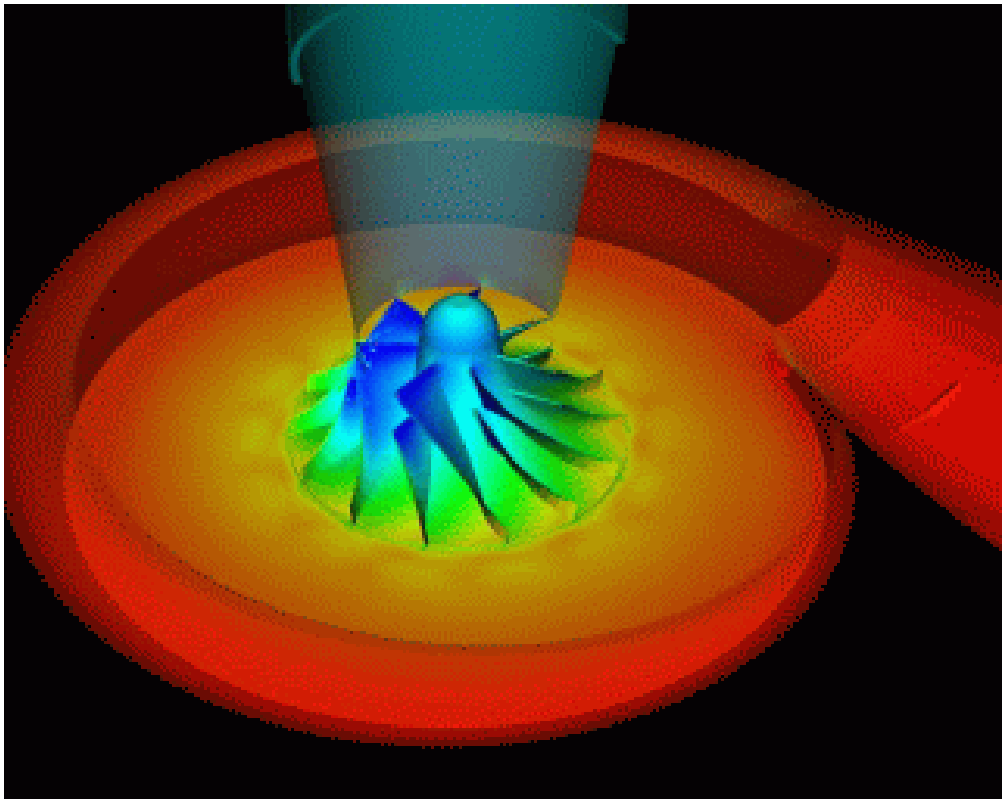
LAPPEENRANTA
UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF ENERGY AND ENVIRONMENTAL TECHNOLOGY

ANNUAL REPORT 2003

RESEARCH



1. RESEARCH

1.1 LABORATORY OF POWER ENGINEERING

Main areas of research

In power plant engineering the main areas of research are power plant and steam boiler engineering and district heating technologies. Environmental aspects are observed specially in separation and measuring technologies preventing flue gas emissions in power production. New areas of teaching are maintenance engineering of power plants, project management and international energy engineering business.

The gas combustion research:

The main themes for research with the combustion of different gas fuels are NO_x formation processes and emission control, heat transfer issues and exhaust gas recirculation alternatives.

Projects

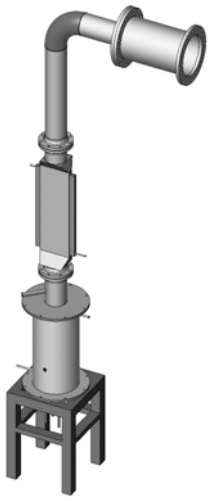
Durability study of pre-insulated bonded pipe systems for underground hot water networks This study is a long term co-operation project between the Laboratory of Power Engineering and Finnish District Heating Association (Sky ry). The main purpose of this study is to test all the different types of pre-insulated bonded pipe systems on the Finnish market and to give them a quality certificate if they full-fill certain requirements set by Finnish District Heating Association. The Laboratory of Power Engineering has FINAS accredit for this research.

Power plant maintenance study

The purpose of this study is to reduce the investment and maintenance costs in power plants by evaluating the maintenance needed for a reliable operation and to extend the economical life of a power plant.

The gas combustion research

Prof. Lasse Koskelainen, Lab.Eng. Ismo Roiha, student Jaakko Koli



The main purpose of the Research is to explore the possibilities to ecological and energy-saving gas combustion. At first we'll study the combustion of liquefied petroleum gas (LPG) and natural gas, later we'll use different kind of gasification gases and also hydrogen.

For this research we have built (year 2002) in the Combustion Research laboratory Experimental apparatus, which include a gas burner of 12-25 kW, combustion chamber (∅ approx. 300 mm, height approx. 800 mm), flue gas heat exchanger and flue gas duct (∅ approx. 200 mm). Total height of the facility is about 5 meters.

The first research period began in April 2003 and is carried out by student (Jaakko Koli) making his Master of Thesis. The main topics are the temperature of gas flame, heat transfer and pollutants in the LGP and natural gas firing.. This research period acts as a comparison material for further researches, which include among other things the use of flue gas recirculation and high-temperature air combustion

The total goals for the whole research will be on one hand the reduction of NO_x emissions (thermal NO emissions is reduced by lowering the maximum flame temperature) on the other hand improve thermal efficiency and reduce the size of facility and also reduce CO_2 emissions.

BIOENERGY TECHNOLOGY, Mikkeli Unit

Main area of research

The main research activities involve bio-fuels production, utilization and refining by developing both technology and business models.

Projects

The Mikkeli Unit has started to prepare joint R&D-project proposals with Mikkeli Polytechnic/YTI Research Centre in Mikkeli at the end of 2003. The projects deal with forest chip long-distance transportation by vessels, forest chip upgrading by high-temperature treatment, evaluation of field grops potential in Eastern Finland.

The Mikkeli Unit has been nominated to work as a representative of Finland in the new task 40, "Sustainable International Bio-energy Trade: Securing Supply and Demand" under the IEA Bio-energy Agreement. The working period is 2004-2006 and Finland has an observer status for the first year. The Utrecht University and Essent Sustainable Energy from Netherlands will be responsible of the task management.

1.2 LABORATORY OF NUCLEAR ENGINEERING

Main areas of research

The main areas of research are experimental studies with test facilities and computer analysis of accidents in nuclear power plants.
SAFIR programme is Finnish national research programme in nuclear power plant safety is (2003-2006). The programme is launched and administrated by Ministry of Trade and Industry (KTM). SAFIR programme supports the safety use of nuclear energy by developing thorough understanding, educating new experts and maintaining knowledge and cautiousness in important areas. Professor Riitta Kyrki-Rajamäki was nominated to the steering group of the programme. Laboratory engineer Juhani Vihavainen was nominated to the reference group of containment and process safety functions.

