Use environmentally friendly hydraulic power to design a hydraulic rapid mixing basin in the drinking water treatment plant

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Abstract. Most cities in Iraq provide drinking water by purifying river water of physical and chemical contaminants. It uses energy from petroleum (electricity). As it seeks to get drinking water from the rivers with clean and renewable technologies and energy, the State of Iraq plans to use one of its most abundant resources to address the shortage of fresh water, namely hydropower. This study is based on the use of hydraulic energy (environmentally friendly) in the purification of water instead of the use of electricity. The use of electrical energy in water purification has a lot of problems, including the continuous interruption of the current and therefore stop the station from work and that it needs periodic maintenance and need to staff specialized for operation and maintenance, so it is expensive while the use of hydraulic energy will help to solve most of these problems. The possibility of replacing the rapid-mechanical mixing basin to the rapid hydraulic mixing, which operates according to the principle of forced forexes, where the study of the performance of the drinking water treatment plant in the eastern district of Al-Hamzah On the ADiwaniyah River in the southern province of ADiwaniyah, where concentrations of pollutants in the river are high in the study area. Where samples were taken from different locations for water in the drinking water treatment plant of Al-Hamzah for different treatment stages. Where the pollutants were examined in the laboratories of the Environment Directorate of ADiwaniyah and the laboratories of the Faculty of Engineering. All concentrations of physical and chemical contaminants were higher than the standards of Iraqi standards and the efficiency of treatment was not as low as 83%. This is due to the continuous interruption of electrical current and the failure of the mechanical equipment of the rapid mechanical mixing basin, which requires periodic maintenance and the continuation of the addition of high coagulant doses which cause high processing costs as well as the high concentration of aluminum used for coagulation. Therefore, a hydraulic mixing basin was used by conducting experiments in the fluid laboratory In the Faculty of Engineering using the Free and Forced Vortex, which has been developed and adjust suit the requirements of the study. There have been various experiments to obtain the best dimension of hydraulic mixer and best amount of coagulant to remove the turbidity and the best mixing speed and the best value of the pH, which achieved processing efficiency of up to 98.0%.

Key Word: Hydraulic Rapid Mixing, Water Treatment Plant, Turbidity. Forex, Velocity Gradient.
1. Introduction

Water is one of the basic natural sources that we need daily and which is prepared through the water purification plants. Therefore, drinking water must be free from contaminants and does not cause damage such as illness or pain, as well as good taste, odor free, and sensitive taste. Surface water treatment is generally aimed at removing the suspended materials that cause turbidity and color and odor change. Most of the treatments for this type of water are limited to sedimentation, filtration and disinfection. The suspended material consists of organic and clay materials, and contains some microorganisms such as algae and bacteria [1, 2]. Due to the small size of these components and the large surface area compared to their weight, they remain suspended in water and not deposited. In addition, their surface and chemical properties are used in the purification process (the main way of surface water treatment). Some chemicals are used to break the balance of the suspended materials and to create suitable conditions for deposition and removal from sedimentation basins. Sedimentation process is followed by filtration using sand filters to remove residual sediments. Sedimentation and filtration processes follow the disinfection process that precedes the delivery of this water to the consumer [3].

The source of potable water in ADiwaniyah (the study area) is the river water, which comes from the Euphrates River. As the water of the Euphrates River is known to be turbid water, especially in the spring and summer season, since the Water Treatment Plants (WTPs) use filters for the purpose of water filtration and removal of turbidity, and due to high turbidity values that cause great pressure on the performance of filters and requires changes in filtration materials such as sand and gravel per month. This causes an increase in the cost of operation and maintenance, reducing the number of working hours and the consequent lack of efficiency of water purification units [4, 5]. The purification of water in the WTPs is done by a mechanical system that depends on the operation of electric power (rapid mixing basin) and needs periodic maintenance and therefore it is expensive and suffers from a lot of problems, including power failure and disruption of mechanical mixing equipment and need to cadres with experience for the purpose of operation and maintenance.

