

QATAR UNIVERSITY

COLLEGE OF ENGINEERING

UTILIZING STEEL SLAG IN THE REMOVAL OF SUSPENDED SOLIDS FROM
DEWATERED CONSTRUCTION WATER: A MECHANISTIC STUDY

BY

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ABSTRACT

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Title: Utilizing Steel Slag in the Removal of Suspended Solids from Dewatered Construction Water: A Mechanistic Study

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Construction dewatering is an operation used to remove shallow groundwater infiltrated into a construction site; this technique is used in most of the construction projects. After collecting the water from the construction site, the water is either discharged to the sea, injected in deep groundwater aquifers, or treated and reused in some other applications. In this study, treatment of dewatered construction water by waste steel slag was performed. The impact of the mass of steel slag, the contact time, steel slag particle size and pH were studied on the quality of dewatered construction water. It was found that the maximum removal percentage of suspended solids was 97%, which occurred when 5 grams of steel slag were in contact with the dewatered construction water. The uptake amount (q) was 63.12 mg of suspended solid per gram of steel slag. It was observed that equilibrium was achieved after a contact time of about 40 minutes. The impact of steel slag particle size was studied, where two different sizes of steel slag particles were considered namely, 425 and 75 nm. An uptake value (q) of 72.24 mg/g and 64.36 mg/g were obtained for steel slag particle size 425 nm and 75 nm, respectively. The impact of pH was studied, where it was found that at pH value of 12, the removal percentage of suspended solids was higher than pH of 2, where the uptake amount of suspended solids was 80 mg/g. In addition,

the performance of steel slag was compared to a commercial chemical coagulant, where steel slag had a higher uptake amount of 72.24 mg/g compared to 60.62 mg/g for the commercial coagulant.

DEDICATION

This work is dedicated to all of my family members and friends, for their continuous support and help until I finished it in this shape.

Thank you all for your help.

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Chapter 1 LITERATURE REVIEW

1.1 Introduction

Water is an essential issue that the countries in the region and around the globe are facing nowadays with major challenges, where the possibility of having a water crisis is rising day-by-day, because of the increase in population proportion with different activities and urban planning development. Scarcity of natural water resources has been a huge concern, in addition to the irresponsible water management and some natural factors in some countries, such as dry hot weather and lack of rains [1]. Additionally, global warming and climate change play an important role in the availability of fresh water. All of these factors lead to start looking for new sources of water that can be easily treated and used for different purposes, or investigating new technologies and methods to treat the existing water sources [2].

One of the most vital causes of life in the world is water, where most of the human body contains water. The same thing applies to other living creatures, in addition to most of human activities, are in need of fresh or clean water [3]. Although the search for new fresh and clean water sources is a necessity these days, especially in countries that have limited resources, water quality is an important factor that has to be considered seriously in addition to the quantity [4]. The fact that almost 70% of earth's surface is covered of water is true, but the biggest problem is that only 3% of this amount is fresh water. Most of this amount of fresh water is in the form of ice, which is difficult to get access to, and the remaining amount is distributed unevenly in the world [5]. Major part of water is being used for irrigation and landscaping activities, especially in dry countries, leaving smaller quantities of water for the daily human needs [6].

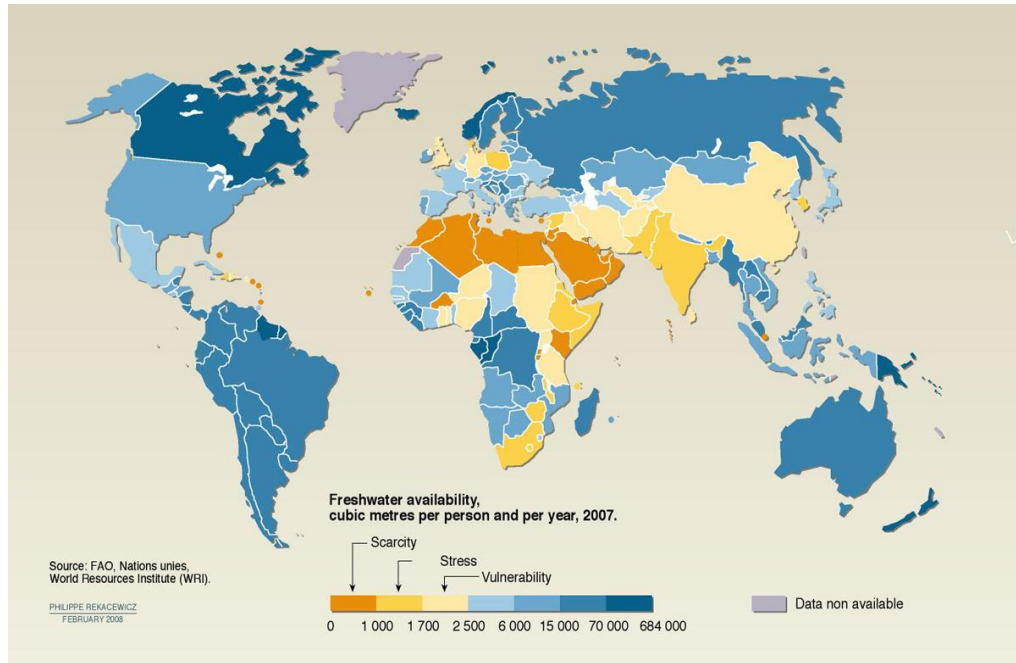


Figure 1: Fresh water availability in the world, 2007 [7]

Consequently, the quantity of water is not the biggest concern, earth has huge amounts of water, but the problem is with the quality, even with the fresh water available. Some of the fresh water resources available in some parts of the world cannot be used directly without a proper treatment, or it cannot be accessed in some poor countries due to its geographical nature or the high cost [8]. Water quality is an important factor to decide whether it can be used or not, especially in different human activities such as drinking, cleaning purposes and in food production industries, which requires a very high quality of water to guarantee the safe practice and prevent any health problems or diseases [9].

The term water scarcity is being well known these days, as it is happening when the demand for water is more than the supply, and it is not satisfactory for all human needs and requirements [10]. Water scarcity is leading into water stress in

some regions as a result of the increase in population and different kinds of development. Based on the statistics of the increase in population and the water stress, around 48 countries around the globe will face a water scarcity conditions within 10 years from now. Most of these countries are in the Middle East. More countries will pass through scarcity conditions by the year 2050, which will affect about 40% of the population of the world [10].

Climate change and global warming are playing a major role in water scarcity around the world as a result of the rapid development in different fields. Looking at the earth's climatic change history, it can be noticed that the change in atmospheric system is significant especially in the last century; this change is rapidly accelerated due to many factors. One of the major changes observed globally is the temperature increase. As a result to the continuous increase in temperature, the global warming phenomenon has been a serious threat to the environment. Accordingly, the presence of global warming will cause a change in the environmental balance, and therefore an obvious change in water cycle [11].

Water scarcity in the West Asia and North Africa region is increasing continuously, this region is considered as the major dry area in the world [12]. The available land for agricultural activities is turning into desert, the forests is being cut enormously, huge increase in industrial activities and most importantly the rapid population growth, about one third of the world's population, are increasing the water stress in the region [13]. It has been predicted that this area might be exposed to the threat of having a water crisis within the coming decades, where the scarcity is moving towards alarming levels [14].

The Middle Eastern region, as part of West Asia and North Africa, has very limited fresh water sources, which will affect the social, economic and political life in different ways [15]. The consumption of water per capita is very high in some of this region countries comparing to others, depends on the availability and access to water sources in general and the wealth of the country itself [14]. Even with the wealthy countries, other factors are playing major role in obtaining a safe water resources, which is more expensive or hard to treat. Most of the countries in the region are relying on desalination process to get potable water for the daily use of human for different activities; it is being more difficult to manage to supply the needs of the society with their high demand [14].

1.2 Water sources in Qatar

Qatar is considered as one of the countries with very limited water sources. The discovery of Oil and gas in Qatar led to a huge expansion and growth of the population of Qatar, leading to a huge demand on water supply for industry, agricultural and domestic use. Due to it's high temperature, and it's geological location, Qatar is considered as one of the sever environment to find fresh water resources. The total of the average amount of water consumption in Qatar is more than 100 million cubic meters per year, which considered very high comparing to the supply and to other countries in the region.

Water resources in Qatar therefore are limited; they are categorized into two categories: conventional and non-conventional water recourses. Conventional water Resources are defined as the natural water resources that are naturally present in the environment without the interference of human; an example of that can be the Rainwater collected in the form of groundwater. Non Conventional Water Resources

are defined as the sources created by human work to provide fresh water resources; desalination process for the surface water and Treated Sewage Effluent (TSE) are examples of that [16].

1.2.1 Ground water:

Ground water accumulated in ground as a result of rainwater fall and is considered as one of the natural renewable water sources in Qatar with an estimated 240 Million m³/Year consumed in 2005. 220 Mm³/Year are used for agricultural purposes and 20 Mm³/Year are used for domestic consumption according to FAO Aquastat (2009) [17].

It is estimated that the groundwater recharge from rainwater is about 56 Mm³/Year. Basically, ground water in Qatar is distributed mainly in two basins; one in North and the other is in the South. The North groundwater basin covers 19% of the land with a depth of 10-40 meters. It is considered as a source that import most of the ground water with a very high quality, where the salinity is low of about 500mg/l, and reaches to a maximum of 3,000 mg/l, therefore it can be used for agricultural purposes. The South ground water Basin covers half of the land area with a water table depth about 30 meters below the surface. The water salinity in this basin is relatively high, varies between 3,000–6,000 mg/l, which is not suitable for agriculture [18].

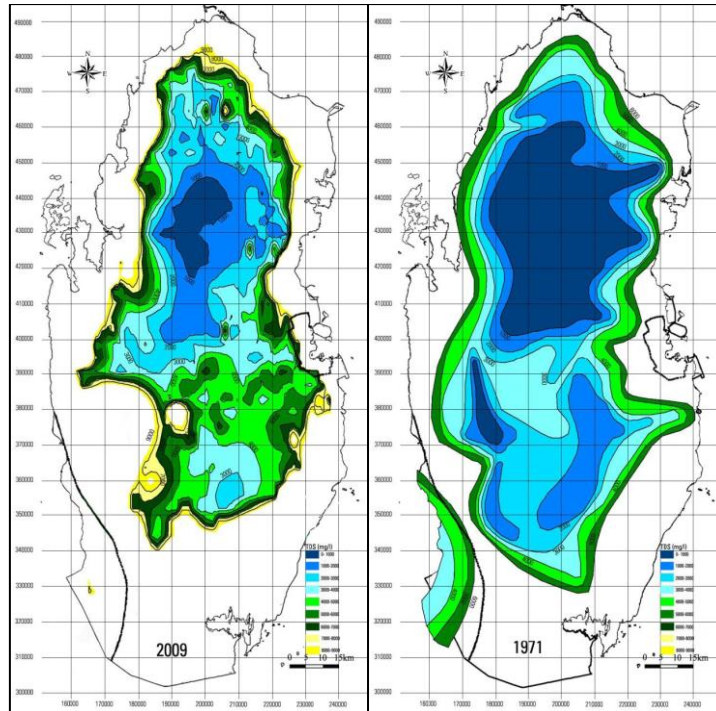


Figure 2: Groundwater in Qatar between 1971 – 2009 [19]

1.2.2 Surface water:

Surface water in Qatar is the main water source represented by the seawater. Seawater cannot be used in its form without treatment, where the treatment process of seawater is called desalination. Desalination process is considered as one of the nonconventional sources of producing pure water, where Qatar is considered as one of the early countries to adopt this technology in 1953 [20]. Total Quantities of desalinated water is estimated at 373 Million cubic meters per year in 2010. The main usage for this water is either for domestic use or to be supplied to industrial sectors. Studies initiated by government sectors in Qatar shows that the production of water by desalination process in the past two decades is being developed significantly [17].

1.2.3 Treated Sewage Effluent:

Sewage networks and systems cover almost two third of Qatar with over one third of wastewater being recycled and treated, the main use for this type of water is for agricultural purposes. The total quantity of treated water is estimated to about 140,000-150,000 cubic meters per day in 2005 [18], which is estimated at 57.7 Million cubic meters per year [17]. The treated wastewater is distributed into different crops farms around Qatar in addition to the landscaping, and the excess is being dumped into emergency lakes or even injecting in the ground to the deep aquifer [21].

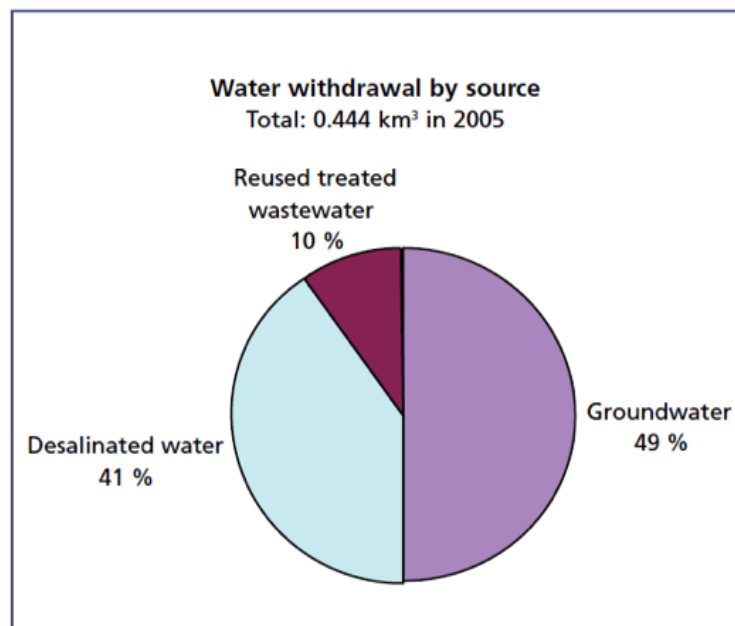


Figure 3: Water withdrawal by source [22]

Table 1: *Water withdrawal by different sectors in Qatar [23]*

Sectors	Agriculture		Domestic		Industry		Total	
	Million m ³ /year	%	Million m ³ /year	%	Million m ³ /year	%	Million m ³ /year	%
Ground Water	218.3	83.5	2.4	1.4	-	-	220.7	49.70%
Treated Sewage Water	43.2	16.5	-	-	-	-	43.2	9.73%
Desalination Water	-	-	171.8	98.6	8.4	100	180.2	40.58%
Total	261.5	100	174.2	100	8.4	100	444.10	100.00%
% By Sector	58.9%		39.2%		1.9%		100.0%	

1.3 Construction produced water

Almost every construction project requires excavation works in order to start the construction. Since the water table in Qatar is very high due to its geographical location of the country as well as the depth of the excavation, groundwater is going to be infiltrated to the construction site. Many locations in the country are being developed to meet the needs and requirements of the increase in the population numbers as well as some huge national projects; consequently, this problem will be encountered a lot during the first stages of the excavation works in the construction site. Therefore to stay in the track of completing the projects in the required timeline, this water need to be controlled and removed out of the construction site, the process of removing this kind of water is called dewatering process [24]. Dewatering process

is an essential process to remove the underground water that has been infiltrated to the construction site to complete the construction works under dry conditions [25].

Construction produced water might delay or stop the construction works, it can also cause damages to the infrastructure or properties in the construction site if not removed properly and carefully [26]. Dewatering methods and techniques are critical elements during the construction works, in order to accomplish a good dewatering methods, an understanding of the geographical details and geological information of the site location is essential, especially the subsurface rocks and soil permeability, type and density, in addition to hydrological properties and characteristics that will determine the water sources [27]. Many other factors can be considered, such as: structures nearby the construction site and the country climate that might affect the level of surface groundwater.

Controlling the groundwater in construction projects present a real challenge, excavations may flood with groundwater and become unstable, which will affect the efficiency of construction operations negatively and will waste money and time. There is a range of dewatering techniques used to control groundwater in a construction site to allow the work below the water level in dry, safe and stable conditions. If well-planned engineered dewatering techniques are implemented to the construction site, the following benefits will be accomplished [28]:

- Geotechnical stability and safety will be improved; it includes steeper side slopes that will prevent the disruption and softening of the excavation formations due to groundwater pressure.
- Excavation and construction operations and conditions will be more efficient; it includes the preparation of concrete mixes, excavations, and piping systems.

- The risk of adverse environmental impacts will be reduced; for example, a risk of having suspended solids that will pollute the water will be reduced due to a good practice of water treatment through dewatering process.

1.4 Dewatering techniques

Well-planned engineered dewatering techniques should be applied in a construction site to work under dry conditions, in order to get the highest efficiency of work and to finish the project without losing time and money. In other words, the control of groundwater can be described as the techniques applied to allow excavations in the construction site to the below the level of groundwater and work in a stable, safe and dry conditions .In order to remove the water from the construction site properly, one of several techniques must be implemented to guarantee the removal of water and complete the project successfully. There is a variety of dewatering systems types that can be used, they have different properties and methods, but they serve the same purpose, which is the removal of the groundwater infiltrated to the construction site [29].

The control of groundwater by the dewatering techniques can be categorized into many types; two main types of methods will be discussed. The first category, it is the most commonly used in controlling groundwater, is the pumping method, it is also known as construction dewatering method. The second category is the cut-off barriers method, it is also known as exclusion method. Each method contains a range of techniques, and each one has its own use and way of work. Table (12) shows the different techniques of each method [30].

Table 2: *Groundwater control methods [30]*

Pumping Methods	Exclusion Methods
- Sump Pumping	- Steel Sheet-Piling
- Vertical Well Points	- Vibrated Beam Walls
- Horizontal Well Points	- Cement-Bentonite
- Deep Wells with submersible Pumps	- Soil-Bentonite Slurry Walls
- Ejector Wells	- Concrete Diaphragm Walls
- Passive Relief Wells	- Bored Pile Walls
- Electro-Osmosis	- Grout Curtains (Permeation Grouting; Rock Grouting; Jet Grouting; Mix in Place)
	- Artificial Ground Freezing

Since there is a wide range of groundwater control methods available, there should be selection criteria to choose the best method to be used in controlling the groundwater. This selection criteria depends on the hydrological and geotechnical investigations of the construction location, in addition to space availability in the construction site, it also varies upon availability of facilities and environmental constraints [31]. The permeability of the soil the generated groundwater plays a primary role in selecting the best controlling method. Figure (4) shows a demonstration of the range of common dewatering techniques, taking into account the soil permeability and the drawdown.

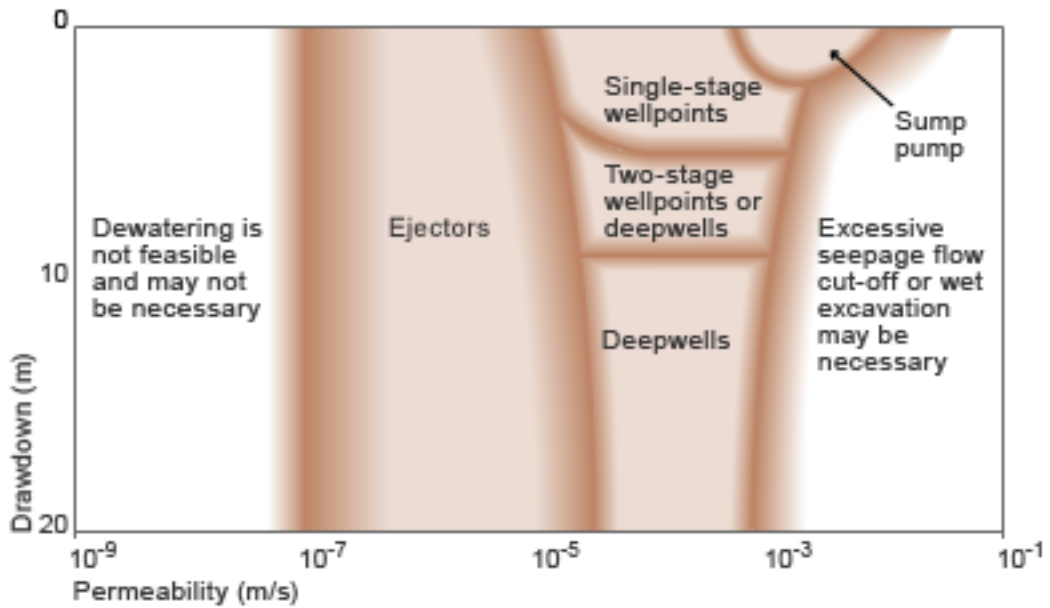


Figure 4: Range of groundwater control techniques depending on permeability and drawdown [32]

The most common techniques used in the region of the pumping methods are the sump pits, trenches, wells deep wells systems, and from the exclusion methods, cut-off walls technique is used with specific material of walls [33].

1.4.1 Sump Pits:

This technique of groundwater control is the simplest technique among other methods of dewatering that can be applied in a construction site; it is working simply by inserting a pump into the infiltrated water in the site and pumps it out. Sump pits technique can be used at the beginning of the excavation stage, where it is a quick and the least cost comparing to other techniques. Sump pits are efficient in filtering the groundwater with low turbidity, in case of high turbidity; geotextile sheets with aggregates should be installed to get better filtration and improve the produced water quality. Figure (5) shows a typical configuration of sump pits used for this purpose.

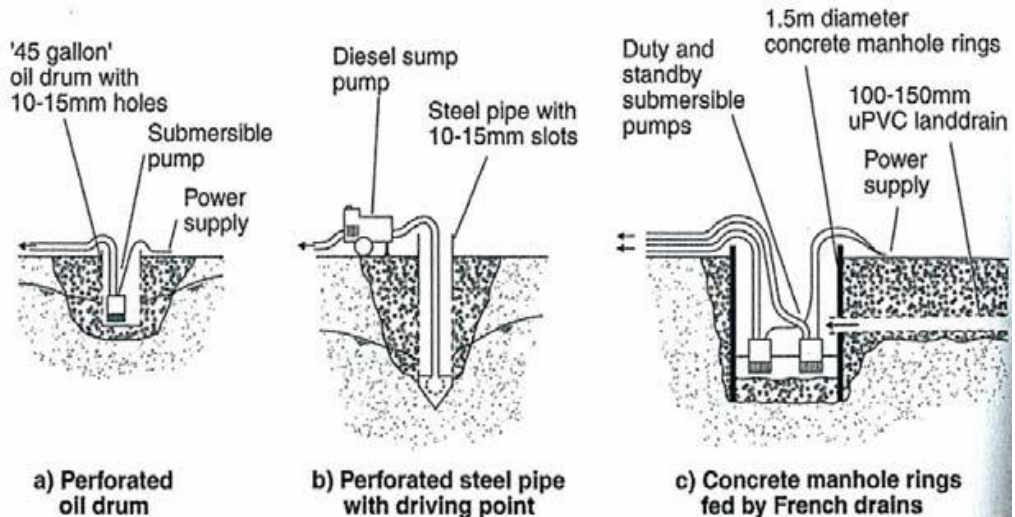


Figure 5: Sump pits typical configuration [32]

Table 3: Sump pits advantages and disadvantages summary

	Advantages	Disadvantages
Sump Pits	<ul style="list-style-type: none"> - Simple and least cost - Effective in cleaning the groundwater from coarse soils 	<ul style="list-style-type: none"> - Drawdown of groundwater capacity is low - Preventing seepage may not happen which will lead into instability

1.4.2 Well System:

Well system dewatering technique is being used commonly in Qatar. Well system is simply implemented by drilling wells systematically around the construction site; submersible pumps are placed into each of the drilled wells. This technique will reduce the water infiltrated into the construction site; it really shows a highly effective

performance in groundwater control in many projects, especially projects that require deep excavations. Figure (6) shows a typical configuration of well system used for this purpose.

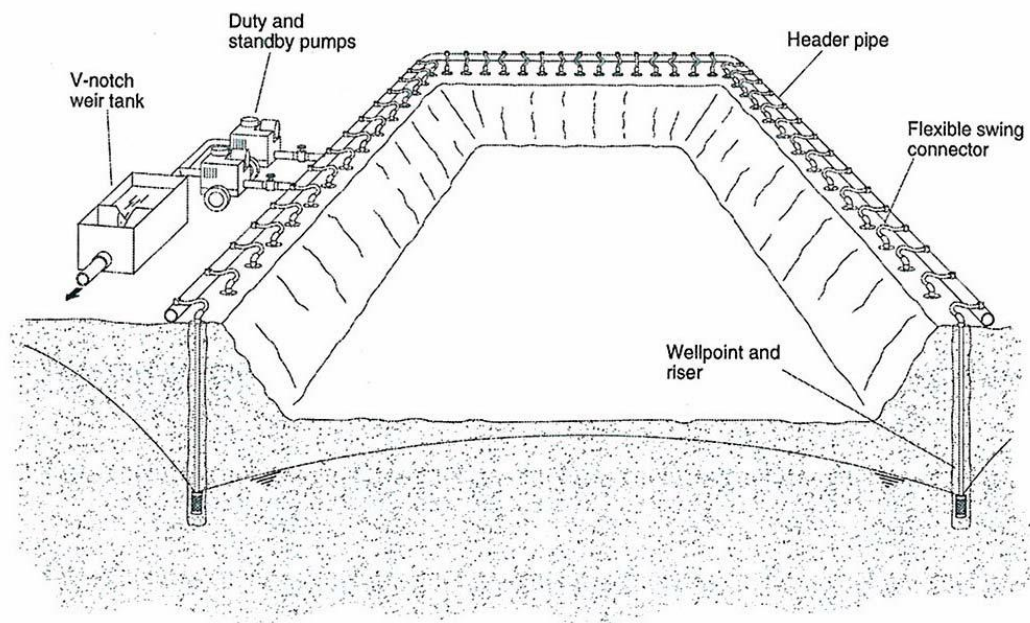


Figure 6: Well system typical configuration [32]

Table 4: *Well system advantages and disadvantages summary*

	Advantages	Disadvantages
Well System	<ul style="list-style-type: none"> - Prove high efficiency in sandy soils - Provide drawdown up to 5-6 meters deep in the sand, and up to 4 meters in soil that contains silt - Flexible and relatively cheap - The installation is easy 	<ul style="list-style-type: none"> - Not effective In case of deeper drawdown is needed (below 6 meters) - Stages of installation might be required

1.4.3 Deep Wells:

Deep wells are almost presenting the same idea of well systems but with more efficiency in deeper drawdowns. Usually deep wells installation equipped with filtration packs and submersible pumps, a control cabin is required for the operation works of the wells. Although deep wells are a high efficiency technique with unlimited drawdowns, it is rarely present in Qatar. Figure (7) shows a typical configuration of deep wells system used for the groundwater control.

