Heat Transfer in High Technology and Power Engineering

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HEAT TRANSFER IN HIGH TECHNOLOGY AND POWER ENGINEERING

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Preface

In order to exchange first-hand information on research results and to promote mutual understanding and friendship for future cooperative effort in research, the U.S. National Science Foundation and the Japan society for the Promotion of Science have twice jointly sponsored binational heat transfer seminars, under the United States-Japan Cooperative Science Program. The first gathering was held in Tokyo in October 1980. The proceedings of the joint seminar were published in 1982 by the Hemisphere Publishing Corporation under the title *Heat Transfer in Energy Problems.* The book title reflects the major theme of the meeting. Five years have passed since then, with a shift in research efforts. During this period, the world has experienced a decline in oil prices and a glut in oil supply. Although efforts on energy savings remain unabated in Japan, which imports over 90 percent of its energy needs, the interest in energy research in the United States has obviously diminished. Instead, high technology has attracted the attentions of the public and government in both the U.S. and Japan during the last several years. In order to keep up with the times, the second binational heat transfer seminar was held, with the emphasis on heat transfer in high technology and power engineering, in San Diego on September 17–20, 1985. This book is the proceedings of the second meeting.

The first chapter introduces current heat transfer research in Japan, which represents a concerted effort of academia, government, and industry. Emphasis is directed toward energy and high technology fields.

The text is divided into four parts: I, Heat Transfer in High Technology; II, High Heat-Flux Technology; III, High-Performance Heat Exchange Devices; IV, Radiative Heat Transfer and Solar Energy Utilization.

In Part I, the role of thermocapillary flow in heat transfer is studied in view of its importance in space processing, such as superpure crystal growth under reduced-gravity environment. Techniques of heat transfer and flow control in space machinery in Japan during the past five years are surveyed. These include thermal control in satellites, electric propulsion, and materials processing in space; flow behavior under microgravity; and space cryogenics. The application of heat pipes in cooling is extended to devices in space and terrestrial uses. Heat transfer related to materials processing, a subject of current interest, is represented by three articles dealing with heat bonding processes, molecular clustering, and the growth of large single crystals. Another subject of current importance is heat transfer in electronic equipment. Amazingly enough, the articles on electronic equipment cooling are contributed by three giants in the electron industry: IBM, TI, and NTT.

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Part II deals with high heat-flux technology, typically boiling and condensation. Recent advances in boiling heat transfer are covered in the articles on critical heat flux, post dryout heat transfer prediction, boiling on high temperature materials, high heat-flux flow boiling, and boiling enhancement techniques. A review on the status of condensation heat transfer is also presented. The applications of high flux heat transfer cover nuclear power systems, very high temperature gas-cooled reactor (VHTR), aeropropulsion systems, and hazardous waste incineration.

High performance heat exchange devices are discussed in Part III. Naturally, high performance can be achieved by applying various enhancement techniques. Recent development in heat transfer enhancement is summarized, specifically for high-temperature heat exchangers. Details are available for the enhancement by mist flow, turbulence promoters, and electric fields. Two important problems in heat exchanger applications, namely fouling and flow-induced vibrations, are reviewed comprehensively. Also presented are the articles on automotive heat exchangers, heat exchanger simulation, optimum design of compact heat exchangers, and turbulent heat transfer.

The fourth part of the text is concerned with radiative heat transfer and solar energy utilization, which are essentially high-temperature technology. In radiation heat transfer enthalpy-radiation energy conversion, plasma-surface interaction, and application of the Monte Carlo method are presented. Some recent developments have been made in high temperature solar thermal energy systems for possible industrial applications. Recent work on numerical simulation of turbulent natural convection in solar application is summarized. The last article deals with natural convection in solar energy utilization as well as high technology applications.

Material in the text is suitable for reference in heat transfer research. The sponsorship of the meeting by the NSF and the JSPS is greatly appreciated. We wish to thank Professor I. Tanasawa of the Institute of Industrial Science of the University of Tokyo and Dr. D. L. Vrable of GA Technology for their efforts and devotions to the meeting. We are also indebted to Miss Ling H. Yang, an engineering graduate student and Mr. Paul P. T. Yang, an engineering student, both at the University of Michigan, for their editorial assistance. Our appreciation is extended to the dedication of all the participants.

