SIMULATING THE LIP-RELEASE EFFECT OF TIPPING PAPER AND ITS INFLUENCE ON THE END USE APPLICATION OF CIGARETTE PRODUCTS

by

Michael Lindner, TANNPAPIER GmbH, Johann Roithner-Straße 131, A-4050 Traun / Austria

SUMMARY

A large variety of commercial tipping paper has been investigated by using various experimental techniques yielding an empirical mathematical model which describes and simulates the absorptivity of coated or printed tipping paper for aqueous liquids in order to reveal its lip-release properties. The proposed theoretical approach makes exclusively use of macroscopic physical and chemical base paper specifications and rotogravure printing process parameters and provides a simplified image of the water transport mechanisms through the tipping paper without considering the details of the microscopic fibrous paper structure. The potential advantages of the outlined absorption model are its simple and rapid application without any huge experimental efforts and the high predictive quality for the expected theoretical lip-release efficiency. However, the physiological perception of the lip-release properties is beyond doubt subjective and depends strongly on the individual smoking habits of cigarette smokers. By taking into account the survey performed with a professional smoker panel on the one hand and evaluating field reports from regular cigarette smokers on the other hand, the correlation between the calculated lip-release efficiency and the real sensation on the human lips will be outlined. Consequently, the findings open the potential to predict and control the quality of the generated lip-release properties during tipping paper production and to customize the tipping paper overprint for specific target groups of cigarette consumers.

INTRODUCTION

Commercial tipping paper, which joins the tobacco rod to the filter tip of a cigarette, needs chemical surface treatment in order to reduce the adherence to a smoker's lips during cigarette smoking. These so-called "lip-release properties", describing the release of contact between the human lips and the tipping paper of a cigarette, have been thoroughly investigated after the introduction of high-speed cigarette machines which require low-sized tipping paper [1].

After the paper making process, base paper is converted into tipping paper during the printing operation, which is conventionally rotogravure printing, where the lip-release properties are generated by the application of lip-release chemicals such as nitrocellulose [2]. Commercial lip-release substances are solvent based, colorless and transparent and thus can be either used directly for the coating of white or pre-dyed base paper or mixed with various printing inks for the realization of colorful overprints.

A closed and homogeneously coated paper surface is one of the main key factors to prevent the saliva on the smoker's lips from penetrating the paper substrate and causing negative lip-release effects. Furthermore, it could be demonstrated earlier that the absorption behavior of tipping paper for aqueous liquids also depends strongly on the fundamental physical and chemical parameters of the used base paper together with the basic rotogravure printing cylinder data [3].

In this former study, a large variety of coated and printed tipping paper qualities has been experimentally investigated by the means of static and dynamic contact angle measurements, ink floating tests, and (TOF)-SIMS (time-of-flight secondary ion mass spectrometry) analysis in order to reveal the individual absorption properties on the one hand and to observe the absorption principle inside the paper material itself on the other hand.

The consequence of the study was an empirical mathematical model which describes on a macroscopic basis the absorptivity of tipping paper for aqueous liquids and simulates the water transport through the fibrous and inhomogeneous paper structure. The output of the model allows for a simple prediction and calculation of the expected theoretical lip-release quality of a certain tipping base paper prior to the converting process.

In the following contribution, the attention is drawn on the physiological perception of the lip-release properties while smoking a cigarette. The personal feeling of the adhesiveness between the human lips and the tipping paper is without a doubt rather subjective and extensively related to the individual smoking behavior of a cigarette smoker. Moreover, climatic conditions of the smoker's environment, the time of the day, his state of health, the prior to smoking consumed

types of food and beverages etc. considerably influence the smoking sensation.
In order to verify the applicability of the absorption model for the calculation of the lip-release properties on the prediction of the human perception of the same, a survey has been carried out amongst regular cigarette smokers as well as with a professional smoker panel. The survey results show the correlation between the theoretical and the physiologically felt lip-release efficiency for a number of selected tipping paper qualities. Hence, the findings may help to understand better the numerous influencing factors which finally determine the lip-adhesive characteristics of a cigarette and to offer possibilities to adapt the lip-release quality during the tipping paper production to the cigarette consumer's individual request.

