The paper deals with the investigation of the effects of the electron beam treatment on the rheological behavior of the wheat starch aqueous suspensions. The apparent and intrinsic viscosities decreased exponentially with the increase of the irradiation dose because of the reduction of both the molecular weight and polymerization degree of the wheat starch.

**Key words**: starch, irradiation, apparent viscosity, intrinsic viscosity, molecular weight, polymerization degree.

1. **INTRODUCTION**

Starch is one of the widespread natural products and used in almost every industrial application depending on its botanical source. Chemically, starch is a macromolecule constitutes of two polymeric components, amylose and amylopectin, which contribute to its remarkable physicochemical properties. Starches are generally modified to obtain convenient rheological behavior of its suspensions for different applications. Recent studies [1,2] showed that the electron beam (e-beam) treatment may change some physicochemical properties such as rheological behavior for corn and sago starches.

In this direction, the objective of the paper is to investigate the possible effects on the rheological behavior of wheat starch which has been treated with accelerated e-beam.

2. **EXPERIMENTAL**

Wheat starch used in the experiments was purchased from the Romanian commercial system.


The packed starch samples were irradiated with e-beam up to 50 kGy using linear accelerator with medium energy of 6MeV.

The rheological measurements were carried out on aqueous suspensions using HAAKE VT® 550 rotational rheoviscosimeter. These measurements were performed on both 5% suspensions at 25°C and different temperatures (55, 75 and 95°C) and suspensions of 1% and 3% at 25°C. The obtained data were analyzed with RheoWin v.3.5 software.

The determination of intrinsic viscosity was performed on diluted starch solutions (<1%) using KOH 1N as a solvent. The prepared solutions were subjected to the measurements with Hoppler viscometer at 25°C and the intrinsic viscosity was obtained by the linear curve extrapolation of the reduced viscosities calculated as a function of the selected concentrations. The molecular weight and polymerization degree were calculated using the intrinsic viscosity according to Pimpa et al. [2].

The presented results in the work are the mean and standard deviation of two different measurements.

3. RESULTS AND DISCUSSION

The control sample indicated non-Newtonian behavior for which the ratio of the shear stress and shear rate is not constant [3], the shear stress dependence of shear rate indicating the pseudoplastic character of the starch suspension. This character was kept for the irradiated samples, even at high irradiation dose, but with trend towards Newtonian behavior.

The suspensions of starch show complicated rheological behavior and thus they impose the analysis using complex rheological models. Taking into account this aspect, the most known models were used to describe the rheological behavior of the investigated samples. The determination factor for each used model is showed in Tables 1 and 2.

<table>
<thead>
<tr>
<th>Irradiation dose [kGy]</th>
<th>Determination factor for different rheological models</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Newton</td>
</tr>
<tr>
<td>0</td>
<td>0.727–0.729</td>
</tr>
<tr>
<td>10</td>
<td>0.938–0.956</td>
</tr>
<tr>
<td>20</td>
<td>0.881–0.892</td>
</tr>
<tr>
<td>30</td>
<td>0.965–0.982</td>
</tr>
<tr>
<td>40</td>
<td>0.981–0.983</td>
</tr>
<tr>
<td>50</td>
<td>0.985–0.986</td>
</tr>
</tbody>
</table>
Table 2

<table>
<thead>
<tr>
<th>Irradiation dose [kGy]</th>
<th>Herschel-Bulkley</th>
<th>Casson</th>
<th>Cross</th>
<th>Carreau-Yasuda</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.991–0.994</td>
<td>0.962–0.965</td>
<td>0.995–0.996</td>
<td>0.993–0.996</td>
</tr>
<tr>
<td>10</td>
<td>0.987–0.991</td>
<td>0.984–0.987</td>
<td>0.989–0.991</td>
<td>0.988–0.991</td>
</tr>
<tr>
<td>20</td>
<td>0.974–0.975</td>
<td>0.965–0.969</td>
<td>0.974–0.976</td>
<td>0.952–0.957</td>
</tr>
<tr>
<td>30</td>
<td>0.985–0.990</td>
<td>0.989–0.990</td>
<td>0.990–0.991</td>
<td>0.989–0.991</td>
</tr>
<tr>
<td>40</td>
<td>0.978–0.983</td>
<td>0.979–0.983</td>
<td>0.982–0.984</td>
<td>0.980–0.983</td>
</tr>
<tr>
<td>50</td>
<td>0.983–0.986</td>
<td>0.982–0.986</td>
<td>0.984–0.987</td>
<td>0.984–0.986</td>
</tr>
</tbody>
</table>

The tendency towards Newtonian behavior was confirmed also by the improving of the determination factor value for Newton’s model as the increase of the irradiation dose.

