https://doi.org/10.2352/AIT.2026.1.1.13

Study on feasibility of processing pigmented screen-printing inks via inkjet

Antonia Götz*[1], Christine Hafermaas[2], Sofia Hagman[2], Olivia Ronczka[2], Ben Hartkopp[3], Jan Christoph Janhsen[2]

[1] Hochschule der Medien, Stuttgart, Germany

[2] Fraunhofer Institute for Manufacturing Engineering and Automation IPA, Stuttgart, Germany

[3] Quantica GmbH, Berlin, Germany

*** Corresponding Author: goetza@hdm-stuttgart.de, +49 711 8923-2159**

Abstract

Screen-printing is a well-established technique valued for its ability to process diverse inks, including highly particle-loaded formulations essential to several applications in the industrial and graphical industry. However, its reliance on manual labor and limited automation constrains broader adoption. Inkjet printing on the other hand offers on-demand flexibility and scalability but is restricted by its material requirements. Particularly viscosity limitations of around 25 mPa·s in conventional piezo printheads. Recent advances by Quantica GmbH have introduced a novel printhead technology capable of jetting fluids up to 250 mPa·s, potentially expanding the range of printable materials. This study investigates the feasibility of adapting highly particle loaded screen-printing inks for use in such high-viscosity inkjet systems. By diluting screen-printing inks with solvents to reduce viscosity, the impact on particle stability, rheological behavior, surface tension, drying dynamics is systematically evaluated. The overall goal is to assess whether particle-rich inks traditionally used in screen-printing can be effectively processed via piezo inkjet technology.

Introduction and Background

Screen-printing is a well-established technique for the industrial application of labeling and product embellishment. Additionally functional applications, such as conductive structures are portrayed by screen-printing. Being an analogue technique the potential for automation here is limited, and the process of screen-printing still requires a high amount of manual labor, while the number of skilled workers is decreasing. Furthermore, the amount of materials used for printing and cleaning is quite high, as well as the set-up times to create the screens. One reason for the persistence of these techniques against more modern and flexible technologies is their wide range of applicable materials. But as the variety of products expands and the lifetimes of product cycles get shorter, it is difficult to portray these needs through screen-printing [1–6].

Another printing technique that offers a high level of individualization and flexibility is inkjet-based digital printing. As a digital technique it facilitates quick on-demand production, is contactless and does not require a printing form. On top of that material is only deposited where needed, meaning the use of material in general and of cleaning solutions is significantly lower. One disadvantage of inkjet printing is the strong limitation when it comes to jettable materials. The maximum viscosity for typical industrial piezo inkjet printheads is around 25 mPa·s [7].

However, with the increasing demand for flexible functional printing new printhead techniques have emerged. One of them is the NovoJet printhead by Quantica GmbH. Due to a different actuation principle compared to conventional piezo inkjet printheads it is supposedly able to jet fluids up to 250 mPa·s. Instead of an acoustic wave generated by the piezo that ejects the material, the piezo in the NovoJet actuates a piston that displaces the material to generate a droplet. Additionally the nozzle diameters are higher as well, opening up not only higher viscosities but also larger particles that could be processed via inkjet [8].

The NovoJet printhead has the following limitations listed in Table 1 for materials, which will be the benchmark used in this study to evaluate if a material could possibly be jetted [9].

Table 1: Overview of parameters for the Quantica NovoJet system

Viscosity	1-250 mPa·s
Particle size	< 9 µm
Surface tension	30-72 mN/m
Jetting temperature	20-80 °C

In this study we evaluated a conductive screen-printing material for potential jettability with the Quantica NovoJet printhead. The material was chosen due to its larger particles, that contrary to other conductive inks are not in the nano scale. This leads to an overall less costly material compared to other silver-inks for screen- or even inkjet-printing. An advantage is that most screen-printing inks are meant to be mixed with a thinner or solvent anyways. This is used to reach a viscosity that is significantly lower than for screen-printing but suitable for the novel inkjet technology. However, the particle content is reduced significantly, which poses new questions that need to be explored. Apart from reaching the desired viscosity the stability of the new solutions, the elastic modulus, material compatibility with the printhead and material supply, stability of the solutions, surface tension and drying behavior is relevant. All these factors will be determined for a screen-printing ink at different stages of dilution.

