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Zhang, S, Wang, X, Yu, Z, Chen, W and Zhou, Q (2021) Experimental Investigation of the Engineering Properties of Coarse Grain Embankment Fill Material with Accumulative Salt Effect by Adding Onsite Brine Groundwater. Journal of Materials in Civil Engineering. 33 (6). ISSN 0899-

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1 **Experimental investigation of the engineering properties of coarse grain embankment** 2 **fill material with accumulative salt effect by adding on-site brine groundwater**

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15 **Abstract**

16 The purpose of this research is to study the accumulative effect of repetitively adding groundwater on the engineering
17 properties of coarse grain salinized embankment fill material. Large-scale compression and engineering characteristics
18 tests were carried out on different salt content samples. Based on the laboratory test results, the influence factors on the
19 engineering properties by repetitively adding groundwater with SO_4^{2-} or Cl^- were analyzed. With the increasing times of
20 added water containing SO_4^{2-} or Cl^- , the compressive deformation of tested samples showed a trend of dramatically
21 increasing at the beginning followed by gradually decreasing, while the collapse deformation of the samples increased
22 continuously. Its coefficient of compressibility showed a typical three-stage variation law, regardless of the salt types of

23 added water. With the decrease of the temperature (simulating the cooling period during construction), the excessive
24 content of SO_4^{2-} in the water resulted in an increase of salt expansion of samples, while the shrinkage behaviour was
25 observed with the excessive content of CL^- in the water. Thus, an obvious accumulative effect in the salt expansion of the
26 sample was observed. With the increasing times of added water containing SO_4^{2-} or CL^- , the collapse deformation of the
27 samples increased continuously. Besides, the mechanisms of added water with SO_4^{2-} or CL^- on the engineering
28 characteristics of the samples were discussed from the following perspectives: the salt accumulation, the distribution of
29 salt in the soil, the interaction of salt ions, and the dissolution of soluble salt. It is further shown that even a small amount
30 of the soluble salt in groundwater, will have a significant impact on the engineering properties of the coarse grain saline
31 soil with the accumulative effect by repetitively adding groundwater.

32 **Keywords:** Embankment fill material, Coarse grain saline soil, Sodium sulfate, Ground Water, Salt content

33 **1. Introduction**

34 Saline soil widely distributes in the arid and semi-arid regions with a total area accounting for 6.5% of the global
35 land area. There is a significant amount of saline soil distribution in China, Pakistan, Saudi Arabia, Iraq, Egypt, Iran, and
36 many other countries, especially Middle East area in which the percentage of saline soil area is far larger than the world's
37 average level (FAO 2002). As increasing demands for highway and highspeed railway, some construction projects have
38 to cross through the saline soil areas considering the construction cost. There is a detrimental effect of salt crystallization
39 due to reduction of ambient temperature, while in a warm condition, the water of crystallization in the saline soil may be
40 released, resulting in a soil volume contraction (Gao et al. 1997b; Wu et al. 2002; Zhang et al. 2020). The salt expansion
41 of sulfate saline soil is one of the most critical factors that cause engineering damage in the saline soil areas (Gao et al.
42 1997a; Liu et al. 2019; Zhang et al. 2020). It was found that the rate of cooling, salt content, water content, ion sort and
43 types of soils had an impact on the crystal of sodium sulfate, thus, could influence the salt expansion of sulfate saline
44 soils (Bing and Ma 2011; Lai et al. 2016). Wan et al. (2017b) and Xiao and Lai (2017) also confirmed the influence of

45 initial supersaturate ratio on the amount of salt expansion and the inhibiting effect of chloride ion on the salt expansion.
46 Durotoye T.O et al. (2016) confirmed that adding sodium chloride to expansive soils can reduce its free swell index and
47 increase its strength characteristics. Wu et al. (2002) found that the salt expansion amount was related to a sensible
48 temperature range, which was from -7°C to 0°C for the coarse grain saline soil.

49 Soil subsidence, caused by dissolving the soluble salts in saline soils (Zhang et al. 2019), could also lead to the
50 damage of embankment structure. In order to study the factors that influence the collapsibility of coarse saline soils, a
51 site collapse experiment was performed by Cheng et al. (2013), which found that not only the water and salt content but
52 also the content of coarse particle, the soil density, and the permeability quotient had an impact on the collapsibility of
53 coarse saline soils. Some scholars (Wang 2009; Song 2017) found that the collapse coefficient increased with the
54 increasing salt content at the same water content level, whereas the collapse coefficient decreased with the increasing
55 water content at the same salt content level (K. Abbeche et al. 2010).

56 To avoid the saline soil induced engineering hazards, several soil stabilization techniques were developed to treat
57 salinized soils by use of sodium chloride, fly ash or lime (Sivapullaiah et al. 2009; Durotoye T.O et al. 2016; Zhang et al.
58 2020; Consoli et al. 2019a). In addition, when those soils were treated by lime or calcium-based stabilizers, the existing
59 sulfate in the soils reacts with the calcium from stabilizers and the free reactive alumina from soils to form a crystalline
60 mineral as ettringite which would result in heaving in the soils, known as sulfate-induced heave (Puppala et al. 2004;
61 Consoli et al. 2019b). Besides, dispersive clay particles come apart and get progressively eroded when subjected to water
62 containing reduced quantities of salt as a large amount of dispersed sodium exist in pore water of dispersive clays (Consoli
63 et al. 2016). It was proved that the adding of fly ash could improve engineering properties of dispersive clays which was
64 treated by lime initially (Consoli et al. 2019c).

65 In general, the groundwater in the saline soil areas often contains a certain amount of soluble salt, which is not high
66 enough to cause damage to the subgrade, as the salt content meets the requirement of construction standards by the water

67 examining. However, due to the lack of accumulative salt content effect awareness, those soluble salt in groundwater
68 may cause potential damage to some subgrades when using this local groundwater during the embankment construction.
69 A recently on-going construction project in the Middle East area (Zhang et al. 2019) reported that because of the dry
70 climate and high evaporation capacity on the construction site, the subgrade filling speed was slow. To maintain the water
71 content of the subgrade, the local groundwater containing soluble salt was added several times during the filling process.
72 This repetitively added groundwater resulted in an increase of soluble salt content in the subgrade fillers due to the
73 accumulative effect, leading to potential salt-expansion damage hazards on the constructing subgrade.

74 Although replacing the local groundwater with the pure water for the subgrade construction could avoid potential
75 hazards, this will cause a steep increase in the construction cost. Currently, there is no study on the accumulative effect
76 of salt in coarse grain soils caused by repetitively adding brine groundwater. Thus, to reduce the construction cost while
77 ensuring the stability of subgrade in the saline soil areas, a study on the accumulative effect of groundwater in the saline
78 soil areas on the coarse grain embankment fill materials needs to be carried out.

79 This study reveals the influence law and mechanism of repetitively added groundwater on the engineering properties
80 of coarse grain saline soil. Therefore, based on the engineering problems existing in the construction project in the saline
81 soil areas, two types of water were prepared in the laboratory: sulfate solution and chlorine solution, simulating the two
82 main types of soluble salt existing in the groundwater of Middle East saline soil areas. The coarse grain saline materials
83 were mixed with these prepared water for 0, 1, 2, 3, 4, 5 times to simulate the on-site subgrade construction process (e.g.
84 in the Middle East construction project), in which the groundwater was added several times to maintain a certain water
85 content for compaction due to the high level of evaporation. Then, large-scale compression tests, salt expansion tests, and
86 collapsible tests were performed on these samples to study the effect of repetitively adding brine water on the engineering
87 characteristics of coarse grain saline materials.

88 **2. Fundamental engineering property of experiment materials**

89 2.1. Materials

90 The materials used in this experiment were obtained from Hosi Corridor, Gansu province, China. Fig. 1 (Google
91 map 2019) shows a satellite map of the sample collection location. According to the standard method (the Code for Civil
92 Engineering Experiment of Railway Project (MOR 2010)), which is the same as (BSI 1990a), the particle size distribution
93 test was performed on the collected samples. The particle size distribution curves of samples, named as TL-1 and TL-2,
94 are shown in Fig. 2. According to the classification standard in the Code for design on subgrade of the railway (MOR
95 2005), the test samples are classified as well-gradation fine round gravel, which is a good subgrade aggregate.

96 According to the standard method (MOR 2010), which is the same as (BSI 1990b), the optimum water content and
97 the largest dry density of the soil sample TL-1 are 6.7% and 2.22 g/cm³, while they are 6.4% and 2.24 g/cm³ for the soil
98 sample TL-2. The salt content analysis was performed on test samples based on the standard methods (MOHURD 2014)
99 and (BSI 2018), giving the results that show a relatively low salt content compared with soils that collected from the
100 highspeed railway project in the Middle East area mentioned in the introduction. To present the on-site soil condition,
101 sodium chloride and sodium sulfate were added to the test samples. The salt contents of these two types of samples were
102 set as the typical salt content level in the Middle East coarse grain saline soil areas (Zhang et al. 2019; William D. 2014).
103 The soluble salt assay result of test samples is presented in Table 1.

104 2.2. Groundwater

105 According to the standard method (MOR 2003), the ion analysis was carried out on the groundwater samples
106 collected in the saline soil areas from the Middle East high-speed railway project. The results showed that the highest ion
107 concentrations of SO₄²⁻, Cl⁻, Ca²⁺, Mg²⁺, K⁺, and Na⁺ were 96.53 g/L, 133.13 g/L, 11.00 g/L, 4.80 g/L, and 63.01 g/L,
108 respectively. The ion concentration of HCO₃⁻ was 0 while the highest ion concentration of CO₃²⁻ was 0.48 g/L in most of
109 the water samples. PH value ranged from 7 to 9, while the highest content of free-state carbon dioxide was 0.04 g/L.

110 To obtain more representative experiment results, based on the ion analysis result, two common types of water

111 samples with medium salt content were chosen. As there is a relatively low ion concentration of HCO_3^- and CO_3^{2-} in the
112 water samples, and the damage of saline soil is mainly related to SO_4^{2-} and Cl^- , the effects of other ions can be ignored
113 (Gao et al. 1997a). Thus, the test water sample-A was prepared in the laboratory by mixing potassium sulfate and sodium
114 sulfate with pure water, while the test water sample-B was prepared by mixing potassium chloride and sodium chloride
115 with pure water. The ion analysis results of these two types of test water samples are shown in Table 2.

