中国新能源和可再生能源

THE DEVELOPMENT OF NEW AND RENEWABLE SOURCES OF ENERGY IN CHINA

中国太阳能学会　编

Edited by CHINESE SOLAR ENERGY SOCIETY

中国科学技术出版社
CHINA SCIENCE & TECHNOLOGY PRESS

目 录

序　言 …………………………………………………………………………… 黄毅诚(1)
中国新能源和可再生能源发展现状及政策 ………………………………… 胡成春(3)
中国太阳热水器的研究与发展 ……………………………………………… 陆维德(8)
中国太阳能干燥的发展现状 ………………………………………………… 李宗楠(12)
中国被动式太阳房的现状及发展前景 ………………………… 王安华　齐国清(20)
中国太阳灶的研制与评价 …………………………………………………… 屠云璋(24)
中国光伏技术的现状及前景 ………………………………………………… 李文滋(28)
中国光伏技术的应用 ………………………………………………………… 王斯成(36)
中国太阳能光化学转换的现状与展望 ………………………… 孙璧媃　肖绪瑞(43)
中国风能的利用现状与发展 ……………………………………… 贺德馨　施鹏飞(52)
中国风力机械制造工业的发展及展望 ………………………… 沈超英　李德孚(59)
中国的风力提水 ………………………………………… 沈德昌　魏建明　施鹏飞(64)
内蒙古风能的开发利用 ……………………………………………………… 李昌善(70)
中国生物质能的发展现状与展望 …………………………………………… 佟树声(73)
中国生物质气化技术的现状与发展 ………………………………………… 高先声(78)
中国薪炭林的建设与薪材利用 ……………………………………………… 郭怀让(83)
中国海洋能资源的开发现状及发展趋势 ……………………… 金鼎华　刘心安(87)
中国地热资源的开发重点 …………………………………………………… 张振国(91)
中国地热资源及其开发利用 ……………………………………… 任　湘　唐宁华(95)
西藏地热资源的开发与利用 ……………………………………… 吴方之　刘时彬(101)
中国小水电的开发利用 ……………………………………………………… 朱效章(106)
中国氢能系统的研究与发展 ……………………………………… 朱亚杰　鲍德佑(113)

彩　图
通讯录 ………………………………………………………………………………… (119)
编后语 ………………………………………………………………………………… (166)

CONTENTS

PREFACE .... Huang Yicheng(2)
PRESENT STATUS AND POLICY ON THE DEVELOPMENT OF NEW AND RENEWABLE SOURCES OF ENERGY IN CHINA .... Hu Chengchun(5)
SOLAR WATER HEATING IN CHINA .... Lu Weide(10)
THE DEVELOPMENT STATUS OF SOLAR DRYING IN CHINA .... Li Zongnan(16)
PRESENT STATUS ON PASSIVE SOLAR HOUSE DEVELOPMENT IN CHINA .... Wang Anhua Qi Guoqin(22)
ASSESSMENT ON THE DEVELOPMENT OF SOLAR COOKERS IN CHINA .... Tu Yunzhang(26)
REVIEW ON THE ADVANCES IN SOLAR PHOTOVOLTAICS IN CHINA ...... Li Wenzi(32)
PHOTOVOLTAIC APPLICATIONS IN CHINA .... Wang Sicheng(39)
PHOTOCHEMICAL CONVERSION OF SOLAR ENERGY .... Sun Birou Xiao Xurui(47)
PRESENT STATUS AND THE DEVELOPMENT OF WIND ENERGY UTILIZATION IN CHINA .... He Dexin Shi Pengfei(55)
THE DEVELOPMENT AND PROSPECT OF WIND MACHINERY INDUSTRY IN CHINA .... Shen Chaoying Li Defu(61)
WIND PUMPS IN CHINA .... Shen Dechang Wei Jianming Shi Pengfei(67)
WIND ENERGY DEVELOPMENT AND UTILIZATION IN INNER MONGOLIA .... Li Changshan(71)
PRESENT STATUS AND FUTURE PROSPECT ON THE DEVELOPMENT OF BIOMASS ENERGY IN CHINA .... Tong Shusheng(75)
THE STATUS AND DEVELOPMENT OF BIOMASS GASIFICATION TECHNOLOGY IN CHINA .... Gao Xiansheng(81)
THE DEVELOPMENT OF FUELWOOD FOREST IN CHINA .... Guo Huairang(85)
THE OCEAN ENERGY DEVELOPMENT IN CHINA .... Jing Dinghua Liu Xinan(89)
DEVELOPMENT PRIORITY IN GEOTHERMAL RESOURCES EXPLOITATION AND UTILIZATION IN CHINA .... Zhang Zhenguo(93)
GEOTHERMAL RESOURCE AND ITS UTILIZATION IN CHINA .... Ren Xiang Tang Ninghua(98)
DEVELOPMENT AND UTILIZATION OF GEOTHERMAL RESOURCES IN TIBET .... Wu Fangzhi Liu Shibin(103)
DEVELOPMENT AND APPLICATION OF SMALL HYDROPOWER IN CHINA .... Zhu Xiaozhang(109)
HYDROGEN ENERGY SYSTEM IN CHINA——RESEARCH AND DEVELOPMENT .... Zhu Yajie Bao Deyou(115)