Ostwald de Waele (power law) model is one of the most used rheological models for starch characterization, reported in literature [4, 5], and it describes well various materials mainly from food industry [6, 7] having the advantage to be a simple model (eq. 1):

\[ \eta_a = k \cdot \dot{\gamma}^{n-1} \quad \text{or} \quad \tau = k \cdot \dot{\gamma}^n \]

where:
- \( \eta_a \) – apparent viscosity [mPa·s]
- \( k \) – consistency index [mPa·s^n]
- \( n \) – flow index
- \( \dot{\gamma} \) – shear rate [s⁻¹]
- \( \tau \) – shear stress [Pa]

Fig. 1 – Evolution of consistency and flow indices with the irradiation dose.
The consistency and flow indices are typical rheological parameters used in the Oswald’s model [8]. The consistency index showed a decrease of its value with the increase of the irradiation dose (Fig. 1) and it can be obviously correlated with the apparent viscosity that also decreased by irradiation. The evolution of the flow index to the value of 1 (typical for Newtonian fluids) as the increase of the irradiation dose (Fig. 1) indicated that the starch suspensions tends to Newtonian behavior by e-beam treatment too.

The comparative analysis realized concerning the rheological models showed clearly, in our situation, the Cross model (eq. 2) was the best in the studied models, though Ostwald de Waele model is frequently used in the starch analysis.

$$
\eta_a = \eta_0 + \frac{\eta_\infty - \eta_0}{1 + \left(\frac{\dot{\gamma}}{\gamma_b}\right)^n} \quad \text{sau} \quad r = \dot{\gamma} \left[ \eta_a + \frac{\eta_0 - \eta_\infty}{1 + \left(\frac{\dot{\gamma}}{\gamma_b}\right)^n} \right]
$$

(2)

where:
- $\eta_a$ – apparent viscosity [mPa·s]
- $\eta_0$ – zero shear viscosity [mPa·s]
- $\eta_\infty$ – infinite shear viscosity [mPa·s]
- $\dot{\gamma}$ – shear rate [s$^{-1}$]
- $1/\dot{\gamma}_b$ – Cross time ratio [s]
- $n$ – Cross rate constant

Thus, the Cross-rheological model can best fitted the rheological behavior of both control and irradiated samples with determination factor between 0.974 and 0.996 as one can see in Table 1.

Fig. 2 – Variation of the apparent viscosity with the irradiation dose.
The apparent viscosity of starch suspensions (25ºC, \( \dot{\gamma} = 200 \text{ s}^{-1} \)) showed exponential decreasing evolution as the increase of the irradiation dose (Fig. 2). This behavior suggests the molecular structure of the wheat starch is fragmentized to lower molecular weight structures.

The starch behavior dependence on temperature and concentration is important mainly for technological procedures. We observed the decreasing evolution of the apparent viscosity (\( \dot{\gamma} = 200 \text{ s}^{-1} \)) with the increase of the temperature, as we expected, for all studied suspensions, both control and irradiated samples (Fig. 3).

Fig. 3 – Variation of the apparent viscosity with the irradiation dose and temperature.

Fig. 4 – Variation of the apparent viscosity with the irradiation dose and concentration.
The study of the concentration influence on the apparent viscosity (25°C, \( \dot{\gamma} = 200 \text{ s}^{-1} \)) revealed its increase with the increase of the concentration for control sample. The irradiated samples showed similar behavior to control one (Fig. 4).

Temperature and concentration dependence of the rheological characteristics presented no significant influence by e-beam irradiation.

The intrinsic viscosity decreased exponentially with the irradiation dose (Table 3) quite similar to the apparent viscosity decrease. This evolution indicates once again the degradation of the starch components in macromolecules with lower molecular weight [5].

### Table 3

<table>
<thead>
<tr>
<th>Irradiation dose [kGy]</th>
<th>Intrinsic viscosity [ml/g]</th>
<th>Molecular weight [x 10^5]</th>
<th>Polymerization degree</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>62.36 ± 1.99</td>
<td>2.03 ± 0.04</td>
<td>461.46 ± 14.73</td>
</tr>
<tr>
<td>10</td>
<td>38.80 ± 1.30</td>
<td>1.19 ± 0.03</td>
<td>287.12 ± 9.62</td>
</tr>
<tr>
<td>20</td>
<td>30.35 ± 1.02</td>
<td>0.90 ± 0.02</td>
<td>224.59 ± 7.55</td>
</tr>
<tr>
<td>30</td>
<td>27.13 ± 1.80</td>
<td>0.80 ± 0.04</td>
<td>200.76 ± 13.32</td>
</tr>
<tr>
<td>40</td>
<td>17.43 ± 0.91</td>
<td>0.48 ± 0.02</td>
<td>128.98 ± 6.73</td>
</tr>
<tr>
<td>50</td>
<td>16.22 ± 1.36</td>
<td>0.45 ± 0.05</td>
<td>120.03 ± 8.45</td>
</tr>
</tbody>
</table>

Calculating the molecular weight and polymerization degree, it was confirmed that the e-beam treatment led to the depolymerization of starch macromolecular structure which influenced obviously its rheological behavior.

### 4. CONCLUSIONS

The study of rheological behavior of the e-beam treated wheat starch showed the rheological parameters were influenced in a dose dependent-manner. The apparent viscosity as well as the intrinsic viscosity decreased exponentially with the increase of the irradiation dose indicating an obvious reduction of both the molecular weight and polymerization degree. The value of the starch apparent viscosity decreased with the increase of the temperature and increased as the increase of the concentration, the irradiated samples keeping the same evolution as the control one.

The investigation of the wheat starch from rheological point of view revealed that wheat starch with modified rheological properties could be obtained using the e-beam treatment.

### REFERENCES