116 **3. The design of the experiment scheme**

117 3.1. Sample preparation

118 In order to study the effect of repetitively adding brine groundwater on the engineering properties of coarse grain
119 sulfate saline fill materials, large-scale compression tests, salt expansion tests, and collapse tests were carried out. The
120 test sample preparing details are shown as follow. When preparing test samples, the total times of added water was 5 to
121 reach the optimum water content, in another word, that is adding the test water for n ($n=0,1,2,3,4,5$) times, while the pure
122 water was added (5-n) times. For instance, if the test brine water is added for 0 times, then the pure water should be added
123 5 times to reach the optimum water content. To be specific, the TL-1 test sample was prepared by adding the test water-
124 A for 0, 1, 2, 3, 4, and 5 times, while the pure water was added for 5, 4, 3, 2, 1, and 0 times, numbered as S0–S5,
125 respectively. The test sample TL-2 was prepared by adding the test water-B for 0, 1, 2, 3, 4, and 5 times, while the pure
126 water was added for 5, 4, 3, 2, 1, and 0 times, numbered as C0–C5, respectively. The test samples were cured for 24 h so
127 that the test water could evenly distribute within the soil samples. Then, the test samples were placed into the
128 corresponding test container according to the requirement of each test. Table 3 presents the design scheme of adding test
129 water.

130 3.2. Large-scale compression test

131 Large-scale compression tests were carried out based on the standard method (MOHURD 2019), by using a 1000
132 kN large-scale consolidometer. The instrument is designed for testing the coarse grain soil, with an allowed maximum

133 particle size of 60 mm. The deformation sensor ranges from 0 mm to 50 mm, with an accuracy of 0.2% F.S (full scale).

134 The pressure sensor ranges from 0 kN to 1000 kN, with a stability accuracy of 1% making it suitable for testing.

135 Test samples were compacted dynamically and evenly into the test container in three layers with the compactness
136 of 92% which is determined by the compaction requirement of the highspeed railway subgrade according to the Code for
137 design on subgrade of the railway (MOR 2005). The dimension of the cylinder test container was $\Phi 500$ mm (inner
138 diameter) \times 250 mm (height). After compaction, the container with samples was placed into the instrument. The soil
139 samples were first pre-loaded and then loaded from 0 kPa to 50 kPa. The next stage load was applied when the specimen
140 deformation was stabilized under the current stage load, which gave the deformation rate no greater than 0.05 mm/h. This
141 procedure was repeated at 100 kPa, 200 kPa, 300 kPa until the designed load 400 kPa was reached. After the deformation
142 of the soil samples was stabilized again at 400 kPa, the unload program was then performed.

143 3.3. Salt expansion test

144 The cooling equipment used in the salt expansion test was a bespoke simple temperature control test box
145 (temperature ranges from -15°C to 50°C). Figure 3 shows the photograph and principle diagram of the temperature control
146 test box. This instrument has two main advantages to ensure the accuracy of the test results compared to other test devices.
147 The temperature inside the test box was maintained stable as the reading could be done outside the instrument without
148 opening the test box. Besides, the dial was placed outside the thermal insulation to ensure the accuracy regardless of the
149 low-temperature influence inside the instrument. The test container used in the salt expansion test is a bespoke organic
150 glass barrel (Fig.3c) with the dimension of $\Phi 240$ mm (inner diameter) \times 250 mm (height). The soil samples were
151 compacted dynamically into the test container in three even layers with the compactness of 92%. After the container was
152 placed into the test box, the temperature control system was turned on. The initial temperature was set as 25°C with a
153 cooling rate of $5^{\circ}\text{C}/60$ min. The temperature was kept at the same level for an hour at each cooling stage. When reached
154 the designed lowest temperature (-15°C), the temperature was kept constant at -15°C for 5 hours. The amount of salt

155 expansion at each cooling stage was recorded. According to the expansion law of sodium sulfate crystallization, the
156 temperature around -10°C and a cooling rate of $0.1^{\circ}\text{C}/\text{min}$ met the temperature requirements for salt expansion (Lai et
157 al.2016; Xiao et al.2017).

158 3.4. Collapse test

159 The test device used in the collapse experiments is shown in Figure 4. The collapse tests were carried out at room
160 temperature (about 20°C). The soil samples were compacted dynamically into the test container in three even layers with
161 the compactness of 92%. The test container was a specially designed barrel made from acrylic glass with the dimension
162 of $\Phi 280\text{ mm}$ (inner diameter) $\times 70\text{ mm}$ (height). The upper and lower sides can drain freely, and there is a steel drainage
163 plate placed on the upper surface of the barrel. This steel plate allows the load applied uniformly towards the soil sample.
164 There are removable iron hoops around the barrel to limit horizontal displacement of the soil sample.

165 The collapse test was followed to the Code for Civil Engineering Experiment of Railway Project (MOR 2010).The
166 collapse test procedure was determined using the single-line method described as follow. The soil samples were loaded
167 to 200 kPa step by step at an interval of 50 kPa without adding water. The pure water was added to the soil samples from
168 top to bottom after the deformation of samples stabilized at 200 kPa. When the deformation of the soil samples reached
169 a stable state after adding the pure water, the load was then increased to 300 kPa. The stable state mentioned hereby is
170 defined as the deformation rate of the soil samples is no greater than 0.01 mm per hour. The designated amount of added
171 water in the collapse test was calculated based on the largest precipitation level of 40mm, which was observed on-site
172 from the Middle East high-speed railway project. The total amount of added water = cross-section area of soil sample \times
173 precipitation quality = $S \cdot H = \pi \cdot R^2 \cdot H = 3.14 \times \left(\frac{28}{2}\right)^2 \times 4 = 2461.8\text{ mL}$.

174 4. Results and discussion

175 4.1. The results and analysis of compression tests

176 4.1.1. The results of compression tests

177 The result of the compression tests is shown in Figures 5, 6 and 7. Fig. 5 shows the variation of the void ratio of
178 samples S0–S5, C0–C5 with the load increasing from 0 kPa to 400 kPa. From Fig. 5, with the increase of loading, the
179 void ratio of the sample decreases in all tested samples. It is interesting to see from Table 4 that the volume changes of
180 samples are the largest with values of 0.010 in TL-1 and 0.006 in TL-2 at 400 kPa when adding the brine water for 3
181 times regardless of the salt types.

182 Fig. 6 shows the variation of compression deformation of the samples with the varied times of adding the brine water
183 under the condition of load increased from 300 kPa to 400 kPa. From Fig. 6, the average total amount of deformation
184 increased gradually from 212 mm to 266 mm upon adding the test water for 0 to 2 times, with a sudden increase to 419
185 mm when adding the test water for 3 times. After adding the test water for 4-5 times, the total amount of deformation
186 decreased gradually from 311 mm to 298 mm, nearly to the level of that (266mm) when adding the test water for 2 times.

187 From Table 5, compared with the deformation when adding the pure water for 5 times, the maximum stabilized
188 deformation increments of coarse sulfate saline fill materials vary from 10.27% to 116.73%, with the maximum values
189 of 116.73% and 79.01% when adding the sulfate and chloride water 3 times respectively.

190 Fig. 7 shows the variation of the compression coefficient of compressibility ($a_{100-200}$) with the increasing times of
191 adding the test water. From Fig. 7, with the increasing times of adding the test water, the coefficient of compressibility
192 showed a three-stage variation trend regardless of the salt types. It decreased slightly followed by dramatically increasing
193 to the maximum, and then decreased gradually until stabilization. The coefficient of compressibility of the sample when
194 adding the brine water for 3 times is about 62% higher than that with only pure water added. Compared with the samples
195 that adding the pure water for 5 times, the coefficient of compressibility of the sample that mixed with the sulfate water
196 for 5 times increased about 0.5 times, while the coefficient of compressibility of the sample that mixed with the chloride
197 water for 5 times increased about 0.4 times. This fact illustrates that the times of adding the brine water have an impact
198 on the compression characteristics of coarse sulfate saline fill materials.

199 4.1.2. The analysis of compression tests

200 The volume of the test container used in the compression tests was fixed. And according to the test water adding
201 scheme, the total water content of each soil sample was the same. Thus, the soluble salt content in the samples increased
202 upon adding the brine water. In the condition of adding the brine water for 0 times, the pure water was added for 5 times
203 to reach the optimum water content. Under this condition (S0 or C0), the largest dry density and optimum water content
204 of the samples were obtained by the heavy compact tests, resulting in the highest density of the soil sample. Thus, the
205 lowest compressive deformation was observed under this condition. In the other conditions (S1-S3 or C1-C3) when
206 adding the brine water from 1 to 3 times to reach the so-called optimum water content, the real optimum water content
207 of the samples increased with the increase of the soluble salt content, in the same manner as Zhang and Yang (2019),
208 which has been proved by an experimental contacted by Zhang. Thus, in the process of adding the brine water for 1 to 3
209 times, the water content of samples decreased compared to the real optimum water content, resulting in a decreased dry
210 density and an increased compressive deformation.

211 Meanwhile, at certain temperatures with small temperature variation, the solubility of soluble salt in water was
212 constant. Fig. 8 shows the variation of the solubility (g/100g water) of NaCl and Na₂SO₄ with temperature (Lai et al.
213 2017; Wan et al. 2017a). From Fig. 8, the solubilities of NaCl and Na₂SO₄ were 36 g and 19.5 g, respectively, when the
214 temperature was about 20°C, as the same as that when the Large-scale compression test was performed in this study.
215 Based on this concept and the result of this compression test, it may be deduced that most the soluble salts that initially
216 acted as the binder of soil skeleton (Zhang et al. 2020) and the pore fillers in the soil samples were dissolved by the
217 process of the first 3 times of adding the brine water. Meanwhile, the density of the samples gradually decreased with the
218 increasing times of adding the brine water, which resulted in an increased compressive deformation. Especially when
219 adding the brine water 3 times, the soluble salt reached its maximum solubility, resulting in the weakest soil structure and
220 the maximum stabilized compressive deformation compared with that in the condition of adding the brine water for 1

221 and 2 times. When adding the brine water for 4 times, the soluble salt content in the soil samples was too high for the
222 water in the soil samples to dissolve all of them. Therefore, parts of soluble salt crystal-separation acted as the binder of
223 the soil skeleton and the pore filler in the soil again. This crystal-separation due to the accumulative effect of adding the
224 brine water enhanced the soil structure. Thus, the amount of the compressive deformation decreased and the compression
225 modulus increased when adding the brine water for 4 and 5 times.

226 4.2. The results and analysis of salt expansion tests

227 4.2.1. The results of salt expansion tests

228 Fig. 9 shows the variation of salt expansion of the sample TL-1 mixed with the test water-A (sulfate) and the sample
229 TL-2 mixed with the test water-B (chloride) under the influence of cooling. The temperature gradient was
230 $25^{\circ}\text{C}\rightarrow 20^{\circ}\text{C}\rightarrow 15^{\circ}\text{C}\rightarrow 10^{\circ}\text{C}\rightarrow 5^{\circ}\text{C}\rightarrow 0^{\circ}\text{C}\rightarrow -5^{\circ}\text{C}\rightarrow -10^{\circ}\text{C}\rightarrow -15^{\circ}\text{C}$. Fig. 10 shows the samples that had been cured for 12
231 hours under the room temperature of 25°C after the test finished.