序　言

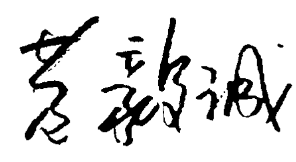
人类社会的发展，面临着各种各样的挑战。随着人类对能源需求的日益增长，地球上的常规能源(碳氢化合物资源)被大量消耗，同时加剧了世界环境的污染。为了应付可能出现的全球性能源匮乏和保护、改善自然环境，研究、开发和利用新能源，发展能源利用技术，已经成为重要的课题摆到了科技工作者的面前。

中华人民共和国成立以来，我们在工业基础极为薄弱的情况下，建立起了独立自主的能源工业，为社会主义经济建设提供了大量的煤炭、石油和电力。但是，随着国民经济的高速发展，我国能源的供需矛盾日益突出，已经成为国民经济的薄弱环节。十一届三中全会给我国广大农村带来了巨大的变革。农业生产投入的增加，乡镇企业的迅猛发展，农民生活水平的不断提高，使得农村能源的需求也急剧增加。新能源的研究、开发和利用，为逐步减少对常规能源的依赖，为缓解农村用能，特别是解决偏远地区的用能以及保证经济的发展提供了可能。

近代新技术和新材料的不断发展，为利用太阳能、风能、生物质能、海洋能和地热能等这些蕴藏丰富的自然资源，开辟了广阔的前景。70年代以来，我国政府非常重视新能源的研究、开发和利用工作，制订了“因地制宜，多能互补，综合利用，讲求效益”的方针。“六五”和“七五”计划期间，新能源和可再生能源都被列为国家重点科技攻关项目，并在此领域开展了广泛的国际合作。国内逐步形成了一支新能源专业队伍、兴办了一批新能源产业，成立了一些专业性的新能源技术开发中心，还安排了不同规模的新能源示范点。目前，有些新能源已经开始进入人们的实际生活，有些尚处在科研或示范阶段。这些都预示了新能源发展的美好前景，并作为新技术和新产业革命的重要内容，引起了国内外能源界和广大科技工作者的关注。

为了介绍我国新能源研究、开发和利用的情况，交流经验，中国太阳能学会组织编辑出版了《中国新能源和可再生能源》一书。我相信，这本书的出版，对推动我国的新能源工作，为增进世界各国对我国新能源的研究、开发和利用情况的了解，将起到很大的促进作用。愿我国的新能源事业兴旺发达，造福于人民。

能源部部长



Huang Yicheng

Minister of Energy

PREFACE

The development of human society always encounters with diverse challenges. The global conventional energy resources (mainly consisted of hydrocarbons)is being greatly consumed due to increasing human demands. This also inevitably results in worldwide environmental problems. For coping with the potential global energy shortage as well as improving natural environment, the program of research, development and utilization of new and renewable sources of energy (NRSE)as well as adopting advanced energy conversion technologies will be a significant task facing the energy scientists in all the countries.

In the beginning of the founding of the People' s Republic of China, an independent and initiative energy industry was established and has supplied huge amount of coal, petroleum and electric power for state socialist economic construction even under a weak industry base at that time. However, the gap between energy demand and supply has been widening along with the rapid development of national economy. Since the 3rd Plenary Session of Central Committee of 11th Congress of Chinese Communist Party, great changes have happened throughout the rural villages in China. The increase of agricultural input, the speedy development of rural township run enterprises and the improvement of farmers' living standard are bringing about an accelerated growth in rural energy demands. So the R & D of NRSE will provide an alternative possible solutions for easing up the rural energy shortage, especially in remote locations, and progressively reducing the reliance on conventional energy supply in those areas.

On the other hand, the development of modern technologies and commercialization of new materials will no doubt provide the possibility and promising prospects for efficient and economical use of the natural energy resources, such as solar, wind, biomass, ocean and geothermal energy.

Since 1970' s Chinese Government has paid much attention to R & D and utilization of new and renewable energy. A coherent strategy governing the R & D and utilization of NRSE has been pursued for planners and decisionmakers. It is stated as "planning in accordance with local resources availabie and economic conditions; multienergy complementary supply; integrated use and concern of commercial and economic viability". During the period of Sixth and Seventh Five-Year Plan, the R & D project of NRSE was listed in the National Science and Technology Development Program, and the international co-operations have been carried out. An expertise team has been organized, a number of technology development centers for NRSE have been set up and some demonstration projects are under way.

At present, some new and renewable energy appliances have served peoples daily life and some others are still in demonstration stage. All these achievements in new and renewable energy application considered as an important part of technological and industrial revolution in forthcoming new era have displayed a picture of promising prospects and attract the attention and concern of energy circle in national and global scale.

For the purpose of introducing the status of research and development of new and renewable energy utilization in China as well as exchanging information with foreign counterparts, Chinese Solar Energy Society edited and published this work —— (THE DEVELOPMENT OF NEW AND RENEWABLE SOURCES OF ENERGY IN CHINA). I am confident that the publication of this book will further promote the NRSE utilization in China as well as provide the up-to-date worthwhile information to the outside world.

With my best wishes to a prosperous future of NRSE utilization for benefitting all the people!