Materials and Methods

As the material in this study on the feasibility of processing highly pigmented screen-printing inks via inkjet, a conductive silver ink by Elantas was chosen. This ink is manufactured for screen-printing but has silver particles that are larger than the conventional nano-scale particles. This makes it less costly than other materials. Due to the larger particles and high particle content, it is a good contestant to test the feasibility and limitations of thinning screen-printing inks for inkjet purposes with the novel Quantica NovoJet printhead. In the following the preparation of the solutions and measurement methods for the different parameters are described.

Solution preparation

To prepare the solutions the screen-printing ink by Elantas was mixed with the respective thinner in different rations by wt%. The ratios were the following:

Table 2: Ratios of Elantas material and thinner used for testing

Elantas_45%	55 % of ink and 45 % thinner
Elantas_50%	50 % of ink and 50 % thinner
Elantas_55%	45 % of ink and 55 % thinner

The solutions were prepared by combining the respective amount of ink and thinner and then mixing first by hand to roughly combine. Afterwards the solutions are placed on a magnetic stirring plate until combined fully.

Viscosity measurements

The viscosity of the samples was determined with an Anton Paar MCR 302 rheometer with a cone-plate setup (diameter 40 mm, angle 0.3 °). A shear rate sweep from 100 to 55000 1/s was performed. The temperature was set to 30 °C. Each solution is measured three times and the mean value with standard deviation is displayed.

Elasticity and dampening behaviour

The elasticity and the dampening behavior upon an added load was determined using a TriPAV rheometer, respectively using the printhead mode of the device. To represent the geometry of the Quantica printhead a gap size of 200 µm was used during measurements. This measurement with an applied load of 2 V was performed in 1 °C increments over a range from 25 to 40 °C. The complex modulus was measured with a gap size of 75 µm at 30 °C with a frequency sweep from 100 to 10000 Hz.

Particle stability and size

The stability of the particles in the dilutions was determined with the TURBISCAN TOWER by Microtrac Retsch GmbH. They kindly measured the samples provided with a dilution of 45 % and 55 %. The method is using static multiple light scattering (SMLS) to determine transmission and backscattering of a sample. By determining this over the whole vial over a certain amount of time the stability of the sample can be assed through the Turbiscan Stability Index (TSI) which is comprised of the difference between transmission and backscattering of the sample. The size of the particles was determined as well.

Material compatibility

To determine the compatibility of the Elantas material with the Quantica NovoJet printhead different components from the printhead are submerged in the thinner at 30 °C for 24 hours, 7 days and 4 weeks. Since the material is comprised of mostly the thinner and the silver particles only the thinner was used for the compatibility testing for easier and more accurate evaluation of the results. The compatibility is evaluated through observation of optical changes in the printhead components, as well as weight changes before and after submerging.

Droplet behavior

Another crucial factor for highly pigmented inks, especially conductive ones, is the behavior of the particles in a droplet once it hits the substrate. To simulate and observe this behavior the solutions were applied to glass microscope slides with the Krüss MSA Flexible Liquid. Afterwards the droplets were observed under the Digital Microscope CVM 6a by Leica to check for the movement of the particles in the applied droplet.

Surface tension

The surface tension of Elantas_45% was determined with a SITA bubble tensiometer, with a set bubble lifetime of 2000 ms.

Results and Discussion

The initial determining factor if the ink can be even worked with is the material compatibility with the printhead. The main components are listed in

Table 3 with the respective evaluation after 24 h, 7 days and 4 weeks. The components were slightly affected by the thinner in terms of weight increase over time. But overall, the components receive a neutral or passing grade even after 4 weeks.

