SUMMARY OF RESEARCH ACTIVITIES
1993-1996

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Preface

Introduction
The International Energy Agency (IEA) was established in 1974 in order to strengthen the co-operation between member countries.
As an element of the International Energy Programme, the participating countries undertake co-operative actions in energy research, development and demonstration.

District Heating is seen by the IEA as a means by which countries may reduce their dependence on oil. It involves the increased use of indigenous or abundant fuels, the utilisation of waste energy and improved energy efficiency. With the same objectives District Cooling is getting a growing interest. The positive environmental effects of improved energy efficiency will give an additional and very strong impulse to raise the activities on District Heating and Cooling.

Annex I
IEA's Programme of Research, Development, and Demonstration on District Heating was established in 1983 at a meeting in Stockholm. In the first phase (Annex I) ten countries took part in the programme: Belgium, Canada, Denmark, Federal Republic of Germany, Finland, Italy, the Netherlands, Norway, Sweden and USA.
The National Energy Administration, Sweden, has been the Operating Agent for Annex I, in which the following technical areas have been assessed:

- Heat Meters
- Cost Efficient Distribution
- Heat Production
- Use of Low Temperature Heat Sources in District Heating
- Conversion of Building Heating Systems to District Heating.

A Summary Report of all research activities carried out under Annex I in the period between November 1983 and December 1987 was published in 1988 by the National Energy Administration Sweden (report Status Energiverk; 1988: R16).

Annex II
In 1987 Annex II was started up under which the following technical items have been included:

- Consumer installations
- Piping
- Advanced Fluids
- Heat Meters
- Advanced Heat Production Technologies
- Thermal Energy from Refuse.

The Netherlands Agency for Energy and the Environment (NOVEM) has been acting as the Operating Agent for Annex II. Nine countries have participated in this Annex, i.e. all countries of Annex I except Belgium.

The Summary Report of all the research activities carried out in the time period between May 1987 and November 1990 was published in 1990 by NOVEM (Report NOVEM 1990 R-12).

Annex III
In May 1990 decisions were taken about an Annex III, in which all participants of the second phase continued their participation for another three-year period. Also the United Kingdom decided to take part.

Items for Annex III were:
- R&D Project Review
- Promotional Activities
- Piping Technologies
- Consumer Heating System Simulation
- Supervision of District Heating Networks
- Advanced Fluids.

Also for this Annex NOVEM has been acting as the Operating Agent. In 1993 NOVEM has published the Summary Report of the Research

Activities carried out between May 1990 and May 1993 (Report NOVEM 1993 P-10).

Annex IV

In May 1993 it was decided to continue the activities; Annex IV was started up. In Annex IV all countries of the previous Annex participate, except Italy. In 1994 Korea decided to take part in the programme. The Executive Committee decided upon the following items for the programme under Annex IV:

- Integrating District Cooling and Combined Heat and Power
- Advanced Transmission Fluids
- Piping Technology
- Supervision of District Heating Networks
- Efficient Substations and Installations
- Development of long-term co-operation with East European Countries
- Low Cycle Fatigue
- Managing a hydraulic Systems in District Heating
- Review of Water Treatment Practices.

Again the Netherlands Agency for Energy and the Environment (NOVEM) has been acting as the Operating Agent. The report you are reading now (NOVEM 1997 N9), contents the summaries of all research activities carried out between May 1993 and March 1997.

Annex V

In May 1996 Annex V has been started up. USA decided not to participate in this Annex, so following countries co-operate in Annex V: Canada, Denmark, Finland, Germany, Korea, the Netherlands, Norway, United Kingdom and Sweden. The Executive Committee has set following priorities:

- Optimisation of operating temperatures
- Balancing the production and demand in CHP
- Cost effective DH&C networks
- Fatigue analysis of district heating systems
- District heating and cooling in future buildings
- Handbook about plastic pipe systems for district heating
- Optimal operation, operational availability and maintenance in DH systems

NOVEM is acting as the Operating Agent for Annex V.

Available budget

The available budgets per Annex are listed below:

Annex I	US$	525,000
Annex II	US$	675,000
Annex III	US$	1,000,000
Annex IV	US$	1,100,000
Annex V	US$	1,000,000

Information

General information about the IEA District Heating and Cooling Programme will be given by:

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Executive summary

Background
One of the major aims of the IEA's activities was, and still is, to reduce the vulnerability of member countries to the interruption of imported energy supplies, particularly their depence on oil. Recent history has shown in which scale disturbances of the supply of energy could be created by international political conflicts.

Encouraging the increased use of indigenous fuels and, where energy has to be imported, ensuring that the sources of such supplies are spread as widely as possible will stay some of the measures that have to be promoted in a still stronger effort than was utilised up to now. Using fuels more efficiently will be a key part of the IEA's member countries' strategies. Fortunately, increasing national self reliance in energy, particular in terms of increasing efficiency and renewable energy use is normally very compatible with the reduction of Green House Gases (GHG's) and Sustainable Development. District Heating and Cooling has proven to be a major contributor to GHG reduction in many member countries and recognition of DH&C's importance is growing. In fact, many countries where District Heating is well established, are renewing their commitment to district energy as they find new ways to use the technology to reduce environmental impacts. District Heating does not, in itself, reduce GHG's. However, it facilitates linkages between supplies that are environmentally desirable and end users that could not otherwise make use of those energy sources.

In general terms, communities concerned about GHG reduction should first adopt policies for the reduction of individual uses of energy and for encouraging the use of renewable energy. Having done this, the community should be considered as a system and should seek to utilise:

- waste heat from industrial and municipal operation
- waste renewable materials such as landfill gas, wood or agricultural wastes or municipal wastes
- new renewable energy such as harvested biomass or cooling from oceans, lakes or rivers
- combined heat and power (CHP) or cogeneration should always be considered, especially if fossil fuel is to be used
- if all of the above have been used to limited then efficiency use of fossil fuel must be considered.