中国新能源和可再生能源发展现状及政策

胡　成　春
（国家科学技术委员会）

中国是一个人口众多的发展中国家，原有的工业基础薄弱。40年来，中国虽然建立起了独立的煤炭工业、石油工业和电力工业，到1989年底形成的生产能力为：煤炭10.4亿吨、石油1.37亿吨、天然气140亿立方米、发电5820亿度。但是，近10年来，国家实行改革开放政策，国民经济迅速发展，能源供需日益紧张。特别是占人口总数80%的农村地区，历来靠薪柴为主要燃料。目前，乡镇企业发展多种经营，能耗迅猛增加，尤其对于电力的需求更为迫切，同时生活用能也大量增加。国家每年增产的常规能源，满足工业和城市的能耗增长都有困难。对于农村地区，只能依靠地方政府，因地制宜发展一些小型能源生产，如开办小煤窑，兴修小型水电站和小型风力发电站等。

由于能源不足，带来的生态、环境问题也很突出。中国政府大力提倡植树造林，但是森林经常遭到破坏。在过去的50年内，全国沙漠化面积增加了约5万平方公里。目前，中国农村每年生产的作物秸杆约5亿吨，但是按燃料、饲料和工业原料需要，秸杆最低要求为7亿吨，为了确保饲料和必需的工业原料，农村燃料就十分紧张，全国大约有8000万户平均每年缺燃料50天。

面对如此严峻的农村能源问题，从70年代以来，中国政府开始注意开发利用新能源和可再生能源，采取了一系列扶植鼓励政策。首先在科学技术研究和示范推广方面做了安排，从国家第六个五年计划起（1981～1985年），新能源和可再生能源就列入了国家重点科技攻关计划，每年由中央政府拨给资金。目前正在执行的第七个五年计划（1986～1990年），也继续拨专款支持。与此同时，政府还鼓励广泛开展国际交流与合作，引进必要的技术和设备。

10年来，中国新能源和可再生能源有了较大发展。先后建立了20多个这一领域的专业研究所，还在各大学和有关企业中支持开展新能源和可再生能源工作。目前，全国拥有约3000名这方面的专业工程技术人员。同时，在地方也兴办了上百家新能源工厂，从事太阳集热器、太阳电池、风力发电设备等的生产。在此基础上，中央有关部门和地方联合成立了几个全国性的技术开发中心和研究培训中心，如中国风能技术开发中心、中国生物质能技术开发中心、中国光电技术发展中心、亚太地区小水电研究培训中心、中国农村能源研究培训中心、成都沼气研究培训中心和天津地热研究培训中心等。

与此同时，中国与联合国、欧洲共同体、意大利、联邦德国、比利时、英国、丹麦、荷兰、日本等国进行了新能源和可再生能源合作项目23项，中国政府投入了大量的人力、物力和财力，国外提供了很多设备和技术，这对促进中国新能源和可再生能源的发展起了积极作用，同时增进了各国人民之间的相互了解与友谊。

现在，中国建立的这些研究培训中心，除对国内服务外，也向世界各国开放，欢迎各国专家来华工作，并为发展中国家培训技术力量，在联合国亚太经社会的支持下，中国已开展了一些地区性的活动，参加者反映良好。中国准备继续作出自己的贡献，努力扩大服务面，希望得到国际的支持，加强国际技术交流。近来，在新能源方面也加强了与苏联和东欧国家的交往。

中国新能源和可再生能源发展的集中表现，据不完全统计，到1989年底为止，全国使用的农户沼气池460万个，小水电总装机容量1240万千瓦，发电343亿度，小型风力发电机10.5万台，连同中型风力发电

机总装机容量 1.5 万千瓦，风力提水机 1600 台，总功率 2110 千瓦，地热发电 20000 千瓦，低温地热直接利用约 38 万千瓦(热功率)，潮汐电站 8300 千瓦，太阳能热水器安装达 150 万平方米，建造太阳房 29 万平方米，太阳能温室 11 万公顷，安装太阳电池 1250 千瓦。

近年来，正在开发利用生物质气化炉、甜高粱制酒精燃料、风帆助航和波浪发电技术。

已经开始的研究项目有非晶硅太阳电池、生物质柴油、城市垃圾处理、风能致热、新型制氢技术和储氢技术等。

中国政府对于发展新能源和可再生能源的总政策是：因地制宜，多能互补，综合利用，讲求效益。在国家级，发挥各部门的联合作用，支持该领域的重点科研和开发，加强国际合作与交流。在地方级，进行试验、示范，建立工业性产业和维修服务站，并制定一些地方财政的优惠政策。

由于中国能源紧张状况不是短期内能够克服的，国家除不断扩大常规能源的生产外，同时要采取节能措施和尽可能多地使用新能源和可再生能源。目前，中国的能源基本上是自给自足，还处于封闭状态，所以国际石油价格的高低对中国的新能源和可再生能源发展影响还不大。但是，中国的人口已占世界总人口的 1/5，尽管中国政府采取了强硬的计划生育政策，但人口基数过大，人口的绝对增长是一个不能回避的问题，它必然关系到整个人类的发展前途。面对人口、能源和环境三大国际性难题，中国迟早要面临能源过渡和参加世界能源大循环。因此，中国支持联合国的倡仪，坚定不移地发展新能源和可再生能源，希望内罗毕行动纲领能较好地实现，中国愿意与世界各国人民为了和平、进步与经济共同繁荣而努力。

PRESENT STATUS AND POLICY ON THE DEVELOPMENT OF NEW AND RENEWABLE SOURCES OF ENERGY IN CHINA

Hu Chengchun

(State Science and Technology Commission)

China is a populous developing country with a very weak industrial foundation. In the past forty years, an independent energy industry has been established, covering coal, oil and electricity generation. Towards the end of 1989, it was estimated that China's annual production capacity stood as follows: 1040 million tons of coal, 137 million tons of oils, 14 billion cubic meters of natural gas and 582 billion kWh of electricity. In the last ten years, the implementation of the reform and open policy has resulted in rapid development of the national economy. But on the other hand, the dramatic growth also gave rise to increased energy consumption, creating an imbalance between energy supply and demand. It was particularly so in the rural areas, where over 80 per cent of the country's population depends on firewood as a major source of fuel for cooking. The recent boom of rural and township industry, which contributes to the formation of a diversified economy in rural China, adds to the severe energy shortage.

