

Thermal Stability and Crystallization Behavior of Contaminated Recycled Polypropylene for Food Contact

Isabelly Veroneze

Federal University of Sao Carlos: Universidade Federal de Sao Carlos

Akemi Letícia

Federal University of Sao Carlos: Universidade Federal de Sao Carlos

Sandra Andrea Cruz (✉ sandra.cruz@ufscar.br)

Universidade Federal de Sao Carlos Centro de Ciencias Exatas e de Tecnologia <https://orcid.org/0000-0002-5548-0166>

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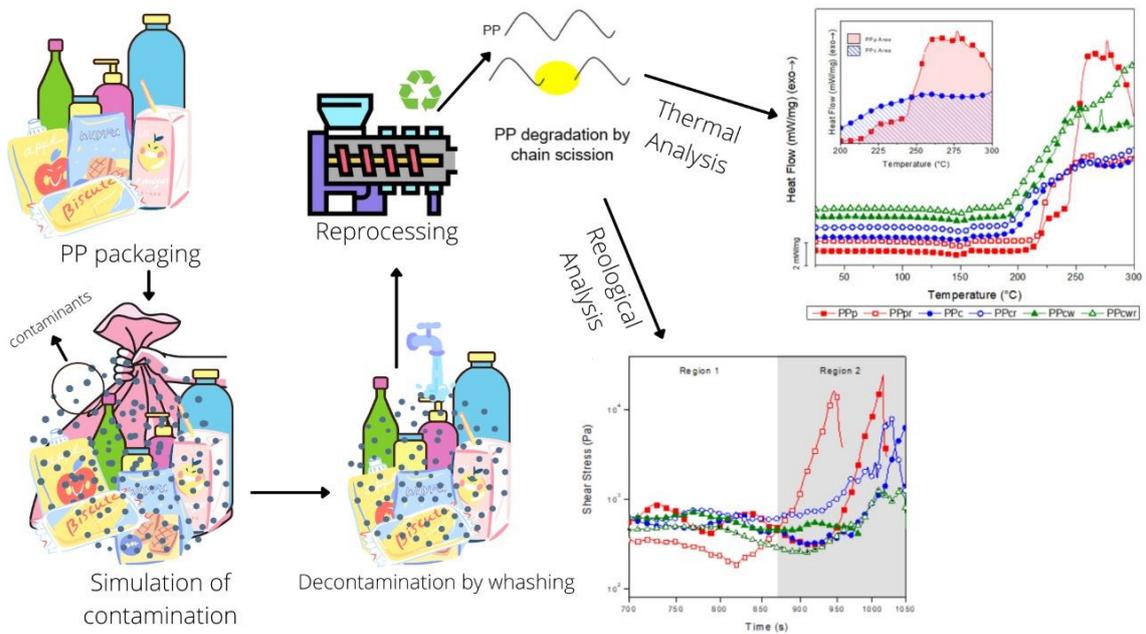
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1 **THERMAL STABILITY AND CRYSTALLIZATION BEHAVIOR OF CONTAMINATED**
2 **RECYCLED POLYPROPYLENE FOR FOOD CONTACT**

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4 Isabelly Bertochi Veroneze^a, Letícia Akemi Onoue^a and Sandra Andrea Cruz^{a*},

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6 a. Chemistry Department, Center for Exact Sciences and Technology, Federal University
7 of São Carlos, Rodovia Washington Luís, Km 235, 10 SP-310, São Carlos, Brazil.



Abstract

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Polypropylene is one of the most widely used polymers, especially in the food packaging industry, which causes negative environmental effects. Recycling is a good option to partially solve this environmental problem. Thus, the polymer was contaminated with a cocktail to simulate the conditions of disposal and recycling following FDA guidelines. The influence of contaminants on recycled PP was analyzed by quiescent and nonquiescent crystallization. It was found that the contaminants alter the crystallization flow since longer induction times were observed for all contaminated samples. Also, the thermal behavior was performed considering that the thermogravimetric (TGA) results indicated an increase in the stability with the presence of contaminants. Therefore, a deep investigation using the induced oxidation time (OIT) and induced oxidation temperature (OITD) was performed. The contaminants play an important role in the crystallization process, as well as, in the degradation of the samples. Furthermore, the use of TGA and DSC as complementary techniques is fundamental to analyze this influence.

