NF/RO – PELLET REACTOR WATER TREATMENT PLANT

Ali Sepehr [1]

ToossAb Consulting Engineers Co.
P.O. Box 91775-1569
Mashhad, Iran

Abstract

In this research, obtained results of a pilot plant are investigated in order to construct a multipurpose water treatment plant in the city of Birjand in east of Iran. The main target parameters for treatment are softening and chromium VI (cr^{+6}) remediation due to its high concentration in water sources.

The plant capacity is 0.64 m^3/s in which 0.42 m^3/s is forwarded to the pellet reactor for softening and the rest stream is fed to a NF/RO (nanofiltration / reverse osmosis) unit for desalination. The pellet reactor is a cylindrical vessel with a conical lower section. The reactor is partially filled with a proper seed material such as silver sand or garnet. The effluent of the pellet reactor is mixed with the outflow of NF/RO unit to reach a desirable quality. Calcium and some chromium are removed by the pellet reactor. Calcium carbonate and chromium deposits are washed out from the pellet reactor. Remaining chromium and probably partially magnesium can be removed in the continuous sand filters.

Present research reveals that it is essential to feed very low turbidity water for proper working of the pellet reactor. In addition, sedimentation pretreatment without media filtration will led to an improper feed stream of the pellet reactor. Effluent water quality results show that pellet reactor treatment decreases calcium concentration about 43%. In addition, 74% reduction in

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[1] Address: ToossAb Consulting Eng. Co.
14, Payam Street, Ershad Blvd., Mashhad, Iran
P.O. Box 91775-1569
Email: asme.mech@gmail.com
Tel.: +98 915 109 9940
Fax: +98 511 768 8868

chromium concentration is obtained by using this treatment technique based on influent water quality.

Introduction

The WTP of Birjand is considered to provide drinking water corresponding to local requirements and WHO standards for the city of Birjand in Iran. Birjand is located in South Khorasan state in 59° longitude and 53° latitude. Main water sources in Birjand are underground sources as different wells in different regions as shown in figure 1.

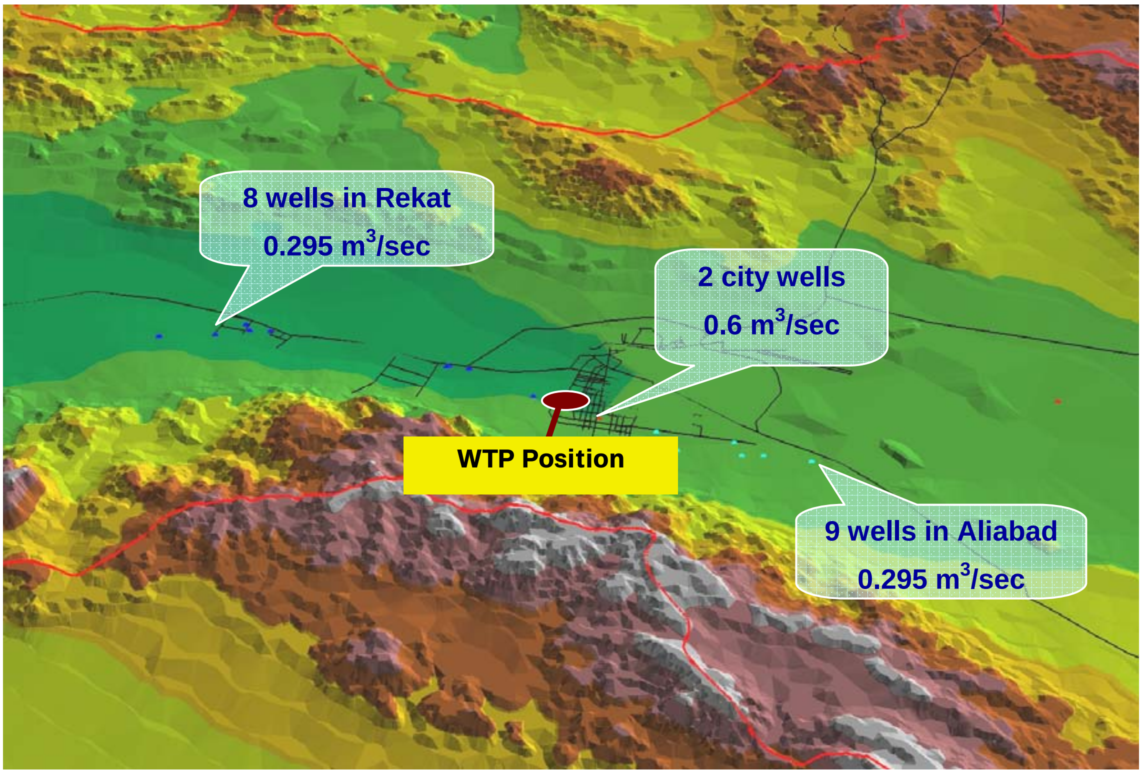

Fig 1. Existing water sources of Birjand

Groundwater motion is based on geological position. Compared to the surface waters, the amount of suspended solids in groundwater sources is inconsiderable; however, mineral materials concentration is usually higher than those in surface waters.

