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Original Research

Treatment of RO Rejects Wastewater by Integrated Coagulation Cum Adsorption Process

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Abstract

This research proposed to treat the RO rejected wastewater in a household plant by the integrated treatment system. The possibility of wellhead water treatment by the combined treatment system of coagulation and adsorption for salinity reduction via flexible high recovery RO system was evaluated through analysis of treatment options on a laboratory scale. The naturally available gooseberry seed used as a coagulant in phase-1. It reduced 99.3% of TDS and hardness. It also increases the DO level of RO reject water, at the same time it increases turbidity and color. Turbidity and color removed by surface-modified zeolite in the phase-2. The zeolite material was taken in temperature 400ºC as adsorbent of 6 cm column achieved 8NTU in 150 mmin. The 12 cm column was achieved 7.5NTU in 150 mins. Thomas and Thomson modelling well fitted with an experimental study. The regression correlation reached up to 0.942, 0.9810 and 0.984. It is apparent from the recorded SEM patterns study. This study concludes that the coagulation by Goosperry seed produced the highest removal of TDS and hardness and in the adsorption process, with 400ºC enhances the surface morphology and porous structure indicates that heating with higher-level temperature enhances the adsorption capacity of the adsorbent material. The highest efficiency is observed in hydrothermal hotness.

Keywords: RO reject, coagulation, adsorption, zeolite, SEM analysis, column regeneration

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Introduction

Drinking water supplied in water – stressed countries was satisfied by desalination of sea water, brackish and recycled water. The treatment of Reverse osmosis wastewater treatment is an invetiable and an unavoidable technology for the current scenario. Reverse osmosis (RO) is the process of removing bulk particles, ions and molecules from the drinking water by using a semi-permeable membrane. The wastewaters extracted from the RO system have high TDS and salinity content [1]. In the RO system, the wastewater having lower molecular waster is passed through the semi-permeable membrane and higher molecular as wastewater [2]. The RO plant installed in the household discharges the high quantity of wastewater with high TDS concentration about 40,000-50,000 mg/L along, with sodium and potassium salt saturation point of 400,000-600,000 mg/L [3]. The dominant expulsion component in membrane filtration is stressful prohibition, to achieve consummate efficiency while paying little attention to parameters, like the fixation and weight of the arrangement. The treatment process involves high cost and complex operation [4]. In household level the RO water plant usage was unavoidable, to get pure and microbial free water, the RO plant was installed in the residential places. For 1 litre pure water 3 litre of wastewater was generated. Compared to reuse of RO wastewater it is high time to identify treatment technology for remediation of RO wastewater. The main intention of this study is to utilize the coagulation and adsorption process for treatment of wastewater. The naturally available gooseberry seed taken as coagulant and sand materials, which heated for 400ºC, used an adsorbent [5]. The coagulation is used to remove TDS and salinity but increases the color and turbidity [6]. To remove these two components the zeolite was used as adsorbent. The removal efficiency was measured by turbidity testing and direct color removal observation [7]. Thomas and Thomson's model were used to determine the internal and external mass transfer and the removal efficiency of the adsorption process [8]. The regression correlation value is matched and predicted with two models were used to find out the removal efficiency.

Materials and Methods

Phase-1

The sample collected from household RO plant (Model- Ultra aqua UX2111). For 15 mins of running condition, the collected quantity of treated water was 2.5 liter and RO rejects wastewater quantity was 2 liter [9]. In the treatment setup, two-phase of treatment was taken place; in the first phase, the coagulation was done with natural coagulant [10]. The goosperry seed was taken as a coagulant. The optimum dose was identified with the filed sample. The coagulation was performed with different concentrated coagulant [11]. Coagulants that are applied to the water are used to withdraw the forces that stabilize the colloidal particles and allow the particles to be suspended in the water. For one liter of the sample, the five different concentrations of coagulant was added as 1-5 gm, after adding the component and 20 mins running condition in different rpm level (100 rpm-500 rpm) [12], the turbidity level was checked with a different concentrated solution. The efficiency of the coagulation process was determined.

