ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XX [2022] | Fascicule 3 [August]

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ASPECTS REGARDING THE TECHNOLOGICAL PROCESS OF CARDBOARD WASTE BALING

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Abstract: This article presents aspects of the process of compacting cardboard waste in vertical flow presses. For this purpose, a vertical press, type PP-1207 Strautmann, was equipped with a piston displacement measurement system, and also for forces at regular intervals. The experimental data were purchased and stored in Ms Excel format for processing. These experimental values are briefly presented in the paper. Thus, maximum compression forces in the range 978 - 997 kgf were obtained. Using the force-displacement variation curve, the energy consumption was determined and the specific consumption when pressing the cardboard waste in the vertical flow presses was calculated. The data presented can be helpful for both designers and vertical flow press builders.
Keywords: carton waste baling, compression force, displacement, energy consumed

1. INTRODUCTION

Paper-based packaging materials come in the form of packaging, bags, pouches, glasses, bags, trays and tubes. These packages have already proved their applicability and have occupied a solid position in the market. The important advantages of paper-based packaging materials compared to petroleum-based products are biodegradability, recyclability, good printability, "green" image and regenerability.

The formability of cardboard, as a property of formation of packaging, can only be improved by chemical and mechanical changes in the fibres and the structure of the fibre network, (*Vishtal and Retulainen, 2012*).

Waste management refers to temporary storage, reuse, collection, transport, treatment, recycling and disposal of waste, the main purpose being to save raw materials by reusing recyclable waste, thus contributing to reducing the pressure on natural resources.

Waste is divided into two main categories: non-hazardous and hazardous and, in Romania, are defined by categories in HG 856/2002 on waste management records.

The costs of waste management operations are borne by the waste producer according to the "polluter pays" principle.

Waste paper and cardboard packaging (cardboard boxes of purchased goods) is classified as non-hazardous waste; code 15 01 01. For these categories of waste the way of management is recycling.

The place for storing recyclable / recoverable waste is closed, on a concrete platform, provided with a roof and protected from the weather.

Waste compaction or baling reduces the volume of waste and has similar benefits. The process depends on the material being reduced and what continues to happen to it. Cardboard waste can be both bailed and compacted.

Bale is a process that compresses the material into a block (bale) that is secured with plastic tape or wire. Baling reduces the volume of waste, which has a number of advantages: it reduces the space occupied and the baling is easier to store and transport due to its regular shape, thus reducing storage, transport and disposal costs.

Recycling cardboard waste also reduces energy consumption and emissions compared to the production of new materials. Under high pressure, cardboard waste can usually be compacted with a compaction ratio of 6: 1, and the bales can be immediately recyclable.

There are balers with horizontal or vertical compaction. The most widely used cardboard waste balers are vertical balers, which compress the material from top to bottom, with a top opening on the front for material supply and a door at the bottom that opens to allow the baler to be produced to be placed on a pallet.

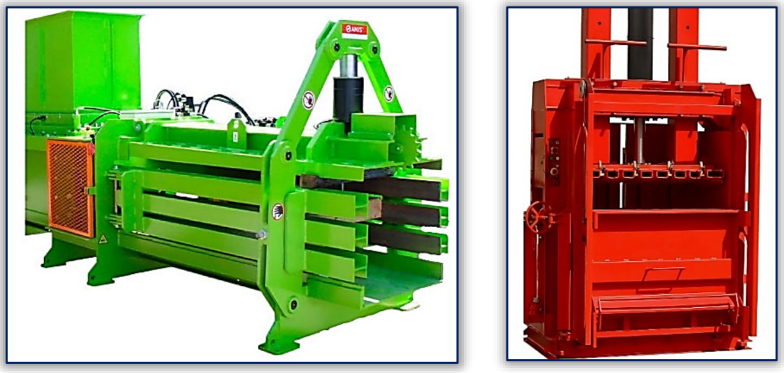

Figure 1 - ATS 110-75B waste baler and vertical baler

In Europe, recycling has increased by almost 20% in recent decades, to around 72% in 2012, (*Pivnenko et al., 2015*). With the increase in recycling rates, the processes have also been improved, and fractions of lower quality paper and cardboard can be added.