232 From Fig. 9, adding the brine water for 1 time had a limited influence on the salt expansion characteristic of the
233 samples. With the increasing times of adding the brine water, the salt expansion characteristic of the samples changed
234 significantly. After adding the brine water for 2 times, the results showed that the amount of salt expansion of the samples
235 mixed with the sulfate brine water increased dramatically from 0.685 mm to 3.964 mm, while the samples mixed with
236 the chloride brine water decreased obviously from 0.495 mm to 0.146 mm, with the shrinkage occurred at the beginning
237 of cooling. As the times of adding the brine water continued to increase, the total amount of salt expansion of the samples
238 mixed with the sulfate brine water continued to increase gradually from 5.594 mm to 6.120 mm. Meanwhile, the total
239 amount of salt expansion of the samples mixed with the chloride brine water continued to decrease gradually from 0.130
240 mm to 0.037 mm, with the shrinkage increasing gradually at the beginning of cooling.

241 In comparison with the samples that added pure water for 5 times, the increasing times of adding the sulfate brine
242 water increased the salt expansion amount, with a maximum salt expansion increasement of 7.9 times. While the primary

243 effect of adding the chloride brine water on the samples was to increase the shrinkage, this decreased the amount of salt
244 expansion to some extent, with a maximum salt expansion reduction of 12.4 times.

245 4.2.2. The analysis of salt expansion tests

246 The reason for this phenomenon found from Fig. 9 is discussed as follow. The Na_2SO_4 that initially dissolved in the
247 water would absorb the water molecule to form $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ under the condition of cooling as presented in Fig. 8
248 resulting in the salt expansion (Wan et al. 2017a). The chemical formulation of this process is $2\text{Na}^+ + \text{SO}_4^{2-} + 10\text{H}_2\text{O} =$
249 $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$. There was a minimum salt content for the salt expansion to occur in the sulfate saline soils (Gao et al.
250 1997a). Because the samples used in this experiment contained a certain level of chloride salt, which can inhibit the salt
251 expansion of the sulfate saline soil (Xiao et al. 2017), while the sulfate salt content in the soil samples was relatively low
252 after adding the test water-A (sulfate brine water) for one time. Therefore, the amount of salt expansion was relatively
253 low after adding the test water-A (sulfate brine water) for one time. However, the sulfate salt was accumulated to a
254 relatively higher level after adding the test water-A (sulfate brine water) for 2 to 3 times with sufficient water content.
255 Thus, the Na_2SO_4 phased to $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$ under the condition of cooling, which resulted in the salt expansion amount
256 increased obviously after adding the test water-A (sulfate brine water) for 2 to 3 times. As the sulfate salt content in the
257 soil samples increased after adding the test water-A (sulfate brine water) for 4 to 5 times, the total amount of water was
258 insufficient for Na_2SO_4 to crystallize to $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$. Thus the amount of salt expansion became stable (Figure 9a).

259 With the test water-B (chloride brine water) added, the $\text{Cl}^-/\text{SO}_4^{2-}$ ratio in the samples continued to increase, the
260 common ion effect of NaCl on Na_2SO_4 reduced the amount of water for Na_2SO_4 crystallization, which resulted in a
261 decreased amount of crystallized $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$. Thus the amount of salt expansion gradually decreased, which was
262 proved by (Lai et al. 2017). Besides, chloride sodium in the test sample reduced the freezing point of water, the higher
263 the concentration of chloride sodium, the more obvious the effect of reducing the freezing point. This effect of lowering
264 the freezing point is much stronger than sulfate sodium (Wan et al. 2017a). Thus, the added chloride sodium reduced the

265 minimum temperature that salt expansion needed, which also inhibited the salt expansion (Figure 9b).

266 4.3. The results and analysis of collapse tests

267 4.3.1. The results of collapse tests

268 The result of the collapse tests is shown in Figures 11 and 12. From Fig. 11, the rule of the final deformation of
269 collapse test is presented as follows: by adding of the brine water, the final deformation increased dramatically at first
270 and reached the largest deformation when added the brine water for three times, and then gradually decrease until stable.
271 This rule is independent of the types of brine water.

272 From Fig. 11, with an increased amount of the brine water added, the collapse deformation of the soil samples
273 increased continuously from 0.198 mm to 1.074 mm and 0.133 mm to 1.204 mm for the sulfate water and the chloride
274 water respectively. From Fig. 12, with the addition of the brine water, no matter what kind of brine water, the collapse
275 deformation of the samples increased continuously. However, the collapse deformation of the soil sample C5 (adding the
276 chloride water for 5 times) was greater than that of the soil sample S5 (adding the sulfate water for 5 times). This result
277 is consistent with that of Wang (2017) and Song (2007). Compared with the samples in which the pure water was added
278 for 5 times, the collapse deformation of coarse grain sulfate saline increased by 4.464 times when adding the sulfate water,
279 while that was 8.052 times when adding the chloride water.

280 4.3.2. The analysis of collapse tests

281 In the samples that mixed with the brine water for 0 to 3 times, as the water within the soil samples dissolved all the
282 soluble salt, there was no crystal salt left to act as a pore filler or binder among soil particles. Meanwhile, the soil structure
283 was weakened in the process of adding the brine water. Thus, the collapse deformation increased gradually with the
284 increase of the load.

285 In the samples that added the brine water for 4 to 5 times, the water within the soil samples failed to dissolve all the
286 soluble salt, resulted in that some contents of soluble salt were in the form of crystallization in the soil samples and acted

287 as a pore filler and binder among soil particles. After adding the pure water at 200kPa (Corresponding to rainfall in nature
288 environment), all the soluble salt was dissolved immediately, which weaken the soil structure as the loss of the crystallized
289 soluble salt that acted as a pore filler and binder among soil particles. Thus, a sudden deformation increase was observed
290 at 200 kPa for all samples and the collapse deformation increased continually after adding the brine water for 4-5 times.

291 The final deformation of the collapse test included three parts: the deformation before adding the pure water, the
292 collapse deformation, and the deformation after the pure water was added. From the results, the deformation before
293 adding the pure water was the same as the compression deformation. In the comparison of the collapse deformation and
294 the deformation after the pure water was added, the deformation before the pure water added was higher. Thus, the final
295 deformation behaviour is similar to that of compression deformation. No matter what kind of brine water was added to
296 the soil samples, the undissolved sulfate and chloride salt acted as a binder or pore filler among soil particles which could
297 all be dissolved in the process of adding the pure water at 200 kPa, resulting in the weakening of the soil structure. Thus,
298 the collapse is occurring independently of salt types. However, as chloride is more soluble in the water than sulfate, the
299 amount of collapse deformation is related to the salt types.

300 When the collapse tests were performed, the environment temperature was approximately 20°C, with the same
301 amount of pure water added to test containers for the samples added with TL-1 and TL-2. At this temperature, the
302 solubility of NaCl (36g/100 g water) was higher than that of Na₂SO₄ (19.5 g/100 g water), which means that more amount
303 of NaCl can be dissolved. Therefore, the increased collapse deformation (1.071 mm) of soil sample mixed with the
304 chloride brine water was higher than that (0.876 mm) of soil sample mixed with the sulfate brine water.

305 **5. Conclusion**

306 This study investigated the influence of adding different times of brine groundwater on the engineering
307 characteristics of coarse grain embankment fill material through the large-scale consolidation compression tests, the salt
308 expansion tests and the collapse tests . The conclusions are summarized as follow:

309 (1) Upon adding the brine water, the compression deformation of coarse gain sulfate saline materials showed a trend
310 of gradual stability after the increased deformation at the beginning. The variation of the compression coefficient
311 presented a typical three-stage law which is independent of the primary ion type in the brine water: 1) decreased stage;
312 2) increased stage; 3) stabilised stage. The compression coefficient of the sample that adding the brine water for 3 times
313 is highest compared with other conditions. The accumulative effect of adding the brine water on the compression
314 characteristics of coarse grain sulfate soil was evident and mainly related to the cumulative salt amount in the soil samples
315 and the distribution form of crystallized salt among soil particles.

316 (2) Under the condition of cooling, with the sulfate brine water added, the salt expansion of coarse grain sulfate
317 saline fill materials showed a trend of a noticeable increase at the beginning followed with a stabilized deformation. The
318 amount of salt expansion increased by 7.9 times at most compared with the samples that added the pure water only. When
319 the salt content in the soil sample reached a certain level—about 2% (after adding the sulfate brine water 4 times), limited
320 by the amount of water to dissolve the soluble salt, the salt expansion tended to be stabilized.

321 (3) Under the condition of cooling, with the chloride brine water added, there was shrinkage behaviour observed in
322 the coarse grain sulfate saline fill materials, which inhibited the salt expansion. The salt expansion deformation was
323 significantly reduced and then stabilized. The salt expansion deformation was reduced by 12.4 times at most compared
324 with the samples that added the pure water only. The inhibition effect of chlorine salt on the salt expansion of coarse grain
325 sulfate saline fill materials was mainly related to the relative content of NaCl and Na₂SO₄ accumulated in the soil after
326 the brine water added.

327 (4) With the brine water added, the collapse deformation of coarse grain sulfate saline fill materials showed a trend
328 of continuous increase, which increased the collapse deformation by 8.05 times at most compared with the samples that
329 added the pure water only. The accumulative effect of adding the brine water on the collapse characteristics of coarse
330 grain sulfate saline fill materials was evident and mainly related to the cumulated salt amount in the soil and the

331 distribution form of crystallized salt among soil particles.

332 According to this study, it is further shown that even a small amount of the soluble salt in groundwater may have a
333 greater impact on the engineering properties of coarse grain embankment fill materials considering the cumulative effect
334 of the soluble salt. It is recommended that preventive measures should be carried out during the construction process for
335 safety consideration in the saline soil areas.

336 **Conflict of interest**

337 There are no conflicts of interest.

338 **Data Availability**

339 Some or all data, models, or code that support the findings of this study are available from the corresponding author
340 upon reasonable request. (1) Ion assay results of soil samples collected along D-Y highspeed railway. (2) Ion assay
341 results of the groundwater samples collected along D-Y highspeed railway project. (3) Other data can be obtained
342 from submitted paper.

343 **Acknowledgements**

344 The authors gratefully acknowledge the financial support of (1) Natural Science Foundation of China (Grant No.
345 51209006), (2) Natural Science Basic Research Program of ShaanXi (Grant No. 2019JM-147), (3) China scholarship
346 council (File No.201906565004), (4) The major scientific research project of the China Railway Group (Grant No. 2017-
347 major-11-04), and (5) Fundamental Research Funds for the Central Universities, CHD (Grant No. 300102219219).