Table 3: Simplified results of material compatibility testing of Elantas thinner with Quantica NovoJet printhead

	24 hours	7 days	4 weeks
Nozzle plate	good	neutral	neutral
Adhesive	good	good	good
Heater	neutral	neutral	neutral
Fluid channel	good	neutral	neutral

The next step after the general evaluation whether the material is compatible with the printhead, is that a suitable viscosity for jetting needs to be determined. This was done by creating different dilutions of the material and measuring the shear dependent viscosity.

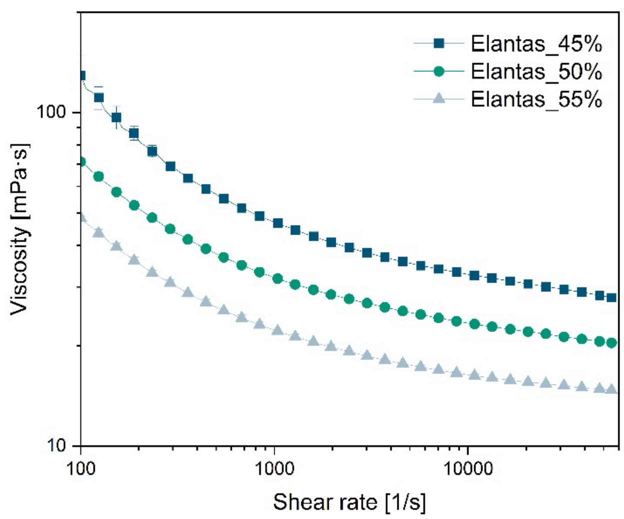

Figure 1: *Shear dependent viscosity of three Elantas solutions*

The shear dependent viscosity in Figure 1 of the Elantas material dilutions shows a strong shear thinning behavior for all the solutions. Even though the NovoJet printhead is able to jet fluids up to 250 mPa·s, the elasticity and shear dependent viscosity plays a big role as well. Therefore, the dilutions were chosen to be more around 100 mPa·s to account for other effects influencing the droplet formation.

Apart from the viscosity the stability of particles is a crucial factor for jetability of highly particle loaded inks. The particle stability measurement by Microtrac Retsch GmbH for the Elantas_45% and Elantas_55% solution showed that the stability of the particles decreased significantly from 45 to 55 % dilution. This is expected due to the reduced viscosity of the solution with more thinner added. The particles have a D_{90} of 4.37 µm. This is well below the limit of the printhead, if no agglomerates are forming over time.

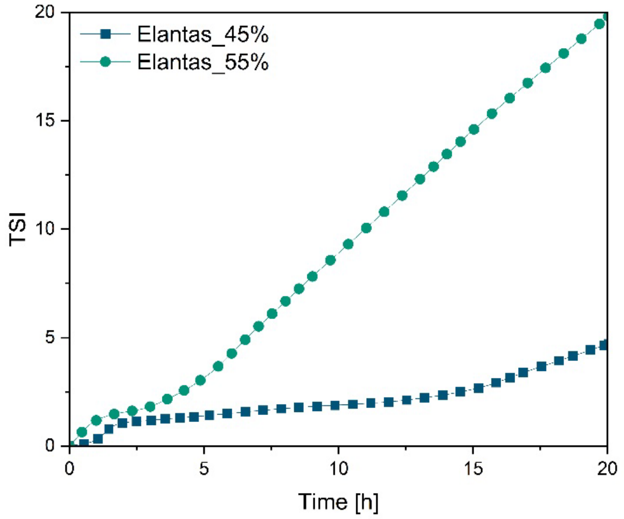

Figure 2: *Particle stability analysis with Turbiscan by Microtrac, Turbiscan Stability Index over time*

As seen in Figure 2 the TSI of the Elantas_45% is below 5 even after 20 h. According to the manufacturer a TSI between 3 and 10 is a sign for the destabilization of the sample [10]. So even though Elantas_45% is significantly more stable than Elantas_55%, the particle sedimentation could still impact the jetting performance. The experiments were repeated by Microtrac after stirring the sample again, and the same results were achieved. Meaning, even though the material destabilizes, it can also be redispersed and perform in the same way again.

The stability analysis for the droplets on substrate is shown in the images in Figure 3, Figure 4 and Figure 5.