ABSORPTION MODEL AND SIMULATION

When an aqueous liquid like an experimentally applied water droplet or saliva on the human lips touches the tipping paper surface, it first gets absorbed gradually by the lip-release layer. Strictly speaking, this lip-release coating is actually no coating since the lip-release substance penetrates the paper surface creating a barrier which is a mixture of the lip-release agent and the paper bulk as it can be seen in Fig. 1. After having passed this lip-release barrier, the liquid starts permeating the pure base paper section. This permeation process becomes considerably accelerated due to the absorptive interaction between the water and the base paper material.

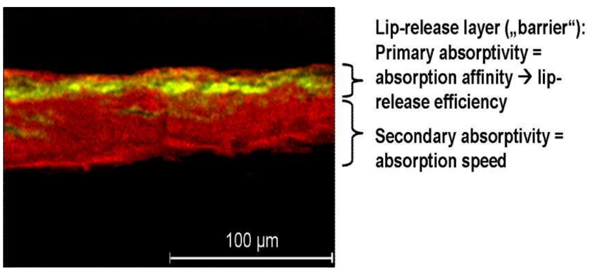

Figure 1: A cross-section image of tipping paper recorded with (TOF)-SIMS microscope illustrating the two absorption regimes inside the material. The nitrocellulose is marked in green color.

The (TOF)-SIMS image in Fig. 1 shows that the tipping paper can be separated into two parts: The 2 to 15 µm wide lip-release barrier and the adjacent area of the natural base paper. These two internal tipping paper regimes are denoted as "primary absorptivity" and "secondary absorptivity" area respectively.
At the beginning, when the water droplet penetrates the tipping paper, the contact angle changes continuously over time. This change of the contact angle as a function of time is significant for the dynamic contact angle. The dynamic contact angle $\Delta\theta(t)$ depends on the spatial and temporal absorption distribution and is given by

$$\Delta\theta(t) = \int_{d_1}^{d} \frac{\eta\sigma}{\sqrt{\pi\alpha t}}[e^{\left(-x^2/4\alpha t\right)} + \sum_{n=1}^{\infty} r^n e^{\left(-(2nd-x)^2/4\alpha t\right)} + r^n e^{\left(-(2nd+x)^2/4\alpha t\right)}]dx \qquad (1)$$

Here, η is the mass density of the lip-release solution, σ the surface tension of water, α the primary absorptivity, r the secondary absorptivity and d is the base paper thickness.
Primary absorptivity can be understood as absorption affinity and is thus directly related to the lip-release efficiency. Secondary absorptivity is denoted as absorption speed for the water after having passed the lip-release barrier. The two parameters can be empirically estimated by

$$\alpha = c_\alpha \cdot \frac{(d_1^2+1)\cdot P}{\sqrt[4]{S}\cdot KW_{5\_calc}\cdot\rho}$$
$$r = c_r \cdot \frac{\sqrt[4]{S}\cdot\rho}{\sqrt{d-d_1}\cdot KW_{5\_calc}} \qquad (2)$$

where P denotes the base paper porosity, S the level of sizing, ρ the base paper mass density and KW_{5_calc} the calculated static contact angle for the base paper 5 seconds after drop deposition. d_1 is the thickness of the lip-release layer and can be determined by introducing the etching depth ED of the rotogravure coating or printing cylinder and the base paper surface smoothness s:

$$d_1 = c_{d1}\cdot\frac{ED}{\sqrt{P\cdot s}\cdot KW_{5\_calc}} \qquad (3)$$

The prefactors c_α, c_r and c_{d1} are experimentally determined constants.
A potential advantage of the illustrated absorption model is its independency from time-consuming paper tests. Only the fundamental base paper specification is necessary to run the simulation, and even the value for the static contact angle can be approached with the information on the filler contents of the base paper composition:

$$KW_{5\_calc} = c_{KW5}\cdot\sqrt[8]{S}\cdot\sqrt[4]{P}\cdot(C_{ta} + \sqrt{C_{ca}} + C_{cc} + C_{al} + C_{si} + C_{ti} + C_{st}^2) \qquad (4)$$

Together with the constant prefactor c_{KW5}, the expression comprises the content for the sizing agent (S), talcum (C_{ta}), calcium carbonate (C_{ca}),

