Development of new products with optimized slot dies – THE scalable process

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Presented at the 16th International Coating Science and Technology Symposium,
September 9-12, 2012, Midtown Atlanta, GA[1]

The development of new products in the electronic field requires thin layers which are way lower in thickness compared to functional layers in the traditional fields of liquid coating. Some very thin layers were applied in the past by means of deposition methods utilizing vacuum atmosphere and mainly carried out in a sheet-to-sheet process which shows high operating costs. Some of these applications are also running in a roll-to-roll process, but the investments for such facilities are very high too.

The goal for the new products, and this will be the key for success, must be to reduce the production costs per unit product. Therefore a liquid application process running continuously in a R2R facility in a "normal" environment seems to be the most attractive way.

Phase 0 / R&D
Development of Fluid
Sheet to sheet process

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Phase 1 / R&D
R2R trials on Lab Coater

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Phase 2 / Pilot line
Small scale R2R production
under production conditions

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Phase 3 / Production
Full scale R2R production in
shifts 24/7 operation

If such a process shall be investigated and used successfully already the first development steps before going into the pilot stage and subsequently to production should focus on the following features:

- The application method should be transferable from the first steps to the future mass production
- The adjustments and calibrations found in the lab should be usable in production
- The precision of the application method in R&D should be comparable with later production
- The consumption of raw materials should be minimized during development

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[1] Unpublished. ISCST shall not be responsible for statements or opinions contained in papers or printed in its publications.

- During the development all possibilities in terms of production methods should be known already – the potential production technologies should be investigated from the beginning on

The development of conventional coatings in areas such as Paper or adhesive so far allowed the application by hand in the laboratory, since the later transfer was tested in production. The application of liquid to the substrate using a hand driven coating knife was possible without any restriction, it was sufficiently precise, only the drying conditions were different from the later production. The economical use of the coating materials was not necessary because the liquids commonly existed in sufficient quantity.

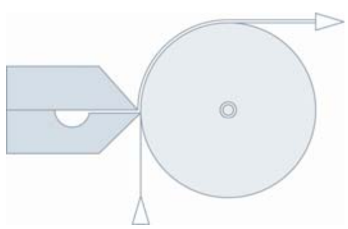
In case of the very thin layers in a sub- micron range (dry) in the field of flexible electronics (with the examples of organic photovoltaic (OPV) and organic LED's (OLED)) or other polymer coatings such a manually operated system is not feasible anymore and the precision does not allow analyzing the performance in the appropriate way. Therefore an application method shall be used already during the R&D phase which is comparable to the future production method. Closed systems avoiding any solvent evaporation are attractive because the average coated film thickness can be determined easier and more safely, and the liquid properties do not change over time. Such systems are mainly belonging to the family of premetered coating methods.

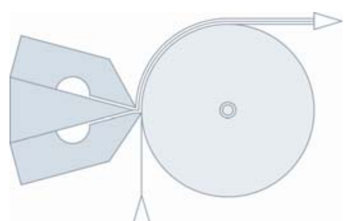
Premetered coating is commonly known as an attractive method to apply single or multilayer structures of functional layers to continuously running substrates and has been used in some industries for decades.
The main advantages of all premetered coating methods with optimized dies are the following:

- Coat weight or film thickness is specified within operating range of process
- Formulation changes do not affect average coat weight
- Reactive liquids (multi- component) systems can be coated
- Multiple layers coated simultaneously
- Excellent uniformity of coated film in both, cross-web and machine direction

The average wet thickness can easily be calculated by the specific flow rate $\dot{q}$ ([cm³/s/cm width]) and the web speed U [m/min], no other parameters are influencing the layer thickness $H_{wet} = \dot{q}/U$. By using premetered coating methods there is no leap between R&D and production facilities.