Our project highlights the use of hydraulic energy as we seek to demonstrate the efficiency of the use of hydraulic energy in the mixing and rapid mixing tanks (centrifugal force) as an alternative to the energy currently used in the drinking water treatment plants. To know what are the positive results from using this energy and removing the previous energy that affects the ecosystem of the universe. This will increase the efficiency of the fast and slow blending pools and significantly reduce the amount of alum added significantly. As you reduce the time required for the rapid mixing process and thus increase the efficiency of the water treatment plant by reducing the percentage of alum [6].

The study area is the drinking water treatment plant in the eastern Hamza in Diwaniyah, which suffers from lack of capacity and quality of water produced and the fact that the water produced from the WTP, which is pumped to houses is not pure 100% and sometimes have a bad smell because of low water level in the well and the problems of electricity and increase The WTP has a capacity of 2200 m$^3$/h since its establishment in 1997 and therefore the capacity of the plant has not been improved despite the increase in the population. Therefore, we aim to improve the WTP performance by using hydraulic power in the hydraulic rapid mixing basin in water purification instead of relying on electric power in the mechanical rapid mixing basin.

In this study, an amendment will be made in the design of the rapid mixing basin to improve the performance of the performance of the drinking water treatment plant in the district of Al-Hamzah for the purpose of reducing the turbidity, which provides rural and remote drinking water and make them within the permissible limits of drinking water and according to Iraqi standards. That modification in the design will reduce the values of the turbidity of the water treatment and thus reduce the number of times the washing of filters and increase the life of the filtration materials. The efficiency of the rapid mixers is increased from electric mechanical system to environmentally friendly hydraulic system, which works with vortex force to obtain the best mixing time and the lowest cost and best doses of coagulants materials [7].
The study aims to prepare the optimal design and implement a model of a rapid hydraulic mixing tank that works in the vortices in the laboratories of the Faculty of Engineering at the University of Al-Qadisiyah and compared it with the mechanical rapid mixing tank at the Eastern Al-Hamzah water treatment plant to obtain clean water efficiently. In this study, a hydraulically rapid mixing tank was created, which acts as vortices to mix the coagulants to make the WTP work more efficiently.

A mini-potable water treatment plant was constructed in the laboratories of the Faculty of Engineering. The plant consisted of a hydro-hydraulic mixing basin, a slow mixing basin, a settling basin, filters and a water tank. Where the physical and chemical contaminants of the water entering and resulting from the mini plant and the drinking water treatment plant in the district of Al-Hamzah were measured and the results obtained were compared. The efficiency of the hydraulic rapid mixing tank was compared with the efficiency of the mechanical rapid mixing tank used in the drinking water purification plant in the district of Al-Hamzah.

2. Material And Methods

2.1. Description of Al-Hamza Water Treatment Plant
The WTP was established in the district of Hamza in 1997 and was started in early 1998. The production capacity of the main WTP is 2200 m³/h. In 2012, an auxiliary station was constructed with a production capacity of 600 m³/h. The WTP serve the Eastern Hamza district and part of the Sudair and Shinafiyah areas. Details of the process of treatment from the outlet to the storage basins of the WTP in the district of Hamza and as shown in Fig. 1 as follows:

- Low lift pumps 6 and a maximum capacity of (2800 m³/h) for each pump operating 5 and one standby.
- The intake pipe is in the form of two parallel lines, one diameter (8 in) to deliver the raw water to the WTP
- Flash Mixer: Add the alum solution to the water and mix quickly to move water into the flocculation tank.
- Flocculation and Sedimentation: The two circular basins, each consisting of two basins. The interior is a slow mixing basin and an external basin is sedimentation tank. The water from these tanks pours into a collection basin where water is subjected here to a primary chlorination process before entering the filtration tanks (Fig. 2).
- Filters: The number 4 of the type of rapid sand filters and add chlorine to the water out of filters in the process (final chlorination) in the ground reservoir by 2.5 mg /l.
- The treated water from the filters is delivered to the ground reservoir
- The pumps then discharge water from the ground reservoir to feed the cities and areas benefiting from the project. There are 9 pumps for distribution of water after treatment 4 main pumps for Al-Hamza and 3 main pumps for Shinafiyah and two pumps for Al-Sudair.
Figure 1. Hydraulic line of Al-Hamza WTP.

Figure 2. Al-Hamza WTP Flash Mixing and Clariflocculator.