An expansion of District Heating and Cooling activities would make it possible to more easily choose between alternative energy sources in order to realise the most efficient energy supply. Where feasible, the combined production of heat and power will have to be promoted as the first option, as it integrates the environmental savings of centralised production units and the energy saving of the combined production. One of the easiest ways to release the environment is to diminish the use of energy. With combined production this goal can be realised apart from efforts to diminish the energy-consumption of the end-users.

In North American countries also District Cooling has got a growing interest. For that reason also attention has been given to the specific aspects of this kind of technology, in relation to energy savings and amelioration of the environment.

Organisation and Participation
Co-operation between the participating countries is governed by an Implementing Agreement. Decisions on the work programme and budget are taken by the Executive Committee which has representatives from all participating countries. For the meetings of the Executive Committee international organisations in the field of District Heating and Cooling from Europe (Euroheat and Power

Unichal) and North America (IDEA) are invited to attend on an observatory basis.

Projects are defined in Annexes to the Agreement. The Operating Agents acts in the interest of all countries and co-ordinates the activities, negotiates contracts etc. within the budget and programme limits decided upon.

In the Annex IV, which results are described in this summary report, the following projects have been included:

Project title	Lead country	Project management
1. Integrating District Cooling with Combined Heat and Power	USA	Resource Efficiency, Inc. Mr. Mark Spurr Wacouta Street, Suite 550 St. Paul MN 55101, USA
2. Advanced Energy Transmission Fluids	Germany	Prof. Weinspach Thermische Verfahrenstechnik GmbH Dr. Artur Steiff Heinrich-Sträter-Str. 12 Dortmund, Germany
3. Piping Techniques	Germany	GEF Ingenieurs Gesellschaft für Energietechnik und Fernwärme Mr. Lothar Gerke Ferdinand Porsche Strasse 4a Leimen, Germany
4. Quantitave Heat Loss Determination by means of Infrared Thermography - The TX Model	Sweden	Fjärrvämeutveckling FVU AB Mr. Heimo Zinko 82 Nyköping, Sweden
5. Efficient Substations and Installations	Norway	SINTEF Mr. Rolf Ulseth Trondheim, Norway
6. Temperature Variations in Preinsulated DH Pipes; Low Cycle Fatigue	Denmark	RAMBØLL Mr. Karl Erik Hansen Teknikerbyen 31, Virum, Denmark
7. Managing a hydraulic System in District Heating	The Netherlands	Jos Claessens Beheer BV Mr. Ab Horeman P.O. Box 1002 NL-6235 ZG Ulestraten, The Netherlands
8. A Review of European and North American Water Treatment Practices	Canada	Natural Resources Canada Mr. Rob Brandon Canmet Energy Techn. Centre 1 Haanel Drive Nepean, ON.K1A 1M1, Canada

For each of the projects an expertsgroup has been created, in which experienced representatives of the participating countries have contributed to the project-definitions and to the progress of the activities.
The results of all these projects are published

in separate reports and are summarised in the following chapters of this report, NOVEM 1997: N9.

In order to reach a large audience in the district heating and cooling field, an agreement was made with the editor of ‘Fernwaerme International’ (FWI) to use this magazine for publishing periodical information about the ongoing activities, results of studies and other publications.
In ‘District Energy’, the official newsletter of the International District Energy Association (IDEA) also attention is given to the IEA-activities.
At international conferences and symposia on District Heating and Cooling presentations have been set up, providing information on the activities and their results.
All county-representatives extended the promotional activities in their home-countries. Mutual information exchange between IEA and Euroheat and Power Unichal, for the European region, and the IDEA for North America will be firmly supported to reach a wide range of interested people.

Most of the Annex IV-reports have been printed in 500 copies. Of these, 400 copies were to be distributed in the participating countries by the national representatives.
The remaining copies have been produced for distribution by the Operating Agent on request to those who are interested.

Integrating District Cooling with Combined Heat and Power (1996 N1)

SCOPE AND PURPOSE

This report describes the energy efficiency, economic and environmental implications of alternatives for integrating district cooling with Combined Heat and Power (CHP). The purpose of the report is to provide guidance to designers of district cooling systems to identify the best options for integrating district cooling with CHP in new plant facilities.

Each case will have its own particular technical and economic parameters, and this report is intended to aid in structuring the essential case-specific analysis, rather than substituting for such an analysis. Capital and operating costs for CHP and chiller technologies are presented, but significant variations in costs can occur due to currency values and other case-specific factors

For the purposes of this report, district cooling is defined as any system which provides building cooling through the distribution of chilled water, hot water or steam from a central plant. Thus, cooling achieved through distribution of district hot water or steam to drive absorption chillers located in buildings is also considered district cooling.

The report addresses:

- the thermodynamic fundamentals of CHP and cooling, providing a conceptual foundation for later quantification of the efficiency of alternative cooling/CHP options;
- the efficiency, air emissions and economics of alternative CHP technologies (gas turbine, reciprocating engine, steam turbine and gas turbine combined cycle);
- the efficiency, refrigerant environmental impacts and economics of alternative cooling technologies (electric centrifugal, steam turbine centrifugal, one-stage steam absorption, two-stage steam absorption and hot water absorption);
- review of fundamental aspects of district heating and cooling systems which are relevant to integrating district cooling with CHP;
- the efficiency and economics of integrated cooling/CHP technology alternatives, including presentation of economic formulas, discussion of key economic variables and calculation of cooling costs for illustrative hypothetical scenarios; and
- case study examples of integrating district cooling/CHP.

ENERGY EFFICIENCY

Basis for Efficiency Comparisons

A consistent “figure of merit” for comparing the energy efficiencies of different options for combining CHP and cooling is problematic because each option, employed in a given circumstance, will produce different annual quantities of electricity, heating and cooling. Efficiency comparisons based on summing these three types of energy outputs will be misleading because they ignore the differing exergy qualities of electricity, heating and cooling.

