Research Progress on Water-based Ink Drying Technology

Xu Jingxiang*, Li Jinyao, Li Haichao, Zhang Mingming and Cai Jifei

School of mechanical and electrical engineering, Beijing Institute of Graphic Communication, Daxing District, Beijing, China

*E-mail:1149843383@qq.com

Abstract. Water-based ink is an environmentally friendly ink that does not contain volatile organic compounds. It conforms to the development tenet of modern society and it doesn’t produce solvent volatilization and solvent residue. Therefore, it has great application prospects in the field of packaging printing where relatively strict sanitary conditions are required, however, due to slow drying speed, high energy consumption, low adhesion, etc., there are still insufficient development and application in the market. There are still some shortcomings in development and application. By searching domestic and foreign materials and literature, this paper studied various drying methods of water-based inks, and analyzed the drying efficiency of water-based inks under various drying technologies. The drying efficiency of the aqueous ink is compared under different drying techniques, and the drying methods include hot air drying, infrared drying, microwave drying, and auxiliary drying. By comparing the advantages and disadvantages of different drying methods, it provides a new idea for the efficient and energy-saving of dry water-based inks.

1. Introduction
Plastic flexible packaging printing (intaglio printing typically) produced VOCs emissions from the largest (of the total emissions of VOCs 32.49%)[1]. Because water-based inks do not contain volatile organic solvents, and low cost, they have broad application prospects in food packaging, flexible printing, gravure printing[2], China's flexible packaging sector uses only 35% of water-based inks[3], the main limitation of water-based ink application is its drying speed. The solution method has the following two directions. On the one hand, it can increase the drying speed to improve water-based inks additives [4]. On the other hand, it is possible to conduct research from the drying method and to study different drying techniques. Research on different drying technologies to improve the drying speed of water-based inks and reduce energy consumption, so as to achieve efficient and energy-saving green printing.

2. Infrared drying
Infrared drying is a kind of radiant heating. The infrared light emitted by the infrared radiator (light source) is absorbed by the material in the form of molecular (atomic) resonance to achieve the purpose of heating the object. This radiant heating method is a very efficient drying method by directly matching the surface of the object and a certain depth with a matching wavelength, selective penetration capability, and orientation. The spectrum of the high-life medium wave radiator is very well matched to the absorption line of water, so it is highly efficient and economical and durable in aqueous ink drying.

Selim [5] proposed to use infrared drying technology to dry in order to solve the problem of ink penetration into paper and evaporation in the course of the drying process of water-based inks. At the same time, a set of drying models was established. It found that for plain paper used in the office environment, the
rate of penetration was at least 20x higher than the rate of evaporation. Thus, Selim believes that the rate of ink drying can be predicted by the paper's penetration curve.

Seaton [6] in order to improve the drying efficiency of water-based inks, accelerate the use of water-based inks in the field of flexible printing, the infrared drying technology is cited in the flexible printing process, the experimental results show that the use of infrared drying in flexible printing, not only can improve the drying effect, At the same time, in the case of security conditions, you can also produce papers with improved dot gain.

The biggest difference between the traditional ink and the water-based ink is the difference in the binder. The dye is fixed on the paper by the binder. The connecting material of water-based inks is basically made of water, and the drying process is simplified. Shi Xiangdong [7] proposed that for infrared drying equipment, the biggest disadvantage of infrared drying equipment is that the installation of the device is complicated and the investment cost is too high.

Imakoma [8] used the idea of temperature change to distinguish the previous measurement of moisture loss from the previous use and to change the temperature change of the substrate during the drying process. The experimental results show that the temperature change during the drying process can better fit the drying rate curve of the infrared water-based paint.

When Manabu [9] studied inkjet printing technology, it was found that printing speeds exceeding 200 m/min caused wrinkles in the non-printing area of the paper, which affected the drying effect. The experimental results show that the traditional infrared drying technology is applied to inkjet printing, which has no effect on the classical printing effect. At the same time, this method can reduce the breakage rate of paper, and is more efficient and economical.

The HP L65500 printer [10] used a small infrared device to dry HP's own water-based latex ink. The classic performance of the L65500 model printer maintains a drying time of 30 s at a drying temperature of 90 °C, allowing the molecules to diffuse enough time to produce a latex film.