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Table 1 Soluble salt content of test samples

Test sample	Natural soil sample /%				After adding salt /%			
	SO ₄ ²⁻	Cl ⁻	HCO ₃ ⁻	Total content of soluble salt	SO ₄ ²⁻	Cl ⁻	HCO ₃ ⁻	Total content of soluble salt
TL-1	0.09	0.02	0.01	0.16	0.16	0.02	0.01	0.36
TL-2	0.10	0.02	0.01	0.18	0.34	0.04	0.01	0.77

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Table 2 The main ion contents of test water samples

Test water	Positive ions (g/L)		Negative ions (g/L)		Total mineralization (g/L)
	Na ⁺	K ⁺	SO ₄ ²⁻	Cl ⁻	
Test water-A	9.70	20.11	45.00	0.00	74.81
Test water-B	9.97	21.45	0.00	35.00	66.42

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Table 3 Design scheme of adding test water

Types of test water	Test samples	number	Time of adding test water	Times of adding pure water
Test water-A	TL-1	S0	0	5
		S1	1	4
		S2	2	3
		S3	3	2
		S4	4	1
		S5	5	0
Test water-B	TL-2	C0	0	5
		C1	1	4
		C2	2	3
		C3	3	2
		C4	4	1
		C5	5	0

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Table 4 Changes of the void ratio of samples added brine water 1-5 times compared with that of adding pure water under the load of 400 kPa

Samples	Times of adding brine water				
	1	2	3	4	5
TL-1	-0.001	-0.002	-0.010	-0.006	-0.007
TL-2	-0.001	-0.002	-0.006	-0.004	-0.004

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Table 5 Stable deformation amount and ratio (compared with samples added pure water for 5 times) of samples mixed with brine water for 0-5 times

Times of adding brine water (Times)	0	1	2	3	4	5
Stable deformation of TL-1(mm)	-203.25	-234.25	-265.25	-440.50	-340.40	-321.63
Stable deformation of TL-2(mm)	-221.50	-244.25	-267.00	-396.50	-281.67	-274.80
Average stable deformation of TL-1 and TL-2(mm)	-212.375	-239.25	-266.125	-418.5	-311.034	-298.214
Deformation ratio of TL-1(%)	0%	15.25%	30.50%	116.73%	67.48%	58.24%
Deformation ratio of TL-2(%)	0%	10.27%	20.54%	79.01%	27.16%	24.06%

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436 **Figure Captions list**

437

438 **Fig. 1** Sampling location (<https://www.google.com/maps/place>)

439 **Fig. 2** The particle size distribution of samples

440 **Fig. 3** Self-made temperature controlling test box. (a) Temperature controlling test box. (b) principle diagram of the temperature
441 control test box. (c) The test container that put inside the test box

442 **Fig. 4** Test device for collapsibility test

443 **Fig. 5** e-p curve of the whole compression process. (a) TL-1 with test water sample-A (sulfate) (b) TL-2 with test water sample-
444 B (chloride)

445 **Fig. 6** The change of soil deformation with the times of adding brine water

446 **Fig. 7** Changes in the coefficient of compressibility (100-200kPa)

447 **Fig. 8** Solubility curve of soluble salt (Lai et al. 2017; Wan et al. 2017)

448 **Fig. 9** The relationship between the sample deformations and cooling time with different added salt types and different added
449 times when temperature reduce from 25°C to -15°C. (a) TL-1 with test water sample-A (b) TL-2 with test water sample-
450 B

451 **Fig. 10** Samples after cooling

452 **Fig. 11** Load-deformation-relation curve of the sample with brine water added times. (a) TL-1 with test water sample-A (sulfate)
453 (b) TL-2 with test water sample-B (chloride)

454 **Fig. 12** Variation of collapse deformation with the times of adding brine water

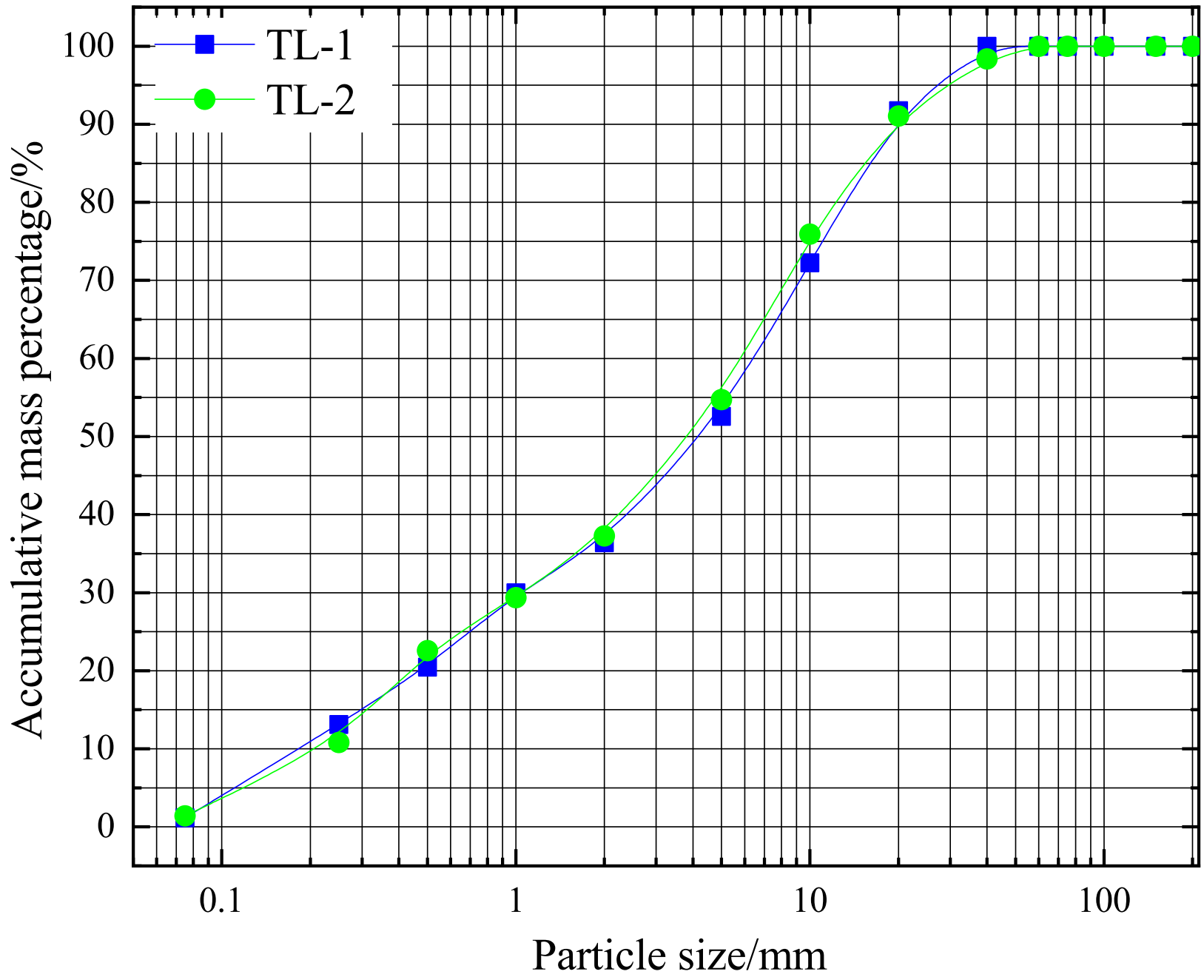
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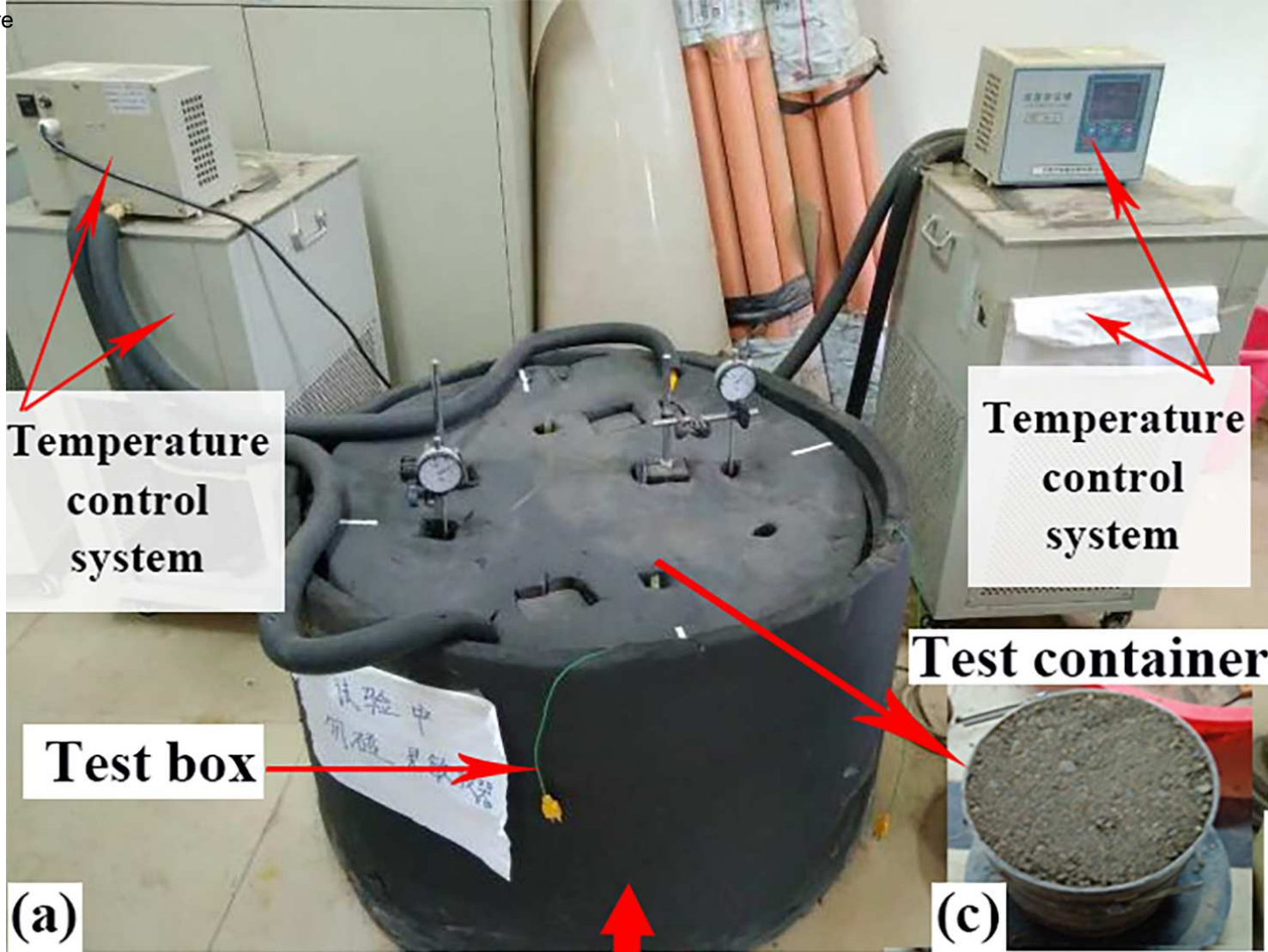
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Figure