39 1. INTRODUCTION

40 Polypropylene (PP) is one of the most consumed polymers in several industrial
41 segments, from toys to automotive parts, due to its good properties and relatively low
42 cost[1]. Unfortunately, its vast application as fast disposal packaging has increased the
43 volume of municipal solid waste, contributing to the aggravation of environmental
44 problems. Additionally, with the COVID-19 pandemic scenario, e-commerce, food
45 deliveries and personal protective equipment have significantly increased, according to
46 Parashar and Hait [2]. Safety concerns about food and personal contamination led to a
47 preference of consumers in plastic containers and bags[3]. Thus, in the current and post-
48 pandemic scenario, a correct destination for waste is essential, and in this sense,
49 recycling is part of the solution by closing the cycle and returning to its original
50 application.

51 However, the use of recycled plastics for direct food contact is restricted by agencies
52 such as the Food and Drug Administration (FDA) and the National Health Surveillance
53 Agency (ANVISA), in Brazil and MERCOSUL. The concern was related to the migration of
54 contaminants from post-consumer use to food contact, putting the well-being of
55 consumers at risk[4,5]. An additional aspect when using recycled materials in direct
56 contact with food is the presence of degradation products, defined as non-intentionally
57 added substances (NIAS) that can migrate into food. The high shear rates and
58 temperatures employed in the recycling process may increase the degradation process,
59 which leads to a change in the physical-chemical negatively affected properties of the
60 polymers restricting their applicability[6–13]. Its complexity comes from the fact that
61 the formed compounds may be the degradation result of (i) the polymer chain, (ii) the
62 intentionally added substances (IAS), (iii) NIAS and (iv) the reaction between all of them.

63 A recent work published by Paiva et al. [6] analyzed the presence of NIAS in the same
64 samples studied in this work. Polypropylene samples were subjected to forced
65 contamination and a recycling process, which led to the identification of 45 different
66 volatile compounds. Recently, a study[6] on the extractability/migration of
67 contaminants from polypropylene (PP) samples into food simulants and the influence of
68 these contaminants on the molecular structure of recycled PP was developed. The
69 authors concluded that the high temperatures and shear rates used in the recycling
70 process, when in contact with the residual contaminants, alter the molecular structure
71 of this polymer.

72 This concern is more critical for PP due to the higher contaminant sorption capacity and
73 its low thermal resistance when compared to poly(ethylene terephthalate)[9,14].
74 Therefore, these are additional factors in the recycling of contaminated polypropylene
75 to be considered for direct contact with food. As described by Palkopoulou et al.[15], the
76 polyolefins have reduced thermal stability, and this may contribute to an increase in the
77 degradation process. Although recycling is environmentally friendly, it is possible to
78 produce materials whose properties are negatively affected by this process, restricting
79 their applicability[15].

80 The decrease in molar mass and deterioration of mechanical properties as a result of
81 degradation becomes an economic disadvantage for the application of recycled PP when
82 compared to pristine material [16–22]. Therefore, understanding the effect of
83 contaminants on the thermal properties of polypropylene is essential to develop a way
84 to add more value to recycled material that makes it suitable for reintroduction into the
85 packaging market [17].

86 Therefore, this study aims to evaluate the degradation of polypropylene in the presence
87 of contaminants in different stages of the recycling process, such as washing and
88 reprocessing. The effect of the presence of contaminants on PP was analyzed by
89 quiescent and nonquiescent crystallization, as well as by thermal analysis.

90

91 **2. METHODOLOGY**

92 The methodology of this work was developed into three main steps as follows: **Step 1**
93 consists of contaminating the PP with a cocktail of surrogates and recycling it; In **Step 2**,
94 the efficiency of the recycling process was evaluated by an extractability test using
95 different food simulants; In **Step 3**, given the presence of contaminants, the molecular
96 structure was evaluated by rheometry after the recycling process.

