

1 Article

## 2 Nutrient Resources Recovery By A Creative Co- 3 Composting Method of Municipal Solid Wastes and 4 Wastewater Treatment Plant Sludge

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12 **Abstract:** The purpose of this study is nutrient resources recovery by achieving the optimal chemical  
13 oxygen demand (COD) and carbon to nitrogen ratio (C/N) in co-composting wastewater treatment plant  
14 sludge with Municipal Solid Wastes (MSW). In this effort, the co-composting has been conducted in form  
15 of a case study in the northern region of Iran. In this research, 192 tests were carried out on four series of  
16 samples examined in terms of waste to sludge ratio, different aeration period, the percent of porous  
17 materials and the moisture content. This study was carried out at a temperature of 50 °C for a 15 day period  
18 by application of the in-vessel system and shows that the best ratio for waste to sludge is 2:1, while the 8  
19 hour period is the best aeration period. The porous material which can be added to the composting process  
20 is limited to 15% in weight. In other words, any more or less amount of this material will adversely impact  
21 the process. Moreover, this research suggests that the sludge dewatering is not required in such processes.  
22 In Addition, the efficiency of both COD and C/N reductions equals to about 40%.

23 **Keywords:** Nutrient Resources Recovery , Chemical Oxygen Demand (COD), Carbon to Nitrogen Ratio  
24 (C/N), Co-Composting, Wastewater Sludge, Municipal Solid Wastes (MSW)

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### 26 1. Introduction

27 The rapid growth of industrial and technological advancements, coupled with rapid population  
28 growth have led to two major challenges in relation to generated urban solid waste and wastewater.  
29 Although various methods have been proposed for disposal of these materials, each of the available  
30 methods has certain disadvantages and demand development of more advanced methods to tackle the  
31 problems. Urban wastewater treatment has long been performed in a variety of ways, with almost all facing  
32 the challenge of filtration the resulting sludge. This sludge, while highly polluted, has abundant of water,  
33 which causes major problems in its management, and it is very difficult for any conventional solution to  
34 deal with it, such as dewatering, landfilling, spreading, etc. Meanwhile, co-composting is known as a  
35 potential solution to this problem [1]. On the other hand, chemical oxygen demand (COD) and Carbon to  
36 Nitrogen ratio (C/N) are two important parameters in composting as they affect other parameters such as  
37 microorganism's activities. By determining the optimum ratio of municipal solid waste (MSW) and

38 wastewater sludge, this paper aims to present a sustainable co-compost solution. Therefore, the reduction  
39 of COD or C/N to an optimal level usually leads to other optimal parameters. In addition, they are chosen  
40 as maturity indicators. In this study using simultaneous optimization of COD and C/N for wastewater  
41 sludge and municipal waste co-composting, the optimal amounts of four co-composting design parameters  
42 including aeration period, the percent of porous material, the moisture content and waste to sludge ratio  
43 are determined.

