Car wash wastewater treatment and water reuse – a case study
R. N. Zaneti, R. Etchepare and J. Rubio

ABSTRACT
Recent features of a car wash wastewater reclamation system and results from a full-scale car wash wastewater treatment and recycling process are reported. This upcoming technology comprises a new flocculation-column flotation process, sand filtration, and a final chlorination. A water usage and savings audit (22 weeks) showed that almost 70% reclamation was possible, and fewer than 40 L of fresh water per wash were needed. Wastewater and reclaimed water were characterized by monitoring chemical, physicochemical and biological parameters. Results were discussed in terms of aesthetic quality (water clarification and odour), health (pathological) and chemical (corrosion and scaling) risks. A microbiological risk model was applied and the Escherichia coli proposed criterion for car wash reclaimed water is 200 CFU 100 mL−1. It is believed that the discussions on car wash wastewater reclamation criteria may assist institutions to create laws in Brazil and elsewhere.

Key words | car wash, column, flocculation, reclaimed water criteria, tannin, water reuse

INTRODUCTION
The car wash industry appears today to be more conscious of the need for wastewater treatment and water reclamation. Worldwide environmental legislation and guidelines concerning this specific issue have been released. Regarding water consumption, for instance, in Queensland, Australia, it is mandatory to use at most 70 L of fresh water in a single car wash, and in Europe some countries restrict the water consumption to 60–70 L per car and/or impose a reclamation percentage (70–80%) (Boussu et al. 2007; QWC 2008).

Reclaimed (reuse, recycling) water is herein defined as the wastewater that has gone through various treatment processes to meet specific water quality criteria (Metcalf & Eddy 2006) the fit for purpose principle. Although some research effort has been made (Nace 1975; Paxéus 1996; Brown 2002; QWC 2008; Almeida et al. 2010) and distinct technologies have been tested/employed (Hamada & Miyazaki 2004; Al-Odwani et al. 2007; Boussu et al. 2007; Rubio & Zaneti 2009), there is a lack of well-defined (accepted) criteria for the quality of car wash reclaimed water. Surprisingly, not many studies have included the presence of coliforms in the reclaimed water.

Rubio & Zaneti (2009) have developed and applied the flocculation-column flotation (FCF) technique for vehicles wash wastewater reclamation in Brazil, and reported a high turbidity and colour removal (>90% and 75%, respectively). Main features were the low surface tension (given by a residual surfactant concentration) of the wash wastewater, which facilitates the generation of microbubbles (Féris et al. 2001); the presence of oil and grease yielding light flocs; and a fairly low suspended solids concentration.

In this work a FCF + sand filtration + chlorination technique was employed in a full-scale car wash wastewater reclamation system, where the wastewater and reclaimed water were characterized. Main objectives were assessing the chemical and microbiological risks and the reclaimed water quality, discussed as a function of the low technology/low cost/controlled risk approach (Anderson et al. 2001).

MATERIALS AND METHODS
The car wash (hand wash) wastewater reclamation system (Figure 1) installed in a washrack in Porto Alegre, South Brazil, was monitored for 22 weeks. In the wash procedure a neutral and an alkali detergent were employed, both with
doi: 10.2166/wst.2012.492
dodecyl benzene sulphonate – $\text{CH}_3(\text{CH}_2)_{11}\text{C}_6\text{H}_4\text{SO}_3\text{Na}$ – as the main surface active agent. Reclaimed water was employed in the wash process (pre-soak, wash and first rinse) and fresh water was used in the final rinse, before the cars were dried. Water usage was monitored using single-jet water meters. To comply with local regulations, a single three-stage oil/water separator was employed after the car wash pit.

The wastewater treatment process (FCF + sand filtration + chlorination – FCF-SC) was run semi-automatically. The reagents employed were Tanflo SL (80–350 mg L$^{-1}$) and sodium hypochlorite (standardized weekly – 0.5 mgCl$_2$ L$^{-1}$). Wastewater and reclaimed water had chemical, physicochemical and microbiological parameters analysed (APHA 2005) in samples which were collected after oil/water separation and after chlorination (Figure 1). Single and composite (four aliquots in 2 h) samples were collected once a week (single samples were analysed for pH, total coliforms and Escherichia coli, and composites for dissolved and suspended solids, chloride, turbidity, conductivity and hydrogen sulphide).