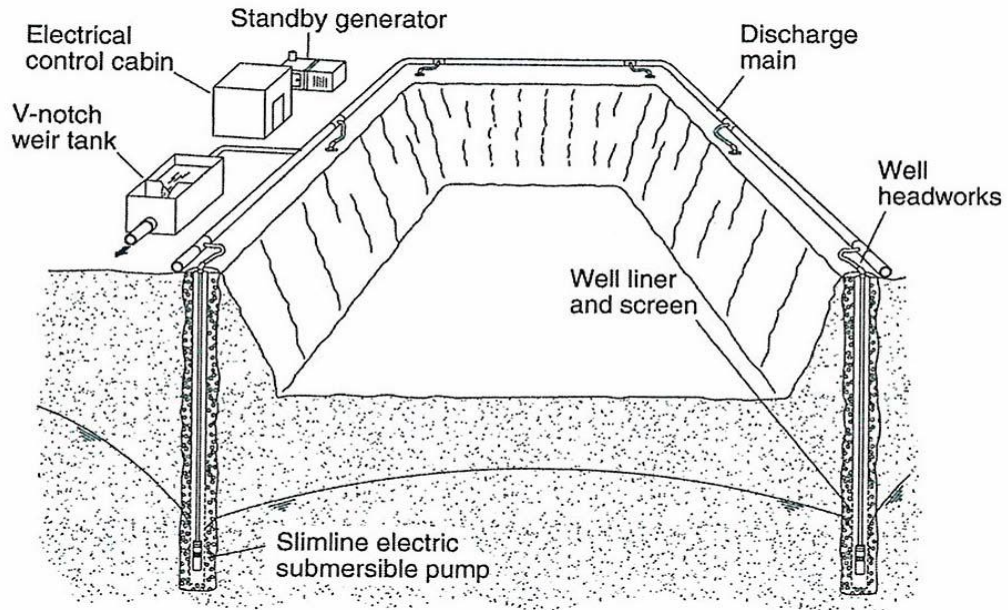


Figure 7: Deep wells typical configuration [32]

Table 5: Deep wells advantages and disadvantages summary

	Advantages	Disadvantages
Deep Wells	<ul style="list-style-type: none"> - Groundwater drawdown is unlimited - Greater spacing between wells, means fewer wells needed with high efficiency 	<ul style="list-style-type: none"> - Installation is very expensive

1.4.4 Ditches or Trenches:

Ditches or trenches are of the common techniques used in Qatar construction sites to control the groundwater. Ditches are a formation that allows groundwater to flow to the surface in deep trenches, it will become easier to reach by inserting perforated pipes into the trenches, and then infiltrated groundwater will be extracted easily through a pipeline to a filtration unit. This technique is being commonly used in

developing infrastructure projects. To maximise the filtration process, geotextile sheets and aggregates should be used when installing the pipelines. Figure (8) shows a typical configuration of ditches or trenches used for the groundwater control.

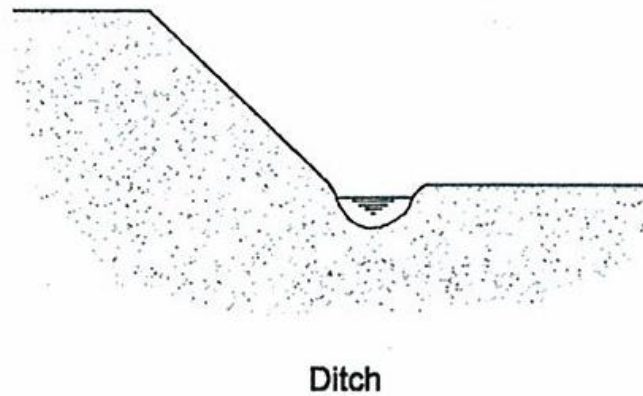


Figure 8: Ditches or trenches typical configuration [32]

Table 6: *Ditches or trenches advantages and disadvantages summary*

	Advantages	Disadvantages
Ditches or Trenches	<ul style="list-style-type: none"> - Relatively inexpensive - Good control for the shallow groundwater 	<ul style="list-style-type: none"> - Traffic obstruction may occur - The control of groundwater will be only in the shallow depths - Low efficiency in fine-grained soils

1.4.5 Cut-Off Barriers:

The cut-off barriers technique is being implemented to limit the infiltration of groundwater to the construction site from the surroundings; it is an efficient technique and can be considered as a step ahead of other methods. Cut-off walls prevent the infiltration to an extent; the wall materials should be chosen selectively depends on the soil permeability and the water table height. The use of cut-off walls in Qatar is common, structural concrete and secant piles are selected for this purpose. Cut-off walls are applicable to most types of soils; they are beneficial in providing slope stability especially in projects with deep excavation. Figure (9) shows a typical configuration of cut-off walls used for the groundwater control.

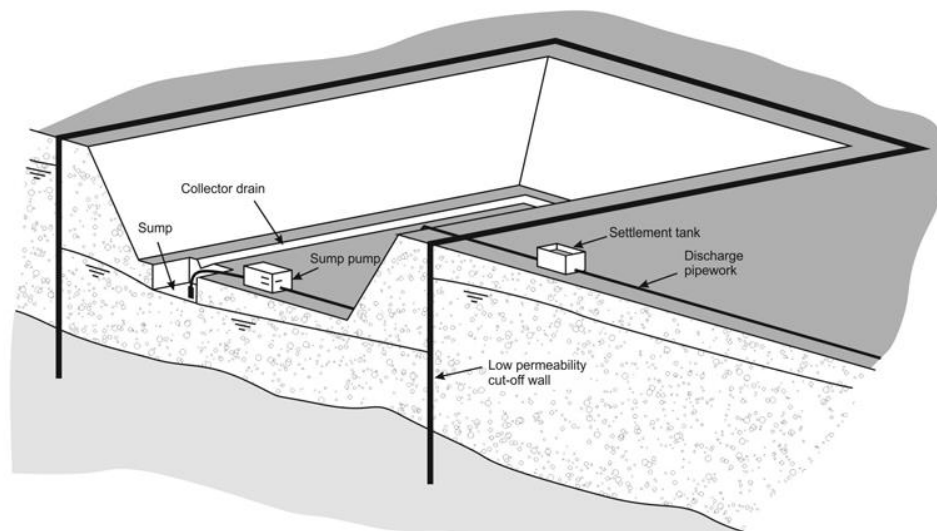


Figure 9: Cut-off walls typical configuration [32]

1.5 Produced water transport and fate

Produced water from any construction site needs to be transferred from that location to keep the work going, consequently, there should be specific location to accommodate this water to be discharged or disposed into, so how to transfer and where this water should be disposed? Typical transport method to transfer this water after pumping it out of the construction site is by pumping it through pipelines into a settlement tanks out of the construction area, the settlement tank will help in settling the suspended particles due to excavations, at that point there are many options that this water might be disposed to, the most common disposal options in Qatar are:

- 1- Discharge to the Sea:
 - a. Direct discharge to the sea.
 - b. Discharge to the sea through surface and groundwater network.
- 2- Discharge to prepared lagoons, this option is temporary.
- 3- Discharge to the deep aquifers through deep well injection.
- 4- Treatment and reuse.

1.5.1 Discharge to the sea:

Discharge the water produced from the dewatering activities to the sea is the most common practice used in Qatar, especially disposal through different discharge points leading to the surface and groundwater network available, this network will lead into different outfalls to the sea in different locations. This option is used only if there is availability of discharge point to the network close to the construction site, in addition to complying with the water quality regulations and parameters. Depends on the network capacity, the amount of water to be discharged can be decided, which will

be decided by the specialized authority. The average amounts of water discharged into the sea through the outfall pumping stations is about 200,000 m³/day [34], which considered as a huge amount of water that can be used in a way or another instead of just dispose it in the sea. The most important parameters to be tested are turbidity, suspended solid and other parameters to be discussed later on.

In case of unavailability of the surface and groundwater network close to the construction site, there will be two options in this case, the first option is by transferring the water through tankers to the closest discharge point, or if it was found that the most applicable option is to discharge to the sea directly, some requirements applies in this case. A secondary treatment at least, depending on the produced water quality, is a must to guarantee that the quality of treated water reaching the sea is complying with the environmental regulations. Additionally, a piping system should be installed from the seashore up to a point in the sea away from the shore. The focus will be on many water quality parameters, some of these parameters are: presence of microbiological content, suspended solid, turbidity, petroleum compounds and heavy metals, this will protect sea environment and keep it in safe conditions.

1.5.2 Deep well injection:

The discharge of groundwater collected from dewatering activities through the injection in the deep aquifer is a common method in different location in Qatar, it is usually used for the discharge of treated sewage effluent, but it has been done for the dewatering produced water in some huge projects. Since this option is dealing with the aquifers, it needs to be more careful in dealing with it so the fresh groundwater won't be affected or polluted, because it is the only source of fresh water of the country, so it is considered as a national fortune.

The geological and hydrological conditions of the proposed site should be studied in order to decide the appropriate depth for the injection, determine the porous water reservoirs locations and identify the suitable discharge rates. The typical depth for the injection is must be more than the range or 400 – 600 m deep. Treatment method has to be used to treat water before discharging it into the deep aquifer. In order to check the water quality that will be discharged, physical, chemical, biological and microbiological analysis should be implemented; the exact parameters will be discussed later.

1.5.3 Treatment and reuse:

The region is living in a water scarce situation with rapid increase in population; the need for new sources of water is really increasing with the depletion of the fresh water source. If new sources of water couldn't be found, alternatives should be discovered and developed. Getting to know the huge amounts of water being discharged from different activates without getting benefit out of it is a big mistake. Huge water amounts being discharged daily from dewatering activities, about 200,000 m³/day being discharged only through surface and groundwater network. Looking at the characteristics of this water, using the appropriate treatment method, this water can be reused in several applications.

Treating the water produced from dewatering activities will make it ready to be used in a variety of applications, such as:

- Domestic uses.
- Agricultural irrigation (crops and landscaping)
- Industrial uses.

- Onsite uses in during the construction phases.

Produced water from dewatering activities is most commonly used onsite within the construction sites in several activates and applications. The following applications could deal with the produced water after treatment stage:

- Onsite dust control.
- Concrete mixes production.
- Excavation activities that require water.
- General cleaning and washing uses around the site, example: machines and equipment.
- Soil compaction.
- Landscaping onsite and around the project area.

1.6 Types of Treatment Methods:

Managing the groundwater after the collection process is a critical issue, this collected water from construction sites after excavation must be either returned to a receiving environment or reused again in some applications. Depending on the application that will be applied fir and the collected water quality, a level of treatment must be applied to this water to comply with the standards and regulations of the country, and to ensure that it is safe for the environment and human being in contact with it [35]. Most groundwater collected from dewatering activities in construction sites are almost contaminated with one or more types of contaminants or pollutants of concern, this confirms the fact that a treatment method is required prior to transport to the final recipient [36].

There are several types of pollutants or contaminants that has to be considered, these pollutants can be specified into two categories: sediments and other pollutants. The sediments category is the most common among other pollutants; it is a result of the excavations and drilling activities during the construction, where soils will be mixing with the water and it can be seen in form of turbidity and suspended solid in water. A level of treatment must be applied to decrease the amounts of these soils to comply with the standards and regulations. The other pollutants include any pollutants other than sediments, these pollutants can be present in water depends on the construction site location and any previous activities on the same land or adjacent to it before the construction starts. The most common pollutants of this category include: nutrients from fertilizers such as nitrogen and phosphate compounds, organic matter, heavy metals like copper and lead, some constituents that might affect pH and hardness and microbiological content such as bacteria, it may also contain oil and grease, hydrocarbon content and pesticides [37].

The treatment method selection depends mostly on the collected groundwater quality, the final recipient environment or the type of application that will be used for later [38]. Treatment methods associated with dewatering activities in construction site includes the following [39]:

- Equalization for preliminary sedimentation.
- Adjustment of pH.
- Coagulation flocculation.
- Settling/ clarification.
- Filtration (media filters or membranes).
- Activated carbon [40].

- Ion exchange.
- Disinfection.

Table (7) shows the different contaminants groups associated with each treatment method.

Table 7: Treatment methods for different contaminants groups [41]

Contaminated Group	Equalization Tank	pH Adjustment	Coagulation Flocculation	Settling/ Clarification	Filtration	Activated Carbon
Dissolved Volatile Organic Compounds	√				√	√
Dissolved Semi-volatile Organic Compounds	√				√	√
Free-Phase Hydrocarbon	√			√		
Metals	√	√	√	√	√	

The proposed treatment method for the groundwater collected from dewatering activities in construction sites can be shown in figure (10):

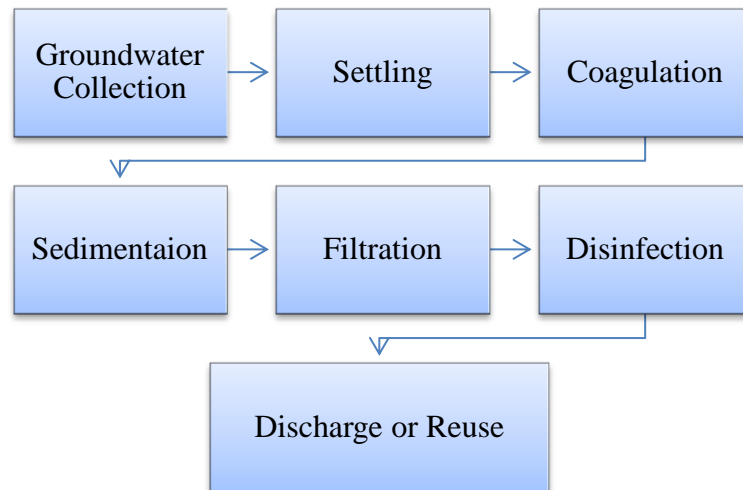


Figure 10: Proposed treatment method for collected groundwater

1.6.1 Settlement Tank:

Settlement tank is almost used in every dewatering activity; it gives the chance to the particles to be settled and reduce the turbidity. This method is a primary step in the treatment process and the most common and effective method, it increases the time and distance that water will move before reaching the discharge point, which will increase the efficiency of the settlement. In other words, Settlement or equalization tank provides a temporary storage facility for the water; it enhances the preliminary sedimentation of the large particles of soils and sand, and prepares the water for the coming steps of treatment.

1.6.2 Coagulation Flocculation:

Coagulation and flocculation process is a process intended to enhance the settling properties of the suspended solids remaining in groundwater from the primary settlement. Coagulation and flocculation treatment method is also applied for the removal of metals precipitated in water [42]. This treatment method must be applied in case of presence of high concentration of silt or bentonite in collected water, it helps in achieving a high level of particles reduction, which can't be removed by other treatment methods, and makes it ready for the coming stage of treatment [43]. Coagulation process happen by the addition of coagulants to the water, several types of coagulants commonly used in coagulation of contaminated groundwater collected from a construction site are: ferric sulphate, aluminium sulphate, sodium aluminate and a list of cationic polymers. In addition to the coagulants used, several flocculants used for the flocculation process such as: non-ionic and anionic polymers. A settling/clarification stage is required after coagulation and flocculation to enable the removal of precipitated solids [39].

1.6.3 Filtration:

Filtration is the process of removing the solid particles from a liquid, it happens in presence of certain types of filtration units with certain pores that can trap the solids [44]. There are a several filtration methods used to treat the groundwater collected from a construction site. This method is used for further clarification of the water after coagulation flocculation settlement, or it can be used alone without previous treatment depends on water quality, especially when water contains a lot of suspended solids amounts and dissolved unwanted contaminants that can't be

removed by other means of treatment. The following filtration methods are commonly used for the treatment of contaminated groundwater [45]:

- Multimedia Sand Filters.
- Activated Carbon.
- Membrane Filters.
 - o Micro Filtration.
 - o Nano Filtration.
 - o Ultra Filtration.
 - o Reverse Osmosis.

1.6.3.1 Multimedia Sand Filtration:

Multimedia sand filter is the most common treatment method used in Qatar. Generally this step is considered as a polishing step in the treatment process or final treatment step; it is used after removing most of the sediments and pollutant by the previous methods. Sand filters are able to remove several pollutants such as: remaining sediments, some metals, Biological Oxygen Demand and turbidity [46]. Sand filters can remove small particles with a size of 0.01 mm with high removal efficiency as of 95%. Sand filters has a lot of advantages, some of these advantages are [38]:

- Compact and portable.
- Can remove very small particles with high efficiency.
- Easy cleaning process, the backwash option reduces additional costs.
- Help in reducing the metals or pollutants associated with the sand particles.
- Installation and maintenance costs are not high compared to other treatment methods.

Although sand filters are very efficient, there are some limitations that need to be taken care of, these limitations are:

- Power is needed when backwash.
- Clean tanks with clean water required for the backwash.
- It is not very efficient in removing colloidal particles.



Figure 11: Multimedia sand filter[38]

1.6.3.2 Activated Carbon:

Activated carbon is a very effective treatment method used in the removal of the dissolved volatile organic compounds in water and some heavy metals to an

extent, such as hydrocarbon petrochemical compounds, some solvents or mercury [47]. Many construction projects in Qatar are using activated carbon for further treatment of groundwater in the construction site. The idea behind the activated carbon filters that it depends on huge surface area per volume with numerous active sites, the huge surface area will maximize the contact time with the surface of the granules which enhance the removal of particulates that will stuck into the granules pores [40]. The surface area per weight of activated carbon granules can reach up to 1000 m²/g of activated carbon. There are a range of materials that activated carbon can be made from, for example: coconut shells, wood, anthracite coal and petroleum cokes [48]. A preliminary treatment stage prior to activated carbon might be needed to reduce the amount of suspended solids, the granules of carbon can be clogged easily and a regeneration of carbon is required. The regeneration process simply obtained by heating with the injection of hot air or steam [49].

1.6.3.3 Micro Filtration:

Micro Filtration membranes are used for separation of impurities (particles, viruses, and bacteria), with a size range of 0.1–10 mm, from a solvent or other low molecular weight components [50]. The separation mechanism is based on the sieving effect where particles are separated according to their dimensions although some charge or adsorptive separation is possible. The development of highly resistant membranes such as polypropylene, polyamide and polysulfone enables the MF technique to be used as a large-scale separation tool [51].

Advantages:

- Microfiltration is generally a low-cost, low energy and safe treatment process. The membrane flux is adequate at relatively low water pressures. Gravity operated systems are commonly applied.
- As a barrier technology, no chemical treatment is necessary to disinfect water. The pore structure rejects components predominantly by an exclusion mechanism.
- MF systems protect against bacterial and cyst hazards without eliminating dissolved minerals and salts, an advantage since these contribute to the health and taste of water.

Disadvantages:

- Microfiltration systems will not remove dissolved contaminants, such as nitrates, fluoride, dissolved metals, sodium and VOCs. Colours, tastes and odours are also untreated.
- Membrane fouling is a serious phenomenon affecting performance and service of membrane filters.
- Fouling is a phenomenon of all polymer membranes, to varying degrees, so using one membrane to pre-treat another is not a meaningful option [52].

1.6.3.4 Ultra-Filtration:

Ultrafiltration is a pressure-driven membrane separation process that helps to remove particulate matter from aqueous solutions such as groundwater, where its membranes bore sizes varies between 0.1 and 0.001 micron. Ultrafiltration used to remove high molecular weight substances, colloidal materials and organic/inorganic

polymeric molecules. Ultrafiltration membranes can be made from both organic (polymer) and inorganic materials.

Ultrafiltration membrane modules classified as plate-and-frame, spiral wound, and tubular configurations, shown in figure (12). Each configuration is especially suited for some specific applications and there are many applications where more than one configuration is appropriate. For example, spiral wound used for high purity water, on the other hand, Plate-and-frame and tubular configurations used for more concentrated solutions. A variety of materials have been used for commercial ultrafiltration membranes, but polysulfone and cellulose acetate are the most common [53].

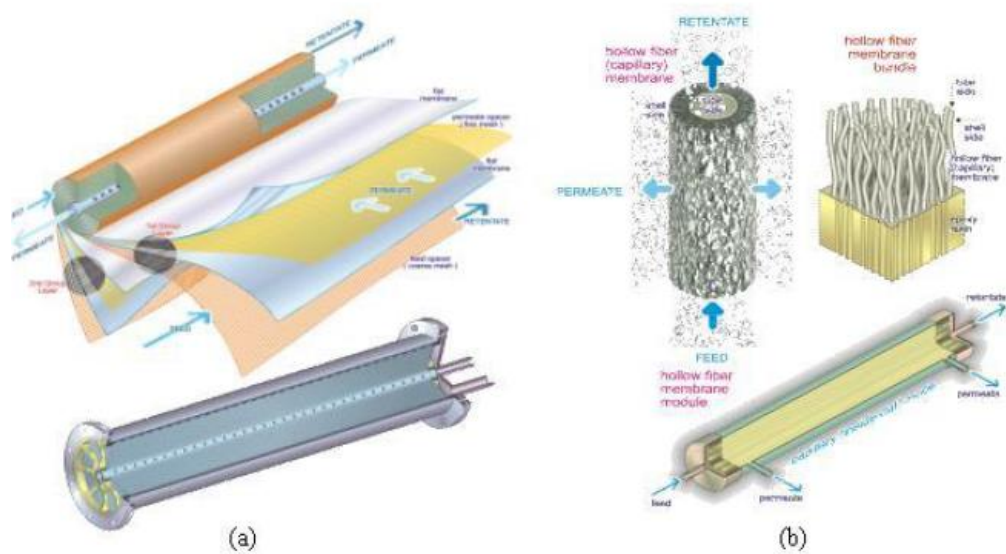


Figure 12: Ultrafiltration membranes configuration: a) Spiral Wound b) Hollow Tube [54]

1.6.3.5 Nano Filtration:

A Nano filtration filter is one of the effective filtration processes of treating groundwater that can't be treated using conventional treatment methods, this type of membranes have a pore size ranging from 0.01 – 0.001 μm . Nano filtration is very close to the reverse osmosis but it is used before it, the difference is the ions removal extent such as chlorides [55]. Nano filtration removes nearly the natural organic molecules, most of the bacteria and viruses, heavy metals and some natural minerals such as salts. Nano filtration removes divalent ions that cause water hard; in fact, it is often used to soften hard water. Nano filtration, however, does not remove dissolved compounds.

Nano filtration uses less fine membranes, so the feed pressure and the fouling rate of Nano filtration is generally lower than other systems such as RO systems [56].

Applications:

- Water softening.
- Specific removal of heavy metals from process streams for reuse of water.
- Reduction of salt contents of slightly brackish water (water that has more salinity than fresh water), it can be used as a pre-treatment of seawater.
- It has some food and pharmaceutical applications.
- Typical Nano filtration membranes performance removes or reject around 50% of NaCl and 90% (or more) of CaSO₄.

Types:

- Spiral membranes: cheapest but more sensitive to pollution.

- Tubular/ straw membranes: the most used membranes seen the costs and effect, they shall not be easily polluted.

1.6.3.6 Reverse Osmosis:

Osmosis is the diffusion or the movement of molecules, solvents basically such as groundwater, from high concentration region to lower concentration region through a semipermeable membrane. The reverse osmosis was first introduced in 1950s, it is the movement of molecules from low concentration to high concentration by exerting a pressure on the high concentration side [57]. This pressure, between 100 and 1000 psig, exerted on the high concentration side will force the solvent, water, to move from the concentrated region to the diluted region and maintain the ions in their concentrated side [58]. Reverse Osmosis is a membrane technology that represents a cross flow technology as permeation in axial direction through the membrane. RO is not sufficient with low molecular weights molecules, less than 200g/mol, but RO doesn't allow ions to pass. It is used to produce high purity water but it is not sufficient alone. The dissolved solids in the produced water is below 500 mg/l, therefore it can be used for different purposes in industry, agriculture, or domestically. A brine is being produced as a by-product as a solution of 35000 mg/l dissolved solids [59].

Uses:

Industrial uses, agricultural uses.

Application of RO:

Treating contaminated groundwater, boiler feed water treatment, pharmaceutical, food & beverage, semiconductor and metal finishing.

Advantages:

System is Simple, installation costs are low, low maintenance, remove organic and inorganic contaminants, minimal use of chemicals, disposing the brine has a negligible environmental impact.

Disadvantages:

Membranes are sensitive, feed water needs to be pre-treated, requires a reliable energy source.

