EFFICIENCY AND ECOLOGICAL IMPACTS OF HOUSEHOLD OZONE LAUNDERING

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Abstract: *Two different laundering procedures were executed in the research. The first investigated procedure was a classical type of laundering procedure at 40 °C which was performed in a household drum washing machine. A two-bath procedure using ozone was the subject of the second investigated laundering procedure. The efficiency of compared laundering procedures were evaluated (washing performance and cleaning performance indices). Impact Factors for both treatments were collected and evaluated with the help of the LCA/LCI methodology.*

Keywords: TEXTILE LAUNDERING, HOUSEHOLD WASHING MACHINE, OZONE LAUNDERING, ECOLOGICAL IMPACTS

1. Introduction

One of priorities of the European Commission is to increase energy efficiency and, thus, to save 20% of the EU's total primary energy by 2020 [1, 2]. The full savings potential in the household sector is estimated to be 27% energy use. Among the most electricity consuming are large household appliances, like washing machines and dishwashers. Therefore, legitimate expectations are that producers should develop energy efficient household products.

Textile laundering is the most frequent household occupation. Household laundering is a complex process where the synergy of temperature, time, detergent, and kinetic energy combine within water to ensure elimination of impurities. Households in the EU consume 2.53 GWh of electricity and 206 Mm^3 of tap water for laundering 101 MT of textiles per year [3, 4, 5, 6, 7].

Ozone (O_3) is a colourless gas at room temperature, toxic, with a characteristic odour readily detectable at concentrations as low as 0.02 to 0.05 ppm, which is below concentrations of health concern [8].

Ozone is formed in the stratosphere, in the **t**roposphere **(**photochemical smog) and by UV lamps, high voltage electric arcs, and gamma radiation plants [9].

It is a strong oxidising agent (2,07 mV), and, as such, has been used for years for disinfection of drinking water [10]. Ozone removes odour, taste and suspended solids, improves biological degradation, reduces the colour of wastewaters and toxicity. Furthermore, it reduces the ecological parameters partially and degrades microorganisms, viruses and algae successfully [11, 12]. Nowadays it is used intensively for cleaning of industrial wastewaters, in the food, fishing, cellulose, paper and pharmaceutical industries, as well as in agriculture.

In the last three decades, the usage of ozone in hospital and hotel laundries has been increased significantly. In most cases, it was empirically proven that ozone can aid in the reduction of natural resources, energy consumption, and extending textile life [13]. Not so long ago, an extensive research began for proper use of ozone in commercial laundries, as influences of ozone on textile quality and hygiene.

The focus of the research was the analysis of laundering quality and evaluation of those environmental impacts caused by various textile laundering procedures. Classical household (40 °C) and newly-developed ozone (30 °C) laundering procedures were performed in a household drum washing machine and analysed.

2. Experimental part

Classical household washing equipment, a commercial ozone generator, cotton base load, stain test strips, and laundering agent IEC A were used. The laundering phase and the evaluations of the washing performance were followed by further research and comparison between environmental impacts.

Laundry equipment All laundering procedures were performed in a household washing machine SensoCare W8665K Gorenje d.d. (SLO) (Figure 1), with a capacity of 9.0 kg. The classical laundering procedure consists of main-washing (40 °C), two rinsing phases, and spinning. The ozone laundering procedure began with pre-washing with ozone, followed by main-washing (30 °C), rinsing with the addition of ozone, and spinning. In the pre-washing and rinsing phases ozone (10 ppm) was added to the inlet water.

***Figure 1**: A household washing machines SensoCare Gorenje (SLO) and ozone-generator OVK-W01 Eco Laundry (CN)*

The investigated laundering procedures were performed according to [14]. Laundering procedures began with loading the washing machine with cotton base load (4.5 kg, sheets, pillow cases and towels) and stain strips WFK (D), followed by automatic dosing of water (conductivity < 10 μS/cm; total water hardness

2,5±0,2 mmol/L = 14±1,12 ^{o}n; pH = 7,3–7,7; T = 15±2°C; bath ration 1:5). In the main-washing phase the laundering detergent IEC A, WFK (D), was added, composed from the following ingredients: 77% of basic powder, 20% of sodium perborate tetrahydrate (oxidizer), and 3% of tetraacetylethylenediamine TAED (bleach activator).

