible ways of dealing with problem of ground water pollution are discussed.

1. Introduction
The Berkeley Pit was founded in 1955 in the city of Butte, Montana, USA. It was done due to the several reasons: the first one was the cost - open-pit mining of copper was cheaper than underground mining which had been used before; the second one was the personnel safety – it was safer to work on the surface. 2500 people died in the process of underground mining of copper in 1860-1976, but after changing the way of mining 6 people died.

By the moment the pit was opened, the core contained only 0.75% of copper, so, to make the mining profitable, the Berkeley Pit united the nearby mines, such as Meaderville, Dublin Gulch и McQueen. Afterwards, gradual decline in prices led to the closure of the pit in 1982 [1].

Montana Bureau of Mines and Geology developed the digital model of all mines in this area shown on figure 1. Red lines are vertical shafts, other colors are horizontal ones. The deepest shafts have the depth of 1600 meters, which is much lower than the bottom of the pit with the depth of 540 meters [5].

2. Materials and methods
The pumps were used while underground and open-pit mining to prevent flooding of the work area. When the pit was closed, the pumping stopped, which led to the filling of underground mines and the Berkeley Pit itself. Nowadays there is a lake and its water is highly acidic due to the interaction of water and sulphide rock. Water contains such metals as copper, iron, arsenic, cadmium. From the moment of stopping the pumps water level reached the level of 270 meters. Soon this level catches up with the level of groundwater in this area and dissolved contaminants will migrate farther [4].

In 1996 water drainage was redirected from the pit, water was treated from the copper and headed to the tailing pond Yankee Doodle which was built for processing plant. Due to this, filling speed reduced to 11 cubic meter per minute.

In 1998 the pumping of water from the pit started for the first time due to the opportunity of copper recovery from the water. In the process water was pumped to the treatment plant and went through concrete cells filled with iron bars. Copper replaced iron on bars, iron dissolved in water [11]. The process took about 30 minutes, then water went back to the pit. Once a week the bars were cleaned of copper, copper was dehydrated, bars went back to the process. In total 181 tons of copper was extracted and sold to pay for the building of the plant. Plant is shown on figure 2a. The process stopped in 2013 when the pit edge slipped and the pump broke.
Figure 1. Digital model of mining area

Figure 2. Water treatment plants:
a – copper extraction plant; b – metals extraction plant with flow of treated water back to the pit
In 2000 redirecting of water stopped. Price for copper went up and mining started again in the Continental pit near the Berkeley pit. Another water treatment plant Horseshoe Bend was opened in 2003. Plant is shown on figure 2b. That plant prevents the drainage of water to the Berkeley pit. Water treatment occurs due to the two-stage sedimentation with combination of calcium hydroxide and high-density sludge technology. Limestone, aeration and polymeric additives help in metal sedimentation. Fully automated system provides 10 times less amount of sludge. High-density sludge is provided by repetition of treatment cycle for a few times. All amount of sludge (151 cubic meters) is returned to the pit. The research shows that sludge storage in the pit may raise the pH level for the next 10-20 years which reduce the cost of water treatment. Treated water may be used in processing of ore or released in the Silver Bow Creek. In 2012 19 thousand cubic meters of water per day was treated in the plant. Project capacity of water treatment plant is 26500 cubic meters of water per day which will be reached when the treatment of water from the Berkeley pit will start.

The critical level of water for Berkeley pit is 1646 meters above sea level. This level means the beginning of water pumping from Berkeley pit and treatment of that water in Horseshoe Bend water treatment plant. Rising of water level is slower than anticipated due to the redirecting of surface discharge from the pit. In 2016 level of water was 1626 meters above sea level [6].

In 2017 quality and amount estimation of water was finished. In 2019-2021 water treatment plant Horseshoe Bend will be improved to be able to pump and treat more water. The recent research shows that it will be necessary to start pumping and treatment of water in the pit in 2023 because the critical level is reached. Level of water may be changed because of bigger amount of precipitation or pit edge slips. Last slip happened in 2013 when water level gained 18 cm at once which means a month rate. The first water treatment plant was also closed. Level of water in the Berkeley pit is checked every month, so, if necessary, it is possible to start treatment earlier or even later.

Quality of water is checked every 6 months. Water samples are taken from different depth and analyzed for dissolved contaminants. Temperature, pH level, dissolved oxygen and electrical conductivity are measured to the depth of 183 meters with increment of 3 meters. In addition, these qualities are measured at the bottom.

Till 2012 chemical composition has been changing with depth. Brown-red water at the top was the cleanest, greenish blue at the bottom was the most poisonous. At some depth chemical composition changed so fast, that the chemical border was formed. Density at the bottom was greater than at the top. Also, the pH level was higher under that border. Concentration of metals was higher at the bottom [2, 3]. Quality levels till 2012 are:

- up to 122 meters: pH=2.57, C(Fe)=0.5g/l, C(Cu)=0.07g/l;
- lower than 122 meters: pH=2.37, C(Fe)=0.9g/l, C(Cu)=0.14g/l.

Border line was at the depth of 123-132 meters.

Nowadays the chemical composition is more homogeneous. According to scientists, stratification occurred because of cleaner water intake which stayed on the top due to its lower density. Copper extraction from lower part of the pit made the quality of water better. Concentration of iron decreased by 56%, arsenic – 87%, copper – 60%. Decrease of metal concentration made the reclamation process cheaper, but much iron sedimented, so water had red colour. Also, concentration of zinc, aluminum, cadmium and manganese is still high [7, 10].

There is some research about ability of algae to reduce concentration of metals dissolved in acidic water. There are some algae in the Berkeley pit, but there are not enough nitrates for them to grow fully. It was experimentally established that algae are capable of reducing the concentration of iron and arsenic in the water if treated with additional number of nitrates [8].

In addition, some new algae species were found in the Berkeley pit which successfully adjusted to the aggressive environment of the pit. They are not only able to reduce the amount of metals in the water but also able to fight cancer cells [9].
3. Conclusion
Thus, this is short description of environmental impact of one of many open-pit mines in the world and methods of dealing with the negative effects of this pit. There are several things that could be improved to better eliminate the effects on the environment, and biological ones must not be excluded.

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