Projects:
The influence and behaviour of dissolved non-condensable nitrogen gas in the reactor coolant is being investigated. A new model for the dissolution and release of non-condensable gases has been developed and tested in collaboration with the CEA Grenoble and added to the French CATHARE code. The results of this research were published also in form of doctorate thesis in the beginning of 2003.
Christine Sarrette

Severe **reactor accidents analyses** have been continued **using the ICARE and ICARE/CATHARE codes.** The Nuclear Engineering Laboratory was a partner in the project "Core Loss During a Severe Accident" (COLOSS) in the 5th Framework Programme of EURATOM. The project was finalized in the beginning of 2003.
Eero Virtanen

New project was started in the beginning of 2003. **The validity and credibility of cost estimates for the decommissioning of nuclear power plants in Finland was evaluated**. The evaluation focused on the coverage and uncertainties of the cost estimates, which form the basis for the preparedness of waste management liabilities of the power companies. The assignment was given by the Ministry of Trade and Industry. The project was completed during 2003.
Riitta Kyrki-Rajamäki, Juhani Vihavainen, Eero Virtanen

New project was started in the beginning of July in 2003 **with a research contract of French Commissariat of Atomic Energy (CEA).** The project **contains calculations of the ISABELLE experimental facility with new version of French CATHARE code.**
Christine Sarrette

József Bánáti has been detached into OECD Halden Reactor Project in Norway. His research tasks have been **development of steam generator model of the TEMPO (Thermal Performance Monitoring and Optimisation) code**. Another task has been **a full safety analysis of the Halden Heavy Boiling Water Reactor with RELAP5 mod3.3 code.**

Laboratory of nuclear engineering has also been involved in preparing for a new integrated project proposal of EU 6th Framework Programme called NURESIM (Nuclear Reactor Simulation).

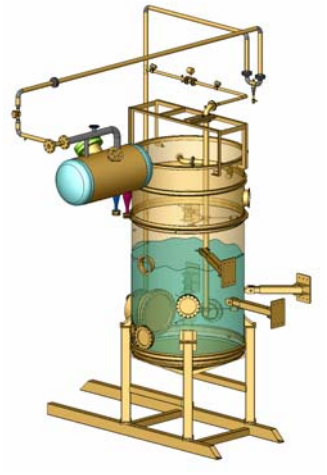
1.2.1 NUCLEAR SAFETY RESEARCH UNIT

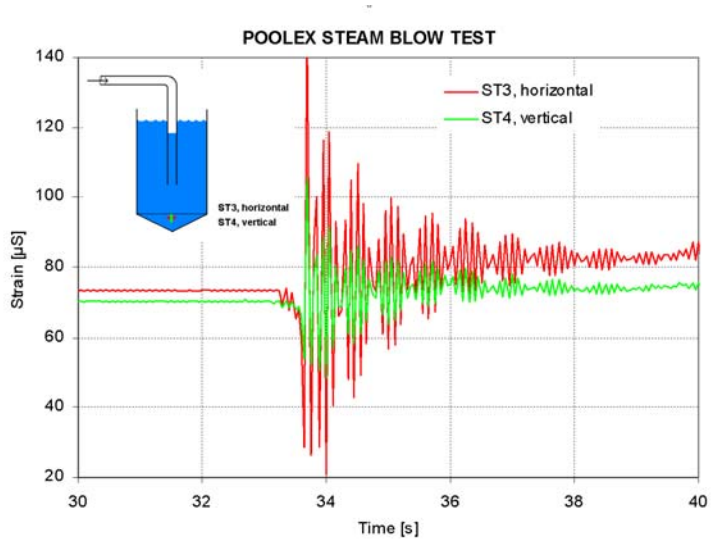
Research

Personnel	***Status***
Heikki Purhonen	*senior researcher*
Markku Puustinen	*senior researcher*
Vesa Riikonen	*senior researcher*
Jani Laine	*researcher*
Tomi Nurminen	*research trainee*
Antti Räsänen	*research trainee*
Harri Partanen	*design engineer*
Hannu Pylkkö	*senior technician*
Ilkka Saure	*senior technician*
Juha Luukas	*research technician*

The POOLEX (**Condensation Pool Experiments)** project of The Finnish Research Programme On Nuclear Power Plant Safety 2003-2006, SAFIR formed the main part of the research activities of the Nuclear Safety Research Unit in 2003. The investigation focused on **steam blow-down into a condensation pool during the initial phase of a BWR main steam line break**. Direct contact condensation at the blow-down pipe outlet as well as the movement of steam-water interface inside the pipe i.e. the chugging phenomenon were studied. Loads on

structures caused by the rapid condensation of steam bubbles were evaluated with the help of strain gauge measurements. In 2003, the main purpose of the experiments was to evaluate the capabilities of the condensation pool test rig and the needs for measurement and visualization devices. DN80 and DN100 blow-down pipes were used. The nearby PACTEL facility acted as a steam source. In 2004, more detailed experiments on steam blow-down into the condensation pool with enhanced instrumentation and data acquisition will be carried out.





Left: POOLEX test rig.

Right: Measured strains show the damped oscillation caused by a water plug hitting to the pool bottom.

During a possible loss-of-coolant accident a large amount of non-condensable (nitrogen) and condensable (steam) gas will be blown from the upper drywell of the containment to the suppression pool through the blow-down pipes at the Nordic type boiling water reactors. **Suppression pool experiments with non-condensable gas** were carried out on a scaled down test rig to provide additional information for conditions applicable to Swedish BWRs with external recirculation pumps. Particularly, the risk of gas pushing its way to emergency core cooling and residual heat removal systems was investigated.

Nuclear Safety Research Unit participated in two EU funded projects in 2003. In the IMPAM project, **experiments with the PACTEL facility on different accident management procedures** during a small break loss-of-coolant accident in a VVER type reactor were carried out at Lappeenranta University of Technology. **Stresses induced on a fast acting boron injection system in varying operating conditions** were studied in the FABIS project. Eleven European research organizations engaged in the IMPAM project activities and four in the FABIS.

1.3. ENERGY ECONOMICS

In Energy Economics the main areas of research are the economics of energy production and the environmental aspects in energy production especially carbon dioxide emissions. Emission mitigation by process integration in forest industry is studied, too.

Projects

Local and Regional Process Integration in Energy Supply between Industry and Community

Professor Risto Tarjanne, Dr. Heikki Malinen, MSc. Mika Laihanen

The aim of this study is to develop process integration on local and regional level. The large industrial units use huge amounts of energy. The flows of waste energy can be utilized efficiently in the local community. The communities can also use fuels that come from the factory.

The Competitiveness of Nuclear Power and its Impact on Reduction of Carbon Dioxide Emissions

Prof. Risto Tarjanne, MSc. Kari Luostarinen

This study focuses on the competitiveness of nuclear power in the near future and its impact on reduction of carbon dioxide emissions in Finland.

1.4 LABORATORY OF THERMODYNAMICS

Main area of research
Research of reactive multi-phase systems

Projects

Study of Transport Properties of Multi-Phase Composite Materials
Prof. Pertti Sarkomaa, Dr. Ali Moosavi

The purpose of the study is the calculation of the effective transport properties of multi-phase composite materials. The composite materials considered in the study are made of a periodic array of inclusions embedded in a matrix. The geometry of the inclusions taken into account are circular cylindrical, elliptical cylindrical and spherical. The inclusions can be solid or multiply coated. The behavior of such composites has been investigated in special cases. For example, composites containing inclusions in the shape of coated circular cylinders are considered.

Also the effect of interfacial resistance on effective conductivity is studied by characterizing interfacial resistance using a non-dimensional parameter. It is shown that this effect is very important, and on the basis of the value of interfacial resistance, even the effective conductivity of the system can fall outside the range of the property of the phases.

Two resistor models are used for deriving the bounds. The results of the bounds are compared for coated composites, and it is shown that having the resistor in a series does not guarantee that better results will be obtained in all cases. By combining these bounds in a specific manner, better results may be obtained than by using one of them alone.

In June 2003, M.Sc. Ali Moosavi published his Doctoral thesis entitled ***"Transport Properties of Multi-Phase composite Materials"*** based on the results of this project.