Wen-Jei Yang
Yasuo Mori

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Present Status of Japanese Heat Transfer Research in Energy and High Technology Fields

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1. INTRODUCTION

It may be said as a review of the last US-Japan Heat Transfer Seminar in 1980 that most of the heat transfer researches at that time concerned energy problems, while recently many demands have been made to solve heat transfer problems in high technology fields. As for energy problems, in the past several years, due to the apparent complacency throughout the world, energy problems seem to have less importance. Consequently, in many advanced countries the governments and private industries have been making more research and development investments in fields associated with what is so called high technologies than in the energy field. It should be noted, however, that the substance of energy problems of a country depends much on her own energy resources and annual energy consumption. For Japan, energy problems and their seriousness have aspects and situations somewhat different from what they are to the US. Consequently, the recent research and development subjects taken up and pursued in the two countries have their own characteristic features. As is well known, Japan is scarce in energy resources. Therefore, while the Japanese Government and private sectors have been fervently promoting research and development activities in various kinds of high technology, the Japanese Government has taken a long range view and has been spending much of its funds for research and development on energy resources and many energy-conserving ways and processes even since the first oil crisis. On the other hand, industries such as steel, chemical and the like that consume much energy have been making serious effort in R & D activities for energy conservation in their production processes or to build new manufacturing systems invented after several researches including those on heat transfer problems.
In what follows recent heat transfer researches in Japan will be summarized and assessed, putting main emphasis on basic researches.

Researches associated with energy are roughly divided into three categories. One is that promoted by the Agency of Industrial Science and Technology, Ministry of International Trade and Industry and is classified into a program to develop new energy technologies for securing future energy supplies, called Sunshine Project. The other has the aim of energy conservation, called Moonlight Project. The Sunshine Project was initiated in 1974, but its major program was modified in 1982 so as to take into account recent energy situations such as mitigation of strain in the international oil supply, various results of development of new energy technologies, the world's trend toward the introduction of alternative energy for replacement of oil as well as the progress in energy conservation activities.
A long-term schedule for the Sunshine Project includes projects for solar, geothermal, hydrogen, wind and ocean energies but not for nuclear energy.

Among these projects which practically include heat transfer problems as one of the main subjects, there have been the solar thermal power generation pilot plants, and the development of a 10MW class binary cycle utilizing geothermal hot brine. However, the solar thermal power plants were dismantled because the experimental power performance was inferior to the estimated value.
As Japan is expected to have wide-spread geothermal energy resources over its whole land, the Japanese Government has set the primary importance on geothermal energy among the natural energies, and has been developing several projects. In one of them, the binary cycle power generation project, the recent results predict that some mixture of freon could have a cycle performance higher than that which uses a single component substance. Boiling and condensation heat transfer performances for mixtures of some kinds of freon such as R-114 and R-115 have been tested by using a loop provided with boiling and condensing parts of practical construction. The researches developed by the Sunshine Project have not so far made any practical contribution to relaxing the energy situation in Japan in the way of reducting oil imports.

