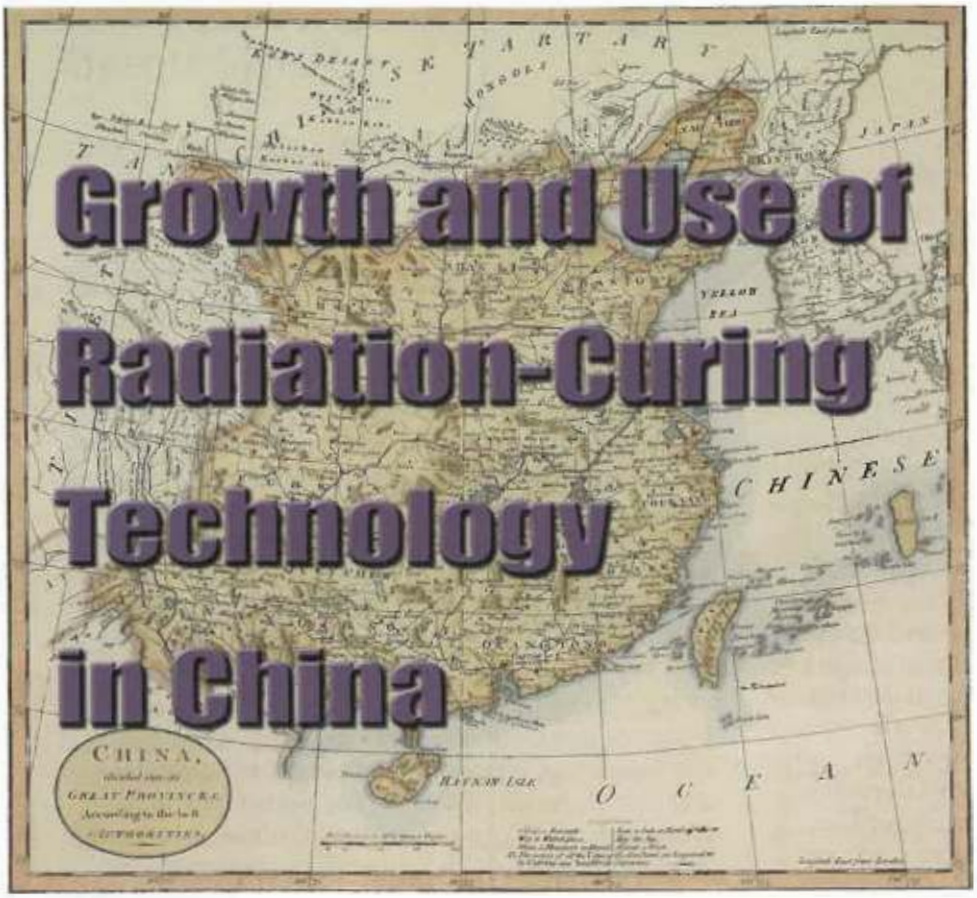

Growth and Use of Radiation-Curing Technology in China

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The markets related to radiation-curing technology in China have expanded and grown along with the development of China's economy in recent years. This article summarizes the input of 109 leading companies, including 37 that produce raw materials, 75 that manufacture UV products, and 12 that supply UV lamps and equipment (some of them supply multiple products). The growth rates of raw materials and UV-curable products were 11.8% and 27.4%, respectively, with the total growth rate of 17.3% in 2004. The production value of raw materials, radiation curable products, and UV lamps and equipment in China increased with the growth rates of 26.3%, 13.4%, and 42%, respectively, and the total growth rate of 19.3% in 2004. Some remarkable progress has also been achieved in basic and application research. Market trends, growth rate of each major segment, and technological developments are reviewed.

INTRODUCTION

Increasing environmental concerns and ongoing legislation to cut the emissions of volatile organic compounds (VOCs) have been the major driving forces behind the development of radiation-curing coatings over the past 30 years. Radiation curing, including ultraviolet (UV) and electron beam (EB) curing technology, is now being increasingly used in various sectors of applications because it is a clean and green technology that increases productivity as compared with other traditional curing methods. This technology is now commonly utilized to perform the ultra fast drying of protective coatings, varnishes, printing inks, and adhesives, and to produce the high definition images required in the manufacture of microcircuits and printing plates. In addition to its great speed and spatial resolution, radiation curing presents a number of other advantages, in particular ambient temperature operation, solvent-free formulations, low energy consumption, and the production of polymer materials with tailor-made properties.