The droplet of Elantas_45% in Figure 3 that was applied directly after mixing the sample shows some migration of the silver particles into the center of the droplet and a small ring of solvent on the outside. However, there is still a homogenous layer of particle in most of the area covered by the droplet. Photos of the dried droplets also showed the same homogenous layer and no signs of the coffee-ring-effect, where particles tend to migrate to the edges of a droplet due to faster evaporation of solvent on the edges [11]. According to these results, with a certain overlap of the droplets during printing a homogenous conductive layer could be achieved. Next another droplet of the same 45 % solution was applied, but after the material was left to sit for roughly 3 h to observe the effects of sedimentation, that were already captured by the sedimentation analysis.

The agglomeration of the particles is displayed in Figure 4 very clearly. Compared to the fresh droplet there are big agglomerates of particles that moved around in the area covered by the droplet. There is no more homogenous layer. With these results an effective layer cannot be printed anymore.

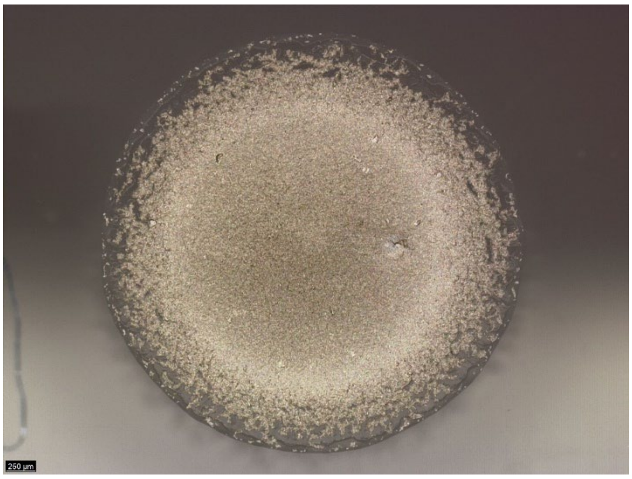

Figure 3: *Droplet of Elantas_45% on PMMA substrate applied directly after mixing the solution*

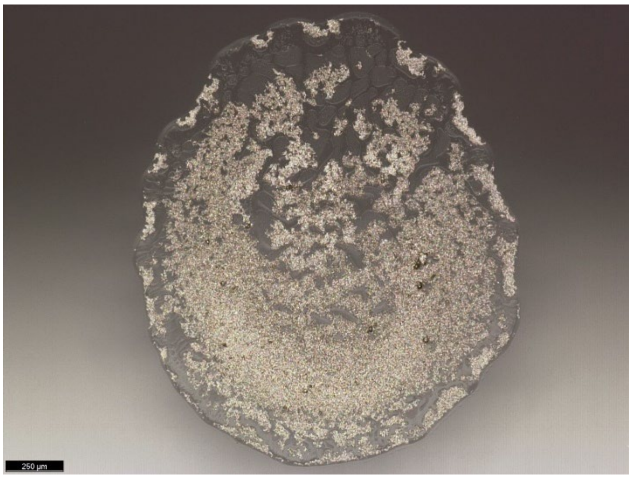

Figure 4: *Droplet of Elantas_45% on PMMA substrate applied after 3 h*

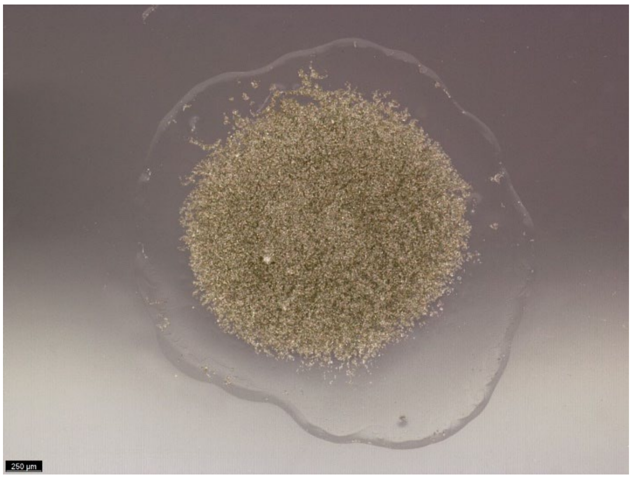

Figure 5: *Droplet of Elantas_55% on PMMA substrate applied directly after mixing the solution*

The last droplet is with the 55 % dilution to once more observe the different behavior of the particles at a higher dilution.