Phase-2

In this phase, the adsorption preceded with continuous column technique. The adsorbent prepared, and it was filled in the class column [13]. The adsorbent fabricated from naturally available zeolite material and surface area of the adsorbent is got activated for better adsorption [14]. The absorbent is heated to 400ºC, Sample flowed from the downstream side of the column. The diameter of the column was 2 cm, the adsorbent packed for 6 cm and 12 cm sized column [15]. The higher heating temperature of adsorbent enhance the surface morphology and porous structure of colloidal particles. As the number of channels/cavities increased the surface area and heterogeneous nature of the materials, an observation of surface area indicates the presence of suspended and colloidal assortments. The quantity of the adsorbent was about 9 gm and 16 gm. The inlet flow was 2 ml/min in the column, the output range about 1.6 ml/min [16]. The removal of color and turbidity was determined.

Modeling Work

Thomas Model

Thomas model is used to calculate the dependence of solute concentration with time. In continuous column technique, the internal and external mass transfer limitations were considered [17]. The model was given by

$$\ln (C_o/C_t - 1) = (K_t * q * m/Q) - k_t * C_o * t \quad (1)$$

...where C_o and C_t-influent and effluent concentrations (mg/L), K_t- Thomas rate constant (mL/ (min.mg), m -the mass of adsorbent and t is a 76 time (min), The adsorption capacity of the bed q (mg/g), Q was the quantity of adsorbent in the column (g) [18], the adsorption kinetics k_t were determined from the plot of $\ln[(C_o/C_t)]$ against t at a constant flow rate [19]. The regression coefficient ranges represent the Thomas model.

Thomson Model

Thomson model was used to find the inter relationship between external and internal processes of adsorption. The Thomson model can be expressed as

$$(C_o/C_t - 1) = (k_{TH}q_eW - k_{TH}C_o * t)/ Q \quad (2)$$

...where k_{TH}- Thomson rate constant (ml/min.mg), q_e is the adsorption capacity, C_o - inlet ion concentration, C_t - effluent ion concentration at time t (mg/L) (Zahra et al. 2020), W -mass of adsorbent (g), Q is the inlet flow rate (ml/min), and t -flow time t (min) [20]. The value of C_o/C_t - the ratio of the inlet to the outlet ion concentrations. $\ln(C_o/C_t - 1)$ against time (t) was strained to establish the values of q_e and k_{TH} from the interception point and slope of the plot [21], respectively.

Characterization of Floc and Adsorbent

The surface morphology of floc in coagulation and adsorbent characterized by SEM analysis. Naturally available material (Goosperry seed) used as a coagulant and surface-modified zeolite used as adsorbent [22]. The monitoring of pores in the surface area was essential to determine the efficiency of the adsorption process.

Column Regeneration

The packaged column was dismantled and the adsorbent carrying the turbid compound [23]. The adsorbent washed twice in distilled water and Sodium Chloride (NaCl) solution and result in the removal of other substances and other components, present in adsorbent material Christopher and Jonathan (2015), which was exposed to evaporation under the sun for 8 hours.

Result and Discussion

Water Quality of RO Reject

The samples for the treatment process were collected from RO reject by manually to determine the quality of water. According to WHO, the pH value of RO reject is collected from the household sample is found to be 8.5 is alkaline nature. The turbidity was 6NTU which indicated that it was in a permissible limit. The hardness of the sample was the higher range of 2800 mg/L and TDS also at an alarming range of 816 mg/L. The dissolved oxygen ranged below the acceptable limit as 3.5 mg/L. The BOD was at the rising range of 0.3 mg/L; likewise COD was also a higher level of 0.6 mg/L. The analysis evidenced that reject from the RO plant had higher hardness and TDS level [24]. For the multi-phase treatment process, has to be conducted by the quality water, it is essential to determine the water quality before and after the treatment process for an estimate the treatment efficiency [25].

