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# Assessment of conductive properties of flexographic inks

***Keywords:*** *flexographic printing, printing inks, conductive inks*

## Summary

The article presents results of assessment of flexographic inks for their conductive properties. Conductive inks for printed electronics are much more expensive than standard graphic inks, thus it was interesting to find out if the standard graphic inks can be a viable substitute in some cases.

Several formulations of solvent-based and water-based flexographic inks were assessed to discover that the surface resistance of layers printed with these inks widely differs. Some inks are not conducting until a certain film thickness is reached. The inks printed on paper in general are more conductive than printed on non-absorbent substrates, and their conductive properties do not change with time. The best results obtained with graphic inks are comparable to the properties of specifically formulated flexographic conductive ink. This indicates that standard graphic inks can be used for some applications where resistivity in the single kOhm per square range is required, and some changes to the formulation may lead to a hybrid ink with good printability and conductivity.

## Introduction

Printed electronics, ie. recreation of electronic structures using graphic arts technologies, is evolving to become a recognized production method for many devices, including RFID tags, photovoltaic panels (OPV) and displays/light sources, eg. OLED (IDTechEx, 2015). Conductive inks (ie. inks that are able to create a conductive layer when printed on a substrate) are widely used in these processes, namely to create antennae, contact pads, conductive tracks, electrodes or even complete elements, eg. strain sensors (IDTechEx, 2015). To maximize conductive properties, an ink must be specifically formulated. Such inks must contain a significant amount of expensive materials, e.g. metal or carbon (nano)particles and/or conductive polymers, making it more expensive than a standard ink. A significant amount of ink remains in the flexo press inking system after printing and must be cleaned (becomes a waste). Moreover, to avoid excessive solvent evaporation and to maintain the correct ink viscosity, an ink chamber system is preferred for the printing unit. The chambered blade systems work best with continuous ink supply (with infeed and outfeed) that require even higher amounts of ink to function properly (Kipphan, 2001). Therefore it is interesting to find out if any lower cost inks can be substituted for printing conductive electronic elements.

Flexographic printing is frequently used in the packaging industry to print on flexible packaging, labels and folding carton (Kipphan, 2001). It is also an important technology in printed electronics production (IDTechEx, 2001; Đokić et al., 2015). Since the concept of active and/or intelligent packaging frequently requires adding an electronic element, or sensor, to the printed packaging (IDTechEx, 2015), it is also important to find out whether the same ink can be used for both purposes. As printing inks are widely available, this could help avoiding problems with production costs and widen the potential market for products printed using flexographic printing technique.

A graphic ink contains colorant particles (typically pigments) dispersed in binder (Eldred, 2001). Most ink formulations contain some additives and solvents which help to create an image on a suitable printing substrate (Eldred, 2001). Pigment concentration in flexographic inks is low, as these inks require a substantial amount of solvent for proper ink transfer (Eldred, 2001). A typical composition of black flexographic ink may contain 23% of pigment (soot), 38% of acrylic resin water solution (binder), 38% of water (solvent), 0.5% of anti foaming agent and 0.5% of surfactant (Eldred, 2001). Of these, only the pigment can be considered conductive. In other inks, polyurethane, nitrocellullose, PVC or other binders, including conductive polymers (eg. PEDOT:PSS) can be used. With low amount of dry content, one may expect that the thickness of dry ink film is much lower compared to wet ink film thickness during printing.

A flexographic ink may be solvent-based, water-based or may be an UV-curable ink. The UV ink formulations do not allow for currently known conductive polymers to be used, therefore the standard graphic UV-curable inks act as insulators rather than conductors; nevertheless, it is possible to use UV curing for special conductive ink formulations (Đokić et al., 2015). However, the solvent-based and water-based inks, especially black inks where amorphic carbon (soot) is used as a pigment, may theoretically exhibit some conductance when printed. The assessment described below has been started to find out how these black inks may be compared with specifically formulated conductive inks suitable for flexographic printing.