Again, the higher dilution in Figure 5 is noticeable immediately. The migration of particles towards the center of the droplet is much stronger than in the 45 % dilution. Also, the ring of solvent that forms around the rim of the droplet is larger and the edges way less defined. With this dilution a conductive layer could presumably not be printed.

Due to this analysis for further experiments and jetting the mixture with 45 % of thinner was chosen. Since the material exhibited significant shear thinning behavior and is highly particle loaded the elasticity could also be a detrimental contributor to the jetability of the dilution.

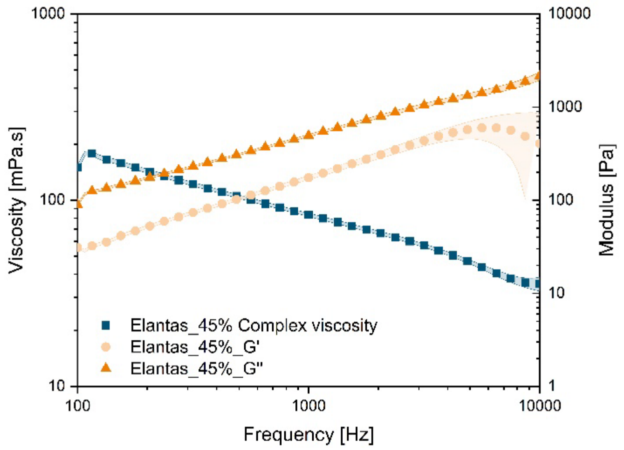

Figure 6: *Frequency sweep of Elantas_45% with high frequency rheometer*

As expected, due to the high particle content the elasticity of the material is high, indicated by a high G'. The results of the complex viscosity align with the previous measurement of the shear dependent viscosity and show highly shear thinning behavior up to a frequency of 10000 Hz. On one hand the highly shear thinning behavior could be beneficial for jetting, since a lower viscosity usually means better ejection. On the other hand, the high elasticity could impede the break-off of the droplet or lead to long ligaments [12, 13]. One last step to previously assess the jetability is the agitation and dampening of the material. The results for Elantas_45% are compared to PEG400 (Polyethyleneglycol), which is a material that has already been proven to be jetable with the Quantica NovoJet at a viscosity of roughly 80 mPa·s at 30 °C. As seen in Figure 7 the response of the PEG400 and Elantas_45% are very similar. Only the response to the actuation of the screen-printing material is slightly lower. This could result in insufficient actuation for jetting, but the

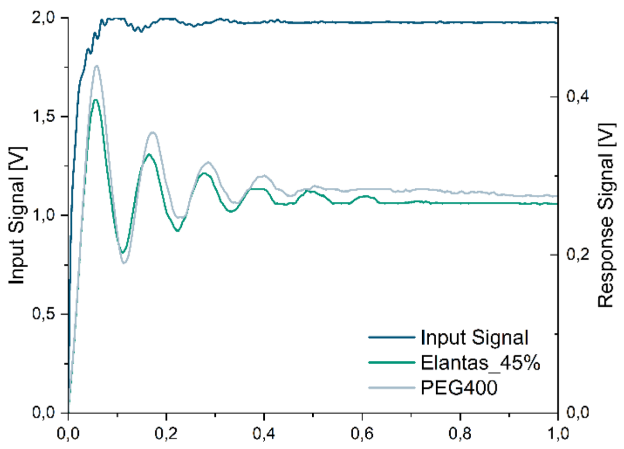

Figure 7: *Actuation and dampening response of Elantas_45% and PEG400 measured with TriPAV Printheadmode in comparison at 30 °C*

difference in peak amplitude is only 0.043 V with Elantas_45% having a peak amplitude of 0.396 V and PEG 0.439 V. The peak amplitude is a means to determine if the material responds sufficiently to the actuation in the printhead to be ejected. Generally, the higher the amplitude, the higher the probability of jetting [14].