Consequently, comparisons of the efficiencies of alternative CHP/chiller options were made on the basis of maximizing chilled water production. Heat-driven chillers were supplemented with electric-drive chillers using available electric output from CHP.

Findings Regarding Efficiency

1. If the goal is maximum cooling output per unit of fuel used, the CHP technologies rank as follows, from highest to lowest output:

- Gas turbine combined cycle
- Diesel engine
- Gas turbine
- Steam turbine

This ranking holds true regardless of the chiller technologies employed, although the extent of differences between the CHP types varied depending on the chiller technologies.

2. With a simple cycle gas turbine, the higher-temperature heat-driven chillers (supplemented by electric drive chillers) provide more cooling output than the lower-temperature options, with the electric-chiller-only option providing the lowest cooling output. This is also roughly true with a diesel engine, although the lower-temperature heat-driven options compare more favorably because the temperature of the useful thermal output of diesel engines is more limited compared to the gas turbine.

3. With steam turbine and gas turbine combined cycle CHP, the electric drive chiller provides the highest cooling output, followed by hot water absorption and other heat-driven options, roughly in order of increasing driving temperature. The differences between chiller types with gas turbine combined cycle are less than those for steam turbine CHP.

4. When combining cooling with CHP in new gas turbine combined cycle facilities, there are only small differences in overall efficiency between maximizing electric production and using electric drive chillers compared to extracting some of the thermal energy and using it to operate absorption chillers. The differences in practical efficiencies are within the range where specific equipment selection and design conditions will determine which alternative is most efficient.

5. Simple cycle gas turbine CHP can appear attractive from an efficiency standpoint when the thermal output is viewed as “waste heat.” However, it can be argued that this is because, from the standpoint of new plant design, total efficiency has not really been optimized with a simple cycle, i.e., generally there is the capability to generate additional electricity in a combined cycle.

6. For a new CHP facility, there is not a compelling argument for using heat generated through CHP to drive chillers as opposed to installing a condensing tail to drive electric chillers. However, this argument does not hold for the smaller end of the scale of CHP facilities (e.g. 5 MWe), where due to economies of scale it is generally not cost-effective to install a steam turbine to drive a generator in a combined cycle.

ECONOMICS

This report addresses the costs of generating cooling energy using CHP. However, distribution costs can be a significant part of the total cost of district cooling. Where a district heating system is well developed, distribution of “cooling energy” via the district heating loop for conversion with absorption chillers has the potential to be the most cost-effective option considering both plant and distribution costs.

The economics of integrated cooling/CHP options are highly dependent on many case-specific factors. The following discussion summarizes the results of the illustrative scenarios presented in the report for new CHP systems in the 20-25 MW_e size range under stated load and economic assumptions.

CHP options

1. In the illustrative scenarios, simple cycle gas turbine CHP provides the lowest cooling

cost at low values of electricity (3 cents/ kWh_e), due in large part to its low investment cost.

2. Combined cycle gas turbine CHP provides the lowest cooling cost at higher electricity values (above 5 cents/kWh_e) as a result of its high electric efficiency. As electricity value rises, the competitiveness of the gas turbine combined cycle increases faster than the other CHP options.

3. With the potential for steam turbine CHP to be fired with lower-cost fuel, this CHP option has the potential to be the most cost-effective option depending on specific fuel costs.

4. In CHP plants under 20 MW_e, reciprocating engine CHP can become more competitive than indicated in the illustrative scenarios, and in CHP plants above 50 MW_e, steam turbine CHP has the potential to be more competitive than indicated.

5. Sensitivity of cooling costs to changes in fuel cost, heat value and electricity value is lowest in the warm climate because net CHP costs are spread over a relatively large number of cooling utilization hours. Conversely, sensitivity of cooling costs to these factors is highest in the cold climate because net CHP costs are spread over a relatively small number of cooling utilization hours.

Chiller options

1. Based on the illustrative scenarios, electric drive chillers combined with gas turbine CHP (at low electric values) and gas turbine combined cycle CHP (at high electric values) provided the lowest cooling costs for centralized chilled water district cooling. However, in many scenarios the cost differences between electric drive cooling and heat-driven options (supplemented with electric drive) were quite small and can be considered insignificant in view of the many case-specific variables which can affect the calculations. In general, the costs of the CHP are more significant than the costs of the chiller equipment.

2. Generally, cost differences between the cooling technologies combined with simple cycle gas turbine and diesel engine CHP are very small because the electric output of these CHP technologies is not affected by thermal extraction. In contrast, with steam turbine CHP and to a lesser extent gas turbine combined cycle CHP, cost differences between chiller technologies are more significant because with the steam cycle the electric output decreases when thermal energy is extracted, and this derate increases with increasing thermal extraction temperature.

3. Aside from direct economic considerations, the value of flexibility and reliability may lead the system designer to install heat-driven chillers. For example, heat-driven cooling can help protect against penalties associated with a loss of power generation capacity at peak, since with heat-driven chillers the system operator can fire up relatively inexpensive standby boiler capacity.

4. For all CHP types, the economic differences between the heat-driven chiller options were relatively small, with costs slightly higher for chillers requiring higher-temperature driving energy. In essence, the higher investment costs for higher-temperature heat-driven options was to a large extent offset by their higher efficiencies.

Advanced energy transmission fluids for District Heating and Cooling (1996 N2)

Introduction

The application of drag reducing additives in district heating networks is a promising technology to improve the competition conditions of those systems. The pressure loss and therefore, the pumping costs of existing networks can be reduced or their capacity can be increased. The pipes and fittings of new planned networks can be designed in smaller diameters. Other possibility to use the drag reducing effect are the decrease of the supply temperature due to an increasing mass flow while keeping the capacity constant or the integration of further (far away) heat sources which becomes only economic due to decreasing pumping costs. Resources can be saved and the pollution of the environment can be reduced.

