Journal of The Heat Transfer Society of Japan

Vol.34, No.134, July, 1995

CONTENTS

第３２回日本伝熱シンポジウム
企画部会特別セッション講演
－中国と韓国の伝熱研究の現状－

CURRENT RESEARCHES ON HEAT TRANSFER IN CHINA

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INTRODUCTION

In China, Scientific researches are usually subdivided into three different administrative levels, that is, basic research, technological research and development research. It is well-known, China still belongs to the developing countries. The state input, which emphasize on the applied researches, is not high. Since the promulgation of National Long- and Mid-Term S&T Development Outline and the formulation of the S&T Progressive Law of People's Republic of China, the new mechanism of combination of S&T with economy has been fostering. The focus of S&T activities gears to the construction of national economy. The key of S&T system's reform is to implement the policy of "holding firm to one end (basic research) and leaving free the rest (R&D to market regulation)". "Holding firm to one end" denote mainly rely on the government financial input to support only a few key research institutes and those in high learning institutions to conduct basic research, state public benefit research, long-term research and high-technological research. It is aimed to increase the state's input to basic research from current 7 percent to 10 percent of the total allocation for S&T. "Leaving free the rest" means to conduct R&D activities, which are closely related with economic construction and demanded by the need of the market. R&D achievements disseminate and open a way of self development, depending on market mechanism operation.

Numerous accomplishments and success in many technologies have resulted from the understanding and basic application of heat and mass transfer, and advances in heat transfer have been used to improve the products of most industrial endeavors. Furthermore, heat transfer is pervasive throughout the existing and emerging technologies including energy, heat exchangers, manufacturing, material processing, aerospace, bioengineering and, microelectronics and information technology etc. Consequently, heat transfer research covers actually all the three different levels: basic research, application-oriented basic research and applied research. However, unlike many other disciplines, there is no single industry or technology that serves as a flagship for the heat transfer. This may explain perhaps why it is difficult for the heat transfer researches to get funding from industry in China.

RESEARCH ACTIVITIES ON HEAT TRANSFER

The research activities in the field of heat transfer in China are quite widespread and profound. There were more than 200 papers submitted each year to the annual nation-wide heat transfer conference sponsored by the Division on Heat and Mass Transfer of the Chinese Society of Engineering Thermophysics (CSETP) since 1980. The National Conferences on Engineering Thermophysics in Colleges and Universities were held regularly every three years since 1983. The 1st Nationwide Thermophysical Property Conference was held in Dalian in October 1984. A nation-wide special symposium on thermal hydraulics and nuclear reactor safety was held in Xiamen in April 1984. Moreover, there were also a few papers on heat transfer presented at various symposiums held by the Chinese Mechanical Engineering Society (CMES), the Chinese Society of Chemical Engineering and Technology (CSCHET), the Chinese Society of Aeronautics and Astronautics (CSAA), the Chinese Metals Society (CMS), the China Society of Measurements (CSM), the Chinese Solar Energy Society (CSES), etc. Such a large number of papers were written in Chinese without exception, and only a few of them were accepted for publication in journals. They therefore are seldom known to the foreign heat transfer communities. However, papers presented at the International Symposiums on Heat Transfer, which were held in Tsinghua University in 1985, 1988 and 1992, will benefit the interaction between Chinese and foreign heat transfer communities. Of course, there are many international conferences with related or special topics had been taken place in China since 1985.

RESEARCHES ON HEAT TRANSFER IN CHINA

It is quite difficult/impossible to make a comprehensive report on all of latest researches on heat and mass transfer in China, especially in such a short description. The authors are devoted themselves to give a brief introduction to some aspects at the 1990's as follows.

A. Heat Conduction

A new method on infrared thermovision examination was proposed based on mathematical models of conduction-convection and conduction-radiation to measure the contact thermal resistance in composite materials. Experiments show that the contact thermal resistance can be up to 25% of the total heat transfer resistance of Ti-Al composite finned tubes with hot water flow inside and exposed to air [A1]. A new technique was reported for measuring thermal conductivity of composite plate by infrared thermovision [A2]. Analytical results on dynamic thermal stress in a semi-infinite object under impact heating were obtained based on the hyperbolic conduction equation. The impact thermal stresses are confined in a thin surface layer and experience twice sudden changes [A3]. A finite speed propagation model in spherical system expressed in a hyperbolic conduction equation was used to predict the transient process of heat conduction in IC chips. Analytical and numerical results show that, compared with the diffusion model, we have the higher peak temperature and thermal stress, greater temperature difference between components and strong thermal noises, which are significant to the reliability of IC chips [A4]. The thermal wave phenomena have been introduced to the analysis of thermal breakdown in semiconductor devices and some relationships between the failure power, failure time and defect dimension were given for specific time domains [A5]. The hyperbolic conduction equation was used to predict the temperature history of bio-specium in the ultra-rapid cooling process [A6]. Non-quasi-steady heat conduction resulting from a moving line heat source was analyzed by use of heat source method. The difference in results of non-quasi-steady from quasi-steady analysis are found to be obvious for Fourier number smaller than 20 [A7].

