

# Utilization of Eco-Friendly Sugar-Based Polymer as Chelating Agents for Reducing Water Hardness

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**Abstract.** High water hardness due to the content of calcium ions ( $\text{Ca}^{2+}$ ) is a serious problem in both the household and industrial sectors, as it can damage equipment and reduce process efficiency. Generally, the compound sodium tripolyphosphate (STPP) is used to address hardness, but it is non-biodegradable and has the potential to pollute the environment by causing eutrophication. This research aims to evaluate the potential of sugar polymer as an environmentally friendly alternative for reducing water hardness. The sugar polymer was synthesized through the polymerization reaction of sugar with oxalic acid at temperature variations of 90°C, 100°C, 120°C, and 140°C and reaction time variations of 10 and 20 minutes. The resulting synthesized sugar polymer was applied to a 36 dH water sample at a sugar polymer concentration of 10g/L of the water sample. Test results showed that the sugar polymer synthesized at 120°C for 20 minutes was able to significantly reduce water hardness from 36 dH to 11.22 dH. High temperatures in the synthesis process proved to increase the reaction effectiveness between the sugar polymer and calcium ions, whereas at low temperatures, the hardness reduction was less optimal. Reaction time also had an effect, especially at temperatures of 100°C and 120°C, but it had no effect at a temperature of 140°C. The sugar polymer resulted in an increase in the Total Dissolved Solids (TDS) value from 997 ppm to 1279-1380 ppm; this figure is still much lower than the TDS from the use of STPP, which is 4887 ppm. This indicates the advantage of sugar polymer over STPP, in addition to its advantages from a sustainability aspect. Overall, sugar polymer has great potential as a more environmentally friendly hardness-reducing agent; however, to match the effectiveness of STPP, which can reduce hardness to 1.67 dH, further optimization of the formulation and reaction conditions is still required.

**Keywords:** Water hardness, sugar polymer, sodium tripolyphosphate, environmentally friendly

## Introduction

Water is a primary necessity for human life. If water needs are not met in terms of either quality or quantity, it will lead to significant social and economic impacts on the community (Amelia, S.P. at al, 2023). Water used must meet quality standards for physical, chemical, microbiological, and radioactivity parameters. One of the chemical parameters for water quality standards is the amount of calcium (Ca) and magnesium (Mg) elements in the water, which is known as water hardness (Kumari, 2016). Water hardness is divided into two types, namely temporary hardness caused by the presence of calcium bicarbonate or magnesium bicarbonate compounds, and permanent hardness caused by anions other bicarbonate ( $\text{Cl}^-$ ,  $\text{NO}_3^-$ ,  $\text{SO}_4^{2-}$ ). It is called temporary hardness because it can be removed by heating, whereas permanent hardness cannot be removed

by heating (Tarigan, K. et al, 2022). At certain levels, hard water is not harmful to health, but high hardness can have negative health impacts, such as cardiovascular disease and urolithiasis (Sahidin et al., 2024). Drinking water quality requirements specify a maximum total hardness (as  $\text{CaCO}_3$ ) of 500 mg/Liter (ppm) (Setiawan et al, 2024). High-hardness water leads to high soap consumption because the presence of hardness ions negates the detergent properties of soap (Alisya, N.N., 2021). Water containing calcium and magnesium also causes various problems in steam boilers. The formation of scale on boiler walls, caused by calcium and magnesium, will impede heat transfer, thereby reducing the boiler's efficiency (Wilastari et al., 2021). Besides hardness, Total Dissolved Solids (TDS) is another critical parameter for boiler feed water. High TDS can lead to corrosion in industrial equipment. Boiler Feed Water Quality Standards (Chem.Treat. Inc.) state that Total Hardness should be 0 and the maximum TDS should be 3500 ppm (Prihardani et al., 2021). Water hardness can be reduced in several ways: namely heating and precipitation for temporary hardness (Rizki Amelia et al., 2023), ion exchange (Setiawan, 2024), and the addition of anti-hardness substances as chelating agent, such as Sodium Tripolyphosphate (STPP) and organic phosphonate compounds (Wardani et al., 2023)..

The industrial use of STPP, which contains phosphate compounds as a chelating agent, can have serious environmental impacts because it is non-biodegradable and can cause eutrophication in water bodies, a condition where phosphate levels increase and trigger excessive algae growth, reducing dissolved oxygen and disrupts the aquatic ecosystem's balance (EPA, 2025).