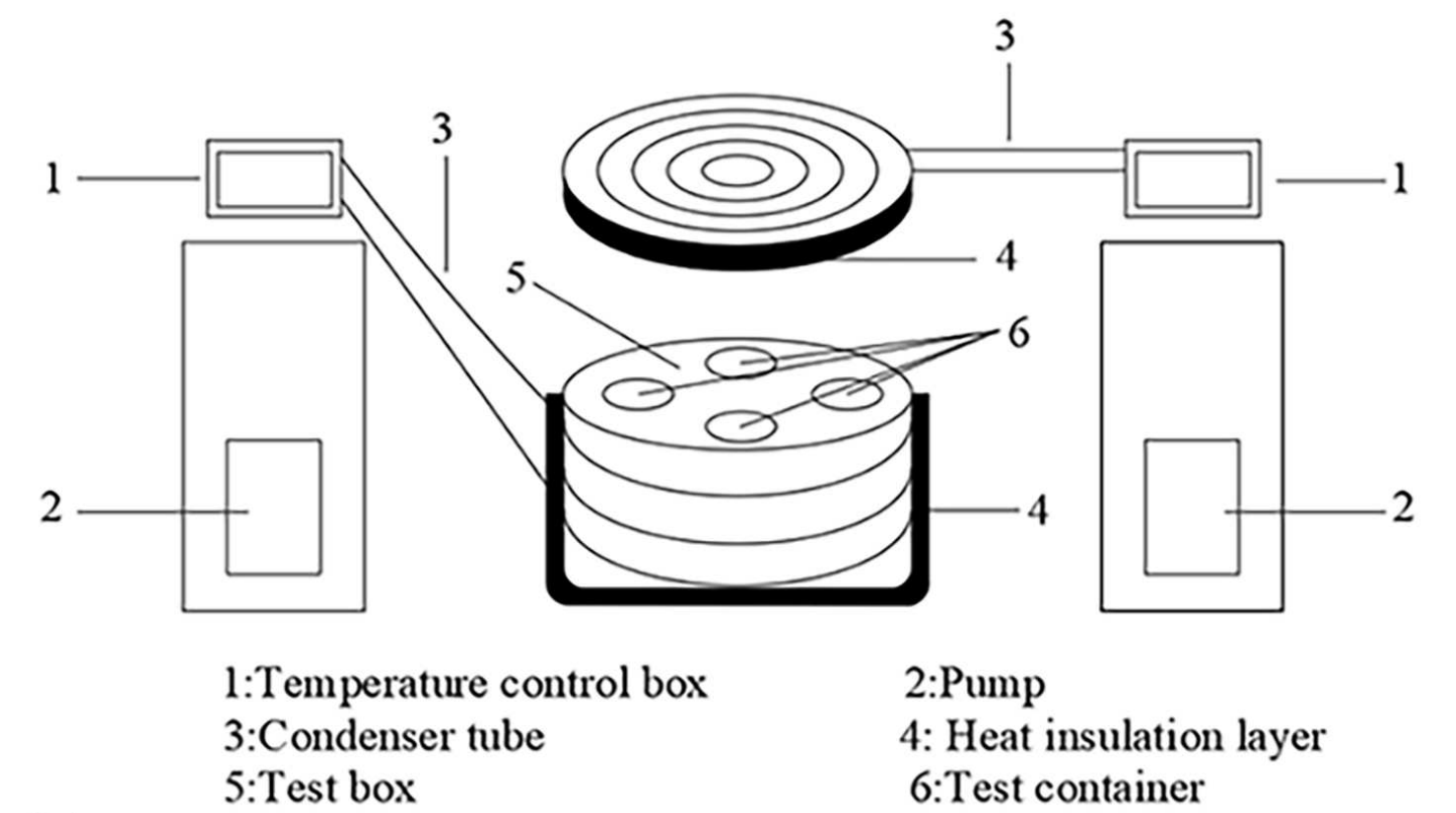
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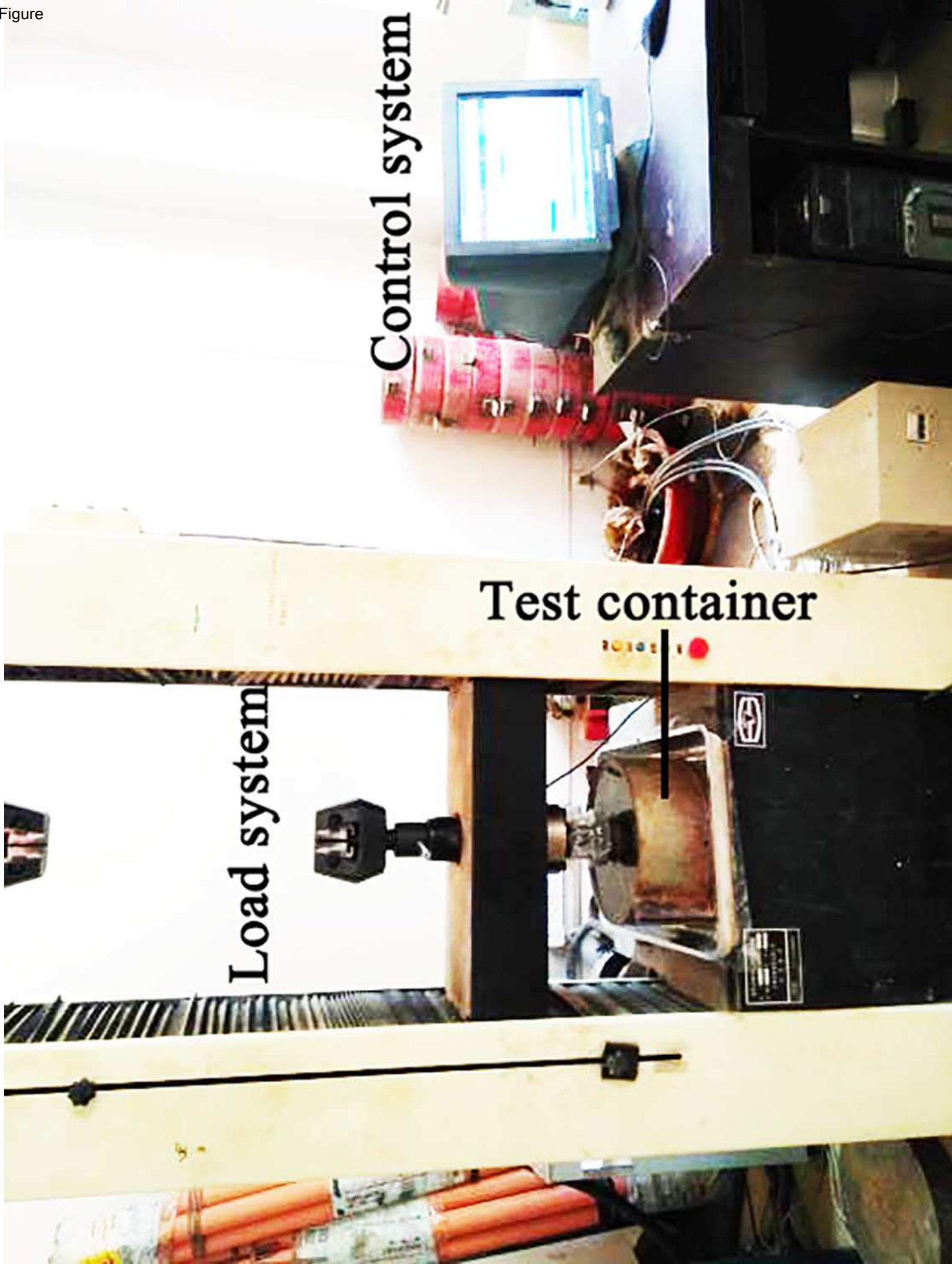


(a)

(c)



(b)