## 44 2. Research background

45 Composting has become precious in the stabilization of MSW due to its environmental adaptability.  
46 Every year, extensive studies have been undertaken on solid waste management systems, especially  
47 compost systems. However, published articles focusing on co-composting of MSW and wastewater sludge  
48 are very limited. For example, Shuval et al. during 1981 to 1989, carried out several economization tests on  
49 various co-composting materials with different proportions. They stated that co-composting of wastewater  
50 sludge with any organic substance waste is possible, but economic issues play an important role in choosing  
51 the primary ratios [2]. Onwosi et al. proposed different types of composting methods reportedly applied  
52 in waste management [3]. Also, the critical factors such as temperature, pH, C/N, moisture content, the  
53 particle size that have been considered relevant in the monitoring of the composting were clarified.  
54 Appropriate procedures to enhance and optimize process effectiveness were also addressed. Still, during  
55 composting, some difficulties such as leachate generation, gas emission and lack of consistency in assessing  
56 maturity indices were imminent. In their study, these challenges were, and some strategies for improving  
57 them were presented. Ultimately, they highlighted some novel technologies that could improve  
58 composting. Cofie et al. presented the potentials and performance of mixed treatment of fecal sludge (FS)  
59 and MSW by co-composting [4]. The aims were to study the relevant MSW type, MSW/FS mixing rate and  
60 the outcome of turning rate on compost quality. Specimens were taken at each turning and examined for  
61 total solids, electrical conductivity, total volatile solids, total organic carbon, pH, ammonium and nitrate  
62 nitrogen and total Kjeldahl nitrogen. Results showed there was no meaningful effect of various turning  
63 repetitions on the temperature changes and the quality of compost. Other researchers studied the co-  
64 composting performance of sewage sludge (SS) and organic fraction of municipal solid waste (OFMSW) at  
65 various proportions [5]. Results revealed that higher SS proportion could quickly initialize the process;  
66 while raising OFMSW prolonging the thermophilic period and expanding the humification degree. But,  
67 extreme OFMSW wanted a longer co-composting period to ensure great compost maturity and quality.  
68 Other study focused on the impact of different bulking waste such as wood shaving, combined with an  
69 OFMSW composting within evaluating their influence on microbial enzymatic actions and kind of  
70 completed compost [6]. The outcomes revealed that OFMSW mixed with wood shaving and the microbial  
71 consortium was a suitable tool to help the enzymatic activity and the shortened composting time. Cai et al.  
72 carried out four test series on co-compost of wastewater sludge and rice husk, and they showed that much  
73 of the semi-volatile organic compounds excluded from the compost after 56 days [7]. Using anaerobic pilot  
74 reactor, some researchers evaluated a composting mixture of municipal solid waste, wastewater treatment  
75 sludge, wood chips and a series of enzymes [8]. Referring to their study, the type of the combining material  
76 in addition to the type of the composting material, and the composition ratios of these materials have also  
77 a substantial influence on the quality of the final product. Brinton examined the history of compost  
78 appreciation and particularly looks at the emerging awareness of the need to distinguish composts from  
79 other re-cycled wastes and common fertilizers [9]. In other research, lab tests using sewage sludge as an  
80 underlying substrate for composting are presented [10]. Values of characteristic parameters for the  
81 composting process, fat content and lipolytic enzymatic action were observed in aerated static lab-size  
82 composters. Results showed co-composting with sewage sludge can be counted as a viable option to treat  
83 solid wastes in high proportions up to 40 % although a maximum ratio of 20 % may be advised to avoid

84 long composting periods. The influences of various municipal organic waste (MOW) on biological matter  
85 stabilization and compost quality were considered by Tognetti et al. [11]. Results showed shredded  
86 treatments presented faster organic matter stabilization than non-shredded treatments. Wood shavings  
87 addition significantly improved the quality of compost but decreased total nitrogen and available nutrient  
88 concentrations. Zhanga et al. [12] investigated the main physicochemical characteristics, i.e., pH and  
89 electrical conductivity (EC), in co-composting pine sawdust with fresh solid swine manure. The results  
90 intimated that N and P decay primarily happened in the mesophilic phase, while organic carbon crumbled  
91 in the thermophilic phase and 30% swine manure with initial C/N ratio of about 40 was more desirable for  
92 composting organic substrates. In a similar work, Millán [13] developed a field trial of co-composting  
93 municipal solid organic waste with wastewater treatment plants (WWTP) sludge in a municipality of  
94 Boyacá, finding the optimum proportion of these materials, characterizing the two raw materials and the  
95 most suitable mixture. Yang et al. [14] studied co-composting of yard trimmings (YT) and food waste (FW).  
96 The goal was to investigate the proper yard trimmings/food waste mixing ratio. Results showed that 1:1  
97 mixing ratio was the best ratio, where the C/N ratio was 14.15. Bian et al. [15] studied the influences of  
98 matured sewage sludge (MSS) amendment on N<sub>2</sub>O emissions during aerobic co-composting of MSW. The  
99 results confirmed that MSW composting with MSS amendments enhanced N<sub>2</sub>O emissions during the  
100 beginning stage.