According to mediafax.ro, Romania produces 5.8 million tons of waste per year, with an average of 272 kg / year / inhabitant and a collection rate of 82.35, according to the Waste Atlas study, published by D-Waste. Of these, 56% is organic matter, 9.9% paper and cardboard, 9.9% plastic, and the rest other categories of waste. Of the total waste, Romania recycles only 3% before 2018, (*mediafax.ro, accessed 20 oct.2021*).

Other countries in Europe recycle much larger amounts of waste compared to Romania. For example, Slovenia recycles about 55% of waste annually, with a collection rate of 100%, but produces only 0.852 million tons of waste, with 414kg / inhabitant / year.

In a circular economy an important practice is recycling, currently considered the main core for returning materials to the supply chain, and the main bottleneck in plastic and paper recycling chains is the lack of continuous selective collection programs with a focus on processes of ecological education, (*Rutkowski and Rutkowski, 2017*). The paper shows that in 2013, about 57% of the paper used worldwide was produced from recycled fibers (~ 233 million tons). Although the amount of recyclable material increases every year, it is difficult to guarantee the homogeneity of separation and avoid contamination.

Recovered paper and cardboard are mainly used for packaging purposes. In recent years, however, various researches have focused on the possibility of developing new products with applications in other fields. Thus, noise-absorbing panels made of recycled cardboard have been developed, which have been shown to have an impact on the environment compared to conventional acoustic materials, but with a potential reduction in energy demand and greenhouse gas emissions during the production process of cardboard-based acoustic materials. These values were, in order, 10% and 34%, respectively, lower than the impact of a conventional drywall, (Secchi et al., 2015). Furthermore, by appropriate processing methods, corrugated waste may be used, in the form of structured boards, in the furniture industry, in the production of thermal and thermal insulation boards suitable for the thermal insulation of buildings or as partitions in buildings. The flexural strength of insulation boards depends on the vectorization of the individual layers, while the coefficient of thermal conductivity does not depend on it, (*Russ et al., 2013*).

It goes without saying that cardboard waste can be used as fuel. Mixed with wood sawdust, the briquettes of the material obtained have optimal heating characteristics (17.41 MJ/kg), a minimum ash content (6.62 %) and maximum compressive strength (149.54 N/mm) for a compressive force of 588.6 kN, a percentage of sawdust 46.66 % and a drying temperature of 22°C, (*Lela et al., 2015*).

Experimental results in the laboratory have shown that chips from recycled cardboard waste mixed with sand can be used successfully in the preparation of concrete for construction, resulting in a more environmentally friendly concrete with low costs of disposing of cardboard waste and with acceptable strength characteristics, (*Seyyedalipouret al., 2015*).

At the same time, paper and cardboard waste can be a major source of cellulose biomass, which can be used as a potential substrate for cellulase production. Thus, experiments show that cardboard treated with 0.1% sulfuric acid is a good substrate with low costs for cellulose production, (*Al Azkawi et al., 2018*).

In order to choose the most efficient method of waste management, life cycle assessment (LCA) can be used, recommending energy recovery by pyrolysis, gasification and combustion only if the heat produced is used for other applications, (*Vukoje and Rozic, 2018*).

Cardboard balers are quite versatile and can compress all types of cardboard, regardless of shape, size or use. Normally, whole boxes, plates, sheets, tubes, corrugated cardboard and plain cardboard can be baled in a baler.

2. MATERIALS AND METHODS

A vertical flow press was used to compact the cardboard waste and bales with a parallelepiped shape were obtained. The press is usually used in compacting plastic waste, foil, PET bottles, cardboard, and is of the PP 1207 type Germany production, with the maximum strength of 50 tons force. The pressing chamber is frontally fed through the median sliding door (see Figure 2).

The bale is formed by successive feeding and compaction and it is connected by 4 strips, before being evacuated from the compaction chamber.

The purpose of compaction and obtaining the bale is to reduce the volume of waste for an economical storage and transport with optimal weight / volume for further processing.

Cardboard waste is a non-homogeneous mixture of packaging boxes of various shapes or sizes, they are sorted before being placed in the press - in order to separate plastic waste or polyurethane foam.

A formed / tied bale can have weights ranging from 150 kg to 350 kg and dimensions given by the pressing chamber: 1180 x 700 x 800 mm.