97

98 **2.1 Materials**

99 In this work, polypropylene was used in pellet form (Prism 2400) supplied by
100 Braskem S.A, Brazil. It presents a melt flow index (MFI) of 20 g/10 min (ASTM 1238,
101 230°C, 2.16 kg) and a density of 0.902 g/cm³ (ASTM D 792). The chemicals used for
102 contamination were chloroform (Vetec, 99.8%, CAS No. 67663), toluene (Vetec, 99.5%,
103 CAS No. 108883), benzophenone (Acros Organics, 99%, CAS No. 119619), tetracosane
104 (Merck, 99%, CAS No. 646311) and heptane (Synth, 99%, CAS No. 1422825). Ethanol
105 (Merck, 99%) and acetic acid (Merck, 99%) were employed to prepare the food
106 simulants, with 10% (v/v) ethanol and 3% (w/v) acetic acid respectively in MiliQ water.

107

108

109 **2.2. Methods**

110

111 **2.2.1 Contamination and Recycling Process**

112 To study the influence of the recycling process, the samples were subjected to forced
113 contamination according to Food and Drugs Administration (FDA) regulations [4].

114 Therefore, the PP pellets were exposed to a contaminant cocktail and placed in a
115 hermetically sealed system kept in constant stirring at 40°C for 14 days to ensure
116 uniform sample contamination (PPc). The contaminant cocktail composition is shown in
117 Table 1.

118 After contamination, contaminated pellets went through the process of washing with
119 water for 10 minutes, followed by a second wash with sodium hydroxide for 5 minutes
120 and, finally, again with water for 10 minutes. This procedure was based on the work of
121 Garcia et al. [9].

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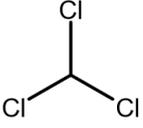
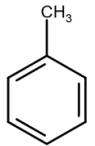
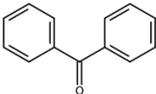
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133 **Table 1:** Contaminants, properties and concentration of the contaminants used in the
 134 cocktail.

Contaminants	Molar mass (g.mol ⁻¹)	Properties	Concentration
 Chloroform (CHCl ₃)	119.38	Volatile and polar	10% v/v
 Toluene (C ₇ H ₈)	92.14	Volatile non-polar	10% v/v
 Benzophenone (C ₁₃ H ₁₀ O)	182.22	Non-volatile polar	1% v/v
 Tetracosane (C ₂₄ H ₅₀)	338.65	Non-volatile and non-polar	1% m/m
 Heptane (C ₇ H ₁₆)	100.21	Volatile and Non-Polar	78% v/v

135

136 Subsequently, the contaminated material was reprocessed in a single-screw extruder
 137 (AX Plastics) (D=16 mm, L/D=26). The screw speed used was 30 rpm and the
 138 temperatures used were 180, 190, and 210°C. The different processes led to a set of six
 139 samples presented in Table 2.

140 **Table 2:** Nomenclature of the PP samples used in this work.

Samples	Nomenclature
Pristine PP	PPp
Pristine -reprocessed PP	PPpr
Contaminated PP	PPc
Contaminated and reprocessed PP	PPcr
Contaminated and washed PP	PPcw
Contaminated, washed and reprocessed PP	PPcwr

141

142 **2.2.2. Thermal analysis**

143

144 *Differential scanning calorimetry (DSC)*

145 The analysis was performed in a DSC 203 F3–Maia (Netzsch). The samples were
146 subjected to a three-step sweep: heating from 20°C to 180°C, with a five-minute
147 isotherm at 180°C, followed by cooling from 180°C to 20°C, with a two-minute isotherm
148 at 20°C followed by a second heating using the same parameters as the first step. The
149 analyses were carried out at a heating rate of 10°C.min⁻¹ and an inert gas atmosphere
150 (N₂) with a flow of 50 mL.min⁻¹. The crystallinity degree data was calculated as follows:

$$151 \quad X_c = \frac{\Delta H_m}{\Delta H_0} \times 100\%$$

152 where X_c is the crystallinity degree, ΔH_m is the melting enthalpy obtained by the
153 integration of the surface of the DSC curve related to the melting process and ΔH_0
154 expresses the heat fusion of perfectly crystallized PP (209 KJ/g)[23].

155

156 *Oxidation Induction Time (OIT)*

157 Analyses were performed in a DSC 203 F3–Maia (NETZSCH). The parameters for
158 the conventional OIT technique were as follows: heating from 20°C to 200°C under an
159 inert gas atmosphere (N₂) with a heating rate of 10°C.min⁻¹, followed by a five-minute
160 isotherm where it was carried out the exchange of gases, from N₂ to O₂. After the
161 exchange, the samples remained in an isotherm for 35 minutes in an oxidizing
162 atmosphere at 200°C, the gas flow used was 50 mL.min⁻¹.