B. Natural and Mixed Convection

A method was proposed to research the natural convection heat transfer from a non-isothermal vertical plate by infrared thermovision [B1,B2]. Influences of the slot width were reported on the natural convection, including flow patterns and heat transfer, between a horizontal cylindrical envelope and an internal concentric slotted hollow cylinder [B3,B4]. The effects of variable thermophysical properties on laminar free convection of gas and liquid were reexamined [B5, B6, B7]. The systematic study of variable property effects on vertical channel natural convection in air indicated that the mass flow rate and heat transfer in vertical parallel plates will experience a non-monotonic variation with increasing wall temperature or wall heat flux, which can lead to the sharp rise in wall temperature up to its damage [B8]. Experimental studies were reported on turbulent natural convection, including natural convection from a horizontal cylinder in high Rayleigh numbers, temperature field characteristics and local heat transfer coefficients of natural convection in an enclosure [B9, B10]. It was found through numerical study of laminar natural convection on a vertical heated plate for water containing metallic corrosion products that there are strong influences of variable properties at super-critical pressure on natural convection heat and mass transfer [B11]. Heat transfer by free convection in air from small horizontal heated surfaces facing upward has been experimentally studied. The random instability of the flow and heat transfer was observed and discussed [B12]. Using the numerical and differential interferometric methods, the natural convection combined with radiation on a non-isothermal vertical flat plate were investigated . The fraction of radiation heat transfer will increase with increasing Gr as Gr ranging from 2.5×10^7 to 5.0×10^8 [B13].

C. Forced Convection Without Phase Change

Thermally induced effects on fluid flow have been systematically studied, including thermal drag, thermal displacement, thermal drive, and thermal instability. Based on these phenomena it can be expected to develop some new technique of thermal control [C1]. Experiments on the forced convection heat transfer of air in microchannels were conducted. Results show that Nu decreases with the decrease of Re for the air force flow in microchannels with diameter of 0.2-1.1mm [C2]. Experiments on forced convection heat transfer for liquid methanol flowing through microchannels were also reported in detail [C3]. The laminar flow transits to turbulent one at Re=700, and heat transfer enhanced greatly. Experimental studies on heat/mass transfer and pressure drop characteristics were performed and discussed for arrays of non-uniform plate length [C4]. Heat transfer and friction characteristics of a square channel with square/triangular ribs were presented and the effects of the rib resistance was discussed [C5]. The temperature field of fluid flow and heat transfer around the heating solid spheres in tandem have been measured by laser holographic interferometer together with infrared scanning technique. The heat transfer characteristics for heating solid spheres affected by various parameters were attained [C6,C7]. The aerodynamic heating was predicted and an enhanced cooling method for the inlet casing central cylinder and its front cone was suggested [C8]. Experimental study on an air-jet impingement on a heated rotating cylinder wall was conducted and its heat transfer correlation was obtained [C9]. Correlations of heat transfer and pressure drop have been proposed for the air flow across chevron and louver finned-tube banks based on experiments in a wind tunnel [C10].

D. Two-Phase Flow and Heat Transfer With Phase Change

Experiments were conducted to investigate the flow boiling of sub-cooled liquid in microchannels with cross-section of 0.6×0.7mm, machined on the stainless plate of 2mm thick. Results indicated that the heat transfer was intensified greatly due to the occurrence of boiling under smaller wall surface superheat than that for normal size channel, yet no any visible bubbles exist within the microchannels, and blustered bubbles is form of a jet just at the exit of microchannel [D1]. Two hypothetical concepts--"evaporating space "and "fictitious boiling" have been proposed [D2], and new efforts are devoted to them. Experimental study of heat transfer characteristics in the evaporator of a two-phase closed thermosyphon was performed. The correlations were suggested for predicting the boiling heat transfer coefficients for the liquid pool, and the liquid film respectively [D3]. Heat Transfer for laminar forced convection film boiling on a horizontal cylinder has been investigated experimentally and analytically, and the corresponding correlation was given [D4]. The mechanism of the bundle effect of a horizontal tube bundle in nucleate pool boiling was investigated theoretically and experimentally. It was shown that the liquid film, impinging and vapor covering effect caused by rising bubbles in the bundle, are responsible for the boiling enhancement in the tube bundle [D5]. Researches on rewetting and advances in flow boiling along hot surfaces were summarized [D6]. A physical model of interfacial heat transfer was developed for flow film boiling at high velocity. Analytical results revealed the heat transfer limit for auto-model flow film boiling and thermodynamic non-equilibrium in the transfer process for non-auto model for flow film boiling [D7]. A new correlation for flow boiling heat transfer of refrigerants in horizontal tube was developed, which is in better agreement with the data than the other existing correlations [D8]. High pressure steam-water two-phase flow instability in a vertical upward helically-coiled tubes ranging from 3-10 MPa were studied experimentally. The oscillation curves of two-phase flow and the effects of various parameter on flow instability were obtained [D9]. Mechanism of heat transfer in dropwise condensation and various surface materials for dropwise condensation have been investigated and reported [D10]. Bifurcation theory has been used to predict the nonlinear dynamic instability of two-phase flow in natural circulation loop for the purpose of safety analysis of nuclear reactor [D11]. Experimental study was conducted on the void fraction of air-water two-phase flow in the shell-side of a segmental baffled horizontal shell-and-tube heat exchanger model. It was found that the average void fraction was lower than that predicted by a homogenous flow model [D12]. The concept of thermal clogging developed from the single-phase flow was extended into gas-liquid two-phase flow systems under heating. An approximate analytical relation between the acceleration pressure drop and the dimensionless Heating number was derived [D13]. Experimental and analytical results were reported on heat transfer for melting in an enclosure at constant rate with emphasis on the effect of wall conduction on melting [D14]. An experimental investigation was performed on the local heat and mass transfer for drying the moist particles in the circulating fluidized bed, including the effect of air superficial velocity, solid circulating rate and initial moisture content on heat and mass transfer [D15]. A cylinder instrumented with a fast responding thin film thermocouple probe was developed for the measurement of instantaneous local heat transfer coefficients around a horizontal tube immersed in a high temperature fluidized bed [D16].