The flow of operations for collecting experimental data is as follows:

≡ Installation of data collection and calibration / sample equipment.

- Weighing the quantities for the first sample and introducing them through the sliding door in the compaction chamber.
- The data regarding the compaction force and the distance from the compaction plate to the fixed mark on the press body are automatically delivered in an MS Excel worksheet.
- Repeat successively the supplies of cardboard waste in the same conditions as in points 2 and 3.
- The data obtained are stored indefinitely and can be used for further processing.

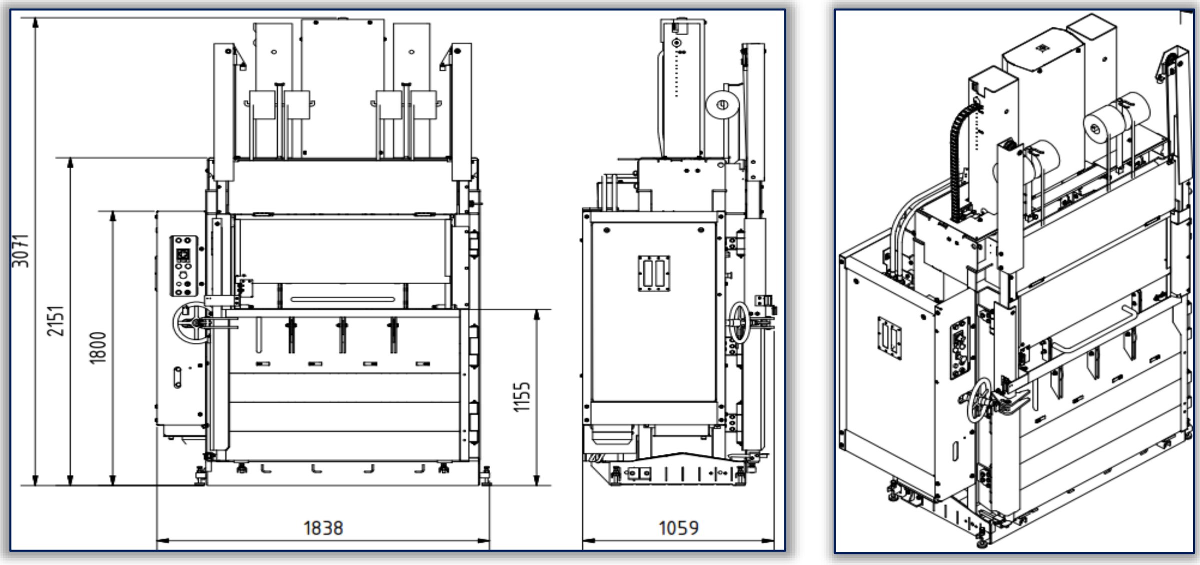

Figure 2 – Vertical flow baler PP-1207, Strautmann *(***the technical book of the press)*

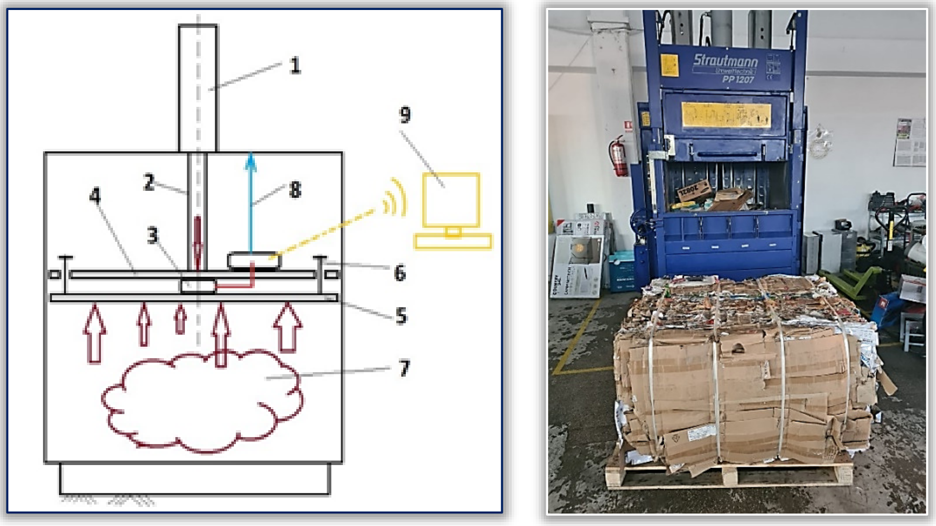

Figure 3. Assembly scheme of the equipment, and appearance during the experimental determination
1 - Hydraulic cylinder, 2. - Hydraulic cylinder rod; 3. Force sensor / transducer, 4 - Pressure plate, 5 - Additional support plate, 6 – Guides, 7 - Cardboard waste, 8 - Displacement sensor, 9 - Laptop

