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THE NOISE ANALYSIS OF A TOUCHLESS CAR WASH

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The study examines the environmental noise levels associated with operation of a touchless car wash. As the number of automated car wash facilities is steadily increasing, their noise impacts are becoming a major concern. Measurements and analysis of noise allowed for identification of the dominant noise sources, evaluation of their environmental impacts and sound characteristics. Results are provided in the form of plotted time histories, spectral analysis data and spectrograms. It was found that the main source is the noise of nozzles supplied with water under high pressure. Calculations were taken of sound levels generated by the noise sources within the car wash and the results were used to determine the noise level exposure at varying distances for several modes of the car wash operation. Due to the high share of higher frequency components in the noise spectrum of sources, it is important in numerical simulations to assume full power spectrum (e.g. in octave bands) in exchange for the global value for the "A" correction filter. It appears that noise generated by the car wash can have an adverse effect on the existing noise environment and that effective monitoring and control measures will be required when pursuing the issuance of the construction permit and then during the car wash operation.

Key words: touchless car washing, environment, noise analysis, noise propagation.

Introduction

The number of self-service touchless car washes has grown considerably in the recent years. This rapid increase has been prompted in the first place by their cost-effectiveness (they are easy to install guaranteeing a short pay-back period) and also by current regulations whereby a ban has been imposed on backyard car washing in a growing number of locations to prevent environmental pollution with toxic substances. Automated car washes are designed for providing touch-free short washing cycles. The main cleaning agent is water applied under pressure 10-15 MPa via spraying nozzles. The washing process is boosted through the use of powdered or foam agents, synthetic wax, finishing agents. Because of the presence of liquid pollutants emerging throughout the process (residues of washing agents and a variety of pollutants already present on the vehicle surface), automated car washes are considered an environmental hazard. That is why effective waste management and environment protection issues are now primary considerations, they are subject to current legal regulations and need to be addressed at the stage of project planning and development. Interestingly, at the stage of car wash planning and operation little attention is given to another environmental hazard, i.e. noise. In environmental impact assessment documents for such projects, the problem of noise is addressed very briefly, just stating the environmental impacts to be minor or non-existent. Sound level calculations results are rarely provided to support this statement and when some noise level predictions are included, in most cases the volumes of modelled sound sources (defined by the sound power levels) differ from the real values. This is so partly because the manufacturer sound level data are mostly inaccurate and because the noise sources associated with car wash operation are typically limited to the flow-generating equipment (pumps, motors), without considering other sources of noise. Noise emissions associated with the car wash would not be a problem were the car washes situated at locations outside the densely populated residential areas (for instance adjacent to filling stations on the motorways). In the context of their functional and economic aspects, however, car washes are often situated in residential neighborhoods, adjacent to noise-sensitive and protected areas. Low investment costs, short development time and relative simplicity of the proposed project, as well as marketing considerations, have prompted the choice of half-open, roofed structures devoid of any walls, which does not seem a desirable solution from the standpoint of noise emission.

Literature on the subject of noise generation associated with car wash operation and the use of high-pressure equipment is rather scarce. In the work [1] the author discusses the advantages and disadvantages of various types of car wash facilities, revealing major trends in their developments and summarises the key legal and environmental aspects involved in car wash operation. In the works [2–8], problems of consumption and pollution of water used during vehicle washing were considered. In paper [9] different techniques of car washing along with issues of water use, water contamination and its purification are presented. The problem of noise generated at the outflow and impact of the stream was tested primarily for supersonic flows [10–13] Noise and vibration of hydraulic systems for handling liquids has received more attention from researchers. The main sources of noise and vibration include the cavitation in the system [14] and pressure pulsation giving rise to dynamic interaction forces [15–19].

The work deals with the problem of noise generated during the operation of touchless car washes and its impact on the environment. Because of the rapid development of this sector, anticipated environmental noise impacts and insufficient level of awareness among the decision-makers issuing the construction permits, providing reliable sound level data demonstrating the gravity of the problem seems fully merited. It is particularly important because reliable sound level data and comprehensive analyses are still rather scant.

1. Noise sources in a touchless car wash

Car wash equipment and facilities have a number of noise sources associated with their operation, such as high-pressure water applicators, machines inducing water flow (pumps, vibration of hydraulic systems), vehicles awaiting the washing and those leaving the site after washing. Vacuum stations also generate a substantial amount of noise. This study is focused on the car washing process, the remaining sources of noise associated with vehicular traffic on the site and operation of ancillary equipment (i.e. vacuum stations) are neglected.

Source identification measurements were performed using a Svantek 958 sound analyser equipped with a microphone ½” located in the proximity of the washing stand at the height of 1,5 m above the ground. The application used enabled the measurement data to be saved in a ‘wav’ file and the offline data analysis was supported by SvanPC++.

A typical car wash cycle involves four steps: washing with the use of micropowder (Programme 1), rinse (Programme 2), preservation with polymer (Programme 3) and rinse with finish (Programme 4). The first series of measurements were taken to identify the main sources of noise associated with the running of particular washing programmes (with the spray nozzle fixed at the distance approximately 30 cm from the vehicle) and to obtain the noise levels pertinent to the remaining sources of noise. The measuring point was situated at the distance of 9,5 m from the source of noise. Figs. 1–5 show the spectral analysis of A-weighted sound levels obtained basing on registered time histories and spectral analysis of background noise. Apparently in each case the background noise level is lower than the level of operational noise, hence the measurement environment can be regarded as satisfactory.