E. Thermal Radiation

An one-dimensional radiation intensity equation in semi-transparent medium was introduced with one side semi-transparent and the other opaque. Inserting the radiation intensities calculated from known temperature field plus some measurement errors in inverse radiation model may lead to the estimation of the temperature field by use of the chained method [E1]. A transmission method combined with the simplified Mie theory has been introduced to predict the complex refractive indices of small particles [E2]. A new kind of blackbody radiation source with simple construction and easy operation was developed. Analytical and experimental results showed that it is possible to construct a blackbody radiation source with total and spectral emissivities greater than 0.99 [E3]. A series of cross-shaped radiative elements was proposed for the combined augmentation and interaction of radiation and convection in a high temperature airpreheater [E4]. Two dimensional transient turbulent free convection-surface radiation interaction was studied numerically in a open square cavity with a heated back wall and insulated top and bottom walls. Results indicated that the radiation can significantly affects the convection flow and heat transfer at the later evolution stage [E5].

F. Mathematical Simulation and Modeling

The rationality of the additional source term method (ASTM) has been proved and its application have been extended to determin the efficiency of slotted fin [F1]. Simplification and discretizition in numerical simulation of fluid flow and heat transfer for injection molding process were discussed and some suggestions were presented for improving the calculation accuracy and raising the computation rate [F2]. A mathematical model with the through-flow calculation for studying the effect of injected cooling air on turbine performance was presented. The effects of three types of cooling on the aerodynamic performance of an air-cooled gas turbine were analyzed and compared [F3]. Numerical studies were reported on the fluid flow and heat transfer in a commercial finned tube using the turbulent model from Patankar. The results in both pressure drop and heat transfer coincided well with the existing experimental date [F4]. Numerical analysis of the natural convective problem in trapezoidal enclosure was conducted by using the upwind finite element scheme with non-symmetric weighting function. Special techniques, including the underrelaxation, the floating of the vorticity boundary condition and the alternation of the mesh grids in computation proved to be effective [F5]. A distributed parameter model was introduced to mathematically simulating and modeling for geothermal reservoir in China, which is a liquid-dominated one with a two-phase zone on the top, the influence of two different reinjection schemes have been taken into account, including the subsequent temperature decline due to reinjection [F6]. Method was reported for mathematical simulation of the temperature field in solidified heavy steel ingots so as to predict the possible defects due to shrinkage cavity and porosity [F7].

G. Heat and Mass Transfer in Porous Medium

A near wall function was suggested for forced convective heat transfer in a vertical annulus filled with porous media and checked through experimental data correlation [G1]. The enthalpy form of energy equation with a proposed transfer scheme was used for numerical study of freezing and moisture migration around a circular cylinder buried in unsaturated porous media. The results show that the moisture migration has an evident effect on the freezing process [G2]. Natural convection around a horizontal, isothermal cylinder in an infinite, fluid saturated porous medium was modeled analytically using the Darcy/non-Darcy flow model. The two-dimensional flow and temperature fields were determined for modified Rayleigh numbers ranging from 0.1 to 10. Local and average Nusselt numbers were given as functions of the modified Rayleigh numbers [G3,G4]. The conjugate diffusion model has been extended to the period of decreasing drying rate for predicting the heat and mass transfer, and it is available to determine the onset of the dry region by analysis of process [G5]. Experimental study was conducted on pool boiling on porous surfaces with micro-grooves and some special features of heat and mass transfer were revealed [G6]. Analytical and experimental results were reported on phase change in a rectangular enclosure filled with the saturated porous medium and heated with uniform heat flux from the vertical side. It showed that the liquid side Stephan number has a profound effect on the heat transfer [G7]. A evaporator model of a porous wall/ micro-thermosyphon was used for analyzing two-phase flow and boiling heat transfer within powder porous layers at pressures above atmosphere. Based on experimental data a correlation was established to predict the performance of boiling heat transfer [G8]. The minimum gradients assumption was adopted to describe quantitatively the hysteretic behavior of capillary liquid flowing and heat transfer in unsaturated porous medium. This method can be applied to more complicated situations, such as the cases of variable volume/shape of solid matrix with the temperature and moisture [G9]. Thermal characteristics and the conductivity of flat screen porous media were studied experimentally by using a transient model of combined conduction and radiation with optically thick approximation. As compared with the steady state method it has advantages of simple measurement device, reduced measurement time and high accuracy [G10]. The experimental and analytical investigations have been conducted to understand the heat flux limit and critical heat flux of boiling heat transfer in a porous bed. Two correlations for calculating these two heat fluxes were proposed [G11]. The natural convection in a porous enclosure was investigated due to the combined driving forces resulted from the horizontal temperature and concentration gradients. With the penalty finite element method, the flow and heat/mass characteristics were analyzed in detail for various cases [G12].