3. Hot air drying
Compared with the high cost of infrared drying, the hot air drying equipment is simple to install and easy to maintain, and has become the mainstream drying processing equipment in the market. In the hot air drying process, the transfer of thermal energy, the evaporation of liquids such as water and solvents, and the barrier of solid materials to fluid evaporation will affect the drying speed of the ink. As the hot air of the drying body, its speed and temperature are the key factors determining the drying efficiency. The higher the speed, the higher the temperature and the higher the drying efficiency, but the corresponding fan power and heating power will also increase. Therefore, the designer of the drying equipment needs to understand the basic drying process to determine the reasonable nozzle size, fan power and hot air temperature.

Imakoma [11] applied water-based paint on glass and passed 10m/s hot air on both sides of the glass to judge the water loss rate of the product before and after drying by the temperature change in the experiment, and then judge the drying effect. Experimental results show that, at a constant speed of hot air, in the middle of the hot air drying of the product to ensure heat uniformity.

Cao Le [12] analyzed the parameters of gravure hot air drying. At the initial dose of 50%, The printing speed of 120m /min, width 1000mm, the drying zone is in the field, speed of the fan under 1100r /min, and for different print convection hot air temperature drying experiment to find the factors affecting the drying of the ink, to establish a multi-form A mathematical model of regression analysis to optimize parameters. The experimental data shows that the faster the hot air speed, the better the printing effect, and doesn't affect the printing quality.

Based on nonlinear regression, Jia Chunjiang [13] used several typical drying models to simulate in the case of hot air temperature of 50 ° and hot air velocity of 6 m/s. The results show that on the Logarithmic model, a new set of page models is obtained after modification. The experimental results are in good agreement with the model predictions, and have a good reference effect on the drying rate and effect prediction of water-based inks.

Plavnik [14] used acoustic vibration and hot air drying technology to dry water-based inks and other water-based materials. The results show that when drying water-based inks, lower heat is
allowed at higher paper web speeds. Air (lifting efficiency) operating temperature performs this process. It can be used in narrow and wide width applications, expanding the range of applications for waterborne inks.

In order to improve the drying speed of the aqueous ink, Nowaczek [15] combined hot air drying with sonic vibration. The experimental results show that the sonic vibration can accelerate the molecular motion of the binder in the early stage of the aqueous ink in the early stage of the drying process. Reduced hot air energy consumption and improved drying efficiency.

4. Microwave drying
Microwave drying is also a way to dry the ink by heating. Under the action of the microwave electromagnetic field, the heated medium molecules become polarized molecules with positive and negative charges. Because microwaves are non-ionizing, unlike ionizing radiation, they can interact with dielectric materials to generate heat by agitating molecules in an alternating electromagnetic field. Microwave energy (in the heat application) by said hollow tube is a metal waveguide transmission, to avoid excessive radiation. They are reflected by metal objects, absorbed by some dielectric materials, and transmitted without significant absorption by other dielectric materials. For example, water, carbon and foods with high water content are good microwave absorbers; glass, ceramics And most thermoplastic materials allow microwaves to pass through with little or no absorption. This is the mechanism by which the water-based ink is dried.

Marios [16] compared several drying methods common to water-based inks, hot air drying, the IR drying, microwave drying rate and energy consumption, finishing the results shown in Table 1. This experiment proves that microwave drying has obvious advantages over both in terms of drying rate and energy consumption.

Table 1. Comparison of drying time and energy consumption of different methods of drying aqueous inks: extend it slightly outside the width of the table. Justify the text. Leave 6 pt of space between the caption and the top of the table.

| Ink type          | Solvent | Drying method | Drying time | Energy consumption(kWh) |
|-------------------|---------|---------------|-------------|-------------------------|
| Water-based inks  | water   | IR drying     | 30sec       | 0.0083                  |
|                   |         | Hot air drying| 60sec       | 0.0238                  |
|                   |         | Microwave drying | 20sec   | 0.0067                  |

Jaiswar [17] designed a novel microwave absorbing device that can evenly distribute the microwave field strength during the drying process of the aqueous ink and greatly increase the drying speed. The experimental results show that in the 5-50 GHz frequency range, the reflection coefficient bandwidth is less than 15 dB at a bandwidth of 31 GHz on a flexible PC board of 5 mm, that is, the drying effect is best at this time.

Norte [18] designed a new dry structure to speed up the drying speed in order to solve the problem that the time of microwave drying water-based ink is too short to match the high drying speed. Experiments have shown that, depending on its microwave field strength and dry length, the device can dry paper as wide as 60 cm.