163

164 *Oxidation Induction Time – Dynamic Regime (OITD)*

165 OITD analyses were performed in a DSC 203 F3–Maia (NETZSCH). The analysis
166 conditions used were the following: a single heating from 20°C to 300°C under an
167 oxidizing gas atmosphere (O₂) with 50 mL.min⁻¹ gas flow and 10°C.min⁻¹ heating rate.

168

169 *Thermogravimetric analysis (TGA)*

170 Thermogravimetric analyzes were performed on a TG 209 F3-Tarsus (NETZSCH).
171 The samples were subjected to heating from 40°C to 600°C under an oxidative
172 atmosphere (O₂) with a gas flow of 40 mL.min⁻¹ and a heating rate of 10°C.min⁻¹.

173

174 *Rheological analysis*

175 For crystallization analysis under nonquiescent conditions, a parallel plate
176 rheometer (Anton Paar MCR 305) was used. The initial temperature used in the test was
177 190°C with 1% deformation at a 1 mm gap between the parallel plates. The isothermal
178 crystallization temperature used was 120°C.

179

180 **3. RESULTS AND DISCUSSION**

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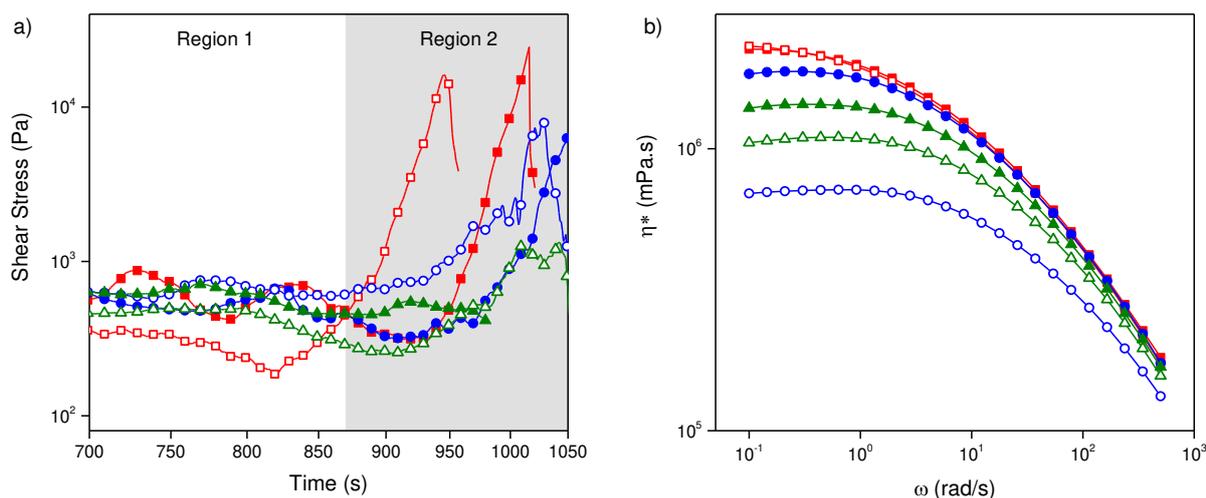
182 **3.1. Nonquiescent Crystallization and Rheological Properties**

183 Although the analysis of crystallization under quiescent conditions is important
184 to understand the crystal structure of the material, usually the polymers processing
185 occurs under shear flow (nonquiescent), which means the crystallization occurs under
186 flow-induced crystallization (FIC). Consequently, the kinetics of crystallization could
187 drastically change under this specific condition, and this aspect is particularly important
188 technologically. The study of crystallization by rheometry allows us to verify the
189 phenomenon of the onset time of crystallization under shear flow. As described in the
190 literature [10,19,20,22], the onset time is obtained when viscosity/shear stress as a
191 function of time abruptly increases [10]. The increase in viscosity ($\rightarrow \infty$) indicates that
192 the material becomes solid, which means crystallization. This induction time is
193 approximately proportional to the inverse of the nucleation rate [10,20].