The assembly scheme of the equipment but also aspects during the experimental determination are presented in Figure 3. In the experiment regarding the compaction of cardboard waste we took sorted material made of cardboard of various shapes, each sample was weighed and placed in the compaction chamber. Humidity was not measured, because in reality, in the waste industry they are stored in covered halls and having atmospheric humidity given by normal conditions.

0.2 m^3 of cardboard waste was introduced into the pressing chamber and the pressing cylinder was actuated. After a first pressing, when the maximum pressure in the system is reached, a sensor reverses the stroke of the piston and another 0.2 m^3 is introduced into the pressing chamber, above the 0.2 m^3 of cardboard waste (see table 1).

3. RESULTS

The experimental data obtained were stored in tabular form, these being generated continuously as long as the press was in operation. (Table 1). The table shows the variations of the compaction force depending on the distance of movement of the compaction plate from a fixed upper point on the cover of the press for 7 samples, but also their mass. Data processing can bring favourable results in order to model the process of pressing cardboard waste.

Based on the graphs drawn in the MS Office Excel program, the areas under the force-displacement curve were determined (Figure 4) which represents the energy consumed in each stage of the compaction process, and its values are presented at the bottom of table 1.

Table 1. Variation of pressure forces with compaction piston displacement for the seven samples

Time (s)	P1 V= 0.2 m^3 m = 11.5 kg		P2 V= 0.3 m^3 m = 23kg		P3 V= 0.5 m^3 m = 34.5 kg		P4 V= 0.7 m^3 m = 46 kg		P5 V= 0.9 m^3 m = 57.5 kg		P6 V= 1.1 m^3 m = 69 kg		P7 V= 1.3 m^3 m = 80.5 kg	
	Displacement (mm)	Force (kgf)	Displacement (mm)	Force (kgf)	Displacement (mm)	Force (kgf)	Displacement (mm)	Force (kgf)	Displacement (mm)	Force (kgf)	Displacement (mm)	Force (kgf)	Displacement (mm)	Force (kgf)
1	1323	457	1234	258	1302	153	1278	193	905	128	915	148	1184	278
2	1244	633	1035	912	1042	914	1235	258	838	390	848	410	985	932
3	1099	705	975	980	991	982	1194	372	760	458	770	478	925	985
4	958	742	896	992	892	992	1111	416	692	510	702	530	846	997
5	810	772	824	980	817	981	1026	521	626	563	636	583	774	985
6	645	960	758	967	748	962	950	586	555	631	565	602	708	972
7	523	955	671	968	668	961	902	632	479	766	489	646	621	973
8	385	968	595	966	602	965	868	662	418	802	428	701	545	971
9	231	980	523	967	510	968	802	706	336	861	346	782	473	972
10	183	979	432	967	422	968	725	803	267	912	277	893	382	972
11			347	966	342	970	630	852	236	983	246	978	297	971
12			271	977	270	975	529	876					221	982
13			233	977	231	977	336	921					183	982
14							237	961						
15							183	979						
Energy	673 J		1544 J		1536 J		1292 J		1065 J		1027 J		1554 J	

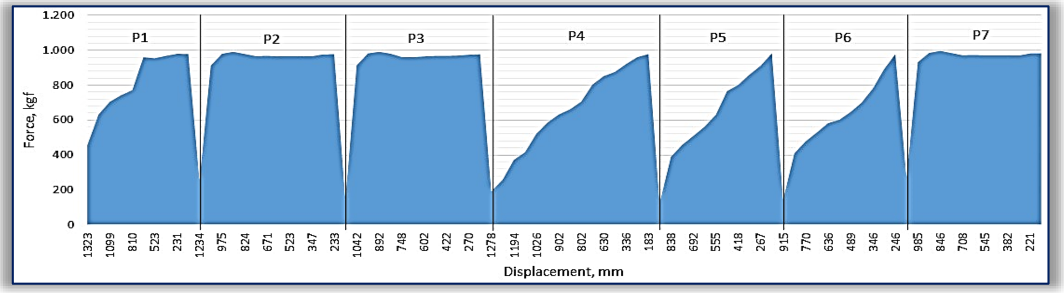

Figure 4. Force - displacement curve for the seven samples of cardboard waste.