H. Heat Transfer Enhancement and Heat Exchangers

A physicomathematical model with distributed heat sink was given for the turbulent convective heat transfer of air-water mist flow along a dry isothermal flat plate. As the result of an approximate solution of the integral equations, a practical semi-empirical dimensionless relation was established for predicting the heat transfer enhancing factor [H1]. Experimental study was performed on heat/mass transfer and pressure drop in a triangular-rib-roughened rectangular channel [H2]. Experimental results of heat transfer and flow resistance in some triangular and rectangular ducts with air and butyl alcohol as working medium were presented and compared with results from four roughened passages with ribs or rib-grooves on the wall[H3]. Measurements of heat transfer coefficients in a blade midchored convergent cooling passage were performed for walls with a single film cooling hole, multiple holes and combination of ribs with holes. Thermochoromic liquid crystals were used as high resolution surface temperature indicators to provide detailed local heat transfer coefficient and enhancement factor [H4]. Experiments on the flow resistance and heat transfer of the forced upward flow in an internal three-dimensional spin-fin - tube at moderate pressures were reported with water as working fluid at Reynolds numbers ranging from 4×10^4 to 2×10^6 and at pressures ranging from 33×10^5 Pa to 41×10^5 Pa. The correlations for the flow resistance and heat transfer were established and compared with that from other typical enhanced tubes [H5]. The heat transfer rate of a single liquid droplet of water, ethanol and F-113 impinging on a hot solid surface has been investigated experimentally. The effects of impinging velocity, wall temperature and impinging angle on the heat transfer rate were examined. By use of convolution principle , the transient surface heat flux was calculated from the measured surface temperature [H6]. An experimental investigation on average and local heat/mass transfer characteristics of a jet impinging on a screen-line rectangular cavity was conducted by means of naphthalene sublimation technique. The response of Sherwood number on bottom surface to the jet exit Reynolds number was examined [H7]. Single-phase liquid jet impingement was studied experimentally for simulated microelectronic chips and its recovery factors were obtained [H8]. An experimental study has been carried out for the forced convection heat transfer in non-Newtonian fluid in a small scale square duct at low Reynolds numbers. When the apparent Reynolds number $Re>11.5$, the non-Newtonian fluid starts to enhance the convection heat transfer depending on the Reynolds number, while friction factors of fluid are almost unaffected by the viscoelasticity [H9]. Flow patterns and their transitions on the shell-side of a segmentally baffled horizontal heat exchanger were studied experimentally. A dimensionless correlation was obtained for predicting flow regime transitions of air-water mixture flow in shell-and-tube exchangers[H10]. Experimental results on air side heat transfer and friction factor were reported for plate fin-and-tube heat exchangers in a wide range of Reynolds numbers. The results showed that the enhancement of heat transfer of slotted plain fin may be as high as 70%-80% compared to the plain plate fin [H11]. A concept of temperature difference field in heat exchangers was developed and a uniformity factor of temperature difference field was defined to measure the degree of uniformity. It was found that the more uniform the temperature difference field, the higher the heat exchanger effectiveness at the given number of heat transfer units and thermal capacity rate ratio[H12]. Based on the uniformity principle of temperature difference field a more vivid nonuniformity factor was recommended and applied to the analysis of multipressure condenser's performance. The optimum distribution of heat exchanger surface over the pressure zone for multipressure condensers was determined [H13].

I. Biological and Cryogenic Heat Transfer

The analytical studies of bioheat transfer was briefly reviewed and an analytical solution on the one-dimensional steady state temperature field of biotissue in vivo for second boundary condition was presented. The predicted results have been checked by experiments [I1]. The basic equation for biomedical heat transfer was analyzed. Based upon the porous medium model a corresponding equation has been proposed[I2]. It provides a hopeful prospect for determining the thermophysical properties of bio-tissue in vivo and a new technique for measuring the thermophysical properties and blood flow velocity of tissue in vivo has been developed [I3]. Analytical and experimental investigation were conducted for the prediction of critical cooling rate, which is significant for the citrification of cryoprotective solutions [I4]. The transient temperature field around a cryoprobe was investigated by applying the enthalpy model to solve the nonlinear bioequation and then the shape, growth rate and ultimate size of the cryolesion can be determined, which provide the fundamental information for cryosurgery [I5]. The boil cooling process of micro-samples quenched into saturated liquid nitrogen was studied on the experimental set-up equipped with a high speed data acquisition system. Four distinct regions of boiling curve measured by quenching method was discussed [I6].