### 101 3. Methodology

102 This study has been done using “Co-Composting Optimization Laboratory Reactor” which is  
103 registered under the IP number of IR-388030506 by Saeed Nematy (Figure 1).



104

105 **Fig 1.** Co-Composting Optimization Laboratory Reactor

106 This system consists of a closed chamber, with the length of 1,100 mm and a width of 700 mm and a  
107 height of 900 mm. Four cylindrical vessels were placed in this chamber. Auto elements and digital sensors  
108 continuously controlled ambient temperature. Four side walls of the frame were made from fiberglass  
109 sandwich panels with double galvanized facings in order to reduce heat exchange. Each cell had a  
110 cylindrical shape with a diameter of 550 mm and a height of 600 mm. In this system, the ambient  
111 temperature is controlled by a digital heating system initially. As the temperature increases, the sensors  
112 will act and attempt to cut off the flow of electricity to the elements. However, it takes a long time to drop  
113 the temperature due to very good insulation system. Depending on the desired accuracy, the amount of  
114 heat loss can be defined from zero to ten Celsius degrees. The pilot is also equipped with a central switch,  
115 fuse, and function indicator. Furthermore, two external fans were installed in this reactor as air blowers  
116 and a heat-gas exhaust which enabled the operator for a range of aeration types, so that the fan can be  
117 turned on and a thermal sensor or its functional interval can be set using a digital timer for both. In the  
118 absence of any specific program, manual control of these fans is possible. In this study, an origin separation  
119 phase was conducted on MSW. In the next stage, going to a mill this material will have the approximate

120 dimensions of 4 cm, which is suitable for compost and has a great effect on the fast reduction of organic  
 121 carbon rate. Tiny wood chips with the approximate area of 1,200 mm<sup>2</sup> were used to control the system's  
 122 C/N. In addition, to produce the needed porosity, flexible PVC parts with an approximate length of 20 mm  
 123 was used (Figure 2). The pH of used waste and wastewater sludge were 6.1 and 7.6 respectively.  
 124



125  
 126 **Fig 2.** Porosity providing additives

#### 127 **4. Test series**

128 In this study, four series of tests were designed and conducted as follows:

##### 129 *4.1. Series 1: Determination of the optimum portions of waste and sludge*

- 130 • Constant parameters: temperature, number of aeration and initial C/N
- 131 • Variable parameters: mixture portions
- 132 • Sampling period: every 3 days
- 133 • Test duration: 15 days
- 134 • Controlling parameters: COD and C/N variation (based on EPA and ASTM methods) [16-17].

135 In this series, the temperature was kept at 50°C for two weeks. All samples were aerated once every 8  
 136 hours for twenty minutes, by mixing the content of the tank. Moreover, C/N ratio for all samples was kept  
 137 constant at 25, by changing the mixing ratio and the number of wood chips. Regarding the similar specific  
 138 gravity of the existing sludge to the applied waste chip, both volumes and weight ratios can be used.  
 139 However, the criterion is calculated based on weight ratios. This fact will facilitate and expedite the  
 140 operations at industrial scale, due to the possibility of applying large scales. In this series of tests, a high  
 141 level of dewatering of the sludge was prevented in order to provide a suitable condition for a rapid  
 142 composting process. Table 1 shows waste to sludge ratio in tanks.

143 **Table 1.** Waste to sludge ratio in tanks

Tank No.	Waste to sludge ratio
A1	1:1
A2	2:1
A3	3:1
A4	4:1

144

##### 145 *4.2. Series 2: Constant parameters: Temperature, mixture portions*

- 146 • Constant parameters: mixture portions, initial C/N and initial COD
- 147 • Variable parameters: aeration frequency and duration (times of aeration)
- 148 • Sampling period: every 3 days
- 149 • Test duration: 15 days
- 150 • Controlling parameters: COD and C/N variation

151 In this series, the optimum mixture portions (blending ratio) had been considered for all four tanks  
 152 while they were aerated for two weeks based on Table 2.