Despite some contradictions and problems, the Chinese economy has been maintaining rapid and sustainable development in recent years. While the economies in much of the world struggled, China's gross domestic product (GDP) totaled 13.65 trillion yuan (1.65 trillion U.S. dollars) in 2004, a jump of 9.5% from the previous year. Quite definitely, the country with the most growth last year and also forecasted for the next five to eight years is China. In this economic environment, the markets for radiation curing in China have been greatly expanded. The strongest growth in radiation curing currently is UV curing technology. Limited by

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accelerators, the development of EB application is still slow. However, as the price of low energy accelerators further decreases, this technology will be very promising in the future markets in China.

As a developing country, China still has a small market of radiation-curable products compared with North America, Europe, and Japan. However, profound changes have taken place in China's markets as reform deepens and China opens wider to the outside world. The introduction of advanced radiation-curing technology from abroad is promoting the market growth of domestic radiation-curing industries through the developments of telecommunications, fiber optics, mobile phones, computers, graphic arts, packaging, household electronic appliances, architectural materials, and so on.

The nationwide association for the Chinese radiation curing community—RadTech China (founded in 1993)—is playing a key role in information exchange and business among its members and Chinese experts, and their counterparts in other parts of the world. It has been making great efforts to develop and to raise the awareness level of RadTech in China, and to organize training programs, and a domestic conference each year. RadTech China is an important member of the RadTech Asia Organization. The secretariat of RadTech Asia Organization was moved to China in 2003.

This article provides a short overview of approximately 109 leading companies, including 37 that produce raw materials, 75 that manufacture UV products, and 12 that supply UV lamps and equipment (some of them supply multiple products). Moreover, the applications of UV products in Chinese industries and the outlook of Chinese market trends and technological developments collected by RadTech China during 2004 are discussed.

GENERAL TRENDS OF UV-CURING MARKETS

Growth in the radiation-curing market is not a simple issue. There are trends away from some chemical types of resins, photoinitiators, and additives, and trends towards others. Likewise, some end-use applications are currently more successful than others. Subsequent growth in these applications stems in some cases from increasing penetration of UV technology, and in others from a buoyant overall market for coated products. For the purpose of market understanding, the industry can be segmented by application areas.

Table 1—Industrial Applications for UV Products

Furniture Construction	*Electronics and Telecom*	*Printing and Packaing*	*Automotive*	*Consumer Goods*
Wood	PCB assembly	Inks	Head lamps	Plastic casings (TV, mobile phone)
PVC flooring	PCB protective coatings	OPV	Clearcoats (interior and exterior)	
Foils	Optics fibers	Release coatings	Printed dashboard components	Skis and equipment
MDF	CD clearcoats			Spectacle lenses
				Mirror coatings

Currently, the largest application area for UV coatings, in terms of volume, is furniture and construction, where these products are used mainly on wooden furniture, and also on various resilient flooring surfaces. This is closely followed by printing and packaging industries, including inks and clear overprint varnishes (OPV). *Table* 1 lists the typical applications for UV products in each of the major industries.

MARKET GROWTH OF RADIATION-CURING PRODUCTS

In the past 10 years, the market growth of radiation curing has been rapid and a wide variety of influences will further drive the growth in China, including the country's entrance into the World Trade Organization (WTO), greater liberalization of its media, and distribution and competition among industries.

It is reasonable for the high market growth to meet the demands and requirements of the rapid Chinese economic development and for production, along with consumption, to start from a lower volume basis. However, in the last three years the upgrading of domestic various outputs and the quality and values of radiation-curing products have become even more significant in comparison with the past. Moreover, their applications have also expanded to some new fields. During this period, there has been an increasing number of domestic companies dealing with radiation cur-

Figure 1—Market share of different corporations working in UV curing in 2003 and 2004.