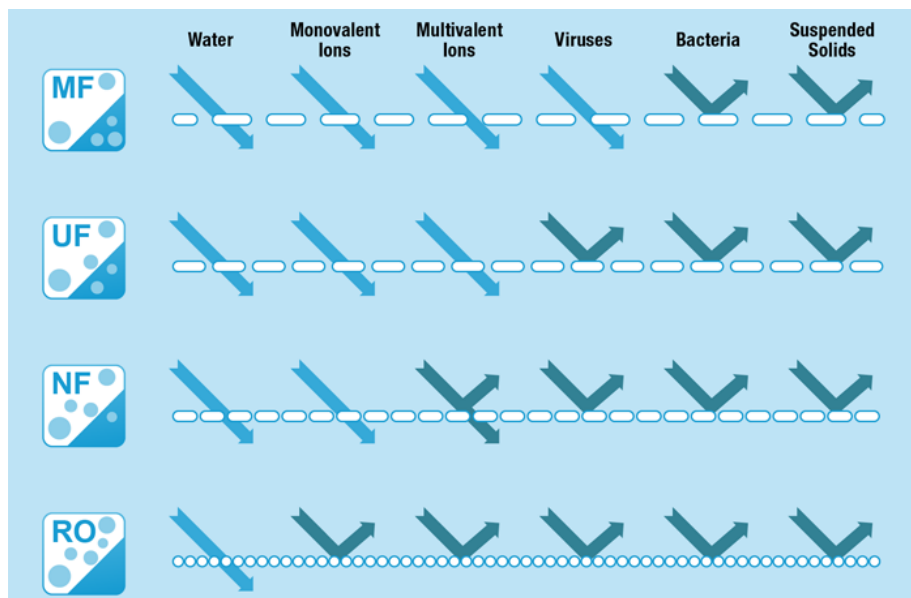


Figure 13: Membrane technology characteristics comparison [60]

1.7 Discharge Regulations and Standards

Whenever there is any risk or impact to the environment and the human beings, there must be some limitations and regulations to protect the nation from any harm. Since the collected groundwater from construction sites is going to an end user

or to a final recipient, a set of regulations are manipulated and standards to be applied. The regulations and standards of Qatar related to the environmental issues are derived mainly from three sources:

- 1- Environmental Protection Agency (EPA)
- 2- Ministry of Municipality and Environment (MME)
- 3- Public Works Authority (ASHGHAL)

When the environmental impacts related to the water resources, Qatar General Electricity and Water Corporation (Kahramaa) would talk the responsibility in addition to the previous organizations. A set of standards and regulations are tabulated in table (8), these standards are set of the discharge to the marine environment.

Table 8: *Discharge limits to the marine environment in Qatar [61]*

Description	Symbol	Max Limit	Unit
1- Physical Experiments			
Total Dissolvent	TDS	1500	mg/L
Total Suspended Solids	TSS	50	mg/L
Hydrogen Base	pH	6-9	
Floating Bodies		Nil	
Temperature	T	Not more than three degrees above the relevant average	(ΔT) °C
Turbidity	NTU	50	mg/L
Colour		Free from colour materials	

2- Inorganic Materials			
Ammonium	NH ₄ ⁺	3	mg/L
Sediment Chloride	Cl ₂	0.05	mg/L
Cyanide	CN	0.1	mg/L
Fluorides	F	1	mg/L
Phosphor in the form of Phosphate	PO ₄ ⁻³	2	mg/L
Sulphur	S ⁻²	0.1	mg/L
Required Vital Oxygen	BOD ₅	50	mg/L
Required Chemical Oxygen	COD	100	mg/L
Urea		2	mg/L
Total Nitrogen	TKN	100	mg/L

3- Heavy Metals			
Aluminium	Al	3	mg/L
Arsenic	As	0.5	mg/L
Barium	Ba	2	mg/L
Boron	B ⁻	1.5	mg/L
Cadmium	Cd	0.05	µg/L
Total Chrome	Cr	0.2	µg/L
Cobalt	Co	2	mg/L
Copper	Cu	0.5	mg/L
Iron	Fe	1	mg/L
Lead	Pb	0.1	mg/L
Manganese	Mn	0.2	mg/L
Mercury	Hg	0.001	mg/L
Nickel	Ni	0.5	mg/L
Zinc	Zn	2	mg/L
Silver	Ag	0.005	mg/L
Selenium	Se	0.02	mg/L

4- Organic Materials			
Oil and Grease	O & G	15	mg/L
Total Phenols		0.5	mg/L
Halogen Hydrocarbons and Different Kinds of Pesticides		0.1	mg/L
Dioxine / Viran		1.34×10^{-7}	Ug/L
Tri Halomethane	THM	100	Ug/L

5- Biological Experiments			
Possible No. of Colon Group in 100 M ³	MPN	100	MPN/100 ml
No. of Infantal Eggs		Nil	
No. of Infantal Worms		Nil	
No. of Fecal Colon Bacillus		100	MPN/100 ml

A set of standards and regulations are tabulated in table (9), these standards are set of the use of the treated water in irrigation.

Table 9: Water usage limits for irrigation purposes in Qatar [61]

Parameters	Unit	Ashghal Standards	MME Standards
pH		(6 - 9)	(6 - 9)
Temperature	°C	43	-
Total Dissolved Solids (TDS)	mg/l	2000	2000
Total Suspended Solids (TSS)	mg/l	400	50
Settleable Solids	mg/l	20	-
BOD	mg/l	400	50
COD	mg/l	600	150
TOC	mg/l	1000	75
Oil & Grease	mg/l	60 (Hydrocarbon) 100 [16]	10
Tar & Tar Oils	mg/l	20	-
Floating Oil & Grease	mg/l	10	-
TPH	mg/l	50	-
Gasoline Range	mg/l	10	-
Heavy Fraction Range	mg/l	40	-
Chloride (Cl-)	mg/l	400	-
Sodium	mg/l	600	-
Cyanide	mg/l	0.05	0.2
Fluoride (as F ion)	mg/l	15	15
Sulphate as SO ₄	mg/l	1000	400
Sulphide (H ₂ S)	mg/l	10 as ions	0.1
Ammonia - Nitrogen	mg/l	80 as NH ₄	15
Total Nitrogen (TKN)	mg/l	150	35
Total Phosphorus	mg/l	50	30
Surfactants (Total)	mg/l	30	-
Phenols	mg/l	0.5	0.5
Total Chlorinated Hydrocarbon	mg/l	0.5	-
Polycyclic Aromatic	mg/l	0.05	-

Hydrocarbons (PAH)			
Organochlorine Persticides	mg/l	0.01	-
Organophosphorus Pesticides	mg/l	0.01	-

Heavy Metals			
Aluminum	mg/l	30	15
Arsenic	mg/l	0.1	0.1
Barium	mg/l	1	2
Beryllium	mg/l	5	-
Boron	mg/l	0.5	1.5
Cadmium	mg/l	0.02	0.05
Chormium Total	mg/l	2 (Total)	0.2
Cobalt	mg/l	5	0.2
Copper	mg/l	4	0.5
Iron	mg/l	30	1
Lead	mg/l	1	0.1
Lithium	mg/l	2.5	-
Manganese	mg/l	5	0.05
Mercury	mg/l	0.01	0.001
Molybdenum	mg/l	0.5	-
Nickel	mg/l	2	0.5
Selenium	mg/l	0.5	-
Silver	mg/l	4	-
Tin	mg/l	10	-
Vanadium	mg/l	1	-
Zinc	mg/l	5	0.5
Other Toxic Metals Individually	mg/l	2.5	-
Total Toxic Metals	mg/l	10	-

Chapter 2 EXPERIMENTAL METHODS AND PROCEDURES

2.1 Water Samples Collection and Characterization

2.1.1 Collecting Water Samples

Dewatered construction water samples were collected from a construction site located in Doha Industrial Area away from Doha city centre of about 13 km, it represents a real case scenario of the water generated from a typical construction site that has excavation works. Figure 14 shows the exact location of the construction site.



Figure 14: Location map of the construction site where the samples were collected

The water samples were collected from three different locations within the construction site as shown in figure (14). The yellow dot represents the raw water that comes directly from the excavation, which was collected for the experiments, the green dot represents the water in the first bond used as a first stage for suspended solids settling, and the red dot represents the last stage of settling to decrease the amount of suspended solids to the minimum needed before sending the water to the treatment facility. Looking at the colour of sample 2 in figure (14) shows the amount of suspended solids as the water almost white, and moving to the second bond with sample 1 give an idea of how much change happened to the water. Although suspended solids was reduced significantly from bond 1 to bond 2, but this process is taking hours just to reach this situation in order to send it to the treatment facility.

The treatment facility includes a settling tank working as buffer zone, series of sand filters, chlorination and de-chlorination units. The sand filters is used to reduce the amount of suspended solids and turbidity of the water to the minimum needed according to the Ministry of Municipality and Environment laws, the chlorination and de-chlorination units are used to remedy the water from any living organisms such as bacteria and viruses. This water is a typical case of any dewatered construction water produced in a typical site with any drilling and excavations during the first stages of construction, which is widely spread in the country due to the huge urban development according to 2030 vision.

2.1.2 Dewatered Construction Samples Characterization

Dewatered construction water samples were analysed before treatment process in order to know what are the main characteristics of it, three samples in beginning

was collected from the bonds not directly from the construction area, but most of the parameters are representing the water situation. A total of 43 parameters were tested, tables (10) and (11) show the main characteristics of the water samples taken from the construction site.

Table 10: *Physical and organic characteristics of dewatered construction water samples*

Parameter	Unit	Sample #1	Sample #2	Sample #3
pH	-	7.59	7.63	7.74
EC	μS/cm	3,456	3,753	3,753
Dissolved Oxygen	ppm	7.56	7.78	8.15
Turbidity	NTU			
COD	ppm	17	16	12
Alkalinity	ppm as CaCO ₃	149	195	185
Bi Carbonate (HCO ₃ ⁻)	ppm	181	238	226
Sulphide (H ₂ S)	ppm as S	0.016	0.016	0.005
Total Solids (TS)	ppm	3,015	3,230	3,155
Total Suspended Solid (TSS)	ppm	91.2	70	13.2
TDS (Calculated: TS - TSS)	ppm	2,924	3,160	3,142
Sulphate (SO ₄)	ppm	1020	1060	1120
Chloride (CL)	ppm	441	500	502
Ammonia Nitrogen - N	ppm as N	1.615	1.792	1.497
Nitrate - N	ppm as N	3.1	3.1	2.9
Nitrite - N	ppm as N	0.182	0.157	0.147
Hardness	ppm	1,273	1,326	1,335
Phosphorus - P	ppm as P	1.22	1.237	0.524

Table 11: *Heavy metals amounts in the dewatered construction water samples*

Parameter	Unit	Sample #1	Sample #2	Sample #3
As	ppm	< 0.05	< 0.05	< 0.05
B	ppm	0.6718	0.7134	0.717
Ba	ppm	0.0572	< 0.05	< 0.05
Ca	ppm	378	389.8	393
Co	ppm	< 0.05	< 0.05	< 0.05
Cr	ppm	< 0.05	< 0.05	< 0.05
Cu	ppm	< 0.05	< 0.05	< 0.05
Fe	ppm	< 0.05	< 0.05	< 0.05
K	ppm	26.4	27.48	27.6
Mg	ppm	79.94	85.8	85.98
Mn	ppm	< 0.05	< 0.05	< 0.05
Mo	ppm	< 0.05	< 0.05	< 0.05
Na	ppm	279	308.4	313.2
Ni	ppm	< 0.05	< 0.05	< 0.05
Pb	ppm	< 0.05	< 0.05	< 0.05
Sb	ppm	< 0.05	< 0.05	< 0.05
Se	ppm	< 0.05	< 0.05	< 0.05
Sr	ppm	9.648	9.722	9.922
V	ppm	0.2468	0.263	0.267
Zn	ppm	< 0.05	< 0.05	< 0.05

Tables (12) and (13) show the testing methods that belong to the tested parameters of the water samples.

Table 12: *List of testing methods of physical and organic parameters used to characterize the water samples*

Parameter	Unit	Testing Method
pH	-	SMWW 4500 H+.B
EC	µS/cm	SMWW 2510 B
Dissolved Oxygen	ppm	SMWW 5520 C
Turbidity	NTU	SMWW 2130 B
COD	ppm	SMWW 5220 D
Alkalinity	ppm as CaCO ₃	SMWW 2320B
Bi Carbonate (HCO ₃ ⁻)	ppm	SMWW 2320B
Sulphide (H ₂ S)	ppm as S	SMWW 4500-S2 D.
Total Solids (TS)	ppm	SMWW 2540 B
Total Suspended Solid (TSS)	ppm	Hach Method 8006
TDS (Calculated: TS -TSS)	ppm	SMWW 2540
Sulphate (SO ₄)	ppm	SMWW 4110 B.
Chloride (CL)	ppm	SMWW 4110 B.
Ammonia Nitrogen - N	ppm as N	ASTM D1426
Nitrate - N	ppm as N	SMWW 4500 NO ₃ C.
Nitrite - N	ppm as N	SMWW 4500 NO ₂ B
Hardness	ppm	SMWW 2340 B.
Phosphorus - P	ppm as P	SMWW 4500 P C.

Table 13: *List of testing methods of heavy metals parameters used to characterize the water samples*

Parameter	Testing Method
As	As1890
B	B_2497
Ba	Ba4934
Ca	Ca3158
Co	Co2286
Cr	Cr2835
Cu	Cu2199
Fe	Fe2599
K	K_7664
Mg	Mg2790
Mn	Mn2576
Mo	Mo2020
Na	Na5895
Ni	Ni2216
Pb	Pb2203
Sb	Sb2068
Se	Se2039
Sr	Sr4077
V	V_3093
Zn	Zn2138

2.2 Steel Slag Characterization and Analysis

Steel slag is a material generated as a by-product from the steel industry that is considered as waste, where huge amounts of steel slag is being produced in Qatar. This huge amount of steel slag must be utilized in a way that is safe to the

environment, many uses was studied and experimented on this material. Steel slag particles have special physical properties; it is solid dark grey aggregates, the surface of these particles is coarse and full of pores, and it is not soluble in water. Steel slag is considered as non-metallic material, its particles consists essentially of silicates and oxides, it is specifically a formation of calcium silicates and ferric oxides, in addition to the oxides of other metals such as aluminium, manganese and magnesium.

Steel slag particles are not very clean material since the pores carries a lot of dust from the steel industry processes; it needs to be washed and dried completely before it is used in the treatment process, thus it will not interfere with the water samples quality and increase the amounts of suspended solids or turbidity. In order to have a smooth contact with the water samples with the largest surface area possible, the slag particles were grinded into two different grades as shown in figure (15), 75 nm and 425nm. Steel slag was analysed through three methods and in different conditions, these methods are FTIR, SEM and EDX, each analysis will be explained accordingly.



Figure 15: Steel slag of different particle size as it was grinded to 75 and 425 nm

2.2.1 Fourier Transform Infrared Spectroscopy Analysis

Fourier Transform Infrared Spectroscopy (FTIR) is the most preferred infrared spectroscopy technology; it is used to generate a spectrum that reflects the molecular structure and functional groups of a sample, basically organic and sometimes inorganic mater. The generation of the spectrum is happening when IR radiation pointed at a sample, it will absorb part of the radiation and transmit the other part; the transmitted radiation will be detected on a detector that gives a signal representing the sample molecular fingerprint. Since each molecule has its own spectral properties, each radiation emitted from the sample will represent a particular molecule, a graph with a range of wavelengths will be generated with many stretches and bends, each one demonstrates different functional group that is known by previously collected data. Two particle sizes of steel slag was analysed by FT-IR spectrometer Frontier/TGA 4000 – Perkin Elmer, it was tested prior to the coagulation process and after applying different pH conditions, the reason is to identify the effect of changing the pH of the water samples on the formation of different functional groups on the surface of the slag.

2.2.2 Energy Dispersive X-Ray Spectroscopy Analysis

Energy Dispersive X-Ray Spectroscopy (EDXS) is a technique to analyse the elemental characterization or the chemical composition of materials, it works in conjunction with SEM analysis as it will be discussed subsequently. EDXS analysis use a focused electrons beam to bombard the sample that needs to be analyzed, it will excite the electrons on the surface of the sample and will reflect this beam by emitting an x-ray radiation, a recipient detector will convert this energy into various signals,

each signal contains different energy amount that reflects the chemical component of the sample attached to it. A graph will be generated showing the different elements absorbed by the surface of the sample and their percentages. EDXS was applied on the steel slag samples of two different particle sizes, before and after the treatment process using a device called FEI Quanta 200, which is mainly used as Environmental Scanning Electron Microscope, which is equipped together in the same device. Figure (16) represents the analysis of the 75 nm and 425 nm steel slag particles before the treatment process using the EDXS system, where it shows the presence of different elements in the steel slag particles, such as calcium oxides, iron and silicon.

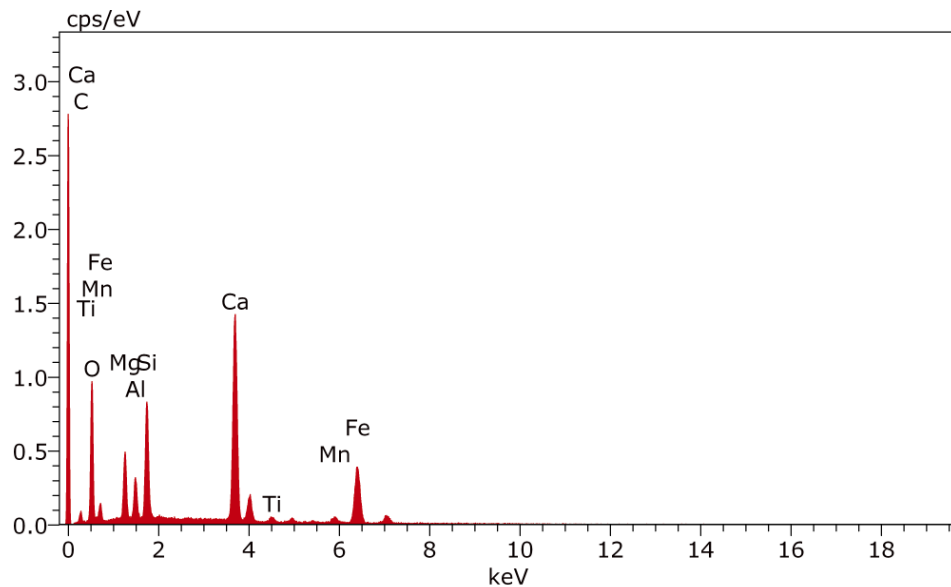


Figure 16: EDXS analysis for Steel slag of 75 nm particle size before treatment process

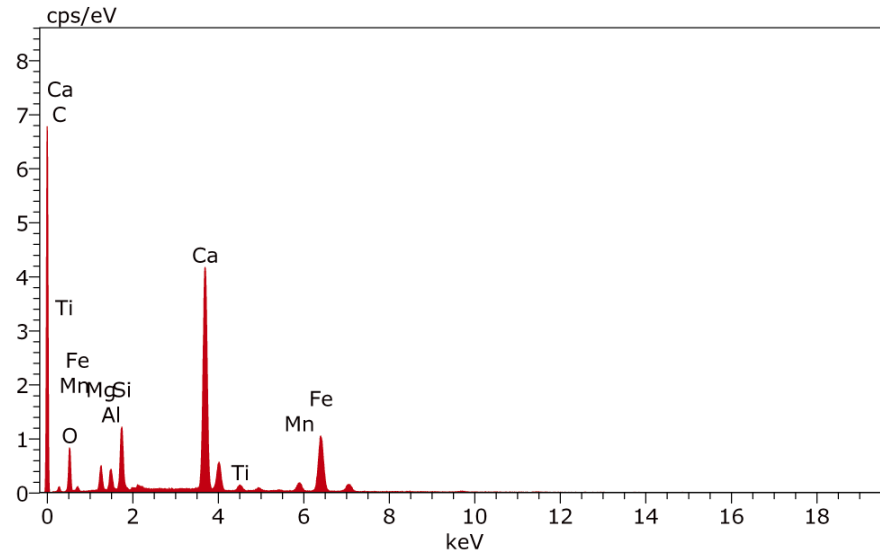


Figure 17: EDXS analysis for Steel slag of 425 nm particle size before treatment process

2.2.3 Scanning Electron Microscope Analysis

Scanning Electron Microscope (SEM) is a technique that produces detailed good resolution grayscale images with high magnifications of the surface of a solid sample; these two-dimensional images generated when a high-energy electrons beam is being shot directly to the needed sample, it will reflect signals from the surface that will be collected by a detector and displayed as an image that shows the topographical information such as crystalline orientation, texture, surface structure and size of the sample. A device called FEI Quanta 200 was used for this analysis, where the sample structure magnification can goes up to 200,000 X times, almost as small as 5 microns in width and gives a resolution of 5 nm. Usually samples are being analyzed with both SEM and EDXS in conjunction with each other, which gives better demonstration on both structural and compositional information. Similar to previous methods, SEM was

applied on steel slag samples before treatment for both particles sizes, in addition to particles after treatment process applying different pH conditions.

2.3 Experimental Setup

After collecting the dewatered construction water samples and analyse them, in addition to the characterization of the steel slag particles, and choosing the most important parameters that needs to be treated, coagulation treatment process was chosen to remove the suspended solids and turbidity from the water samples by enhancing their settling properties, and it was done by jar test apparatus, PHIPPS & BIRD STIRRER 7790-402, as shown in figure (17).



Figure 18: Jar test apparatus used for the treatment of dewatered construction water samples

The coagulation treatment process using jar test apparatus can accommodate up to 6 beakers at the same time, 600 ml of water samples was added to each beaker in the beginning, this amount is enough to guarantee that the stirrers already submerged with the water. Different amounts of steel slag of two particle sizes was used as a coagulant, they were added to the water samples for 40 minutes of rapid mixing carried out for better distribution and to enhance the contact between the slag and the water. When the system is turned off, the samples should be allowed to stay still for few minutes to settle down the suspended solids attached to the steel slag particles. Schematic diagram of the coagulation system is shown in figure (18).

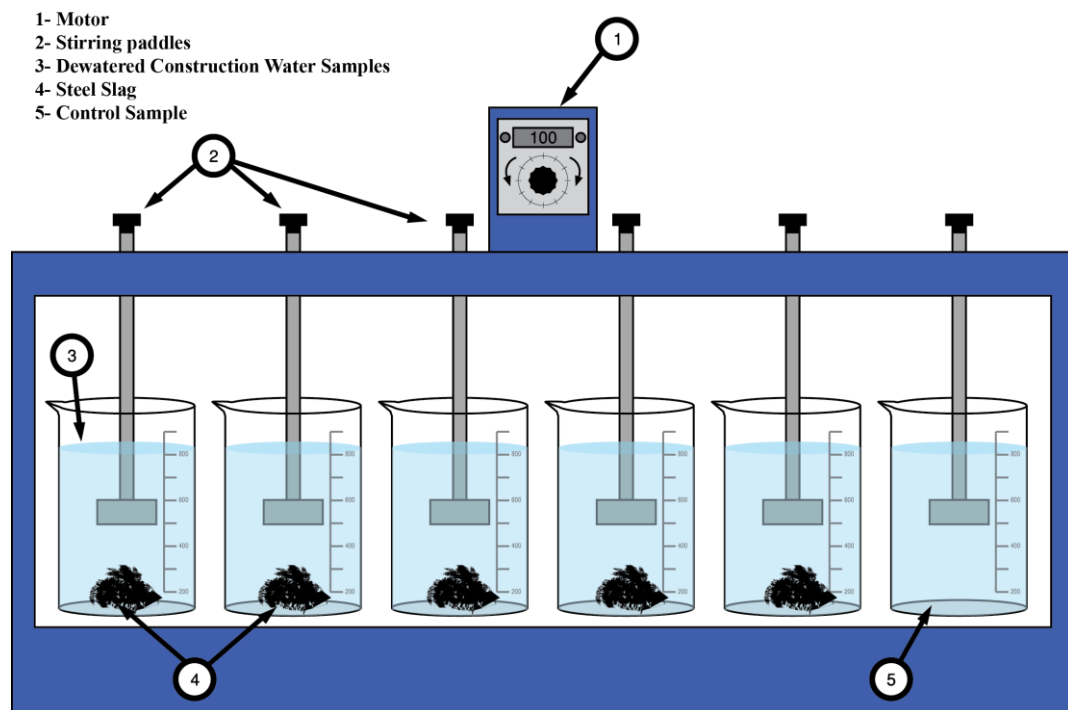


Figure 19: Schematic diagram of the coagulation system used to treat the water samples

Additionally a polymer coagulant called polyacrylamide was used as well to enrich the collected data by comparing its efficiency with the steel slag. All of the samples were experimented in moderate pH conditions at room temperature. Furthermore, different pH conditions were applied to the water solutions to inspect the effect on the work of coagulation process. Many tests were applied to the water after the treatment process to check the enhancement on the water quality that was achieved by the coagulation process, the most important parameters to be measured is suspended solids and turbidity, these tests and others will be discussed in the following section.

2.4 Experimental Analysis and Measurements

After completing 40 minutes of reaction time, the system will be stopped in order to settle down the suspended solids, a representative sample will be taken from the middle of the beaker to be analysed with different measurement methods as it is explained subsequently.