153 **Table 2.** Aeration Condition

Tank No.	Aeration frequency	Aeration Duration
B1	continuous aeration	
B2	every 8 hours	15 minutes
B3	every 16 hours	15 minutes
B4	every 24 hours	15 minutes

154

155 *4.3. Series 3: Determination of optimum amount of additives for increasing porosity*

- 156 • Constant parameters: temperature, mixture portions, times of aeration, initial C/N and initial COD
- 157 • Variable parameters: amount of additives for increasing porosity
- 158 • Sampling period: every 3 days
- 159 • Test duration: 15 days
- 160 • Controlling parameters: COD and C/N variation

161 In this series, different amount of additives were added to the samples in order to determine the  
 162 optimum amount for the best level of porosity. The evaluated ratios are shown in Table 3.

163 **Table 3.** Amount of additives in each tank

Tank No.	C1	C2	C3	C4
Additives amount (by volume)	5%	10%	15%	20%

164

165 *4.4. Series 4: Optimum moisture determination*

- 166 • Constant parameters: temperature, mixture portions, times of aeration, amount of additives for  
 167 increasing porosity, initial C/N and initial COD
- 168 • Variable parameters: moisture content of sludge cake
- 169 • Sampling period: every 3 days
- 170 • Test duration: 15 days
- 171 • Controlling parameters: COD, C/N and weight variation

172 At this stage, the optimum moisture content was determined by varying the water content of sludge  
 173 cake. The considered moisture contents are shown in Table 4.

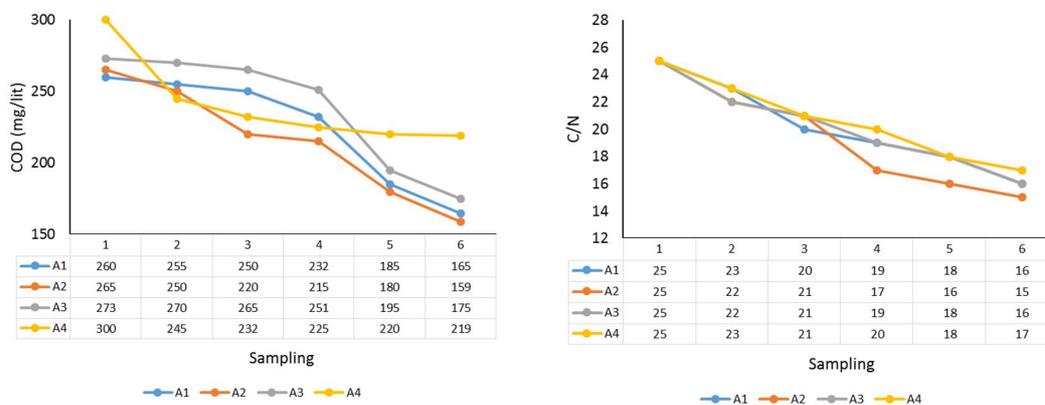
174 **Table 4.** Moisture content in each tank