2.2. **Mechanical Flash Mixer**

It is constructed from reinforced concrete, divided into a receiving basin, mixing and drainage basin, and a distribution basin. Chlorine solution is attached to the pump chamber on one side and the other is connected to the sedimentation basin and equipped with control gates (Fig. 3). The converted chlorine gas is pumped into a liquid after mixing it with water using the chlorine pump to the flash mixer unit and the ground tank. Where there are two pipes pour in flash mixer the first pipe containing water mixed with the alum, and the second pipe contains water mixed with chlorine.
The purpose of Flash Mixing is to spread the material in the water as quickly as possible, and in a short period of 20-60 seconds [8, 9, 10], during which the hydraulic distribution of the water on the settling basins is equally effected through the path of the outlet divided into several sections equal to the number of settling basins. The material helps to complete the sedimentation process efficiently, as it interacts with some water components to collect its impurities into larger granules that are easier to deposit in sedimentation basins. Increasing the sedimentation efficiency reduces turbidity concentration and helps increase the efficiency of the filters afterwards. It is used in the drinking water treatment plant in the district of Al-Hamzah Aluminum Sulphate as coagulants.

2.3. Hydraulic Flash Mixer
In this study, a laboratory device known as Free and Forced Vortex, imported from the English company ARMFILED (Fig. 4), was used in the Fluid Mechanics Laboratory at the Faculty of Engineering, Qadisiyah University. A series of experiments were carried out using free (Fig. 5) and force swirls (Fig.
6) to achieve the best design for the rapid hydraulic mixing basin which achieves the best mixing speed and the best dose. The device consists of the following structures [11]:

- Tank diameter: 245mm
- Height to overflow point: 180mm
- Orifice diameters: 8, 16 and 24mm
- Forced vortex measuring probes Distance from center: 0, 30, 50, 70, 90 and 110mm
- Pitot tubes having measuring point (nose) at: 15, 25 and 30mm radius
- Inlet tubes: 9 and 12.5mm diameter

This device consists of a plastic cylinder placed on the base of a PVC board containing four holes on both sides of the cylinder allow water to enter and exit with a surplus water outlet at the top of the cylinder where the out of the excess water. There is a hole in the base of the cylinder where holes are fitted with different diameters. In the case of the free vortices experiment, these openings are used to generate vortices in different diameters. A fan is placed in the case of force vortices. The entire parts are placed on a hydraulic tank for water treatment, speed control and discharge of water.

Two pipes are used in diameter (12mm) and at a 15 ° angle to enter the water in the free vortex experiment. In this case, the water will come out of the container through one of the interchangeable openings in the storage base. Three slots with diameters of 8mm, 12mm and 16mm will be provided. Two pipes (9mm) and 60 ° Water flow in the force vortices experiment. The flow of water from these pipes affects the propeller which acts as an instigator of water circulation and which is fixed by a screw in the central hole. In this case the water will come out of the container through the control valve through the hole 12mm diameter [11]. A bridge containing a measuring needle is used to determine the depth of the vortex where the needles are set at a fixed distance from the storage center. If a free vortex depth is required, it is possible to replace the needles using a scale that measures the depth of the vortex at different diameters. Size can calculated the amount of discharge through volume difference and time calculation. Then, the best experiment to determine the design determinants of the hydraulic mixing basin is selected in terms of number of cycles, angular velocity, optimal alum concentration and optimum flow.

2.4. Experimental Methods
ADiwaniyah River is the main source of raw water supply to the WTPs in ADiwaniya province. The process of treatment at the WTP in Al-Hamza district by chemical methods in the coagulation, flocculation, sedimentation and filtration with lumber and liquid chlorine and then pumped water to the
strengthening pump stations where the addition of chlorine enough to secure a limited amount of free chlorine remaining in the water distribution network.

As a result of the water scarcity flowing in the Iraqi rivers, including the Al-Diwaniyah river and the accompanying damage to its physical and chemical properties, the water quality in the Al-Hamzah WTP was evaluated by conducting some physical and chemical tests to compare and identify the plants efficiency and its conformity with the national and international specifications of water Drinking. Fig. 7 shows the quality of the water when taking the project of drinking water purification plant in Al-Hamza and from the figure we notice the high turbidity of the water of the ADiwaniyah River in the study area.