J. Measurement Techniques

The surface temperatures of semiconductor devices were measured by means of micro-thermal video system and their body temperatures were obtained by numerical calculations. It was seen that the thermal contact resistance plays an important role in chip temperature rise [J1]. An image processing technique was developed for measuring the luminous-flame temperature distribution [J2]. A special pipe line, in which an upward inclined pipe was connected with a steeply downward pipe by an elbow, was used to produce slug or plug flow in the upward pipe and break up the film flow at the elbow. The slug flow velocity and the time fraction were measured by two bubbly flow void fraction sensors mounted on the upward pipe near the elbow [J3]. A periodic heat flow method for measuring diffusivity was developed using a laser beam as a periodic heat source. Diffusivities of stainless, molybdenum and copper films with the thickness ranging from 30-100μm were measured. Some effects such as heat loss and edge effect were discussed [J4]. Experiments were conducted for test method of thermal property of thin materials. Some improvements were made in setting the measuring point , reduced appendant thermal resistance and the determination of the thickness in order to raise the accuracy of measurements [J5]. An adiabatic calorimeter based on quasi-steady method for measuring the true specific heat of underground oil rocks in the range of 300-55K has been designed and constructed. The special features of this apparatus are fast measuring, easy replacement of sample, high accuracy of measurement and having a result indicator [J6]

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第３２回日本伝熱シンポジウム
企画部会特別セッション講演
－中国と韓国の伝熱研究の現状－

A Survey of Thermal Engineering Research Activity in Korea

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1. Introduction

Making a survey of the present status of thermal engineering research in a country is certainly no easy task. More than anything else, it is not altogether clear to what extent and on what basis such a scanning should be conducted. Thermal engineering, as we are well aware, encompasses broad spectra, covering the fundamental scientific aspects as well as the application-oriented disciplines of highly practical endeavors. When one is about to assemble pertinent information, one realizes that a status report of this type can never be completely objective. Faced with a simple demand that some kind of survey, although imperfect, should be produced, it has been decided that arbitrary criteria could be established to proceed with the project.

In an effort to portray the outlines of current status of thermal engineering research in Korea, data have been compiled from three major engineering journals in Korea, i.e., the transactions of Korean Society of Mechanical Engineers, the Journal of Air Conditioning and Refrigeration Engineers of Korea, and the Journal of Korean Institute of Chemical Engineers. A list has been made of the titles and authors' affiliations of the research articles in the above three publications. These are printed in the Korean language, although the majority of the references cited are in foreign languages. In order to emphasize the present state of affairs, the articles of the past three years (1992-95) have been targeted for this list.

I have to be quick to point out that the list thus obtained represents only a partial coverage of the current research activities of Korea. It is stressed that significant portions of the research output now find their appearance in non-Korean (international) journals and proceedings. Such research papers are therefore excluded from the present survey. Also, there is a trend in recent years in Korea that thermal engineering research projects are multi-disciplinary and large-sized. The results of such long-term, huge undertakings are oftentimes summarized in the form of project reports, rather than published in the open literature. Consequently, the present survey does not touch upon these recent overgrown-sized thermal engineering research projects.

One important, but difficult, question in a survey is how the quality of an individual research work can be assessed. It will be desirable if we could sift through these research articles and evaluate the merit and scope of contribution of each paper. However, in view of the fact that quality appraisal of individual papers is impracticable, only a superficial statistical sorting job has been done in the present survey. Despite all these shortcomings, it is hoped that a rudimentary outline can be drawn of the depths and widths of the present research activities in the realm of thermal engineering in Korea. It is added that I am apologetic to those researchers whose contributions might have accidentally been missed in this survey.

Before proceeding further, a declaration is made that the present survey does not necessarily reflect the views of any organizations or institutions. It is simply a task performed by my own personal initiatives, and it docs not bear official recognitions of any groups or establishments.

2. Research organizations and specializations

There could be several ways to illustrate the findings of the survey. One main motivation of the survey is to provide baseline information for future interactions and cooperations between thermal engineers in this part of the globe. In line with this spirit, the findings are arranged in a format which would describe the nature of the research and the individual research organizations concerned. The names of the researchers are omitted in light of the space limitations.