This is further aggravated by the increasing energy consumption needed to improve the livelihood of urban residents. Given her present financial constraints, China is unable to increase government inputs to satisfy her annual conventional energy demand in industry and everyday life in urban areas, not to speak of meeting the needs in rural areas。 The only way to ease energy shortage in rural areas is to mobilize local governments' resources and develop small-scale energy production patterns suited to local conditions, which include, among other things, the construction of small coal mines, small hydropower stations and small wind power stations .

The acute energy shortage also has led to the worsening of the environment and caused an undesirable ecosystem imbalance. Despite the vigoroues efforts by the government to plant trees, little progress was attained as indiscriminate deforestation by the peasantry in search of firewood more often than not offsets achievement made along that line. Serious consequences arose: in the last fifty years, the total area of desertified land in China has expanded by 50,000 square kilometers. It is believed that the annual agricultural wastes consumption in rural China totals 500 million tons. But the yearly need in China for agricultural wastes as fuel, animal feed and industrial raw materials is estimated to amount to at least 700 million tons. To ensure the basic supply of agricultural wastes for animal feed and industrial raw material, the farmers' need for fuel can not be met. It is estimated that every year about 80 million households in the countryside suffer the lack of firewood for about fifty days .

Indeed, this grave energy shortage poses a big challenge to the Chinese government. In the teeth of the crisis, a number of measures have been taken by the Chinese competent authorities since the late 70s, which included, among other things, the adoption of a set of preferential policies to encourage the exploitation of new and renewable sources of energy (NRSE). Research and development in NRSE received national priority in the Sixth Five—Year Plan (1981—1985) and demonstration projects , established on the basis of research achievements, went into operation to develop a keen public awareness of availability of NRSE. Efforts were made to pool wisdom and resources to tackle key technological obstables that hindered progress in that direction . A fairly big amount of financial resources were earmarked for that purpose . Under the current Seventh Five—Year Plan (1986 — 1990), now still under implementation, the central government persists in allocating a special fund for priority projects in NRSE research and development. In the meantime, extensive international exchanges and cooperation were encouraged and received a prominent place in the NRSE program, including some selected NRSE technology and equipment.

All these national efforts, as mentioned above, have contributed to the remarkable progress that have been achieved over the last 10 years. This includes the establishment of over 20 NRSE research institutes across the country and development of programs in some universities and colleges as well as industry in support of research and development in NRSE. Up to now, there are some 3000 engineers and technicians in China specialized in NRSE research and development. In the various provinces, more than 100 factories were set up and devoted to the manufacture of solar heaters, photovoltaic cells and wind powered electricity generators. Furthermore, a number of national technology development centres as well as training centres concerned with NRSE were also established to bring together and capitalise on the strengths found in different localities and ministries. They include the Chinese Wind Energy Development Centre, the China Biomass Development Centre, the China National Photovoltaic Technology Development Centre, Hangzhou Regional Centre (Asia-Pacific) For Small Hydropower, the China Centre of Rural Energy Research and Training, the China Chengdu Biogas Research and Training Centre for Asia and the Pacific and the Tianjin Geothermal Research and Training Centre.

To complement these national efforts, extensive international exchanges and cooperations in NRSE were also conducted. So far, 23 cooperative projects between China and the UN system, European Economic Community, Italy, the Federal Republic of Germany, Belgium, England, Denmark, the Netherlands and Japan. To ensure the successful completion of these cooperative projects, the Chinese government put in an enormous amount of human, material and financial resources, whereas the foreign counterparts provided the Chinese institutions involved with large quantities of equipment and expertise. These cooperative efforts have not only vigorously promoted the development of NRSE in China, but also helped strengthening the mutual understanding and friendly ties between China and these international organizations and countries.

Needless to say, the various types of research and training centres serves first of all the domestic needs, but they are open to international trainees as well. International experts are welcome to undertake cooperative research in these centres and offer consultant services and technical training to trainees from other parts of the world. In fact, in these centres a number of regional training activities have already been carried out in cooperation with the United Nations Economic and Social Commission in Asia and the Pacific. They were well received. We plan to expand both international and regional cooperative activities in these centres, so that they can provide a wider range of services to a greater number of foreign visitors from a broader geographical area. International scientific communities are cordially invited to join us in this lofty undertaking. Recently, we have more contact with Soviet Union and East European Countries.

The rapid development of new and renewable sources of energy in China finds forceful expression in the following statistics, which, though incomplete, tell its own tale. By the end of 1989, biogas digesters currently in use in rural China total 4.6 million. A total installed capacity of 12,400 MW of mini-hydropower stations had been registered with electricity generated therefrom reaching 34 billion kWh. Small-scale wind power generators 105,000, the total installed capacity of these small-scale wind turbine generators including that of medium-sized ones amounting to 15,000 kW. Wind pumps also come up to 1,600 with a total capacity of 2,110 kW. Geothermal power station 20,000 kW. A total of 380,000 kilowatts of low temperature geothermal energy had been exploited for direct application. Tidal power stations had generated some 8,300 kW. Solar water heaters installed had totaled

1.5 million square meters. Solar houses built had taken up 290,000 square meters. Solar green houses constructed had occupied 110,000 hectares. And the solar cell installed reached 1,250 kW.