## Methods

The ink layers were deposited on the substrate using the applicator rod (ink drawdown test) method as it was an easy way to precisely control the thickness of wet ink film. The applicator rod is tightly wound with stainless steel wire (cf. Fig. 1), and the diameter of the wire, in the wound form, regulates the thickness of the wet ink film (Gardner, 2016). In the assessment, the rods applying film of 4, 6 and 8 micrometres were used.

Ink drawdown test is one of the standard ink testing procedures in the printing industry (cf. Laden, 1997). A5 (145×210 mm) test pad with an appropriate set of applicator rods were used. The printing substrates for the test have been chosen

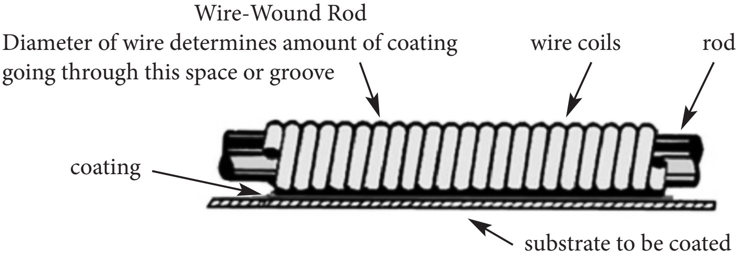

Fig. 1. The applicator rod [Gardner, 2016]

to match the supplier's recommendation for the ink: either Gardner coated paper (as supplied with the drawdown equipment) or corona-treated 400 micrometer GAG Folienwertk Wolfen PET foil. The activation status of the PET foil was checked to be above 38 mN/m with an appropriate Fischer Quicktest marker.

Inks to be assessed were standard black ink formulations, developed by Chespa Farby Graficzne Ltd. (a Polish ink supplier), identified by their laboratory symbol and prepared up to 2 weeks before testing. The inks contained no specific conductive content other than pigment. The tested inks were as follows:

Table 1. A list of inks used in the assessment

| Ink symbol | Solvent type | Pigment type | Recommended substrate type |
|---|---|---|---|
| 1WXGraf1 | Ethanol | Soot | PET |
| 1WXGraf2 | Ethanol | Soot | PET |
| 1WXGraf3 | Ethanol | Soot | PET |
| 1WXGraf4 | Ethanol | Soot | PET |
| 1WX5W-08 | Ethanol | Soot | PET |
| Wiflex WXT5 LAB | Ethanol | Soot | PET |
| LAB14DK0000097 | Water | Soot | Paper |
| LAB14DK0000098 | Water | Soot | Paper |
| LAB14DK0000099 | Water | Soot | Paper |
| LAB14DK0000100 | Water | Soot | Paper |
| LAB14DK0000101 | Water | Soot | Paper |
| LAB15AK0000062 | Water | Soot | Paper |
| LAB15AK0000063 | Water | Soot | Paper |
| LAB15AK0000064 | Water | Soot | Paper |
| LAB15AK0000066 | Water | Soot | Paper |

Each ink was used to produce two strips on the recommended substrate. The inks were stirred immediately before the samples preparation. The ink samples were then left to dry in the room temperature for 15 minutes before the first set of resistivity measurements have been taken. To verify the influence of drying time,