These measurements and tests are necessary because there are many sources of pollution of river water and for the purpose of ensuring that they are suitable for human use, because their effects will be serious and direct on humans and the environment.

2.4.1. Sample collections
The samples were collected from the catchment (Al-Hamzah River), the rapid mixing basin, the slow mixing basin, the sedimentation basin, the filter basins, the ground reservoir, and the tap water in the houses, and weekly, and three replicates according to the recommendations of the APHA 1998 October 2018 until March 2019 in cooperation with the laboratory unit / Water Department and Environment Directorate / Diwaniya province.

2.4.2. Physical Tests
These tests included some physical and chemical properties of water as shown below:

- **Temperature**
The water temperature in the WTP was measured directly using a mercurial mercury gradient of 100-0 °C.

- **Electrical conductivity**
Electrical conductivity was directly measured using an electrical conductivity meter and results were expressed in µs/cm [12].

- **Total solids**
The drying method was used to estimate total solids using the electric furnace at 106 °C and expressed the results in mg/l [12].

- **Total suspended solids**
The method described in APHA (1998) for the measurement of total suspended matter after filtration was followed by Millipore filter papers with 0.45 μm diameter. If the suspended material was not passed through the paper, the results were reported in mg / l.

- **Total dissolved solids**
Total soluble solids were estimated by taking the filtered water through the Millipore filter paper and expressing the results in mg / l [12].

- **Turbidity**
The Turbidity of the water samples was measured using the HACHC.C 16800 Turbidimeter, the results were reported in Nepheloturbid unit [12].

2.4.3. Chemical Tests

- **pH**
The pH of the water samples was measured using the pH meter (Hana) after calibration with buffer solutions.
- **Total alkalinity**
  Dissolve 100 ml of water with a 0.02 mL hydrochloric acid solution (using the phenolphthalene reagent and the orange instance detector), expressing the results in mg/l [12].

- **Total hardness**
  The total hardness was determined according to what was mentioned in [12]. The ammonia solution was added to the water sample to raise pH to 10 and the Eriochrome black-T-stain was present with the standard EDTA solution (0.01) and the results were expressed in mg / L.

### 3. Results And Discussion

The design calculations of the hydraulic rapid mixing basin will be presented based on laboratory experiments, optimal pH values, optimum concentration of alum material, optimum mixing speed, and then obtain the highest efficiency for the WTP and access to safe drinking water conforming to the Iraqi Standard.

#### 3.1. Analysis of the Results of the Sampling of Water from the Project of WTP Al-Hamzah:

Table 1 shows the measured concentrations of different treatment stages of the potable water treatment plant in the district of Al-Hamza, starting from the intake of the Al-Hamzah River, the rapid mixing basin, the slow mixing basin, the settling tank, the filtration, the ground storage tank and one of the taps in the houses. The concentration of pH, E.C, T.D.S, T.S.S, Turbidity, ALK, Acidity, and T.H, where the results showed that the water is not suitable for drinking and does not meet the Iraqi specifications and that the WTP efficiency is up to 83%. Therefore, a rapid hydraulic mixing basin has been designed to achieve the highest efficiency of the plant and obtain safe drinking water, conforming to specifications and at the lowest cost of treatment.

| Tap water | Storage tank | Filtration | Clarifier | Flocculation | Flash mixer | Intake | Test Type | No. |
|-----------|--------------|------------|-----------|--------------|-------------|--------|-----------|-----|
| 8.09      | 8.05         | 8.08       | 8.03      | 7.97         | 7.89        | 7.34   | pH        | 1   |
| 1341      | 1369         | 1416       | 1438      | 1448         | 1465        | 1751   | E.C - µs/cm | 2   |
| 681       | 693          | 725        | 744       | 765          | 773         | 872    | T.D.S - mg/l | 3   |
| 8.90      | 15.8         | 22.17      | 36.75     | 42.00        | 49.23       | 64.6   | T.S.S - mg/l | 4   |
| 14.24     | 22.20        | 36.45      | 49.62     | 62.16        | 86.35       | 137.1  | Turbidity | 5   |
| 45.24     | 52.80        | 74.61      | 81.43     | 96.05        | 107.3       | 145.2  | ALK - mg/L | 6   |
| 6.70      | 7.24         | 8.12       | 8.64      | 9.15         | 9.84        | 11.29  | Acidity mg/L | 7   |
| 75.83     | 92.68        | 119.14     | 128.47    | 138.01       | 171.6       | 198.4  | T.H - mg/l | 8   |