In recent years, great efforts have been made to develop technology on biomass gasifiers, sorghum-based alcohol fuel. Useful work is also being carried out to utilize wind power for navigation and wave power for electricity generation. Other projects already under way include amorphous silicon solar cells, biomass-based diesel production, energy production—oriented urban wastes dispersal, wind power heaters, new technology on hydrogen production and hydrogen storage technology. It is gratifying to note that progress has been achieved to differing degrees.

The Chinese government adopts an overall policy on NRSE which is characterized by integrated development and efficient utilization of various forms of energy sources for complementary and practical purposes, with local conditions taken into full account. At the national level, attention is given to pooling resources from government departments in support of research and development in priority NRSE projects, while international cooperation should also be strengthened to supplement national efforts. At the local level, care should be taken to work out preferential measures to develop NRSE pilot industrial enterprises with accompanying service stations.

Shortage of energy in China can not be expected to be overcome in a short period of time. The only way out is to adopt various kinds of energy conservation measures and increase the utilization of NRSE, while expanding the production of conventional energy. At present, China's energy production is carried out on a self-reliant basis by and large. For this reason, fluctuations in oil prices in the international market produce no major impact on our energy situation. However, China's population is so large that it accounts for one fifth of the world's total, despite its vigorous family planning efforts, the absolute population growth would still be considerable due to its enormous population base line. This can not but affect the future of the whole mankind. Faced with the three global problems of population explosion, energy shortage and the environment deterioration, soon or later, China will be dragged into the global energy cycle. We therefore resolutely favour the development of NRSE and support the implementation of Nairobi programme of Action for the Development and Utilization of NRSE. The Chinese people are ready to work together with the peoples of the whole world for peace, progress and the common economic prosperity.

中国太阳热水器的研究与发展

陆　维　德

（北京市太阳能研究所）

太阳热水器在中国已经有20多年生产和应用的历史。目前全国已有100多个小型工厂生产太阳热水器，年产量已超过40万平方米（采光面积）。全国太阳热水器的总使用面积已达150万平方米，其中绝大多数为城乡居民提供生活热水和用于公共浴室，在节约常规能源、减少环境污染和改善人民卫生水平方面已初见成效。

中国使用的太阳热水器主要分为整体式（或称闷晒式）和循环式两大类。

整体式热水器的集热装置和贮热水箱合二而一，结构简单，易于安装且价格较低。中国生产的太阳热水器中15%属于整体式，此类热水器主要供家庭使用。

循环式系统的集热器与贮热水箱互相分开，可以泵送或自然循环的方式运行。中国以往使用的循环式热水系统大多为自然循环式。

80年代，太阳热水器在中国开始作为一个新兴但又幼小的能源产品行业出现，是中国政府对新能源利用比较重视，在政策上给予支持以及自从70年代以来中国科学工作者不懈地努力，将科研成果转化为生产力的结果。

早在1958年，在天津大学和北京天堂河农场相继建成了中国最早的用自然循环式太阳热水器供热水的公共浴室。尽管那些太阳热水系统还比较粗糙，性能也较差，但它向人们证实了利用太阳能产生热水是可行的。然而，要推广使用这种太阳能热水装置，仍需要完成许多基础的和应用的研究工作，以使它作为产品在技术上和经济上都能为用户所接受。

目前使用的循环式太阳热水器，大都采用平板型集热器作为集热装置，供热水温度在40～70℃的范围内。研究工作主要致力于与平板型集热器的优化设计有关的热工分析及材料选择，为批量生产研制合理的加工工艺和专用设备。早期的平板型集热器的吸热板大多为钢制管板槽结合式（用铁丝捆扎），通过测试及理论分析，指出了其结合热阻过大是导致集热器效率因子F'恶化的主要因素，从而产生了若干传热性能优良的吸热板设计及制造工艺，例如扁盒式、拉制铝翼式及全铜管板式连续焊接结合等。中国在1986年自加拿大引进的铜管铝翅片复合型翅片管吸热板(SUNSTRIP)生产线，为国内市场提供优质平板型集热器作了有成效的示范。经过近10年的实践，对集热器吸热板水道的腐蚀问题有了清楚的感性认识，从全面的技术、卫生和经济考虑出发，已逐步摈弃了钢和铝制的管板式和扁盒式吸热板（合金铝翼管仍在一些地方使用），而代之以铜质水流道。塑料吸热板正在开发中，其关键是塑料材料的开发以适应耐紫外线和闷晒高温的要求。可以预见，塑料集热器（特别是无盖板的）在我国南方具有开发的前景。在集热器优化设计方面，进行了集热器空气夹层内自然对流换热的研究，建议夹层间距一般在4～6厘米为宜；还探讨了在空气夹层中加透明蜂窝结构对提高集热器性能的有利作用及其实现的可能性。此外还建立了分析集热器参数最佳化的数学模型及计算机分析的软件，为优化设计奠定了基础。