### Microorganisms inactivation – bench-scale studies

Aliquots of 500 mL of reclaimed water samples (sampled after the chlorination step – see Figure 1) were chlorinated (initial concentrations of 1–40 mgCl$_2$ L$^{-1}$) and gently mixed over different contact time periods (30–240 min). Following chlorination, sodium thiosulphate was added to neutralize chlorine action (Winward et al. 2008). Neutralized samples were stored at 4 ± 1 °C for a maximum of 24 h prior to E. coli enumeration.

### Coagulation–floculation + chlorination – bench-scale studies

Jar-tests were accomplished with 1 L wastewater samples (see sampling point in Figure 1) to determine optimum clarification conditions for: (a) polyaluminium chloride (PAC) + floculant and (b) Tanflo SL. Aliquots of supernatant (clarified) liquid were chlorinated with 15 mgCl$_2$ L$^{-1}$ initial dose and kept in darkness for 24 h at 20 ± 3 °C. Chlorinated samples (duplicate) were analysed by total dissolved solids (TDS) and chloride (Cl$^-$).
Table 1 | Microbiological risk calculation: model and parameters

<table>
<thead>
<tr>
<th>Organism</th>
<th>Model*</th>
<th>Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>E. coli</td>
<td>$P_n^t = 1 - (1 - N/\beta)^{\alpha}$</td>
<td>$\alpha = 0.1705$, $\beta = 1.61 \times 10^6$, $N$ – Exposure, as number of organisms ingested</td>
</tr>
</tbody>
</table>

Activity | Exposure route | Dose$^a$ (mL) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Car wash</td>
<td>Aerosol</td>
<td>$T^a$ (0.01, 0.1, 0.5)</td>
</tr>
<tr>
<td>Car wash</td>
<td>Ingestion (routine exposure)</td>
<td>$T$ (0.1; 1.0; 2.0)</td>
</tr>
</tbody>
</table>

Extrapolation of daily risk$^c$

$$P_n = 1 - (1 - P_1)^n$$

$^a$Huertas et al. (2008); $^b$Ashbolt et al. (2005); $^c$Hunter et al. (2003).

$^d$Probability of infection after a single exposure.

$^e$Triangular distribution (minimum; mode; maximum).

$^f$Probability of infection after repeated (n times) exposures.

Microbiological and chemical risks studies

Microbiological risk was evaluated utilizing a model which estimates the probability of infection of an exposed individual – quantitative microbiological risk assessment (QMRA). Once the etiologic agent is identified, the next step is to determine how exposure to different concentrations of the pathogens might elicit a response in humans (Huertas et al. 2008). Herein, the etiologic agent chosen was E. coli and exposure routes of aerosol and ingestion were considered for car wash customers and operators. Single-event ingestion doses and the infection model for E. coli are shown in Table 1. The ingestion dose for the car wash activity was the same used by Ashbolt et al. (2005) for the irrigation activity.

The operational (not health) chemical risk (corrosion and scaling – Metcalf & Eddy 2006) was evaluated by the employment of a mass balance model (Equations (1), (2) and (3)). The evaluated parameters were TDS, and Cl$^-$, as their concentration in the wastewater is high and enhanced along the water cycles.

The following hypotheses were considered: (a) the mass value added during the car wash and wastewater treatment operation is constant (Equation (2)), as a function of water cycles, and there is no water loss (Equation (3)); (b) one water cycle is considered to occur when the total water volume used in the washes overcomes the storage capacity of the system (10 m$^3$).

$$C_{RI+1} = \frac{CS + (F \cdot V_{LI} \cdot C_{RI} + (1 - F) \cdot V_{LI} \cdot C_N)}{V_{LI}}$$ (1)

$$CS = V_{LI} \cdot (C_1 - C_N)$$ (2)

$$V_{EI} = V_{LI} = F \cdot V_{RI} + (1 - F) \cdot V_{NI}$$ (3)

Table 2 | Water usage and saving as a function of time (weeks) and/or water cycles

<table>
<thead>
<tr>
<th>Total used water, m$^3$</th>
<th>Water cycles</th>
<th>Number of washings</th>
<th>Average total water, L/vehicle$^{-1}$</th>
<th>Average fresh water, L/vehicle$^{-1}$</th>
<th>% Water reclamation</th>
</tr>
</thead>
<tbody>
<tr>
<td>274</td>
<td>27.4</td>
<td>2095</td>
<td>131</td>
<td>44</td>
<td>66</td>
</tr>
</tbody>
</table>