Fig. 1–4 suggest that noise generated during the car washing cycles has the characteristic of broadband noise. Presented spectra take into account the audibility range characteristics (described by the A-weighted correction curve) hence the reduced sound levels

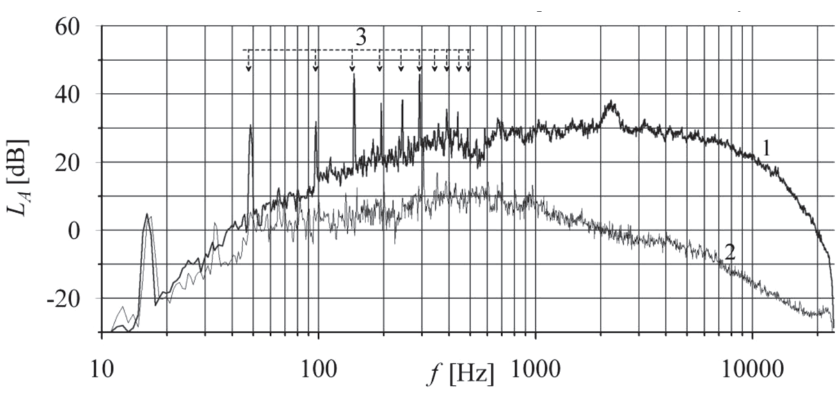

Fig. 1. Spectral analysis of operational noise – Programme 1

1 – operational noise; 2 – background noise; 3 – pipes noise

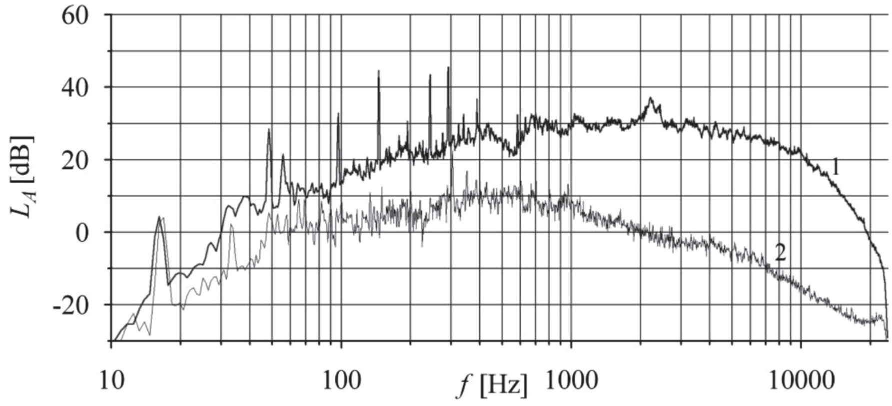

Fig. 2. Spectral analysis of operational noise – Programme 2

1 – operational noise; 2 – background noise

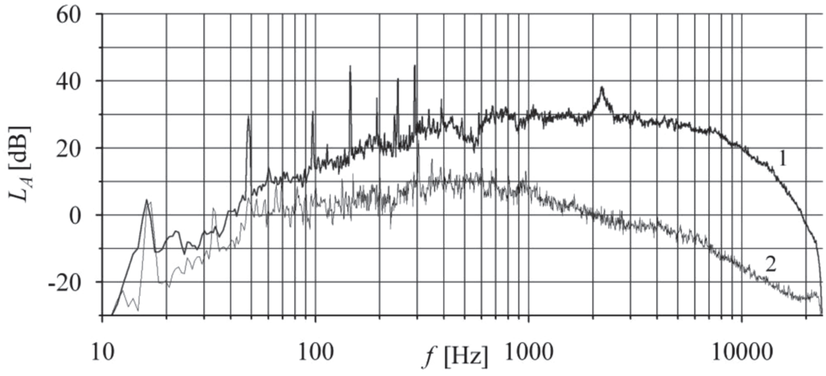

Fig. 3. Spectral analysis of operational noise – Programme 3

1 – operational noise; 2 – background noise

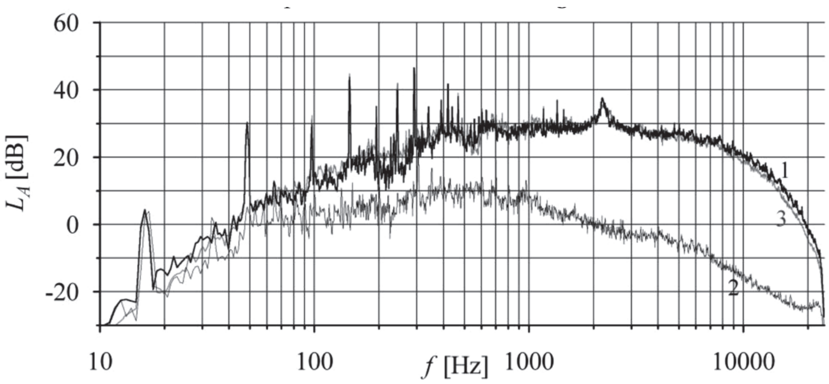

Fig. 4. Spectral analysis of operational noise – Programme 4

1 – nozzle with washing; 2 – background noise; 3 – nozzle without washing

in the low and high frequency range. The highest energy signals are registered in the range from 500 Hz to 8 kHz, with a marked increase by several decibels in the range 2 kHz to 3 kHz. Because of the large proportion of high-frequency components, the noise is subjectively perceived as "bright" and rather intrusive. Each plot reveals a sequence of components registered at frequencies 48,3 Hz, 96,7 Hz, 145,0 Hz, 193,4 Hz, 241,7 Hz, 290,0 Hz, 339,8 Hz, 387,1 Hz, 435,4 Hz, 483,8 Hz with the sound levels exceeding those associated with spraying nozzle operation. This noise shares the characteristic of polyharmonic noise and is attrib-

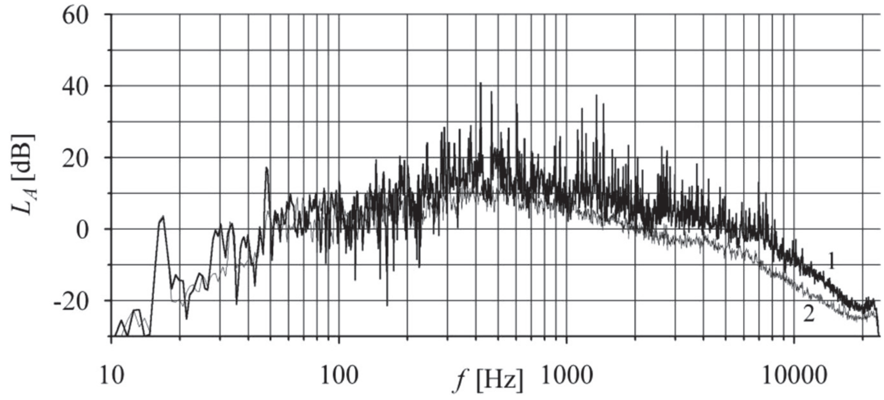

Fig. 5. Spectral analysis of hydraulic supply unit noise

1 – operational noise; 2 – background noise

uted to vibrations of pipes supplying water to the nozzles. These pulsating flows of water give rise to pipe vibration [19], which in turn generates ambient noise. The spectra obtained during the particular wash cycle programmes are found to be similar, their comparison reveals only minor differences. Of particular importance is the operating pressure and, though in a lesser degree, the actual composition of the cleaning agent.