2.4.1 Conductivity and pH Measurements

Measuring pH is essential when dealing with water samples; basically it is a measurement of the alkalinity or acidity of the water. A range of pH values is between 0 and 14, where 7 is the neutral value of a sample, going below 7 is considered acid and above 7 is a base. The pH was measured in the lab using pH probe of a model HI 2211 pH/ ORP Meter for all of the steel slag and polymer coagulant samples during the experiments, before and after the coagulation. The pH probe was inserted into the water samples directly, the reading appeared on the pH device monitor immediately,

but the reading was considered after few minutes to make sure that it is already stabilized.

On the other hand, conductivity of the water samples is an indication of the ability of the water sample to transfer electrical charges; it measures the total amount of ions in the sample. Similar to pH device, a conductivity device was used, and an electrode was submerged directly into the water samples to measure the conductivity, the reading appeared on the screen of the device in few moments.

2.4.2 Turbidity Measurement

The turbidity in NTU was measured for the raw sample of dewatered construction water before coagulation, and for all steel slag and polymer coagulant samples after the coagulation, in order to compare between the initial and the final turbidity amount. The turbidity measuring device used is HACH 2100P TURBIDIMETER, it was calibrated before using it by standard samples or known turbidity values, and then cleaning the sampling tubes by distilled water to ensure that no interference of any other solutions inside or outside the tubes. A representative sample was collected from each beaker to measure the turbidity; about 15 ml was used to fill the sampling tube that will be inserted in the measuring device, the turbidity value appeared on the digital monitor in few seconds and was recorded. The turbidity removal percentage was calculated using the following equation:

Turbidity Removal %

$$= \frac{\text{Original Sample Turbidity} - \text{Treated Sample Turbidity}}{\text{Raw Sample Turbidity}} \times 100\%$$

2.4.3 Total Suspended Solids Measurement

Similar to turbidity measurements, the amount of total suspended solids was measured for the raw water sample as a control sample, in addition to all of the samples after the coagulation process, removal percentage will be calculated as well. 50 ml of each sample was collected for the measurement; each sample was poured into Buchner funnel where glass fiber filter of 1.5 μm size and known weight was placed, a suction pump sucks all the water and the suspended solids remains on the filter paper. The filter papers were dried for 2 hours using an oven at 105 $^{\circ}\text{C}$. The filter papers were removed from the oven, placed in a desiccator until cool down and their weight were recorded. The amount of total suspended solids was calculated by getting the difference between the filter paper weight before and after adding the sample, and dividing by the sample volume, using the following equation:

$$\begin{aligned} &TSS \text{ (ppm)} \\ &= \frac{\text{Final Filter Weight (g)} - \text{Initial Filter Weight (g)}}{50 \text{ mL}} \times \frac{1000 \text{ mg}}{\text{g}} \times \frac{1000 \text{ mL}}{\text{L}} \end{aligned}$$

Furthermore, the total suspended solids removal percentage was calculated using the following equation:

$$TSS \text{ Removal } \% = \frac{\text{Original Sample TSS} - \text{Treated Sample TSS}}{\text{Original Sample TSS}} \times 100\%$$

2.4.4 Total Dissolved Solids Measurement

The amount of total dissolved solids measurement procedure is similar to total suspended solids measurement procedures, where it was measured for the raw water sample as a control sample, and to all of the treated samples. A representative 50 ml

amount of each sample was collected for the measurement; each sample was poured into a pre-weighted ceramic crucible and inserted into the oven at 105 °C to be dried for 24 hours. The crucibles were removed from the oven and placed in a desiccator until cool down, and then each one was weighed and recorded. The amount of total solids was calculated using the same equation of the suspended solids as follows:

$$TS \text{ (ppm)} = \frac{\text{Final Crucible Weight (g)} - \text{Initial Crucible Weight (g)}}{50 \text{ mL}} \times \frac{1000 \text{ mg}}{\text{g}} \times \frac{1000 \text{ mL}}{\text{L}}$$

The amount of total dissolved solids was calculated by getting the difference between the total solids and the total suspended solids, using the following equation:

$$TDS \text{ (ppm)} = TS \text{ (ppm)} - TSS \text{ (ppm)}$$

2.4.5 Sludge Measurement

Sludge measurement is an important parameter that reflects the amount of suspended solids that was removed and precipitated after using the steel slag and the polymer coagulant. After analysing all the needed parameters discussed previously, each of the remaining water samples amounts was poured into an Imhoff sedimentation funnel of 1 litre size, where the amount of generated sludge was measured after all the solids being settled in the bottom of the funnel after 24 hours. This was done for the samples after the treatment using the steel slag and polymer coagulant, and in different pH conditions. The sludge measurement was considered in mL of sludge per Litre of sample volume.

Chapter 3 RESULTS AND DISCUSSIONS

In this chapter, the impact of steel slag and polymer coagulant on the treatment of dewatered construction water was studied. The main parameters that were analyzed are turbidity and total suspended solids by varying different factors: amount of steel slag, contact time, size of steel slag particles and pH .

3.1 Impact of Steel Slag Amount on the Removal of Suspended Solids

3.1.1 The Impact on the Removal of Suspended Solids and Turbidity

The impact of the mass of added steel slag on the removal of suspended solids and turbidity was studied. Different masses of steel slag were added to a 600 mL of dewatered construction water for 1 hour of contact time and a mixing speed of 200 rpm, to determine the optimum weight that gives the best treatment, the results are shown in the figures below.

Table 14: 425 nm Steel slag weights (g) with their respective turbidity (NTU) and TSS (mg/l) values

Slag Weight (g)	0	5	10	15	20	50
Turbidity (NTU)	546	25	25	27	27	48
TSS (mg/l)	542	16	14	14	14	28

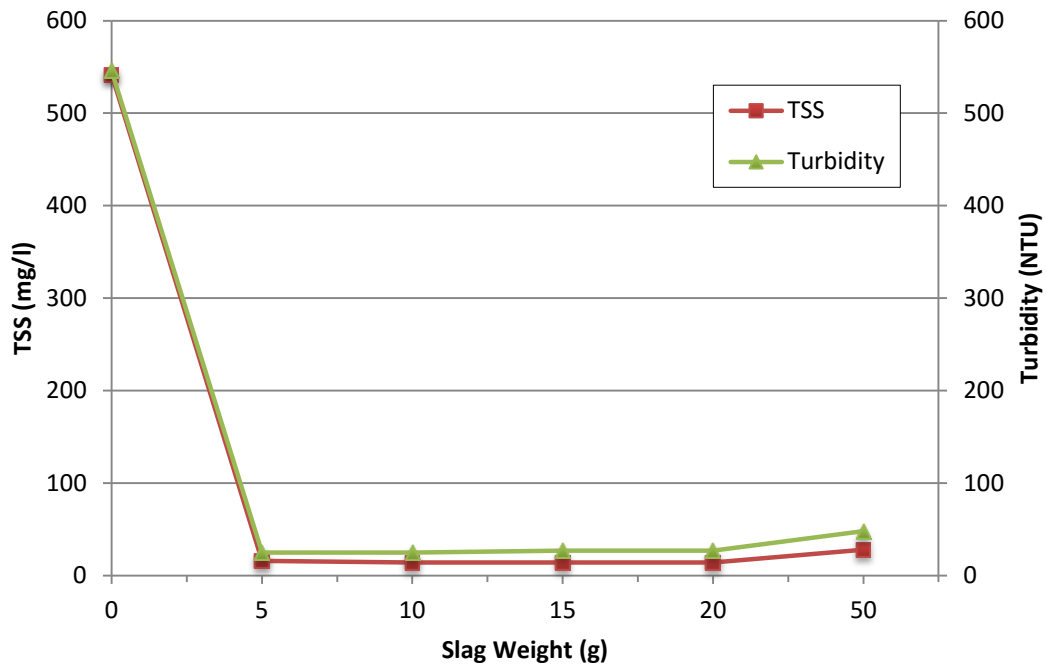


Figure 20: Different weights (g) of 425 nm steel slag turbidity (NTU) and TSS (mg/l) values

The initial suspended solids concentration was 542 mg/l. From figure (19) it can be seen that at a mass of 5 g of steel slag the suspended solids concentration went down to 16 mg/l. It was noticed that when the weight of steel slag increased beyond 5 g, the concentration of suspended solids remained almost constant. At 50 g of steel slag, it was observed that the concentration of suspended solids increased by double of the amount to be 28 mg/l, which is giving an indication that the steel slag was adding turbidity to the water, so 50 g will not be considered for further study and 5 g was selected to be used based on the best treatment performance.

Table 15: Steel slag weights (g) with their respective turbidity and TSS removal % values

Slag Weight (g)	5	10	15	20	50
Turbidity Removal %	95.42%	95.42%	95.05%	95.05%	91.21%
TSS Removal %	97.05%	97.42%	97.42%	97.42%	94.83%

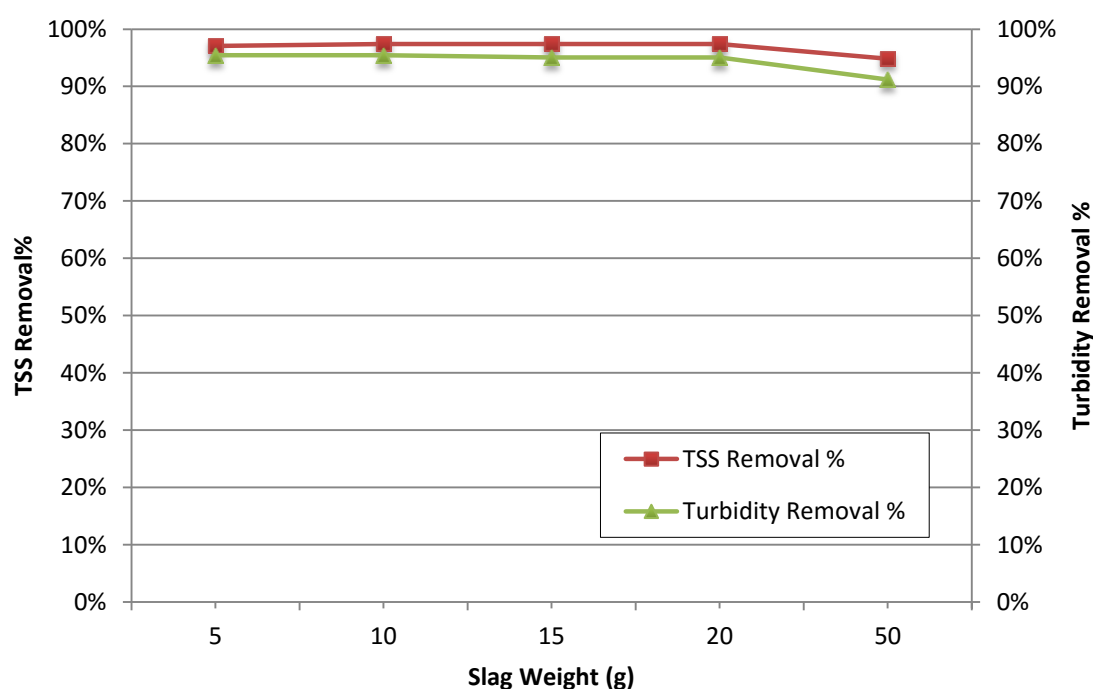


Figure 21: Different weights (g) of 425 nm steel slag turbidity and TSS removal % values

The removal % of suspended solids was calculated and plotted in figure (20). When the steel slag weight is 5 g, the suspended solids removal % was almost 97%. As the weight of steel slag increased, the removal % of suspended solids is almost constant. As the weight of steel slag approach 50 g, the removal % of suspended solids decreased to reach 93.8%, it gives an indication that the more weight of steel slag, the less treatment efficiency will happen, and for that reason the 50 g of steel slag will not be used in the coming tests.

3.1.2 The Impact of Steel Slag Weight on the Uptake Amount

The uptake amount (q) is an indication of the removal of the suspended solids, it represents the removal of suspended solids in milligrams per weight of steel slag added in (g) or volume of coagulant in (ml), the more the uptake value, the more the removal of suspended solids. It was calculated using the following equation:

$$q = \frac{(C_o - C) \times (\frac{V}{1000})}{m}$$

Where:

- q = The Uptake Amount (mg/g) or (mg/ml)
- C_o = The Sample Initial Suspended Solids Concentration (mg/l)
- C = The Current Sample Suspended Solids Concentration (mg/l)
- V = Volume of the Sample (ml) = 600 ml
- m = The Added Steel Slag Weight (g) or Coagulant Volume (ml)

The uptake amount compared to different weights of steel slag is presented in the following figure.

Table 16: *Uptake amount (mg/g) for different steel slag weights (g)*

Slag Weight (g)	5	10	15	20	50
q (mg/g)	63.12	31.68	21.12	15.84	6.168

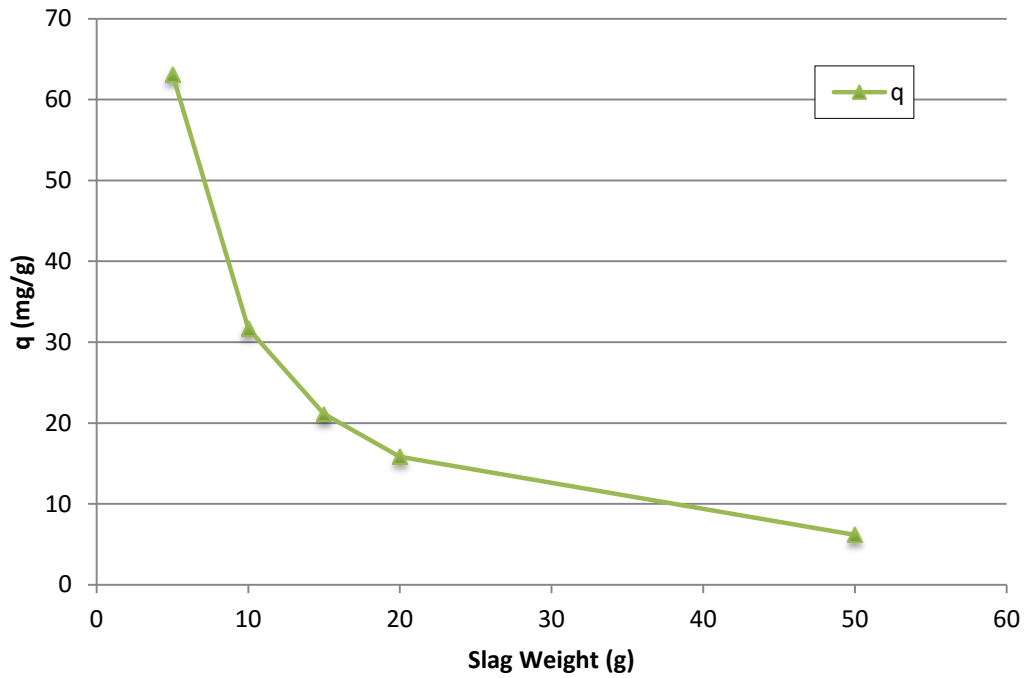


Figure 22: Uptake amount (mg/g) for different steel slag weights (g)

In figure (21), the calculated uptake amount is almost 63 mg/g when the weight of added steel slag is 5 g, where it is the maximum uptake amount compared to other weights of steel slag added. when the steel slag weight is 50 g, the uptake amount is almost 6 mg/g, which is almost 40 % of the uptake resulted using 20 g of steel slag. The weight of steel slag will be fixed at 5 g; it was observed that it is the best amount that does the optimum treatment, however, the other weights of steel slag will be tested in order to compare the data collected.

3.2 Impact of Contact Time on the Removal of Suspended Solids

After selecting the optimum amount of steel slag to be 5 g that gives the best treatment performance, the impact of time of contact between the dewatered construction water samples and different particle sizes of steel slag was studied. There

are two particle sizes were experimented, namely 425 nm and 75 nm. A range of contact times was used to find the optimum time for the treatment process using the 425 nm steel slag.

3.2.1 The Impact of Contact Time on TSS and Turbidity

Removal Using Steel Slag Size 425 nm:

Starting with a steel slag size of 425 nm, the impact of the contact time was studied on the turbidity and suspended solids. The turbidity of raw sample was 693 NTU and the suspended solids was 502 mg/l. The following figure shows the relation between the used size of steel slag and a range of contact times starting from 5 minutes and reaching a point where the removal is about to be constant.

Table 17: *Turbidity (NTU) and TSS (mg/l) over a contact time range (min) of 425 nm steel slag*

Time (min)	5	15	30	60
Turbidity (NTU)	651	268	99	72
TSS (mg/l)	202	136	64	42

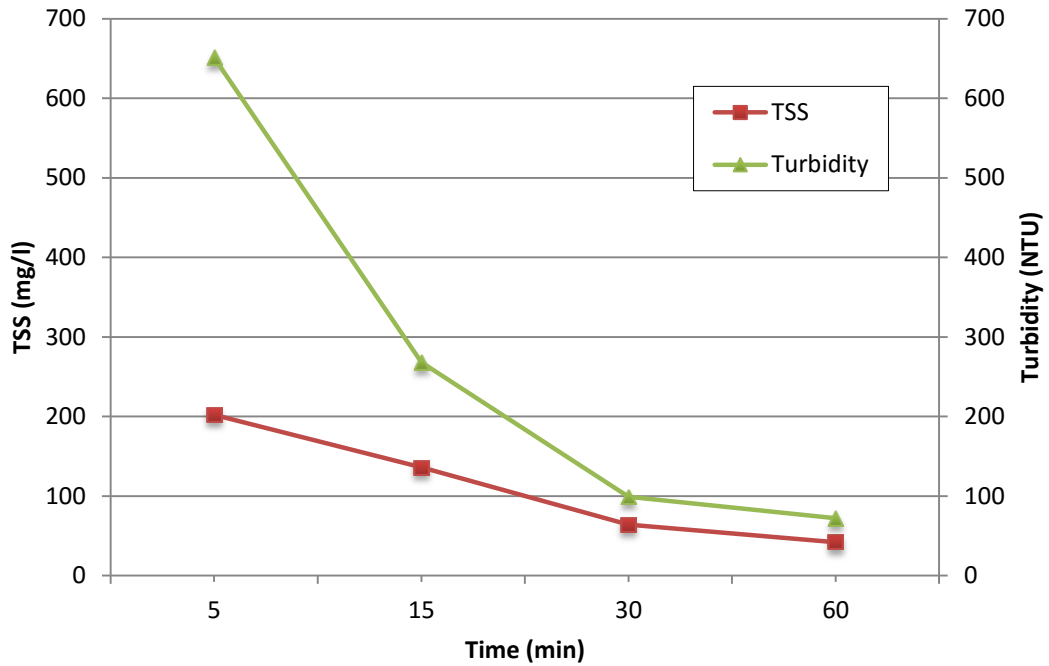


Figure 23: Turbidity (NTU) and TSS (mg/l) over a contact time range (min) of 425 nm steel slag

From figure (22) it can be observed that in the first 5 minutes of the contact with steel slag of size 425 nm the suspended solids concentration decreased dramatically to be 202 mg/l. The amount of suspended solids continue to drop down until it is almost stable between 30 minutes to 1 hour of contact time.

Table 18: Turbidity and TSS Removal % over time range (min) of 425 nm steel slag

Time (min)	5	15	30	60
Turbidity Removal %	6.06%	61.33%	85.71%	89.61%
TSS Removal %	59.76%	72.91%	87.25%	91.63%

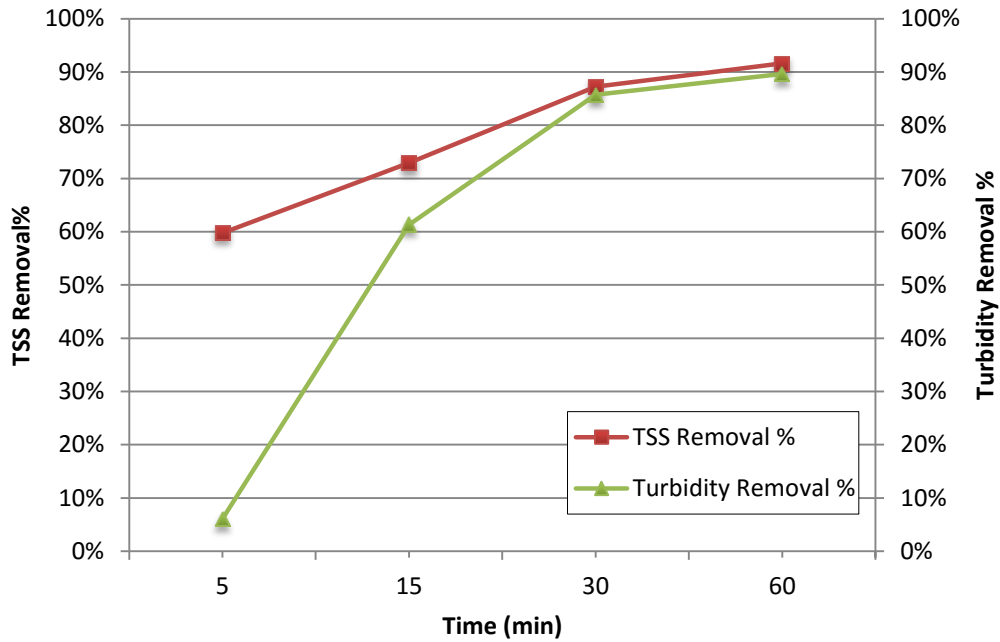


Figure 24: Turbidity and TSS removal % over time range (min) of 425 nm steel slag

Figure (23) shown the removal % of suspended solids as it was calculated and plotted. It is clear that after 5 minutes of contact with the steel slag, the suspended solids removal % was almost 60%. As the contact time increased, the removal % of suspended solids is also increasing. As the contact time approaching 1 hour, the removal % of suspended solids is almost contact to reach about 91.6%, it is giving an indication that there is a time that the slag is reaching which it will remove an efficient amount of suspended solids, this point is almost between 30 minutes to 1 hour.

3.2.2 The Impact of Contact Time on the Uptake Amount by Steel Slag Size 425 nm:

Figure (24) shows the uptake amount that was calculated for different weights of steel slag in the selected contact time range.

Table 19: The uptake amount (mg/g) of 425 nm slag different weights (g) over contact time range

Time (min)		5	15	30	60
q (mg/g) at different slag weights	5 g	5.04	51	71.28	74.52
	10 g	1.92	27.54	34.26	36.6
	15 g	4.6	20.76	23.88	24.84
	20 g	7.38	16.02	17.94	18.72

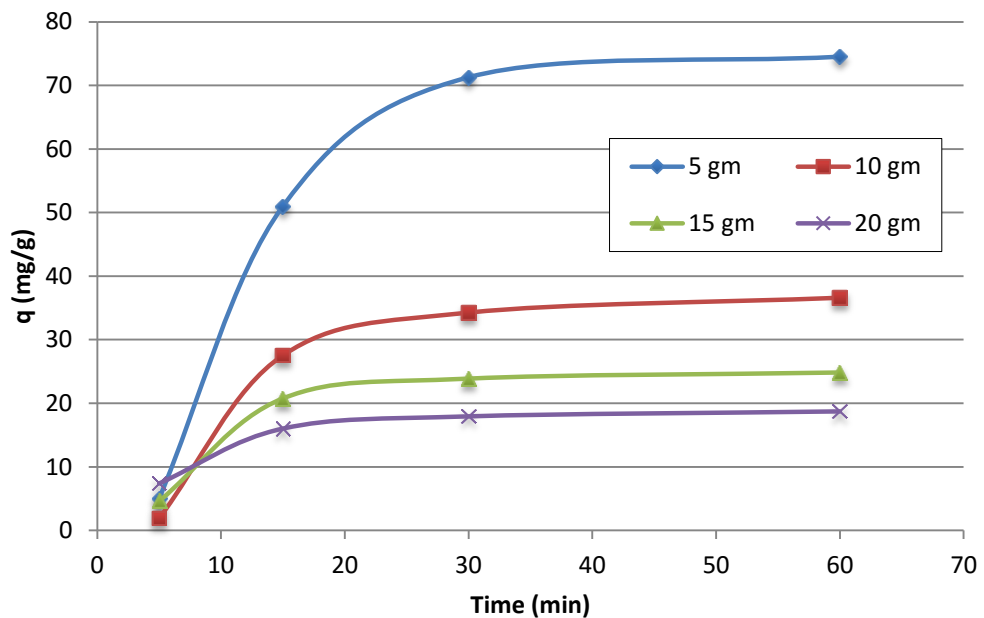


Figure 25: The uptake amount (mg/g) of 425 nm slag different weights (g) over contact time range

The uptake amount was calculated in the selected contact time range for the different amounts of steel slag. It was observed that as time passes, the more the uptake amount, and more removal of suspended solids is happening. In figure (24), the reaction reached equilibrium between 30 and 60 minutes, the maximum value of uptake amount is happening when 5 g of steel slag used with about 74.5 mg/g. When

10 gm of steel slag is used, the maximum uptake amount after 60 minutes is 36.6 mg/g. The uptake amount is reduced when 15 and 20 g of steel slag was used, after 60 minutes the values was 24.8 and 18.7 mg/g respectivley. The time was fixed to be 40 minutes; it was found that the equilibrium reached almost at this time.

3.3 Impact of Different Weights of Two Steel Slag Particle Sizes on Removal of Suspended Solids

After fixing the time to 40 minutes, two different sizes of steel slag particles were tested over the fixed contact time, knowing that 5 g was selected to give the best performance, different weights were examined to compare the results.