KAIST(韓國科學技術院) (大田)

Combustion (Radiative & conductive transfer, boiling, incinerator design, combustion technologies, mass transfer)
Turbulent heat transfer, turbo-machinery
Multi-phase (liquid spray) transfer
Heat engine (heat pump)
Convective heat & mass transfer
Energy technologies (radiation, thermal convection)

Seoul National University (Seoul)

Combustion (flame diffusion, turbulence)
Heat engine (diesel engine)
Convective transfer (stability, natural convection, porous mass transfer, two-fluid convection, Mixed convection, low-temperature natural convection, laminar heat transfer, convection in an enclosure)
Energy (co-generation, gas turbine, combustion, optics)

KIST (韓國科學技術研究院) (Seoul)

Combustion (combustion of used tires, delayed ignition)
Turbulent heat transfer
Heat engine (stirling cycle)
convective heat transfer (porous media, pipe flow)

KIMM (韓國機械研究院) (大田)

Combustion (droplet vaporization, ignition)
Heat engine (gasoline engine)
Heat transfer (jet impingement, image processing)

ADD (國防科學研究所) (大田)

Combustion (propulsion systems, solid propellant)
Heat engine (heat exchanger, internal combustion engine)
Convective heat transfer (radiation)

產業科學技術研究所 (Seoul)

Combustion (furnace technologies)

韓國Energy 技術研究所 (大田)

Combustion (coal-burning)
Multi-phase(steam technologies, desalination)
Energy (evaporation, capillary, porous media)
Environment (large-scale environmental chamber, individualized air conditioning)
Convection (thermo-electric conversion)

韓國動力資源研究所 (大田)

Combustion (municipal incinerator, heat exchanger)
Turbo machinery (blade cooling)

韓國Gas公社研究所

Combustion (optics application)

韓國原子力安全技術院

Multi-phase (stability)

韓國電力

Multi-phase (steam technology,desalination)

Convection (natural convection, internal heat generation)

生産技術研究院

Multi-phase (performance evaluation of air-conditioner, refrigerator)

Convection (cooling systems)

西江大學校 (Seoul)

Combustion (fluidized bed)

Energy (refrigeration cycle)

高麗大學校 (Seoul)

Combustion (gas diffusion flame, coal-burning)

Heat engine (gasoline engine)

慶熙大學校 (Seoul)

Combustion (mixing technology, ignition)

Multi-phase (counter-current flow)

仁荷大學校 (仁川)

Combustion (coal-burning, mixture burning)

Turbulent heat transfer

Convection (porous media)

成均館大學校 (Seoul)

Combustion (lean-burning, flame promoter)

Multi-phase (evaporation)

Convection (natural convection, stability theory)

Energy (energy-saving construction, solar energy)

漢陽大學校 (Seoul)

Turbo machinery (blade cooling, convection)

Convection (convection in enclosure, heat & mass transfer in evaporation, spray)

Combustion (pulsating heat transfer, blade cooling)

Turbulent heat transfer (film cooling, blade)

崇實大學校 (Seoul)

Combustion (Schliren technique)

國民大學校 (Seoul)

Turbulent heat transfer (natural convection, internal heat generation)

韓國航空大學校 (Seoul)

Heat engine (heat exchanger, propulsion)

延世大學校 (Seoul)

Convection (heat exchanger, fluidized bed, porous medium)

Material processing (CZ crystal growth)

Heat engine (heat exchanger, internal combustion engine)

建國大學校 (Seoul)

Heat engine (diesel engine, combustion)

中央大學校 (Seoul)

Heat engine

Combustion

陸軍士官學校 (Seoul)

Convection (plume, heat transport)

Energy (heat pump, dryer)

東國大學校 (Seoul)

Radiative heat transfer

Heat transfer enhancement

弘益大學校 (Seoul)

Multi-phase (film boiling, interface)

嶺南大學校 (大邱)

Combustion (temperature measurement)

Heat engine (engine cycle,thermodynamics)

Convection (numerical technical techniques, natural convection)

釜山大學校 (釜山)

Combustion (gas turbine, burner, fluidized bed, coal-burning)

Turbulent heat transfer

Heat engine (heat exchanger, LDV, gasoline engine, diesel spray)

東亞大學校 (釜山)

Combustion (liquid drop evaporation)

Convection (fin, natural convection)

浦項工科大學校 (浦項)

Combustion (furnace technology)

Experimental techniques (jet impingement, image processing)

韓國海洋大學校 (釜山)

Heat engine (MHD, plasma)

Heat exchanger

慶尙大學校 (慶南)

Heat engine (VM heat pump, regenerator, insulation techniques)

昌原大學校 (慶南)

Diesel engine, Combustion

錦烏工科大學校 (慶北)

Thermal power (thermohydraulic)

Heat transfer (mixed natural convection, radiative transfer)

釜山水産大學校 (釜山)

Heating & Refrigeration

慶北大學校 (大邱)

Convection (low-temperature natural convection)

安東大學校 (慶北)

Low-temperature natural convection

慶北産業大學校 (慶北)

Convection (plume)

全北大學校 (全州)

Mixed convection

順天大學校 (全南)

Forced convection

群山水産專門大學 (全北)

Combustion (laser applications)

朝鮮大學校 (全南)

Multi-phase (counter - current flow)

Combustion (laser applications)

木浦大學校 (全南)

Combustion (laminar flame)

江原大學校 (江原)

Combustion (Coal-burning)

Fin heat transfer

忠南大學校 (大田)