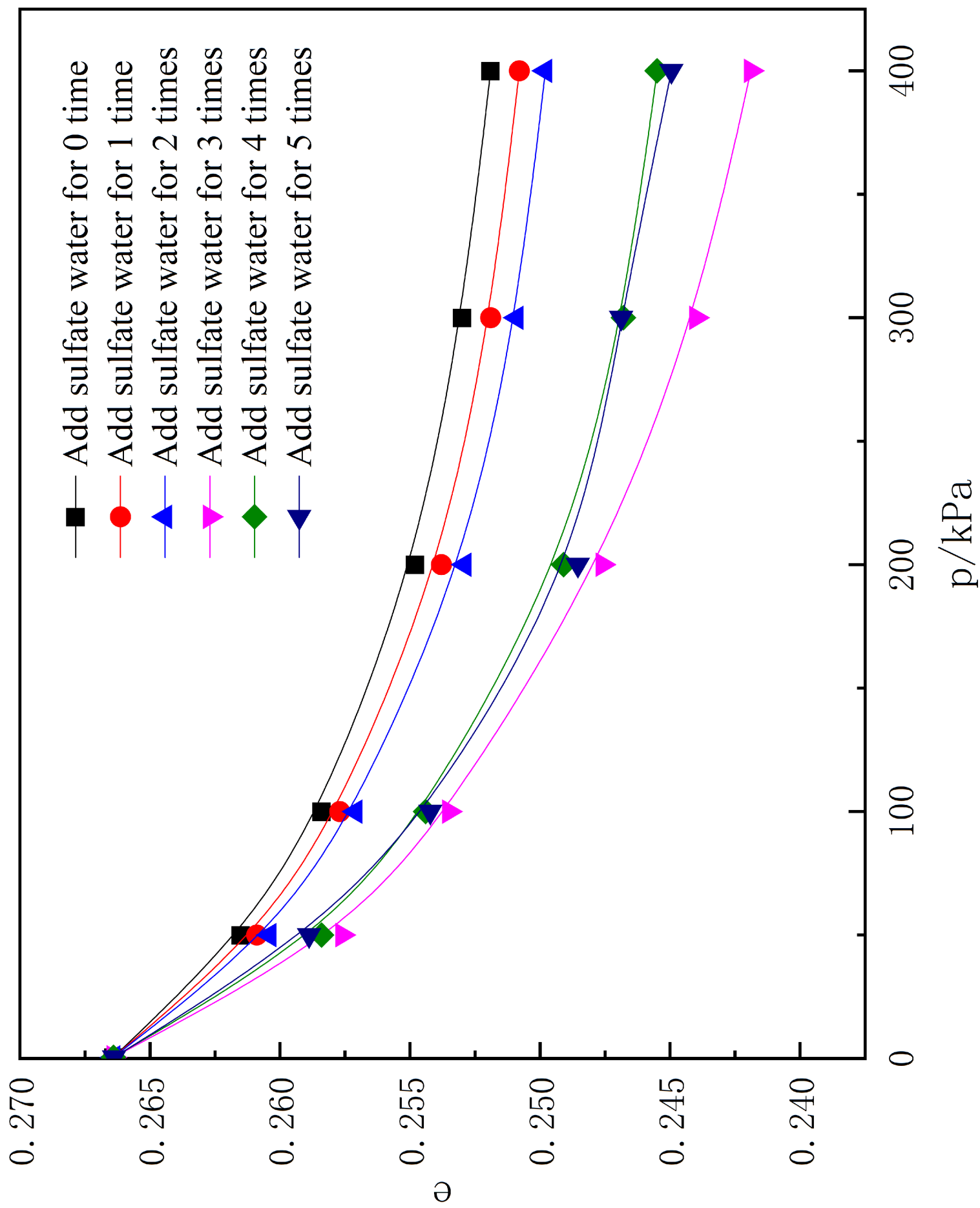


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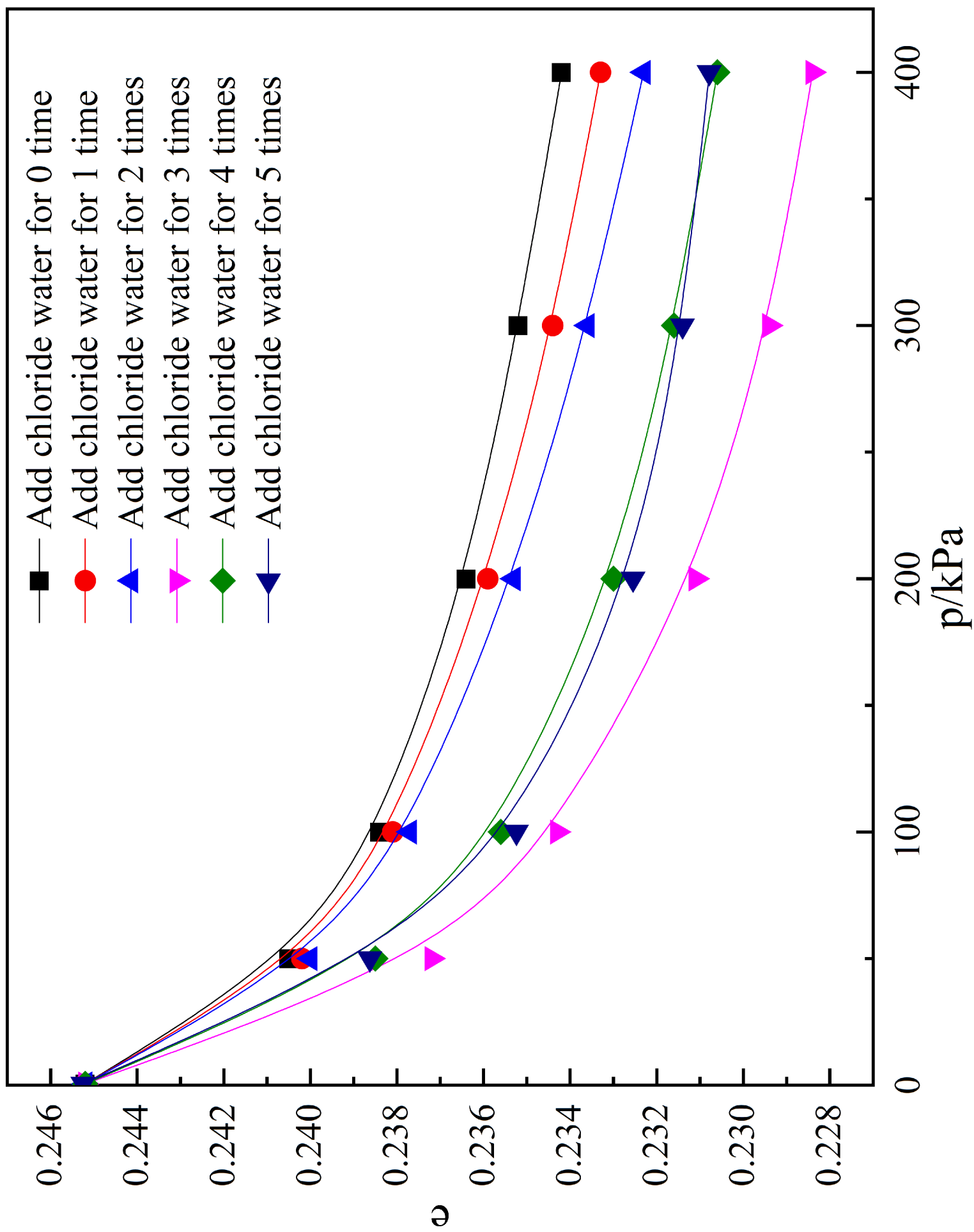
Test container