目前，在国内市场上销售的太阳热水器的吸收涂层多是普通黑色涂料。研究指出，对于产生低温热水而言，非选择性黑色涂层价廉物美恰到好处。选择性吸收涂层的制备工艺，作为研究课题大都处于实验室

阶段。硫化铅选择性涂料喷涂在抛光的铝板或镀锌铁板上($\alpha_s=0.85\sim0.91$，$\varepsilon=0.23\sim0.40$)，工艺简单，易于制备，成本也较低；电镀型选择性黑铬和黑镍($\alpha_s=0.91\sim0.98$，$\varepsilon=0.06\sim0.14$)尚未得到推广；在铝材上采用阳极氧化电解着色方法制备的涂层($\alpha_s=0.92\sim0.96$，$\varepsilon=0.1\sim0.2$)正在进行小试，可望用于SUNSTRIP条带上作为商品推出。

此外，中国已建立了"平板型集热器热性能试验方法"的国家标准(GB4271-84)和平板型集热器产品技术条件的国家标准(GB6424-86)，成为集热器产品的质量监督的依据。国家技术监督局已委托太阳能热利用检测站对各太阳热水器生产厂家的产品进行抽检。中国生产的平板型集热器性能的典型数据是：$F'(\tau\alpha)=0.6\sim0.8$；$F'U_L=6.0\sim8.5W/m^2℃$。要成功地设计太阳热水系统，需要透彻地了解热水系统的动态特性以及各个因素(包括气候和系统设计参数)对系统热性能的影响。在以往的10年间，中国学者曾对各种太阳热水系统的特性进行了深入的实验和理论研究，特别是对国内较为广泛采用的自然循环系统，已经建立了非稳态运动的数学模型，编制了通用计算机程序，并最终绘制了图表为设计者提供参考依据，从而避免了以往曾出现过的由于盲目设计和安装而造成系统不能正常工作的失误。对于大型热水系统，如果设计不当，经常会出现因流量分布不均匀而引起系统性能下降。在这方面也进行了研究，并提出了恒量热水系统内流动均匀性的判据，对提高系统的设计水平做了奠基的工作。

中国在直流式定温放水太阳热水系统方面的理论和实验研究成果在世界上处于领先地位(有关这方面的论文在1983年国际太阳能学会世界大会上被评为优秀论文)。由于它具有构造简单、水箱不必高置于集热器的上方(自然循环系统因防止夜间倒流，必须将水箱高置)的优点，近年来在中国得到迅速的普及和推广。此外，对于在多层住宅楼中如何设置家用太阳热水系统也进行了多种方案的探索，并在北京、天津、兰州等地进行试点。它的可行性取决于造价及系统本身的可靠性及维修的落实等因素。

为了提高热水使用温度，扩大应用范围，已着手研制了两种真空管式集热器，即全玻璃式和热管式，可用它们组装成平板型集热器。全玻璃真空管集热器的研制始于70年代末，在选择性膜材料、制备工艺乃至集热器结构等方面进行了大量高水平的研究工作，至80年代中期已投入小批量试生产及示范应用，取得较为满意的结果。热管式真空管集热器的研制为中国-德国技术合作项目，始于1986年，已经开始小批量生产，其性能接近Philips公司的同类型产品的指标，耐久性考验尚在进行中。

SOLAR WATER HEATING IN CHINA

Lu Weide

(Beijing Solar Energy Research Institute)

A variety of solar water heaters have been produced in China for twenty years and now is at commercialization stage with a gradual increase of annual output, although its technology has to be improved. At present, there are more than a hundred of small factories and workshops manufacturing solar water heaters with a yearly output of 400,000 m^2 (aperture area). The total amount of installed solar water heaters reaches 1.5 million m^2, mainly for domestic hot water supply while a few for public bath rooms and other commercial uses in rural as well as urban area for saving conventional energy and improving hygienic condition.

The solar water heaters developed in China could be classified into integrated and separated systems. For integrated water heaters, a solar collector and hot water tank are integrated into the same unit, simple to install, and cheaper in price. So they are of interest to the domestic sectors, of which around 15% of solar water heaters produced in China pertain to integrated type. Separated systems, with collector and storage tank, can be operated either on pumped or natural (thermosyphon) circulation. In China most of them are of thermosyphon type.

The newly formed solar hot water industry in China, which started in 1980's, receives the encouraging support from Central Government as well as the technological support from the research institutions and universities and has got positive results on improving cost-effectiveness of the products.

Early in 1958, two pilot solar water heating systems of natural circulation supplying hot water for public bath rooms were built in Tianjin University and Beijing Tiantanghe State-run Farm respectively. Their operation and service experience proved that the systems did work, inspite of their imperfect design and poor performance.

During the last decade, research and development were focused on design optimization of various kinds of solar water heaters. In early years, the collector absorbers were made of steel and in tube-in-sheet structure in which round tubing is mechanically fitted by clamps or wires leading to a bad thermal bond conductance. Based on heat transfer analysis and thermodynamic tests on the existing panels, the processing technology has been greatly improved, for instance, the extruded fin-tubing and continuous soldering now are used in collector absorber processing. A SUNSTRIP production line mainly consisting of a rolling machine and a inflating-cutting machine was imported from Canada in 1986. It produces the aluminum fin-copper tubing SUNSTRIP absorber strip in excellent quality with high thermal bond conductance and fewer copper consumption meeting the international quality standard. Some aluminum fin-copper tubing production technology similar to SUNSTRIP's has been domestically developed in Shanghai, Liaoning and Yunnan. Owing to the corrosion problem in water passage of steel or aluminum absorber, copper water passages are now widely used and become popular. Plastic absorbers are still under development and the R & D work is focused on screening the materials which are able to stand ultra-violet radiation and high stagnation temperature. However, at present it seems promising to install plastic collectors without glazings in some locations of Southern China. Scientific investigation on the collector's optimized design has been carried out, and it is found that the optimal spacing between absorber and glazing is recommanded as 4—6 cm where heat transfer is mainly conducted by natural convection. The performance of the collector with transparent honeycomb structure sandwiched between the spacing of absorber and glazing to suppress collector's heat loss was proven positive in the laboratory. However its commercialization still needs further efforts. Besides, a mathematical model for collector optimized design has been worked out.