Removal of TDS, Hardness and DO by Coagulation Process

The coagulation process was chosen for the phase-1 treatment process, Goosperry seeds well grained, converted into powdered material and taken as coagulant [26]. The coagulant added in a powdered form in a different ratio to find out the optimum coagulant range. The initial TDS level was at 2600 mg/L, hardness 250 mg/L and DO were 3.5 mg/L and the dose taken as 2, 4, 6 and 8 mg/L. The TDS is observed in the range of 2600, 2524, 2000 and 2004 mg/L within the acceptable limit of WHO. The hardness determined in the range of 385, 335, 263, 226 mg/L and the dissolved oxygen ranged from 3.5, 3.8, 4.7 and 4.9 mg/L [27]. This study proved that the main component of water quality parameters insisted on the positive output of the coagulation process [28]. The agitation given by jar test apparatus enumerates the water quality parameters in a better way. The different dose of coagulant produced the various reactions in the effluent. The second jar has obtained the optimum level of efficiency [29]. In this part, 6 gm of coagulant added in 1 litre effluent and it mixed in a different rpm level. At the same time, the level of turbidity and the effluent changed into green color because of the presence of pigment chlorophyll in Goosperry seed.

Optimization Based on the pH Level

The synthesized column is performed to determine turbidity and color removal efficiency. The study revealed that maximum adsorption of turbidity by zeolite adsorbent occurred at pH 7.2 [30], while the efficiency decreases at higher pH. At pH 7.2 surfaces has a charge which attracts the charged turbid molecules and adsorption occurs through electrostatic interactions [31]. However, when pH increases adsorbent acts as a charged particle and an electrostatic barrier developed between the negative surfaces of zeolite adsorbent. During this scenario, adsorption strongly inhibited resulting in the reduction within the adsorption rate [32]. In determining the pH level of the surface charges in zeolite adsorbents played an important role.

Adsorption with a Zeolite Material

The completion of phase-1 produced superior performance in the removal of TDS and hardness. Phase-2 intended to remove turbidity and color from the treated effluent [33]. The fine zeolite activated by heating upto 400ºC and it was packed in a glass column. The continuous adsorption mode is preceded. Samples released from top to bottom level. For every 15 min sample were collected and turbidity were

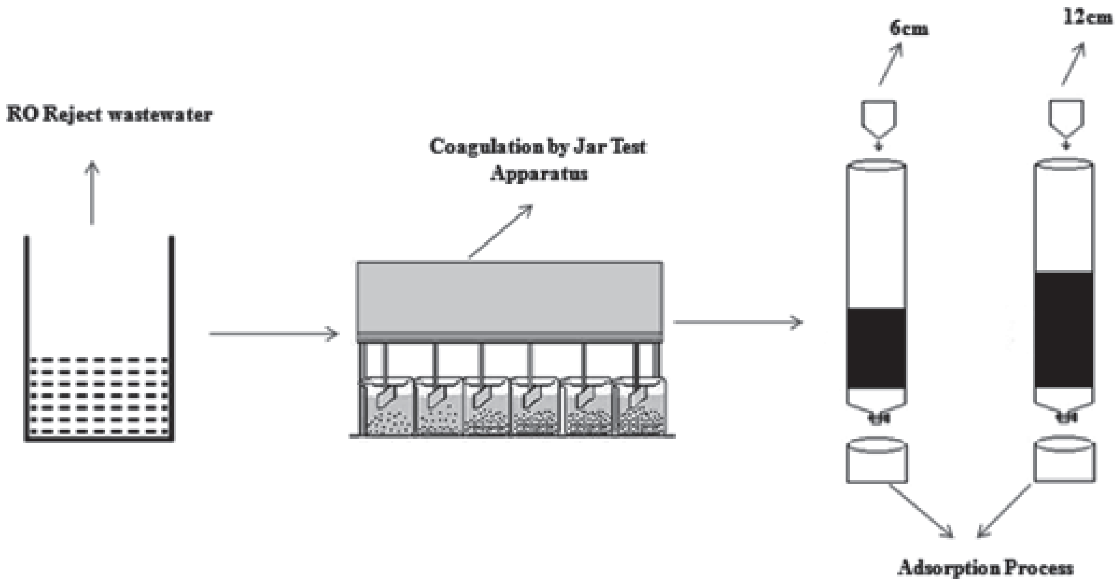

Fig. 1. Flow diagram of the integrated treatment system.

checked [34]. The color removal was studied by direct observation. For the 6 cm column, 135NTU of turbidity observed at the first 15 min collected sample. For 150 min, the removal of turbidity observed as 8NTU and green colour shade removal is achieved 100%. For 12 cm, column the turbidity level 135NTU at first 15 mins and 150 mins, it was 7.5NTU and the colour removal was 100% attained. As shown in Fig. 2 the removal efficiency gradually increased in 6 cm and 12 cm column and the column gets saturated about 150 mins when compared to 6 cm the removal proficiency is higher for 12 cm column due to the height of bed and time took for infiltration into adsorption bed.