3.3.1 The Impact of Steel Slag Size 425 nm Weight on TSS and Turbidity Removal Over 40 Minutes:

The first steel slag particle size was 425 nm, the impact over the selected contact time on the removal of suspended solids and trubidity removal must be studied. Figure (25) presents the relation between the different weights of 425 nm steel slag over a constant time of 40 minutes, starting with a value of 693 NTU of turbidity and 502 mg/l of suspended solids in the water sample.

Table 20: *Turbidity (NTU) and TSS (mg/l) of different weights of 425 nm steel slag over 40 minutes*

Slag Weight (g)	0	5	10	15	20
Turbidity (NTU)	693	113	95	91	89
TSS (mg/l)	502	59	61	52	48

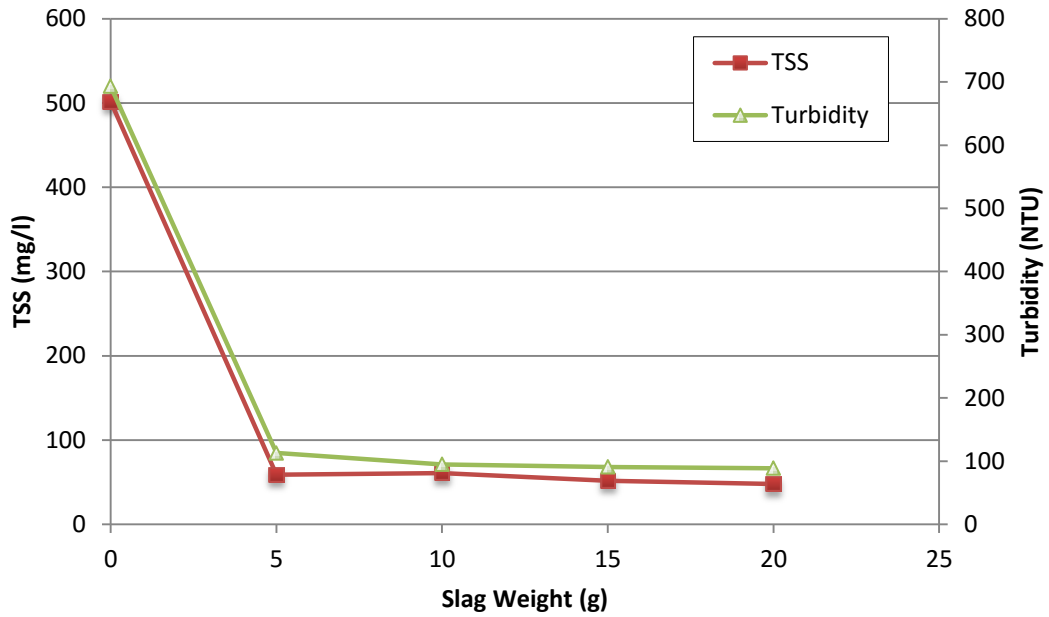


Figure 26: Turbidity (NTU) and TSS (mg/l) of different weights of 425 nm steel slag over 40 minutes

It can be observed from figure (25) that when using 5 g of 425 nm slag, the amount of suspended solids dropped down to reach 59 mg/l from its initial amount of 502 mg/l. A slight increase in the suspended solids was noticed when 10 g of 425 nm steel slag was added to reach 61 mg/l, however it dropped down again when 15 and 20 g of steel slag was added to reach 52 mg/l and 48 mg/l respectively. Moreover, 425 steel slag performance was good in removing turbidity from water samples, where it reached as low as 89 NTU from an initial value of 693 NTU when 20 g of slag was added.

3.3.2 The Impact of Steel Slag Size 425 nm Weight on the Uptake Amount Over 40 Minutes:

Figure (26) shows the relation between the uptake amount and the corresponding 425 nm steel slag weight over 40 minutes of contact, where it gives an indication about the performance of the steel slag and its efficiency in removing suspended solids.

Table 21: Uptake amount (mg/g) for 425 nm steel slag of different weights over 40 minutes

Slag Weight	5	10	15	20
q (mg/g)	69.6	35.88	24.08	18.12

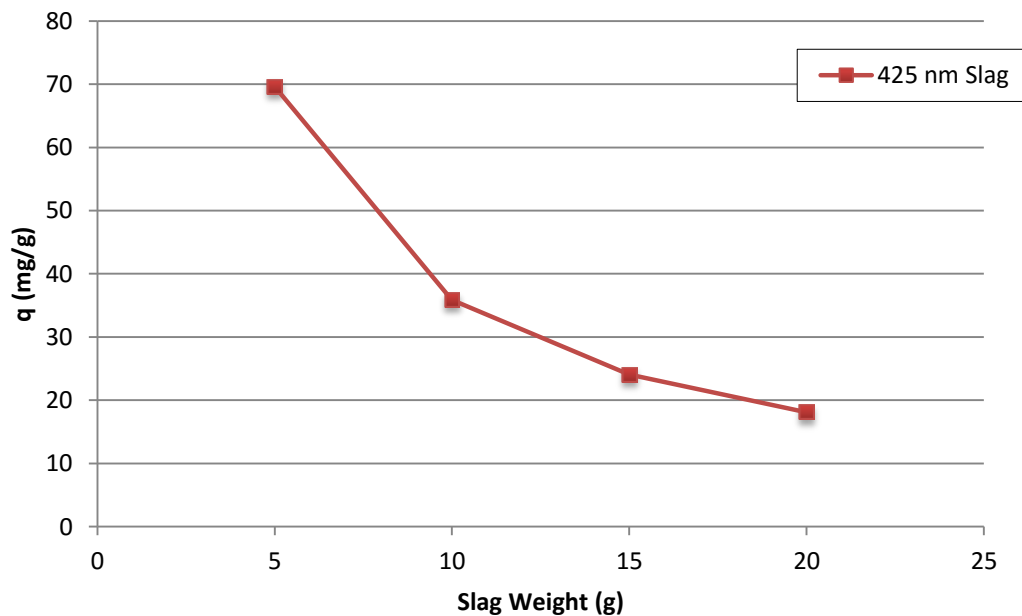


Figure 27: Uptake amount (mg/g) for 425 nm steel slag of different weights over 40 minutes

Adding 5 g of 425 nm steel slag definitely gave the best performance in the mentioned contact time, with a maximum value of uptake amount of 69.6 mg/g compared to the other steel slag weights. It was observed that when 10 g of 425 nm steel slag added to the water samples, the uptake amount reduced to reach almost 38.9 mg/g. Further reduction in uptake amount was recorded when more weight of steel slag used to treat the water, the minimum uptake amount was calculated as low as 18.12 mg/g when 20 g of slag added.

3.3.3 The Impact of Steel Slag Size 75 nm Weight on TSS and Turbidity Removal Over 40 Minutes:

The second steel slag particle size was 75 nm, the effect of this particle size on the turbidity and suspended solids tested after fixing the contact time. The initial turbidity of water sample was 637 NTU and the suspended solids was 428 mg/l. Figure (27) shows the relation between steel slag of a size 75nm with different weights and a constant time of 40 minutes.

Table 22: Turbidity (NTU) and TSS (mg/l) of different weights of 75 nm steel slag over 40 minutes

Slag Weight (g)	0	5	10	15	20
Turbidity (NTU)	637	100	91	74	72
TSS (mg/l)	428	67	58	42	42

From Figure (27), it can be noticed that when 5 g of 75 nm slag was used, the suspended solids concentration was reduced from 428 mg/l to be 67 mg/l.

Accordingly, using 10, 15 and 20 g of 75 nm steel slag gives close values of suspended solids of 58, 42 and 42 mg respectively. The same behavior was observed for the turbidity, but it was still decreasing, which is an efficient experiment.

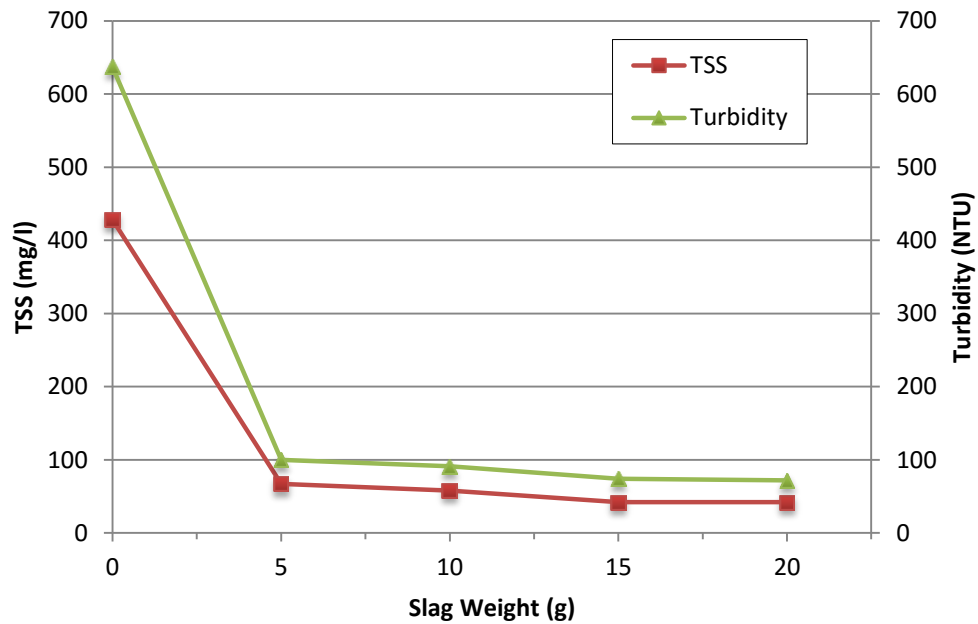


Figure 28: Turbidity (NTU) and TSS (mg/l) of different weights of 75 nm steel slag over 40 minutes

On the other hand, the amount of turbidity and suspended solids can be represented in removal % as it was plotted in figure (28). When 5 grams of 75 nm steel slag was used, the removal % of suspended solids was almost 84.4 %, and 85.7 % when 10 g was used. Using 15 and 20 grams of 75 nm steel slag removed the same amount of suspended solids of about 90 %. The performance of removing the turbidity was similar, and the value of removal % was close as shown below.

Table 23: Turbidity (NTU) and TSS (mg/l) removal % of different weights of 75 nm steel slag over 40 minutes

Slag Weight (g)	5	10	15	20
Turbidity Removal %	84.30%	85.71%	88.38%	88.70%
TSS Removal %	84.35%	86.45%	90.19%	90.19%



Figure 29: Turbidity (NTU) and TSS (mg/l) removal % of different weights of 75 nm steel slag over 40 minutes

3.3.4 The Impact of Steel Slag Size 75 nm Weight on the Uptake Amount Over 40 Minutes:

Comparison between different weights of 75 nm steel slag particles and its impact on the uptake amount is presented in figure (29).

Table 24: Uptake amount (mg/g) for 75 nm steel slag of different weights over 40 minutes

Slag Weight	5	10	15	20
q (mg/g)	64.44	32.76	22.52	16.95

The calculated uptake amount when 5 g of 75nm steel slag was added is 64.4 mg/g, it is the maximum removal of suspended solids per steel slag added compared to the other weights added. The removal is reduced while more steel slag is added. The uptake amounts of the weights 10, 15, 20 g are 32.8, 22.5 and 16.95 mg/g respectively.

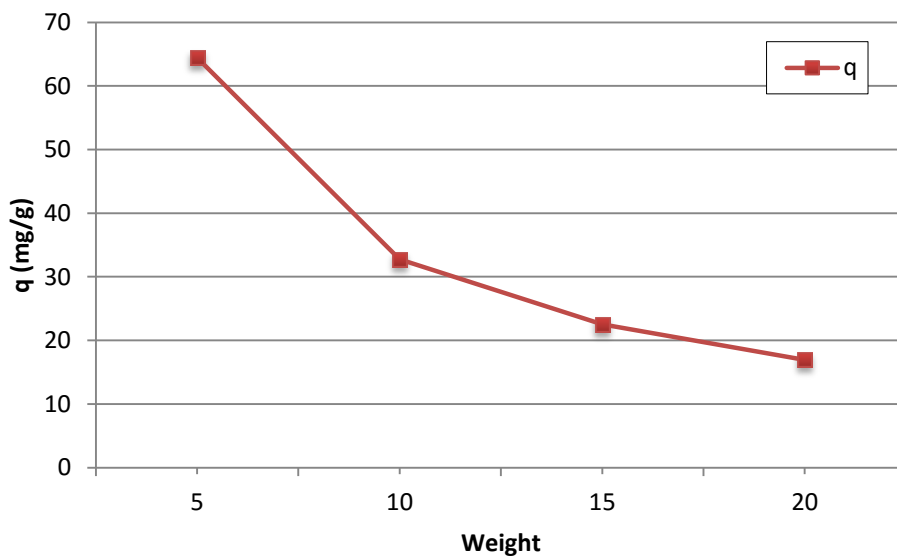


Figure 30: Uptake amount (mg/g) for 75 nm steel slag of different weights over 40 minutes

3.3.5 Comparison Between the Impact of 425 nm and 75 nm Steel Slag Size Different Weights on the Uptake Amount Over 40 Minutes:

A comparison between the two particle sizes of steel slag must be made, in order to determine the size that gave the best performance in removing suspended solids. Figure (30) show this comparison between the uptake amount of 425 nm and 75 nm steel slag reacted with the water samples over 40 minutes of contact time.

Table 25: Uptake amount (mg/g) for 425 nm and 75 nm steel slag of different weights over 40 minutes

Slag Weight	5	10	15	20
425 nm Slag	69.6	35.88	24.08	18.12
75 nm Slag	64.44	32.76	22.52	16.95

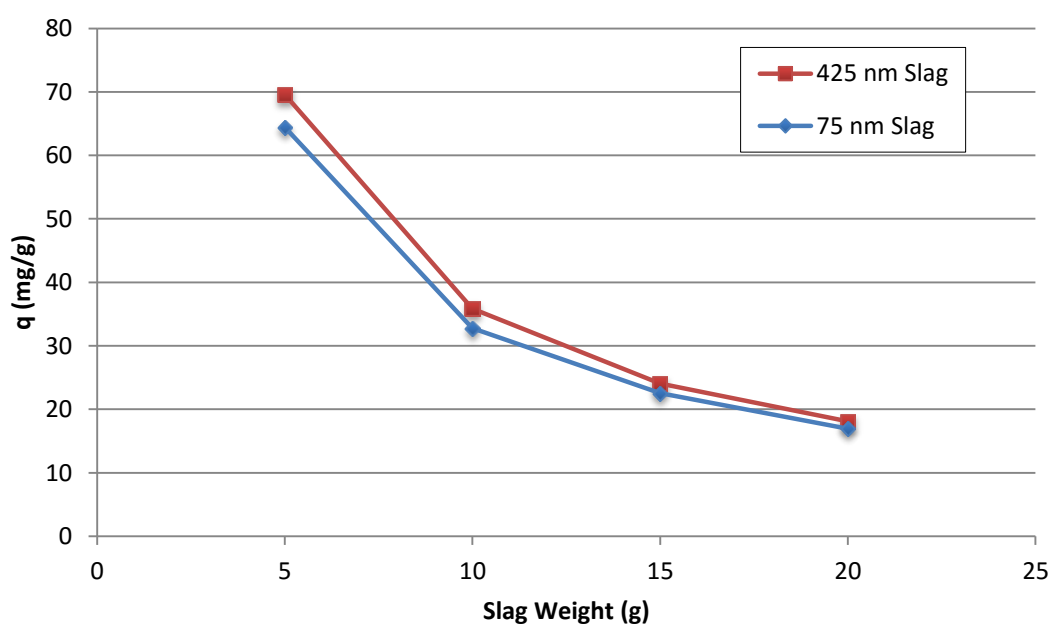


Figure 31: Uptake amount (mg/g) for 425 nm and 75 nm steel slag of different weights over 40 minutes

It was observed that both of the two particle sizes of steel slag affect the amounts of suspended solids in the water samples significantly in a specific time, and the uptake amount is representing this kind of effect. As presented in figure (30), 425 steel slag shows better performance in removing suspended solids compared to 75 nm steel slag, where the uptake amount calculated from the addition of 5 g of 425 steel slag was 69.9 mg/g compared to 64.44 mg/g when the same amount of 75 nm was used. Adding more steel slag of both particle sizes has a role in reducing the uptake amount, where the lowest performance was observed when 20 g of 425 nm and 75 nm steel slag was added, with an uptake amount of 18.12 and 16.95 mg/g respectively.

3.4 Comparison Between the Impact of Steel Slag and Polymer Coagulant on Removal of Turbidity and TSS

The impact of two different particle sizes of steel slag on the removal of suspended solids and turbidity was obvious on a constant time; therefore more experiments must be taken into consideration in order to validate the previous findings. A comparison between the impact of the two different particles of steel slag and a polymer coagulant called polyacrylamide was examined on the removal of the suspended solids and turbidity.

3.4.1 The Impact on Turbidity Removal:

The impact of steel slag and polymer on removing the turbidity of raw water sample was tested. 4 samples of 600 ml of dewatered construction water were used for each of 75 nm and 425 nm steel slag, in addition to the polymer coagulant, with a fixed contact time of 40 minutes. The findings are shown in the figures below.

Table 26: Turbidity (NTU) resulted from using steel slag (g) and polymer coagulant (ml)

Coagulant Volume (ml) and Slag Weight (g)	0	5	10	15	20
Coagulant	504	1	1	2	4
Slag (75 nm)	637	100	91	74	72
Slag (425 nm)	693	113	95	91	89

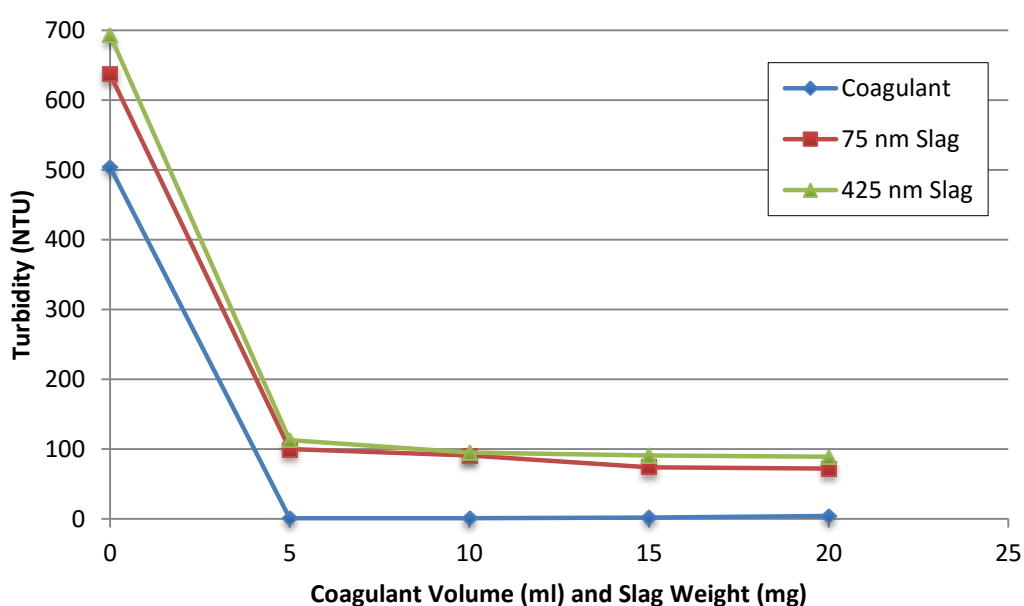


Figure 32: Turbidity (NTU) resulted from using steel slag (g) and polymer coagulant (ml)

Figure (31) represents the first 4 samples that contained polymer coagulant, the initial turbidity was 504 NTU in the raw samples, the polymer coagulant shows a great performance in removing turbidity from the water. Using only 5 ml of the prepared coagulant almost removed most of the turbidity to be 1 NTU, as of the other samples that contains 10 and 15 ml of coagulant, the turbidity values are almost close

to each other, but it shows a little rise in turbidity value when 20 ml of coagulant added, it means that adding more coagulant will increase the turbidity in the sample.

On the other hand, steel slag samples show a good performance compared to polymer coagulant samples. Starting with turbidity of 637 NTU and 693 NTU for 75 nm and 425 nm steel slag respectively, adding 5 g only was good enough to remove more than 500 NTU from the water sample. Adding more weight of steel slag as of 10 and 15 g, a good amount of turbidity was removed. A little turbidity amount was removed when adding 20 g of steel slag compared to the other weights.

Table 27: Turbidity removal % resulted from using steel slag (g) and polymer coagulant (ml)

Coagulant Volume (ml) and Slag Weight (g)	5	10	15	20
Coagulant	99.80%	99.80%	99.60%	99.21%
Slag (75 nm)	84.30%	85.71%	88.38%	88.70%
Slag (425 nm)	83.69%	86.29%	87.16%	87.73%

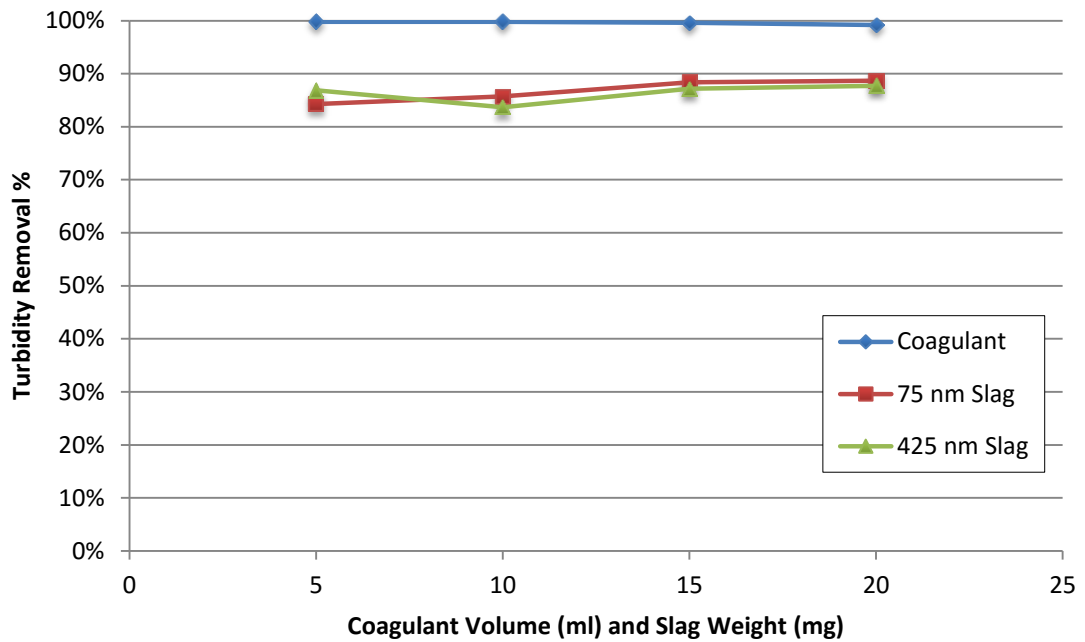


Figure 33: Turbidity removal % resulted from using steel slag (g) and polymer coagulant (ml)

Turbidity removal % was calculated and plotted in figure (32). The removal % of the samples that contained polymer coagulant is very high, it gives a range of removal from 99.21% for 20 ml of coagulant, and it is reaching up to 99.8% for 5 and 10 ml of coagulant.

Furthermore, turbidity removal % data generated from steel slag samples is less than the removal % of coagulant, but it is acceptable. The lowest removal % is 83.7% for the sample contains 5 g of 425 nm of steel slag. The maximum removal % is 88.7% for the sample that contains 20 g of 75 nm steel slag. Thus, the range of the turbidity removal % of steel slag is between 83.69% and 88.7%. It can be concluded that 75 nm steel slag is better in the removal of turbidity.

3.4.2 The Impact on Suspended Solids Removal:

Steel slag and polymer effect on removing the suspended solids of dewatered construction water sample was examined. Different weights of 75 nm and 425 nm steel slag, in addition to different volumes of polymer coagulant were added to 600 ml of the mentioned water sample, a total of 12 samples were tested in a time of 40 minutes. The results of these tests are presented in the figures below.

Table 28: TSS (mg/l) resulted from using steel slag (g) and polymer coagulant (ml)

Coagulant Volume (ml) and Slag Weight (g)	0	5	10	15	20
Coagulant	434	7	10	16	20
Slag (75 nm)	428	67	58	42	42
Slag (425 nm)	502	59	61	52	48

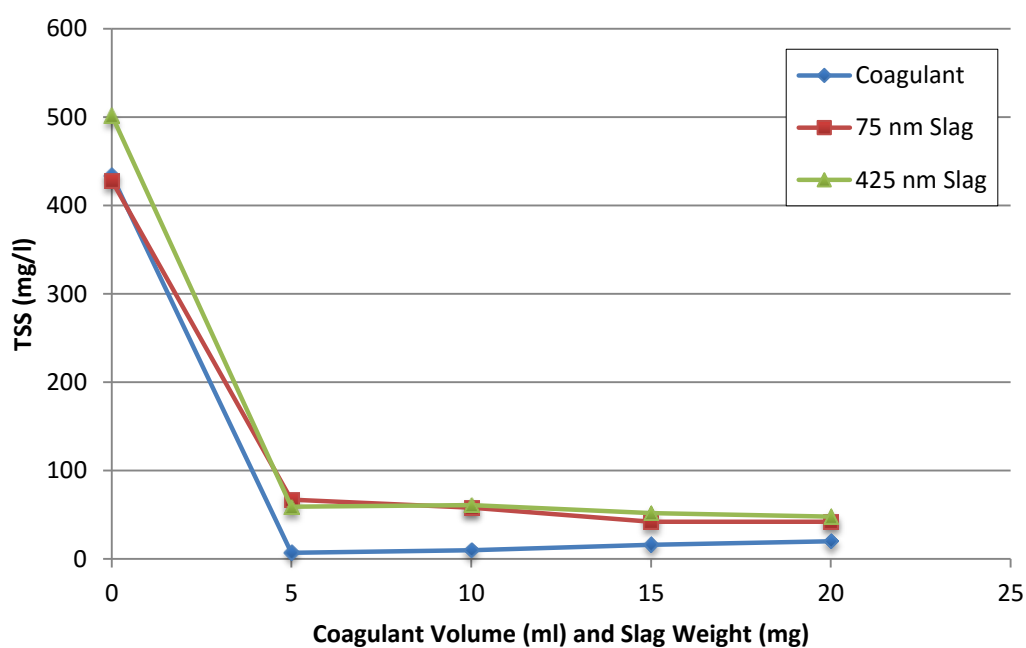


Figure 34: TSS (mg/l) resulted from using steel slag (g) and polymer coagulant (ml)

From figure (33), starting with a water sample that contains 434 mg/l of suspended solids, and after adding the 4 different volumes of the polymer coagulant, it can be observed that the suspended solids amount reached 7 mg/l when adding 5 ml of the coagulant, which is the lowest value among other samples. The suspended solids amount in the other solutions is a little higher than the first solution as it reached 20 mg/l when adding 20 ml of coagulant, it gives an indication that the more the polymer is added to the water sample, the less the removal will be, and it will add up some suspended solids to the sample.