China clay (C_{cc}), aluminium hydroxide (C_{al}), silicate (C_{si}), titanium dioxide (C_{ti}) and starch (C_{st}) specified in weight %.
The above outlined model parameters hold strongly for white tipping base paper. In case of plain cork tipping qualities, the influence of the incorporated iron oxide has to be additionally considered in the expression for KW_{5_calc} according to

$$KW_{5\_calc} = c_{KW5} \cdot \sqrt[8]{S} \cdot \sqrt[4]{P} \cdot (C_{ta} + \sqrt{C_{ca}} + C_{cc} + C_{al} + C_{si} + C_{ti} + C_{st}^2 + C_{iox}^2) \tag{5}$$

with C_{iox} as the iron oxide quantity in weight %.
White base paper may be finished with an extraordinary color overprint exhibiting certain effect pigments for e. g. a pearlescent appearance or other colorful specialities. Since the special pigments are located within the upper layer of the printed paper, the parameter for the penetration depth of the printing agent needs some adaptation:

$$d_1 = c_{d1} \cdot \frac{ED}{\sqrt{P \cdot s \cdot KW_{5\_calc}} \cdot \sqrt[8]{C_{pigm}}} \tag{6}$$

Again, C_{pigm} describes the pigment content in the printing ink.
As a demonstration of the absorption or lip-release model, Fig. 2 and 3 show the time-dependent contact angle measurement results and their best simulated approximations for an unsized and a semi sized white tipping paper sample respectively. The black solid lines refer to the measurement curves while the blue dashed lines represent the simulation results (Equ. 1). It can be clearly seen that compared to unsized paper the maximum of the curve of the semi sized paper is shifted towards longer penetration times. Since the increasing branch of the curve represents primary absorptivity (indicated by the blue double arrows), enhanced lip-release properties are expected for the second sample. The confirming results from the ink floating tests are illustrated in Fig. 4 and 5, revealing that the semi sized tipping paper sample shows higher water repellent effect than the unsized sample.

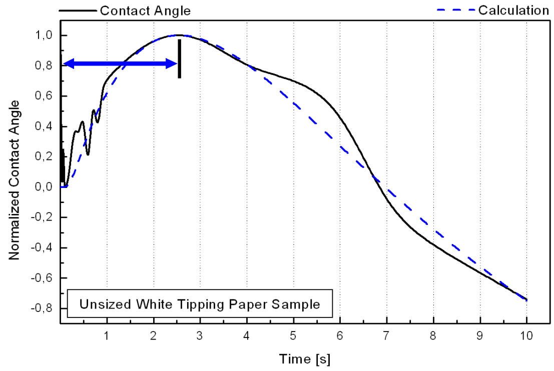

Figure 2: Measured (black solid curve) and calculated (blue dashed curve) dynamic contact angle for unsized tipping paper. The blue double arrow points out the range of the primary absorptivity which is equivalent to the lip-release efficiency.

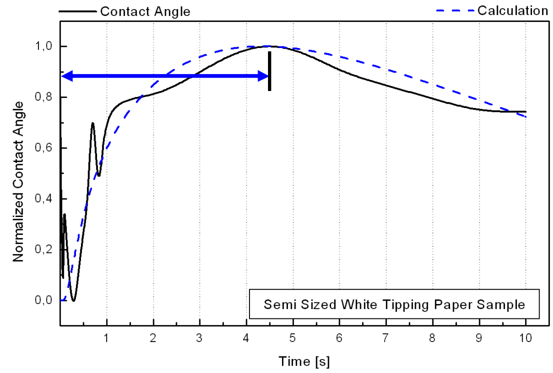

Figure 3: The dynamic contact angle for a semi sized tipping paper sample together with the model approximation.

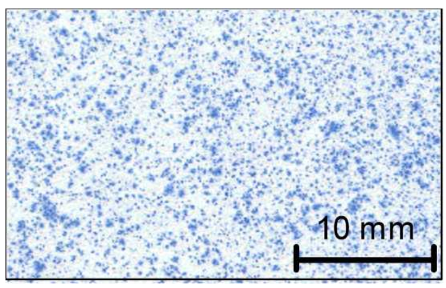

Figure 4: Scanned image of the uncoated side of the unsized tipping paper sample after the ink floating procedure.

Figure 5: Ink floating test with the semi sized tipping paper sample: Coating, sizing as well as paper filler properties provide for sufficient lip-release ability.