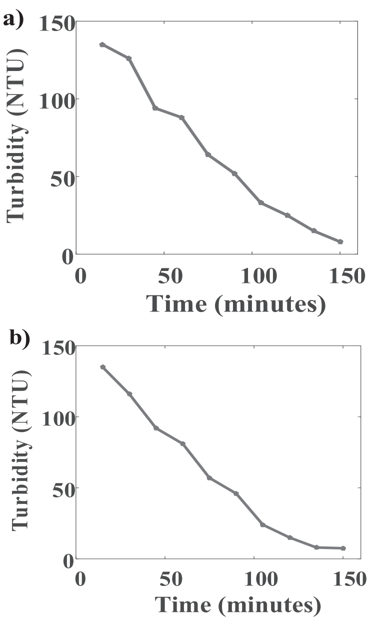

Fig. 2. a) Treatment efficiency of 6 cm zeolite Column and b) Treatment efficiency of 12 cm zeolite Column

Thomas Model for Adsorption Study

The progression of adsorption is controlled through ionic adsorption speciation and the binding site. The Thomas model assessed and the accuracy of the adsorption experimental and predicted development curve has been achieved [35]. The parametric statistic for 135NTU (R^2) ranged from 0.901, 0.914, 0.927, 0.900, 0.916, 0.914, 0.910, 0.921, 0.964 and 0.922 acknowledged that the Thomas model portrayed the column experimental data for the adsorption process alright. The worth of k_t depends upon the mass (m). Initially, k_t values were in decreased condition and next level, k_t (ml/ min.mg) values increased as 0.181, 0.193 and 0.213 which was given in Table 3.

Thomson Model for Adsorption Study

The adsorption process for 135 NTU and the Table 4 showed that the Thomson rate constant K_{TH} was 0.072 ml/min.mg for 6cm and it decreased to 0.009 ml/min.mg [36]. The adsorption efficiency for 6cm, the column was 11.50 mg/g and for 12 cm it increased to17.17 mg/g [37]. The regression coefficient of 6cm was 0.954 and for 12 cm the correlation was 0.929 which showed compatible correlation.

Characterization of Coagulant and Adsorbent

SEM analysis of coagulant revealed mostly they were in pulverized nature due to powdery form it showed in the size of 10μm [38]. The study has developed the particles with an extra-ordinary stable side and found to be dispersed within the solution to avoid their mutual agglomeration (Fig. 3) The structures

Table 1. Water Quality Characteristics of RO reject before the treatment process.

Sl. No	Parameters	Values
1.	pH	8.5
2.	Turbidity (NTU)	6
3.	Hardness (mg/L)	385
4.	TDS (mg/L)	2600
5.	DO (mg/L)	3.5
6.	BOD (mg/L)	0.3
7.	COD (mg/L)	0.6

Table 2. Determination of TDS, Hardness and DO by coagulation.

Sl. No	Dose response (gm/L)	TDS (mg/L)	Hardness (mg/L)	DO (mg/L)
1.	2	2600	385	3.5
2.	4	2524	335	3.8
3.	6	2000	263	4.7
4.	8	2004	226	4.9

Table 3. Validation of Thomas model for adsorption study.

Thomas Model		
kt x 10^{-3} (ml/(min.mg)	q_o (mg/g)	R^2
0.154	1.312	0.901
0.142	0.201	0.914
0.013	19.37	0.927
0.011	19.21	0.900
0.013	17.83	0.916
0.012	15.72	0.914
0.181	12.31	0.910
0.193	14.34	0.921
0.204	0.014	0.964
0.213	18.10	0.922

Table 4. Validation of Thomson model for adsorption study.