Single layer slot coating

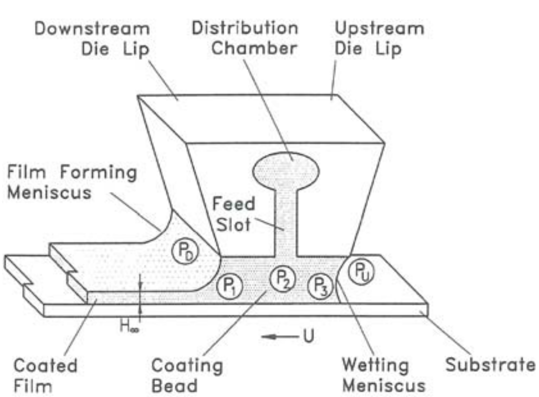


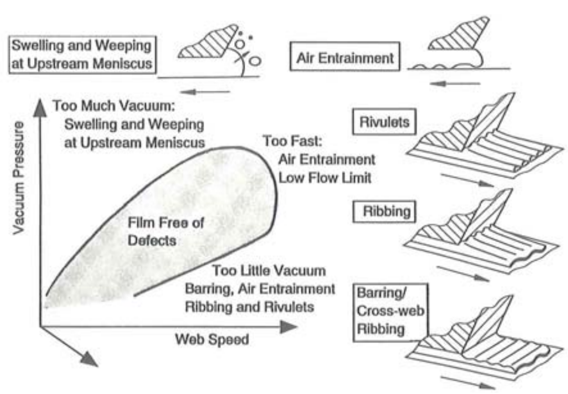


Double layer slot coating

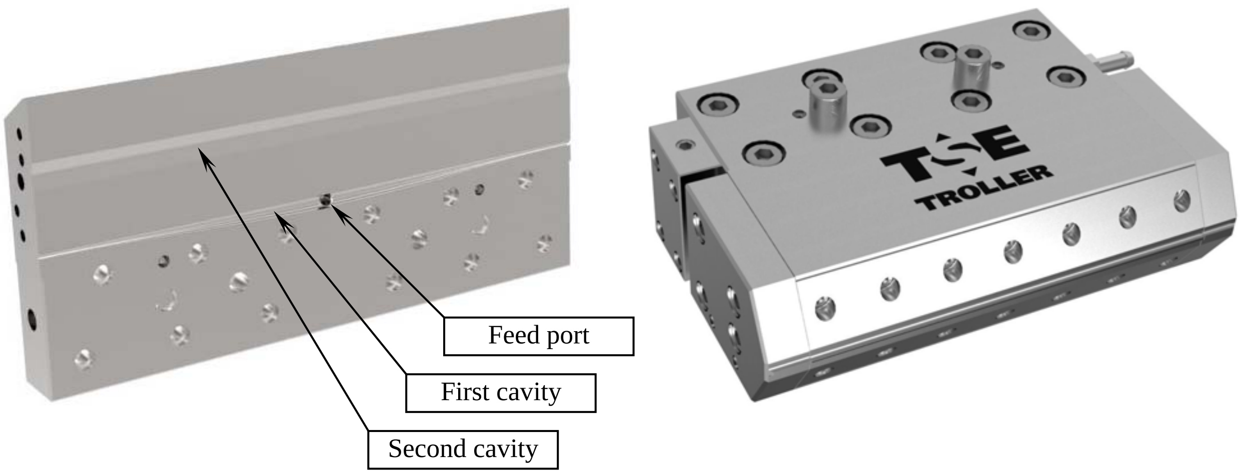
Among the other premetered coating methods (slide- and curtain coating) slot coating is appreciated as the method with the largest operating range in terms of liquid properties, film thickness and coating speed. Very low viscous liquids below 1 mPas (1 cps) can be coated as well as fluids with rather high low shear viscosities in the order of 10'000 mPas or higher. Applying very thin coatings below 5 microns wet up to thick layers in the 1000 micron range is possible just as machine speeds between less than 1 m/min up to a few 100 m/min.

The main definitions and the general shape of the operating window are shown in the following pictures [1]:





Modern product development increasingly requires uniform thin layers to achieve both, product performance and small material consumption. Especially saving raw materials enables an economic development process. Using a R2R process like liquid coating with slot dies should be investigated from the beginning on as a manufacturing method for future production. The possibility to scale-up from the laboratory over pilot trials to future production is very important. By using an optimized slot die the transfer of all settings from the lab into the final production is possible.



Single layer slot die with detailed view of internal fluid distribution system.

The internal TSE- die design consists of a dual chamber fluid distribution system, which will be optimized for a wide application range of products. The liquid is delivered through a feed port into the internal distribution system. The first distribution cavity is designed in a coat-hanger shape maintaining a certain wall shear stress throughout the entire width of the die. This helps to minimize the settlement of particles during the operation and to optimize the cleaning process just by flushing with solvent. The second cavity serves as a damping system and allows maximizing the application window of the die. Also the wall shear stress in this cavity should be above a certain value. Both slots are being designed and manufactured in order to achieve the required precision of the cross-web distribution. Due to this optimization work neither adjustment nor calibration is needed on the dies when changing the product or operating conditions. Even during development stages with unknown future conditions an optimized die can be used with great success. By pre-calculating the expected cross web uniformity of a new product the properties could be optimized first before running expensive trials.