Fig 4 shows the spectrum of noise generated when a stream of water is released from the spraying nozzle while no consideration is given to water jets hitting the car body sheets. The spectra obtained in this case are slightly different, particularly in the frequency range 100 Hz to 500 Hz (weaker noise) and in excess of 8 kHz (slightly increased noise levels). Identification of noise sources in this case will require a full modal analysis of car body sheets [20].

Water flow generation requires the use of a hydraulic supply unit, its main sub-assembly being a high-pressure pump. Operation of such systems generates a substantial amount of noise, though they can be enclosed to reduce their noise emissions. Fig. 5 shows the spectrum of noise produced by a hydraulic supply unit, revealing a sequence of components with frequencies being the multiples of a fundamental frequency component associated with rotating motion or combinations of several frequency components (for instance due to modulation). The spectrum pattern is complex, yet they obtained sound levels are generally lower than sound levels associated with the spray nozzle operation.

Measurement data were used to determine the sound power levels associated with individual sources (for several versions of the washing cycle). Fig. 6 plots the sound power levels in particular octave bands (A-weighted) and the overall sound levels L_{WA} which are as follows: Programme 1 – L_{WA} = 92,9 dB; Programme 2 – L_{WA} = 93,3 dB; Programme 3 – L_{WA} = 92,6 dB; Programme 4 – L_{WA} = 92,5 dB; Programme 4 (without washing) L_{WA} = 91,7 dB; pumps – L_{WA} = 77,8 dB; pipes – L_{WA} = 79,9 dB.

Sound power levels associated with the spraying nozzle operation in various washing programmes differ very slightly (the largest values are registered for the Programme 2 – rinse). The predominant and audible sounds are registered in the frequency range 2 kHz to 8 kHz. When the water jet released from a spraying