In the research, we used the commercial ozone-generator OVK-W01 Eco Luandry (CN), (conc 0.5~1.0 mg/L, water flow: 4.5 L/min), shown schematically in Figure 2. The main components of the ozone-generator are: Water inlet (1), water outlet (2), flow switch (3), mixing chamber, venturi injector (4), static mixer (5), Photo Catalytic Oxidation (PCO) cell (6), control module (7), oxidizing module (8).

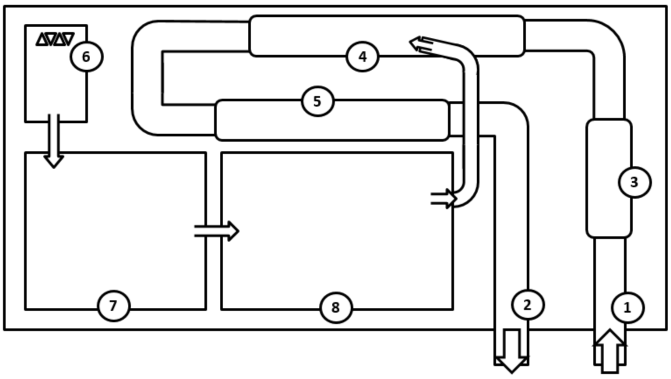

***Figure 2**: Scheme of the ozone-generator OVK-W01 Eco Laundry (CN)*

Determination of soil removal efficiency Reflectance measurements of non-laundered and laundered stain strips were determined with the spectrophotometer Datacolor SF600 (CH) under the following conditions: d/8 measurement geometry, measurement wavelength range from 400 nm to 700 nm, measurement area of 20 mm in diameter and SIN-specular included measurement mode. *XYZ*, CIE *L*a*b**, *C** CIELAB 1976 and colour difference $dE^*_{D65/10}$ were calculated with Datacolor Datamaster software (CH) according to [15].

The washing performance *q* was evaluated in accordance with [14]; meanwhile, the Cleaning performance index $CPI_{dE}*$ was calculated based on Equation (1) [16, 17, 18, 19],

$$CPI_{dE^*} = \left[1 - \frac{dE^*_{wash-unsoil}}{dE^*_{soil-unsoil}}\right] \cdot 100\ (\%) \qquad (1)$$

where

CPI_{dE^*}	Cleaning performance index (%)
$dE^*_{wash\text{-}unsoil}$	Colour difference $dE^*_{D65/10}$ between washed soil sample and unwashed unsoiled fabric
$dE^*_{soil\text{-}unsoil}$	Colour difference $dE^*_{D65/10}$ between unwashed soil sample and unwashed unsoiled fabric

Determination of environmental impact factors The goal of the LCA was to collect, evaluate and compare the environmental impact of two laundering procedures. In the study, only the laundering process was included, other life cycle stages (detergent production, all types of transport, packaging, water treatment, etc.) were excluded.

All parameters for each laundering procedure were recorded during the first step. The recorded and collected data were the base for preparing a technological block-diagram with inlets (laundering detergent, water, energy, laundering time), and outlets` parameters. LCI schemes of laundering processes were prepared based on these data. The following environmental impact assessments of laundering procedures (LCIA) were performed by considering the databases of the characterisation and emission factors obtained from the Intergovernmental Panel on Climate Change [20], ELCD database of EC Joint Research Centre, Institute for Environment and Sustainability [21, 22], and the Global Emission Model software package for Integrated Systems [23]. The environmental impact assessments of classical and ozone laundering procedures were done according to the method [24]. The measured energy consumptions for laundering procedures were the base for calculating the greenhouse gas (GHG) emissions of 27 Member States of the European Union (EU27). These calculations took into consideration the structures of the sources for electricity production (electricity-mix), as available in the database [25]. Later, the Global Warming Potential indicator GWP_{GHG} (100 years) and potential Acidification Indicator *AP* were calculated, regarding the GWP_i *and* AP_i factors. The methodology for determining the environmental impact assessments for laundering procedures has been described briefly previously [26, 27].