The collectors available in China's market are usually coated with black paint. As a result of computer simulation, it is indicated that for low temperature heat collection, or not for year round use, the black paint is in practice a cost-effective option. Selective coatings with various preparation methods are still in laboratory stage. The radiation properties of PbS selective paint on polished aluminum of galvanized steel reaches $\alpha_s = 0.85 \sim 0.91$, $\varepsilon = 0.23 \sim 0.40$. For black chrome and black nickel, $\alpha_s = 0.91 \sim 0.98$, $\varepsilon = 0.06 \sim 0.14$, but their durability and cost~effectiveness are still not proven, while the anodized electroplating colored selective absorption coating on aluminum surface ($\alpha_s = 0.92 \sim 0.96$, $\varepsilon = 0.1 \sim 0.2$) has been succesfully developed and serves as selective coating on SUNSTRIP absorbers.

The National Standard for Rating the Thermal Performance of Flat Plate Collectors (GB 4271-84) and National Standard for Evaluating the Quality of Solar Collector Products (GB 6424-86) were published in 1984 and 1986 respectively. The National Supervision Bureau of Products Quality conducts spot check on flat plate collectors once every year based on the guidance of these Standards. The typical efficiency parameters of the flat plate collector products made in China are reported as: $F'(\tau\alpha) = 0.6 \sim 0.8$ and $F'U_L = 6.0 \sim 8.5 W/m^2 ℃$.

The dynamic characteristics of thermosyphoning system and the effect of various factors (e. g. climate, design parameters of the system etc.) on the system behavior were studied in connection with computer modelling as well as experimental methods for obtaining a clear picture of its operation mechanism in order to provide performance prediction for different designs and guidance for correct installation. An once through type solar water heating system operating with a thermostat was suggested with its remarkable advantage of flexible siting of the water tank at a suitable location instead of placing it well above the upper part of the collector like the thermosyphon systems do. Through theoretical and experimental study, it was indicated that the once through type and the thermosyphonic system have the same whole day performance if they operate under same conditions (including weather, cold tap water and hot water temperature level, collector and water tank structure, and ratio of collector area to water capacity). In recent years, the once through type water heating system has been widely installed in newly built solar water heating systems. In addition, the demonstrations of domestic solar water heating systems integrated with the multi-story apartment building have been undertaken in Beijing, Tianjin and Lanzhou with 1 m^2 collector, 70 liter water tank for each residential flat. The flow distribution in large collector system is often a significant design problem. Hydraulic modelling for such systems has been conducted and provides the useful results for collector arrangement and layout.

For producing hot water at a temperature around/above 100℃ as well as for year round use, two types of evacuated tubular collector in flat plate pattern are under development. The R & D of all glass concentric tubular collector started in 1979. During the past decade, numerous fundamental research on its coating preparation method, glass-work technology, collector tube assembly and system design were carried out. A small scale of trial production and demonstration of this type of evacuated collectors are under way. A China-Germany international co-operation project on heat pipe evacuated tubular collectors started in 1986, and has completed the prototype research and development, now it enters the intermediate experimental stage. However, there are still lots of work to do for practical uses as well as economic feasibility study of this kind of higher operation temperature collectors.

中国太阳能干燥的发展现状

李　宗　楠
（中国科学院广州能源研究所）

一、前言

在中国的太阳能热利用领域中，太阳能干燥的研究与应用比其它项目的发展较迟。在70年代只有几个单位从事这项工作，那时全国仅有7座太阳能干燥器，总面积只有479平方米，但最近几年发展非常迅速。目前全国有各种形式的太阳能干燥器108座，总采光面积达10178平方米，其中85%是在1983年以后建立起来的。

通常，中国广大农村的农产品和农副产品的干燥都是靠露天摊晒的。这不但容易受到风沙、尘灰及蝇虫的污染，而且受气候环境的影响很大。每年夏秋季节，正是农产品大量收获的时期，却阵雨频繁，下雨前农民怕产品淋湿而不敢在晒场摊晒，而下雨以后场地又非常潮湿，不适合于摊晒作物，所以生产安排上十分被动。80年代以来，中国农村新能源的开发与利用发展迅速，在农业生产上如何利用太阳能技术，引起了人们的充分重视。如果说，太阳热水器、太阳房和太阳灶主要是用于生活的话，那么太阳能干燥器则主要是用于生产。

根据中国各地研究利用太阳能干燥器的经验，太阳能干燥器用于农副产品、食品、木材、中药材及工业原料的干燥作业中，都收到了良好的效果，一般的投资回收期不超过三年，甚至有使用半年即可将投资偿还的，取得了显著的经济效益。从总的方面来说，其优点可以概括为：