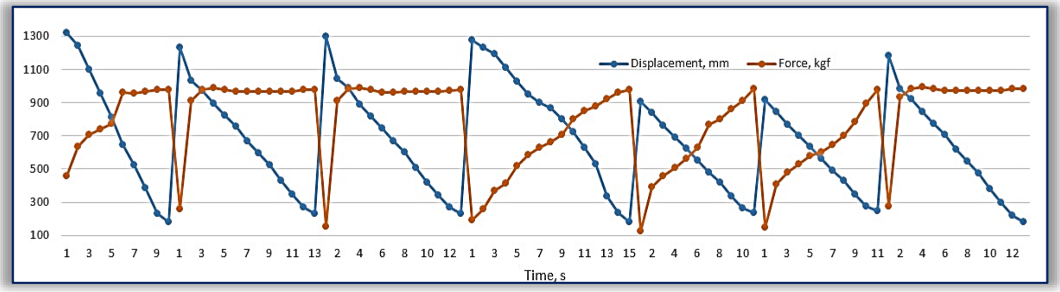

Figure 5. Variation of force and displacement over time for the seven samples analysed

From the analysis of the data in table 1, but also of the graphs presented, it is found that the pressure plate travels, at first, in a vacuum, a certain distance until it comes into contact with the material to be compacted and, only from now on, begins the actual pressing process and follows the registration of s compression forces value, that relative increase exponentially as the pressure plate reaches the maximum position comes down and the lowest of the piston (respectively the maximum compaction force that the press presents). Usually, the lower the material level inside the press, the later the recording of the compression force value will start.

Thus, the variation of the compressive forces according to the displacement of the piston can be followed in Table 1, for all the seven samples. It is observed that the hydraulic system of the press is upper pressure limited. Given that the contact surface with the material is constant (0.826 m^2) it can be said that only the pressing force varies until it reaches the maximum corresponding to the maximum pressure in the system. This maximum is close to 980 kgf, depending on the sensitivity of the sensor that detects the maximum pressure and commands the reversal of the piston stroke.

Figure 5 shows the curves of variation of the pressing force and the displacement of the piston in time (s), curves in phase opposition. In Figure 6 shows the variation of the maximum force and of the energy consumed at pressing for the seven samples, as well as the regression curve for energy. It can be seen from figure 6 that the regression was made with a polynomial law of the third degree, the correlation coefficient having the value 0.985.

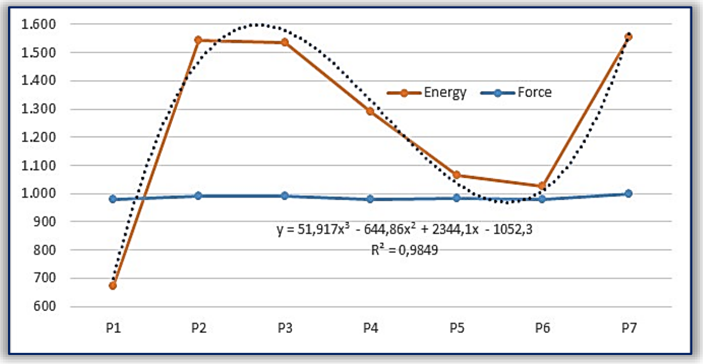

Figure 6. Variation of maximum force and energy consumed for each of the seven samples of cardboard waste