3. Results and discussion

Two laundering procedures, the classical and the developed two-bath ozone procedure, were carried out regarding washing quality and environmental impact assessments. The laundering quality parameters for both performed procedures are shown in Table 1, whilst the results of the LCA analyses and the environmental impact assessments are in Tables 2 and 3.

The washing performance *q* for the classical procedure (*q*=1.097) is slightly higher (0.075 units) compared to the ozone procedure (*q*=1.022). We can conclude that both procedures ensure efficient and comparable washing quality.

From the results of total colour differences average between unwashed and washed samples with soils and the CPI_{dE^*} average (Table 1) it can be concluded that the ozone laundering removes a somewhat lower amount of stains (8.17%) than the classical. This could be attributed mostly to the solubility of ozone in water, temperature of the laundering bath, low ozone concentration (10 ppm), and the short contact time between ozone and soils (30 min).

It is known that ozone is an unstable molecule that decomposes spontaneously, thus generating free radicals, which react with impurities in water. Basic chemistry research has shown that solubility of ozone declines with a rising water temperature (at 15 ^{0}C= 0.456 LO_3/ L H_2O, at 40 ^{0}C= 0.0112 LO_3/L H_2O, at 60 ^{0}C= solubility of ozone in water is interrupted) [9, 28, 29]. Ozone degrades in 12 minutes in pure water with a temperature of 20 ^{0}C, and in 8 minutes when the water is heated to 35 ^{0}C.

***Table 1:** Colour differences dE* CIELAB and Cleaning performance indices* CPI_{dE^*} *for classical and ozone laundering procedures*

Soil	dE* (D65/10)		CPIdE* (%)	
	Classical	Ozone	Classical	Ozone
Unsoiled	2.79	1.87	--	--
Sebum	12.99	10.80	75.00	63.50
Carbon black/mineral oil	15.99	15.46	41.37	40.18
Blood	42.57	42.05	94.16	96.44
Cocoa	25.80	18.09	74.71	51.65
Red wine	20.95	18.93	73.04	65.65
Average:	20.18	17.86	71.66	63.49

It was found that the most efficient removal (Table 1) for both treatments was noted for blood (pig's blood, fresh and stabilized by the addition of ammonium citrate), followed by moderate soil removal of synthetic sebum (cows fat, wool fat, free fatty acid, cholesterol, squalen, coconut oil, hard paraffin, carbon black, kaoline, iron oxide) cocoa (unsweetened cocoa (22 % fat, not alkalised) with sugar, full-cream cow's milk and water) and red wine (red wine treated with hot air), meanwhile for carbon black (carbon black, oil. paraffin oil) the soil removal was noticeably low.

The most efficient removal after the ozone washing cycle (Table 1), was noted for blood (96.44%), lower for sebum (63.50%), and red wine (65.65%), and the lowest for carbon black soils (40.18%).

The analyses of data in Table 2 showed that the classical laundering procedure consumed 858 kJ of energy, whilst the ozone procedure consumed 61.53% less energy (330 kJ).

Table 2: *Results of LCA/ LCI analysis and environmental impact assessments for classical household and ozone laundering procedures (for 1kg of laundered textile)*

Parameter	**Unit**	**Laundering procedure**	
		Classical	**Ozone**
Energy	kJ	858.00	330.10
Duration	min	110	105
Water	L	14.13	8.40
Laundering agent	g	0.02	0.02

Table 3: *Emissions of greenhouse gases and acidification substances for classical and ozone laundering procedures for the EU27 average (for 1kg of laundered textile)*