Main part of this WTP is considered for softening by pellet reactor. Moreover, a NF/RO unit is specialized to desalination. Capacity of WTP is 0.64 m^3/s in the primary stage of construction.

Raw water quality

In order to choose a proper treatment method, chemical and microbiological experiments have been periodically done on different water wells in Birjand. It is found from microbiological experiments that there is no a special case inside influent water; however, chemical quality of water depends on the geological origin, precipitation rate, groundwater speed, groundwater direction, and the mean temperature in various seasons. The raw water quality into water treatment plant is given in the following table. Theses values are considered for process design.

Table 1. Water quality based on chemical experiments

Parameter	Concentration (mg/lit)	Unit (mg/lit as $CaCo_3$)	Total ions (mg/lit as $CaCo_3$)
PH	8	8	-
M Alkalinity	260	-	-
P Alkalinity	7	-	-
TDS	3500	-	-
Total Hardness	-	835	-
Cl^-	580	817	1616.866
SO_4^-	552	575	
NO_3^-	20	16.3	
NO_2^-	1	1.1	
PO_4^{3-}	0.5	0.8	
CO_3^{2-}	3.4	5.666	
HCO_3^-	246	201	
Cr^{6+}	0.15	0.866	1616.866
Ca^{2+}	80	200	
Mg^{2+}	155	635	
Na^+	350	761	
K^+	15	20	

Target Parameters

Quality experiments of Birjand water wells reveal that critical parameters to remediate are chromium with high concentration and hardness. Based on recent guidelines published by WHO and Iranian standard organization, chromium concentration over 0.05 mg/lit in drinking water is dangerous. As seen in table 1, chromium concentration in the wells of Birjand is greater than standard level. In addition, sum of calcium and magnesium ions which are formed total hardness is higher than allowable level. Harder water results in scale formation in pipeline. Other problem we face it is salinity of some wells. Water salinity is related to sodium concentration. Minimum concentration of salt is 200 mgt/lit based on European standards. Therefore, the main target parameters for treatment are softening and chromium removal due to its high concentration (0.15 PPM). As mentioned earlier, the plant capacity is 0.64 m^3/s in which 0.42 m^3/s is fed to pellet reactor for softening and rest stream (0.22 m^3/s) is fed to a NF/RO plant for desalination. The effluent from these plants will be mixed together in order to supply the proper drinking water for the city of Birjand.

Treatment process

In the preliminary design of Birjand water treatment plant, a set of pretreatment processes including cascade aeration, flocculation, and coagulation are considered for whole raw water flow (0.64 m^3/s). After coagulation and sedimentation, 0.42 m^3/s is fed to pellet reactor and sand filters. It should be noted that pretreatment processes result in considerable consumption of lime to increase the pH on pellet reactor input due to usage of $FeSO_4$ in coagulation prior to pellet reactor. In the present research, pellet reactor system for softening along with NF/RO unit is investigated. Pellet reactor unit is designed in order to remove calcium, chromium, and partial magnesium. Calcium carbonate and chromium deposits are washed out from the pellet reactor. Probable remaining chromium and partially magnesium can be removed in the continuous sand filters. This treatment method is generally only successful at removing calcium bicarbonate hardness. It is not appropriate for systems with high magnesium content because of fouling of magnesium hydroxide inside the reactor. Magnesium removal usually requires post-treatment.

In brief the treatment process is based on the following scheme:

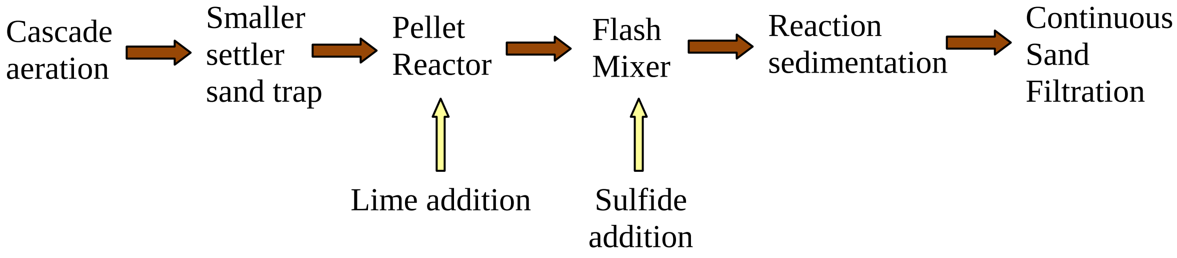

Fig 2. Schematic of treatment sequences

Pellet softening

The schematic structure of a pellet reactor is shown in figure 3. A cylindrical vessel forms the basis of a pellet reactor. Lower section of a pellet reactor can be conical. The reactor is partially filled with a suitable seed material, e.g. silvers and or garnet. The hard water is upwardly pumped through the reactor at such a velocity that the sand bed is fluidized. The sand grains move freely inside the upward flow of water, but nevertheless there is a sharp distinction between the fluidized bed and the supernatant.