During the last 13 years, lots of investigations concerning the application of cationic surfactants as drag reducing additives have been carried out in Canada, Denmark, Finland, Germany, Korea, The Netherlands, Sweden and the United States. Experiments with different kinds of cationic surfactants such as Ethoquate, Habon(-G), Obon(-G), Dobon(-G), C_{16}TASal etc. have been carried out. The effects on pressure drop behaviour in straight pipes, helical tubes as well as the heat transfer behaviour in those geometries have been investigated. The heat transfer of shell and tube, helical tube and plate heat exchangers has been examined. Furthermore, heat meters, fittings, pumps, the corrosion behaviour, environmental aspects and water hammering have been investigated when using drag reducing surfactants.

In laboratory tests and full scale investigations in Denmark, Germany and the Netherlands, the general suitability of cationic surfactants - especially of Habon-G and Dobon-G in combination with Sodiumsalicylate - as drag reducing substances for district heating systems could be proven. Based on those results, strategies to apply surfactants in real district heating systems have been developed.

Several important projects have been supported of the IEA. Important subjects such as environmental aspects, the influence in a large scale plate heat exchanger, corrosion behaviour etc. have been investigated within the bounds of projects supported by the IEA.

Under IEA Annex IV, four projects concerning the field of research “Advanced Transmission Fluids for District Heating and Cooling”, have been supported. Several institutes and companies of different countries have been carried out theoretical and experimental work. Some of this work has been planned and carried out in cooperation with various partners.

The first project (project A) is dealing with the simulation of the behaviour of comprehensive transport networks with special consideration of heat exchangers which separate the transport system from the distribution network. Simulation results for the application of surfactants in a real system are given. Within the context of project A, economic calculations have been carried out. These calculations consider general models and give an overview of the savings in costs which can be expected under certain conditions.

In the second project the influence of drag reducing additives in small domestic heat exchangers and on flow meters which are installed in small consumer stations has been determined. Four different kinds of heat exchangers and four different flow meters have been investigated.

Aim of project C was the collecting of data and information about commercially available drag reducing surfactants and of regulations of different countries concerning the approval of drag reducing additives in district heating systems. Therefore, a questionnaire has been developed, which was handed to all members of the Experts Group “Advanced Transmission Fluids for District Heating and Cooling” to register the state of conditions of the different IEA member countries.

When using drag reducing additives inside pipes, the heat transfer from the fluid on the inner pipe area is reduced significantly. Therefore, the last project has been carried out in which the improvement of the heat transmission conditions in tube bundle heat exchangers by installing turbulence increasing obstacles inside the pipes was investigated.

A. Modelling of the Location and Requirements for Heat Exchangers in District Heating Networks using Friction Reduction Additives

In the context of this study, a simulation program for calculating the behaviour of district heating systems operating with drag reducing additives has been developed. The behaviour of district heating transport systems as well as of single components - especially typical heat exchangers such as plate, shell and tube and helical tube heat exchangers - can be calculated with the program "TenSim", when applying drag reducing additives.

The simulation program can be used to modify existing networks and create new district heating systems to realize the operation with surfactant solutions. Single system parts (existing and additional necessary devices) - especially heat exchangers - can be designed or modified to achieve a design which guaranties a well working operating mode.

By simulating several cases of modified systems and comparing the results of the simulations, an optimum technical solution can be achieved.

In an example calculation the simulation program has been tested. The test system (the system Völklingen Luisenthal) has also been used for a long term full scale test (application of Dobon-G/Sodiumsalicylate), so that all technical data (data for apparatus like pumps, heat exchangers, pipes, geographical data etc.) were available as well as results for the operation with drag reducing additives. Therefore, simulation results could be compared with results of a real application. The comparison showed that the simulation results calculated with "TenSim" reproduce the real results sufficiently.

A necessary condition for the application of drag reducing additives is the economic viability. Comparing the modified system working with drag reducing surfactants (that means the optimum technical solution which has been found with the simulation tool) and the original system, operating with pure water, it is possible to estimate the savings in cost due to the application of surfactants.

Therefore, cost functions have to be evaluated in further studies to be able to calculate the investigations that are caused by the additives. Those functions for German conditions have been developed in several studies carried out at the University of Dortmund.

Furthermore, economics calculations have been carried out. In this studies, a general model has been used to estimate the potential in saving costs on principle.

Next step concerning the application of drag reducing additives in district heating systems should be the simulation of concrete transport systems with "TenSim" - including the modifications. Furthermore, economics calculations (estimations) should be carried out for real systems to get the necessary informations about the economic aspects of the application of drag reducing additives in existing district heating networks.

B. Experiments on the Effects of Friction Reduction Additives on Substances

This report discusses the results a NOVEM-supervised investigation aimed at assessing in how far the surfactant Habon-G can reduce friction losses in domestic water supply systems utilizing heat from district heating systems.

Earlier work has shown that Habon-G, when added to heat transport systems, has a beneficial effect on the required pump capacity. Habon-G produces a laminar flow, and this reduces not only the friction losses in pipelines but also the heat transfer.

This report discusses the effect of Habon-G on both parameters as observed in four different heat exchangers and heat flow meters used for domestic water supply systems.

For the purposes of the present investigation a test facility was made in which the district heating circuit is simulated by a closed loop which included an adjustable electric heater. The domestic water circuit was connected to a high-capacity water supply booster. The heat exchangers and heat flow meters were integrated in the facility and could be inserted one at a time into either circuit by means of ball valves.

Measurements made on the heat exchangers indicate that all four heat exchangers meet the specified requirements, although there are some differences. The flow in them still seems to be turbulent, despite the laminising effect of Habon-G.