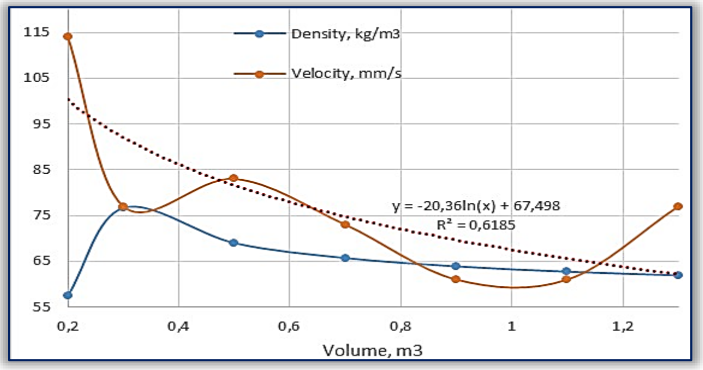

Figure 7. Variation of bale density and piston speed with carton waste bale volume

In addition to the data that can be observed directly from the data table or from the graphs presented, it was found that the speed of the press plate during the compression of the cardboard (that is, as long as the plate is in direct contact with the material to be compacted, and the force increases continuously) it differs from one press to another. Thus, it showed values from 114 mm/s in sample 1 to about 61 mm/s in samples five and 6, with variations between these values in the other samples. However, the value of the pressing plate velocity depends on the compressive strength of the material, but also on the condition of the material to be pressed.

Analysing the values of energy consumption in those for the seven compressed samples, it can also be found that the highest values are shown by the sample 7 (1554 J), because the volume of press material is large. If at the first test (P1), energy consumption is low (673 J), starting with sample 2 the energy consumption exceeds 1000 J. Overall, the total compression energy (the sum of the consumptions from the seven compressions of the seven samples) reaches about 8691 J, which compared to the mass of cardboard waste in the pressing chamber (80.5 kg) determines the specific pressing energy, ie about 108 J per 1 kg of cardboard waste.

In paper (*Lazea et. al, 2021*) the authors analysed the compaction process of polyethylene-terephthalate cylinders, but on a vertical flow press model type HSM-V 605 (GmbH, Germany). Following the research, a maximum energy consumption of 1730 J was obtained, the maximum force of 730 kgf (at a contact surface of approximately 0.5 m2), the average speed of the piston being 50 mm/s.

4. CONCLUSIONS

Compaction of cardboard waste in small and medium capacity vertical flow presses is generally carried out during the collection stage before it is sent to processing companies. Compaction using stationary presses is done in several stages, with recompressions and the addition of new material, until it is sufficient to form a parallelepiped bale with the dimensions of the bottom of the press chamber. The bale is then tied with plastic strips (usually four strips), with a much lower volume compared to the initial free state of the cardboard waste. Compression in several successive stages leads to the relocation of the material in the pressing chamber and to its increase in density. The degree of compaction depends, including, on the pressure in the cylinder (or cylinders) of the compaction plate that the press can develop, but also on the initial state of the cardboard waste (thickness, rigidity, etc.).

When pressing the cardboard waste, with the vertical press of 50 tons force, the maximum compression forces showed variations in the range 978-997 kgf. For the maximum loading of the press (at test P7) the compression force reached the value of 997 kgf, ie a pressing pressure of about 0.0116 MPa.

With regard to the compression energy, it recorded values between 673 J (in sample P1) and 1554 J (in sample P7). However, the average value of the specific compression energy for the whole process was around 108 J / kg of compressed material..

Acknowledgement

<<The paper was funded both from the project "Improving the base of practical applications in solariums, gardens, orchards and vineyards (IMPRASGLIV)", CNFIS-FDI-2021-0021, from the Ministry of Education through the Executive Agency for Financing Higher Education, Research, Development and Innovation.>>

Note: This paper was presented at ISB–INMA TEH' 2021 – International Symposium, organized by University "POLITEHNICA" of Bucuresti, Faculty of Biotechnical Systems Engineering, National Institute for Research-Development of Machines and Installations designed for Agriculture and Food Industry (INMA Bucuresti), National Research & Development Institute for Food Bioresources (IBA Bucuresti), University of Agronomic Sciences and Veterinary Medicine of Bucuresti (UASVMB), Research-Development Institute for Plant Protection – (ICDPP Bucuresti), Research and Development Institute for Processing and Marketing of the Horticultural Products (HORTING), Hydraulics and Pneumatics Research Institute (INOE 2000 IHP) and Romanian Agricultural Mechanical Engineers Society (SIMAR), in Bucuresti, ROMANIA, in 29 October, 2021.

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ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665