Parameter	**Unit**	**Laundering procedure**	
		Classical	**Ozone**
CO_2	g	45.31	17.43
NO_2	g	25.30	9.73
CH_4	g	2.20	0.84
SO_2	g	0.26	0.10
NO_x	g	3.56E-10	1.37E-10
NH_3	g	3.50E-04	1.35E-04
HCl	g	1.43E-09	5.52E-10
GWP_{TGP}	g CO_2Eq	72.80	28.01
AP	g SO_2Eq	0.26	0.10

The classical laundering procedure consumed the most energy for heating the laundering bath to 40 °C during the main-washing (66%) phase, whilst the rest of electrical energy (34%) was consumed during the rinsing phases. With regard to the composition of the second laundering procedure, firstly cold washing with ozone was performed, and with the main-washing at 30 °C, during which the most electrical energy was consumed. The classical laundering procedure lasted about 5 min longer when compared to the ozone procedure. It is important to emphasise that the ozone procedure demanded the usage of only one rinsing phase, whilst the classical procedure needed two phases to assure the final quality of laundered textile (alkalinity). An important advantage of the ozone procedure is the fact that 40.54% less water was consumed compared to the classical laundering procedure (Table 2, Figures 3 and 4).

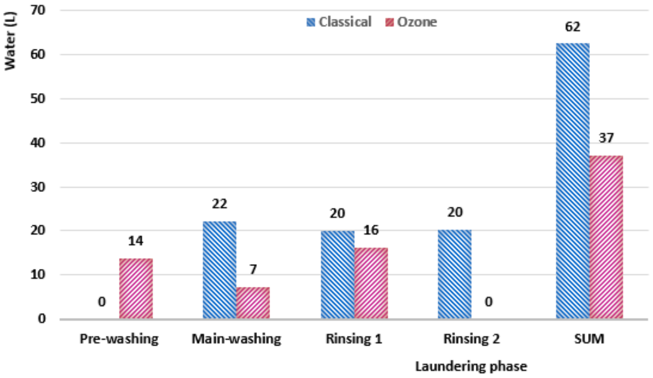

Figure 3*: Water consumption for classical and ozone laundering procedures*

It is important to draw attention to the fact that emissions of greenhouse gases are 61.54% lower for the ozone procedure than those emissions from the classical household laundering procedure (Table 3).

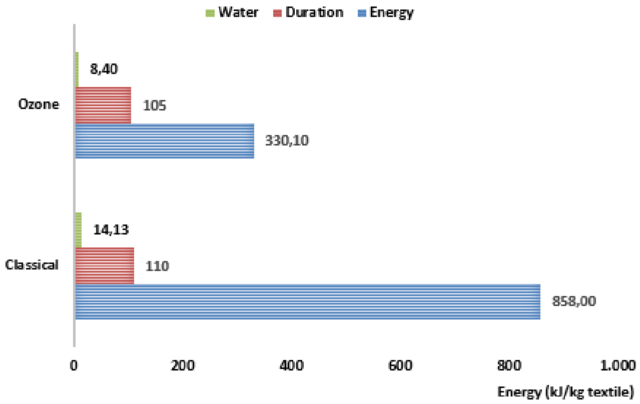

Figure 4*: Duration (min), energy (kJ/kg fabric) and water (L/ kg fabric) consumption for classical and ozone laundering procedures*

4. Conclusions

There is almost no human activity which does not create emissions of GHG that result in climate changes, which is reflected in the rising of average global temperatures, an increase in the average amount of precipitation, sea-level rises, shrinking glaciers, and occurrences of extreme weather events. The fact causing the most concern is that concentrations of GHG in the air, caused by human activities, is increasing much faster than in the natural way [20]. The development of economic and environmental protection is based on the replacement of existing products, and by developing new technologies, on the exchange of fuels and raw-materials, and regarding sustainable production and energy consumption [5, 30, 31,32, 33].

From the results, it can be concluded that all performed laundering procedures proved satisfactory washing performance. The results also show that the two-bath ozone treatment needed 61.63% less energy compared to the classical household laundering procedure. Evidently, the classical laundering procedure has two times higher Global Warming Potential (GWP_{TGP}) and Acidification Potential (*AP*) than the ozone laundering procedure.

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