Load system

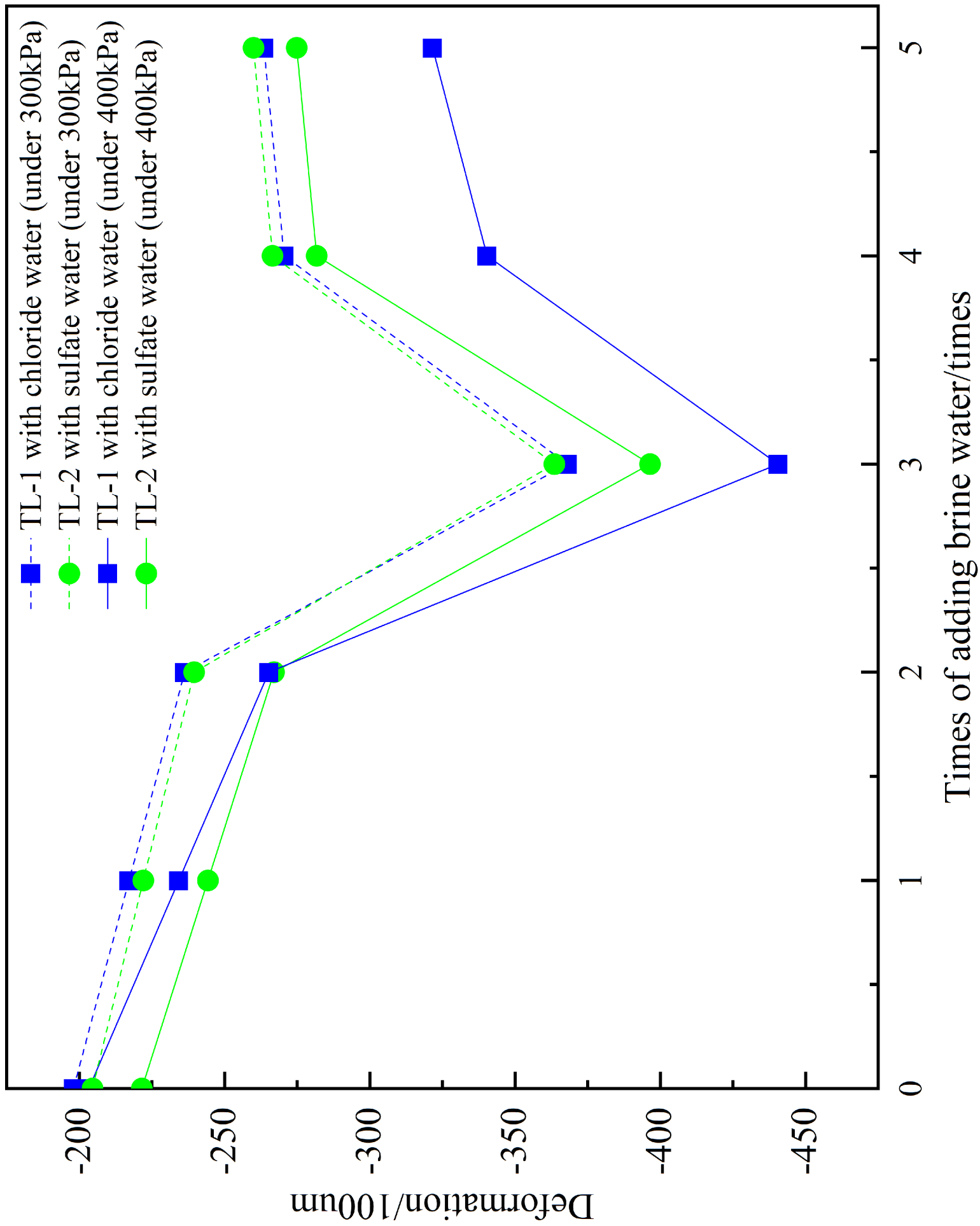
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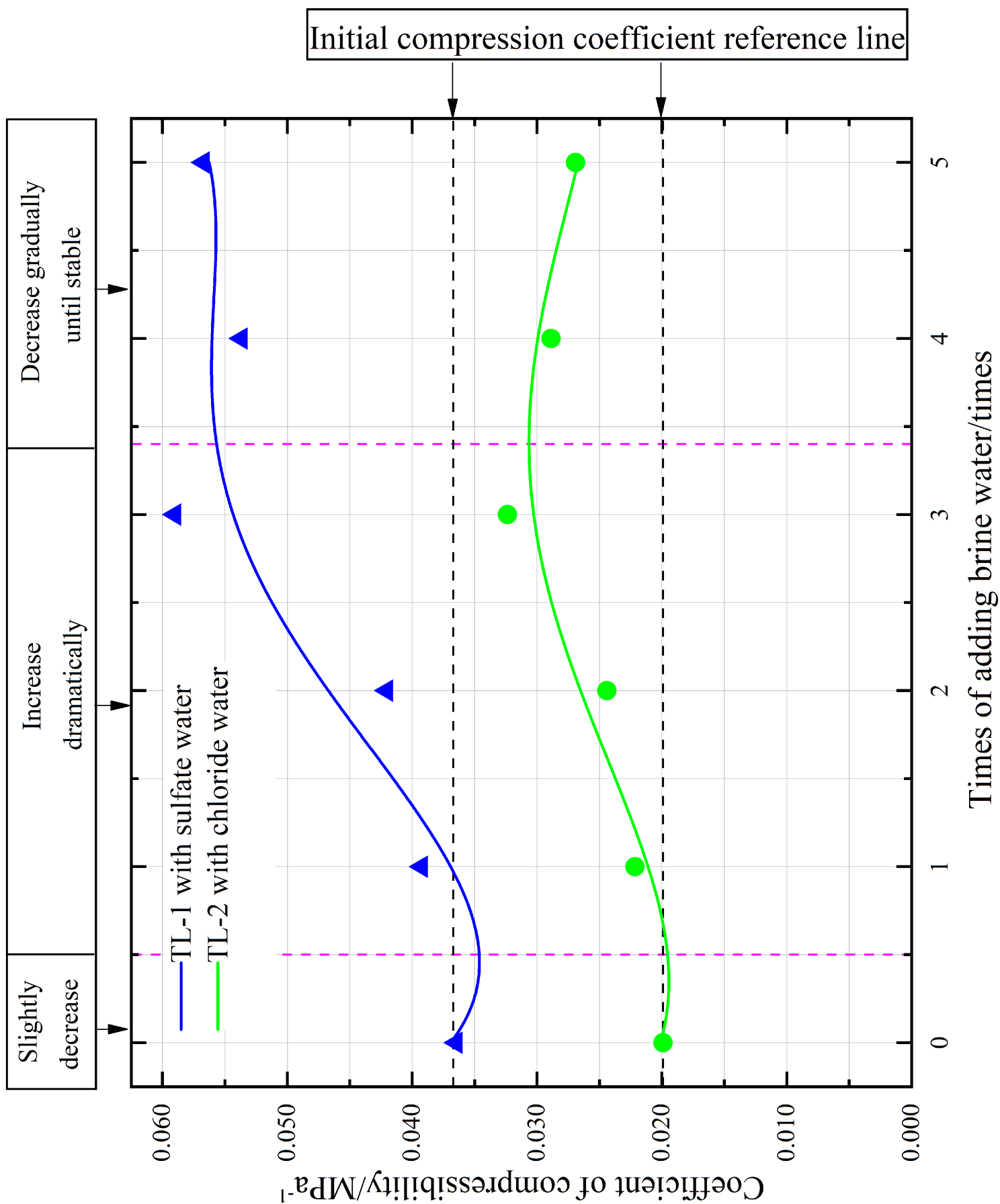
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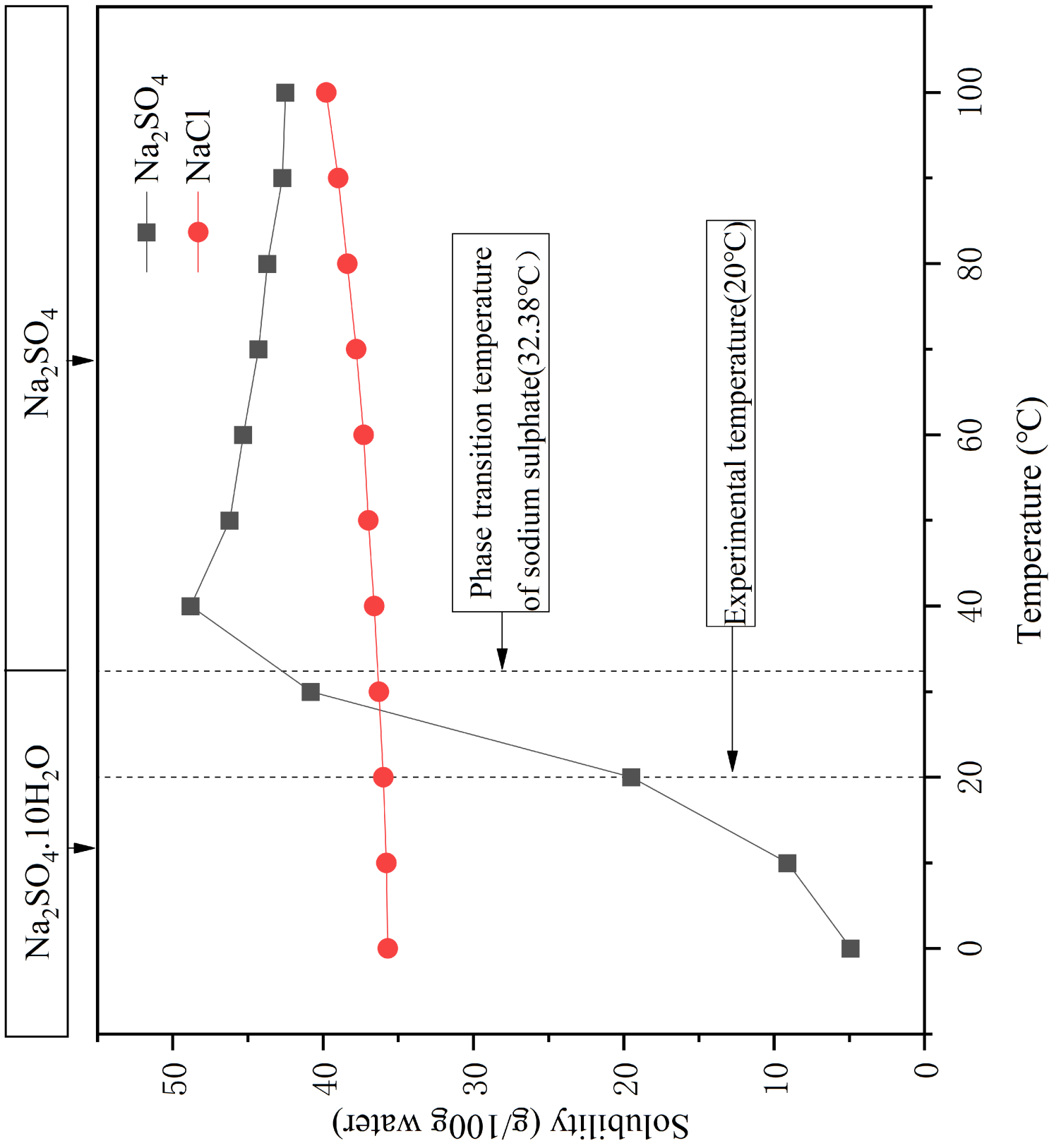
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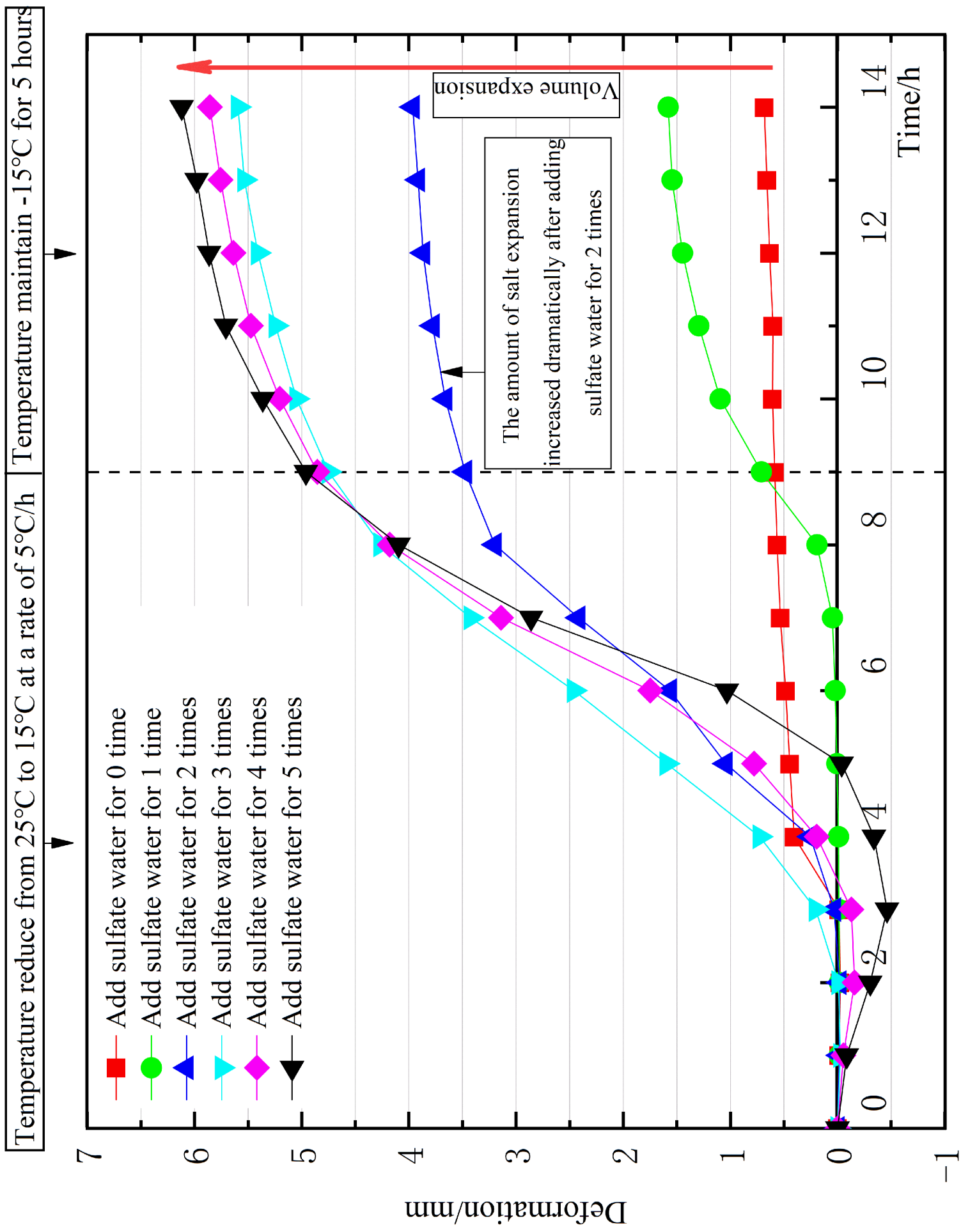
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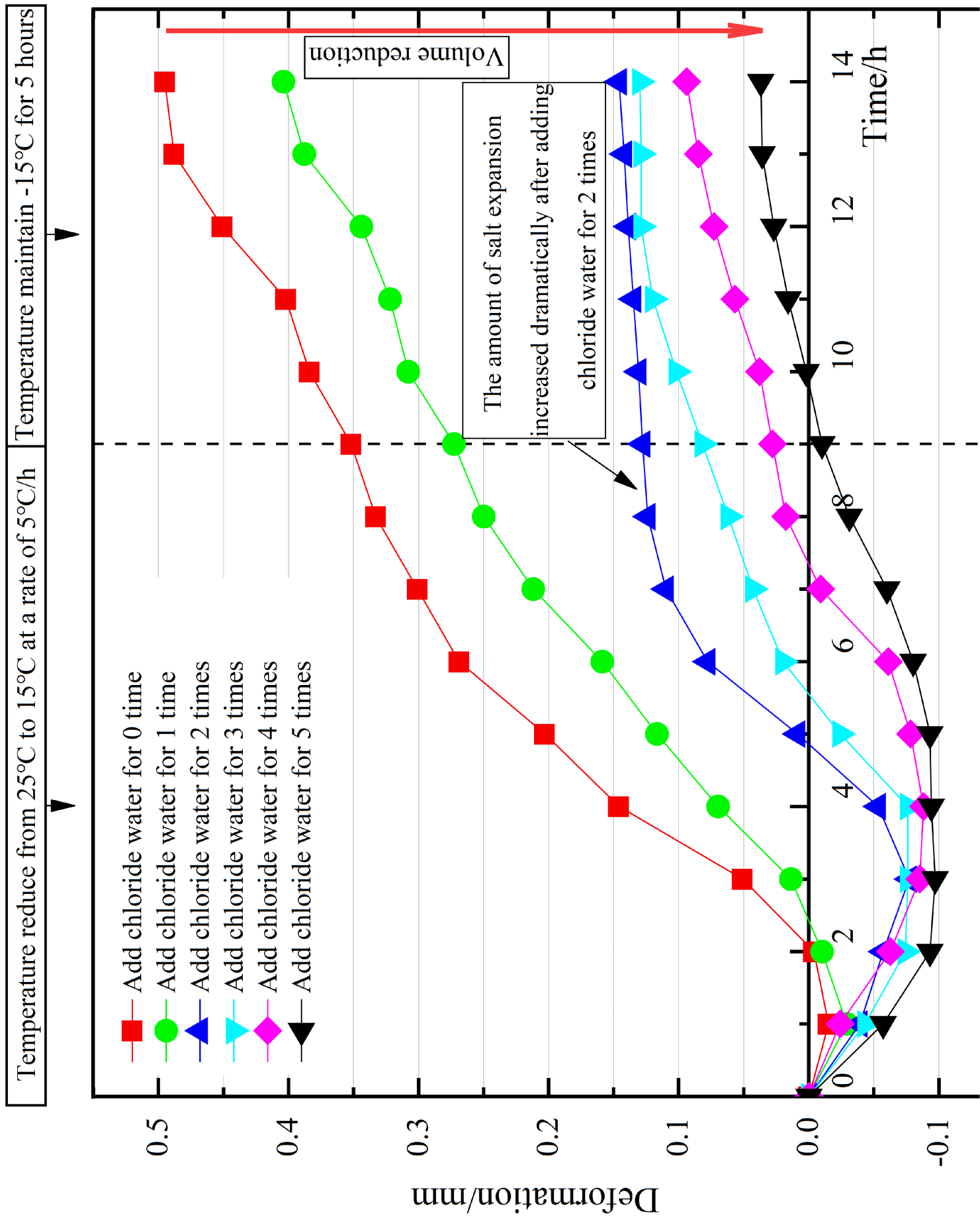
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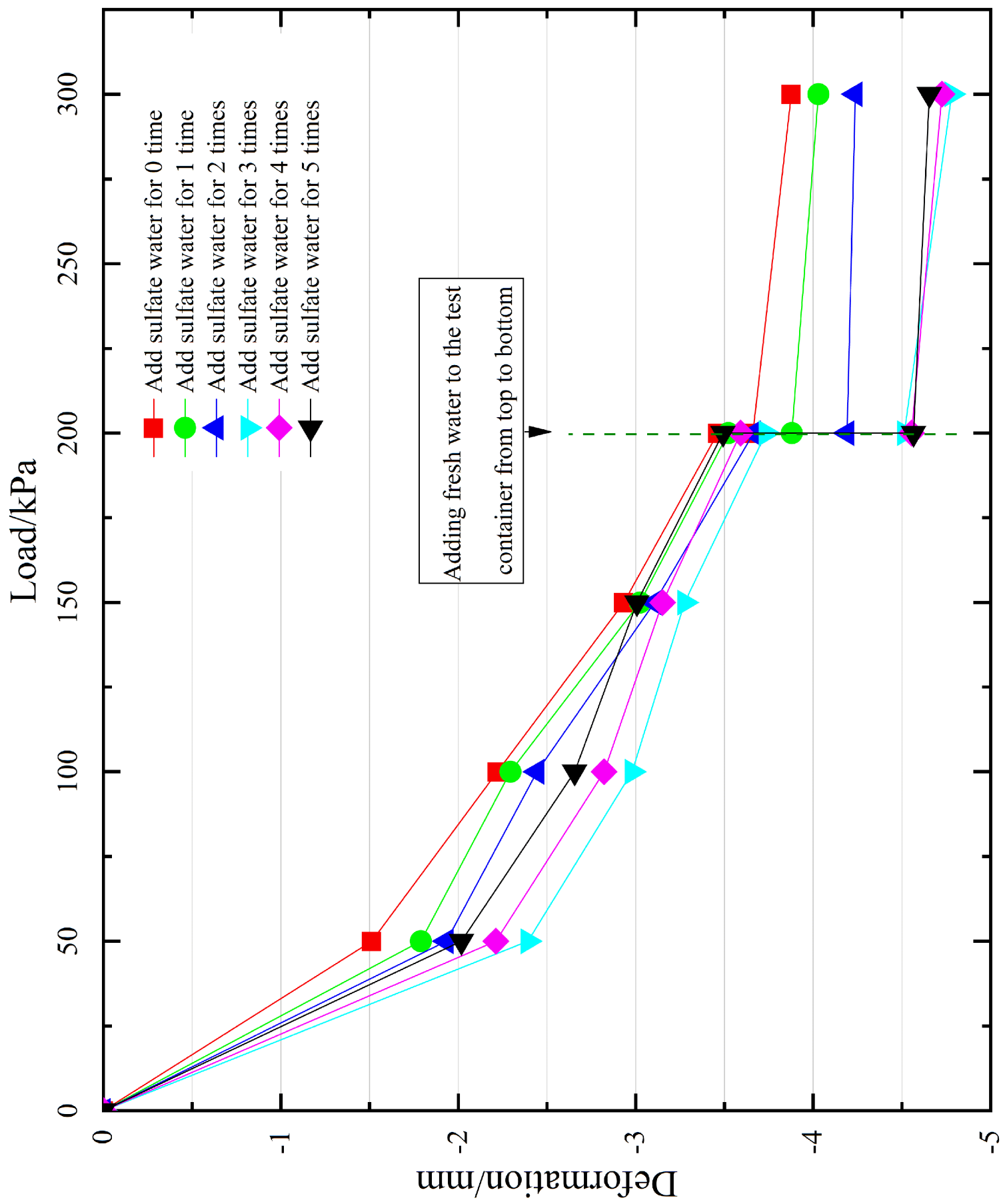