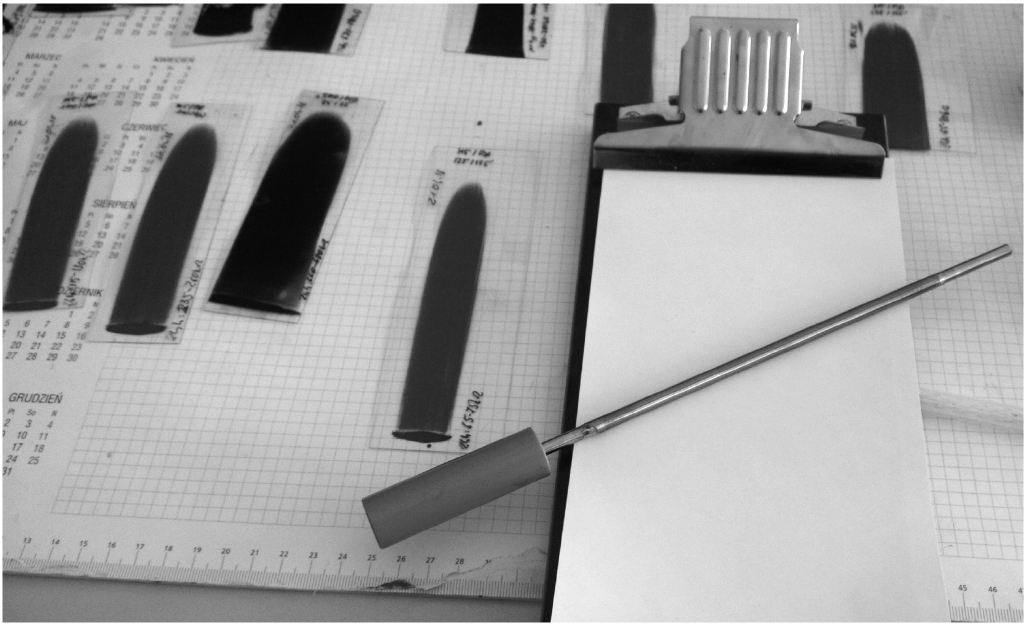

Fig. 2. Applicator rod with the test pad and sample ink strips

a second set of measurements was taken after 6 days of drying the ink strip in the room temperature.

The resistivity measurements were taken with Sanwa PC-5000a digital multimeter using 2-point probes 25 mm apart. For each sample, three measurements were taken along the ink strip and three across the ink strip, and an average value of all measurements for two samples of the same ink was used as an indication of ink layer resistivity.

As a reference, Vorbeck Materials Vor-Ink$^{TM}$ F101 conductive ink was also drawn down and measured in the same manner. Under typical process conditions, Vor-Ink F101 sheet resistivity should be in the range of 150–200 Ohms/square with dry ink thickness approx. 1 micrometre (Vorbeck Materials, 2013). The viscosity of this ink is much higher than of standard graphic inks: >2 mins elution time from Zahn #2 cup, which corresponds to approx. 100 s from Ford #4 cup (used to control viscosity of most fluid inks) or 3.5 Pa·s (Vorbeck Materials, 2013), where typical flexographic inks viscosity is approx. 20–25 s (Ford #4 cup) or 0.6 Pa·s (Eldred, 2001). Vor-Ink F101 is also shear-thinning (thixotropic) unlike standard flexographic ink. However, this does not seem to influence the results in any way.

## Results and Discussion

The ink strips were observed to be uniform, with the observed drying time between 20 and 30 seconds, with the exception of Vor-Ink F101, where some irregularities, probably resulting from high ink viscosity, were visible on the strip.

The summary of measurements is shown in Table 2.

Table 2. Average resistivity of assessed inks (2-point measurement 25 mm apart)