194

195

196



197

198 **Figure 1** - (a) Shear rate as a function of time and (b) Complex viscosity as a function of
 199 the frequency of the following samples: (■) PPp, (□) PPpr, (●) PPC, (○) PPcr, (▲) PPCw
 200 and (Δ) PPCwr.

201

202 In the FIC tests (Figure 1.a) performed at 1% strain in a linear viscoelastic range, it is
 203 possible to verify two distinct regions: Region 1 where the shear rate remains practically
 204 the same and Region 2 where the shear rate increases abruptly after some time [19].
 205 This time is known as the beginning of crystallization and, after that, the shear rate tends
 206 to infinity [20]. It is observed that reprocessing (without the presence of contaminants)
 207 reduces the induction time, which can be attributed to a lower molar mass (Figure 1.b)
 208 and, therefore, the crystallization process occurs in less time. This behavior was also
 209 observed by Fitaroni et al. in their study on the thermal and crystallization behavior of
 210 post-consumer recycled PET [20]. It was observed that the more degraded samples
 211 showed a reduction in the time to start crystallization, which was attributed to a lower
 212 molar mass that facilitated this process. The presence of contaminants significantly
 213 alters this process, since longer induction times were observed for all contaminated

214 samples. Although this is an important issue, studies on the influence of the presence of
215 contaminants on FIC were not found in the literature.

216 As can be seen in Figure 1 (b), contaminated, washed, and reprocessed sample (PPcwr)
217 showed lower complex viscosity (η^*), near the unwashed sample (PPcr) and that
218 presents the lowest value of η^* . Since the washed samples present lower molar mass
219 than that shown by the contaminated one (PPc), this might mean that: (i) the washing
220 process does not efficiently eliminate the contaminants and (ii) the washing process,
221 combined with the reprocessing step, also contributes to the degradation of PP chains
222 once the viscosity of PPcw is lower than that of PPc.

223 Paiva et al. [21] proved that the washing process, despite helping to decontaminate the
224 material, cannot completely decontaminate the material, under the conditions carried
225 out. Additionally, the authors indicated that the presence of residual contaminants leads
226 to degradative processes in PP.

227 It was expected that the samples that showed the lowest molar mass, that is, PPcr and
228 PPcwr, had a shorter induction time. As it is described in the literature [19,20,22,24], the
229 rate of crystallization is related to nucleability and transportability, so it is strongly
230 dependent on the mobility and diffusivity of the chain. FIC is a nonequilibrium
231 thermodynamic phase transition controlled by chain relaxation and crystallization.

232 When the chains are subjected to a flow/shear stress, the chains are oriented and
233 stretched. This reduces the conformational entropy, while the free energy of the
234 polymer melts will increase by a factor of $T\Delta S$ that corresponds to the nucleation barrier.
235 Therefore, the free energy associated with the nucleation barrier of the critical nucleus
236 decreases, as described by Wang, Ma and Li [24]. On the other hand, the contaminants
237 hinder this process once an increase in FIC time was observed despite lower molar mass.

238 The diffusion process of small molecules is mainly governed by the surrogate molar mass
239 and temperature. During the nucleation step, they remain between the chains
240 increasing the entropy of the system and making this process difficult. As observed by
241 the DSC results, under quiescent conditions, the presence of contaminants also
242 interferes with the crystallization process, reducing the X_C values (Table 3).

243

244 **3.2. Quiescent Crystallization**

245 The different methods applied to PpP seem to interfere with the degree of
246 crystallinity (X_C) of the samples (second heating). As can be seen in Table 3, there was a
247 slight decrease in the degree of crystallinity for practically all samples compared to PpP.
248 It is known that the crystallinity of PP can be influenced by several factors such as the
249 molar mass, molar mass distribution, presence of additives, degradation, and processing
250 history. In a study by Fitaroni et al., it has been reported that the presence of
251 contaminants influences both quiescent and nonquiescent crystallization in
252 contaminated polyethylene (PET) samples, as the contaminant acts by hindering the
253 approximation and, consequently, the packaging of the chains [15]. Because the degree
254 of crystallinity is related to the enthalpy of fusion, which is influenced by the diffusivity
255 of the chains, the results indicate that the crystallinity degree decreases in the presence
256 of contaminants.