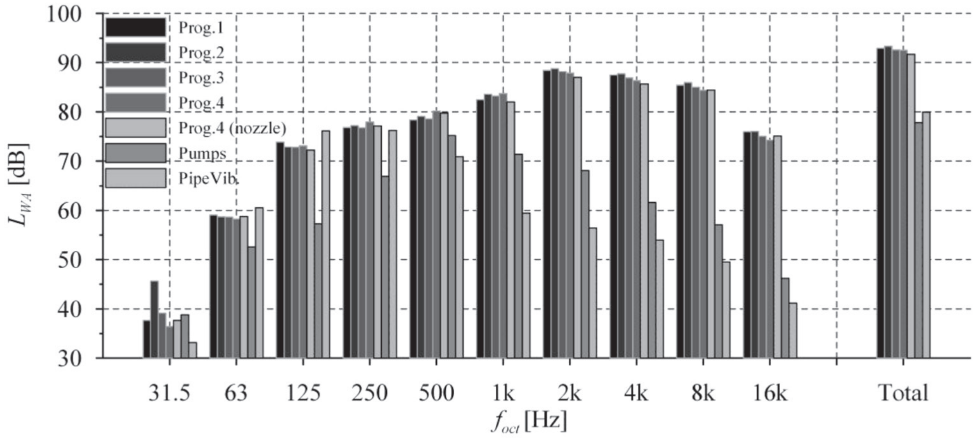

Fig. 6. Sound power levels LWA associated with noise sources in a car wash

nozzle does not hit the car body, thus generated sound levels are lower by about 1 dB. When the nozzle is positioned at smaller distance than recommended (posing a threat to the lacquer condition), the contribution of noise produced by water jets are expected to rise significantly. Sound power levels associated with pipe vibrations in the low frequency range (below 500 Hz) are comparable or higher than noise levels associated with the washing. As sound levels in higher octave bands are lower, the contribution of this source to the overall noise emission is relatively minor. Under certain conditions, however, this source can become audible and be perceived as objectionable because of the tonal and low frequency nature of sounds (as the damping in the air becomes lower with increasing distance). This aspect is of great importance because in many cases this noise is a consequence of poorly designed piping installation and can be eliminated simply by re-configuring the pipes or providing adequate support.

Sound power levels associated with pump operation (hydraulic supply unit) are decidedly lower than the noise levels registered during washing (by nearly 15 dB in the entire band and by 5 to 30 dB for each octave band). The highest sound power levels associated with pump operation are registered in the frequency range 250 Hz to 1 kHz. Manufacturers of car wash equipment give the noise level specifications for this source exclusively. That is why other major sources are often neglected in predictions of noise emissions by car wash facilities and their environmental impacts, consequently the modelled noise levels are found to be decidedly lower than the real ones.

The standard car washing cycle involves 4 stages (Programmes). Fig. 7 plots the sound pressure levels versus time (bottom plot – Fig. 7b) registered throughout the full washing cycle and spectrograms (upper plot – Fig. 7a) giving the results of spectral analysis of sounds in the function of time. During the measurements the spray nozzle was moved around the vehicle though the standard distance was maintained. Plots reveal four distinct phases separated by breaks required to switch between the programmes. During the breaks the sound pressure level L_A is reduced by nearly 20 dB, going down to the background noise level. Spectrograms illustrating the phases of the washing cycle are in line with the spectral analysis data (Fig. 1 – Fig. 4). Alongside the broadband background noise (associated with spraying nozzle operation) there are lines representing discrete frequencies (noise generated by pipes). At certain time instants the sound levels in the specified frequency ranges are momentarily increased, which is associated with noise generated when water jets hit the vehicle components (wheels or resonating parts of the car body).

Fig. 8 plots the octave-band sound power levels registered throughout the entire washing cycle and the overall sound level L_{WA}. These values are recalled in further considerations of environmental impacts of the car wash noise.

