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Printing Process Recommendations, Single-Wall Carbon Nanotube (SWCNT) V Series Inks

SWeNT's V Series CNT Inks, based on V2V™ Ink Technology[1] have been designed specifically for use in conventional printing processes, without the need for any secondary operations beyond conventional oven drying. To date the inks have been successfully applied by screen printing, pad printing, Meyer Rod and Gravure coating techniques. Additional inks for flexographic printing are expected to be added to the range shortly. The CNT ink flows and levels well on surfaces such as polyester and glass and line resolution of 0.3 mm has been demonstrated.

Inks are available as Conductive and semi-conducting grades. Currently available inks are:

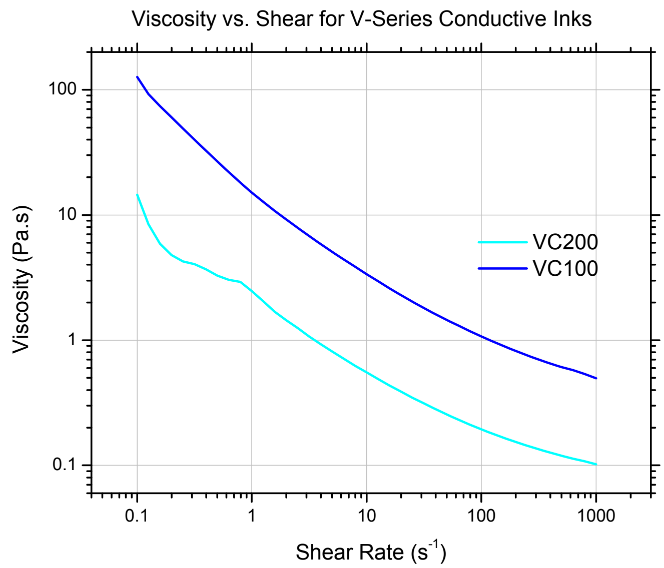
Printing Method	***Conductive Ink***	***Semi-Conducting Ink***
Screen Printing	VC100	XVS100
Pad Printing	VC100	XVS100
Meyer Rod	VC100	XVS100
Gravure	VC200	XVS200

Fluid Preparation:

The V Series Inks are delivered premixed and ready to use. It is recommended that bulk ink be stirred using a conventional stirrer (low shear at 100 to 200 rpm) before use. This will reduce the viscosity of the ink to its optimum working value. Samples supplied in the 20 ml Syringe do not require this step as the dispensing action shears the fluid to its working viscosity.

[1] V2V™ is a trademark of Chasm Technologies, Inc., patents pending.

The CNT inks show typical shear thinning behavior as shown for the VC100 and VC200 inks in the adjacent graph. The semiconducting inks are expected to show similar viscosities as a function of shear.



Normal mixing and pouring will typically generate shear rates in the region of 1 to 10 sec^{-1}, whereas the actual screen or gravure printing processes will typically generate shear rates ≥ 1000 sec^{-1}.

The ink also shows rapid recovery of most of its original viscosity (70% recovery in 5 to 7 sec.) when the shearing is removed.

Shear Rate (s^{-1})	Viscosity			
	VC100 (Pa.s)	VC100 (cP)	VC200 (Pa.s)	VC200 (cP)
1	15.1	15,100	2.47	2,470
10	3.37	3,370	0.55	550
100	1.07	1,070	0.19	190
1000	0.50	500	0.10	100

Rod Coating:

Wet coating thicknesses between 9 and 32 μm at speeds up to 4.5 m/min (15 ft/min) have been demonstrated on an automated rod coater. Hand drawdowns samples have also been successfully made with the same rods. With any of the Meyer rod techniques, automated or hand, be advised that there may be evidence of wire marks, especially on thicker wet gap samples, depending on fluid viscosity and rod coating speed. This may lead to small variations in performance associated with coating direction orientation.

For high CNT coverage, it is recommended that multiple, thinner coatings are prepared rather than one thicker coating. 27μm is the maximum wet coating thickness recommended for a single pass.. Coatings with higher CNT coverage can be prepared by the use of multiple thinner coatings (<27μm). It is important to fully dry the ink after the first coating to ensure that the CNT is fully fixed to the substrate before the application of the second coating. The result of a multiple coat would be more uniform coverage and properties versus one thicker coat.

Screen Printing

SWeNT has demonstrated excellent hand-screened printed images with 230 through 420 micron mesh screens, with height off-sets of approximately 2-4 mm (1/16 to 1/8"), in the laboratory. It is not recommended that direct screen contact on the substrate be employed, as there may be excessive coverage or smearing. A squeegee durometer of 75 or greater is recommended to control ink coverage. Squeegee pull angles between 65 and 75^{o} at speeds of roughly 0.75 m/min (30"/min) have been found to be best in yielding uniform coverage without excessive ink or smearing.

As with the Meyer rod coatings, it may be better to print and dry multiple thin layers of CNT for higher coverage.

Ventilation

It is essential that laboratory coating trials be conducted in a well-ventilated environment such as a chemical hood. Consult the MSDS for proper handling and precautions.

Drying Condition Recommendations

SWeNT's CNT inks will dry at low temperature (~100ºC). Factors that affect the drying time of any coating fluid, such as airflow, ink/wet film thickness, temperature, and relative humidity, also affect the drying time of SWeNT's V series inks. With an understanding of how these factors can be controlled with your specific equipment, very efficient drying of the ink system can be achieved.

SWeNT has dried screen printed coatings (280 and 355 mesh) and Meyer Rod coatings under the following lab conditions:

Vented Lab oven with minimal airflow:

- 115^{o}C for 15 seconds
- 100^{o}C for 45 seconds

Note: these are minimum times necessary to produce a dry film that could be recoated if needed with another layer. Increasing airflow or temperature should reduce drying time significantly. Naturally, thinner coatings will dry faster.

Temperatures below 100^{o}C even with extended drying times or airflows are not recommended, due to the evaporative properties of some of the fluid components. As stated previously, if multiple coating passes are required, it is critical that the previous coated layers are fully dried and cooled before the next pass is attempted.

SWeNT offers these conditions as a starting point for developing a process for drying the ink and recommends that end users develop their own drying profiles specific to their coating and drying equipment.

Adequate ventilation, such as a chemical fume hood or vented oven, are required for drying the film due to the nature of the volatile species given off during the drying process. Consult the material MSDS for further guidelines.

Clean Up

Ink residues can be cleaned up using paper towels or similar material. The addition of isopropanol to the paper towel should be adequate for removal of the final residue.

For printing surfaces (screen print screens, flexoscreens, gravure rolls), remove as much of the bulk ink as possible with a plastic scraper or spatula followed by a dry paper towel or rag. Use an acetone or i-propanol spray rinse first to dissolve the ink into a much lower viscosity fluid and release the ink from the printing surfaces. This can be followed by lint-free wetted cloth of i-propanol until clean. It is highly recommended that cleaning of screens or rolls be done as soon as possible after the printing run operation is complete. The ink will slowly dry making removal of the all of the material more difficult.

Cleaning should be conducted in a well-ventilated area such that operators are not exposed to vapors above the designated limits for the solvent used. Under EPA regulations no discharge of CNT materials to the drain is allowed. **All materials containing carbon nanotubes must be treated as hazardous waste and incinerated.** See MSDS for details.