Theoretical and Numerical Study of Complex Fluid-Particle Suspension Flows
Prof. Pertti Sarkomaa, M.Sc. Tero Tynjälä

This study is about the theoretical and numerical modelling of complex fluid-solid suspension systems. In colloidal suspensions the interactions between phases plays important role to the dynamics of the system. In addition to the internal interaction forces between the particles and between the fluid and the particles, there may be external forces, like gravity or magnetic force, which have different effect on solid particles and fluid surrounding them.

As an example case of a fluid-solid suspension, magnetic fluids have been studied. The magnetic fluids are suspensions of nanoscale magnetic particles in appropriate carrier liquid, which are sensitive to external magnetic field. Magnetic forces can be used to control the properties and the flow of these liquids. For example, when a magnetic liquid is placed near a magnetic field gradient the liquid exhibits increased viscosity and increased apparent density. In most studies, the concentration of magnetic particles is assumed spatially uniform and stable against sedimentation. However, the recent experiments have shown, that the concentration gradients resulting due to the gravitational settling of magnetic particles may play an essential role in magnetic fluid convection. In this study a two-phase mixture model is developed, where the carrier and magnetic phase are allowed two move at different velocities, to take account for the sedimentation of the magnetic particles. Several different cases have been studied in order to validate the model.

Experimental and Theoretical Investigations in Granular Flows
Prof. Pertti Sarkomaa, M.Sc. Jouni Ritvanen, Dr. Payman Jalali

The present project is in the continuation of previous research in the area of multiphase flow and granular flows within past years. The objectives of this project are to perform series of experimental and theoretical investigations of rapid granular flows. Granular material used in these experiments is consisted of steel ball bearings with diameters ranging from 2 to 4 mm. This material is continuously sheared in an annular Couette geometry to study the dynamical behavior of system. Experiments are performed at a specific mean packing density through different shear rates. The main goal in our experiments is to investigate the dynamics of instantaneous local and overall force fluctuations tolerated at the bottom of the bed due to contacts and collisions with grains in bulk.

Fluctuations can occur over an order of magnitude larger than the mean stress. Such intermittent behaviour in sheared granular materials may be reproduced using a dynamical system

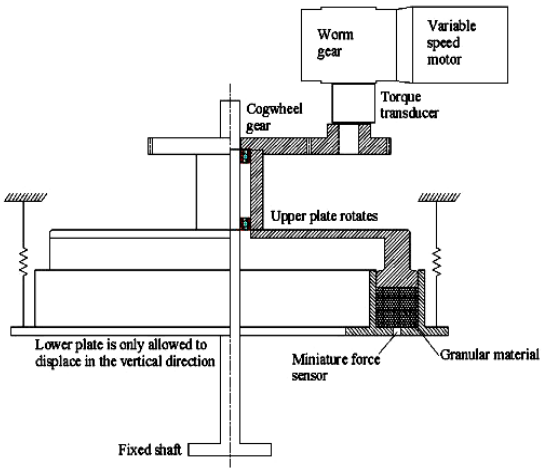


Figure 1 The schematic of the annular shear cell

approach to turbulence. The relation-ship between turbulence and granular flows can be physically justified through the role of coherent structures in the dynamics of both systems.

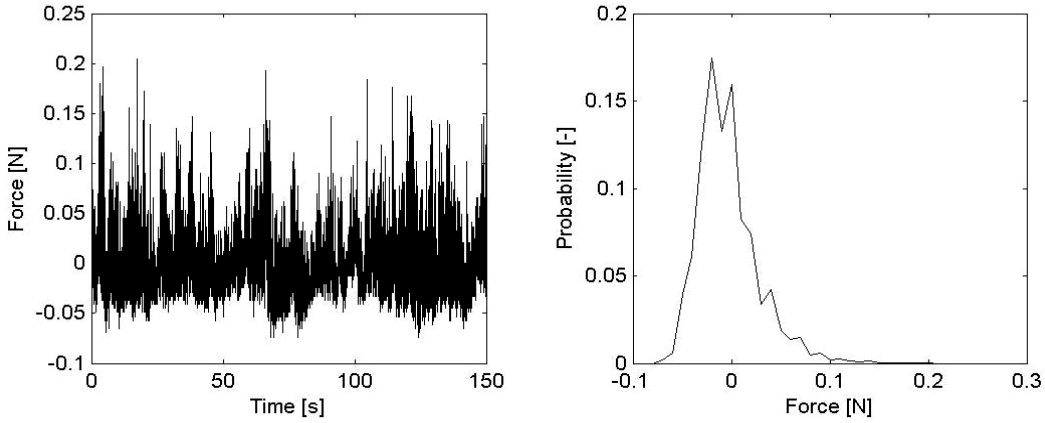


Figure 2 Force fluctuations at the bottom of the bed and probability density function for the force

Minimizing the Infrared Signature by the Use of the Nozzle Plate Structure
Prof. Pertti Sarkomaa, M.Sc. Petri Kuisma

Infrared reconnaissance systems, thermal sights and infrared guidance systems of precision-guided weapons have evolved rapidly in recent years. The goal of the research was to find structural solutions that would reduce the target's IR signature. In this research we studied the IR-signatures of a wall of two parallel vertical plates cooled by a horizontal airflow in between. In addition, a nozzle plate structure was placed between the plates to enhance the cooling of the structure. The ranges of the studied wavelengths were 3-5 μm and 8-12 μm.

In the studied wall structure the horizontal flow of cooling air between two parallel vertical plates has a strong tendency to become vertically layered with warm air rising to the flow channel. The heat transfer in the studied structure is dominated neither by forced nor free convection and the solution of mixed convection should be considered.

The criterions used for the IR signature reduction were based on the average and the biggest temperature differences between the surface of the target and the surroundings. The research produced computational methods and guidelines for the design of the low IR-signature structures. The method is based partly on heat transfer equations found from the literature, and partly on empirical correlations based on the measurements of the studied structures.

Hierarchical Wavelet Approach for Spatial-Temporal Analysis of Turbulence in Two-Phase Flows
Prof. Pertti Sarkomaa, Dr. Payman Jalali, M.Sc. Tero Tynjälä, M.Sc. Jouni Ritvanen

The study of turbulence is crucial for physicists and engineers because of the complex physics behind the problem and its wide range of fluid mechanics applications. In direct numerical simulations, a vast number of grid points are needed to represent eddies at the smallest scales, especially at very large Reynolds numbers. However, the limited computational power does not lead to an efficient and inexpensive way to handle such huge calculations. Moreover, the solution is obtained in the physical domain, which may not readily provide any simple physical understanding of the phenomenon. In contrast, the main focus in a dynamical system approach is on the fundamental mechanism for energy cascade at small scales. However, the importance of geometry is not considered in common approaches such as shell models. In this context, the hierarchical features of turbulence may have some major difficulties in quantitative statement. For instance, Fourier modes result a proper localization in Fourier space but they are delocalized in physical space. In contrast, finite difference schemes are well localized in physical space. However, in order to obtain the localization properties in both space and scale apace a sophisticated type of functional basis has been introduced, namely wavelets. Therefore, one will be able to trace the dynamics of coherent structures and determine their contributions to the energy spectrum. The space localization property can definitely facilitate studying the effects of geometry in high Reynolds turbulent two-phase flows.

In this project, the idea of developing hierarchical wavelet analysis to 2D and 3D particulate two-phase flows will be conducted to understand the features of turbulence associated with intermittency, energy cascade and turbulent structures. The project is financially supported by the Academy of Finland. In 2003, preliminary research for this project was conducted. Full-time research within this project has started in 2004.