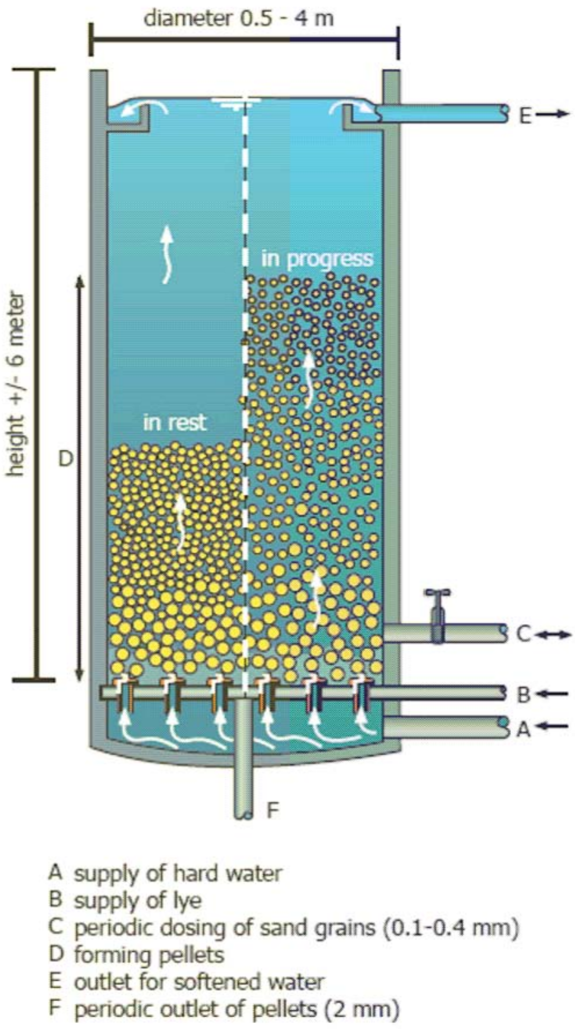

Fig 3. Schematic structure of a pellet reactor

At the bottom of the reactor, non-softened water and chemicals are injected separately. The way how this is done depends on the reactor type. Intense turbulence at the reactor bottom causes water to be perfectly mixed with chemicals. As the water moves to up, the flow quickly turns vertical with a uniform velocity profile over the horizontal cross-section of the reactor. The fluidized bed provides a large crystallization surface (usually 4000 m^2/m^3). Fluidization occurs in a fast rate so that $CaCO_3$ crystallizes on the seed material. The grains thus grow into pellets. As only a part of the pellets is removed, this procedure can happen during full operation.

Water softening is commenced by adding a base to it. This base is applied to increase the pH value of the water. As a result, the hydrogen carbonate which is present in the water is converted into carbonate. As additional base is added, the carbonate content increases further until the calcium carbonate solubility is exceeded. Then, Calcium carbonate precipitate and softening takes place. Bases which can be considered for water softening are caustic soda (NaOH) and milk of lime ($Ca(OH)_2$).

NF / RO plant

Nanofiltration is a cross-flow filtration using low pressure spiral wound fouling resistant membranes. The transport of water through the membrane is partially through the physical pores present in the membrane but mainly by means of diffusion through the membrane from one bonding site to another. Reverse Osmosis is a cross-flow filtration using high pressure spiral wound fouling resistant membranes. The Nanofiltration followed by Reverse Osmosis system is applied to produce desalinated water for a part of Water Treatment plant of the city of Birjand. The desalinated water produced by membrane system is mixed with portion of softened water from pellet reactor unit to provide drinking water with acceptable quality according to WHO and Iranian standard organization.

Figure 4 shows block diagram of NF/RO unit. The Nanofiltration unit consists of nanofilter membranes. In first stage, 735 m^3/hr of raw water is received with recovery of 80% and in second block the permeate of nanofilters is introduced to Brackish Water RO block for further desalination in which will produce 544 m^3/hr of desalinated water. In third unit the brine of Nanofilters (160 m^3/hr) is introduced to a High Brackish RO unit for further desalination in which produce 80 m^3/hr of desalinated water with recovery of 50%. In operation this recovery value could be even higher (up to 65%) based on the feed water TDS.