Tank No.	D1	D2	D3	D4
Moisture content	30%	40%	60%	not dewatered

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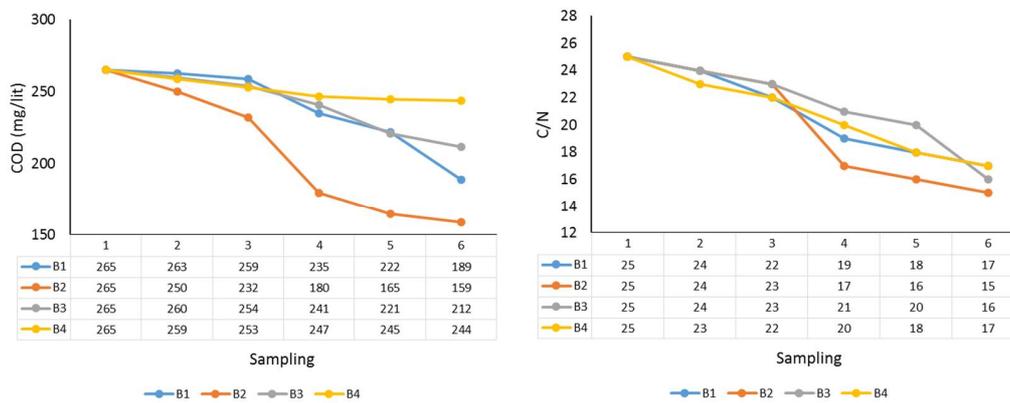
176 **5. Results and discussion**

177 Figures 3 to 6 illustrate the results of COD control in the first series of tests in a 15- day period.



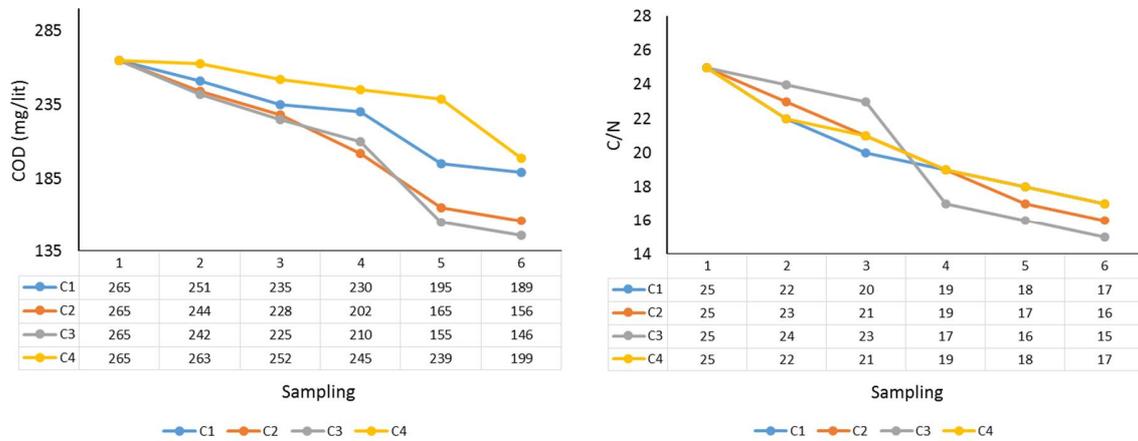
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179 **Fig 3.** COD (left) and C/N (right) variation in different tanks after 15 days in the first series of tests

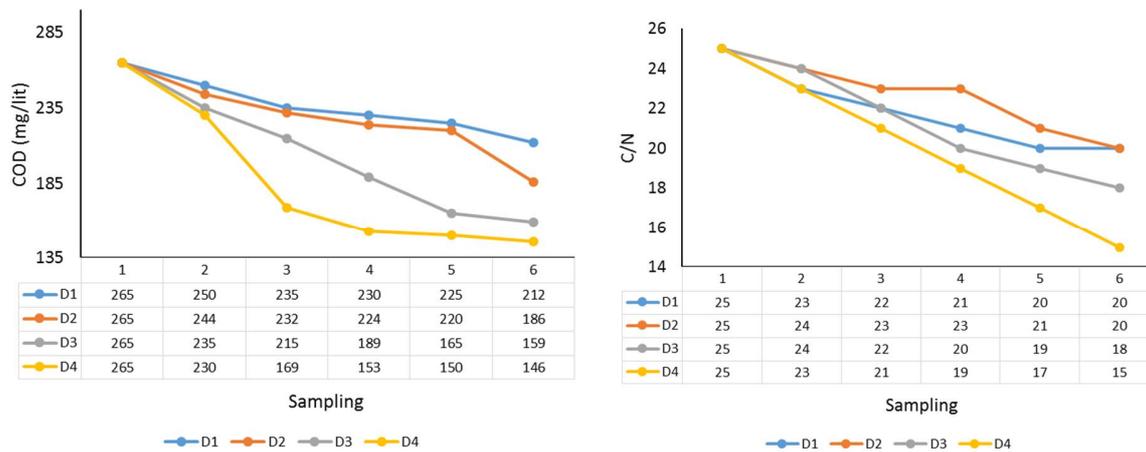


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181 **Fig 4.** COD (left) and C/N (right) variation in different tanks after 15 days in the second series of tests