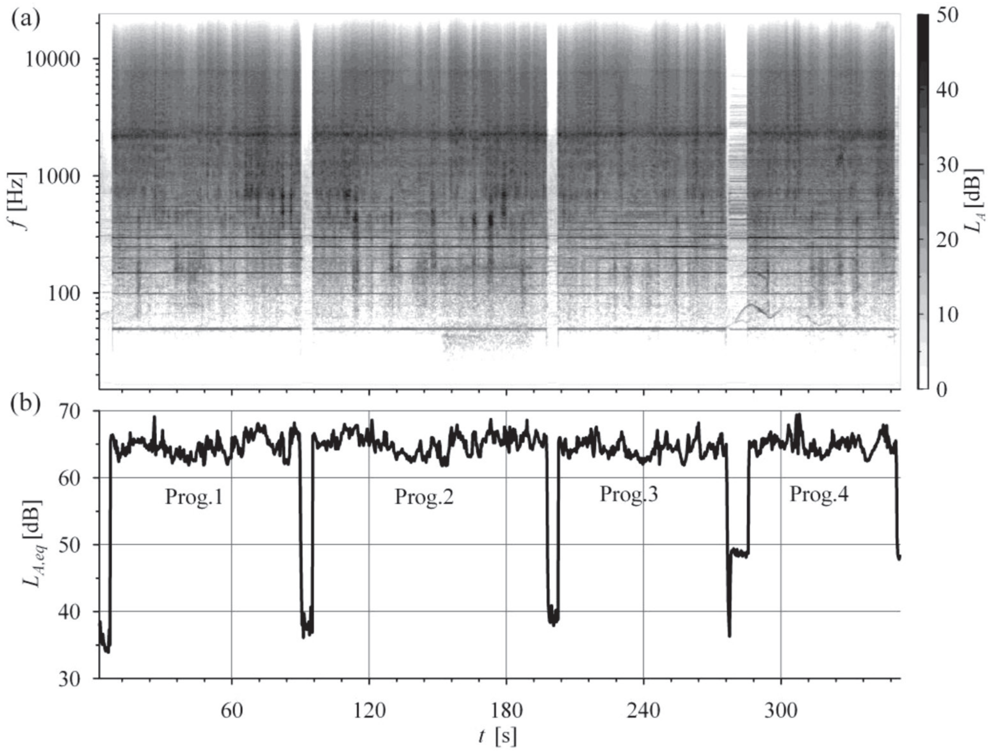

Fig. 7. Car washing cycle

a – spectrogram; b – noise level time history

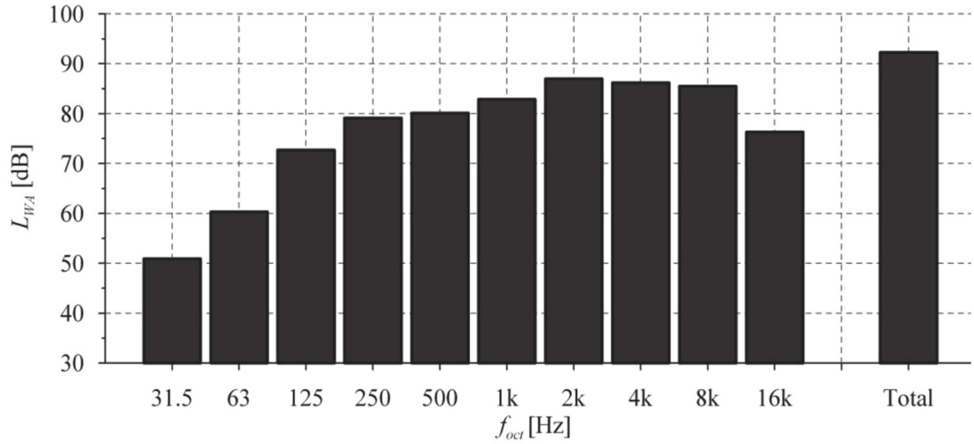

Fig. 8. Sound power levels throughout the entire washing cycle

2. Environmental impacts of the car wash noise

For economic reasons, automated car washes using high-pressure facilities are mostly located in densely populated built-up areas (to guarantee the patronage) and are not enclosed so as to attract potential customers. That is why the generated noise is not effectively suppressed whilst the distance from noise-sensitive zones is not large (applicable rules and regulations are summarized in [22]). In many cases car washes are situated adjacent to the noise-sensitive or protected zones or these zones are distant by less than 100 m. A further complication is associated with car wash operation in the night time, when the admissible noise emission levels are significantly lower because the inhabitants of the nearby residential district have a right to night-time peace and quiet.

This chapter summarizes the numerical simulations using the method recommended by the standard ISO 9613-2 [21]. The washing stands and other noise sources were modelled as single point sources. Accordingly, noise sources are assigned the sound power levels modelled in section 2 (Fig. 6, Fig 8) and expressed in octave bands. The total (overall) sound pressure level L_A was obtained as the sum of octave-band sound pressure levels. The calculation procedure used the grid of points situated in the neighborhood of the noise sources, the distance from the source not exceeding 500 m and calculations of on-site operational noise were performed for each direction. It was assumed that there were no noise barriers or screening structures (buildings) on the site and the ground surface was taken to be flat, hard and reflective.

Figs. 9 and 10 show contour maps of sound level L_A distribution in the proximity of a car wash with a varied number of operated washing stands (1 and 2 – Fig. 9; 4 and 8 – Fig. 10). Continuous car wash operation was assumed, with all wash stands fully utilized. The maps have equal loudness contours given in colors representing 35 dB, 40 dB, 45 dB, 50 dB, 55 dB, 60 dB. The sound levels 40 dB, 45 dB, 50 dB and 55 dB are the maximum allowable noise exposure levels defined in standards and regulations addressing the noise exposure in Poland, specified depending on the projected land use and the time of day [22]. On-site conditions produced symmetrical and uniform sound propagation in each direction, therefore the contour maps have the form of concentric circles around the source of noise (car wash facility). The range of impact represented by each loudness contour (i.e. circle diameter) tends to increase with an increase in a number of operated wash stands because the total sound power level of the investigated system will rise as well. Obviously, the area exposed to noise exceeding the admissible decibel levels specified in [22] will extend, too.

Fig. 11a shows the predicted noise impact range r_{lim} where the admissible noise levels 40 dB, 45 dB, 50 dB, 55 dB are exceeded [22], depending on the number of operated washing stands. Respective distances tend to increase with increasing number of operated stands. For each operated stands these distances are: approximately 27 m for 55 dB, approx. 46 m for 50 dB, approx. 77 m for 45 dB and approx. 126 m for 40 dB. Thus the zone of excessive night-time noise exposure extends beyond 100 m. For large car washes with eight operated washing stand the impact zones of excessive sound exposure become: approximately 69 m for 55 dB, approx. 113 m for 50 dB, approx. 187 m for 45 dB and approximately 321 m for 40 dB, which indicates a 2.5-fold increase of the impact zone. These are high noise levels which impact on the adjacent structures and noise-sensitive areas even at day time.