The heat flow meters do not all meet the requirements. Two were found to be at error and their inaccuracy increased with increasing Habon-G concentrations. The percentage errors of the other two meters were below the threshold and were not affected by the presence of Habon-G.

As observed earlier, adding Habon-G to the water in district heating systems has a beneficial effect on the flow resistance and reduces the heat losses in the feed lines. The present investigation shows that addition of Habon-G does not affect the heat transfer in the domestic water supply system in any material way. However, a critical assessment of the type of heat flow meter to be used is called for.

C. Survey of Environmental Restrictions to the Use of Additives in District Heating and Cooling Systems

Aim of this project is the collecting of data and information about commercially available drag reducing surfactans and of regulations of different countries concerning the approval of drag reducing additives in district heating systems.

Bruun & Sörensen has created a questionnaire, which was handed to all members of the Expert Group to register the state of conditions of the different IEA member countries.

The project was started at the beginning of October 1994. The questionnaire was answered from nearly all member countries (Canada, Denmark, Finland, Germany, Korea, Sweden, The Netherlands and USA). B& S has analysed the answers ans summarized the information. An unambiguous conclusion covering the situation in all countries cannot be drawn. In most countries there are no concrete rules related to this new technology.

It seems to be clear that a certain reluctancy towards the intoduction of new additives in general is a common attitude. Zhe technology has not been declined in any of the countries.

The activities on this field are finished. The final report of project C, “Survey of environmental Restrictions to the Use of Additives in District Heating and Cooling Systems” was closed in May 1995 and is available.

D. Improving of Heat Transmission Properties of Tube Bundle Heat Exchangers by Installing Obstacles inside the Pipes

In this study the heat transfer and pressure drop of drag reducing surfactant solutions inside straight pipes with obstacles has been investigated. Therefore, an existing test rig, mainly consisting of two closed loops (one for cooling and one for heating), has been modified. As cationic surfactant, Habon-G (hexadecyldimethlypolyoxethylammonia-cation and 3-hydroxy-2-naphthoate as counter-ion) has been applied.

Spiral springs of different pitches have been used as obstacles to increase turbulence and therefore, the heat transfer which is significantly decreasing when applying drag reducing additives (up to 95 %). The springs consist of wire made of stainless steel of a diameter of 1 mm. The diameter of the spring has been a little bit higher than the inner diameter of the pipe to guarantee a certain support.

For pure water the installation of the obstacles leads to an increase in heat transfer of nearly 100 % in maximum. The behaviour is dependent on the pitch. The characteristic for the 8 mm and the 16 mm springs are almost identical while the Nusselt numbers of the 24 mm spring are smaller.

For surfactant solutions the heat transfer behaviour strongly depends on concentration, temperature and pitch. For 500 wppm the improvement in heat transfer is only small. The conditions of the origin state (water without obstacles) - which is the requirement for a sufficient operation with surfactants - cannot be reached with this concentration.

The Nusselt characteristic is parallel below that one for water without springs.

In contrast to the 500 wppm solution, the 125 wppm and 250 wppm show a completely different behaviour. At low Reynolds numbers the characteristics start in the range of that one for water without obstacles and rise - at a certain Reynolds number - up to the values for water with obstacles. This critical value is dependent on concentration, temperature and pitch of the spring. With increasing pitch the critical point is moving to higher Reynolds numbers as well as with increasing concentration. With increasing temperature, the critical values also move to higher flow velocities until a certain temperature, which is dependent on concentration, is reached. Behind this point, the values are moving to lower Reynolds numbers and the characteristic is moving to higher Nusselt numbers because the drag reducing effect is weakening.

For a concentration of 250 wppm, the heat transfer conditions of the origin state can be reached with the 8 mm spring above Reynolds = 25,000 and with the 16 mm spring above 56,000. For 125 wppm, the conditions of the origin state can be reached with all investigated springs (for the 24 mm spring, the condition Re > 47,000 has to be fulfilled). Therefore, the aim to reach the heat transfer coefficients of pure water without obstacles could be reached under certain conditions.

On the other hand, measurements of the pressure drop showed a significant increase. This increase is - compared to the increase in heat transfer - superproportional.

The strongest increase could be observed for the 8 mm spring for 250 wppm. In this case the pressure drop is increasing of about 850 %.

The characterisitc course of the drag characteristic mainly shows the same dependencies as the Nusselt characteristics. The most important influence has the pitch of the spring. Comparing the 8 mm and the 24 mm spring for a 250 wppm surfactant solution, the pressure drop increase of the 8 mm spring is 850 % in maximum compared to 200 % in maximum for 24 mm.

Considering the technical application and assuming that the heat transfer has to be at least as large as for water without obstacles, an enormous pressure drop increase has to be spent. Thus, for the technical application, detailed calculations of the changed conditions of the complete system have to be carried out in order to check the installation of spiral springs inside pipes as a measure to improve the behaviour of tube bundle heat exchangers when using drag reducing additives.

Guideline to Planning and Building of District Heating Networks (1996 N3.1)

The handbook

District heating networks fulfill an important service role and construction of these calls for large-scale investment. Consequently, network systems must meet special criteria in terms of network operating life, reliability of supply and cost-effectiveness. A body of specialized knowledge has been assembled from the development of numerous heat and distribution services in northern and central Europe, some of them large, and this will be passed on here. Heating distribution systems of considerable size have also been built in Eastern Europe, albeit under different economic circumstances.

This handbook is intended for the trained engineer and contains information on particular aspects of building heat distribution lines. It is not a textbook for teaching the basics to engineers. It discusses only the fundamental aspects involved in design and construction but does not touch on specialized products or on specific construction alternatives.

This publication has been put together with the collaboration of experts from nearly ten countries. It is written in everyday engineering terms as well as those of routine planning for district heating systems. The text details many important situations and difficulties. This is not intended to intimidate the reader with the numerous interrelationships and problems but rather to make those less experienced aware of the hidden pitfalls.