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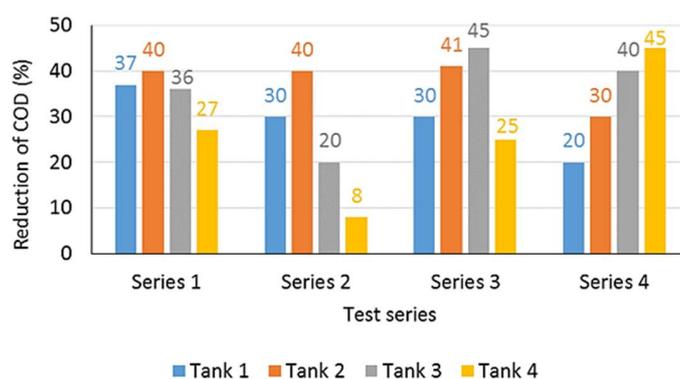
183 **Fig 5.** COD (left) and C/N (right) variation in different tanks after 15 days in the third series of tests

184

185 **Fig 6.** COD (left) and C/N (right) variation in different tanks after 15 days in the fourth series of tests

186 The results of COD investigation in the first series of tests revealed that in tank 2 with waste to sludge  
 187 ratio of 2:1, COD reduced by 40% and hence this sample experienced the most successful composting  
 188 process. A 100% increase in the ratio of waste to sludge (tank 2 / tank 1) results in an 8% increase in system  
 189 efficiency, one of the reasons being the increase in the microbial substrate. However, re-increasing this ratio  
 190 almost linearly reduces the efficiency of the system (Figure 7). This negative effect can be attributed to the  
 191 excessive amount of toxic gases produced by microorganisms, as well as the lack of nitrogen and the  
 192 imbalance between organic carbon and nitrogen. Furthermore, the process was not stopped inside the tank  
 193 2 in any period that is the evidence of system stability. Therefore, it can be concluded that the optimum  
 194 waste to sludge ratio is 2:1. This ratio dictates an initial COD of 265 for the second series of tests. Examining  
 195 the C/N changes also shows the same behaviour in the tanks (Figures 3 and 8). In the second test series for  
 196 continuous aeration, the door of tank 1 was opened and air blew continually. Also, due to the impossibility  
 197 of continuous humidity control in continuous aeration, the primary moisture was set as the criterion.  
 198 Finally, the results of COD and C/N were obtained as illustrated in Figure 4. In this series of tests, it was  
 199 also observed that 40% of both COD and C/N reduction occurred in tank 2 (Figures 7 and 8). This indicates  
 200 that an 8-hour increase in aeration intervals resulted in a 20% reduction in system efficiency, which is due  
 201 to the reduction of the available amount of oxygen for the microorganisms. In addition, although the