Finally, the surface tension of the Elantas_45% dilution is 42.8 mN/m, which is well within the range of the Quantica NovoJet printhead. With these results the material seems to at least be jettable, however the long-term effects in the printhead directly cannot be predicted.

Therefore, with assessments, jetting trials were conducted by Quantica GmbH in Berlin. They jetted a mixture of Elantas_45%. Even though the stability was not ideal, the previous test also showed that the solution could be stirred up quite well and have the same properties again. Generally, the material seemed to be jettable at first and lines could be printed as seen in Figure 8. However, aligning with our experiments beforehand even at 45 % dilution, sedimentation was an issue. During the jetting process the material agglomerated specifically in the fluid supply system and led to unstable jetting and problems over time.

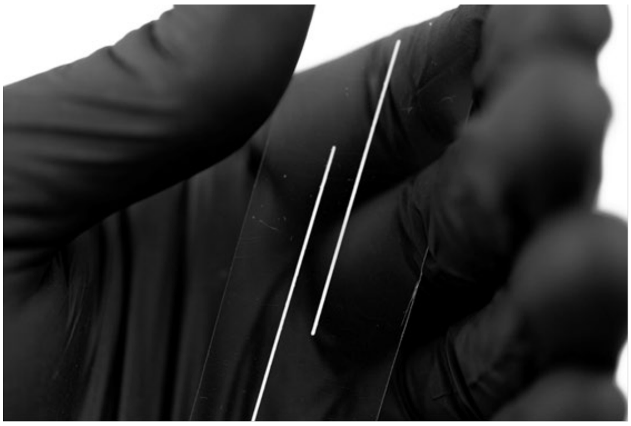

Figure 8: *Lines of Elantas_45% printed with the NovoJet printhead by Quantica GmbH in Berlin*

Summary and Outlook

A highly pigmented, conductive screen-printing ink, in the form of the Elantas silver paste was successfully diluted to a jettable range. The particle size was in a range that should be jettable for the Quantica NovoJet printhead. However, the stability of the pigments at dilutions, especially above 45 %, was very poor. Even the sample Elantas_45% showed significant destabilization of the particles over time through a stability test by Microtrac, as well as in droplets applied to PMMA substrates. Subsequently the material was still tested on jetability, since the material is constantly moving in the printing system, so maybe the sedimentation could be prevented, but unfortunately this was not the case. Even though the material was jetted by Quantica GmbH to print lines the agglomeration of the particles prevented longer stable jetting.

This leads to several conclusions. Firstly, it was achieved to dilute and jet a screen-printing material for inkjet printing successfully. Secondly, as expected the stability of the particles remains an issue. The first approach to addressing the destabilization is reducing the amount of solvent that needs to be added to the material, because a significant increase of sedimentation was observed above a critical concentration. To still get a viscosity in the jettable range the additives that are supposed to make the off-the-shelf screen-printing material more viscous are left out. With this new material, a new dilution can be found to achieve the same viscosity. Then the stability of the pigments is assessed again at the new dilution. The final step would be to add stabilizing additives to the new formulation to make the pigments stable enough for longer jetting.

Acknowledgements

The material and solvent used in the experiments was kindly provided by ELANTAS GmbH.

Measurements with the TURBISCAN TOWER by Microtrac Retsch GmbH were kindly conducted by Kai Düffels in Haan, Germany.

Initial jetting trials were conducted at Quantica GmbH in Berlin, Germany.