Theoretical study of shock wave due to pressure vessel explosion
Prof. Pertti Sarkomaa, Dr. Heikki Kurttila

An accident burst of a pressure vessel is an uncontrollable and explosion-like batch process. In this study it is called an explosion. The destructive effect of a pressure vessel explosion is relative to the amount of energy released in it. However, in the field of pressure vessel safety, a mutual understanding concerning the definition of explosion energy has not yet been achieved.

In this study the definition of isentropic exergy is presented. Isentropic exergy is the greatest possible destructive energy, which can be obtained from a pressure vessel explosion when its state changes in an isentropic way from the initial to the final state. Finally, after the change process, the gas has similar pressure and flow velocity as the environment. Isentropic exergy differs from common exergy in that the process is assumed isentropic and the final gas temperature usually differs from the ambient temperature. The explosion process is so fast that there is no time for the significant heat exchange needed for the common exergy. Therefore an explosion is better characterized by isentropic exergy.

By means of isentropic exergy and the known flow theories, equations illustrating the pressure of the shock wave as a function of distance are derived. A method is proposed as an application of the equations. The method is applicable for all shapes of the pressure vessels in general use, such as spheres, cylinders and tubes. The results of this method are compared to measurements made by various researchers and to accident reports on pressure vessel explosions. the test measurements are found to be analogous with the proposed method and the findings in the accident reports are not controversial to it.

In November 2003, M.Sc. Heikki Kurttila published his Doctoral thesis entitled ***"Isentropic Exergy and Pressure of the Shock Wave Caused by the Explosion of a Pressure Vessel"*** based on the results of this project. The research continues and in the next phase the focus is on the research of the underwater explosions.

Influence of Weather Elements on the Thermal Signature of the Target
Prof. Pertti Sarkomaa, M.Sc. Pasi S. Salonen

Operational conditions and weather conditions have a significant effect on the thermal signatures of ground targets. The weather parameters are solar irradiance, wind speed, wind direction, rainfall, rate of rainfall, air temperature and humidity. In this research project we create a simple method or technique, which allows us to assess the influence of the different weather elements on the signature of the target. The project includes preliminary study, theoretical study and measurements. Literature searches about the topic and a survey of typical weather parameters were done during the preliminary study phase. The weather parameters were studied because we had to know both temporally and geographically typical values for the different weather variables. Several energy balance equations for the different parts of the target were created during the theoretical study phase. We also built 3-D models for the parts of the target and used them to calculate the thermal properties of the different parts of the target with modelling tools. Several measurements were also needed during this research. Small parts were selected in order to represent the different parts of the target. The signatures of these small parts were measured in the laboratory weather chamber where the weather parameters could be controlled during the test. The thermal signatures of the target were measured in the field during different weather conditions. The thermal signatures of the target were measured with thermal cameras both MWIR 3 – 5 µm and LWIR 8 – 12 µm (AGEMA THERMOVISION 900). The values of the weather parameters were recorded using a portable weather station (Davis Weather Station). The goal of the research project was to create a verified technique for the weather elements impact assessment.

Optimization of Heat Pump and Cooling Systems
Prof. Pertti Sarkomaa, Prof. Juha Kaikko

The total costs of the heat pumps and cooling machines are strongly affected by the vaporization and condensing temperatures in the systems and, due to the selected materials, by the cost of the heat exchangers. Especially in industrial applications, heat pump and cooling systems are typically designed to minimize both the amount of the refrigerant in the process and the area required by the refrigerant. This is enabled by using series-connected heat exchangers on the vaporization and condensing sides in the system. The heat capacity flow rates between the series-connected heat exchangers, their design temperatures and design temperature differences, have a strong influence on the investment and operating costs of the heat pump and cooling systems, too. Other parameters that have a strong influence on the economy are the case-specific operating time and the return requirement.

This research focuses on developing a general method for the economical optimization of heat pump and cooling systems. In the optimization, the following factors are taken into account: the overall heat transfer coefficients, the marginal costs of the heat transfer surface areas, the maintenance costs, the factor of the present value of periodic payment during the operating time, the annual peak-load power time, the efficiency of the heat pump or cooling process and the price of electricity. Equations are derived for determining the dimensioning parameters of economically optimized heat pump and cooling systems.

As a result of the optimization, the economically optimal values are obtained for the recuperation ratios and surface areas of the condenser and evaporator. If the system has several series-connected heat exchangers on the

vaporization and condensing sides of the heat pump or cooling machine, economically optimal surface areas and connecting heat capacity flows of the heat exchangers and temperatures in the corresponding conditions are also obtained.

Optimization of Cooling Systems that Utilize Free Cooling
Prof. Pertti Sarkomaa, Prof. Juha Kaikko

In the Northern and Southern regions of the globe, ambient air can be utilized during the cold seasons for cooling down the coolant in air-conditioning or other cooling systems. This application is referred to as free cooling. The use of free cooling permits the reduction of the electricity consumption and, thus, the energy costs of the cooling machine. In this research, general methods are developed for the economically optimal dimensioning of the free cooling system as well as the cooling machine.

Both direct and indirect free cooling is considered. In direct free cooling, a heat exchanger of the counter-flow or cross-flow type is applied to the heat transfer between the ambient air and the coolant that returns from the cooling application. The indirect free cooling system comprises of two fluid-connected heat exchangers that are applied to cool down the coolant by ambient air. Cooling machines that are considered include the basic vapour compression type and a modification where the condenser is fluid-connected to a counter-flow type heat exchanger in the ambient air.
The presented methods for the economically optimal dimensioning improve the quality of the design and increase the profitability of the investments while saving finite resources. For the free cooling systems, a criterion is also provided to determine the profitability of the additional investment in free cooling.

Development of a Gas Burner with Wide Operating Range
Prof. Pertti Sarkomaa, Prof. Juha Kaikko, Risto Partamies

Gas burners can be applied, for instance, in process furnaces and heaters as well as in boilers. In this project, a small-scale gas burner (0.5 MW) with wide operating range was developed to be used for heat treatment. The burner uses liquefied petroleum gas as a fuel. It is capable of operating at low load levels, down to 10 % of nominal fuel power while maintaining stable operation.

Experimental Modeling of Heat Transfer Enhancement and Pressure Loss in a Tube with Wire Coil Inserts
Prof. Pertti Sarkomaa, Lic.Tech. Raija Lankinen, Prof. Juha Kaikko

Various non-freezing heat carrier fluids such as glycol-water mixtures are typically applied in the energy transfer on the evaporation side of refrigeration machines and heat pumps. The lower the operating temperature, the higher the glycol content must be, which increases the viscosity of the mixture. As a consequence, the Reynolds number may fall to a level where the flow changes from turbulent to laminar. This causes the heat transfer coefficient to decrease substantially.

Heat transfer can be intensified, for instance, by placing a turbulator wire in the heat exchanger tube, but at the same time the pressure losses increase. The diameter and pitch of the turbulator wire have a decisive impact on the heat transfer and pressure loss. At sufficiently high concentrations of anti-freeze substances, several heat transfer liquids become non-Newtonian fluids. Their consistency affects the shear strain in the liquid. In the case of such fluids, the heat transfer coefficient and friction factor become fluid-specific.

This research focused on the determination of the heat transfer coefficient and friction factor for a commercial straight copper tube with an inner diameter of 13 mm using different values for the diameter and the pitch of the wire coil insert. A mixture of mono-propylene glycol and water with two different concentrations was applied as the heat transfer fluid. Altogether, eight different wire coil inserts were used and ca. 3000 measurements were performed for the test cases.