Research by Philip J. Charley et al. proved that reducing sugars can form stable complexes with a series of iron metals at a basic pH (Charley, P.J, 1963). Ferlin, N. et al. also conducted research on using glucose to bind calcium ions ( $\text{Ca}^{2+}$ ) through a chelating process. In surfactant synthesis, the glucose structure is modified by adding complex chelating functions, such as amino acids and hydroxylamine (Ferlin N et al, 2011). Bhange S.B., et al. also researched an ecofriendly sugar polymer for use as a toilet cleaner, concluding that it provided "excellent in cleaning and give shine as desired" compared to commercial products. The sugar polymer synthesis in that study was conducted at 120°C for 20 minutes.

The purpose of this research is to determine if a sugar polymer can be used to bind calcium ions in hard water and to study the influence of synthesis temperature and time on hardness reduction and its effect on the TDS content. The novelty of this study is the application of sugar polymer for hardness reduction and the variation of synthesis conditions (temperature and time). The synthesis temperature was varied at 90°C, 100°C, 120°C, and 140°C, with time variations of 10 minutes and 20 minutes.

## Methods

The method used in this study adapts the methodology developed by Bhange from the Department of Oil Technology, LIT Nagpur, India (2017). Bhange applied a sugar polymer as a toilet cleaner, with synthesis performed at 120°C for 20 minutes (Bhange, S.B., 2017). In this study, the sugar polymer is applied to reduce water hardness, and its synthesis is performed with variations in temperature and time

The research was conducted at the Laboratory of PT. Bozzetto Indonesia, located in Banjarnegara, Bandung Regency, from January to May 2025. The equipment used was a Mini reactor with a stirrer (500 mL capacity), homogenizer, analytical balance, syringe, pipette, and glassware, and buret. The materials used were glucose, PEG 400, oxalic acid, Sodium Bisulfate, Water, EDTA, pH 11 buffer, calmagite indicator.

### Sugar Polymer Synthesis

The sugar polymer was made by mixing sugar, PEG, oxalic acid, sodium bisulfat, and water in a reactor, with quantities as shown in Table 1. This mixture was heated gradually with stirring, starting at a low temperature (around 50°C) for 30 minutes. It was then heated again at varied temperatures (90°C, 100°C, 120°C, and 140°C) and for varied times (10 minutes and 20 minutes). The mixture was cooled and filtered to obtain a clear polymer. This polymer was then applied to reduce water hardness, after which the reduction in dH and TDS was measured.

Table 1. Sugar Polymer Synthesis Formula and Condition

Material	R/1	R/2	R/3	R/4	R/5	R/6	R/7	R/8
Glucose, g	50	50	50	50	50	50	50	50
PEG 400, g	15	15	15	15	15	15	15	15
Oxalic Acid, g	20	20	20	20	20	20	20	20
Na Bisulfat, g	3	3	3	3	3	3	3	3
Temperature, °C	90	90	100	100	120	120	140	140
Time (minutes)	10	20	10	20	10	20	10	20

Figur 1 shows the flow diagram of sugar polymer synthesis.

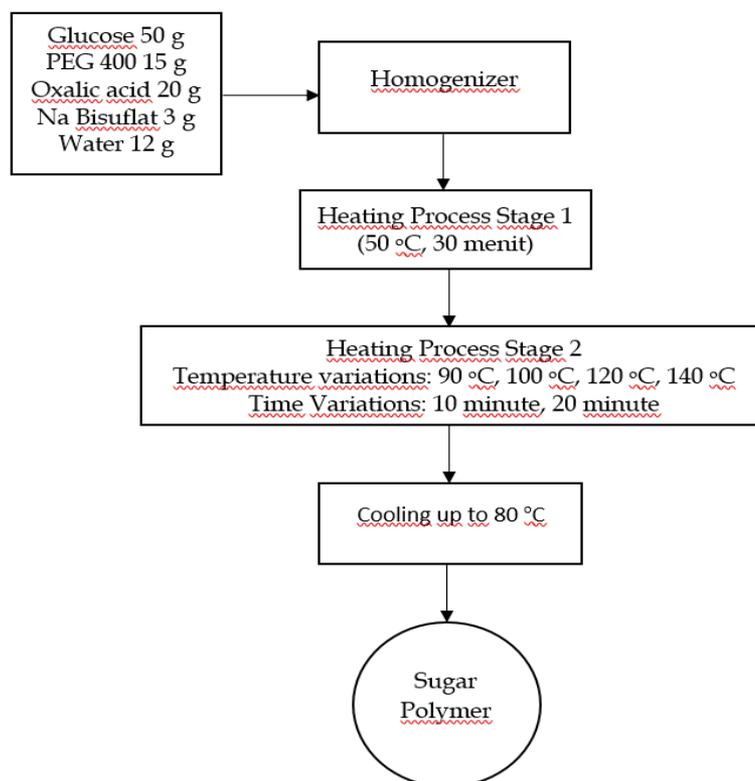


Figure 1. Sugar Polymer Synthesis Flow Diagram

Preparation of the Hard Water Sample.