Actually, the conditions when all washing stands are operated simultaneously (100 % utilisation) are encountered only at some specific times of the year (between the winter and spring season or during warmer

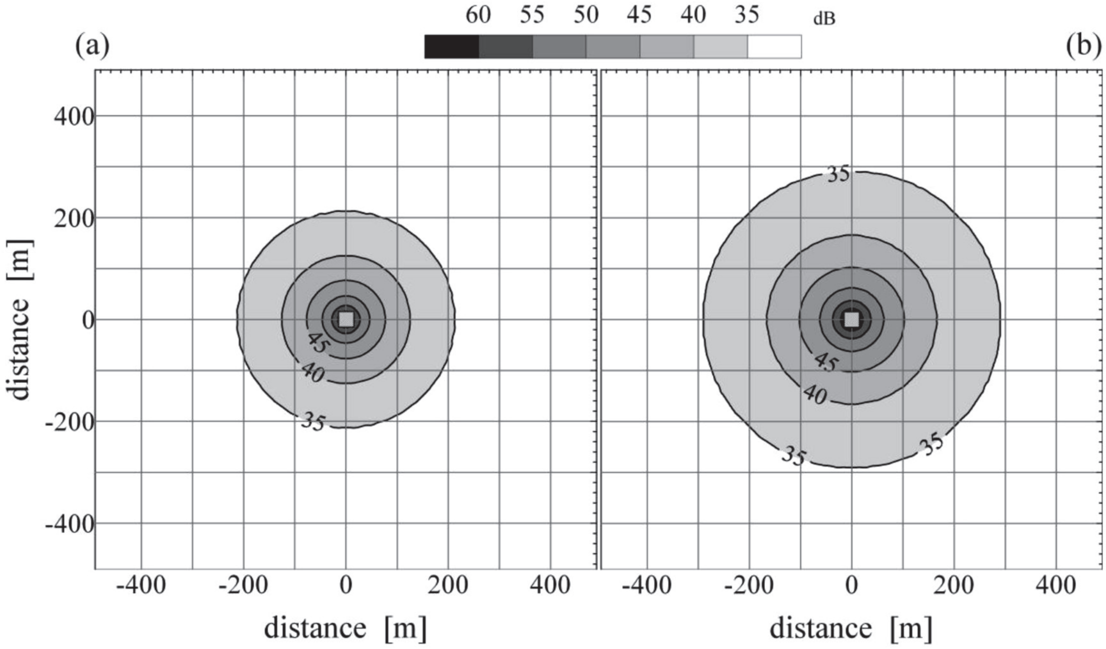

Fig. 9. Car wash noise contour map'
a – one wash stand operated, b – two stands operated

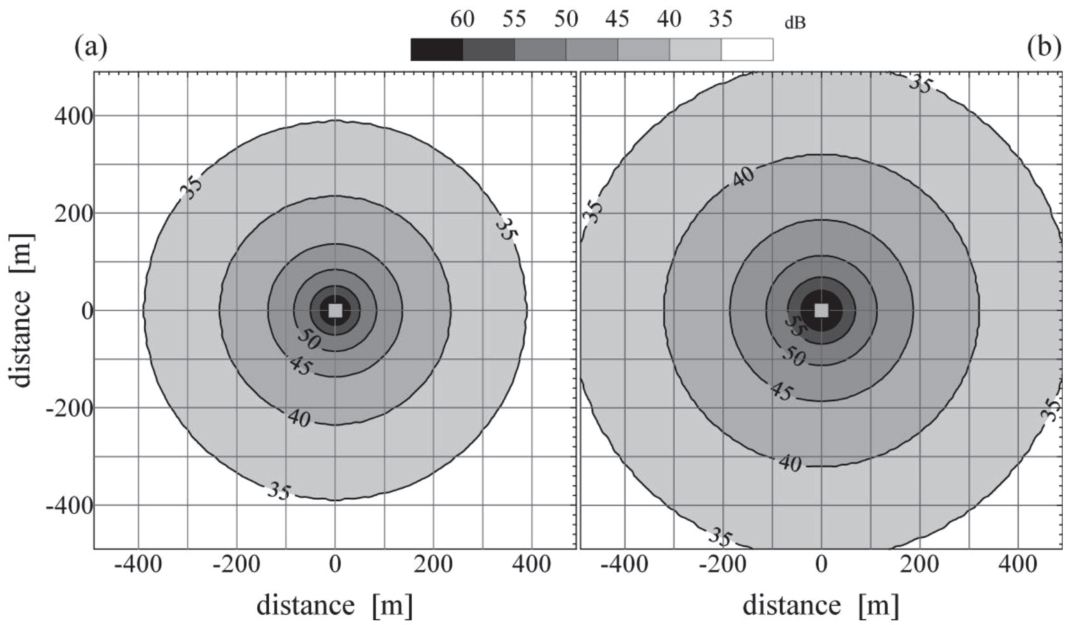

Fig. 10 Car wash noise contour map
a – four stands operated, b – eight stands operated

periods in winter). Fig. 11b illustrates how a one-stand car wash utilisation should affect the range of impact zone, related to the different regulatory criteria [22]. The range of an impact zone will decrease with a decrease of the relative length of operation time, going down to the half of its first value for 20 % utilisation (2 vehicles handled per hour) and to 1/3 of its first value for 10 % utilisation (1 vehicle per hour) in the course of continuous operation. Nevertheless, these impacts will still extend to the adjacent areas.