The measurements indicate that the concentration of glycol has an insignificant effect on the coefficient of friction. Instead, the concentration of glycol affects the heat transfer properties. The lower the concentration, the higher the convection heat transfer coefficient is. The convection heat transfer coefficient and friction pressure loss in the tube are very sensitive to the Reynolds number and the dimensioning of the wire coil insert. For different regions of the Reynolds number, the specific optimal dimensioning of the turbulator wire can be determined. Optimum dimensioning that is based on research of the equivalent fluid, flow conditions and the tube with the wire coil insert offers the possibility to design more efficient heat exchangers for cooling and other processes.

Model-Based Optimization of Gas Turbine Maintenance
Prof. Juha Kaikko, Prof. Pertti Sarkomaa

Gas turbines, together with other prime movers are facing ever-increasing demands for competitiveness. Condition based maintenance (CBM) helps to meet the demands by omitting unnecessary maintenance actions and maintaining the condition of gas turbine components at an optimal level. In addition to increasing the plant economy, the availability of the plant is also increased.

As a prerequisite for the optimal performance of maintenance actions, the thermodynamic condition of the gas turbine components as well as the cost effects of possible performance degradation and countermeasures must be known. Estimation for the cost flow due to performance degradation can be gained using a steady-state gas turbine

model that takes into account the condition of the engine. In this research, the necessary measured data and the component-specific condition parameters are determined to evaluate the condition of a gas turbine in relation to the selected faults. The special requirements and application principles for a steady-state gas turbine model to be used for cost flow estimation are also addressed. The resulting information from condition monitoring is applied to a model-based optimisation of gas-turbine maintenance with the focus on two example cases: the timing for compressor on-line and off-line washing, and the timing for the inlet filter change. For both example cases, general formulation of the minimizing cost functions, together with optimization principles are developed. The presented optimization methods can be easily applied to determine optimized maintenance intervals for the studied cases, thus increasing the availability and economy of the plant when compared to pre-scheduled maintenance.

Performance Analysis of Micro Gas Turbines
Prof. Juha Kaikko, Prof. Pertti Sarkomaa

Small-scale distributed energy systems are gaining increasing popularity in the current energy market. To be successful, these systems have to fulfill various demands, such as high reliability and availability, high efficiency both in power generation and in cogeneration of heat and power, also at part-load operation, low specific costs, wide operating range, and high operating flexibility. Micro turbines provide one option for distributed energy systems in the 25 - 200 kWe range. They feature typically a single-shaft arrangement and may be equipped with a recuperator. The power generation efficiencies are in the range of 15 - 30 %. At part load operation the efficiencies decrease rapidly.

This research focuses on micro turbine applications where high efficiency is gained through intercooling, recuperation and reheating, instead of using high turbine inlet temperatures. Low operating temperatures eliminate the need for hot gas path cooling and enable the use of less expensive materials.

The suggested micro turbines apply high-speed technology where the turbomachine and the electric machine (generator) have a common shaft rotating at an optimum speed determined by the turbomachine. The high-frequency current from the generator is converted via an inverter, which enables variable-speed operation. This is the key factor in maintaining the power generation efficiency at part load.

The performance of a single-generator type micro turbine is compared to an application where all the shafts have their own generator. The effect of different numbers of intercoolers and combustion chambers is analyzed along with different shaft arrangements. The sensitivity of the performance against the main cycle parameters is also studied. The emphasis is on investigating the potential of variable-speed operation in maximizing the power generation efficiency at part load.

Improvement of cycle efficiency at pressurized-water type nuclear power plant
Prof. Juha Kaikko, Heidi Mononen

In large-scale power production, any improvements in energy conversion efficiencies have high impact on plant economy, either by reducing the required amount of fuel or increasing the generated power. This research focuses on examining the potential for efficiency improvement on a secondary circuit at an existing pressurized-water type nuclear power plant. A commercial process simulation software APROS is applied for comparing the impact of viable low-cost process modifications on cycle efficiency. The studied modifications include, for instance, changes in the extraction piping and feedwater heaters. Based on the results, the most promising options can be selected for a comprehensive economic evaluation to examine the feasibility of the particular modifications.

Development of Web-Based Education in Engineering Thermodynamics
Prof. Pertti Sarkomaa, Prof. Juha Kaikko, Miia Hautala, Heidi Mononen, Jussi Saari, Päivi Sikiö

Beginning from 2002, the Laboratory of Engineering Thermodynamics has participated in a virtual university project at LUT. As part of the project, the course on Engineering Thermodynamics has been restructured into a partially web-based course. The content and depth of the course has remained relatively intact, but web-based teaching methods have been introduced to facilitate a more effective learning process.

The new partially web-based teaching approach places comparatively less emphasis on the lectures, and more on the students setting their own goals, working on their own time and observing their learning process. The number of lectures has been reduced, and their role changed from teaching technical details to clarifying the main issues of the subject to the students. After the lectures, the students are expected to study the subject from the web-based learning material being created for the course, answer mandatory web-based questionnaires, and return their homework for the assistant for grading. The classroom exercises remain unchanged from the past years.

The main work for the project has included the development of a relatively complete web-based learning material for the students. The material supports the department's teaching approach better than the existing literature. The core of the material has been created throughout the year as the course was being taught, with the goal being to finish the remaining parts during the year 2004.

1.5. LABORATORY OF FLUID DYNAMICS

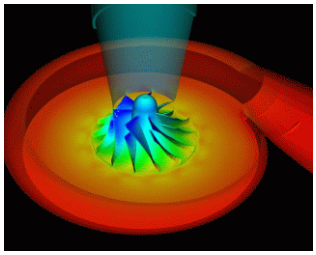
Main area of research: High speed technology

High speed technology research develops new generation technology, like environmentally friendly oil free compressors for waste water aeration, for paper machines and for refrigeration technology, and ORC-Power (Organic Rankine Cycle) for decentralized production of electric energy. Research is conducted in close co-operation with High Speed Tech (HST) Oy and the Laboratory of Electromechanics in Helsinki University of Technology and is funded mainly by High Speed Tech Oy Ltd, by TEKES, by Sarlin-Hydor Oy and by several foreign (Holland, U.S.A., Brazilia) enterprises. The research group consisted of 8 researchers and 3 engineers and technicians (part time researchers included) and the research activities of the group are described below.

Projects:

CFD-calculation of flow in radial turbo machinery
Professor Jaakko Larjola, Dr. Arttu Reunanen, MSc Teemu Turunen-Saaresti

The Laboratory of Fluid Dynamics has been concentrating for several years in developing CFD-calculation for flow in turbo machines. The flow is modeled and the results of the calculations are compared with measured data. CFD calculation means that the flow field is divided into a very large amount of small gas elements, for which flow equations are calculated. The result is a fairly exact model of the development of pressure and temperature in the turbo machine. The calculation needs very high computing capacity, and it is often done on supercomputers. The final goal is to reach a calculation accuracy which would make it possible to predict the efficiency of a turbo machine within the limits of a couple of per cents before the machine is constructed.



The Finnish CFD calculation program FINFLO is used in the calculation. This pro
has been developed by the Laboratory of Applied Thermodynamics at HUT
calculations. In the project at LUT the calculation has been done in cooperation wi
HUT with three methods to be better suited for turbo machines, and the calculatio
results have corresponded well with test data.

Left: Pressure fields in a radial compressor.

CFD has also been used in the project to calculate the flow in the supersonic stator and rotor of the radial turbine in the ORC power plant. In this calculation the circulating gas is a real gas (toluene), and for this a real gas model was installed into the calculation code (for the time being into the 2-D code). The calculation results help in raising the efficiency of the turbine, as irregularities in the flow passages can be easily detected.