257 The crystallization temperature upon non-isothermal cooling (T_C) was slightly
258 shifted to higher temperatures meaning a slight increase in crystallization kinetics. Due
259 to the increased mobility of the shorter chains, formed as a result of degradation by
260 chain scission (Figure 1-b), the quiescent crystallization process is slightly enhanced.
261 Furthermore, the crystallization rate (ΔT) values, obtained by the difference between

262 the crystallization onset temperature (T_{onset}) and T_c , mainly reduce when contamination
 263 is applied (PPc).

264 To better understand the quiescent crystallization kinetics, the maximum time
 265 for a sample to be fully crystallized, known as T_{full} , was determined. As can be seen (Table
 266 3), although non-isothermal crystallization was slightly enhanced by higher T_c values,
 267 the time it took for this process to complete was the same regardless of the recycling
 268 methods applied. This might be due to the presence of contaminants that slow the
 269 crystallization rate, keeping T_{full} unchanged.

270

271 **Table 3** - DSC crystallization parameters of PP samples.

		PPp	PPpr	PPc	PPcr	PPcw	PPcwr
1st Heating	X_c (%)	30.3±2.6	19.8±1.5	19.0±2.8	16.4±1.4	22.8±1.6	18.9±0.4
2nd Heating	X_c (%)	22.4±2.8	17.9±2.1	18.6±1.1	21.0±5.0	19.1±5.9	19.7±1.5
Cooling	T_c (°C)	113.4±0.2	114.9±0.7	115.3±0.3	115.5±0.3	115.1±0.3	114.1±1.0
	ΔH_c (J/g)	77.7±6.4	63.9±6.4	52.2±2.7	63.8±1.2	71.4±1.8	67.9±5.2
	T_{onset} (°C)	120.47±1.0	121.5±0.1	121.7±0.2	121.7±0.3	121.6±0.3	121.6±0.6
	ΔT (°C)	7.12±1.2	6.6±0.7	6.4±0.02	7.1±0.5	6.5±0.6	7.6±1.6
	T_{full} (min)	11.0±0.020	11.0±0.1	11.1±0.0	11.1±0.1	11.1±0.1	11.1±0.0

272

273 The melting temperature (T_m) and melting enthalpy (ΔH_m) results for both the
 274 first heating and the second heating practically do not change are shown in the
 275 Supplementary Material.

276

277

278 3.3. Thermal Analysis

279 The initial mass loss (T_i) temperature data from the thermogravimetric analysis
280 were obtained considering the loss of 5% of the initial mass. As can be seen in Table 4,
281 there was a decrease in the T_i value when the material was reprocessed. PPcwr sample
282 showed a significant reduction in T_i when compared to pristine PP, which can be
283 attributed to a reduction in molar mass and, therefore, the easier initial release of
284 volatiles. On the other hand, the presence of contaminants in all samples (PPc, PPcr,
285 PPcw, PPcwr) increased the maximum speed mass loss temperature (T_{max}) determined
286 by the maximum value of the first derivative, even with a reduction in molar mass. This
287 behavior is reflected in another parameter, ΔT , which represents the difference
288 between T_{max} and T_i and allows to obtain information on the mass loss kinetics.

289 The presence of contaminants significantly affects the kinetics of mass loss.
290 Clearly, an increase in ΔT can be observed, indicating that the presence of contaminants
291 alters the internal structure of the polymer in a way that hinders the production of
292 volatiles. Fitaroni et al. [14] observed similar behavior on the influence of
293 montmorillonite clay on the thermal stability of PP. T_i values were not significantly
294 changed, but an increase in T_{max} was observed with increasing clay content. This effect
295 was attributed to an increase in the mean free path for oxygen entry and volatile exit
296 due to the presence of clay, meaning slower gas diffusion inside the polymer matrix.