Combustion (Coal-burning)

Turbulent heat transfer

Diesel engine

Solar energy

忠北大學校 (忠北)

Turbulent heat transfer

Convection heat transfer

Thermal storage

忠淸專門大學 (忠南)

Heating (Ondol heating)

大宇自動車

Electronic ignition

Combustion promoter

現代重工業

Natural convection

現代自動車

Radiative heat transfer

Combustion promoter

Schliren photography

三星電子

Thermal imaging

三星綜合技術院

Solid propellant combustion

金星社

Turbulent heat transfer

起亞自動車

Diesel engine combustion

汎洋冷房工業

Large - size refrigerator

Cooling fan

京仁機械

Cooling tower

Seyoung 空調

Apartment heating

大宇 Carrier

Refrigerant

慶原世紀

Absorption - type , heat pump

金星電線

Absorption - type

3. An overview

As is apparent in the above list, there seem to be several technical subjects under intense study, i.e., various aspects of combustion-related topics, multi-phase heat and mass transfers, practically-oriented heat engines, and air-conditioning and refrigerations. One may say that these are rather conventional technical issues, and the so-called leading-edge technological innovations do not appear to be numerous. A historical summary may be in order.

Substantive research and development activities in thermal engineering in Korea began in early 1970's. This coincides with the period of rapid industrialization, particularly in petrochemical and high-tech heavy industries, in Korea. Also, around this time universities started serious endeavors in post-graduate education in engineering and technology. In this sense, the history of meaningful R&D in thermal engineering covers the past 25 years or so. However, it is important to note that the pace of R&D expansion, in quantity as well as in quality, has been remarkable, and it is further accelerated in recent years.

Another noticeable factor for such a fast-growth research environment is the trained manpower. As indicated earlier, the bulk of R&D workers in Korea tends to be young, the median profile being probably around 40 years old. A large number of college graduates proceed to post-graduate-level engineering educational institutions, in and out of Korea. The percentage of high-level R&D personnel in Korea is believed to be quite high in comparison to other industrialized nations.

Another thrust is in the direction of globalization. The initial impetus of research efforts in Korea in early 1970's was carried out mostly by those Korean students who were returning to Korea after having undergone post-graduate trainings in the United States. It was therefore natural that the methodologies and materials of research have been influenced by the teachings and orientations of the U.S. universities. Also, out of a desire to become more "international", emphasis was placed on interactions and cooperations with the international research communities. Let's take an example of KAIST. From its inception more than twenty years ago, KAIST has had a firm and unquestioned policy on the acceptance of a Ph. D. dissertation. The requirement is that, in order to present a qualified Ph. D. thesis, parts or the whole content of a Ph. D. thesis should have been published (or accepted) in an internationally-recognized professional archive journal. One may argue the merit of such a policy, however, this academic regulation has helped uphold the scholastic tradition of KAIST and gain a footing in the international science & technological theaters.

In summary, R&D in thermal engineering in Korea is still in a developmental stage. However, it is stimulating that the major work force is relatively young and motivated. There also is a growing tendency to diversify the international contacts, apart from the once-dominant liaison with the U.S. institutions.

Finally, in an effort to depict the cross-section of the most current thermal engineering research, the titles of the papers presented at the 1995 Spring Meeting of the Korean Society of Mechanical Engineers are shown below.

1. Transient natural convection cooling in a vertical open top cavity with discrete heat sources.
(慶北大學校)
2. Three-dimensional natural convection cooling of the electronic device with vents.
(漢陽大學校)
3. Natural convection cooling of discrete heat sources located symmetrically in a vertical open top cavity.
(慶北大學校)
4. Weakly nonlinear horizontal layer in a buoyant driven cavity flows.
(電子部品綜合技術研究所)
5. The study on fluid flow and heat transfer around the circular cylinder located on a flat plate in crossflow.
(釜山大學校)
6. A program to predict the performance of condenser coil used in air-conditioner.
(浦項工科大學校)
7. Modeling of the combined mode heat transfer in 3-D furnaces with laminar anisotropic scattering media.
(中央大學校)
8. Heat transfer from a round jet impinging on convex hemispherical surface.
(仁濟大學校)
9. A numerical study on heat and mass transfer in a vertical tube absorber cooled by air.
(生産技術研究院, 漢陽大學校)
10. Development of a P.C. software for design of shell and tube heat exchanger.
(嶺南大學校)
11. Effect of gap width on conjugate heat transfer in cylindrical annulus for an insulated tube.
(東亞大學校)
12. Transient heat transfer in thin films.
(嶺南大學校)
13. A study on the radiative heat transfer of compressible turbulent flow in a backward facing step.
(KAIST)
14. Light scattering and absorption by a radially inhomogeneous sphere.
(弘益大學校)
15. Cusp magnetic field applied Czochralski method analysis simulating radiative heat transfer.
(浦項工科大學校)
16. Analysis of equation of transfer using finite volume method and its application.
(KAIST)
17. Analysis of particle deposition in the flow past a circular cylinder including the effect of radiative heat transfer.
(Seoul大學校)
18. Heat transfer and pressure drop with the turbulence promoter in a vertical PCB channel.
(萬都機械, 漢陽大學校, KIST)
19. A study on the heat transfer characteristics of closed two-phase thermosyphon with small tilt angle.
(成均館大學校)
20. A experimental study for the effect of an electric field on boiling heat transfer of R113+wt4% Ethanol.
(中央大學校)
21. Prediction of R-22 condensation heat transfer

coefficient inside horizontal tube in annular flow regime.