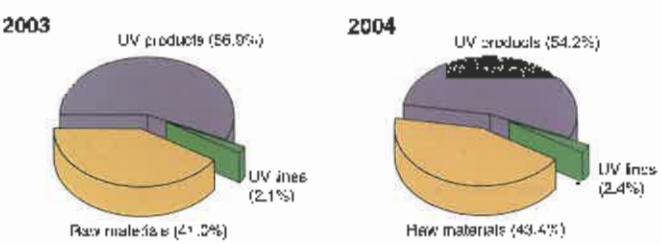
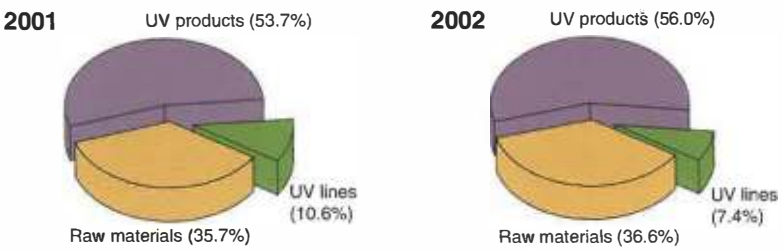


Figure 2—Market share of different corporations working in UV curing in 2001 and 2002.



ing. According to the study of the 109 leading companies mentioned earlier, the developing positions of different companies with respect to their products in 2003 and 2004 are shown in *Figure* 1, compared with those in 2001 and 2002, as shown in *Figure* 2.

Coatings and inks remain the largest application areas for UV-curable materials in China. In the past years, although a portion of radiation-curable products were imported, the numbers of products produced by Chinese manufacturers have expanded rapidly. The total outputs of radiation-curable coatings and inks were 23,300 tons and 9,056 tons, respectively, in 2004, while in 2003 they were 19,007 tons and 6,514 tons, respectively. As a result, the growth in production value was 34.5% for coatings and 34.3% for inks.

RAW MATERIALS

During the period from 2003–04, the world chemical industry was once again greatly impacted by a combination of factors including core material and energy price surges, and some non-market factors. The growth rate of raw materials was slowed due to the geopolitical uncertainty and rocketing oil prices. The production value of monomers increased from 2003 to 2004 with a growth rate of 19.6%, which is listed in *Table* 2. However, the output decreased from 24,739 tons to 24,350 tons with a negative growth of 1.6%. Some human error in 2003 statistics was found to cause the decrease. Deducting from the 2003 statistics the output of a Taiwan factory, which was not included in 2004's data, the actual output should have had a slight increase in 2004. The production of the second-generation alkoxy acrylates had considerable growth. The output of EO-TMPTA and PO-NPGDA reached 600 tons and 465 tons, respectively. The volume of total exports of raw materials was 6,162 tons, earning $22.27 million U.S.

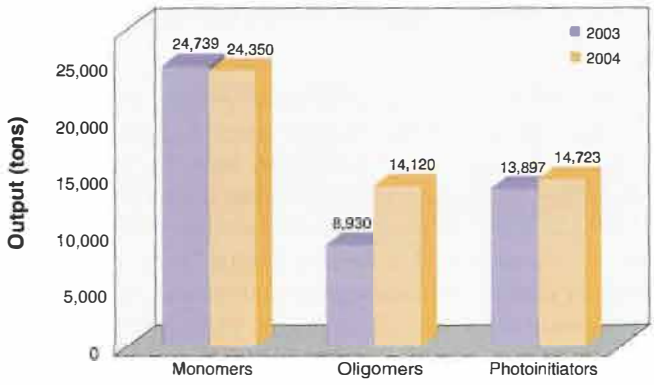
Oligomers are another important raw material for UV curing. Although most oligomers were formerly imported, their production in China has increased rapidly in recent years. In 2004, the output of oligomers was 14,120 tons with a growth of 58.1% compared to 2003, which registered 8,930 tons. The production value increased to $27.51 million U.S. with a growth rate of 43.3%. Now, not only are the common kinds of oligomers, such as epoxy acrylates, modified epoxy acrylates, aromatic urethane acrylates, and aliphatic urethane acrylates, but also polyester acrylates, amide acrylates and alkaline-developable acrylates are being manufactured in large scale by Chinese companies. In fact, the variety and amount of oligomers have become more abundant and they have now started to be exported to other countries.