The Moonlight Project has five large-scale projects and other programs such as the financial assistance to private enterprises and energy conservation through standardization. The five big projects are going on. They are an advanced gas turbine, advanced battery electric power storage system, fuel cell power generation technology, Stirling engine for wide use and super-heat pump energy accumulation system. An advanced gas turbine of 1300°C inlet temperature is expected to afford about 50% thermal efficiency by use of a combined cycle. The feature of the cycle is to adopt a high pressure ratio such as 55, but no important heat transfer problems are involved, as the problem caused by high turbine inlet temperature is to be solved by R & D of ultra-high heat resistant metal or ceramics.
In the project of the fuel cell, several stages of research and development have been planned with the view to develop a commercial scale power plant of high efficiency and of capability to supply heat to houses and industries. The construction of two 1000kW of low and high pressure types is under way and they will be operated within a couple of years. After these first generation fuel cell plants as they are called, MITI is planning to proceed to the second generation fuel cell by using the molten carbonate fuel cell and the third one by using the solid oxide fuel cell. On the other hand, Tokyo Electric Power Company imported a fuel cell plant of the second generation from United Technology Co. in the US, and generated the world's largest electric output of 4.5MW last year. But after a couple of operations, they found some breaks and flaws in the high temperature compact plate-fin heat exchanger which was operated at an inlet temperature of about 650°C. There has been an alternative proposal to replace this compact heat exchanger by a shell tube heat exchanger. But in consideration of construction space an investigation to develop a compact heat exchanger that can be used for a long time at 650°C has been carried on by a committee of the Tokyo Electric Company. The committee has been putting importance on a study of stress distributions in the compact exchanger at high temperatures and on relaxing the high stresses by providing the optimum distribution of heat transfer coefficient in the hot and heated flow channels. In other words, first a construction adequate for less stresses is to be selected by a two-dimensional heat transfer and stress analysis. This kind of research approach should be used in future heat transfer research associated with high technology. In other words, from now on, not only the maximum heat transfer performance but heat transfer problems under the condition that has not studied so far or optimizing factors other than heat transfer performance as described in the above example will require clarification.
As one of the measures for the promotion of conserving energy mainly in the private sector not only by generating mechanical power but by supplying heat to surrounding houses and also for utilization of alternative fuels, the Stirling

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engine has been taken up in the Moonlight Project. Low emission and less noise features of the engine also have stimulated various engine makers to R & D. but several heat transfer problems are associated with the regenerator and heater. Particularly these problems should be solved by developing a new way of heat transfer enhancement and several researches have been carried on in National Mechanical Laboratory and private sectors.
Another interesting project in the Moonlight Project is a large-scale R & D project for energy conservation called Super-Heat Pump Energy Accumulation System. This project started to recover low-grade exhaust heat which has so far been wastefully released to the surrounding area and which amounts to about 50% of total energy consumption in Japan. The reasons why this heat pump project is given a nickname of Super-heat-pump is that the project aims to increase the coefficient of performance up to 6 or 8 from the conventional value of 3 or 4 and to pump the heat from a low temperature source up to about 300°C. The project aims to develop a chemical heat pump system by using chemical reactions such as exothermic absorption of water to zeolite. In this project, one of the most interesting heat transfer problems is a research project to develop a high performance condenser by use of electro-hydrodynamic phenomena and Dr. A. Yabe, who is in this Seminar will disclose the fundamental mechanism of EHD enhancement of condensation and some of his recent results for practical condensers.

Concerning future nuclear power plants, many heat transfer problems associated with FBR are studied for its safety. However, it should be stressed here that the Japanese Government has been putting importance on the high temperature gas cooled reactor. In 1973, the research and development of direct steelmaking with the use of high temperature reducing gas obtained from HTGR had been taken up as one of the large scale projects by MITI. In this project the world's largest loop of 1000°C highest temperature and of 4.5MP pressure was built and equipped with a 1.5MW He-He heat exchanger. The project was successfully completed after operating over 3000 hours. In this project, researches on many heat transfer problems were performed to bring the project to success and the results were reported. In parallel with this project, the Japan Atomic Energy Research Institute at Tokai Mura has proceeded with the project of a 50MW experimental high temperature gas cooled reactor for power generation and multi-purpose use. The high thermal efficiency of about 40% and the effective utilization potential to chemical processes requiring high temperature heat should be the main features to stimulate the R & D of HTGR. The concrete applicable fields of high temperature heat, based on the promising prospect of technical and economical feasibility, have been seriously studied in Japan. One of the promising fields is hydrogen production not only by the conventional reforming process, but by the thermo-chemical decomposition of water. Use of hydrogen as the future fuel should be discussed and studied from a long-range standpoint, because the environmental problem of the increase of CO_2 concentration in atmosphere is becoming aggravated more and more with the increase in consumption of oil, natural gas and coal. A recent cost estimate of hydrogen production by the advanced water decomposition process using heat from HTGR is reported to be only about 1.2 times higher than that by the conventional reforming process. In the R & D of HTGR of high reliability and with the reactor outlet temperature of about 950°C, many heat transfer problems have to be explored and solved. Some of the recent research results will be reported in this Seminar by a researcher of JAERI.