#### 3.2. Analysis of the Results of the Sampling of Water Lab Hydraulic Flash Mixer

The operation at any drinking water treatment plant needs to determine the dose of alum and the appropriate conditions accurately without excessive chemicals. Therefore, the mind is reminded of the need to simulate the operating conditions to reduce the wasted chemicals in the experiment. Before starting the experiment we record pH, alkalinity, and turbidity. The WTP is simulated through several variables (alum dose, contact time, rapid mixing, optimum pH, and subsequent design of the hydraulic mixing basin that optimizes the project efficiency). Based on laboratory tests on a laboratory device known as Free and Forced Vortex, imported from the English company ARMFIELD and A mini-potable water treatment plant as well as the results of the jar test to determine the optimal dose for alum used in
the mixing process. As well as to determine the optimum pH concentration and optimum mixing speed and to determine the optimal design of the hydraulic rapid mixing basin at the Al-Hamza water treatment plant.

The results of the jar test were combined with the results of the hydraulic mixing basin test. Fig. 8 to 12 shows optimal pH values and alum concentration using different turbidity of the Al-Hamzah water from 25 to 300 NTU, different pH values of 5 to 8 and different concentrations of alum from 0 to 25 mg/l. On the best pH of 7 and the best dose of 10 mg/l and the mixing speed of $G_t=1600$, which achieved the efficiency of removal of turbidity 98.0%.

![Figure 8](image)

**Figure 8.** The effect of alum concentration on the efficiency of the removal of the pH from 4 to 8 and the values of the turbidity 25 and 300 NTU.
Figure 9. Effect of alum concentration on the efficiency of turbidity removal

Figure 10. Effect of pH on turbidity removal efficiency

Figure 11. Effect of mixing intensity on the efficiency of turbidity removal
3.3. Design Calculations for Hydraulic Rapid Mixing Basin

Depending on the laboratory results shown in the above paragraphs, below is the optimal design of the hydraulic mixing basin, where velocity gradient is the main factor in the design of rapid mixing tank. It is denoted by the symbol (G) in the velocity gradient containers calculated from the following equation [13]:

$$G = \left( \frac{P}{\mu V} \right)^{0.5}$$

Where $P$ is the energy of the mixing consumed and $\mu$ is the viscosity and $V$ is the size of the mixing tank.

The amount of suspended solid in the water that stick together when adding coagulant material in proportion to the product of $G_t$, where $t$ is the mixing time and its value is large if the flow is turbulent and a good mixing occurs. The shape of the hydraulic rapid mixing basin proposed in this study, which achieves the best mixing speed and less operational cost is cone shape. The purpose of the conical form in the rapid mixing basin is to mix the alum coming from the fermentation tanks with the raw water coming from the inlet pumping stations. This phase is a rapid mixing phase where alum is used as a coagulant for suspended solids (turbidity).

The conical form of mixing is the blending of raw water with the coagulants and its purpose is to generate large flocs. The fluid behaves in this cone as free eddies. The main equations for the design of the rapid mixing basin are associated with the radial velocity $V_r$ and the diameter [14]. Below are the design equations for the rapid mixing basin as follows:

$$V_r = \text{Constant}$$  \hspace{1cm} (2)

$$P = eg \left( A - Br^2 \right)$$  \hspace{1cm} (3)

Where $A$ and $B$ are constants. Also:

$$V = \sqrt{V_e^2 + V_r^2}$$  \hspace{1cm} (4)

Where $V$ = Resultant velocity, $V_e$ is Tangential velocity component equal to $A/r$, and $V_r$ is Radial velocity component equal to $B/r$ and

$$V = \frac{1}{r} \sqrt{A^2 + B^2}$$  \hspace{1cm} (5)

$$\tan \alpha = \frac{V_r}{V} = \frac{A}{B} = \text{Constant}$$  \hspace{1cm} (6)