Table 3 | FCF-SC process: characterization of wastewater and reclaimed water (mean values ± 0.5 standard deviation)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Wastewater</th>
<th>Reclaimed water</th>
<th>Examination methods$^a$</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.4 ± 0.8</td>
<td>7.3 ± 0.5</td>
<td>-</td>
</tr>
<tr>
<td>BOD$_5$, mg L$^{-1}$</td>
<td>68 ± 13</td>
<td>27 ± 11.5</td>
<td>5,520 B</td>
</tr>
<tr>
<td>COD, mg L$^{-1}$</td>
<td>191 ± 22</td>
<td>71 ± 25</td>
<td>5,210 B</td>
</tr>
<tr>
<td>TSS, mg L$^{-1}$</td>
<td>89 ± 54</td>
<td>8 ± 6</td>
<td>2,540 D</td>
</tr>
<tr>
<td>TDS, mg L$^{-1}$</td>
<td>345 ± 27.5</td>
<td>387 ± 47</td>
<td>-</td>
</tr>
<tr>
<td>Conductivity, $\mu$S cm$^{-1}$</td>
<td>469 ± 39.5</td>
<td>572 ± 69</td>
<td>2,520 B</td>
</tr>
<tr>
<td>Turbidity, NTU</td>
<td>103 ± 57</td>
<td>9 ± 4</td>
<td>2,130 B</td>
</tr>
<tr>
<td>Total coliforms, CFU 100 mL$^{-1}$</td>
<td>$3.1 \times 10^5$</td>
<td>$3.3 \times 10^4$</td>
<td>9,223 B</td>
</tr>
<tr>
<td>E. coli, CFU 100 mL$^{-1}$</td>
<td>$2.1 \times 10^9$</td>
<td>$7.4 \times 10^7$</td>
<td>9,221 E</td>
</tr>
<tr>
<td>Hydrogen sulphide, mg L$^{-1}$</td>
<td>0.19 ± 0.01</td>
<td>0.02 ± 0.01</td>
<td>4,500 NH$_3$ C</td>
</tr>
<tr>
<td>Chloride, mg L$^{-1}$</td>
<td>30.9 ± 4.5</td>
<td>59.3 ± 14.5</td>
<td>4,110 B</td>
</tr>
</tbody>
</table>

BOD$_5$: biochemical oxygen demand; COD: chemical oxygen demand; TSS: total suspended solids.

$^a$Standard Methods for the Examination of Water and Wastewater (APHA 2005).
where: \( C_{Ri} \) and \( C_{Ri+1} = \text{TDS or Cl}^{-1} \) concentration in reclaimed water on cycle \( i \) and \( i + 1 \), \( i = 1 \ldots n \); \( CS \) = mass of the TDS or \( \text{Cl}^{-1} \) added during the car washing/water treatment processes; \( F = \) recycling ratio (0–1); \( V_{Li} = \) total volume of water used in the car wash; \( V_{Wi} = \) wastewater volume; \( V_{Ni} \) (L) = fresh water volume; \( C_N = \text{TDS or Cl}^{-1} \) concentration in fresh water.

The bench-scale (Jar-test: PAC versus Tanfloc SL plus hyperchlorination) and full-scale (20 weeks observation) results were utilized in the mass balance equations.

**RESULTS AND DISCUSSION**

Reclamation system

Table 2 shows results of water usage and saving. More than 2,000 cars were washed, during the 22 weeks of operation, with the average used volume of water per car being about 120 L. The total used volume was 27 times the storage capacity (27 water cycles). The water consumption per wash was in the same range already reported (Brown 2002; Hamada & Miyazaki 2004; Al-Odwani et al. 2007; Boussu et al. 2007). Moreover, results show that this system met some strict water regulations regarding the amount of fresh water per vehicle (QWC 2008; Boussu et al. 2007). The percentage of water to be reclaimed was close to 70%, and it is believed that, by using automatic wash (in-bay or tunnel) rather than hand wash, this reclamation percentage will rise.

The characterization of wastewater and reclaimed water is presented in Table 3. The mean values presented demonstrate the high efficiency of the process in reducing TSS (91%) and turbidity (91%). Jefferson et al. (2004) reported aspects of public acceptance for urban water recycling in the UK. Regarding car wash application, their research revealed that low turbidity is fairly acceptable.