The proposed macroscopic simulation model can be directly applied for printed cork base paper and base paper with an extraordinary or colorful coating. Fig. 6 refers to the water droplet on its way through an unsized white base paper sample printed with a cork design (see inset in Fig. 6 for illustration) and Fig. 7 indicates the corresponding results for plain cork base paper with a cork design overprint (see also inset in Fig. 7). Fig. 8 and 9 represent the absorption curves for unsized white base paper exhibiting a color overprint (see inset in Fig. 8) and a semi sized white tipping paper comprising a pearlescent effect surface layer (see also inset in Fig. 9) respectively. From the results it can be stated that even exceptional properties enhancing the optical appearance of tipping paper can be considered with the presented lip-release model only by empirical variation of certain model parameters.

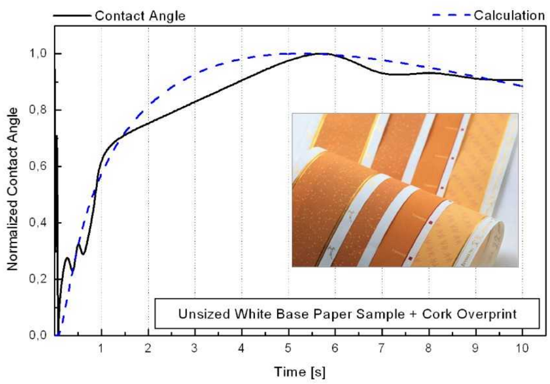

Figure 6: Absorption and simulation curve for unsized white base paper with a printed cork design.

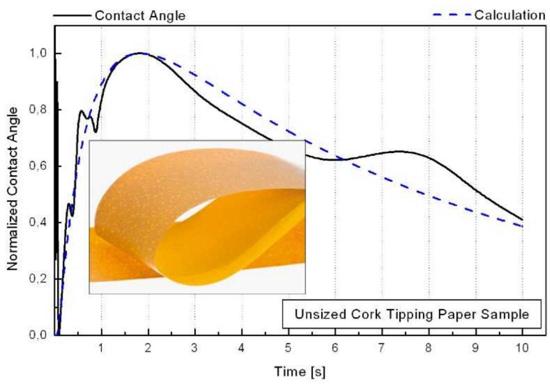

Figure 7: Lip-release investigation of a plain cork tipping paper.

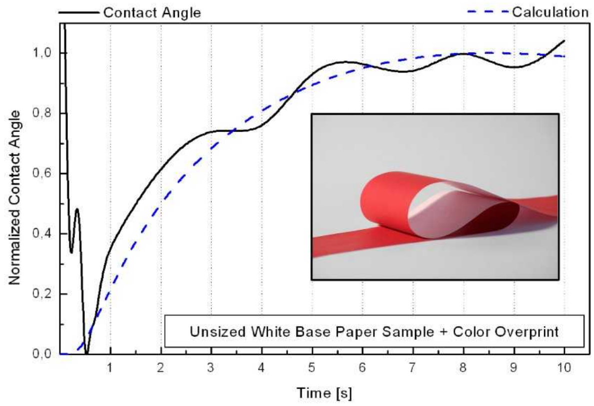

Figure 8: Dynamic contact angle measurement and its theoretical approximation for a white base paper sample printed with red color.

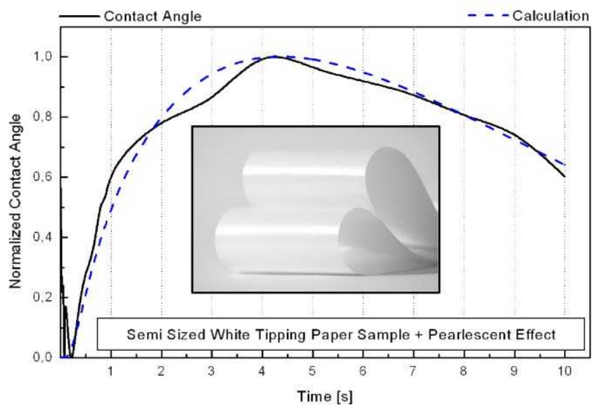

Figure 9: The influence of special effect coatings can be also taken into account with the proposed model.

SMOKING SENSATION AND SAMPLE SELECTION

When smoking a cigarette, the physiological perception of the adhesiveness between the smoker's lips and the tipping paper depends on a multitude of influencing factors. Thereby, the individual smoking habit of a cigarette consumer plays the most decisive role for the personal evaluation of the lip-release properties. The way how to smoke a cigarette is definitely controlled by the current state of health or generally by the emotional state. One smoker enjoys his cigarette in a relaxed situation and a quiet surrounding while another one is forced to finish his tobacco product rapidly during a stressful event or even physical activity. The time of the day when the cigarette is going to be consumed unambiguously affects the manner of salivation inside the human mouth.