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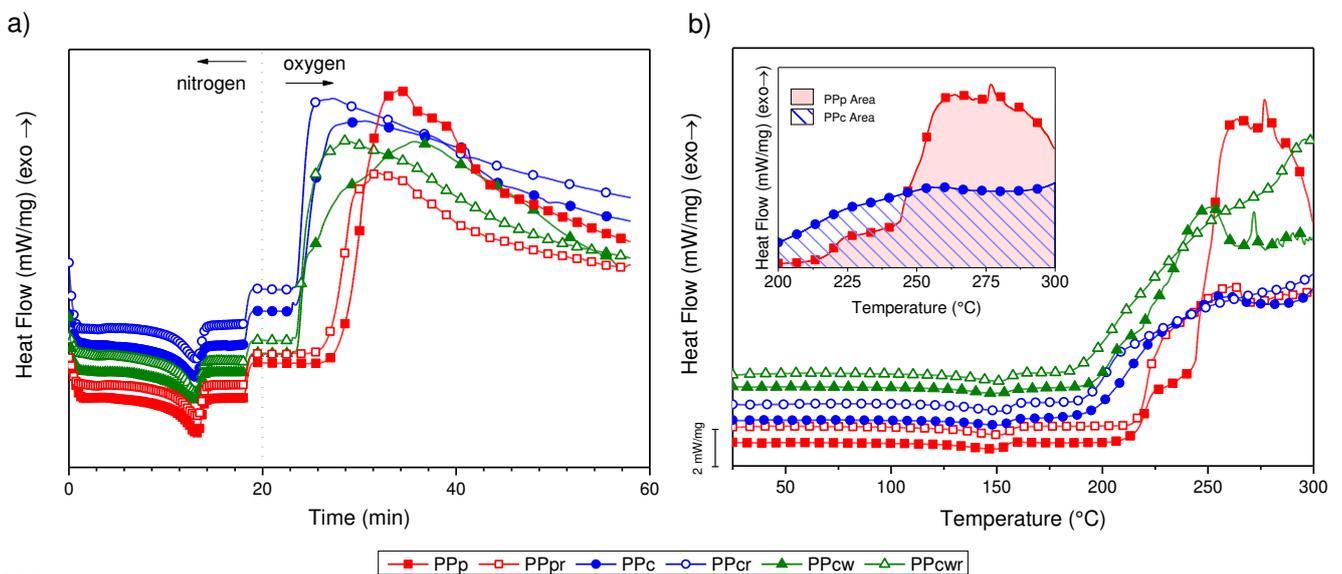
302 **Table 4** – Parameters obtained from TGA curves for PP samples.

	Parameter	PPp	PPpr	PPc	PPcr	PPcw	PPcwr
TGA	T_i (°C)	229.6±5.5	232.6±1.3	229.8±1.5	232.5±1.3	226.7±0.9	218.5±7.2
DTGA	T_{max} (°C)	283.6±8.1	271.6±2.8	298.4±1.0	306.8±0.5	296.6±2.1	304.1±3.6
	ΔT (°C)	54.0±13.6	39.0±4.1	68.6±2.5	74.3±1,8	69.9±3.0	85.6±10.8

303

304 As the TGA results indicated an increase in thermal stability in the presence of
 305 contaminants, which is not consistent with the data from the literature[14],
 306 conventional and dynamic OIT analyses were performed, Figure 2 (a) and (b).

307



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311 When comparing the reprocessed sample with the pristine PP, a reduction in the
 312 dynamic and conventional OIT is observed, which indicates that it is more susceptible to
 313 degradation processes and, therefore, to oxidation. Furthermore, all contaminated
 314 samples showed an even more significant reduction in induction time. This indicates that

315 contaminants catalyze the degradation reaction of contaminated polypropylene [14,17].
 316 A previous study [6], carried out on the same set of samples, indicated that both the
 317 washing process and the reprocessing help in decontaminating the material. However,
 318 as previously described, several residual contaminants were still observed, which was
 319 confirmed by their migration through direct contact with food simulants, where the
 320 extractability tests were carried out using solid-phase microextraction (SPME) and
 321 analyzed by gas chromatography coupled to the mass spectrometer (GC-MS). As shown
 322 by the rheometry results, the applied washing process was not enough to eliminate all
 323 of the intentionally added contaminants, and the results of OIT indicate that the
 324 presence of these contaminants still prevailed, even at low concentrations, significantly
 325 helps to reduce the oxidative stability of polypropylene.

326 For better visualization, Table 5 presents the oxidation induction time and
 327 temperature values, as well as the difference between the initial temperature of the
 328 mass loss obtained from TGA (T_i) and the initial temperature of the OITD exothermic
 329 reaction (T_{re}^*) for PP samples.