1. 节约燃料、降低产品成本；
2. 减少污染、提高产品质量；
3. 改善条件，提高生产效率。

太阳能干燥被列为中国科技攻关的重要项目，进一步促进了它的研究与开发利用。

二、太阳能干燥的发展概况

中国各地的太阳能干燥器可以归结为五种形式，即温室型、集热器型、混合式、聚光型及整体式等。我国各种形式的太阳能干燥器的数量及采光面积如下表所示。

太阳能干燥器的形式及数量

形式 / 数量	温室型	集热器型	混合式	聚光型	整体式	合计
干燥器台数	24	42	8	5	29	108
采光面积（平方米）	2720	3096	1298	213	2851	10178

1. 温室型太阳能干燥器

温室型太阳能干燥器结构简单，发展最早，它和栽培农作物的温室相似。被干燥的物料放在温室内，直接接受阳光的照射。这种干燥器运行多为被动式，物料蒸发出来的水份靠自然通风排走。山西省从70年代起在农村推广，建成了10多座温室型太阳能干燥器，用于干燥红枣、棉花、黄花菜、毛皮等农作物。浙江

省义乌县森工站1985年建成一座采光面积为543平方米的大型温室型太阳能干燥器，用于干燥包装箱木料，效果使人十分满意。河北省利用温室型太阳能干燥器干燥兔皮及果脯，在石家庄平山冷冻厂建成了采光面积为212平方米的温室型太阳能干燥器。为了收集到更多的太阳能，在干燥器进风口外又增建了638平方米的太阳能空气预热器，若将这部分接受阳光的面积也计算在内，此装置的总采 光面积为850平方米，为目前中国采光面积最大的太阳能干燥器。装置的结构简图示于图1中。温室内安装了三台轴流式鼓风机，提高掠过物料表面的空气速度，以强化脱水过程。目前许多温室型太阳能干燥器都安装了风机，改为主动式操作，以改善干燥器的性能。

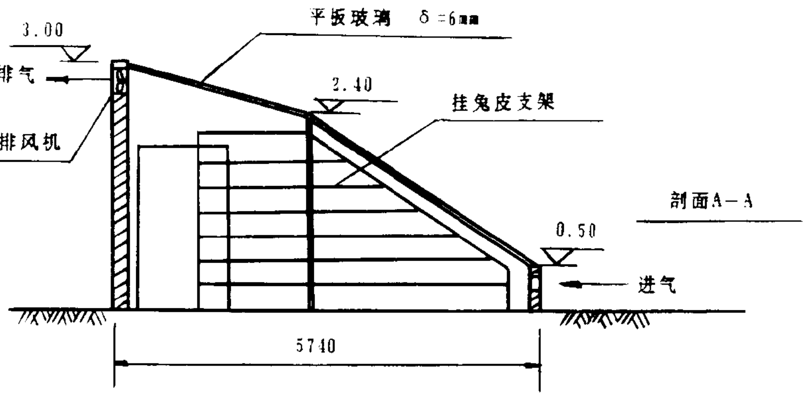


图1　温室型太阳能兔皮干燥房

2. 集热器型太阳能干燥器

集热器型、又称为间接受热式的太阳能干燥器的数量最多，应用也最广。这种形式的干燥器利用太阳能空气集热器，使空气加热到60～70℃左右，然后通入干燥室，物料在干燥室内实现对流干燥过程，所以干燥器大多数设计成主动式的，靠风机鼓风以增强对流换热。中国几个规模较大的太阳能干燥器，如江西赣州第二木材厂的太阳能木材干燥室、广东新会县的太阳能腐竹凉果干燥窑、上海第一制药厂的太阳能中药干燥房、河南洛阳美术陶瓷厂的太阳能陶坯烘干房、甘肃兰州陇丰食品厂的太阳能瓜子干燥器等均属此种类型。图2所示是洛阳美术陶瓷厂的太阳能干燥窑，这是一个典型的集热器型太阳能干燥装置。

空气集热器是此种类型干燥器的关键部件。根据集热器吸热板的结构不同，有不同型式的空气集热器，国内应用较多的有波纹板式、整体拼装平板式、梯形交错波纹板式、可渗透金属网状吸热板式、铁屑刨花结构等。

3. 混合式太阳能干燥器

温室型太阳能干燥器的效率比集热器型太阳能干燥器的效率高，但温室型干燥器的温升较小。在干燥含水率较大的物料(如水果、蔬菜等)时，温室型干燥器所获得的能量不足以在较短时间内使物料干燥至安全含水率以下。为增加能量以保证被干物料的干燥质量，在温室外增加一部分集热面积，这种具有太阳能空气集热器的温室型干燥器就称为混合式太阳能干燥器。由于干燥器本身具有温室效应，对于干燥那些允许被阳光曝晒的物料，利用混合式结构比集热器型提供的能量多，干燥周期缩短，效率也相应地有所提高。中国混合式太阳能干燥器的数量不多，比较典型的是广东省东莞县的太阳能水果干燥器，但因工厂转产，该装置目前尚未正常使用。

4. 聚光型太阳能干燥器

利用聚光器集热，可使干燥器达到较高的温度，实现物料快速干燥。中国于1979～1981年期间，在粮食部门先后建立过五座聚光型太阳能干燥器用于干燥谷物，但由于结构复杂、成本较高、机械故障较多、操作管理不便，用作粮食干燥并不适宜，1981年后已没有继续发展。