Some regular smokers report that they can feel variations in the stickiness of their preferential brand of cigarette during the summer and winter season. Therefore, also all kind of climatic and environmental parameters have a distinct impact on the lip-release sensation which makes is nearly impossible to generalize the lip-release determining properties of a certain tipping paper quality.

A further aspect is the physiological production of saliva as a consequence of the human metabolism. The consumption of spicy or salty food, hot, chilly or sweet beverages etc. certainly provoke enhanced salivation inside the average citizen's mouth than neutrally seasoned dishes. And almost every smoker prefers to finalize an excellent dinner with a tobacco dessert.

The above mentioned examples just provide a rough overview of the endless driving factors which make the personal feeling of the lip-release efficiency to a pure subjective experience. Details on the reason for variations in the saliva production of the human beings are related to medical topics and thus are not the scope of this article.

The idea for the present study was to use the lip-release calculation model in order to understand and to predict the smoker's perception of the tipping adhesiveness. This was realized by making a correlation between the simulation results of the tipping paper absorptivity from the lip-release model, the experimentally achieved findings from the ink floating tests and evaluation reports from surveys carried out amongst selected regular smokers and with a professional smoker panel from a renowned tobacco manufacturer.

The laboratory tests were performed with cut tipping paper samples whereas the surveys were conducted with finished cigarettes produced on a commercial cigarette machine with the same tipping paper qualities as for the laboratory purposes.

Tab. 1 summarizes the selection of the white tipping base paper qualities for the laboratory and field investigations together with their main physical parameters. As already stated, the lip-release model fully abandons microscopic effects, which are related to the intrinsic fibrous pore structure of the base paper, and requires only macroscopic numbers, that can be simply measured during the base paper incoming quality inspection, and information about the base paper composition from the supplier's ingredients disclosures.

Sizing agents are added to the base paper for improving its resistance to the penetration by liquids. Depending on the sizing level, which is also gained from the ingredients disclosures, paper grades are denoted as unsized, semi sized and fully sized respectively.

The physical data is derived from measurements according to ISO standards. Grammage follows the ISO 536:1995 and thickness the ISO 534:1995. The determination of surface smoothness is described in ISO 5627:1995, whereas the numbers for the porosity or air permeability are related to measurements by the standard method specified in ISO 2965. As a unit for the porosity the CORESTA unit CU = $cm^3/(cm^2 \cdot min \cdot kPa)$ will be used in the following [4].

The cigarette samples for the surveys comprise conventional American Blend tobacco, the tipping has been perforated online with an air permeability of approximately 250 CU. For each tipping paper quality, 275 sticks of cigarettes were produced and stored under suitable climatic conditions.

SURVEY CRITERIA

A selected number of regularly smoking people one the one hand and professional smokers from a tobacco company's smoker panel have been polled in order to obtain a multitude of validations for the adhesive properties of the chosen tipping paper qualities on the human lips during the smoking procedure. In case of regular smokers, 55 candidates were provided with two cigarette sticks per tipping paper quality and requested to evaluate the stickiness or adhesion of the tipping on the lips while smoking the cigarette with numbers from 1 to 10, where

1… Absolutely no adhesion of the tipping on the lips

10… Tipping sticks on the lips and can only be removed painfully

Sample Number	Sizing	Grammage [g/m²]	Thickness [µm]	Density [kg/m³]	Smoothness [Bekk-Sec.]	Porosity [CU]
1	Unsized	36	46	782,6	80	10,8
2	Unsized	36	41	878,0	200	6,4
3	Unsized	36	37	973,0	200	2,3
4	Unsized	36	33	1090,9	650	1,7
5	Semi Sized	36	45	800,0	100	8,4
6	Unsized	33	34	970,6	200	2,2
7	Fully Sized	32	36	888,9	200	3,3

Table 1: Base paper parameters for white tipping paper used for the investigations.

Concerning the smoker panel inquiry, 10 professional cigarette smokers from Shanghai Tobacco (Group) Corporation (STC) were also equipped with two cigarette sticks per tipping paper quality, and the same evaluation criteria were valid as for the survey amongst regular smokers.
The data gained from these surveys have been statistically analyzed in respect of mean values, standard deviations and variation coefficients respectively and related to the primary absorptivities and ink floating test results.