(嶺南大學校, 安東專門大學)

22. A study on condensation heat transfer enhancement of low-finned tubes.

(仁川大學校,大宇自動車,錦烏工科大學校)

23. The analysis of flow and transient heat transfer for 2-cylinders with heat generation.

(現代自動車, 高麗大學校)

24. Numerical analysis on the fluid flow and heat transfer around two tandem cylinders in the presence of an oscillating flow.

(釜山大學校, 韓國重工業)

25. A numerical study of jet impingement for turbine blade cooling.

(大宇自動車, 中央大學校)

26. Study for a secondary air affecting fluid flow in a solid waste incinerator.

(公州大學校)

27. A study on turbulent flow and heat transfer in the roughened concentric annuli with uniform wall heat flux.

(慶尚大學校, 釜山大學校)

28. A numerical study on the effect of turbulence models on the cold flow patterns in an entrained flow gasifier.

(韓電技術研究院, 韓國ENERGY技術研究所)

29. Particle-imaging thermometry and velocimetry (PITV); simultaneous spatial temperature and velocity measurement of a vertical buoyant jet.

(海洋大學校)

30. A study on the natural convection flow measurements using multiple exposure particle image analysis.

(大宇重工業, 國民大學校)

31. A study on tomographical transformation of liquid spray structure for 2 hole nozzle by multiangular scanning.

(Seoul大學校)

32. An experimental study of heat transfer and particle deposition during the outside vapor deposition process.

(Seoul大學校)

33. Evolution of the particle size distribution during the flame symthesis of the fine particles.

(Seoul大學校, 延世大學校)

34. Analysis of solute redistribution during solidification of a binary metal alloy by the integral approximation.

(崇實大學校)

35. Erosion characteristics of in-bed tubes in fluidized bed cold mode reactor.

(韓國ENERGY技術研究所, 忠南大學校)

36. Analysis of combined thermocapillary flow with rotation in a cylindrical liquid column.

(韓國電力技術(株), 高麗大學校)

37. Three dimensional analysis of in-cylinder flow and combustion in a direct injection diesel engine.

(浦項工科大學校)

38. Discussions on the combustion response function of solid propellants.

(國防科學研究所)

39. Flame structure and NOx emission characteristics of natural gas.

(Turbo 動力機械研究 Center, Seoul大學校)

40. A study on the stabilization characteristics of the diffusion flame with the auxiliary fuel injection.

(韓國原子力研究所,全北大學校)

41. Numerical study of swirling turbulent reacting flows.

(漢陽大學校, 韓國機械研究院)

42. Design and testing of an annular combustor for aircraft turbo-fan engine.

(韓國航空宇宙研究所)

43. The exhaust gas liquefaction system of the closed cycle heat engine operating in underwater.

(蔚山大學校, Seoul大學校)

44. A new approach of exergoeconomic analysis of thermal systems.

(中央大學校, 曉星重工業)

45. A study on the design of high-temperature superconductor current leads.

(全南大學校)

46. A study on the characteristics of radical luminous intensity and flame structure of turbulent diffusion flame.

(釜山東義工業專門大學, 釜山大學校)

47. Characteristics of lean burn by multi spark capacitor discharge ignitor for engine.

(仁德專門大學, 起亞自動車, 成均館大學校)

48. A study on the characteristics of mixtures and flame scale.

(釜山大學校)

49. An one-zone heat release analysis of 6 cylinder compression-ignition engine.

(延世大學校)

50. Effects of discharge energy characteristics of high frequency ignition system(HIS) and flow on the ignitability.

(東亞大學校)

51. A study on the combustion characteristics of methane/hydrogen-air mixtures.

(江原大學校, 九州工業大學)

52. A study on the development of high efficiency type heat pump.

(釜山水産大學校, KIMM)

53. The performance analysis of the refrigeration system using alternative refrigerant HFC-131a.

(嶺南大學校)

54. Evaporative heat transfer of refrigerants inside a tube heated by a fluid.

(Seoul大學校)

55. A study of receiver dryer for automotive air-conditioning system.

(大宇電子,自動車部品研究院,慶熙大學校)

56. Effect of design factors on frost formation of fin-tube heat exchanger.

(漢陽大學校)

57. A study on the heat recovery from boiler exhaust gas with combined system of direct contct heat exchanger & heat pumps.

(韓國ENERGY技術研究所, 忠北大學校)

58. Droplets behavior characteristics in sprays/spray flames of non-swirling and swirling air blast nozzle using phase/Doppler technique.

(釜山大學校)