In this Seminar, researches on the basic sciences of heat transfer problems would be attractive and worthy to be discussed, since the majority of the participants in this Seminar are university professors. Most of the essential researches in this category in Japan have been carried out in the frame of the Special Project Research of Energy under Grant in Aid of Science Research of the Ministry of Education, Science and Culture. The projects, closely associated with heat transfer researches, are divided into the first and second phases. The project of the first phase was performed from 1978 through 1980. The researches involved in this first phase were reviewed by Professor Emeritus T. Mizushina, Kyoto University and the details were reported by individual researchers at the last Heat Transfer Joint Seminar. Therefore it is referred to here no more.

The second phase started in 1981 after a serious check and review of the results of the first phase. The selection of a new research title and formation of a new research organization adequate to the new title were made. The second phase project on thermal energy contained many heat transfer researches and was also performed in the frame of the Special Project of Energy by MESC. The second phase continued for three years and the symposium for reporting the final results of its researches was held this past January. The title of the second phase project is Effective Use of Thermal Energy, but the project was asked to put special emphasis on the limits of utilization of thermal energy such as critical heat flux and the maximum performance in heat transfer. The research was conducted in the following three divisions.

(1) Research on the optimum utilization and the utilization limit of available energy of low and medium grade.
(2) Utilization limits of available energy at high temperature levels.
(3) Fundamental researches on the limit of energy conversion by combustion.

The researches in the first and second divisions are closely related to heat transfer sciences. 19 subjects in the two divisions were studied by researchers from universities. The subjects and the names of respective researches are listed below with a number at the head. Those which belonged to the first division begin with 1 and the second with 2.

1.1 Inquiry into selection of optimum working fluid from simple and compound systems, by N. Ototake, Tokyo University of Agriculture & Technology.
1.2 Optimization of convective heat transfer and its application to energy conversion, by Y. Mori and K. Hijikata, Tokyo Institute of Technology.
1.3 Development of the highest performance boiling surface and its application to heat exchanger, by K. Nishikawa, T. Ito, S. Yoshida and Y.Fujita, Kyushu University.
1.4 Two-phase flow instability and its effect in cryogenic systems under boiling-condensation existence, by S. Hasegawa and K. Fukuda, Kyushu University.
1.5 Prediction of capillary limit in wicked heat pipes, by S. Ohtani, Tohoku University.
1.6 Augmentation of forced convection heat transfer using novel rib-type turbulence promotors, by I. Tanazawa, S. Nishio, K. Takano and H.Miyazaki, University of Tokyo.
1.7 Development of energy-saving materials utilizing superelasticity, by K. Ohtsuka and S. Miyazaki, Tsukuba University.
1.8 High performance of combined type of latent-and sensible-heat thermal storage, by Y. Hayashi, A. Takimoto and S. Kawahara, Kanazawa University.
1.9 Basic study for optimum design of heat exchanger to be used for recovery of thermal energy from waste gas, by K. Suzuki, Kyoto University.
1.10 Augmentation of direct-contact liquid/liquid heat transfer by the application of an electric field, by Y. H.Mori, N.Kaji and A.Nagashima, Keio University.
2.1 Boiling heat transfer from high temperature surface, by I. Michiyoshi, Kyoto University.
2.2 A series of studies focussed into a systematic understanding of critical heat flux in forced convective boiling, by Y. Katto and S. Yokoya, University of Tokyo.
2.3 Boiling transition phenomena and heat removal limits at transition high power generation, by Y. Kozawa and S. Aoki, Tokyo Institute of Technology.

2.4 Optimization of fin array in boiling heat transfer, by T. Takeyama, Tohoku University.
2.5 Studies on heat transfer and critical heat flux condition in subcooled flow boiling, by T. Ueda, University of Tokyo.
2.6 Basic thermal performance of thermal storage materials for high temperature use, by K. Kobayashi, N. Araki and Y. Iida, Shizuoka University.
2.7 Assessment of technical feasibility of energy conversion system using gas clathrate as working medium, by H. Nishiyama, University of Tokyo.
2.8 Effects of hydrodynamically influential factors on the full-coverage film cooling, by M. Hirata, N. Kasaki, M. Kumaka and M. Akiyama, University of Tokyo.
2.9 Heat Transfer to freon in the critical region, by S. Yoshida, H. Mori and M. Ohno, Kyushu University.