Most of the manuscript was written in Germany. Correspondingly, the majority of the illustrated material has also been drawn from German sources. It should be said in this regard that cost considerations alone restricted the use of illustrated material from outside Germany. Scandinavian engineers have had no less success in developing the heat distribution systems in their own countries. This work looks at the problems primarily from the standpoint of the engineer. The business background is discussed to the extent necessary for proper understanding.

Even technically discussion is confined to the planning and construction of pipelines for hot water and not for steam. The issues involved in thermal generation or customer’s service installations are touched on only as they affect network planning.

The present handbook is intended to provide engineers with stimulus for their everyday planning work. It will have achieved its purpose if it saves them from having to acquire some costly knowledge or other on their own.

As far as the organization of the contents is concerned, the handbook discusses the basic aspects required for network planning in the initial sections (up to and including Section 5). In Section 6 the reader is given a look at the technical and economic parameters which most affect network engineering. This is intended to provide a sufficient overview from which to recognize the most troublesome factors in the welter of interrelated aspects.

Section 7 deals with the process of network planning itself. The first general part discusses the various stages in the engineering aspects of planning while also describing the business situation and its implications on construction costs. Other technical discussions involve a detailed look at system hydraulics as well as issues relating to structural engineering, thermal insulation and even operating costs.

Lastly, Section 8 discusses pipeline engineering focussing on the laying of plastic- sheathed pipe. Other pipelaying techniques are discussed only as an adjunct. There is also discussion of special components involved in district heating lines such as compensators, inspection chambers, thermal insulation etc.

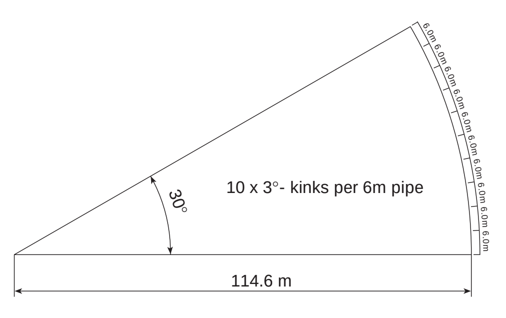
The case study in Section 9 is designed to illustrate the preceding theoretical sections. The handbook concludes with the requisite bibliographical data and editorial information.

Bend Pipes (1996 N3.2)

Introduction
Bend-pipes are components of pre-insulated bonded pipes made from straight pipes by bending. Bend-pipes have clearly larger radii in comparison with bends:

- Bend-pipe radius > 50 x Dsteel pipe
- Bend radius = 1.5 to 2.5 x Dsteel pipe.

The use of bend-pipes is particularly advisable when the best possible lay out requires a large radius. If for example the bend of a street is to be followed, bend-pipes offer a lay out possibility which means the lowest expenditure with regard to installation lengths, construction site and compensation expenditure with the corresponding radius.
At the realisation of changes of direction with pre-insulated bonded pipes normally 3° kinks are applied for small angles. Larger changes of direction (e.g. 30°) can be realised without statical test by applying several 3° kinks with a minimum distance of 6 m. However, only relatively large lay out radii (R - 114.6 m) can be created this way (see picture 1-1).



Picture 1-1: Example of a 30° change of direction with 10 x 3° kinks per 6 m of straight pipe, resulting lay out radius R = 114.6 m.

This radius is independent of the pipe dimension. At DN 100 the installation radius is realised with 3° kinks for about 1000 * Dsteel pipe compared with a minimal bending radius at DN 100 of 15 m, that is 130 * Dsteel pipe. Bends frequently cannot be used for such lay out situations for the very high loads on the little radius of the bend. Bend-pipes on the other hand behave mechanically almost like straight pipes, the load on the bend-pipe is hardly higher than in the straight pipe. Bend-pipes are therefore virtually ideal installation elements for changes of direction between 15° and 70°.

The admissibility of bending at cold installation is differently assessed in Germany. At field try outs at Fernwärmeversorgung Dinslaken with continuous flows in cold installed 3° kinks a temperature lift of 120 K was measured. Further parametric FEM calculations proved, that at this temperature level only installations without kinks are permitted. Changes of direction then had to be created with bend-pipes. According to assessments of Rumpel the opinion should be that cold installed kinks with segment angles up to 5° certainly are able to resist the full temperature lift without larger deformations.
Bend-pipes are no standardised components and are therefore differently laid out and manufactured, resulting in different smallest radii for bend-pipes for different manufacturers. The differences in permissible bending radii depend on one hand on calculation methods, and on the other hand on applied methods of manufacturing. To get a summary of the backgrounds of the offered bend-pipes, the manufacturers became a questionnaire on bonded pipes with the topics

- Laying out of bend-pipes,
- Manufacture of bend-pipes,
- Economy of bend-pipes.

The following explanations are based on the evaluation of this questionnaire which was answered by the manufacturers:

- Pan-Isovit (Germany),
- ABB-I.C. Moller (Denmark),
- Tarco (Denmark),
- Powerpipe (Sweden),
- Isoplus (Austria) .

Summary

Bend-pipes are virtually ideal installation elements since they are mechanically more trustworthy than straight pipes and offer high freedom of installation by allowing many curve angles.
There is not any norm internationally for bend-pipes in which the smallest permitted bend-pipe radius is stated. Therefore many different smallest admittable bend-pipe radii are stated by different manufacturers. These smallest radii are partially manufacturer conditioned, partially due to different installation processes of bend-pipes. Due to planning clearly smaller bend-pipe radii often are possible than those offered by the manufacturers. In the planner's vision this is very un-satisfying.

Therefore all leading European manufacturers of pre-installated bonded pipes were addressed for the questionnaire in the context of this essay on lay out, production and cost of bend-pipes. Five manufacturers from Denmark, Austria, Sweden and Germany have answered this questionnaire.