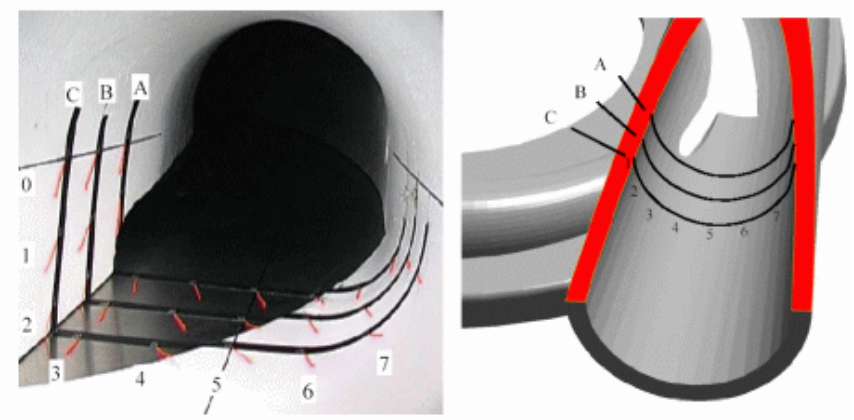
Design, optimization and testing of turbo machines
Professor Jaakko Larjola, Dr. Arttu Reunanen, MSc Petri Sallinen, MSc Juha Honkatukia, MSc Teemu Turunen-Saaresti

The basic study made in the Laboratory of Fluid Dynamics has been one of the sparks that has started the commercial production of high speed turbo compressors in Finland. The High Speed Tech Oy Ltd (HST) compressor factory in Lappeenranta is working in close cooperation with the Laboratory to develop their products, where the design, optimization and testing are important tools.

Various modelling programs have been developed in cooperation with HST to simulate the operation of a radial compressor to obtain control algorithms. The basic program can be used to produce the performance map of the compressor from the measurement data, and at the same time check the logicality of each measuring point and compare it to calculated data.

Programs for radial compressor design have been developed at LUT in cooperation with HST to ensure optimal command of the design process. Almost all the radial compressors used by HST have been designed at LUT, and their performance characteristics have met the requirements well.

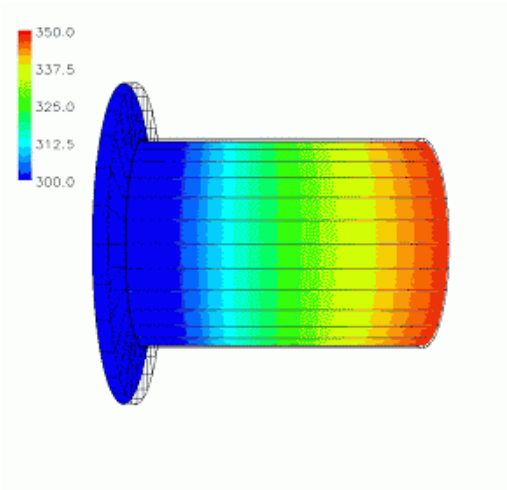
An important stage in the design of a compressor is the exact measurement of its performance. The measurement station complying with international standards has been running in the Laboratory of Fluid Dynamics actively in 2003. With this test station it is possible to measure high speed compressors accurately up to the electrical power of 500 kW and pressure ratio of four. Both the inlet and the outlet cones are equipped with exact control valves to enable smooth measurement of low pressure and high pressure compressors. The measured signals are saved with a measurement computer, which accepts each measurement point only when the temperatures and pressures are steady enough.



Above: Flow visualization of the flow in the radial compressor volute

Gas friction and heat transfer in the air gap of rotating cylinder
Professor Jaakko Larjola, Dr. Maunu Kuosa, MSc Petri Sallinen, BSc Jukka Lattu, Petri Pesonen

This work deals with the cooling of high-speed electric machines, such as motors and generators, through an air gap. It consists of numerical and experimental modelling of gas flow and heat transfer in an annular channel.

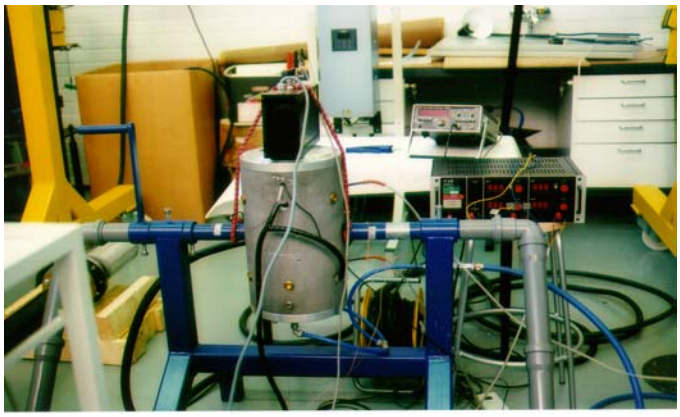


Velocity and temperature profiles are modelled in the air gap of a high-speed test machine. Local and mean heat transfer coefficients and total friction coefficients are attained for a smooth rotor-stator combination at a large velocity range.

The FINFLO software has been used in the flow solution. The annular channel is discretized as a sector mesh. Calculation is performed with constant mass flow rate on six rotational speeds. The effect of turbulence is calculated using three turbulence models. The friction coefficient and velocity factor are attained via total friction power.

Left: This picture shows the temperature fields in the air gap.

The first part of the experimental section consists of finding the proper sensors and calibrating them in a straight pipe. After preliminary tests, a RdF-sensor is glued on the walls of stator and rotor surfaces. Telemetry is needed to be able to measure the heat transfer coefficients at the rotor. The mean heat transfer coefficients are measured in a test machine on four cooling air mass flow rates. The calculated values concerning the friction and heat transfer coefficients are compared with measured and semi-empirical data.



Left: The laboratory prototype used to verify the CFD -calculations.

The tests conformed one major part of Dr. Kuosa's dissertation that was approved in 2002.

Heat is transferred from the hotter stator and rotor surfaces to the cooler air flow in the air gap. On constant mass flow rate the rotor heat transfer coefficient attains a saturation point at a higher rotational speed, while the heat transfer coefficient of the stator grows uniformly. The magnitudes of the heat transfer coefficients are almost constant with different turbulence models.

Friction and heat transfer coefficients are presented in a large velocity range in the report. The goals are reached acceptably using numerical and experimental research. In 2003 the research was concluded with results for grooved stator-rotor combinations. The velocity field by the numerical method does not match in every respect the estimated flow mode. The absence of secondary Taylor vortices is evident when using time averaged numerical simulation.

Design, building and testing of an Organic Rankine cycle power plant

Professor Jaakko Larjola, Dr. Jari Backman, Juha Honkatukia MSc, Jukka Lattu BA, Laboratory workshop

Beginning from January 2001, the Laboratory of Fluid Dynamics has been participating in an international research project to design, build and test a ORC power plant. The basic design of the high-speed ORC power plant was been carried out by the laboratory. This work has been focused on the long term development of a high-speed turbo-generator for ORC applications that will allow for a completely hermetic power plant, a compact size turbo-generator with no need for lubricating oil as well as a high turbine and electromechanical efficiency. The commercial rights over the applications of high speed ORC technology for power generation are owned by Tri-O-Gen B.V, which has financed the construction of a 175 kW_e pilot plant for verifying the functionality and efficiency of the technology.

The building of the plant started in June 2002 and the first tests were carried out in December 2002. Testing work did go on until June 2003, when the plant was transported to Holland for further tests and use. At the time of writing the plant has successfully produced power to network at partial load.