We are now in the third phase of the Special Research Project on Energy. The target and organization of the third one are more or less different from the second in putting less importance on combustion and in introducing several new researchers on studying boiling and condensing heat transfer performances of mixtures. However, the third phase started in the last fiscal year. Few results will be reported in this seminar.

Besides the project of Research on Efficient Use of Thermal Energy by MESC, the project of Research on Natural Energy also by MESC has been carried on. In this research project, several heat transfer researches are included such as heat transfer associated with OTEC, but no detailed explanation will be made in this paper.

Researches on heat transfer science and technology in the so-called high technology fields in Japan are carried on in many subjects. However, over most of the high technologies serious competition in research and development is going on in Japan; mainly among private sectors and the substance and function of a high technology is developing and varying day by day. A fairly large number of so-called high technologies include heat transfer problems under a specified condition. Quite a few researches, however, are classified and the recently developed results are not positively disclosed. Scientific parts of researches, however, do interest heat transfer researchers if they are more basic and scientific. Three months ago, an advanced course entitled Advanced Technologies and Thermal Control was held by the Thermal Engineering Committee of Japan Society of Mechanical Engineers. In the following the topics taken up in the advanced course are explained. Those topics are believed to fairly reflect serious concern about heat transfer problems in high technology in Japan which are attractive and interesting to researchers in universities and industries. Ten topics were finally selected by the Committee and among them one is related to combustion of extremely low caloric fuel and combustion enhancement techniques. The other nine are directly concerned with heat transfer and two of them with heat transfer science. Among the remaining seven, one is related to heat storage by use of latent heat in consideration to solar heat and waste heat recovery applications. The scientific topics cover heat transfer enhancement by use of electro-hydrodynamical effects and of radiative heat transfer at high temperatures. The former will be reported in detail by Dr. A. Yabe in this Seminar. A feature of the latter should be explained. The speaker on the latter topic was Mr. H. Hirano, Mitsubishi Heavy Industry Co. He developed and proposed a new enhancement mechanism of radiative heat transfer by taking into account the multi-band feature of radiative gas such as combustion gas. In consideration of the fact that the conventional approximation treatment of radiative gas as a gray gas does not give a correct answer when heat transfer enhancement is made by placing radiative plates in the gas, he made clear the difference of the results analyzed by the newly developed multi-band treatment and the gray gas approximation, and has come to the conclusion that a more exact result is obtained by a complicated analysis and numerical calculation and that a higher enhancement can be expected by the new analysis. He stressed that an application of his results to furnaces heated by combustion gas and reforming equipment is a promising one.

The followings were the selected topics by the Committee:

(1) The technology of extremely rapid cooling for producing metallic amorphous materials.
(2) The control technology of thermal condition in space vehicles.
(3) The technology for cooling electronic devices.
(4) Heat transfer problems at cryogenic temperatures.
(5) Heat transfer problems related to fusion reactors.
(6) Thermal engineering technology used in various kinds of sensors.

Among the technologies for manufacturing amorphous materials, one newly developed method which is different from what uses two exceedingly cooled parallel rollers is the application of the molecular cluster technique by use of rapid cooling in highly expanded flows. The science of this technique and some of its applications related to amorphous manufacturing will be reported in this Seminar by Prof. S. Kotake, while at the advanced course the conventional technique was explained by Prof. I. Ohnaka, Ohsaka University. The control technology of thermal condition in the space vehicle was explained at the advanced course by Dr. Y. Miyazaki, Toshiba Co. In this Seminar, however, this particular topic and other related heat transfer problems in the space vehicle is reported by Dr. S. Enya, Ishikawajima-Harima Heavy Industry. A review of an aspect of this problem in Japan is explained in the chapter after the next. The technology for cooling electronic devices was one of the most attractive topics in the advanced course and it should be in this Seminar, too. The topic was pursued by Dr. W. Nakayama, Hitachi Co. and he will speak on it again in this Seminar. Heat transfer problems at cryogenic temperatures would include those associated with helium liquefiers, the cryostat equipped with super-insulation and techniques already employed in devices that use superconductors, but no explicit report will be made from the Japanese side in the Seminar. Concerning the topic about heat transfer techniques related to fusion reactors, the present status of thermal designing in case of disruption and some fundamental experiments carried at JAERI were taken up by Mr. A. Seki, but no report will be presented in the Seminar.