RESULTS AND DISCUSSION

The results from the survey amongst regular cigarette smokers performed with the selection of 7 different tipping paper qualities according to Tab. 1 are summarized in Fig. 10. This figure plots the calculated and normalized values for the primary absorptivity α (black symbols) according to Equ. 2, the normalized absorbed ink quantity from the digitally analyzed ink floating test images (blue symbols) and the averaged evaluation numbers from the survey reports (red symbols). For illustration, the individual symbols are connected with dashed lines in order to demonstrate the tendency of the particular values from one tipping paper sample to the next. The results for the samples 1 to 6 are in a good agreement within a small variation range proving the strong correlation between the model parameters, the experimental observations and the physiologically sensed lip-release efficiency. Only sample number 7 shows a divergent behavior, since the smoking sensation indicates pretty high adhesiveness but model and test results reveal rather low stickiness. An explanation for this discrepancy will be given later.

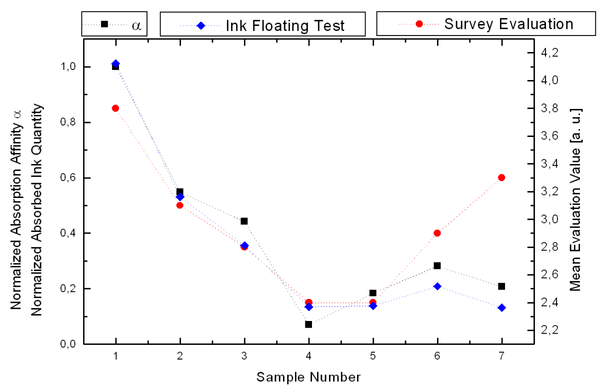

Figure 10: Regular Smokers: Comparison of the calculated (black) and the sensed (red) values for the lip-release efficiency together with the evaluation of the ink floating tests (blue).

A statistical evaluation of the survey output is outlined in Fig. 11. The black symbols again refer to the physiological lip-release evaluation, and also the standard deviation for each mean value is additionally displayed. The green symbols describe the corresponding coefficients of variation which is calculated from the quotient of the standard deviation and the mean value multiplied by 100. One can easily recognize that the variation coefficient significantly increases with values of higher adhesiveness. This can be explained by the enhanced uncertainty of the smoking candidates in respect of a clear interpretation of the lip-release perception when the tipping paper type becomes more absorptive and thus more complex concerning the interaction between the liquid and the substrate. Therefore, the smokers in this case seem to find it more difficult to make a distinct subjective differentiation of the lip-release efficiencies.

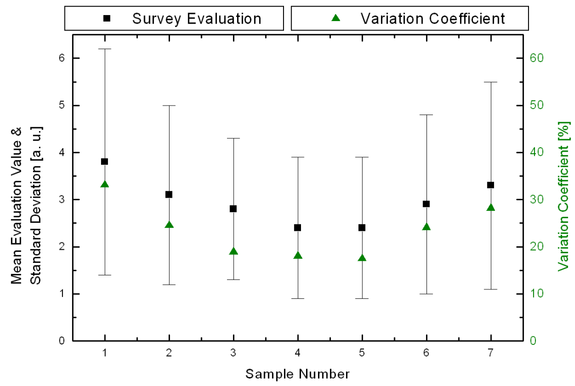

Figure 11: Illustration of the mean values (black) together with their standard deviations and coefficients of variation of the statistical lip-release evaluation.

The primary absorptivities, the soaked amount of ink and the survey results of the feedback from STC are depicted in Fig. 12 by black, blue and red symbols respectively. Again, a satisfying correlation between the data can be demonstrated although the same significant deviation between the values for the tipping paper quality number 7 can be noticed. However, it is obvious that the adhesive properties of the cigarette samples have been evaluated similarly by both, the regular smoker community and the professional smoker panel. This means that even despite of cultural diversity, the unequal relation to smoking itself and different local conditions, the fundamental and average smoking sensation is basically the same.
Finally, Fig. 13 represents the statistical analysis of the evaluation numbers provided by the STC smoker panel. In contrast to daily smokers, people from the smoker panel exhibit comparable smoking habits and lip-release perception since practically no explicit tendency in the variation coefficient can be observed.