202 aeration intervals increased linearly, efficiency reduction process is non-linearly affected. This efficiency  
 203 reduction is exactly as much as the amount which occurs if continuous aeration is applied. In other words,  
 204 if extended aeration is applied to the system, due to the rapid loss of moisture, biological processes are  
 205 impaired but its maximum would be 32%. Therefore, in this situation, the optimum aeration is the period  
 206 of 8 hours. As illustrated in Figures 7 and 8, the highest composting for both COD and C/N removal rate  
 207 in the third series of tests occurs in tank 3 during almost the first 12 days of system launch and after this  
 208 period, it has remained relatively constant. In addition, it was also observed that the reductions of COD  
 209 and C/N are 45% and 40%, respectively. During the first six days of the system launch, three other tanks  
 210 had a slow decline. This continued for COD reduction in tank 4 for the entire 15 days. It can be seen that  
 211 any percentage of additives to increase porosity other than the 15%, causes the reduction of COD removal  
 212 rate. Therefore, in real scale, applying this amount of porosity producing additives are recommended. As  
 213 can be seen from this diagram, changing the amount of this material from 5% to 10% does not significantly  
 214 change the C/N ratio. Also, 20% of this material, due to its high porosity, causes early evaporation of the  
 215 moisture, resulting in about 50% reduction in the efficiency of the system. The most important point is that,  
 216 although the best C/N ratio is achieved at 15% porosity, this amount is exactly the same as in the absence  
 217 of such additives. The reason for this is that porosity of up to 15% does not alter significantly in oxygen  
 218 uptake of microorganisms, but higher than 15% it can reduce the efficiency of the system by decreasing the  
 219 local moisture content. In addition, it was also observed that the reductions of COD and C/N are 45% and  
 220 40%, respectively. As can be seen, tank 4, which has un-dewatered sludge, has the best composting process  
 221 with a 40% reduction in C/N ratio. Dewatering up to 60% has reduced its efficiency by up to 30%. In the  
 222 same way, dewatering to 40 and 30 percent, without having a significant difference, caused another 30%  
 223 reduction in the efficiency of the system. Hence, the needs of microorganisms involved in the composting  
 224 process to high humidity can be determined. In the fourth series of tests, the optimum moisture content  
 225 has been evaluated only by varying the moisture content of sludge cake as 30, 40 and 60 percent in the first  
 226 three tanks and non-dewatered cake in the fourth tank. It can be observed that the highest rate of compost  
 227 COD loss, as well as C/N changes, occur in tank 4 (Figures 7 and 8). After about 6 days, the COD reduction  
 228 rate in this tank increased by 65%. This reduction rate is the same for moisture contents of 30% and 40%  
 229 and equals 10% over six days. Therefore, it can be concluded that the microorganisms involved in the co-  
 230 composting need high moisture content.



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Fig.7. Comparison between COD variations in different test series

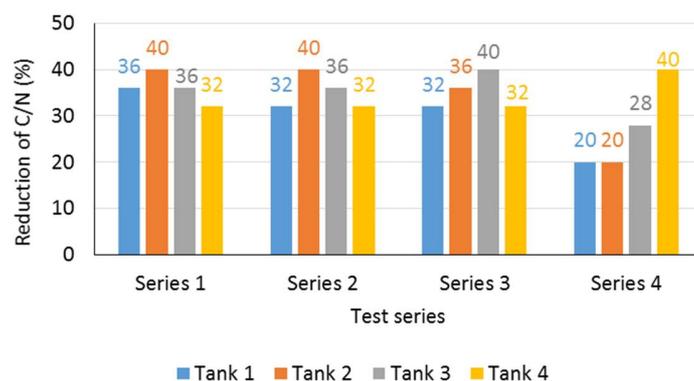


Fig. 8. Comparison between C/N variations in different test series

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234

235 According to the findings of this research, the following results can be obtained regarding in-vessel co-  
 236 composting of municipal wastes with wastewater treatment plant sludge:

- 237 • Co-composting of municipal wastes with wastewater treatment plant sludge must be done without any  
 238 dewatering.
- 239 • At the temperature of 50 °C and a constant carbon to nitrogen ratio, if an 8- hour aeration period is  
 240 applied, the maximum loss of COD occurs in the MSW to sludge ratio of 2. In this situation, the  
 241 maximum loss of both COD and C/N are equal to 40%.
- 242 • An 8-hour increase in aeration intervals causes a 20% system efficiency decrease
- 243 • At the temperature of 50 degrees C, the optimum amount of porosity producing additives is 15% of the  
 244 mixture volume.

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