Moreover, water samples where steel slag was added, recorded an acceptable removal rate of suspended solids when it is compared to the coagulant. The initial suspended solids amount in the first solution where 75 nm steel slag was used is 428 mg/l. When 5 grams of steel slag was added, the suspended solids amount was reduced to reach 76 mg/l. Adding more steel slag was efficient to remove more suspended solids to reach 42 mg/l when 20 g of steel slag was added. Furthermore, the last water samples with a suspended solids concentration of a 502 mg/l, and using 425 nm steel slag particles, it shows almost a similar performance as the previous 75 nm steel slag samples. Adding 5 g of steel slag was sufficient to make the suspended solids amount reach 59 mg/l. The suspended solids was reduced to reach as minimum as 48 mg/l when adding 20 g of steel slag.

Table 29: TSS removal % resulted from using steel slag (g) and polymer coagulant (ml)

Coagulant Volume (ml) and Slag Weight (g)	5	10	15	20
Coagulant	98.39%	97.70%	96.26%	95.33%
Slag (75 nm)	84.35%	86.45%	90.19%	90.19%
Slag (425 nm)	88.25%	87.85%	89.64%	90.44%

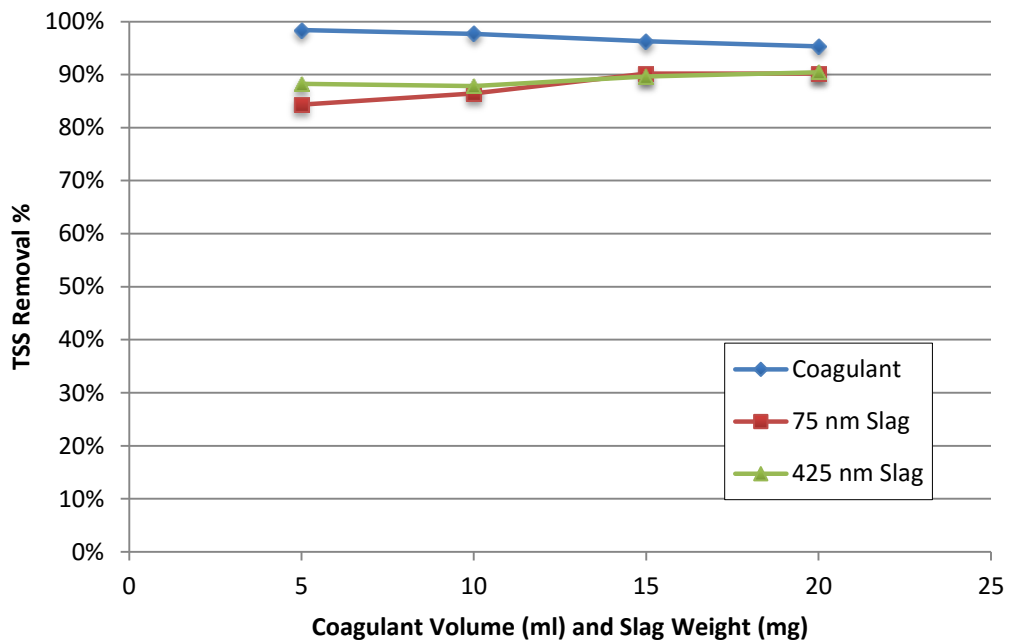


Figure 35: TSS removal % resulted from using steel slag (g) and polymer coagulant (ml)

Removal % of suspended solids calculations are presented in table (29), and plotted in Figure (34). Samples that contain polymer coagulant are having a high removal % compared to the other samples of steel slag. The maximum removal % was 98.39 % when 5 ml of polymer coagulant was used; it was decreased to down to reach 95.33 % when an amount of 20 ml of coagulant was added.

Polymer coagulant samples show a great performance in removing suspended solids. However, using steel slag to remove suspended solids is also efficient. Removal % of suspended solids from both particle sizes of steel slag samples was almost close to each other. As low as 84.35 % removal of suspended solids when 5 g of 75 nm steel slag used, it was raised up to 90.19 % when 20 g of the same particle size was added. A sample that contains 5 g of 425 nm steel slag removed almost 88.25 % of suspended solids, the removal % was raised up to 90.44 % when 20 g of steel slag was added to the water sample. Both steel slag particle size performed well on removal of suspended solids in a similar manner.

3.4.3 The Impact on Uptake Amount:

The impact of 75 nm and 425 nm steel slag and polymer coagulant on uptake amount over a 40 minutes contact time and 4 samples each is shown in figure (35).

Table 30: *The uptake amount resulted from using steel slag (g) and polymer coagulant (ml)*

Coagulant Volume (ml) and Slag Weight (g)	5	10	15	20
Coagulant	60.36	30.18	20.08	15
Slag (75 nm)	64.44	32.76	22.52	16.95
Slag (425 nm)	72.24	34.8	24.16	18.24

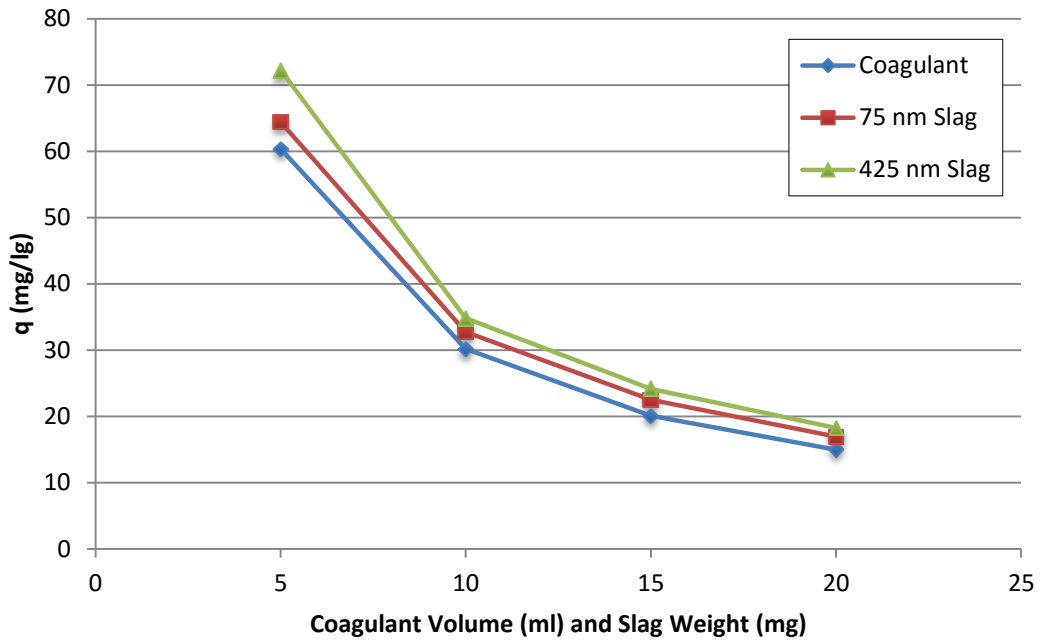


Figure 36: The uptake amount resulted from using steel slag (g) and polymer coagulant (ml)

Looking at the effect of polymer coagulant in figure (35), it can be observed that when 5 ml of the coagulant added to the water sample, the uptake amount was 60.36 mg/g. The uptake amount was reduced to reach 30.18 mg/g when using 10 ml of the coagulant, it is almost the half of the previous value. Another reduction into almost the half was observed with 15 mg/g when 20 ml of coagulant added.

The uptake amount was calculated for 75nm steel slag that was added to the water samples, when 5 g was added, the uptake amount was 64.44 mg/g, It decreased gradually to be as low as 16.95 mg/g when 20 g of steel slag added. Similarly, The performance of 425 nm steel slag gave the best removal of suspended solids compared to the other slag particle size and polymer coagulant. The maximum uptake amount reached was 72.24 mg/g when using 5 g of the steel slag; it is the highest value among others. The lowest amount of removal was observed when 20 g of the steel slag was added to be 18.24 mg/g. The most important observation that the ratio

of removing suspended solids was higher when using steel slag compared to polymer coagulant, consequently, the performance of the steel slag is better than the polymer coagulant in removing suspended solids from dewatered construction water.

3.5 Impact of Steel Slag and Polymer Coagulant on Removal of Turbidity and TSS while Varying pH:

After determining the optimum steel slag weight, fixing the contact time to be 40 minutes, testing two particle sizes of slag and comparing the performance of slag with a polymer coagulant, another factor must be added for further validation of the effectiveness of the steel slag on treating the dewatered construction water. Varying the acidity and alkalinity by changing the pH of the water sample is a major parameter, where all of the previous tests were working with a neutral pH of around 8. Changing the pH was done by adding a diluted amount of Hydrochloric Acid (HCl) to decrease the pH as low as 2, and adding a diluted amount of Sodium Hydroxide (NaOH) to increase the pH as high as 12. A comparison between the impact of steel slag and the polymer coagulant on the removal of suspended solids and turbidity from the water samples while changing the pH of the sample was done, in addition to measuring the generated sludge in the water samples.

3.5.1 The Impact of pH on Turbidity (NTU):

Experimenting the change of pH value of the dewatered construction water samples and its impact on the removal of turbidity, using steel slag 425 nm and 75 nm, in addition to the polymer coagulant as shown in figures (36), (37) and (38). A total of 36 samples were tested of 600 ml each in a contact time of 40 minutes, 12

samples were examined in low pH, 12 samples in neutral conditions and 12 samples in high pH condition.

Table 31: *Turbidity (NTU) after using slag (g) and coagulant (ml) in different pH conditions*

Coagulant Volume (ml) and Slag Weight (g)	0	5	10	15	20
pH = 2					
Slag (425 nm)	696	64	71	105	95
Slag (75 nm)	704	105	110	135	143
Coagulant	643	2	2	3	4
pH = 7					
Slag (425 nm)	693	113	95	91	89
Slag (75 nm)	637	100	91	74	72
Coagulant	504	1	1	2	4
pH = 12					
Slag (425 nm)	603	14	16	22	21
Slag (75 nm)	704	27	31	39	57
Coagulant	643	1	2	1	1

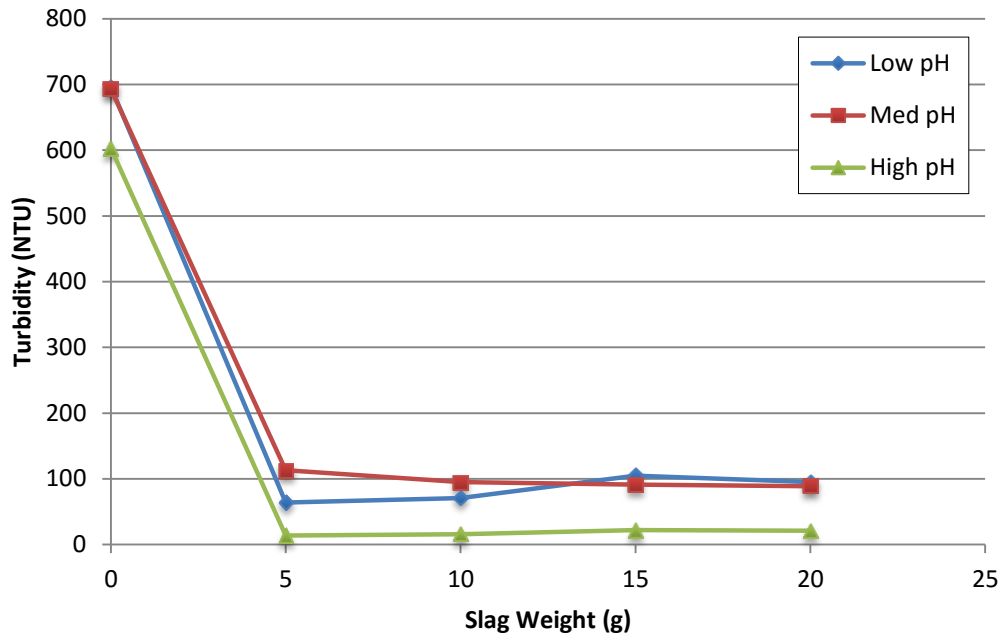


Figure 37: Turbidity (NTU) after using 425 nm steel slag (g) in different pH conditions

Figure (36) shows the relation between the Turbidity (NTU) and 425 nm steel slag weight in different pH conditions, the removal was determined and compared to each other when the water sample is in low pH condition, neutral or in high pH condition. Starting with neutral condition when the initial turbidity was 693 NTU, the performance of the 425 nm steel slag was acceptable, where more than 580 NTU of the turbidity amount was removed using 5 g of the slag, and reaching an amount of more than 600 NTU of turbidity was removed when 20 g was used.

Similarly, the slag shows a good performance when the water sample is in acid condition (pH = 2). Starting with turbidity of 696 NTU, using 5 and 10 g of slag decreases the turbidity to reach 64 and 71 NTU, where it is better than the neutral condition using the same weights of slag. However, the turbidity increased again when 15 and 20 g of slag was used, the turbidity reached 105 and 95 NTU respectively, it shows a bad performance compared to the neutral condition.

Furthermore, the basic condition (pH = 12) presents the best performance among the other samples in the neutral and acid conditions. Starting with 603 NTU of turbidity, adding 5 g of steel slag contributed in most of the turbidity amount to reach 14 NTU, which is the best performance compared to other weights. The turbidity started to rise when more weight of steel slag was added to the water samples; it reached an amount of 16, 22 and 21 NTU when 10, 15 and 20 g of slag was added. Basic condition shows good removal ability as it was observed, and it will be verified in the next experiments.

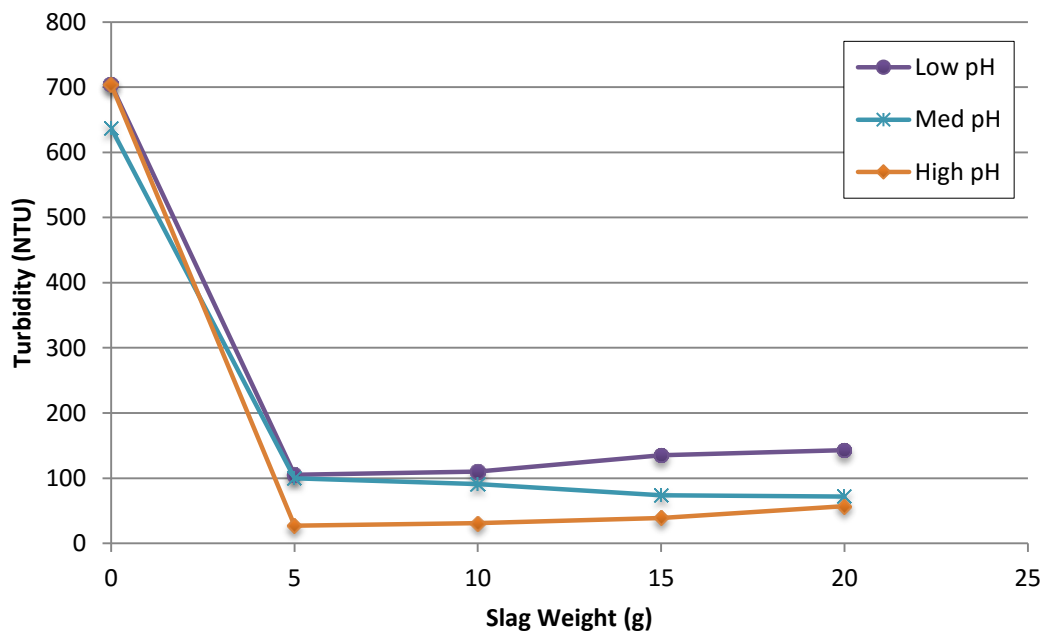


Figure 38: Turbidity (NTU) after using 75 nm steel slag (g) in different pH conditions

Turbidity (NTU) amount and its relation with 75 nm steel slag weight in while varying pH conditions is shown in figure (37). Similar low, neutral and high pH conditions were applied on the water samples to determine and compare the amount

of turbidity removed. With an initial turbidity of 637 NTU, Neutral pH condition gave an acceptable performance; the measured turbidity after 40 minutes was 100 NTU when 5 g of 75 nm steel slag. The turbidity amount was reduced slightly when 10 g of slag was used to reach 91 NTU. When 15 and 20 g of steel slag were used, the turbidity decreased gradually to reach 74 and 72 NTU respectively.

Contrariwise, and applying acidic conditions ($\text{pH} = 2$), the slag shows worse performance compared to the neutral condition. When 5 g of 75 nm steel slag was used, the initial turbidity of 704 NTU was reduced to reach 105, unusually, adding 10 g of slag increased the turbidity to reach 110 NTU. Similar behavior was observed when 15 and 20 g of steel slag were added to the water samples, the turbidity increased again to reach 135 and 143 NTU respectively. Acidic condition seems to be contributing in adding more turbidity into the water sample, which is unacceptable.

Applying alkaline condition ($\text{pH} = 12$) into the water samples shows a performance compared to the neutral and acid conditions. Water sample started with an initial turbidity of 704 NTU, and adding 5 g of steel slag to it, the turbidity amount dropped down to reach 27 NTU, which is obviously the best performance of 75 nm steel slag particles. A slight increment in turbidity values was recorded when the weight of steel slag increased in the samples, where the maximum turbidity recorded was 57 NTU when 20 g of steel slag was used. Alkaline condition proved again that it had the best performance in turbidity removal compared to neutral and acid conditions.

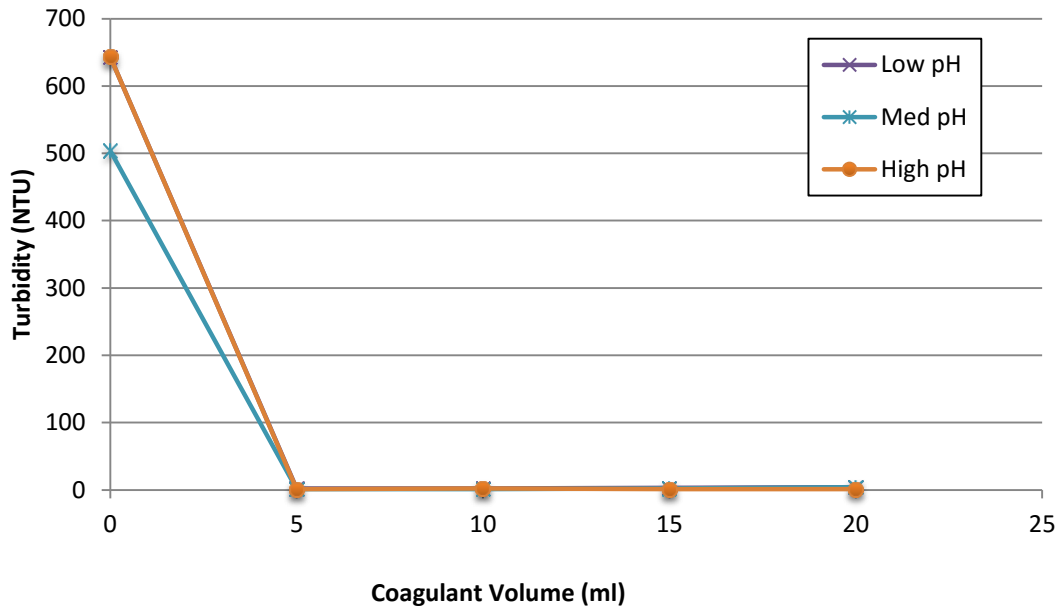


Figure 39: Turbidity (NTU) after using polymer coagulant (ml) in different pH conditions

Varying pH was also applied to the samples that used polymer coagulant, in order to check its effect on the removal of turbidity. Similar to previous experiments, acid, neutral and alkaline conditions was applied on the water samples, while adding different volumes of the coagulant over 40 minutes, figure (38) shows the measured turbidity removed and its relation with the amount of coagulant added. It can be observed that almost all of the pH conditions applied to the dewatered construction water samples gives the same behavior, where the final turbidity was between 1 and 4 NTU, which is almost giving over 99% removal. The different pH conditions seem that they didn't affect the performance of the coagulant. A little rise in the turbidity was observed when it was under acidic condition. However, it is neglected and very minimal to be considered as an effect on the removal of turbidity.

3.5.2 The Impact of pH on TSS (mg/l):

Varying pH condition was an essential element that affected the turbidity as experimented previously; therefore its effect on the removal of suspended solids from dewatered construction water samples must be tested, in presence of 425 nm and 75 nm steel slag, in addition to the polymer coagulant as shown in figures (39), (40) and (41). Different pH conditions were applied to the water samples, starting with low pH, neutral and high pH values for 36 samples, and comparing the results in order to find out the optimum condition of the maximum removal percentage of the suspended solids.

Table 32: TSS (mg/l) after using slag (g) and coagulant (ml) in different pH conditions

Coagulant Volume (ml) and Slag Weight (g)	0	5	10	15	20
pH = 2					
Slag (425 nm)	520	56	58	58	50
Slag (75 nm)	658	52	56	62	44
Coagulant	528	19	20	20	20
pH = 7					
Slag (425 nm)	502	59	61	52	48
Slag (75 nm)	428	67	58	42	42
Coagulant	434	7	10	16	20
pH = 12					
Slag (425 nm)	520	19	20	26	32
Slag (75 nm)	658	23	24	24	26
Coagulant	528	23	28	12	6

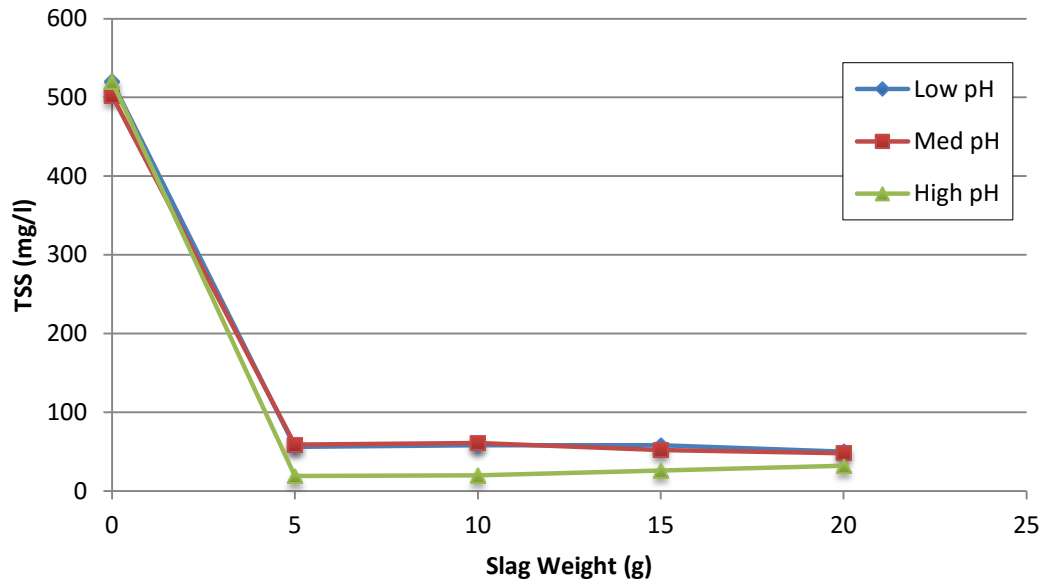


Figure 40: TSS (mg/l) after using 425 nm steel slag (g) in different pH conditions

The relation between the total suspended solids (mg/l) amount in a water sample and steel slag weight of 425 nm particle size while varying pH is shown in figure (39). Suspended solids removal from the water samples were measured in low, moderate and high pH value. Looking at the performance of the steel slag when the suspended solids was 520 mg/l and the pH was low, as a result to that, the amount of suspended solids dropped to reach 56 mg/l when 5 g of steel slag was used, 58 mg/l when 10 and 15 g of steel slag was added, and it slightly decreased to be 50 mg/l when 20 g of slag was added. The removal of suspended solids in each water sample was close in all of the samples when the acidic condition was applied.