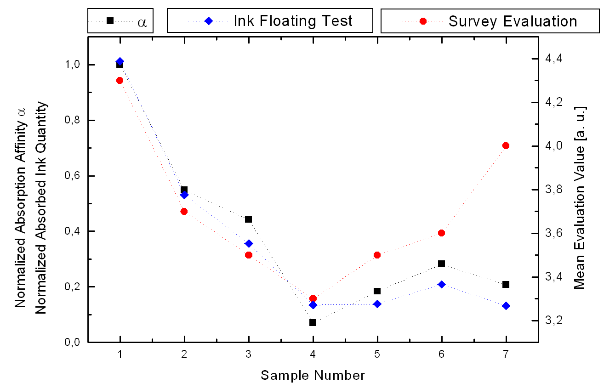

Figure 12: The results of the survey with Shanghai Tobacco (Group) Corporation (STC) verified by the simulation model and laboratory investigation.

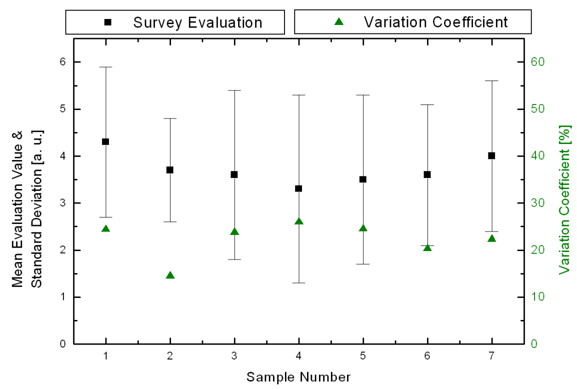

Figure 13: Statistical analysis of the smoking survey data from the STC smoker panel.

What remains is the interpretation of the remarkable variance in the individual investigation results for the tipping paper type number 7 showing a contrary behavior between the lip-release sensation and the simulation or experimental findings. For this paper quality, the smoking sensation refers to relatively high adhesiveness, whereas the theoretical and experimental values imply rather low effects. According to Tab. 1, sample number 7 is fully sized, which means that the quantity of incorporated sizing agent is larger than 1 weight %. At a certain level of sizing, the human saliva on the smoker's lips starts to activate distinctly the water-soluble sizing agent of the base paper, provoking a noticeable interaction between the lips and this sizing agent. As a conclusion, a part of the total adhesive perception is caused by this interaction and not by absorption. Therefore, this type of paper adhesiveness cannot be fully explained with experimental techniques based on absorptivity. And furthermore, the proposed lip-release model, which is also related to absorption effects, does not reasonably describe the physiological lip-sticking properties. The lower the sizing content gets, the lower is also the negative contribution of the sizing agent to the lip-release efficiency. For semi-sized tipping paper for instance, this interaction can be already neglected. In contrast to semi sized and unsized base paper, fully sized material is not very common any more in cigarette industry since it reduces the runnability of high-speed cigarette machines due to its lower absorptivity for the applied glue which joins the tipping paper with the filter plug and the tobacco rod.

CONCLUSIONS AND PROSPECTS

In the present study, an empirically derived macroscopic model was employed in order to calculate and simulate the lip-release properties of coated or printed tipping base paper. The proposed simulation model could be successfully applied for the theoretical investigation of standard tipping paper and tipping paper exhibiting extraordinary and unusual overprints. The simulation results are in a good agreement with various experimental methods to determine the water absorptivity of the tested samples.
Surveys amongst regular smokers and among a professional smoker panel about the subjective perception of the lip-release efficiency on the human lips have been carried out with sample cigarettes comprising different tipping paper qualities. By analyzing the field reports it could be demonstrated that the model output delivers a reliable interpretation of the expected tipping paper lip adhesiveness. Moreover, the evaluations show that even for regional and cultural differences, the overall subjective lip-release feeling is similar.
The comparison between the test and survey results also indicate that a large quantity of incorporated sizing agent – like in the case of fully sized base paper – may reduce the simulation accuracy since the activation of the sizing agent by the human saliva influences the adhesive sensation. However, the tendency in cigarette industry goes towards lower sized base paper in order to guarantee a smooth and fast runnability of the cigarette makers.
The approach with the illustrated lip-release application model provides possibilities to predict the lip-release efficiency prior to tipping paper production especially for specific target groups of cigarette consumers.

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