In the next chapter, recent research activities of heat transfer in energy field in Japan will be reviewed, putting emphasis on those involved in Special Project of Research on Energy supported by Ministry of Education, Science and Culture, but excluding those which will be reported in this Seminar by the researchers themselves. In addition to these, heat transfer research and development activities in steel industries in Japan during the past decade for energy conservation will be explained, because they have contributed enormously to the decrease of the amount of imported oil in Japan. I would like to take up this problem found in private sectors, because many energy consuming industries in Japan have followed up the examples of steel industries to save energy and lower the cost of their products. These facts have lead to annual decreases of imported oil in Japan. In the chapter after the next, of which concerns heat transfer in the high technology field the present status of heat transfer research related to the cooling of electronic components and thermally controlling techniques in space machinery will be reviewed.

2. HEAT TRANSFER IN ENERGY FIELD

The projects performed in the Research on Effective Use of Energy under Special Project Research of Energy by Ministry of Education, Science and Culture (SPRE-

MESC) from 1981 to 1983 are listed in the INTRODUCTION. The projects related to heat transfer are divided into two groups with the research titles of
(1) Research on Optimum Utilization and the Ultimate Limit of Available Energy of Low and Medium Grade and
(2) Utilization Limits of Available Energy at High Temperature Levels.
The former group project aimed at carrying out fundamental researches on utilization and recovery of available energy of low and medium grade. It consisted of researchers on heat transfer surfaces of optimum heat transfer performance for energy utilization, conversion and recovery and the limit of flow instability due to heat transfer.
Prof. H. Ototake made research on"Inquiry into Selection of Optimum Working Fluid from Simple and Compound System" and a technical method for the selection of optimum working fluids was studied. The ideal combination of basic properties leading to the most desirable condition was determined first by optimizing technology concerning the essential factors in the equation of state. Peng-Robinson's equation of state was selected because of its convenience of plain calculation and its excellent ability. Typical compound systems of R-22+R-12 and R-114+R-12 were experimented on. Transport properties of liquid state over the range of boiling points were correlated. The results of those studied have been applied to over 200 kinds of system.
"Two-phase flow Instability and its Effects in Cryogenic Systems under Boiling-Condensation Existence" was studied by Prof. S. Hasegawa. Two-phase flow instability caused operation limits in cryogenic systems due to decrease in heat transfer rate, increase in pressure drop, and oscillations of composing structures. In this study, experimental results of two-phase flow instability in liquid nitrogen heat exchangers were shown. Visual observation study revealed that two unstable regions existed at low flow rate and high flow rate conditions and that the corresponding flow patterns were the slug and the annular flows, respectively. By use of a newly developed computer code, experimental data were analysed and it was found that the oscillations were those of the density wave mode.
Prof. S. Ohtani studied "Prediction of Capillary Limit in Wicked Heat Pipes". A new measurement technique was presented for working liquid transport properties, such as capillary suction pressure, permeability and apparent diffusivity. Validity of the new method was confirmed by comparing it with the steady state drying method. Saturation distribution within the wick was calculated for several kinds of heat pipes under various operating conditions. The maximum rate at the capillary limit was predicted by taking account of the saturation dependent permeability and apparent liquid diffusivity. Good agreement was obtained between predicted and experimental data for maximum heat transfer rate at the capillary limit.
"Development of Energy-saving Material Utilizing Superelasticity" was made research by Prof. K. Ohtsuka. His work was undertaken to find out the metallurgical factors to improve superelasticity characteristics in Ti-Ni alloys. The key point was found to increase the critical stress for slip. For that purpose, the effect of aging, cold work and Ni content on the superelasticity was systematically investigated. The superelasticity characteristics were found to be improved remarkably by aging and/or by annealing after cold work. The energy density and the energy storing efficiency thus obtained were $42MJ/m^3$ and 81% respectively for Ti-50.6 at % Ni alloy.