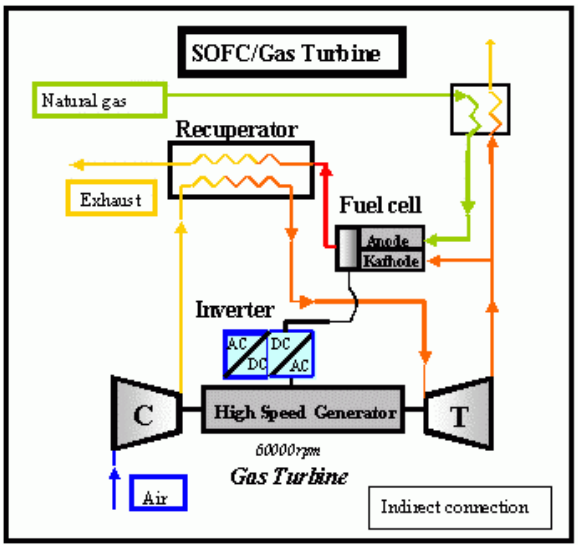
Left: The turbo generator main parts, the super sonic turbine in front. **Right:** The ORC power plant in tests in LUT.

Left: The ORC power plant in use at the test facility of Tri-O-Gen in Goor, Holland (the power plant is assembled to a standard container, which makes transport easy). In this cite the plant is run by burning natural gas, but later the plant will be transported to its final cite, where fuel will be biogas.

Development of a Finnish Fuel Cell Gas Turbine

Dr. Jari Backman, Professor Jaakko Larjola., Arttu Reunanen MSc, Juha Honkatukia MSc, Hannu Esa MSc, Jukka Lattu BA

Beginning from October 2001, the Laboratory of Fluid Dynamics has researched the possibilities to design a high speed gas turbine to be used in connection with solid oxide fuel cells (SOFC). Studies with Fuel Cell Technology combined with a Gas Turbine Cycle are promising very high thermal efficiencies compared to conventional Gas Turbine Cycles. This research comprises the design of a single shaft radial high speed gas turbine, optimised especially for operation together with a fuel cell.



The gas turbine includes the high frequency generator and active magnetic bearings, which components have been used in high speed turbo compressor applications with good results. The gas turbine with oil-free bearings without contact to the rotating shaft has very long operating life, is environmentally friendly and needs practically no service.

Left:
This simplified chart shows the indirect gas turbine connection, where the fuel cell is working in the ambient pressure and the recuperator of the systems heats the air for the turbine.

The turbine exhaust (clean, hot air) will be directed to the fuel cell process and will substitute an external blower.

The project included the detailed design of the compressor and turbine as well their connection to the high speed motor. The inverter connected to the fuel cell also would run the motor. The first phase of the research was finished in December 2002, but there are small initiatives going on with this technology.

Development of Web-Based Teaching Methods in Turbo machinery

Doc. Jari Backman, MSc Teemu Turunen-Saaresti, MSc Pekka Punnonen, Jani Keränen, Miia Hautala

Beginning from 2002, the Laboratory of Fluid Dynamics has participated in a virtual university project at LUT. The courses Thermal Turbo machinery, Measurement and Construction Technologies and Gas Dynamics have been restructured into partially WebCT. The content and depth of the course have not been altered, but web-based teaching methods have been introduced to facilitate a more effective learning process.
The teaching approach places comparatively less emphasis on the lectures, and more on the students setting their own goals, working on their own time and observing their learning process. The number of contact hours with the students has been reduced, and their role changed from teaching technical details to clarifying the main issues of the subject to the students. Before the lectures the students are expected to study the subject from the web-based learning material being created for the course, answer mandatory web-based questionnaires, and return their homework for the assistant for grading.
The main work for the project has included the development of a relatively complete web-based learning material for the students. The core of the material has been created throughout the academic year as the course was being taught, with the goal being to finish the remaining parts during the year 2004.

1.6 Laboratory of Fluid Mechanics

Projects

Laboratory of the Fluid Mechanics major ongoing research works are

Fundamental investigations in the field of granular flows using kinetic theory approach as well as molecular dynamic type simulations of large scale system . It is worth mentioning that one of professor Zamankhan's earlier journal publications in the field of granular flows has been cited nearly 50 times by other researchers. Recently, we used the Wavelet-Galerkin approach, an innovative "mesh-less" technique, to solve problems such as dense gravity-driven granular flows between rough walls and supersonic gas particle flows. We believe that these studies can improve our understanding of the physics necessary to describe the deformation and flow of poorly understood systems such as dense gas-particle flows, where precise experimental measurements are very difficult to obtain. It should be noted that these systems are important to many industries such as the power plant industries.[*with Azita Soleymani*]

Numerical studies of flow-structure interaction (FSI), in which the coupling of unsteady fluid flow and elastic and viscoelastic structures is considered. Here, the grid of fluid domain is deformed simultaneously with the structure. Indeed, this is an important field of computational applied mechanics with a number of industrial applications such as those in the web-handling and paper industry. Other applications of FSI which would be of my interest include Biomedical, Material Processing and MEMS. [*With Simo Nurmi & Vesa Tanskanen]*

Theoretical investigations of lubrication by charged polymers with applications in the design of lubricated surfaces in artificial implants. Briefly, brushes of charged poly-electrolytes can reduce massively sliding friction between the surfaces to which they are attached. *[with Azita Soleymani]*

Turbulence modelling using Large-Eddy-Simulations (LES) with applications for natural ventilation design and environmental technology problems. Here, the use of LES allows for fewer modelling assumptions to more accurately calculate room air flows. The emphasis of the current investigation is to develop more effective large eddy subgrid models.[*with Antti Aliloyto & Simo Nurmi]*

Application of different numerical approaches including Lattice Boltzmann in simulations of magnetic liquids.*[with Hassan]*

Professor Piroz Zamankhan is also in the board of Ph.D. studies of Mr. Mahmood Gorgi and Mr. Hussain Ghazanfari who are Ph.D. students at Dept. of Chemical Engineering in Sharif University of Technology (Tehran).

1.7 LABORATORY OF ENVIRONMENTAL TECHNOLOGY

Research in the Laboratory of Environmental Technology is emphasized on the following main areas:

- Reduction and utilization of waste and byproducts coming from industrial processes and communities,
- Environmental management and design for environment (DFE) utilizing for example life cycle assessment (LCA),
- Environmental technology of buildings and construction.

The objective of the research work is to find out new technologies, business opportunities and ways to improve competitiveness of companies and reduce the environmental impacts of production at the same time. To find the most effective means to realize these goals it is essential to know the environmental impacts from the whole lifetime of the products.

A new field of research and education in the laboratory is environmental technology of buildings and construction. Nowadays the main topic in this area is air conditioning systems but the research is being expanded to cover the control of environmental impacts of buildings from construction to demolition and recycling of materials. New equipment for research and development of air conditioning systems is being prepared. This system will be taken in operation during the year 2004.

The Laboratory of Environmental Technology has a modern teaching and research laboratory where it is possible to study and develop utilization, measuring and separation technologies. Emission measurements can be carried out on location using our mobile laboratory, which is well-equipped with modern laboratory apparatus.

- Continuous flue gas measurement: O_2, CO, CO_2 , NO_x, SO_2, TRS, CH_4, NH_3
- Sample based analysis: solid matter content, odour gases
- Fuel analysis: humidity, ash, sulphur, and calorimetric heating value
- Infrared imaging and temperature measurements, and efficiency measurements.

The research projects are always carried out in collaboration with enterprises and other research institutes working in the field. The size of the projects varies from small ordered searches carried out as student rehearsals to the master's and doctor's thesis works and large co-operation projects that last several years.