The hard water sample was made with a content of 1000 ppm  $\text{Ca}^{2+}$ . Pure water was placed into a 1-liter volumetric flask until it was half full, then 3.67 grams of calcium chloride ( $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$ ) was added. The flask was swirled to dissolve the solid and more distilled water was added up to the mark.

Application of Sugar Polymer to the 1000 ppm (36 dH) hard water

To 100 ml of hard water, 1 gram of sugar polymer was added and shaken, then its degree of hardness (dH) and TDS level were tested. The hardness testing was done using the complexometric method with an EDTA solution, while the TDS level was tested using a digital TDS meter.

## Result and Discussion

The tested sugar polymer product was proven to be able to significantly reduce water hardness, especially when its manufacturing process was carried out at high temperatures (120°C and 140°C). At these temperatures, the water hardness dropped from 36 dH to 11.22 dH, for both reaction times of 10 minutes and 20 minutes. Reaction time also influenced the performance of the sugar polymer, especially at temperatures of 100°C and 120°C. At R/3 (100°C, 10 minutes) the hardness dropped to 20.94 dH and at R/4 (100°C, 20

minutes) the hardness dropped to 19.27 dH. At 120°C, the reduction was sharper from 13.4 dH (R/5) to 11.22 dH (R/6). However, at a temperature of 140°C, the reaction time no longer had an influence because the hardness had already reached a saturation point (11.22 dH). This indicates that for sugar polymer synthesis at a certain temperature, the performance as a chelating agent is not influenced by reaction time and has the same performance as at a reaction temperature of 120°C. This can be seen in Table 2 and Figure 1.

Although effective at reducing hardness, the sugar polymer product caused an increase in Total Dissolved Solids (TDS) from 997 ppm to 1279–1380 ppm. This increase was caused by the release of soluble compounds from the sugar polymer into the water. A high TDS value can affect water quality and potentially leave a residue.

Table 2. dH and TDS Test Results of the Application of Sugar Polymer to Hard Water

Material	R/1	R/2	R/3	R/4	R/5	R/6	R/7	R/8
Glucose, g	50	50	50	50	50	50	50	50
PEG 400, g	15	15	15	15	15	15	15	15
Oxalic Acid, g	20	20	20	20	20	20	20	20
Na Bisulfat, g	3	3	3	3	3	3	3	3
Temperature, °C	90	90	100	100	120	120	140	140
Time (minutes)	10	20	10	20	10	20	10	20
dH hasil aplikasi	1279	1298	1324	1329	1334	1356	1376	1380
TDS Hasil Aplikasi	31,6	31,67	20,94	19,27	13,4	11,22	11,2	11,2