After testing low pH condition, moderate pH values were applied to the water samples in order to study its effect on the removal of suspended solids. With a 502- mg/ l as an initial suspended solids, the suspended solids decreased to reach 59 mg/l when 5 g of slag was added. A slight rise in suspended solids was recorded when 10 g

of steel slag was used, however it decreased down again when 15 and 20 g of steel slag was used to reach finally to 48 mg/l. Both of the moderate and low pH water samples have almost the same values and similar behavior in removing suspended solids.

Moreover, starting with a water sample of an amount of 520 mg/l of suspended solids, and when basic condition applied ($\text{pH} = 12$), the performance of 425 nm steel slag compared to the other samples in neutral and acid conditions is considered the best. Adding 5 g of steel slag was able to remove most of the turbidity to be 19 mg/l, it is the maximum removal of suspended solids compared to other weights. Suspended solids in the water sample increased slightly when 10 g of steel slag was added; it reached 20 mg/l. suspended solids amount increased again to reach 26 and 32 mg/l when 15 and 20 g of slag was added. It is proved that when applying basic conditions to the water samples, the performance of steel slag in removing suspended solids and turbidity is increased significantly, more verification will be shown in the coming observations.

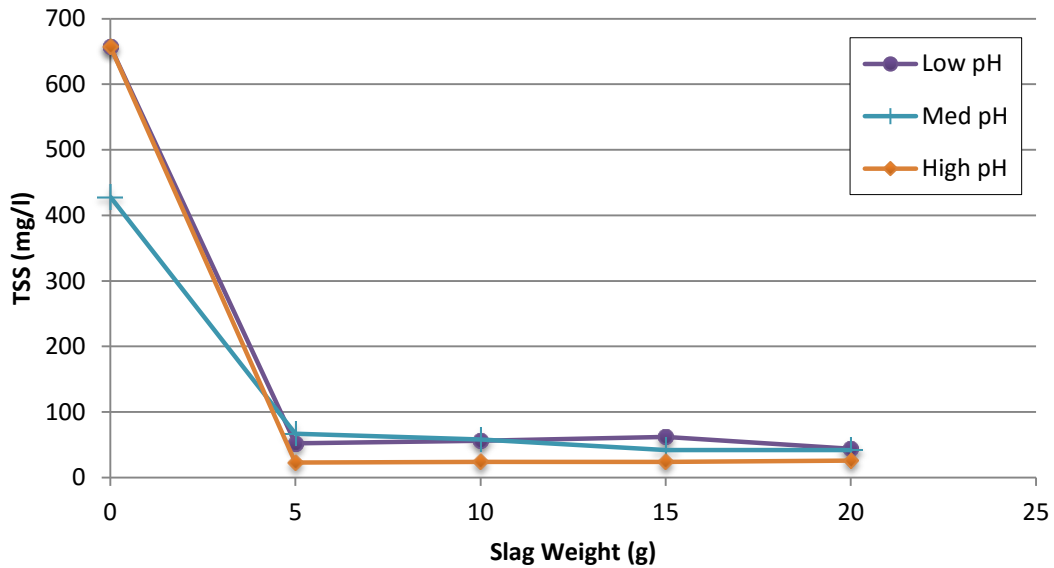


Figure 41: TSS (mg/l) after using 75 nm steel slag (g) in different pH conditions

Figure (40) represents the relation between suspended solids amount (mg/l) and 75 nm steel slag amount used while applying different pH conditions from low to high. The main objective is to determine and compare the effect of pH on the amount of suspended removed using the steel slag. When low pH conditions applied to the water samples, the suspended solids dropped down from 658 mg/l to reach 52 mg/l with more than 90% removal when 5 g of steel slag used, which is an acceptable performance. When 10 and 15 g of 75 nm steel slag was added to the water samples, the suspended solids amount increased slightly to reach 56 and 62 mg/l respectively. Reduction in suspended solids amount was observed when 20 g of slag was used to reach 44 mg/l.

Experimenting the water samples in neutral conditions, the slag shows almost similar performance compared to the low pH condition. The initial suspended solids in the water samples was 428 mg/l, after adding 5 g of 75 nm steel slag, the suspended solids was reduced to reach 67 mg/l. Adding more weight of 75 nm steel slag enhance

the removal performance and help to decrease the suspended solids concentration. Adding 10 g of steel slag reduced the concentration of suspended solids to 58 mg/l, and adding 15 and 20 g of steel slag to the water samples enhance the removal more to reach 42 mg/l each.

Finally, when high pH conditions (pH = 12) applied to the water samples, the performance is still high compared to the other conditions, which is a confirmation to the previous experiments in the same conditions. The initial concentration of suspended solids of the water samples was of 658 mg/l, it was reduced to be 23 when 5 g of steel slag was added in the first sample. A little rise of the final suspended solids concentration was observed when 10 and 15 g of 75 nm steel slag was added to the samples with a value of 24 mg/l each, and reached 26 mg/l when 20 g of slag was added. Basic conditions show an outstanding performance in removal of suspended solids and turbidity, it is definitely more effective than acidic and neutral conditions.

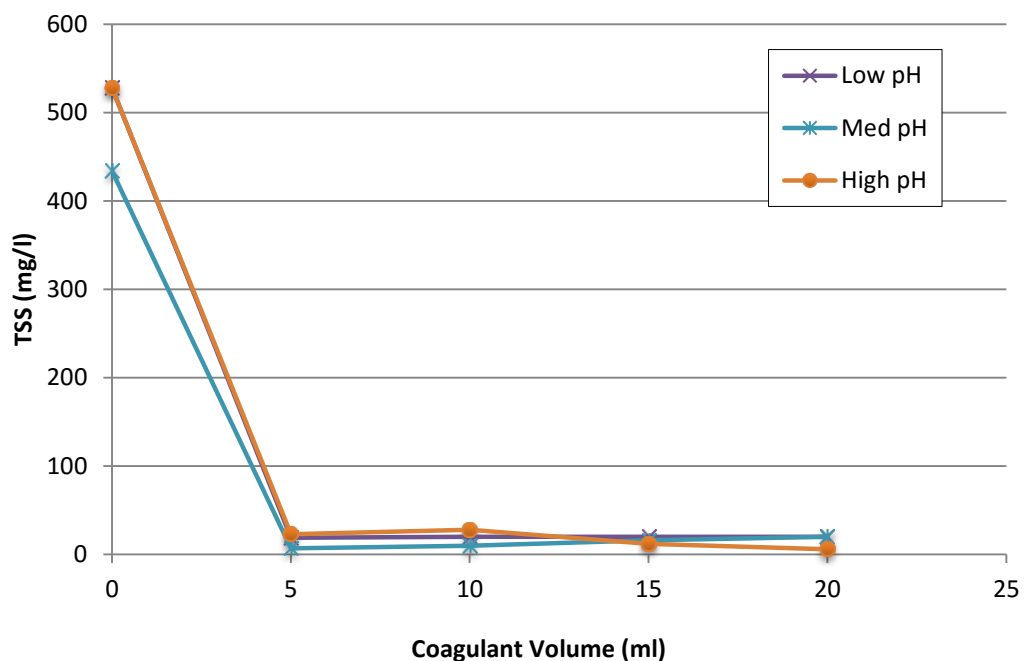


Figure 42: TSS (mg/l) after using polymer coagulant (ml) in different pH conditions

The relation between the suspended solids concentration (mg/l) in a dewatered construction water samples and the amount of coagulant added is shown in figure (41). The same pH conditions as in the previous experiments were applied to find out its effect on the removal of suspended solids. Starting with low pH (pH = 2) condition and an initial suspended solids concentration of 528 mg/l, and after adding different volumes the polymer coagulant, almost all of the final concentration dropped down to the same range between 19 and 20 mg/l.

Looking at the neutral pH samples, which started with an initial suspended solids concentration of 434 mg/l, adding 5 ml of coagulant did a good performance by removing most of the suspended solids to reach 7 mg/l. The removed suspended solids increased slightly in each of the other samples compared to the previous one, with 10, 15 and 20 ml of polymer coagulant produced samples of final concentrations of 10, 16 and 20 mg/l. It seems that the polymer coagulant contributing in the concentration of the suspended solids, although it is a very minimal amount.

Finally, applying high pH into the last water samples present a good performance. Starting with a suspended solids concentration of 528 mg/l, it decreased to be 23 mg/l when 5 ml of coagulant was added, it increased to reach 28 mg/l when 10 ml of coagulant used. Adding 15 g of coagulant had an adverse effect on the removal of the suspended solids, where the concentration dropped down to reach 12 mg/l, more reduction was observed to be 6 mg/l when 20 ml of coagulant was added, this was the best performance of coagulant while varying pH conditions.

3.5.3 The Impact of pH on Uptake Amount (mg/g):

The uptake amount is the ratio between the initial suspended solids concentration and the current concentration, and since the change of pH conditions for the dewatered construction water samples affect the concentration of suspended solids significantly, the same effects must be applied and the uptake amount must be calculated for the mentioned conditions, and figures (42), (43) and (44) show these relations. Having two different particle sizes of steel slag and polymer coagulant to be added to the water samples, low, moderate and high pH values were tested in order to calculate the uptake amount within the same contact time of 40 minutes. 36 samples was tested and compared with each other as in the figures below to find the best material that removed more suspended solids.

Table 33: Uptake amount (mg/g) after using slag (g) and coagulant (ml) in different pH conditions

Coagulant Volume (ml) and Slag Weight (g)	5	10	15	20
pH = 2				
Slag (425 nm)	75.84	37.5	23.64	18.03
Slag (75 nm)	71.88	35.64	22.76	16.83
Coagulant	76.92	38.46	25.6	19.17
pH = 7				
Slag (425 nm)	69.6	35.88	24.08	18.12
Slag (75 nm)	64.44	32.76	22.52	16.95
Coagulant	60.36	30.18	20.08	15
pH = 12				
Slag (425 nm)	70.68	35.22	23.24	17.46
Slag (75 nm)	81.24	40.38	26.6	19.41
Coagulant	77.04	38.46	25.68	19.26

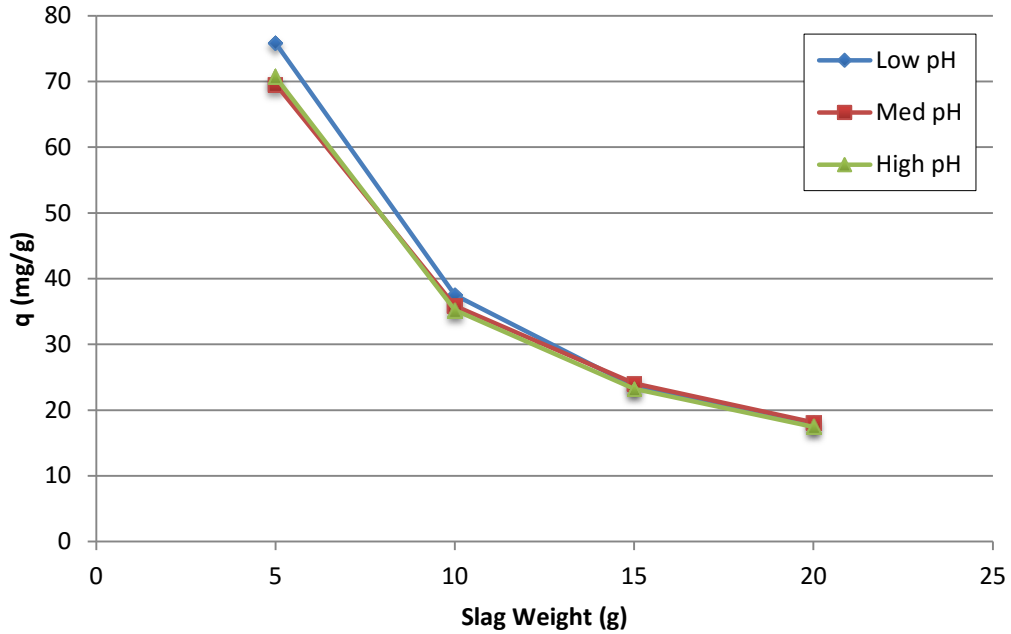


Figure 43: Uptake amount (mg/g) after using 425 nm steel slag (g) in different pH conditions

The relation between the uptake amount and the 425 nm steel slag is shown in figure (42). The comparison made between the amounts of suspended solids removed compared to the amount of steel slag added in different dewatered construction water samples, while varying the pH from low to high, between 2 and 12. Starting with the low pH conditions, it is clear that applying acidic solution into the water samples improved the removal of suspended solids. The uptake amount recorded when 5 g of steel slag added to the water samples was 75.84 mg/g, which is the maximum removal compared to other weights and pH conditions. More weight of steel slag decreased the uptake amount to reach 18.03 mg/g when 20 g of steel slag added.

On the other hand, moderate and high pH conditions show almost a similar behavior, where the uptake amount values are nearly close to each other. Adding 5 g of steel slag gave an uptake amount of 69.6 and 70.68 when neutral and high pH conditions was applied respectively. The uptake amount was calculated and found to

be the lowest when 20 g of steel slag added to the samples, the values was 18.12 mg/g when it is under neutral pH and 17.46 mg/g when it is under high pH. Consequently, it can be concluded that best performance of 425 nm steel slag is happening when it is under acidic conditions.

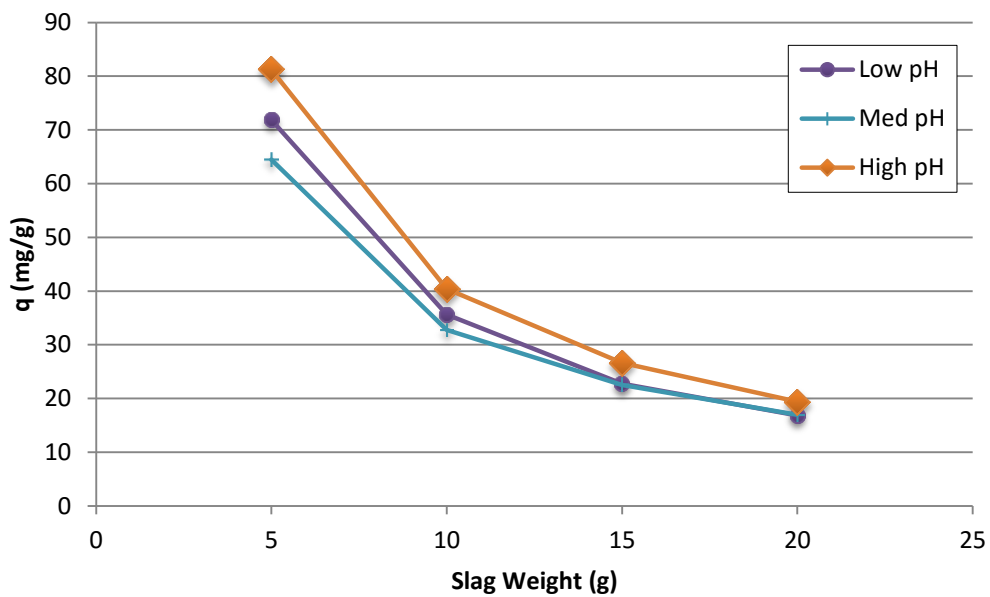


Figure 44: Uptake amount (mg/g) after using 75 nm steel slag (g) in different pH conditions

Figure (43) shows the relation between the uptake amount and the 75 nm steel slag amount added to the water samples, it represents the removal of suspended solids when specific amount of slag added when there is a change in the pH. In the beginning, looking at the data plotted in the figure, it is obvious that the minimum removal using 75 nm steel slag was recorded when the samples are in neutral conditions. The uptake amount was calculated to be 64.44 mg/g when 5 g of steel slag

used, and it dropped down to its minimum to reach 16.83 mg/g when adding 20 g of slag, which is the lowest value among other samples.

The uptake amount increased when using acidic solution to decrease the pH compared to the neutral conditions, the maximum-recorded value was 71.88 mg/g when 5 g of slag was added, and reached as a minimum as 16.95 mg/g when using 20 g of slag. Furthermore, the highest uptake amount was measured when the pH increased to reach around 12, and exactly when 5 g of steel slag added, the uptake amount was 81.24 mg/g. the minimum value calculated in the same pH conditions was when 20 g of slag was used, where it reached 19.41 mg/g. Therefore, the calculated uptake amount based on the measured data shows that the highest performance for 75 nm steel slag occurred when alkaline conditions applied to water samples.

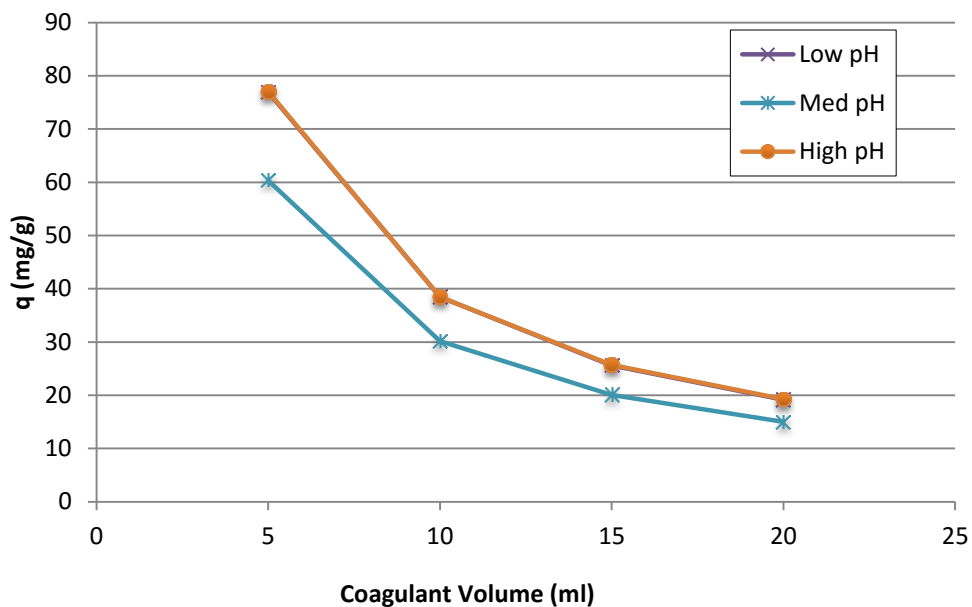


Figure 45: Uptake amount (mg/g) after using polymer coagulant (ml) in different pH conditions

After using steel slag of two different particle sizes, another material must be added to compare all of the calculated data, in order to figure out which material is the best in removing suspended solids. The effect of Polymer coagulant on the uptake amount was tested while varying the pH value of the water samples. Figure (44) presents the mentioned relation, where the minimum removal of suspended solids to the amount of coagulant added was recorded when the water samples were in neutral conditions. The maximum calculated uptake amount was 60.36 mg/ml when 5 ml of coagulant was added and dropped down to 19.17 mg/ml when 20 ml was used.

Furthermore, better removal was observed based on the experiments and the calculated data when the samples and low and high pH conditions. Both of the mentioned conditions almost represent the same performance to each other where the calculated data is very close to each other. When 5 ml of polymer coagulant added to the water samples, the uptake amount when the pH was low was 76.92 mg/ml, while it is 77.04 mg/ml when it is under high pH. The minimum uptake amount was calculated to be around 19 mg/ml when 20 ml of coagulant added to the water samples for both low and high conditions applied.

Looking at all the calculated data based on the measurement and observations, and the impact of changing pH of the samples on the removal of suspended solids over the amount of the steel slag or polymer coagulant added, it is clear that the best performance was recorded when 75 nm steel slag was used when applying high pH conditions, where the calculated uptake amount was 81.24 mg/g. The lowest uptake amount recorded was when 20 ml of polymer coagulant added to the water sample of moderate pH, the calculated value was 15 mg/ml. The performance of the 75 nm steel slag was definitely better than 425 nm steel slag and the polymer coagulant.

3.5.4 The Impact of pH on Sludge Generation (ml):

After investigating the impact of changing pH on the removal of turbidity and suspended solids, as a result its impact on the calculated uptake amount, another important factor that determine the effectiveness of the removal must be taken into consideration. The waste that is produced in the treatment process is an important factor that decides if the way of treatment is acceptable and reliable in the industry or not, the coagulation process is generating waste called sludge, its amount must be studied in order to find the proper and efficient way of treatment with the least possible sludge. The following figures represent the amounts of sludge generated with respect to the amounts of steel slag and polymer coagulant added, and considering the effect of changing the pH of the water samples. The generated sludge was measured by Imhoff funnel in ml of sludge per liter of water sample.

Table 34: *Sludge generated (ml) after using slag (g) and coagulant (ml) in different pH conditions*

Coagulant Volume (ml) and Slag Weight (g)	5	10	15	20
pH = 2				
Slag (425 nm)	17	20	26	29
Slag (75 nm)	15	19	23	28
Coagulant	17	19	22	25
pH = 7				
Slag (425 nm)	25	29	32	38
Slag (75 nm)	17	19	22	25
Coagulant	30	33	37	41
pH = 12				
Slag (425 nm)	81	84	86	89
Slag (75 nm)	93	96	97	99
Coagulant	36	44	49	58

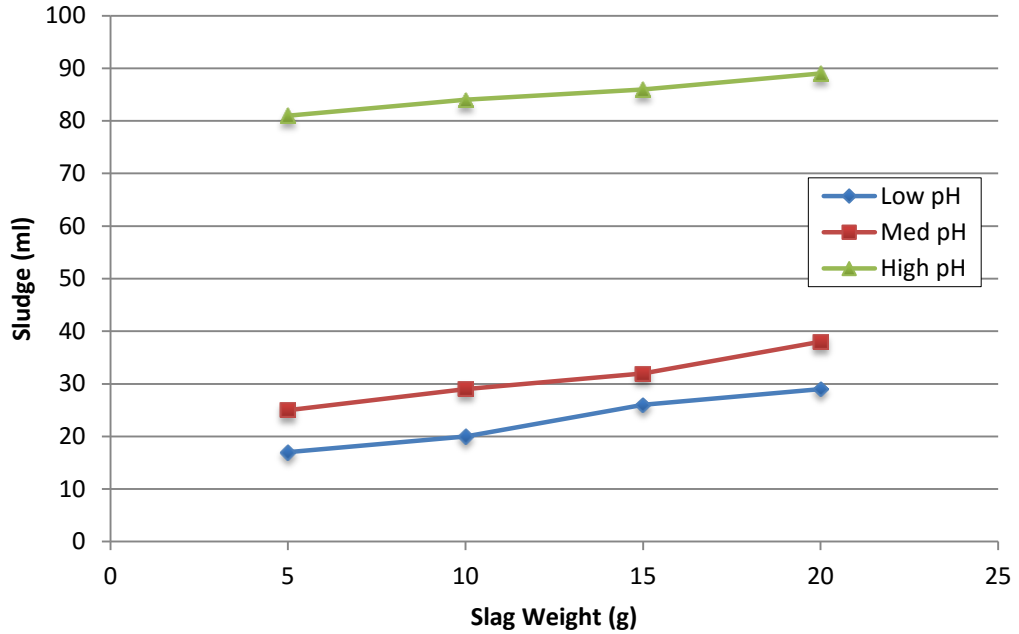


Figure 46: Sludge generated (ml) after using 425 nm steel slag (g) in different pH conditions

The amount of the generated sludge from dewatered construction water sample after the adding by 425 steel slag while varying pH is shown in figure (45). Looking the figure, it is obvious that the maximum generated sludge was produced by the steel slag when the pH is high. Starting with an amount of 81 ml of sludge that was generated when 5 g of steel slag was added, it was increased gradually to reach to the maximum value of 89 ml when 20 g of steel slag was added. The high amount of sludge generated means that the removal is acceptable, but more the sludge generated might not be effective industrial wise.

Neutral and acidic conditions of the water samples present a very close behavior in terms of the amount of generated sludge. The lowest amount of the generated sludge was recorded when 5 g of steel slag added in the acidic conditions with 17 ml, and it increased to reach 29 ml when 20 g of steel slag was used. On the

other hand, the lowest generated sludge when it is under neutral conditions measured to be 25 ml, and more sludge generated when 20 g of slag added to reach 38 ml.

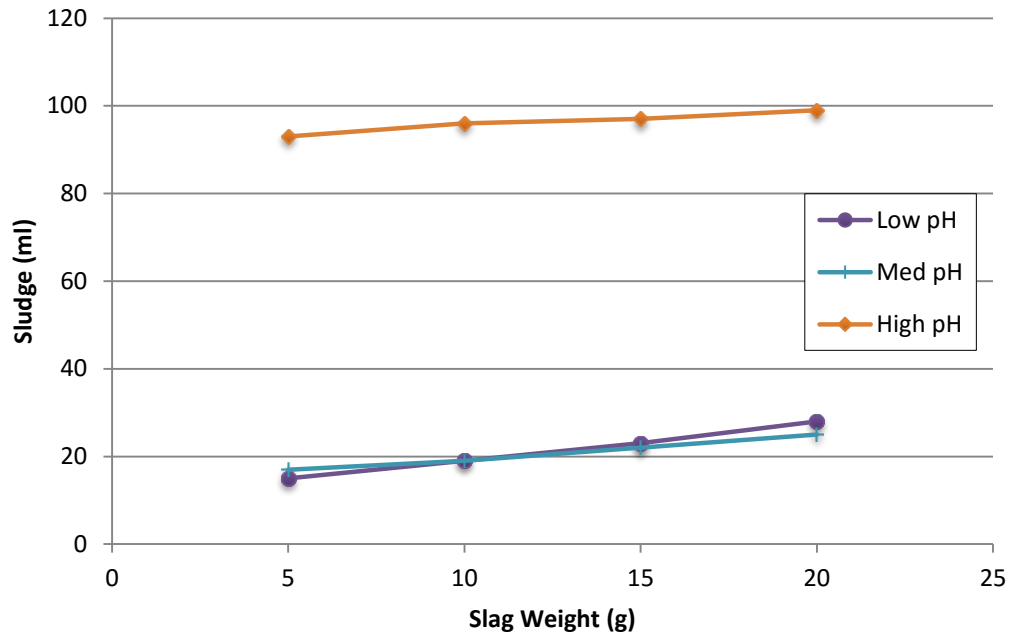


Figure 47: Sludge generated (ml) after using 75 nm steel slag (g) in different pH conditions

Figure (46) shows the impact of changing pH on the amount of sludge generated from water samples, where 75 nm steel slag was added. The main observation from this experiment was that the maximum removal of suspended solids was when the pH of the samples is high. Maximum removal can be distinguished by the amount of generated sludge, where it was measured to be 93 ml when 5 g of steel slag was added. The amount of generated sludge increased slightly to reach 99 ml when 20 g of slag added to the water samples, which indicates a good removal compared to the other samples.