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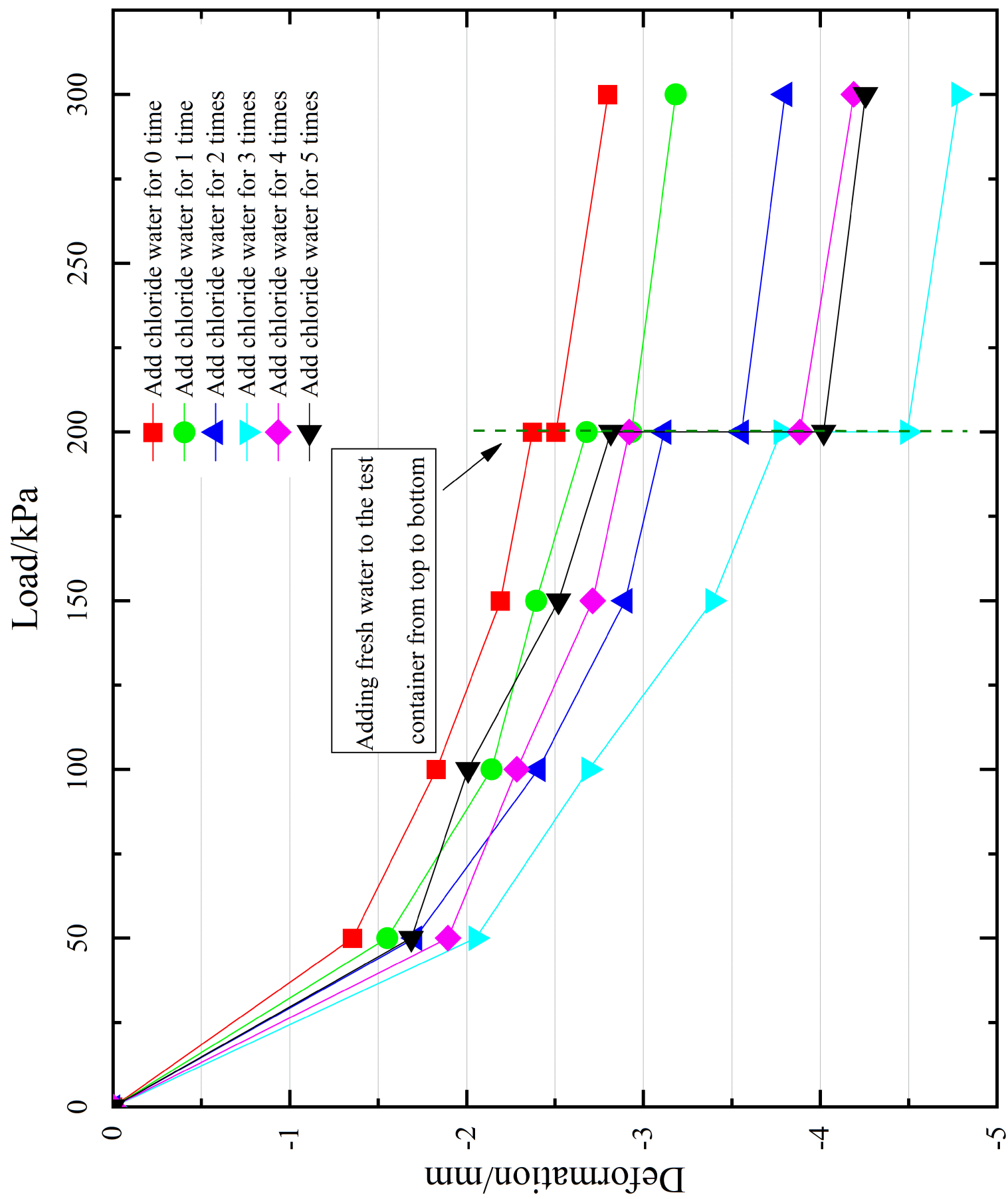




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Figure



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