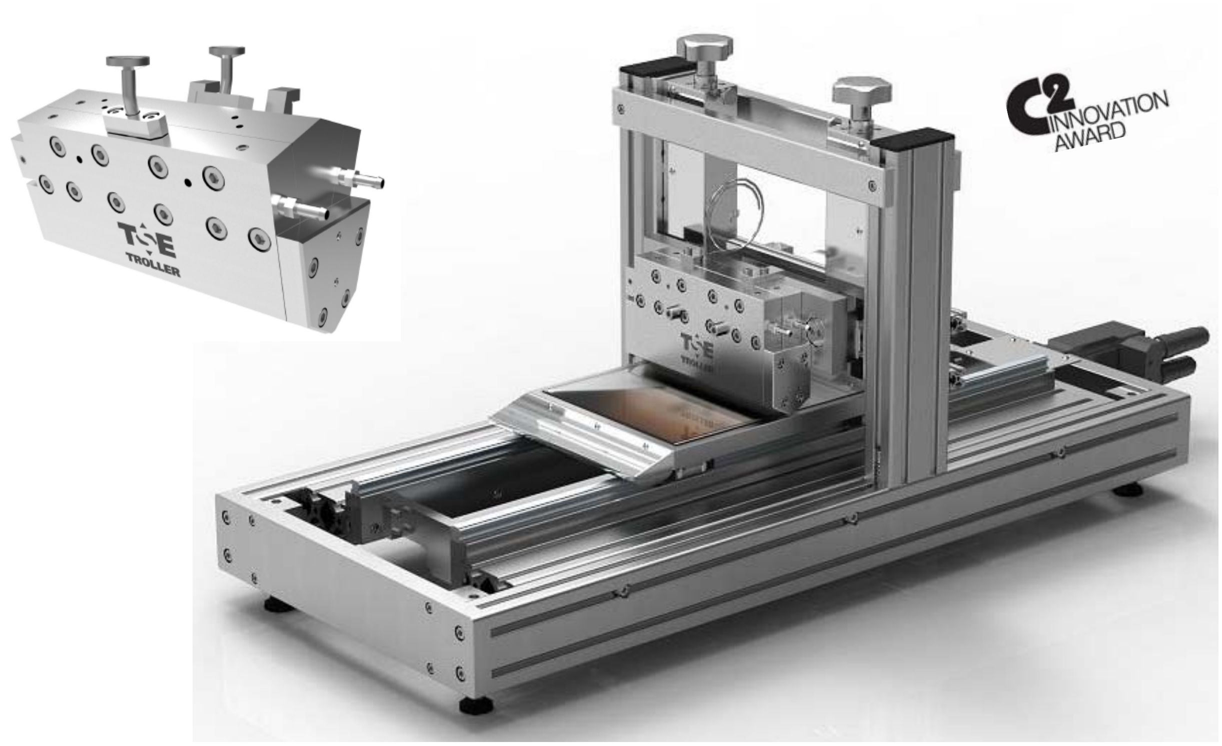
Pilot or R&D coating dies need to be very flexible. Therefore TSE slot dies can be equipped also with exchangeable lip inserts in order to test different lip geometries and potentially to run the die under various conditions of different application methods. As an example the slot die shown above has been used either for very low viscous liquids for organic electronics as well as for rather high viscous slurries in the field of Li-Ion batteries.

New product formulations often are extremely costly and also available in small quantities only, so the possibility to run trials with very low material consumption helps to reduce development costs significantly. With the optimization process a narrow slot die can be designed with lowest dead volume possible in order to maintain both, good to excellent film thickness uniformity and low usage of expensive liquids.

As an example an optimized slot die of **200mm** width can have an internal volume below **4 ml** only. By this with only 10 or 15 ml of a new product some samples can be coated under real conditions and analyzed afterwards. Of course the fluid delivery system has to be designed for very low flow rates and a pulsation-free supply.

With TSE slot dies companies and institutes are able to mimic future production processes in small scale with appropriate uniformity and functionality. The latest example of TSE development equipment is the awarded TableCoater. In conjunction with small scale production dies electronic and optical layers with dry thicknesses far below 100nm have been coated successfully. Wet layers in the order of 2-3 microns are able to be coated on a sheet-to-sheet basis and in a later R2R facility.

It is even possible to apply two or maybe three layers in one pass on such a unit by using an appropriate coating head.



TSE TableCoater with single layer slot die and dual layer die as an option.

The slot dies used on this lab- scale coater can be used in a R2R- process later on without any changes, and the settings such as distance between die lips and substrate can be transferred precisely.

Summary

- When developing new products it is beneficial to introduce future production conditions as soon as possible in the process
- Slot coating is an attractive application method to develop high performance products
- Optimized die design helps to achieve the required product performance and low operating cost during development and production
- With an optimized dual cavity design a large range of different products can be coated without any calibration during operation
- Low volume die in combination with appropriate fluid delivery system helps to save expensive and rare coating fluids during development
- Optimizing coating dies needs dialog between die manufacturer and end user
- During the development of the process a partner with designated experience is highly beneficial
- Scaling up with slot dies is very well possible by transferring the results from R&D through pilot scale to production environment
- TSE is your highly experienced partner for high precision pre-metered coating since over 50 years, everywhere in development, pilot and production scale

References

[1] S.F. Kistler and P.M. Schweizer: *Liquid Film Coating*, Chapman & Hall, 1997.