Microbial inactivation with chlorine can reach 4 to 6 log reduction, depending on chemical concentration and exposure time – the Ct concept (Metcalfe & Eddy 2006). Nevertheless, the chemical disinfection efficiency is affected by the quality of the water: mainly organic, inorganic and particles (TSS) concentration. Organic/inorganic substances can react with chlorine, demanding and preventing its use for inactivation of the microorganisms. Further, particulate material can shield microorganisms, according to some authors (Winward 2007; Winward et al. 2008). Another important parameter is medium pH because hypochlorous acid (HOCL), which has a killing effect many times higher than that of hypochlorite ion (OCl\(^{-}\)), is predominant at neutral pH 7 and at 20 °C (Metcalfe & Eddy 2006).

Herein, total coliforms and \( E. \ coli \) counting were reduced by 95 and 99% (2 log removal), respectively. These results are somewhat lower compared with those already reported probably because of the low initial chlorine dosage (0.5 mg L\(^{-1}\)) and the characteristics of the reclaimed water (Table 3): pH higher than 7, residual concentration of particles (TSS) and organic/inorganic substances (BOD\(_5\), COD, ionic strength). Nevertheless, a clear relation between \( E. \ coli \) counting, COD and TSS concentration in reclaimed water is not established – Figure 2.
Hydrogen sulphide (H₂S) formation appears to be a result of a microbial process taking place at anaerobic conditions (Hvitved-Jacobsen et al. 2000) and its odour threshold is substantially low - varying from 410 ng m⁻³ (Kim & Park 2008) to 1 ng m⁻³ (Boon 1995) according to different authors. In the present work, its mean concentrations in wastewater and in reclaimed water were 0.19 and 0.02 mg L⁻¹, respectively, corresponding to 88% removal. It is believed that this removal occurs mainly by H₂S escaping into the atmosphere (during FCF process – high turbulence) and/or by oxidation (during FCF and chlorination processes) (Boon 1995).

Microbiological and chemical risks assessment

The microbiological risk that customers and operators are exposed to, in a typical by-hand car wash in Brazil (different scenarios) was estimated (Table 4). Customers do not have

<table>
<thead>
<tr>
<th>User</th>
<th>Route</th>
<th>Water</th>
<th>E. coli, CFU, 100 mL⁻¹</th>
<th>V*</th>
<th>N°</th>
<th>Frequency of exposure</th>
<th>Annual risk c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customers</td>
<td>Aerosol</td>
<td>Waste</td>
<td>2.1 x 10⁴</td>
<td>0.1</td>
<td>3</td>
<td>Once a week</td>
<td>1.7 x 10⁻⁵</td>
</tr>
<tr>
<td>Customers</td>
<td>Aerosol</td>
<td>Reclaimed</td>
<td>7.4 x 10²</td>
<td>0.1</td>
<td>0</td>
<td>Once a week</td>
<td>5.8 x 10⁻⁷</td>
</tr>
<tr>
<td>Operator</td>
<td>Aerosol</td>
<td>Waste</td>
<td>2.1 x 10⁴</td>
<td>0.1</td>
<td>315</td>
<td>15 washes a day</td>
<td>1.0 x 10⁻²</td>
</tr>
<tr>
<td>Operator</td>
<td>Aerosol</td>
<td>Reclaimed</td>
<td>7.4 x 10²</td>
<td>0.1</td>
<td>11</td>
<td>15 washes a day</td>
<td>3.7 x 10⁻⁴</td>
</tr>
<tr>
<td>Operator</td>
<td>Ingestion</td>
<td>Waste</td>
<td>2.1 x 10⁴</td>
<td>1.0</td>
<td>3150</td>
<td>15 washes a day</td>
<td>1.0 x 10⁻¹</td>
</tr>
<tr>
<td>Operator</td>
<td>Ingestion</td>
<td>Reclaimed</td>
<td>7.4 x 10²</td>
<td>1.0</td>
<td>111</td>
<td>15 washes a day</td>
<td>3.7 x 10⁻³</td>
</tr>
<tr>
<td>Operator</td>
<td>Ingestion</td>
<td>Ideal reclaimed</td>
<td>2.0 x 10²</td>
<td>1.0</td>
<td>30</td>
<td>15 washes a day</td>
<td>1.0 x 10⁻³</td>
</tr>
</tbody>
</table>

*aVolume ingested per exposure.