Table 2—Output and Production Values for UV-Curing in 2003 and 2004

Products	Corporations 2003	Corporations 2004		Output (Tons Per Year) 2003	Output (Tons Per Year) 2004	Output (Tons Per Year) Growth (%)	Production Value (in Million U.S.$) 2003	Production Value (in Million U.S.$) 2004	Production Value (in Million U.S.$) Growth (%)
Raw materials	13	14	Monomers	24,739[b]	24,350	-1.6	69.40	83.01	19.6
	18	25	Oligomers	8,930	14,120	58.1	19.19	27.51	43.3
	18	18	Photoinitiators	13,897	14,723	5.9	77.65	99.44	28.1
UV products	39	44	Coatings	19,007	23,300	22.6	79.36	106.75	34.5
	32	35	Inks	6,514	9,056	39.0	53.36	71.67	34.3
	3	4	Print plates	2,239 x 10^4 (m^2)	2,436 x 10^4 (m^2)	8.8	97.21	80.49	-17.2
	9	10	Adhesives	76	242	218.4	0.823	2.831	243.8
UV lines	5	5	Lamps	38.4 x 10^4	29.3 x 10^4	-23.7	3.99	3.45	-13.6
	12	10	Equipment	1,489	1,410	-5.3	4.21	8.20[c]	94.7
			Raw materials	47,566	53,193	11.8	166.24	209.96	26.3
Total	95[a]	109[a]	UV products	25,597	32,598	27.4	230.75	261.74	13.4
			UV lines	—	—	—	8.20	11.65	42.0
			Total	**73,163**	**85,791**	—	**405.9**	**483.35**	**19.3**

(a) Some corporations supply multiple products.
(b) Including the output of a Taiwan factory.
(c) Including the production value of 43 UV coating lines.

Figure 3—Output of different raw materials in 2003 and 2004.



Photoinitiator is a key product for UV curing, having the fastest growth rate in the last three years in China's market. The domestic routine photoinitiators not only meet the need of the market, but are also exported to foreign markets including the United States, Europe, and other regions. The output of photoinitiators in China increased from 13,897 tons in 2003 to 14,723 tons in 2004. Among them, the outputs of benzophenone and photoiniator 1173 both exceeded 3,000 tons. Cationic photoinitiators and visible photoinitiators were also manufactured in certain scale. Moreover, the production value increased from $77.65 million U.S. in 2003 to $99.44 million U.S. in 2004 with a growth of 28.1%. The products exported to foreign markets increased from 7,450 tons in 2003 to 11,299 tons in 2004, earning $77.37 million U.S. with a growth of 48.8%. *Figure* 4 shows the market shares of different raw materials used in UV curing industries.

UV FORMULATIONS

There are a very large number of end-uses for radiation-curable industrial products in China. The data listed in *Table* 2 attempts to segment and evaluate the status of the output, growth, and production values of this diverse market. The major markets of UV-curable coatings are wood/bamboo, flooring coatings, and PVC coatings. Overprint varnish (OPV) for paper is another important market. *Figure* 5 shows that there are still numerous areas where radiation-curable systems have barely penetrated, such as automotive coatings, anticorrosive coatings, metal coatings, and electronic appliances.

The output of UV coatings was 23,300 tons in 2004, with a growth rate of 22.6%. The production values increased from $79.36 million U.S. in 2003 to $106.75 million U.S. in 2004 with a growth of 34.5%. Industrial wood/bamboo coatings still represent the largest share of end-uses. Other segments like plastic coatings and high-grade coatings for mobile phone and optical disk also seem to inject a high level of stimulation into the market.

China is the sixth largest manufacturer of inks and represents 6% capacity of production in the world. The fastest growing ink areas in China are jet inks, as well as the whole gamut of offset printing inks from simple news inks to high gloss inks, or coldset web offset inks. The total output of 35 UV ink manufacturers was 9,056 tons in 2004 with a growth of 39.0%, compared to 6,514 tons from 32 manufacturers in 2003. The production value increased to $71.67 million U.S. with a growth of 34.3%, as listed in *Table* 2. The outputs of offset, gravure, flexographic, screen inks and so on are shown in *Figure* 6. Excitement also comes from coloring inks for optical fibers, which are produced in China for the first time.

The Chinese are also emphasizing the development of top grade and fine package printing products, increasing the additional value of products, and meeting the needs of some domestic markets and exports. To do so, Chinese officials stress that the printing industry must consolidate and develop existing offset printing ability; increase gravure printing, screen printing, ink jet printing, and curve surface printing; develop flexo printing; and improve post-press integration and technology.