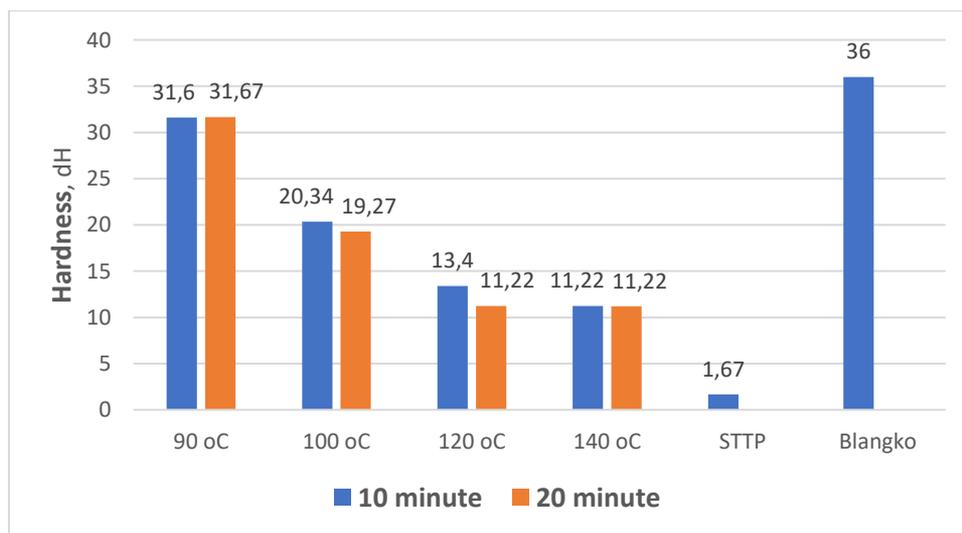


Figure 2. dH Values from the Application of Sugar Polymer, STTP to Hard Water, and a Hard Water Sample without the addition of a chelating agent

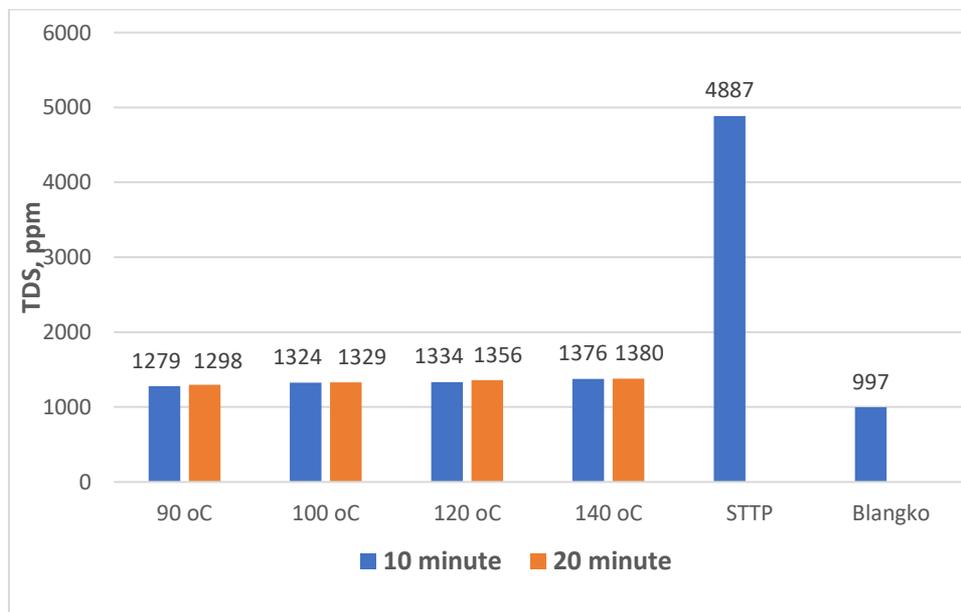


Figure 3. TDS Values from the Application of Sugar Polymer, STTP to Hard Water, and a Hard Water Sample without the addition of a chelating agent



Figure 4. Sugar Polymer Synthesis Results

The synthesis of sugar polymer with raw materials of glucose, polyethylene glycol, oxalic acid, and sodium bisulfite as well as water will produce a condensation esterification reaction that yields diester cross-links (Li, D. et al, 2017), an acetylation reaction that does not form diester cross-links and potentially reduces the ability to bind metal ( $\text{Ca}^{2+}$ ), and a glucose dehydration reaction that produces humin (a brown solid). The degree of polymerization and the structure are highly influenced by temperature and time. The ability of the resulting sugar polymer as a chelating agent is due to the presence of electron donors ( $\text{C}=\text{O}$ ,  $-\text{OH}$ ,  $-\text{O}-$  carboxylate groups / unesterified free  $-\text{COOH}$ , and the bridge oxygen  $-\text{O}-$  in the ester). To produce a sugar polymer with good performance as a chelating agent, the condensation esterification reaction should be maximized, or in other words, reactions other than condensation esterification should be minimized. Figure 1 shows that the higher the temperature and the longer the time, the greater the ability of the resulting sugar polymer to reduce the degree of hardness, but at a temperature of  $140^{\circ}\text{C}$  the result is the same as at a temperature of  $120^{\circ}\text{C}$ . This is because the rate of the condensation esterification reaction will be higher with an increase in temperature. However, an increase in temperature also increases the rate of the acetylation and glucose dehydration reactions that produce humin. This is proven by the color of the sugar polymer becoming browner at higher

temperatures. The presence of humin from the glucose dehydration reaction causes the brown color in the sugar polymer.

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