Answers concerning laying out of bend-pipes confirmed preliminary expectations for large differences with regard to criteria for lay out and the bend-pipe radii resulting. The example enclosed in the questionnaire of a bend-pipe DN 300 with a radius of 20 m shows these differences clearly. The smallest bending radius for such an installation the manufacturers needed up to 50 m. The indicated criteria for the installation differ greatly, now the "highest allowable earth pressure" was mentioned, than the "highest allowable compression in the PUR foam".
A unity of criteria for installation seems to be needed urgently to remove the predominant uncertenties.

Clearly smaller differences manufacturers show at the manufacturing of bend-pipes.
It is the same at practical all manufacturers:

- Up to the dimension DN 80 bend-pipes are produced on the construction site with the help of transportable bending tools.
- For larger dimensions (> DN 100) bend-pipes are manufactured at the factory, in which in principle up to a dimension of approx. DN 200 the complete pipe is bent.
- For dimensions larger than DN 250 as well complete as separate bending is practised. Bending the complete pipe is limited by the compression of the PUR foam and by the lateral displacement of the PE casing. When bending separately the smallest bending radius is determined by the bending force of the casing. Therefore at small bending radii the PE casing is created by some manufacturers by welding segments.
- At all dimensions elastic bending in the pipe trench on the construction site is possible for several pipes which are welded together.

Costs for bend-pipes manufactured at the factory were indicated by manufacturers as additional costs percentages in relation to straight bonded pipes. The price margin of the manufacturers goes up to 200 % from 115 % in which 100 % apply to the straight pipe. Single manufacturers have mentioned price details depending on the dimensions of the pipes. On the average one can use the following additional costs for bend-pipes:

<	DN 300	120 - 130 %
	DN 300 - 600	140 - 160 %
>	DN 600	160 - 200 %

The economy of use of bend-pipes with assumed changes of direction at two examples of 45° and 15° are not rejected.

In conclusion a current project experience was described to reveal problems that may appear at using bend-pipes at a DN 800 transport pipeline.

Execution of connections to pipelines in operation (1996 N3.3)

Introduction

The expansion of district heat supply to areas with low heat demand requires a consistent use of all possibilities to cut costs, in the pipeline construction too. One of the possibilities examined in this work is the forceful application of drilling-in techniques on pipelines in operation.

The essential use of this technology is the production of additional connections. First shall be revealed with an example that the drilling-in technique in principle offers a cost cutting potential. This allows already for a reduction of the building costs at the planning of the distribution network where at larger dimensions a variety of shut-off armatures requires considerable investments.

A reduction of the construction costs is possible because by this approach one can do without installing connection support nozzles for all potential customers along a main distribution line. Many nozzles appear to be abundant later on. Construction costs can be limited this way too because the time needed to realise connections with the drilling-in techniques is very limited. It is even possible to create open works which can be operated with simple safety measures.

Operation costs can be reduced by this drilling technique while the distribution company has no losses of revenue due to longer fall outs of operations. No costs appear for emptying and filling of additional parts of the network.

The drilling-in technique is not used as often as possible. Goal of this examination is to present and to compare in function and handling all common drilling-in techniques on the European market. Next to the description of the technology are presented the limits of use, opportunities and matters of security on the job. A comparison of costs of the available drilling-in techniques is in the conclusion.

Summary

The execution of connections to pipelines in operation is a proven technology for long time in the field of gas and water and is used more and more in applications in the field of district heating. The advantages are clear:

- No more emptying the pipeline.
- Heat distribution is not interrupted.
- Construction of networks is possible without a variety of shut-off devices and inspection chambers. Drilling-in is a fast and inexpensive technology.
- Repair of damaged pipelines possible by drilling-in without interrupting the service.

Welding the drilling support at the filled-up pipeline was seen for long time as the critical point for the application of the drilling-in technique. In a detailed essay of the Technische Werke Stuttgart (TWS), in co-operation with the TUV, welding to water-filled pipes was examined and the conclusion was that with certain requirements, e.g. the use of specific electrodes, a sufficient welding seam quality is obtained. From a welding point of view nothing opposes drilling-in.

Five manufacturers altogether are present on the market with equipment to create connections to filled pipelines without interruption. At this time two principally different procedures are offered:

- The drilling-in and milling procedure.
- The shear-off procedure (firing-off).

The drilling-in and milling procedure is offered by four manufacturers and uses a milling drill in combination with a centre drill for milling the pipe wall. The procedure requires a drain armature which is either connected directly with the drilling-in machine (a so called drain-drill-machine) or is separated from the actual drilling-in machine and connected to it. The drilling-in machines are on the market for several years partially and have proved themselves at a variety of drillings.

At the shear-off procedure the pipe wall is separated by means of a cutting club . The ripped off pipe wall is caught in the system-unit cover. The cutting club is accelerated by a priming mechanism, therefore it is called ”Anschießen”, firing off. The firing-off is a new development and has been on the market only for a short time.

The limitations of the drilling systems are enclosed by:

• Max. Temperature	Approx. 130 °C
• Max. Pressure	Approx. 16 - 25 bar
• Max. Drill size	DN 400

Therefore all are applicable in normal district heating installations.

For firing-off an especially dimensioned piece of equipment is required for every combination of drill size and main pipeline size. The connecting dimension is limited to DN 25/32 and the main pipeline to DN 80.

A comparison of the costs points out that prices for purchasing a drilling machine with appliances differ greatly and are hard to compare while the machines do cover different dimensions. Prices vary from DM 6.000,- to DM 40.000,-.

A comparison of the costs for producing a connection has shown that the drilling-in machine of TONISCO is the most economic one and that shearing-off is the most expensive. It should be considered though that a drilling-in closure with a closing disc is used at the TONISCO system as drain armature which is very inexpensive compared to other armatures. Safety reconsiderations oppose this system since a total closeness at drilling cannot be guaranteed.