The output for radiation-curable adhesives was 242 tons in 2004 by 10 corporations compared with 76 tons in 2003 by nine corporations. The production value increased to $2.83 million U.S., a growth of 2.4 times that of 2003. Besides the adhesives used in medicine, glass, craftwork, packing, and fishing equipment, those used in LCD, DVD, instruments and optics also have been produced and represent a nice start as an alternative to imports. The development of radiation-curable adhesives is quite recent in comparison with industrial coatings and graphic arts. In addition to environmental reasons, other factors such as unique cure properties and the mushrooming development of the automotive and DVD industry are strongly influencing the growth rate of radiation-curable adhesives.

UV LAMPS AND EQUIPMENT

The production of equipment related to UV curing saw a slowdown in its growth in 2004. While 293,000

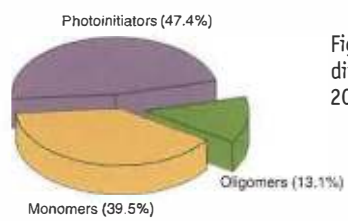
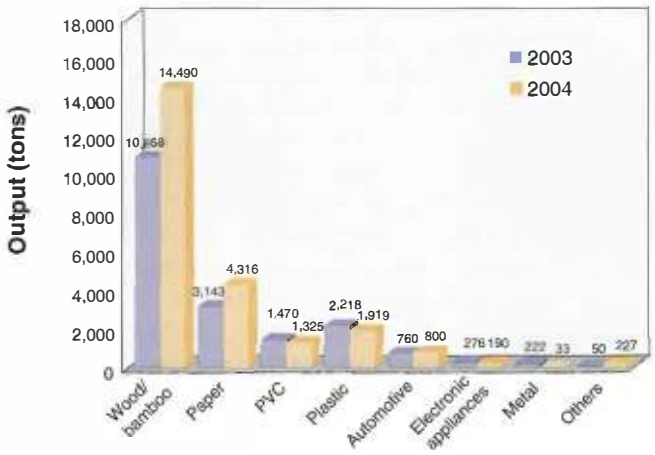


Figure 4—Market share of different raw materials in 2004.

Figure 5—Output of UV coatings (tons) in 2003 and 2004.



UV lamps were manufactured in 2004, this is a decrease of 91,000 from 2003 levels. In 2004, 1,410 sets of UV curing equipment were produced, representing a decrease of 79. However, the total production value was $8.20 million U.S. with a remarkable growth rate of 94.7% due to the enhanced production of 43 coating lines. And, for the first time, one UV curing line was exported.

It is recognized that EB curing has great advantages in comparison with UV curing for formulating materials without using photoinitiators. However, EB-curing technology has not been widely accepted in China. Although EB accelerators are normally used in radiation processing heat shrinkage materials and crosslinked cables and wires, there are very few EB facilities for radiation curing on an industrialized scale due to the expensive cost.

DEVELOPMENT OF CORPORATIONS INVOLVED IN RADIATION-CURING TECHNOLOGIES

There are definite opportunities for many companies to flourish in the radiation-cure market. Although double-digit growth rates are no longer the norm, the radiation-cure market continues to seek positive growth rates. According to a recent survey of 109 main corporations, there are a total of 6,648 employees working on UV curing, among them 1,225 (18.9%) are technicians. ISO 9001 or ISO 9002 has certified 59 corporations among all those currently operating. The output of more than 10 corporations exceeded 2,000 tons and the largest one exceeded 10,000. There are eight corporations whose production value has exceeded $10 million U.S., two more than in 2003. The details are listed in *Table* 3. *Figure* 9 offers a classification of these corporations by region.