References

[1] FESPA News. "The Future of Screen Printing." Accessed: Jan. 15, 2024. [Online]. Available: https://www.fespa.com /en/news-media/industry/the-future-of-screen-printing

[2] Kubi Sertoglu. "Nano Dimension and Fraunhofer IPA partner to develop new electronics 3D printing process." Accessed: Feb. 12, 2024. [Online]. Available: https:// 3dprintingindustry.com/news/nano-dimension-and-fraunhofer-ipa-partner-to-develop-new-electronics-3d-printing-processes-196150/

[3] I. Campbell, O. Diegel, R. Huff, J. Kowen, and T. Wohlers, *Wohlers Report 2023: 30 Printing and Additive Manufacturing Global State of the Industry*. Washington,DC: ASTM International, 2023. Accessed: Oct. 9, 2023. [Online]. Available: https:// wohlersassociates.com/product/wr2023/

[4] C. Bodenstein, H. Sauer, K. Hirmer, and E. Dörsam, "Printing process and characterization of fully pad printed electroluminescent panels on curved surfaces," *Journal of Coatings Technology and Research*, 2019.

[5] Stephan W. Eder. "Solarzellen für Rucksäcke & Co.: Individuell gedruckt nach Maß: Individualisierte, flexible Dünnschicht-Solarzellen schon ab Losgröße eins wirtschaftlich herstellen: Eine verkettete Rolle-zu-Rolle-Fertigungsanlage soll das einer österreichischen Firma ermöglichen. Dafür hat ein Forschungsteam vom Fraunhofer IPA eine spezielle Inkjet-Druckstation entwickelt und integriert." Accessed: Feb. 3, 2025. [Online]. Available: https://www.vdi-nachrichten.com/ technik/energie/solarzellen-fuer-rucksaecke-co-individuell-gedruckt-nach-mass/

[6] D. E. Riemer, "The Theoretical Fundamentals of the Screen Printing Process," *Microelectronics International*, vol. 6, no. 1, pp. 8–17, 1989, doi: 10.1108/eb044350.

[7] W. Zapka, Ed. *Handbook of industrial inkjet printing: A full system approach : Volume 1 & 2*. Weinheim: Wiley-VCH, 2018. [Online]. Available: http://onlinelibrary.wiley.com/ book/10.1002/9783527687169

[8] M. S. Ben Hartkopp, Ramon Borrell, and Quantica GmbH, "Quantica_NovoJet_Technology_Whitepaper," 2022.

[9] Quantica GmbH. "Specs NovoJet™ Printhead." Accessed: Nov. 26, 2025. [Online]. Available: https:// www.quantica.io/novojet-printhead

[10] MICROTRAC. "Turbiscan Applications: Coatings: Paints, Inks, Varnishes." Accessed: Nov. 30, 2025. [Online]. Available: https://www.microtrac.de/files/436468/ turbiscan-for-coatings.pdf

[11] H. Hu and R. G. Larson, "Marangoni Effect Reverses Coffee-Ring Depositions," *The Journal of Physical Chemistry B*, vol. 110, no. 14, pp. 7090–7094, 2006, doi: 10.1021/jp0609232.

[12] A. Götz, J. C. Janhsen, S. Güttler, O. Refle, and O. Ronczka, "A systematic approach to evaluate jetability of high-viscosity resins for 3D inkjet printing applications," *Prog Addit Manuf*, vol. 10, no. 3, pp. 1707–1712, 2025, doi: 10.1007/s40964-025-00958-0.

[13] T. Tuladhar, R. Harvey, J. Tatum, and P. Drury, "Understanding Inkjet Inks and Factors Influencing the Jetting Behaviour," *print4fab*, vol. 25, no. 1, pp. 423–426, 2009, doi: 10.2352/ISSN.2169-4451.2009.25.1.art00004_2.

[14] Z. Hussain *et al.,* "High-Frequency Rheological and Piezo-Voltage Waveform Characterization of Inkjet-Printed Polymer-Based Dopant-Source Inks," *Micromachines*, early access. doi: 10.3390/mi14010080.

Author Biography

Antonia Götz is a doctoral student at the Hochschule der Medien (HdM) and the Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) in Stuttgart. During her current research she is developing a systematic approach to evaluate the jetability of high viscosity fluids in piezo-inkjet printing.

This combines the knowledge of her degree in chemical engineering, where she focused on the formulation of paints and coatings, with her master's degree in polymer science.

Recently she was investigating the possibilities of using screen-printing inks with novel inkjet printheads.