KUST [19] has developed a set of microwave drying equipment that can be used in industrial applications. The device can be used for fast drying aqueous inks as well as water based coatings. The study shows that the microwave drying technology can achieve the same speed as the drying instruments commonly used on the market in the case of drying the aqueous ink. At the same time,
according to the study by Marios, the energy consumption of microwave drying is much smaller than that of hot air drying.

Trembley [20] proposed the possibility of applying an electromagnetic field to dry aqueous inks. A stable electromagnetic field can produce a dielectric thermal effect. The experimental results show that the electromagnetic field heating can effectively dry the aqueous ink in the case of the gravure printing machine motor 1500r/min. Although this speed is too slow, it can be combined with high-speed hot air drying, infrared drying, and other conventional drying methods to increase the drying speed.

Giles [21] modified the drying facility of the gravure press to address VOC emissions during the printing process. Giles used a paper length of 80 mm and a width of 40 mm to study the relationship between drying time and drying efficiency under constant microwave field strength. The research results show that in the gravure printing machine, the printing speed reaches 60m/s, the energy consumption is 2kw, and the drying time is only 0.0038 seconds, without affecting the printing quality. The study also showed that microwave drying does not cause damage to the non-printing area of the paper.

5. Other drying method
Wei [22] uses a chemical agent to assist the aqueous ink drying process, and develops a temperature-controlled microcapsule desiccant that releases calcium oxide which reacts with water and generates heat when heated in a drying oven of a gravure printing machine, thereby promoting ink drying. The experimental results show that, for the conventional gravure printing machine, the aqueous ink containing no desiccant does not have a good printing effect at a printing speed exceeding 60 m/min, and is not suitable for industrial production, and the aqueous ink to which the desiccant is added exceeds In the case of a printing speed of 80 m/min, a good printing effect is maintained.

The core process of water-based ink drying is that water evaporates from the surface of the ink film. The main factors affecting the drying speed of the aqueous ink are the surface tension of water and the heat of evaporation. Zhang [23] improves the release of water by adjusting the tension of the surface of the system. Increasing the contact area between the ink film and the substrate to achieve the purpose of increasing the drying speed. The results show that the surfactant has a great influence on the drying speed of the aqueous ink. The proper addition of dispersant and wetting agent can promote the drying speed; the addition of the inappropriate amount not only reduces the drying speed, but also the water-based ink. Other properties such as viscosity, fineness, and adhesion fastness have an adverse effect.

In the process of printing on paper, the water-based ink has uneven density, and there are gaps of millimeters to millimeters. The ink drying speed is studied, and these gaps are not negligible. Swerin [24] also studied the effect of surfactants on the drying speed of aqueous inks. The researchers studied several aqueous inks and desiccants commonly found on the market and explored the reaction of cationic fixatives and polyvinyl alcohol binders with pure water binders in inks. The results show that the reaction between cations and polar molecules can increase the drying speed of aqueous inks, but the amount must be appropriate, otherwise the drying speed will decrease, and the adhesion fastness will be greatly reduced.

6. Conclusion
The microwave system effectively and quickly and efficiently dries the water-based inks on the paper. It also compares the environmental benefits of using a microwave-assisted drying system compared to a conventional drying system. The environmentally friendly effect is significant because the microwave drying system offers the possibility of using water-based inks instead of solvent-based inks.

Drying using microwaves can provide significant energy and cost efficiencies, and the quality of rapid offset printing will also increase while using a microwave system for paper drying between prints.

At the same time, the industrialization of microwave equipment and the production restrictions of
water-based inks have been solved, which provide a powerful birth condition for microwave drying aqueous ink systems.

Acknowledgments
Here, I would like to thank my teacher, Professor Li Jinyao, for his selfless guidance, and also to Professor Cai Jifei and Zhang Mingming for answering my questions. Thanks to the fund support from the project Collaborative Innovation Center - Green Printing and Packaging Security (04190118003/001) and the project Beijing Municipal Education Commission - UV-LED array ink curing light source system key technology research (04190118002/019) and Beijing Municipal Education Commission General Project(KM20161005009).