The imbalance between different geographical areas has been rising with the development of industrial scale. Among the 109 corporations, only five of them are located in western China, sharing a small fraction (1.5%) of the total production values. Raw materials are mainly produced in eastern China. Thirty corporations in southern China represent the majority (71.0%) of the total output of UV products, while eight of the 12 equipment manufacturers operate in northern China. The Chinese market has established a fair environment to enable enterprises of all kinds of ownership, including private companies, joint ventures, and state-owned companies dealing with radiation curing to compete on an equal footing. In addition, some foreign companies, such as Fusion, Sartomer, Ciba, Cytec, DSM, ChemFirst, BYK, BASF, Tego, Bayer, and so on, have established offices or conducted business in China, contributing to the development of the Chinese radiation-curing markets. Implementation of the ambitious western development campaign will also provide new business opportunities for radiation-curing technology. In fact, the Chinese government is supporting the country's strategy of opening up the western region with preferential policies, including an increase of funds for infrastructure construction, environmental protection, and incentives for overseas investment.

RECENT RESEARCH PROGRESS IN CHINA

Great attention has recently been paid to the research and development of radiation-curing technology in China, and some remarkable progress has been achieved. The following is a review of research conducted by Chinese scientists.

Figure 6—Output of UV inks (tons) in 2003 and 2004.

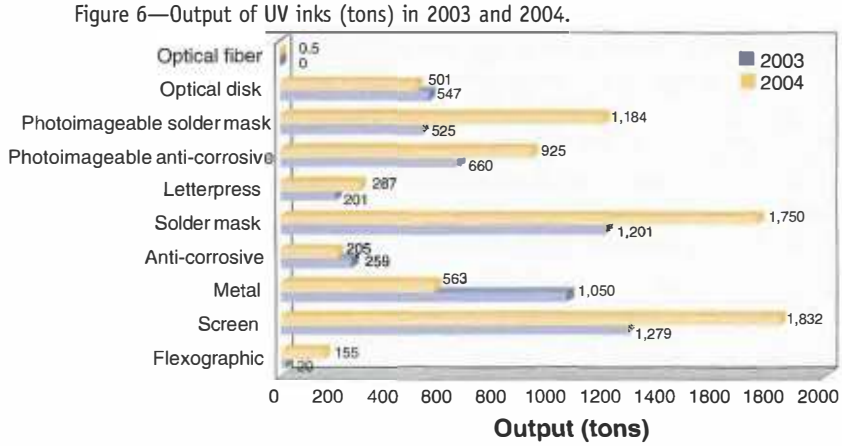


Table 3—Classification of Corporations by Output and Production Value in 2004

Products	Corporation	ISO Certified	Patents	Output (10^3 tons/years) <0.5	0.5–1.0	1.0–2.0	2.0–5.0	>5.0	Production Value (in Million U.S.$) <1.0	1.0–5.0	5.0–10.0	10.0	>20.0
Raw Materials	31	18	9	12	6	7	4	2	4	15	7	3	2
UV Products	71	39	30	48	13	4	4		34	29	5	2	1
Equipment	7	2	2						3	4			
Total	**109**	**59**	**41**	**60**	**19**	**11**	**8**	**2**	**41**	**48**	**12**	**5**	**3**

Hyperbranched Oligomers

Several UV-curable hyperbranched oligomers have been prepared by Shi et al.[1] A series of hyperbranched polyurethane acrylates containing phosphorus were prepared. The oligomers obtained were found to polymerize rapidly under UV irradiation. Its cured films were flame retardant with a limiting oxygen index of 27.0. A novel UV curable waterborne hyperbranched polyester (WBHP) was also synthesized in Shi's laboratory.[2] The WBHP, endcapped with methacrylic groups and salt-like structure, could polymerize rapidly under UV irradiation. Water showed a favorable viscosity reduction effect in the formulations containing WBHP. A natural good control over the solubility of the formulations was possible by salt-like functionality and raising the temperature.

Hong et al.[3] prepared a hyperbranched polyol with flexible chains used for cationic UV-curing system as a chain transfer agent. This oligomer improved the cure rate of the resin and the mechanical properties of the cured product.

Macromolecular Photoinitiators

Han et al.[4], from Insight High Technology Co., Ltd. (IHT) in Beijing, had promoted two novel macromolecular photoinitiators, Omnipol TX and Omnipol BP. These two photoinitiators were found to have similar initiation reactivity as BP and ITX, but much lower odor after curing. Moreover, lower migration and better compatibility with monomers were observed according to their investigation.