Almost similar amounts of generated sludge were measured when neutral and acidic conditions were applied. Adding 5 g of steel slag help in generating 15 and 17 ml of sludge when the pH is low and moderate respectively, which is the lowest amount of sludge compared to the other samples. The production of sludge was increased to a maximum of 28 ml when 20 g of steel slag was added in acidic sample, and 25 ml when the same amount of steel slag was used in neutral conditions.

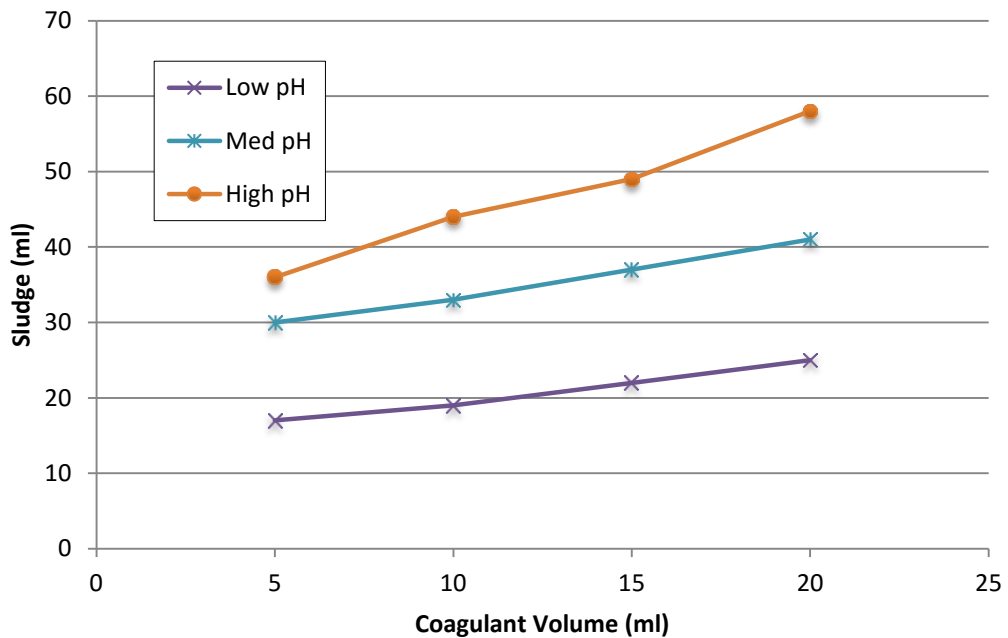


Figure 48: Sludge generated (ml) after using coagulant (ml) in different pH conditions

The last experiment was testing the effect of the polymer coagulant on the sludge generation from dewatered construction water samples, with the same pH conditions applied previously. Adding 5 ml of the polymer coagulant enhance the generation of 17 ml of sludge when the sample under acidic conditions. An increase of sludge was observed when more amount of coagulant added to the samples, 19, 22

and 25 ml of sludge were produced when 10, 15, 20 ml of coagulant was used in treating the water, the amounts of the sludge are low, thus it is the lowest removal among other samples.

Better removal was observed when the samples were under neutral pH, with an increase of sludge generated after the fixed contact time. The generated sludge amount was measured to be 30 ml when 5 ml of the coagulant was added, while the maximum amount of sludge generated was 41 when 20 ml of the coagulant was used. The highest performance was recorded when alkaline conditions were applied to the water samples, even though higher amounts of sludge were generated. The lowest amount measured was 36 ml of sludge when 5 ml of polymer coagulant was added. Adding 20 ml gives the highest sludge amount of 58 ml, which is the best removal observed when polymer coagulant was used.

Finally, analyzing the measured data of the generated sludge that is affected by the pH variation of the samples is important to determine the best removal conditions, where steel slag of two different particle sizes and polymer coagulant was used. The amount of generated sludge represent the amount of the suspended solids removed from the water samples, consequently, the more sludge generated, the more removal of suspended solids. Looking at the measured data, it is obvious that the best removal was recorded when 75 nm steel slag was used under high pH conditions, although it is the highest amount of sludge between 93 and 99 ml, it is the best performance among the other materials used and the applied conditions. On the other hand, the lowest amount of generated sludge was recorded also when 75 nm of steel slag was used but under acidic conditions.

3.5.5 The Impact of pH on Steel Slag Particles:

3.5.5.1 FTIR Analysis:

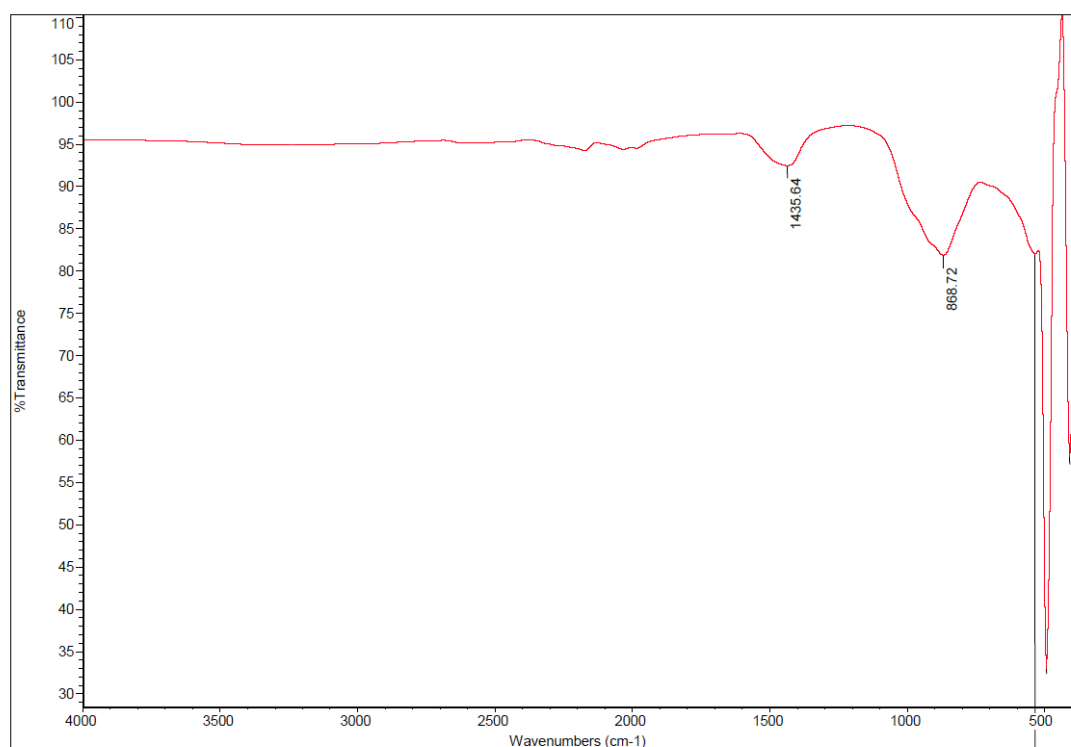


Figure 49: FTIR image of 75 nm steel slag before treatment

Figure (48) shows the FTIR image of the pure steel slag particles before using it in the treatment of the dewatered construction samples. Few bends can be observed on the FTIR image, it shows few functional groups on the steel slag surface that are active. The first considerable bend can be observed when the wavenumber is 1435.64 cm^{-1} , this frequency located in the absorbance range that indicates the presence of Silicon Oxides (Si-O) functional group. The presence of Carbon Oxides (C-O) functional group can be observed on the second bend in the FTIR image when the wavenumber is 868.72 cm^{-1} [62]. Table (35) present the composition of used steel

slag particles generated by the EDXS analysis, which confirms the presence of the mentioned functional groups.

Table 35: Steel slag composition percentage measured by EDXS analysis

Si (%)	Ca (%)	C (%)	O (%)	Fe (%)
5.92	21.64	4.33	40.68	17.54

Figure (49) shows the FTIR image of the steel slag particles after the treatment of the dewatered construction water.

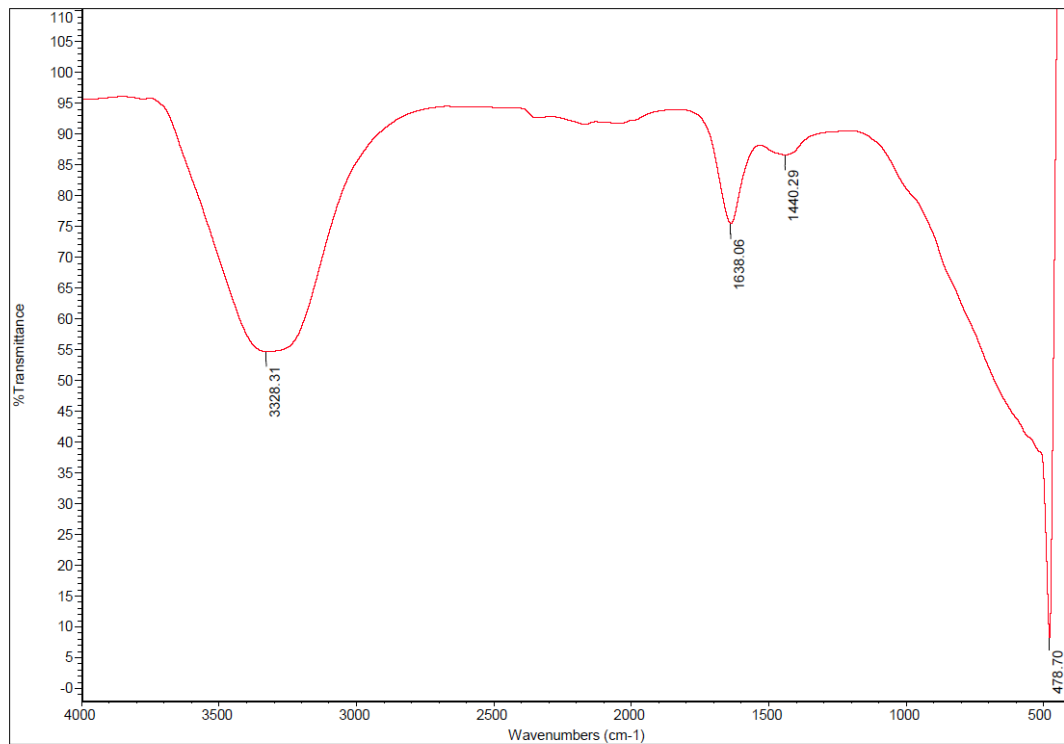
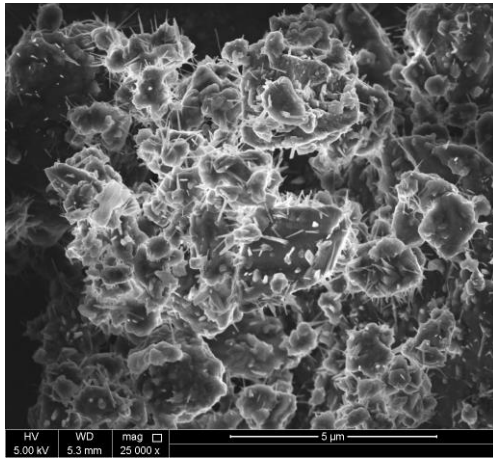


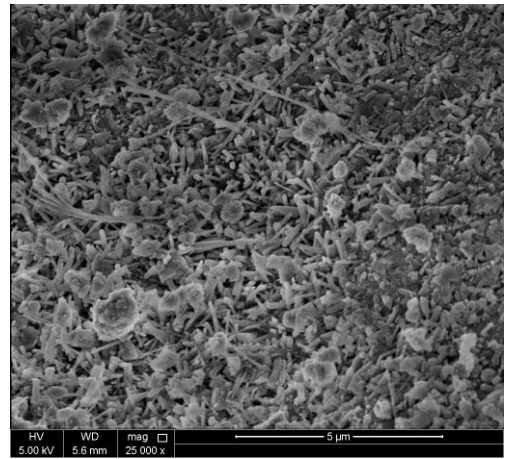
Figure 50: FTIR image of 75 nm steel slag after treatment

After using steel slag for the treatment of the dewatered construction water, it was obvious the improvement of the removal efficiency of the suspended solids and turbidity, where different functional groups were activated as it was reflected on the FTIR image, many bends appeared compared to the image of the pure steel slag particles before treatment as shown in figure (49). The first stretch appeared around a wavenumber 3328.31 cm^{-1} , it represents the hydroxyl functional group (O-H) that was activated after the treatment. Another stretch was noticed when the wavenumber is 1638.06 cm^{-1} , this frequency indicated the activation of (C=C) functional group, The last appeared bend is at wavenumber of 1440.29 cm^{-1} , it presents the activation of Silicon Oxide (Si-O) functional group in the surface of the steel slag particles [62].

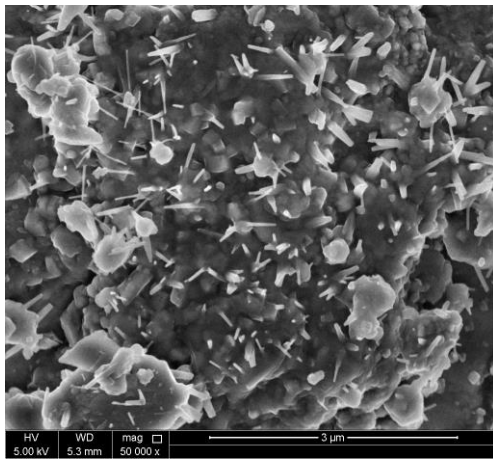
3.5.5.2 SEM Analysis:



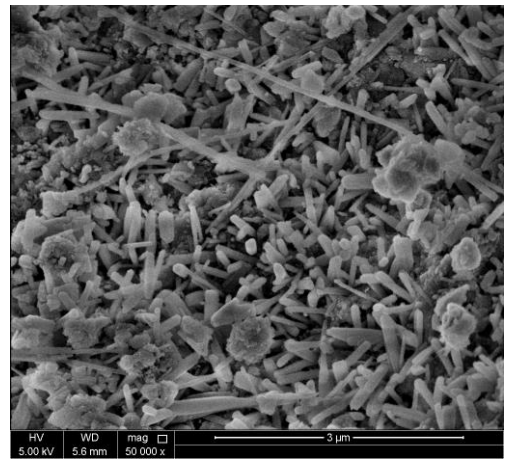
(A)



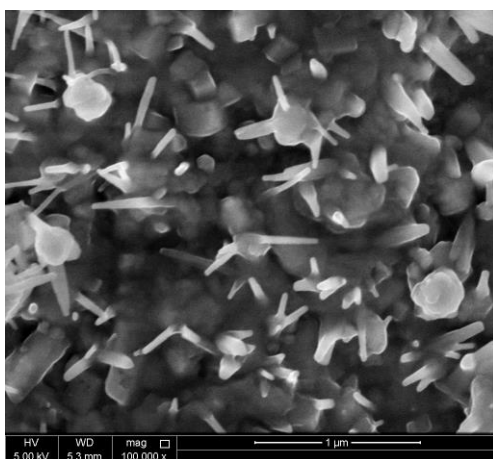
(B)



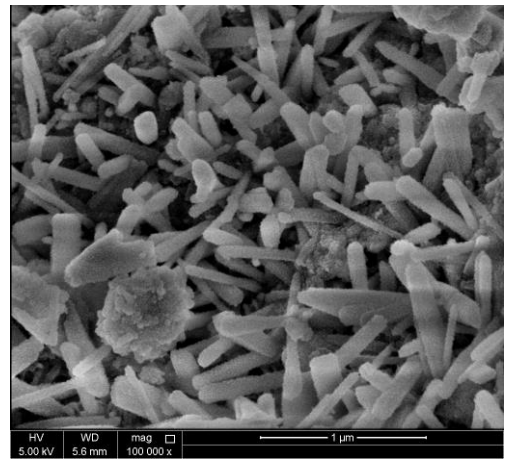
(C)



(D)



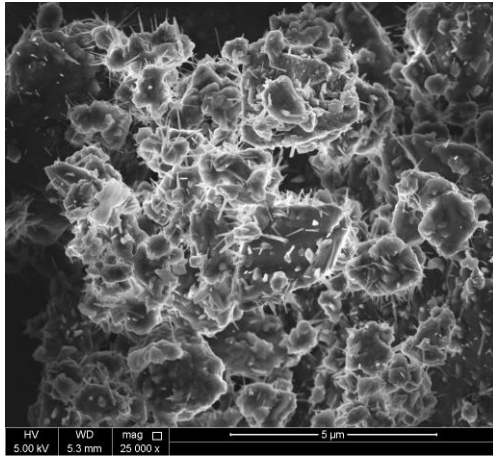
(E)



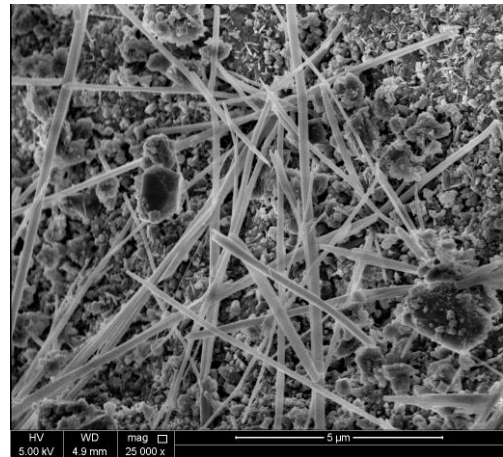
(F)

Figure 51: SEM images of 75 nm steel slag before treatment and after treatment in low pH conditions at different magnifications: A) Pre-treatment at 25K X, B) After treatment at 25K X, C) Pre-treatment at 50K X, D) After treatment at 50K X, E) Pre-treatment at 100K X, F) After treatment at 100K X

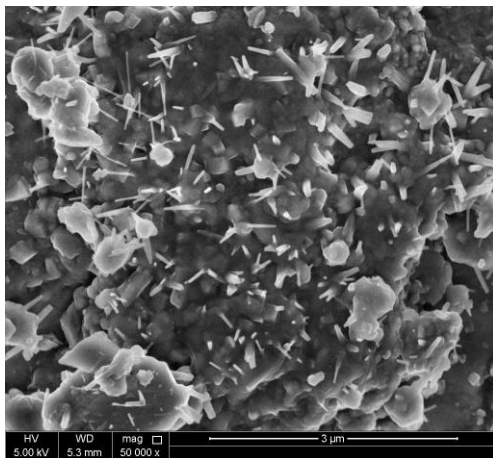
Figure (51) shows different magnifications of SEM images generated for the 75 nm steel slag particles before and after treatment of the water samples in low pH conditions. Looking at the surface structure of the steel slag in figure (A) of magnification X25K, it is clear that it is almost smooth with a lot of gaps between the textures and large crystalline structures compared to figure (B), where these large crystalline structures becomes smaller and the gaps are being filled with colloids, they are attached to the surface and in between the structures to form smaller crystalline structures. Rising the magnification to X50K in for the steel slag pure particles in figure (C), it is becoming clearer that the surface structures are having angular shapes with a rough textures and sharp edges of an inconsistent order unevenly distributed along the surface. On the other hand, figure (D) gives a clear image of the surface structures of the steel slag particles in low pH medium, where the structures become rougher with cylindrical shapes almost uniformly distributed along the surface of the slag particle. Figures (E) and (F) gives a better visualization of the surface shapes and structures along the steel slag particles with X100K magnification.



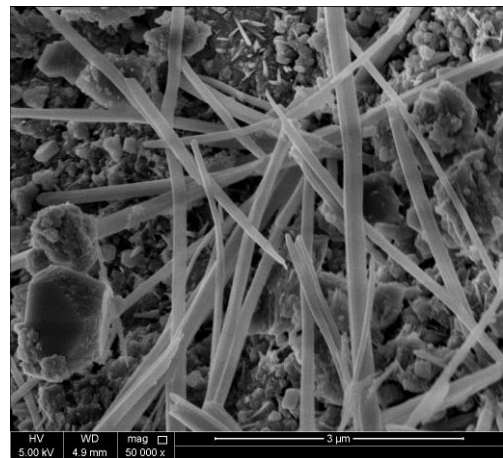
(A)



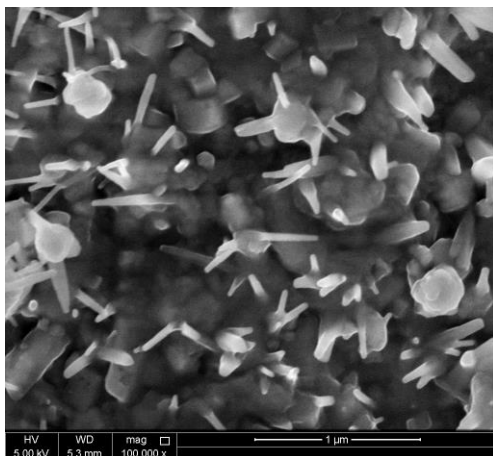
(B)



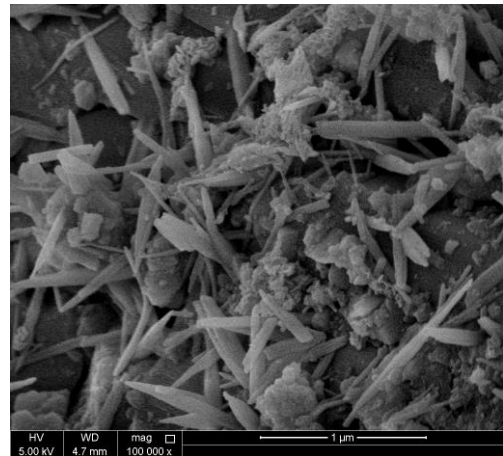
(C)



(D)



(E)



(F)

Figure 52: SEM images of 75 nm steel slag before treatment and after treatment in high pH conditions at different magnifications: A) Pre-treatment at 25K X, B) After treatment at 25K X, C) Pre-treatment at 50K X, D) After treatment at 50K X, E) Pre-treatment at 100K X, F) After treatment at 100K X

Different magnifications of SEM images generated for the 75 nm steel slag particles before and after treatment of the water samples in high pH conditions are presented in figure (52). Starting with magnification of X25K in figure (A) for the pure steel slag sample, it is obvious that there are large crystalline structures on the surface compared to slag samples after treatment in figure (B), where the gaps have been filled with rough colloids and the surface structure changed completely, these colloids formed a long crystalline columns of angular coarse structures. When the magnification was increased to X50K, it was observed more clearly in figure (C) for the pure slag samples the rough and sharp shapes and textures when comparing to figure (D), where less gaps were visible and disordered structures existed all around the surface of the slag particles and the crystalline columns are clearer when applying high pH to the slag particles. Lastly, Figures (E) and (F) shows higher magnification of X100K, the steel slag particles were covered with long colloids that was absorbed and distributed on the surface of the slag particles. It was concluded from analyzing the steel slag particles by SEM system that applying high pH conditions to the water samples with 75 nm steel slag was efficient in removing suspended solids, the best removal was observed as a lot of colloidal particulates was absorbed on the surface, which was reflected on the generated images with different magnifications.

CONCLUSIONS

The impact of steel slag amount on the removal of suspended solids was studied. A weight of 5 g of steel slag was observed to be the optimum weight that has the best performance in the removal of suspended solids from solution. The impact of contact time on suspended solids removal was studied for two different steel slag particle size, the optimum removal efficiency was achieved at a contact time of 40 minutes. After fixing the optimum contact time, the impact of different weights of the two steel slag particle sizes was studied, where the best removal percentage was recorded when 5 g of 425 nm steel slag was added to the water samples, where the uptake amount was calculated to be 69.9 mg/g compared to 64.4 mg/g for the other steel slag size of 75 nm. Further comparison was done between the suspended solids removal efficiency of steel slag and a polymer coagulant called Polyacrylamide, this comparison is important to validate the other findings and results. Steel slag of particle size 425 nm recorded the highest uptake amount of 72.24 mg/g among the other slag size and the polymer coagulant. Moreover, the impact of steel slag and polymer coagulant on the removal of suspended solids was studied in different pH conditions: low pH=2, moderate pH=7 and high pH=12. The best performance in removing suspended solids was recorded when 5 g of 75 nm steel slag was added to the water sample and the pH was 12, where the calculated uptake amount was 81.24 mg/g. Furthermore, the impact of varying pH was studied on the sludge generation, where it indicates the removed amount of the suspended solids. The highest removal was observed when 75 nm steel slag was used under pH of 12 where the sludge amount was above 90 ml. FTIR results show that Hydroxyl functional groups were the main group to adsorb suspended particles from solution.

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