The other research group worked on at utilization of important available energy at high temperature levels which forms a large part of usable thermal energy in the present-day world, and the studies on the promotion of its effective use are extremely desired. One of the urgent problems concerned is to develop effective means to control the critical phenomena of setting a limit to the capability of the used technology of heat transfer with phase change. So nearly half of the researches selected for this project were carried out for the purpose of performing the studies on the critical phenomena and of overcoming the heat transfer limit.

Prof. S. Aoki did a research on "Boiling Transition Phenomena and Heat Removal Limits at Transient High Power Generation". In this study, the transition boiling heat transfer characteristics at large step-wise power was studied, experimentally. It was found that there was a limiting value of heat flux, above which the effective heat removal in the transition nucleate boiling could not be expected at all. This transient critical heat flux is lower than the CHF in a steady state under system pressures, because the superheat energy stored in the thermal boundary layer at the boiling incipient is remarkably high. The transition boiling heat removal can be increased remarkably by applying a subcooled liquid jet, because the boiling transition is suppressed due to an increase of the subcooling near the stagnation point as well as the strong forced flow.

Professor T. Takeyama made an investigation on "Optimization of Fin Array in Boiling Heat Transfer". This study consisted of experimental and analytical studies made on the boiling heat transfer from copper fin arrays to R-113. The boiling curves predicted analytically for the fin arrays were found to fail to agree with experimental ones. This disagreement is mainly caused by the interference of boiling bubbles in a narrow space between adjacent fins, resulting in the heat transfer enhancement in low heat flux regions and the heat transfer deterioration in high heat flux regions. The interference of vapor and liquid flows has been observed by means of high speed photography. In conclusion, the fin array of 2mm in fin height, 0.2mm in fin thickness and 0.5mm in fin spacing has been recommended as the most effective geometry.

"Studies on Heat Transfer and Critical Heat Flux Condition in Subcooled Flow Boiling" was studied by Prof. T. Ueda. His study was made for invesigating the characteristics of subcooled boiling flow and the process to reach the CHF condition. Experiments were performed on the subcooled boiling of R-113 in a vertical annular channel with an inner tube heated. The results suggest a DNB mechanism due to momentary liquid film dryout underneath the large coalescent bubbles. The heated wall temperature variations before and at CHF condition were also measured to examine the DNB process further. The experimental results indicate that the wall temperature fluctuation accompanied with successive passing of large coalescent bubbles, results in a sharp temperature rise under the film boiling state.

Prof. H. Nishimura made a research on "Assessment of Technical Feasibility of Energy Conversiton System Using Gas Clathrate as Working Medium". In this study, the use of a gas clathrate was proposed as a working fluid of heat engines, where the clathrate means a kind of crystal formed of a host molecule of liquid and the guest gas, and brings it to a higher temperature where it is dissociated to liquid and gas, which expand separately to generate power. The rate of total process was found to be controlled by the absorption rate of gas into liquid as well as the growth rate of nucleous from the dissolved gas.

"Effects of Hydrodynamically Influential Factors on the Full-coverage Film Cooling" was studied by Prof. M. Hirata. In this study, an advanced film cooling technique termed full-coverage film cooling was experimentally studied, focusing on the hydrodynamical factors which are influential to FCFC performance. Particularly, the effect of wall curvature was investigated by using the concave, flat and convex test walls. By the flow structure observed, the cooling effectiveness measured is favorable and unfavorable on the convex and concave wall, respectively, as compared with that on the flat plate.

Prof. S. Yoshida made experiments on "Heat Transfer to Freon in the Critical Region". In this study, experiments were made on heat transfer to R-22 and 115 in uniformly heated vertical tubes in the range of reduced pressure of 0.68 to 1.10. Heat Transfer coefficient at the deteriorated condition got to the

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