Examples of the projects during 2003*:*

Utilization of local by-product streams in distributed energy systems, pre-study
LUT: MSc *Niko Eriksson, MSc Antti Koski, Dr. Mika Horttanainen, Dr. Petri Kouvo, Prof. Esa Marttila*
University of Kuopio*: Researcher Marjaleena Aatamila, Prof. Juhani Ruuskanen;* University of Joensuu: *Researcher Päivi Peltola, Prof. Kalle Määttä*

Finland is a sparsely inhabited country. Distances between the places where the waste is generate and large waste incineration plants, which are under planning, are often long. This increases the costs of usage of refuse fuel. In the same time the demands of directive 2000/76/EC on the Incineration of Waste for small-scale and large combustion plants are the same. Relatively this increases the costs of usage of refuse fuel more in small-scale combustion plans. Possibilities to use refuse fuel in distributed energy system are investigated with two different cases. This has been done from technical, environmental, economical and legislative point of view.

First case is carried out using city of Virrat as an example. Today plastic-, paper-, and wood waste are collected separately and used as refuse fuel in local district heating plant. System is effective and other fuels can be displaced with a quality waste fuel. Still the demands of continuation the energy use of waste are relatively expensive for the plant. Solutions for this problem are studied.

Second case carried out for the area of South-Karelia. In this case we consider the best fractions of the waste that is produced in the larger area. The packaging waste of local markets and energy waste from construction sites are included to the study. Today this energy waste is transported over a long distance and used in large utility boilers of pulp and paper mills as dual fuel. Opportunities for local use are studied. Commercial activity plays a big role in this study. One major goal is to find economically viable business around the refuse fuel system.

Project began in October 2003. The first part of it, which is a pre-study, will be finished in the end of April 2004. The results of this pre-study will be used as source information for a possible continuation study. The project is financed by TEKES, five Finnish companies and a Finnish town.

Thermo-chemical conversion of the by-products and wastes of industry and communities

MSc Mika Luoranen, MSc Sami Lappalainen, MSc Niko Eriksson,Dr. Mika Horttanainen, Dr. Petri Kouvo, Prof. Esa Marttila

At the end of year 2002 was so called CSC (Controlled Solids Circulation) test apparatus completed at the environmental laboratory of LUT for the purpose of scientific research of thermo-chemical conversion of solid materials. The term "thermo-chemical processing" is understood here as a thermal method to process solid materials in desired conditions, including complete combustion and gasification, depending on needs.
This CSC-reactor, which is designed for the nominal fuel input of 200 kW, enables us to study for example energy use possibilities of solid wastes and by-products, which originate from industry, communities and agriculture.

CSC technology enables more accurate control of temperatures inside the process than the "traditional" fluidized be d combustion technologies. Through the development in controlling temperature it is possible to achieve significant improvement steps in reducing process emissions, avoiding corrosion and controlling the behavior of ash and different bed materials during the combustion process.

Besides the research concerning streams of by-products and solid wastes, the CSC test apparatus is used in the research work that deals with the formation of different flue gas emission components, such as NOx and PCDD/F's. Aim of the research work is to identify and study the mechanisms that occur inside the complicated burning process, and to find out technically and economically feasible means to control emissions from the boilers of industrial processes and energy production.
Along with LUT's own research, the CSC test apparatus is also available for the research purposes of business enterprises.

During the year 2004 another thermo-chemical processing unit will be built in the LUT environmental laboratory. The unit is based on commercial Bubbling Fluidized Bed (BFB) technology.

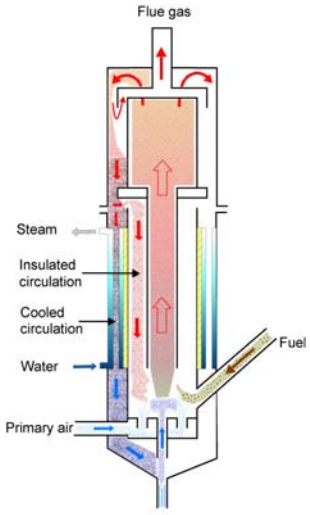


Fig. A schematic picture of the CSC-reactor

InnoEnvi

Prof. Esa Marttila, Dr. Mika Horttanainen, MSc Tuomo Hilli, MSc Hannariina Honkanen, MSc Pauliina Uusi-Penttilä, MSc Mari Ruotsalainen, MSc Sami Lappalainen

InnoEnvi project (05/2002 – 01/2004) aimed at networking the environmental business in Southern Finland and developing the information society. InnoEnvi was a part of the InnoElli program established by the Southern Finnish provinces. The main objective of InnoEnvi was to create a nascent environmental cluster in Southern Finland. Today, most Finnish companies specialized in environmental technology are small, young and fragmental, as a result of which they need support and teamwork, especially when attempting to enter the international markets.

In LUT one essential objective in the project was to find the possibilities for and the advantages of cooperation between companies in the waste and wastewater management business in Southern Finland. It was made a master's thesis about the subject. In addition, the study also aimed at ascertaining the effects of this cooperation on domestic and international business activity.

LUT had also other roles in the project: to develop a database in Internet about the amounts, management and recycling of all kinds of waste flows and to conduct the development of the Southern Finland energy cluster. In energy cluster the co-operation triggered a new project directing to northwest Russia: FRESCO.

Fresco

MSc Hannariina Honkanen, Dr. Mika Horttanainen, Prof. Esa Marttila

Project "Promotion of the Finnish energy business in Northwest Russia" (FRESCO, 10/2003 – 12/2005) is carried out with several partners (e.g. Vantaa Energy, Green Net Finland ry, Kymenlaakso Polytechnic and Kvaerner Power). This Interreg III A project aims at studying the possibilities and potential of ESCO business (Energy Service Company) in Northwest Russia. Other objectives are building the contact network for Finnish energy

enterprises in the destination area, co-operation strategy for promotion of optional energy source utilization and Finnish technology export and a prepared model for ESCO business in Northwest Russia for Finnish companies.

Sustainable development action plan for Lappeenranta University of Technology
Prof. Risto Soukka, MSc Tiina Lehto

The aim of this study was to establish a sustainable development action plan for Lappeenranta University of Technology. The departments of the university can obtain information on sustainable development indicators and managing programs from the action plan. The study examines aspects and indicators of sustainable development for every department as well as how the indicators and the Baltic 21E program can be used.

The sustainable development action plan is based on the 2002 reporting instructions of the Global Reporting Initiative and partly on the ISO 14001environment standard. The Baltic 21E report is taken into account in the action plan in accordance with instructions from the Ministry of Education.

The study describes the organisation, vision, strategy and management systems of Lappeenranta University of Technology. The sustainable development survey was mainly performed using interviews. The interviews revealed the aspects of sustainable development of the university's departments. These aspects were arranged into activities, products and services based on the environmental standard. The Baltic 21E report is taken into account in the aspects. The study recognised unit-based indicators for monitoring sustainable development. These indicators are formulated on the basis of GRI's Sustainability Reporting Guidelines publication. The study also clarified what the uses of the indicators are and, using examples, assessed the practical implementation of the indicators and Baltic 21E program.

The sustainable development survey indicated that the university's aspects of sustainable development are linked to teaching, research, further education and publishing activities. Sustainable development can also be achieved through regional effectiveness in the form of stakeholder engagement and new information production. The awareness of sustainable development is also important.

A large number of sustainable development indicators were recognised; they were mostly related to the social aspect. Classifying the indicators by their use reduced the number of indicators for each purpose. Afterwards, the most significant indicators should be identified through stakeholder dialogues. The main use of the indicators in this study would be in the internal development of the university's departments and communication and, to a lesser extent, in performance discussions.