In the consequence of acoustic wave propagation from the source (in a point source model) sound energy density decreases with distance (attenuation by 6 dB when the distance from the source is doubled); besides sound energy gets dispersed in the air and through interactions with the ground surface. The actual damping

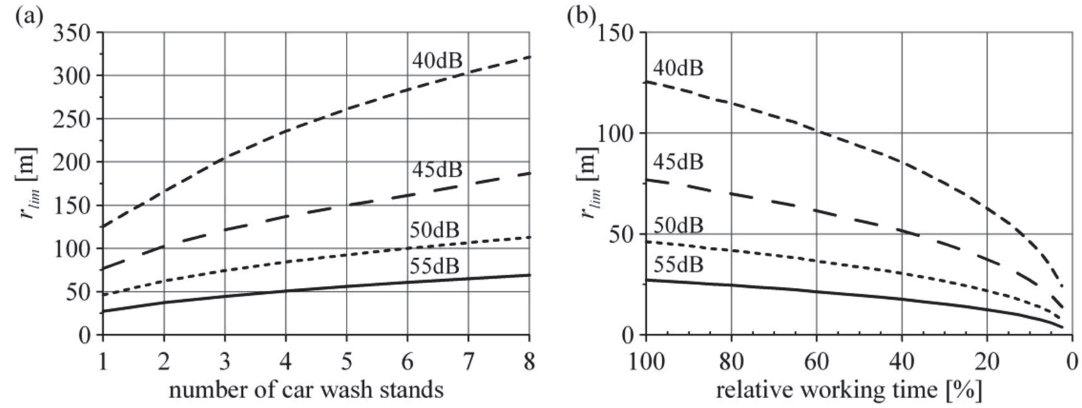

Fig. 11. The predicted noise impact range r_{lim} of the car wash

a – vs the number of washing stands; b – vs relative length of operation time

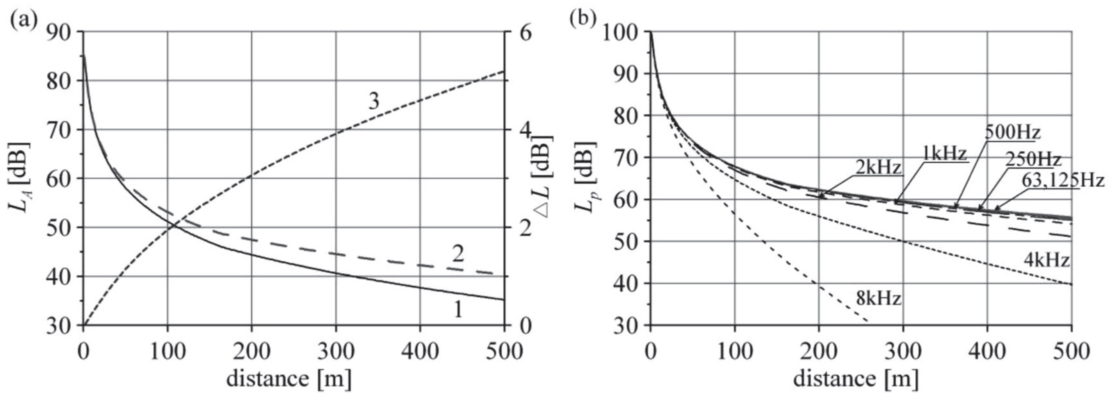

Fig. 12. Sound level decrease with the distance from the car wash

a – the influence of the calculation method on the L_A values, 1 – calculating from octaves; 2 – calculating direct; 3 – calculating error; b – the effect of the use of octave bands on the sound level L_p values

levels are dependent on the sound frequency [21]. Fig. 12b plots the octave-band sound levels in the function of distance from the source. Apparently, the damping effect is enhanced with increased frequency and hence the sound levels tend to diminish at a faster rate with increasing distance. For example, at the distance of approximately 200 m the sound level in the band 8 kHz is quieter by 20 dB than sounds in lower octave bands. Noise associated with car wash operation contains a large proportion of high-frequency components, so this effect is of key importance when modelling this type of noise sources. Fig. 12a shows the dependence of the total sound level L_A obtained from octave-band sound levels and the value based on the specified sound power level L_{WA}. The octave-band sound levels tend to decrease at a faster rate with distance. Interestingly, the difference between the predicted values (error curve) tends to increase with distance as well. Typically, the input parameter in such simulation procedures is the global (overall) sound power level instead of the octave-band sound levels, which may result in some calculation errors. In the case of noise-generating sources where the higher frequency components are predominant, the full characteristics of frequency-band sound power levels should be thus required.

Conclusions

Measurement and simulation data collated in this study fully evidence the gravity of the addressed issue. The range of environmental noise emissions in excess of maximum allowable levels is extensive, encroaching upon the areas in the proximity of the car wash. The predominant source of on-site noise is the washing process utilizing high-pressure water installation. Of particular importance is water outflow from the spraying nozzles whilst the noise associated with water jets hitting the car body further raises the on-site noise level by approximately 1 dB.

