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Calibration transfer of a Raman spectroscopic quantification method for the assessment of liquid detergent compositions between two at-line instruments installed at two liquid detergent production plants

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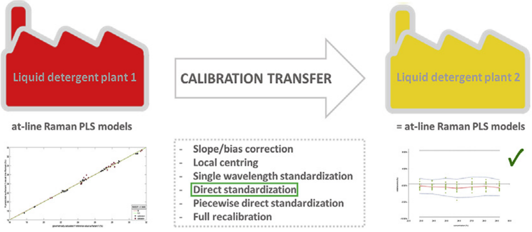
HIGHLIGHTS

- Raman spectroscopy as a PAT tool monitoring a liquid detergent production process.
- Quantitative PLS models for determination of the main ingredients concentration.
- Calibration transfer between two at-line Raman instruments for two production plants.
- Comparison of univariate and multivariate standardization approaches.
- Evaluation transferred quantification models through accuracy profile approach.

GRAPHICAL ABSTRACT



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ABSTRACT

Calibration transfer of partial least squares (PLS) quantification models is established between two Raman spectrometers located at two liquid detergent production plants. As full recalibration of existing calibration models is time-consuming, labour-intensive and costly, it is investigated whether the use of mathematical correction methods requiring only a handful of standardization samples can overcome the dissimilarities in spectral response observed between both measurement systems. Univariate and multivariate standardization approaches are investigated, ranging from simple slope/bias correction (SBC), local centring (LC) and single wavelength standardization (SWS) to more complex direct standardization (DS) and piecewise direct standardization (PDS). The results of these five calibration transfer methods are compared reciprocally, as well as with regard to a full recalibration. Four PLS quantification models, each predicting the concentration of one of the four main ingredients in the studied liquid detergent composition, are aimed at transferring. Accuracy profiles are established from the original and transferred quantification models for validation purposes. A reliable representation of the calibration models performance before and after transfer is thus established, based on β-expectation tolerance intervals. For each transferred model, it is investigated whether every future measurement that will be performed in routine will be close enough to the unknown true value of the sample. From this validation, it is concluded that instrument standardization is successful for three out of four investigated calibration models using multivariate (DS and PDS) transfer approaches. The fourth transferred PLS model could not be validated over the investigated concentration range, due to a lack of precision of the slave instrument. Comparing these transfer results to a full recalibration on the slave instrument allows comparison of the

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predictive power of both Raman systems and leads to the formulation of guidelines for further standardization projects. It is concluded that it is essential to evaluate the performance of the slave instrument prior to transfer, even when it is theoretically identical to the master apparatus.

1. Introduction

Calibration transfer or standardization could be defined as a mathematical transformation of spectroscopic data or calibration models in order to make the developed method compatible with different instruments or measurement conditions. The purpose of these multivariate calibration standardizations is to ensure the interchangeability of an analysis method without having to execute time-consuming and labour-intensive recalibrations for each situation [1–3].

After the United States Food and Drug Administration (FDA) launched their process analytical technology (PAT) initiative in 2004 [4], companies from various industries globally focused on implementing spectroscopic tools such as near-infrared and Raman spectrometry into their production processes. These process monitoring and understanding techniques require multivariate data analyses [5,6]. For quantitative purposes, chemometric calibration strategies, such as partial least squares (PLS), multiple linear regression (MLR) and principal component regression (PCR) are popularly applied [7–11]. Developing and validating those calibration models is often an elaborate and time-consuming process, requiring many resources. Hence, it is essential that the implemented models are robust and can be employed for an extended period of time.

Unfortunately, after considerable time, cost and effort to establish such multivariate calibration models, they might turn out to be inapplicable when changes in instrumental response occur. Several sources of altered spectral outcome can herewith be noted. Firstly, within a single spectrometer, ageing of the equipment may cause a drift in the instrumental response or require a replacement of a particular part, in its turn inducing a response shift. Secondly, variations in physical or chemical constitution of the samples (e.g. particle size, viscosity, surface texture) may yield prediction errors, as may environmental conditions such as temperature or humidity variations. Furthermore, usage of an alternative instrument, even though theoretically identical, may generate a deviating spectral outcome. It is thus of utmost importance to be able to tackle these situations by creating forceful calibration models that are transferable from one spectroscopic apparatus to the other, or analogously, from one instrumental condition to the other, without needing to perform a full recalibration [1–3].

Various mathematical methods exist to efficiently correct the dissimilarities between these altered situations. The strategies for dealing with such non-calibrated variation can be clustered into three main classes: standardization of the regression coefficients, standardization of the spectral responses or standardization of the predicted values [3]. Univariate as well as multivariate approaches have thus been applied successfully in a variety of industries [12–20].

This research is located in the consumer goods business, where spectroscopic and other PAT tools are gradually replacing conventional compliance approaches based on univariate sensors and wet chemistry analyses. The investigated samples are liquid detergent compositions, consisting of several cleaning agent constituents, whose dosing needs to be controlled. Therefore, at-line PLS-based calibration models have been developed to predict the concentration of the liquid detergents main ingredients from Raman spectra [21]. After validation of these constructed models to ensure their applicability in routine analysis, it would be beneficial to be able to use them simultaneously at several manufacturing sites. This way, the exact same calibration models and hence quality assessment could be executed globally at all production plants producing that type of liquid detergent composition, while each locally using their own Raman equipment. Furthermore, in case of unexpected instrumental issues, another Raman spectrometer could easily replace the defect apparatus, avoiding the risk of halted release.

Therefore, this study aims at exploring several standardization techniques for transferring existing calibration models from one production plant to another. Both univariate and multivariate standardization approaches, namely slope/bias correction (SBC), local centring (LC), single wavelength standardization (SWS), direct standardization (DS) and piecewise direct standardization (PDS) are considered and compared.

The Société Française des Sciences et Techniques Pharmaceutiques (SFSTP) has introduced the accuracy profile approach for validation of quantitative analytical methods [22,23]. As this manner of assessing the applicability of an analytical procedure has proven to be useful for assuring the predictive power of the liquid detergent calibration models before [21], the same technique is applied in this study for evaluating the calibration transfer. Accuracy profiles are constructed for each transferred quantification model, allowing evaluation of the predictive abilities of the standardized models, based on β-expectation tolerance intervals.

2. Materials and methods

2.1. Liquid detergent composition

The investigated liquid detergent composition is a complex combination of sixteen raw materials, listed in Table 1. Since the proprietary confidential formula cannot be revealed, the

Table 1
Composition of the investigated liquid detergent formulation. The relative concentration of each detergent ingredient is illustrated in percentage.

Ingredient	Concentration *(%)*
Surfactant 1	26.01
Surfactant 2	18.11
Builder 3	7.371
Solvent 4	9.385
Ingredient 5	6.275
Ingredient 6	0.8717
Ingredient 7	4.630
Ingredient 8	12.44
Ingredient 9	4.672
Ingredient 10	2.789
Ingredient 11	0.05811
Ingredient 12	2.609
Ingredient 13	0.01860
Ingredient 14	3.951
Ingredient 15	0.4110
Ingredient 16	0.4002