| Ink symbol | Resistivity [kOhms] 4 µm applicator rod | | Resistivity [kOhms] 6 µm applicator rod | | Resistivity [kOhms] 8 µm applicator rod | |
|---|---|---|---|---|---|---|
| | immediate | after 6 days | immediate | after 6 days | immediate | after 6 days |
| 1WXGraf1 | ∞ | ∞ | 350.0 | 325.0 | 55.0 | 45.0 |
| 1WXGraf2 | 750.0 | 600.0 | 85.0 | 60.0 | 35.0 | 27.5 |
| 1WXGraf3 | ∞ | ∞ | ∞ | 18500.0* | 290.0 | 125.0 |
| 1WXGraf4 | ∞ | ∞ | 10000.0 | 3500.0 | 320.0 | 225.0 |
| 1WX5W-08 | 20.0 | 20.0 | 15.0 | 15.0 | 8.0 | 8.0 |
| Wiflex WXT5 LAB | 6.5 | 6.5 | 4.5 | 4.5 | 3.2 | 3.2 |
| LAB14DK0000097 | 10.0 | 10.0 | 8.0 | 8.0 | 6.2 | 6.2 |
| LAB14DK0000098 | 7.0 | 7.0 | 5.0 | 5.0 | 3.0 | 3.0 |
| LAB14DK0000099 | 10.2 | 10.2 | 6.2 | 6.2 | 5.0 | 5.0 |
| LAB14DK0000100 | 11.2 | 11.2 | 7.5 | 7.5 | 5.2 | 5.2 |
| LAB14DK0000101 | 17.0 | 17.0 | 16.0 | 16.0 | 16.0 | 16.0 |
| LAB15AK0000062 | 3.3 | 3.3 | 2.5 | 2.5 | 1.7 | 1.7 |
| LAB15AK0000063 | 5.2 | 5.2 | 2.9 | 2.9 | 1.7 | 1.7 |
| LAB15AK0000064 | 4.0 | 4.0 | 2.4 | 2.4 | 1.9 | 1.9 |
| LAB15AK0000066 | 3.6 | 3.6 | 2.4 | 2.4 | 2.1 | 2.1 |
| Vor-Ink F101 | 3.6 | 3.6 | 2.8 | 2.8 | 1.5 | 1.5 |

*some areas still not conducting

It is notable to see that some of the inks were found to have comparable resistivity as the dedicated conductive ink. As a rough rule, inks printed on paper have lower resistivity than inks printed on PET. Solvent-based inks required thicker layer to develop a significant conductivity, and there was a measurable difference in resistivity after 6 days of drying. By contrast, the resistivity of water-based inks did not change with time. This may indicate that the solvent absorption increases the speed of ink layer shrinkage and the resulting forces increase the areas where pigment particles contact, creating a conductive structure with thicker cross-sections.

The measurements for Vor-ink F101, although not reaching the values quoted by its supplier, were within the expected range, taking into account the methods of deposition and measurement. This ink required however frequed stirring to prevent sedimentation and to homogenize the ink.

It was found that for some solvent-based inks a film must be thick enough to be conductive, which is consistent with the low pigment concentration and supports the theory that only the pigment particles are conducting. However, the variation in resistivity between different solvent-based inks were found to be much higher than between water-based inks. As water-based inks use also water polymer dispersions as binders, while solvent-based inks contain polymer solutions, it is supposed that the interaction between the pigment and binder during drying (ie. removing the solvent) may ultimately decide upon the resulting conductive properties.

For most inks, resistivity decreases with thicker ink layer, as shown on Fig. 3. The decrease in resistivity in general should be inversely proportional to ink layer thickness, but there are exceptions to this rule. With one of the inks, the resistivity does not decrease with ink layers above 6 micrometres. By contrast, for two other inks the slight increase of wet ink film thickness resulted in disproportionately high decrease of resistivity (cf. 1WX5W-08 on Fig. 3). This indicates that the pigment particles structure and size must be carefully considered if a standard graphic ink could be used in place of a conductive one.