Column Depth	6 cm	12 cm
$q_{e\,(mg/g)}$	11.50	17.17
k_{TH} (ml/min.mg)	0.072	0.009
R^2	0.954	0.929

a)

b)

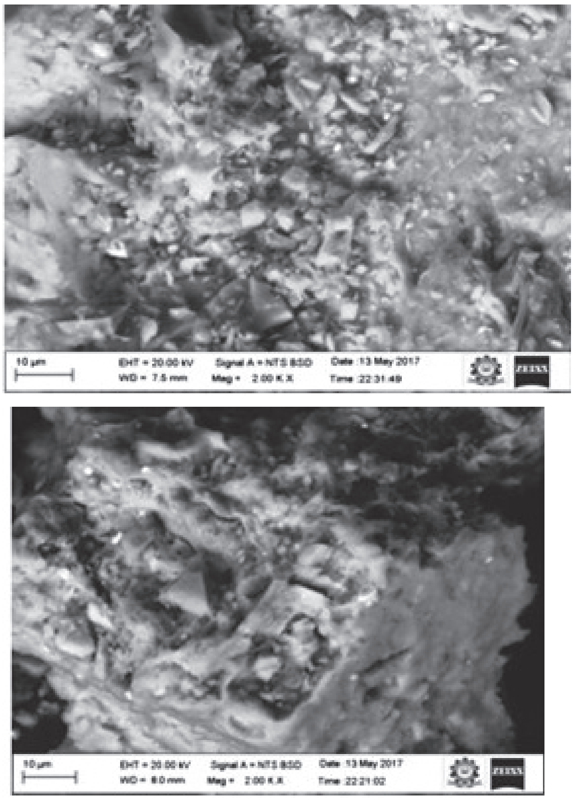

Fig. 3. a) SEM image of coagulant b) SEM image of Adsorbent.

of adsorbent after the adsorption process were pale petals with the smooth facade where channels and cavities were at micro-level [39]. The morphology of the packed column appears porous and rough with defined channels and cavities (Fig. 3) [40]. According to literature the pore morphological change of column material from homogeneous to heterogeneous formation is due to the drop off particle structure [4`].

Regeneration of Adsorbent

The adsorbent is an inert material of the turbid molecule adsorbed in the surface area of the column [42]. The NaCl wash and solar evaporation eradicated the turbidity and coloured particles in the surface area [43]. After the regeneration process, the adsorbent acted as a freshly prepared column [44]. It showed that the column had been used several times as an adsorbent [45].

Conclusion

Laboratory scale studies were carried out at the household RO plant installed to remove TDS, hardness, and turbidity with the application of coagulation and adsorption technique. In phase-1 the TDS and hardness removed by the coagulation process. The Gooseberry seed used as coagulant the optimum level determined by the various concentration levels. In this process TDS level reduced from 2600 mg/L to 2004 mg/L, meanwhile, it was higher than the WHO limit of 500 mg/Land the hardness decreased to 226 mg/L from 385 mg/L, it came under WHO permissible limit. Meantime the turbidity increased from 6NTU to 135NTU. In phase-2 to remove the excess turbidity and color level; the adsorption proceeded with zeolite as adsorbent. The increasing temperature of 400ºC accelerated the adsorption capacity. Thus, the column study has exhibited with 6 cm have produced a turbidity level of 8NTU and 12 cm, column produced 7.5NTU turbidity level as per the permissible limit of 10NTU recommended by WHO. The green colour shade goes to break down from the effluent by adsorption process, it observed by direct observation. These experimental studies investigated with Thomas and Thomson's modelling. The Thomas model well correlated with experimental study, the worth of k_t depends upon the mass (m). Initially, k_t values were in decreased condition and next level, k_t (ml/ min.mg) values increased as 0.181, 0.193 and 0.213 and the regression correlation was in the lane between 0.901-0.964. The Thomson rate constant K_{TH} was 0.072 ml/min. mg for 6 cm and it decreased to 0.009 ml/min. mg. The adsorption efficiency for 6 cm column 11.50 mg/g and for 12 cm it increased as 17.17 mg/g. The regression coefficient of 6 cm was 0.954 and for 12 cm the correlation 0.929 which showed compatible correlation. It showed an enhancement of surface morphology and porous structure indicated that heating with higher-level temperature enhanced the adsorption capacity of column material. Thus, the RO reject water has been utilized as recyclable water by the multifunctional treatment process. It suggested using this water for residential purpose in this hard water scarcity situation.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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