Sounds generated during car washing operations have a large proportion of high-frequency components and that is why they are subjectively perceived as objectionable and intrusive. On the other hand, such sounds get attenuated at a faster rate with distance from the source. Without the frequency characteristics, numerical simulations of noise sources will be encumbered with a calculation error growing with the distance from the source.

This study investigates the operational noise generated by car washes, emphasizing their environmental impacts in the context of a growing number of such facilities, and its aim is to arouse the general awareness of the problem. In many cases no assessments are made of project noise levels, or the measurement procedures prove unreliable because some major noise sources are still overlooked. When planning the location of a projected car wash, its environmental impacts should become a major consideration. If necessary, noise control strategies and mitigation measures (noise barriers, screens, baffles) ought to be provided already at the stage of engineering design. In the context of limiting the negative environmental impacts of an automated car wash, care must be taken to avoid manufacturing and engineering design errors which can give rise to additional noise emissions (for example due to vibration of pipe systems).

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References

1. *Zielińska E.* Autobusy: technika, eksploatacja, systemy transportowe. 2016. V.17. P. 250–253 (in Polish).
2. *Sasi Kumar N., Chauhan M.S.* Treatment of Car Washing Unit Wastewater—A Review. *Water Quality Management*. 2018. P. 247–255.
3. *Al-Odwani A., Ahmed M., Bou-Hamad S.* Desalination. 2007. V. 206. N. 1–3 P. 17–28. https://doi.org/10.1016/j.desal.2006.03.560
4. *Fall C., Lopez-Vazquez C.M., Jimenez-Moleon M.C., Ba K.M., Diaz-Delgado C., Garcia-Pulido D., Lucero-Chavez M.* Revista Mexicana de Ingeniería Química. 2007. V. 6. N. 2. P. 175–184.
5. *Lau W.J., Ismail A.F., Firdaus S.* Sep Purif Technol. 2013. V. 104. P. 26–31. https://doi.org/10.1016/j.seppur.2012.11.012.
6. *Oknich J.* The perceived environmental impact of car washing. 2002. Ramsey-Washington Metro Watershed District.
7. *Tony M.A., Bedri Z.* Adv Environ Chem. 2014. V. 2014. http://dx.doi.org/10.1155/2014/958134
8. *Zaneti R., Etchepare R., Rubio J.* Journal of Cleaner Production. 2012. V. 37. P. 115–124. https://doi.org/10.1016/j.jclepro.2012.06.017.
9. *Janik H., Kupiec A.* Polish Journal of Environmental Studies. 2007. V. 16. N. 6. P. 927–931.
10. *Sheen S. C., Hsiao Y. H.* Journal of occupational and environmental hygiene. 2007. V. 4. N. 9. P. 669–677. DOI: 10.1080/15459620701513466.
11. *Sheen S. C. International Journal of Occupational Safety and Ergonomics*. 2011. V. 17. N. 3. P. 287–299. DOI: 10.1080/10803548.2011.11076895
12. *Sheen S. C.* Journal of occupational and environmental hygiene. 2011. V. 8. N. 6. P 349–356. DOI: 10.1080/15459624.2011.576331.
13. *Laffay P., Moreau S., Jacob M. C., Regnard J.* Journal of Sound and Vibration. 2018. V. 434. P. 144–165. https://doi.org/10.1016/j.jsv.2018.07.036
14. *Ruchonnet N., Alligné S, Nicolet C., Avellan F.* Journal of Fluids and Structures. 2012. V.28. P. 180–193. https://doi.org/10.1016/j.jfluidstructs.2011.10.001.
15. *Borisyuk A.O. Journal of Fluids and Structures*. 2010. V. 26. P. 658–674. https://doi.org /10.1016/j.jfluidstructs.2010.03.005
16. *Hayashi I., Kaneko S.* Journal of Fluids and Structures. 2014. V. 45. P. 216–234. https://doi.org/10.1016/j.jfluidstructs.2013.11.012.
17. *Kudźma Z., Stosiak M.* Acta of Bioengineering And Biomechanics. 2013. V. 15. N. 2. P. 51–64.
18. *Klop R., Ivantysynova M.* International Journal of Fluid Power. 2011. V. 12. N. 3. P. 17–30. https://doi.org/10.1080/14399776.2011.10781034.
19. *Łuczko J., Czerwiński A. Journal of Sound and Vibration*. 2016. V. 373. P. 236–250. https://doi.org/10.1016/j.jsv.2016.03.029
20. *Dziechciowski Z., Kozień M. S.* Archives of Acoustics. 2014. V. 39. N. 4. P. 653–663. DOI: 10.2478/aoa-2014-0071.
21. ISO 9613-2. Acoustics – Attenuation of sound during propagation outdoors – Part 2: General method of calculation. Technical report, International Standardization Organization (1996).
22. Regulation of the Minister of Environment of 14th June 2007 on permissible levels of environmental noise (Dz. U nr 120 poz. 826), (in Polish).