The two permeate streams will joint together to produce 544 + 80 = 624 m^3/hr of desalinated water.

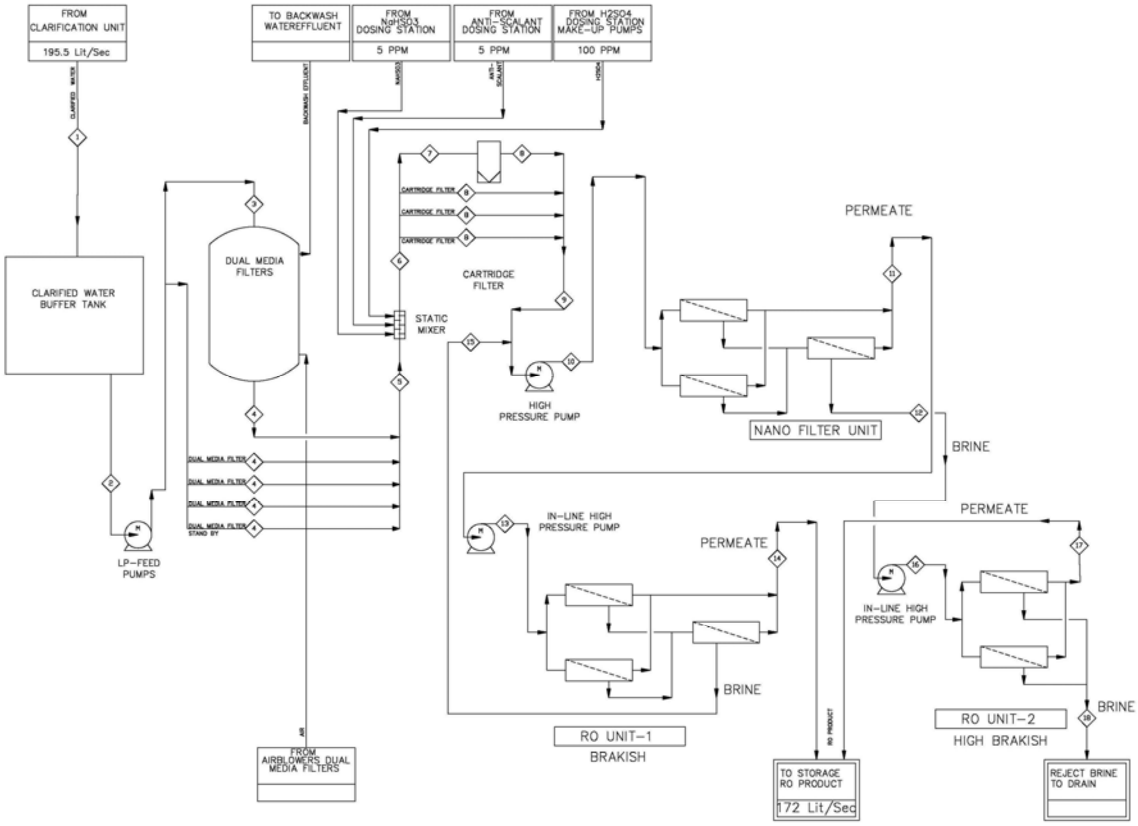

Fig 4. Block diagram of membrane process

Results and Conclusion

The pH of the feed water to the pellet reactor should be at least 8. If pH is lower this value, more carbon dioxide is present in the feed water. Carbon dioxide has to be removed at first by addition of lime before $CaCO_3$ can precipitate. This means that a low pH of the feed water increase the chemical consumption. If pH is low, one might consider the placement of a degasifier in front of the pellet reactor. For proper working of the pellet reactor, it is essential that the feed water has a very low turbidity. So, turbidity must be considered as a design parameter. Sedimentation pretreatment without media filtration leads to an improper feed stream of the pellet reactor. In addition, it is necessary that iron, manganese and phosphate are not present in quantities because existence of these may disturb the pellet formation.

The pellet reactor is designed to reduce calcium hardness to approximately 1 mmol/l. Deeper softening results in unallowable carry-over of the pellet reactor effluent. It can be concluded that magnesium is not removed in the pellet reactor.

The average expected water quality after post-treatment by continuous sand filtration corresponds to the following table.

Table 2. Water quality by using pellet reactor treatment

Parameter	Unit	Maximum Value
Calcium	Mg/lit	40
Turbidity	FTU	1.0
Chromium	Mg/lit	0.04

In addition, table 3 shows chemical consumptions based on the feed composition and effluent quality.

Table 3. Chemical Consumptions

Parameter	Unit	Maximum Value
Quick lime	Kg/day	2720
Hydrochloric acid 30% for decarbonation	Kg/day	106
Sulphuric acid 98% for effluent pH adjustment	Kg/day	196

References

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