The input velocity is 1 m/s and the exit water velocity is 0.36 m/s to form the flocs [15, 16]. Thus, discharge in the vortex basin is equal to the total discharges in the storage basin and alum basin. For most mixing tanks the water intake velocity should not be more than 1 m/s, to facilitate the proper mixing process between water and alum dose. The Fig. 13 and 14 show the optimum design of the environmentally friendly hydraulic rapid mixing basin for a average flow rate of 0.003 m³/s. Fig. 15 and

**Figure 12.** Effect of $G_t$ value on turbidity removal efficiency

![Figure 12](image_url)
show the rapid mixing basin that was implemented at the drinking water treatment plant in the district of Al-Hamzah.

Figure 13. a) A side view in the hydraulic rapid mixing basin, and b) A front view in the hydraulic rapid mixing basin.

Figure 14. Image of top view to hydraulic rapid mixing basin in the Al-Hamzah WTP

Figure 15. Image of side view to hydraulic rapid mixing basin in the Al-Hamzah WTP.
Table 2 shows the efficiency of removal (%) in the WTP Al-Hamza for turbidity for treated water for 12 months after the implementation of an environmentally friendly rapid-mixing tank. Using the hydraulic rapid mixing basin and comparing these characteristics with the Iraqi standards that determine the turbidity value is not more than 5 NTU, the turbidity was noticed that in the water produced falls within the required specifications and that the removal efficiency reaches 98%, and this applies to the rest of the pollutants.

Table 2. The removal efficiency (%) of the treatment plant for the turbidity.

| No. | Turbidity % | Month      |
|-----|-------------|------------|
| 1   | 98.5        | January    |
| 2   | 97.5        | February   |
| 3   | 99.6        | March      |
| 4   | 98.0        | April      |
| 5   | 98.0        | May        |
| 6   | 98.4        | June       |
| 7   | 98.5        | July       |
| 8   | 98.7        | August     |
| 9   | 97.4        | September  |
| 10  | 98.5        | October    |
| 11  | 97.5        | November   |
| 12  | 98.5        | December   |

4. Conclusion
Through the above we conclude the following:
1. All basic characteristics such as of pH, E.C, T.D.S, T.S.S, Turbidity, ALK, Acidity, T.H are not within the applicable standards of both raw water and treated water prior to implementation of the hydraulic fast mixing basin.
2. The efficiency of treatment at Al-Hamzah WTP is unstable, which affects the efficiency of the plant.
3. The WTP is of the type of conventional WTP and therefore it is an unacceptable efficiency in removing turbidity, which represents the proportion of suspended materials.
4. The WTP inefficiency in removing dissolved and hardness pollutants, ions and dissolved solids.
5. The values of pH in the raw water are relatively high, which affects the working mechanism (alum) and thus the efficiency of sedimentation and this requires reduction to be less than 7.
6. Using laboratory experiments and field measurements, a hydraulic rapid mixing tank with a hydraulic power is designed to give the best mixing efficiency and the lowest cost of treatment and the highest efficiency of the treatment plants.
7. The specifications of the rapid mixing tanks and the preparation of design calculations for the environmentally friendly hydraulic mixing basin were presented. As well as showing the results of the Jar Test to determine the optimum pH values and the optimum concentration of alum. As the amount of
alum added to the plant is (0-25) mg/l, which is very high quantity and harmful to human health, while found in this research that the optimal concentration of the alum is 10 mg/l and also the pH was 5-8 while in this study optimal pH is equal to 7. The optimum mixing speed was 1600 seconds at the concentration of alum 10 mg/l and pH 7 and an ideal design was prepared for a hydraulic rapid mixing tank with an eco-friendly hydraulic power. The efficiency of the WTP has been improved as the WTP is of the type of conventional and therefore has an unacceptable efficiency in removing turbidity. It has an efficiency of approximately 71.5% -83.4%. Therefore, the plant is not effective in removing dissolved and hardened pollutants, ions and dissolved solids. The efficiency of the plant has been improved to reach 98.0% and is identical to the values of turbidity less than 5 NTU and this is identical to the Iraqi and international units for drinking water.

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