UV-Curable Powder Coatings

A series of urethane-based crystalline monomers, which are promising for use in UV-curable powder coatings, have been synthesized by Zeng et al.[5] Modified by some hydroxyl-containing compounds, the melting point of aliphatic urethane divinyl ether crystalline monomer can be decreased to around 75–90°C, which is suitable for UV-curable powder

Figure 7—Market share of different UV products in 2004.

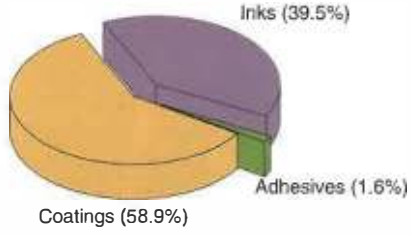


Figure 8—Major contributing outputs showing the development of UV curing in China in the past three years.

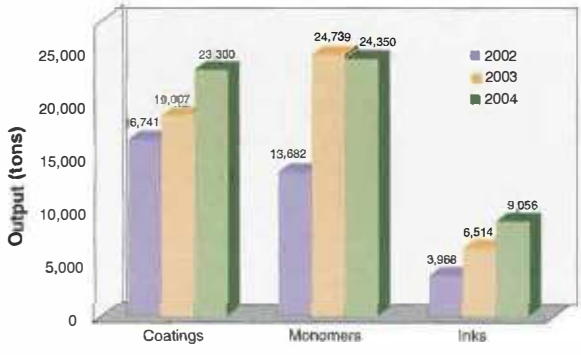
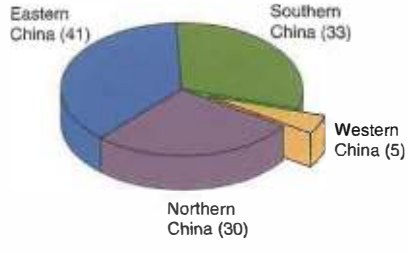


Figure 9—Distribution of corporations related to radiation-curing technology by regions.



coatings. It was also found that the crystalline monomers polymerized rapidly under UV irradiation.

Wei et al.[6] have conducted research focusing on the improvement of performance of UV-curable powder coatings. Based on their study of six kinds of nanoparticles, it was found that nano-SiO_2-$CaCO_3$ had optimal effect on the modification of UV-curable powder coatings, while an anti-abrasive coating could be obtained by the addition of nano-Al_2O_3 particulates.

Electron Beam Curing Systems

Zhang et al.[7] have described their investigations on the EB-curing process of epoxy resin systems. They found that the addition of a small amount of nano-SiO_2 particles and the increasing of radiation dose could enhance curing degree, glass transition temperature, and the high temperature modulus of EB-cured epoxy resin systems. They also studied the EB-curing mechanism of nano-SiO_2/bisphenol-A epoxy resin system.

Sui et al.[8] have applied a BF-5 EB accelerator at the Beijing Radiation Center to study the effect of iodonium salt initiator on the EB-curing of epoxy resin. According to their research, optimal concentration of the initiator should be around 3 wt% at a high dose of radiation.

MARKET POTENTIALS AND FUTURE PERSPECTIVES

China is a developing country with one fifth of the world's population and vast territories. This fact alone reveals the potentials and opportunities for radiation-curing technology. The economic impact on the world economy of China, with its growth of over 9% annually for more than two decades, has been rising. With its external sector expanding more vigorously than that of the rest of the world by a wide margin, China is integrating into the global economy rapidly and ubiquitously. China's international economic linkages are becoming more diversified. The sustaining development of China's economy is accompanied with urgent requirements for high and new technologies, including radiation-curing technology. Moreover, Beijing has been selected as the Host City of the 2008 Summer Olympic Games. This event means a number of key projects related to the Games will be starting before long. The paint and coatings industry appears to be a major beneficiary of this event, which can possibly bring a promising application field for radiation-curing technology.

CONCLUSIONS

As can be seen, there are still many opportunities for growth in radiation-curing. Despite the tendency towards banality in many of the traditional markets, there now appears to be a new surge of enthusiasm for radiation-curing technology in many more diverse and technically demanding applications. High growth will continue through evolution in well-established areas (wood coatings, screen and offset inks, etc.), addressing technological shortcomings by developing new technologies and new raw materials (UV-curable waterborne, UV-curable powder), and by entering new application fields (composite and gel coats, automotive OEM, and refinish coatings, etc.).

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