References
[1] WANG Xiaofang, LI Zhao, SUN Jianming. Analysis of the current status and application of environmentally friendly water-based inks [J]. Science Technology and Engineering, 2017(15):172-180.
[2] Xin Xiulan , Wei Yana. Research Progress in Water-based Inks [J]. China Printing and Packaging Research, 2011, 03(3):1-8.
[3] Lai Ho. The aqueous ink and the development status analysis [J]. Paper and Paper, 2017 (5).
[4] Sun vibrator, Weixian Fu, Huangbei Qing, et al. Drying factors aqueous plastic gravure ink [J] Effects Packaging Engineering, 2010 (17): 118-120.
[5] Selim MS, Yesavage VF, Chebbi R, et al. Drying of Water-Based Inks on Plain Paper [J]. Journal of Imaging Science & Technology, 1997, 41(41): 152-158.
[6] Seaton, Wayne. Improved line and process graphics [J]. International Paper Board Industry, 2000 , 43 (9).
[7] Shi Xiangdong, Cheng. Now often physical drying process and mechanism of a printing ink [J]. Packaging engineering, 2004, 25 (2).
[8] Imakoma, Hironobu; Takenaka, Kei; Kawano, et al. Measurement of infrared drying rate of coating by an extended temperature-change method [J]. Kagaku Kogaku Ronbunshu, 2014, 40 (1).
[9] Numata M, Sakamoto A, Ogasawara Y, et al. Drying Technology Using Laser Exposure for High-speed Inkjet Printing[C]// NIP & Digital Fabrication Conference. 2013.
[10] Maza J G. HP Designjet L65500 Drying and Curing Systems[C]// Nip & Digital Fabrication Conference. 2012.
[11] Imakoma H, Nagaoka S, Takigawa T. Measurement of drying rate of water-based coat by temperature change method [J]. Kagaku Kogaku Ronbunshu, 2007, 33(6): 586-592.
[12] Cao Yue, Wang Anita. Analysis of MATLAB-based gravure hot air drying parameters [J] Packaging Engineering, 2008, 29 (6): 69-70.
[13] Jia Chunjiang, Chan school, Li Xiao-week. Study based ink and hot air drying mechanism mathematical model [J] China Printing and Packaging Study, 2011 (3): 47-50.
[14] Plavnik, Gene. Drying at the speed of sound [J]. Coating International, 2012,45(2).
[15] Nowaczek E J. The Application of Air-Blowing Ultrasonics in Drying of Water-based Inks on Films and Foils[J]. American inkmaker, 1997, 75(9).
[16] Marios T, Eugenia P, Anastasios P, et al. Using microwave drying systems in the Graphic Arts. Modern solutions for environmental industrial applications [J].
[17] Jaiswar R, Mederos-Henry F, Dupont V, et al. A thin ultra-wideband microwave absorbing structure printed on flexible substrate with resistive-ink made of multiwall carbon-nanotube[C]//2017 11th International Congress on Engineered Materials Platforms for Novel Wave Phenomena (Metamaterials). IEEE, 2017: 160-162.
[18] Norte D. Human Exposure Design Considerations For Machine Directed Microwave Dryers For Drying Ink On Paper Webs For The Inkjet Printing Industry [C]//2018 IEEE Symposium on Electromagnetic Compatibility, Signal Integrity and Power Integrity (EMC, SI & PI). IEEE ,
2018: 193-198.

[19] Shaohua J , Singh P , Jinhui P , et al. Recent developments in the application of microwave energy in process metallurgy at KUST [J]. Mineral Processing and Extractive Metallurgy Review, 2017:1-10.

[20] Trembley J F, LORING C M. Drying printing inks and coatings by radio frequency heating [J]. Tappi, 1969, 52(10): 1847-&.

[21] Saad A A E R E. Environmental pollution reduction by using VOC-free water-based gravure inks and drying them with a new drying system based on dielectric heating[D]. Universität Wuppertal, Fakultät für Elektrotechnik, Informationstechnik und Medientechnik» Medientechnik» Dissertationen, 2008.

[22] Xu Yingjie, Zhang Fuzhong, Wei Xianfu, et al. Study on the efficacy of temperature-controlled microcapsule desiccant for water-based gravure inks[J]. Journal of Beijing Institute of Graphic Communication, 2013(6): 31-33.

[23] Zhang Song, Yang Xijiang, Yang Wei. Effect of Surfactants on Drying Rate of Water-based Inks[J]. Liaoning Chemical Industry, 2010, 39(3): 245-247.

[24] Swerin A, König A, Brandner B, et al. The use of silica pigments in coated media for inkjet printing: Effects of absorption and porosity on printing performance and depth-profiling using confocal Raman spectroscopy[C]//TAPPI Advanced coating fundamentals symposium proceedings. 2008: 178-203.