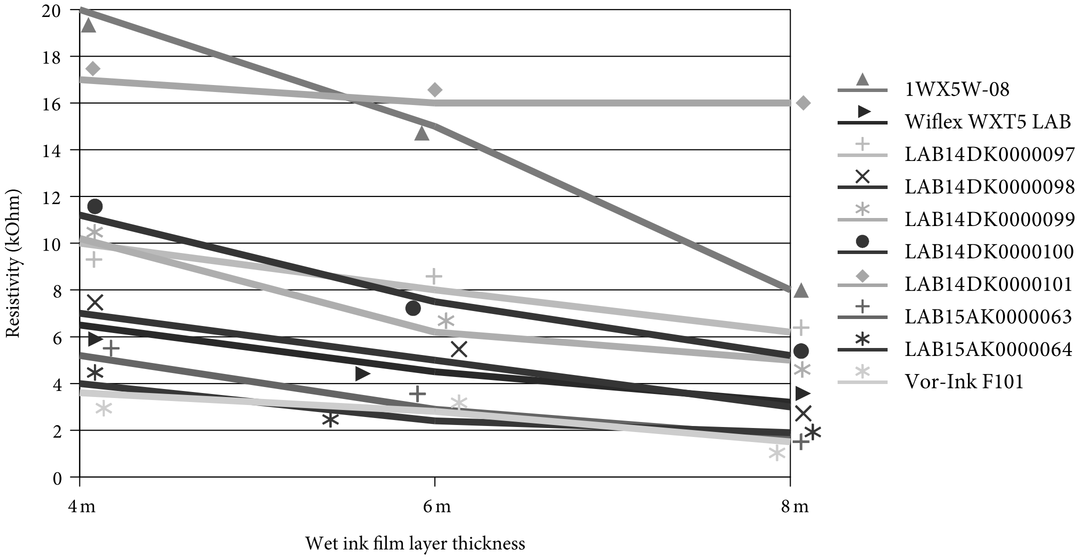

Fig. 3. Influence of ink layer thicknes on the resistivity of selected inks

## Conclusions

The assessment has shown that flexographic inks may display significant conductive properties, in some cases comparable to the dedicated formulations of conductive inks suitable for flexographic printing. However, the resistivity of standard flexographic inks too high to consider them truly conductive, and forbids their usage for antennae and similar applications. This does not exlude their usage as contact pads for some types of sensors, interactive devices or connectors. These inks may also be used to print resistors and heat elements, for which the amorphic carbon pigment is suitable. Layers of these inks will also dissipate static charges quickly enough to consider them anti-static, which may be desirable in some types of packaging.

The assessment indicates also a necessity of further investigation into conductive properties of graphic inks, and a deeper research to discover the influence of ink formulation and production techniques on these properties. Furthermore, an investigation into possible modifications of graphic inks may lead to new kind of hybrid printing inks with good conductivity and printability.

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## Streszczenie

*Ocena przewodności farb fleksograficznych*

W artykule przedstawiono wyniki badań dotyczące oceny właściwości przewodzących standardowych farb fleksograficznych. Z uwagi na wysoką cenę farb przewodzących stosowanych do druku elementów elektronicznych, możliwość wykorzystania w tej roli farb graficznych jest interesującym rozwiązaniem dla przemysłu poligraficznego.

Zbadano kilka dostępnych na rynku standardowych farb fleksograficznych (rozpuszczalnikowych oraz wodorozcieńczalnych), przy czym stwierdzono, że ich rezystancja powierzchniowa znacząco się różni. Niektóre farby zaczynają wykazywać właściwości przewodzące dopiero po przekroczeniu pewnej grubości warstwy. Farby nanoszone na papier wykazują z reguły lepszą przewodność niż farby nanoszone na podłoża niechłonne, a ich właściwości elektryczne nie ulegają zmianie z czasem. Niektóre zbadane farby osiągnęły przewodność porównywalną ze specjalistyczną farbą przewodzącą opracowaną dla techniki drukowania fleksograficznego. Wskazuje to na możliwość zastosowania standardowych farb graficznych do druku niektórych elementów elektronicznych, gdzie rezystancja powierzchniowa na poziomie pojedynczych kiloomów na kwadrat jest wystarczająca. Wyniki badań sugerują także, iż możliwe jest opracowanie modyfikacji farb graficznych w kierunku stworzenia farby hybrydowej, posiadającej dobre właściwości elektryczne i graficzne jednocześnie.