330

331 **Table 5** – Average thermal analysis parameters for PP samples.

	Parameter	PPp	PPpr	PPc	PPcr	PPcw	PPcwr
OIT	Time (min)	6.3±0.8	4.9±1.1	0.9±0.1	0.6±0.0	0.7±0.1	0.4±0.2
OITD	T_{exo}^* (°C)	214.5±5.6	216.8±4.6	192.2±0.8	189.4±0.1	193.1±0.8	189.8±4.9
TGA	T_i (°C)	229.6±5.5	232.6±1.3	229.8±1.5	232.5±1.3	226.7±0.9	218.5±7.2
	$T_i - T_{exo}^*$ (°C)	15.0±11.1	15.8±3.4	37.6±0.8	43.1±1.2	33.5±0.2	28.7±2.4

332

333 Oxidation induction temperature (OITD) tests are an important tool in the evaluation of
334 the thermal stability of polymers, especially those that undergo thermo-oxidation, such
335 as PP. The technique is beneficial once the diffusion of oxygen through the sample
336 occurs during all the analysis, in the same conditions as TGA. As the heat flow is
337 measured, it is possible to identify when the exothermal oxidation started and associate
338 it with the mass loss obtained by TGA. It is observed that the samples that went through
339 the contamination process showed a decrease in the temperature at the beginning of
340 the exothermic reactions. These data are contradictory and can be the basis for
341 questioning the use of thermogravimetric analysis as the only technique to
342 determine thermal stability, which has already been observed by Fitaroni et al. [14]
343 for multicomponent polymeric materials using an inorganic filler. To the best of our
344 knowledge, for pure polymers and contaminated ones, there is no discussion about this
345 limitation, which must be considered in all evaluations using TGA. The oxidative
346 degradation reaction is one of the most important mechanisms for PP
347 degradation[14,17]. Also, as described previously, the presence of contaminants
348 significantly influences this parameter, as may be observed when T_{exo} is compared with
349 the sample without (PPp and PPpr) and with contaminants (PPc, PPcr, PPcw and PPcwr).
350 For all samples that present contaminants, the initial time of the exothermic reactions
351 does not seem to change much. However, additional information could be evaluated by
352 analyzing the different heat profiles for each sample. For the more degraded samples,
353 there is less variation in the heat flow. On the other hand, the heat flow variation, which
354 can be analyzed by the area under the curve of the heat flow variation as a function of
355 temperature for the least degraded samples (PPp) is significantly higher, indicating that
356 more samples can be degraded, as shown in Figure 2 (b).

357 **4. CONCLUSION**

358 The effect of the presence of contaminants in recycled polypropylene on the
359 quiescent and nonquiescent crystallization was evaluated. Their effect on the thermal
360 stability of the samples was more accurate when TGA analysis and OIT (conventional
361 and dynamic) were used as a complementary technique. The results indicate that the
362 residual contaminants decrease the molar mass, although a reduction in flow-induced
363 crystallization time is expected. However, the contaminants' induction times were
364 increased for all contaminated samples. On the other hand, in quiescent conditions, the
365 maximum time for a sample to be fully crystallized (T_{full}) remains constant. This behavior
366 highlights the importance of analyzing the crystallization process under different
367 conditions.

368 The presence of contaminants in all samples (PPc, PPcr, PPcw, PPcwr) increased the
369 maximum speed mass loss temperature (T_{max}) indicating a contradictory increase in the
370 stability when compared to PP. Thus, a deeper analysis was performed employing a
371 complementary technique OIT (conventional and dynamics). All contaminated samples
372 showed an even more significant reduction in induction time and a decrease in the
373 temperature at the beginning of the exothermic reactions. This indicates that
374 contaminants catalyze the degradation reaction of contaminated polypropylene. These
375 analyses were important to avoid misleading conclusions about the stability of recycled
376 polymers.

377

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380

381 **Conflict of Interest**

382 The authors confirm that they have no conflicts of interest with respect to the work
383 described in this manuscript.

384

385 **Availability of data and material**

386 The data are in public repository at UFSCar: <https://repositorio.ufscar.br/>

387

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