*bCFU ingested/day.

*cAccording to Table 1.

Figure 3 | TDS and Cl⁻ concentration as a function of water cycles – (a) TDS concentration in the reclaimed system (full-scale), and estimated by the mass balance; (b) and (c) TDS and Cl⁻ estimated by the mass balance for different scenarios (chemical risk studies); P = PAC + flocculant; T = Tanfloc SL.
direct contact with the reclaimed water whatsoever, but operators have routine exposure to the reclaimed water and accidentally ingest some water drops.

According to Haas et al. (1996), a risk threshold of $1 \times 10^{-4}$ (1 person infected in 10,000) ‘may be far too stringent’, as that of waterborne illness in the USA may be as high as $1 \times 10^{-2}$. It can be stated therefore, that a risk of $1 \times 10^{-3}$ may be acceptable (FDEP 1998). Here, medium (average of 22 samples) E. coli counting in wastewater and reclaimed water was used for quantitative microbial risk assessment (QMRA). Results in Table 4 show that even this lower value (not the maximum) delivered a microbiological risk 3.7 times higher than the threshold for operators when washing the cars with the reclaimed water. Yet, while utilizing wastewater without any treatment, the risk for operators is $1 \times 10^{-3}$ and may be 100 times higher than the accepted threshold. To fit the proposed $1 \times 10^{-3}$ risk it is necessary to diminish the E. coli in the reclaimed water to 200 CFU 100 mL$^{-1}$.

Once the achieved E. coli field deactivation was not satisfactory to control microbiological risk, bench-scale studies were conducted using FCF process reclaimed water (turbidity = 9 NTU; TSS = 58 mg L$^{-1}$; COD = 151 mg L$^{-1}$; BOD = 41 mg L$^{-1}$). The limit suggested for E. coli counting (200 CFU 100 mL$^{-1}$) was always reached with an initial chlorine dose of 15 mgCl$_2$ L$^{-1}$, after 2 h reaction time.

Regarding the chemical risks, Figure 5(a) shows that TDS concentration predicted by the proposed mass balance is always higher than the TDS concentration during the full-scale study, but with a similar tendency. Figure 5(b) shows that there is no remarkable difference in TDS concentration when utilizing PAC $+\,$ flocculant, rather than Tanflc SL. On the other hand, when comparing TDS concentration for 70% and 80% recycling ratio, a marked difference is observed. Therefore, considering 1,000 mgTDS L$^{-1}$ as the limit (potable water standard in Brazil), 80% recycling ratio is a limiting factor for the practice. Figure 5(c) presents the concentration of Cl$^-$ as a function of coagulation–flocculation reagents, water recycling rate, and number of water cycles. The maximum chloride concentration observed was 332 mg L$^{-1}$, which is lower than the limit of 400 mg L$^{-1}$, proposed by Nace (1975). Therefore, the chlorine dosage applied here does not seem to be a limiting factor for the water recycling practice.

CONCLUSIONS

A full-scale car wash wastewater treatment by FCF-SC and water reclamation was monitored during 22 weeks of operation. Different chemical, physical and microbiological parameters were measured thoroughly. It was possible to reclaim almost 70% of odourless and clear (average turbidity of 9 NTU) water. More than 2,000 cars were washed during the study and no problems regarding the wash service quality were reported. A microbiological risk model was applied. Although users were not at risk, even when wastewater is recycled without any treatment, a criterion for E. coli of 200 CFU 100 mL$^{-1}$ is suggested to guarantee a controlled health risk for operators. A mass balance was calculated to predict TDS and Cl$^-$ concentration as a function of water cycles. Chloride concentration was not a limiting parameter, but TDS with 80% recycling ratio was a limiting factor. It is believed that results found may assist a future regulation for safe reclamation of car wash wastewater in Brazil and elsewhere.

ACKNOWLEDGEMENTS

The authors wish to thank all institutions supporting research in Brazil (CAPES, FAPERGS, Finep, and UFRGS), particularly CNPq, which directly sponsored this research. Special thanks to Hidrociclo Ind. e Com. Ltda., Ecoagua Serv. Lav. Ltda. and students of UFRGS for their kind technical assistance.

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First received 10 April 2012; accepted in revised form 9 July 2012