The shear-off system however is more advantageously compared to drilling-in only than if a distribution company practises only a few drillings per annum out or if narrow working space excludes the use of a drilling-in machine.

Doubts on grounds of technical safety are further argument against the drilling-in technique. Demands of trade organisations led to requirements for a construction admittance for drilling-in machines in which the equipment is checked for technical safety and a clearance certificate is emitted.

Exact checking guidelines are in process but not yet formulated.

To sum up

Drilling-in is starting to become a frequently used technology in district heating.

It facilitates the production of an additional connection without interruption of service.

The equipment offered on the market has partly proved it self already for years and there are dedicated machines and procedures for almost every case in district heating.

Technical safety risks have to be classified low under consideration of specific requirements.

Quantitative heat loss determination by means of infrared thermography - The TX model (1996 N4)

Summary
This report is the final report of the IEA District Heating Project, Annex 4, “Supervision of District Heating Networks. The aim of the project was to further analyze and verify a method developed earlier for determining the heat loss from buried district heating pipes by measuring the temperature profile on the ground surface above the pipes. The temperature measurements can be made by means of infrared (IR) thermography using equipment such as modern IR thermography cameras.

The report describes the work done in the four co-operating countries Denmark, Finland, Sweden and USA for verifying the TX model established in work performed in IEA, Annex 3. The TX model hypothesizes that the temperature distribution on the ground surface above the pipes corresponds - under certain circumstances - to the heat loss from the pipes. By including the major influences of the climate, especially of the wind and the changing surface temperature, we have derived a semi-empirical equation for the heat loss when the TX factor, i. e. the integral of the surface temperature profile across the pipe, is measured. This model is called the advanced TX-interpretation model ATXIM.

Two kinds of investigations have been performed during the verification phase: Simulations and experimental evaluations on test fields.

Simulations have been performed with a finite difference program simulating the heat flow in the ground and between the ground surface and the surroundings. A computer program developed earlier was modified for reading actual weather data based on hourly mean values. The program was used for simulating a multitude of cases with different climate and soil conditions. As a result of these studies we determined that the wind is a very important parameter affecting the TX value. By including the mean wind velocity of the last 7 hours in the ATXIM, the agreement between the simulation and ATXIM could be significantly improved. Other important parameters are the burial depth of the pipes, and the change of the pipe temperatures during the preceding week.

In parallel, experimental evaluation of the TX model was carried out on test fields in the four countries with pipe systems where heat loss was monitored separately. In these test fields in Denmark, Sweden and USA, temperature and energy losses could be monitored continuously, and in some cases also the TX factor could be derived by measurements of the surface temperature profile with temperature sensors. We discovered, however, that IR measurements are the most reliable way of measuring the TX factor. When the ATXIM was applied to IR measurements of the TX factor on the three test fields, and also to a TX evaluation of earlier measurements on a test field carried out in Finland, the result was in reasonable agreement with the heat losses measured in conventional ways.

Hence it can be concluded that under certain well controlled conditions, the heat loss of pipes in district heating networks can be determined quantitatively by analysing the TX profile. The TX profile is best measured using an IR thermography camera, of which there are a number commercially available. The surface must be uniform over the integration width which should be between 3.5 and 5 m. Thermography can be applied at both night and day conditions, but the surface of the test area must have been irradiated uniformly during the last hour, preferably longer. Wet surfaces and rain conditions must be avoided. Grass surfaces and uneven surfaces are difficult to evaluate. If these caveats are observed, it is expected that measurements will achieve an accuracy within ± 20%.

Introduction

In those countries which have used district heating for many years, a new concern has recently arisen: Certain district heating networks are approaching the end of their technical lifetimes and the heat loss in older piping networks has the potential to increase significantly. In order to chart the requirements and resources for maintenance measures, it is important to be able to diagnose the conditions of the piping network, most importantly the heat losses from the pipes.

Historically, several different methods have been used for determining the heat loss from buried pipes. A survey of these methods is given by Borgström, 1991. The most commonly used method of measuring heat losses from pipes has been to take out a pipe specimen to the laboratory and to measure the heat loss in a controlled steady-state experiment. Such type of measurements of different types of pipe systems including water pipe, insulation and outer casing has been performed by Carlsson et. al. 1963. In these experiments, temperature sensors and water flow meters were used for determining the overall heat loss from the pipes. Jonasson,1986, has performed measurements on prefabricated joint pipes by essentially measuring the temperature difference between distribution water and pipe casing, together with air and ground temperature, by means of thermocouples and comparing the results with theoretical expressions fitting the right set of parameters. Phetteplace et al., 1991, has conducted field experiments comparing several methods of measuring heat losses on operating systems. Benny Bøhm, 1990, introduced heat flux meters for measuring the heat loss from buried pipes and compared these results with results calculated from the measured temperature distribution in a section perpendicular to the pipe. The problem of heat flux meters has been attributed to their calibration with the surrounding (unknown) ground properties. Margaretha Borgström, 1994, made a very detailed study of the heat loss from prefabricated pipes by means of heat flux meters. In this case however, the pipes were locally uncovered from all soil and hence the surrounding media was air and a well known shielding insulation.

One other method increasingly used for qualitative heat loss detection and status control of district heating networks is based on airborne and ground borne thermography. In this method the mapping of the ground temperature can be used to give qualitative information about the network condition, mainly with the aim of finding leaks (Bartsch, 1979; Ljungberg, 1987; Hansen, 1987). These techniques rely primarily on relative changes of the temperature pattern along the pipe.

With the help of more refined analytical methods it should be ultimately possible not only to trace leaking media pipes, but also to determine the condition of the insulation.
In the quantitative heat loss analysis, it is presumed that the temperature profile on the ground surface above the pipes, measured in the direction perpendicular to the pipe alignment, is related to the pipe heat loss.
The basic idea is that the integral of the temperature variation across the pipe, called TX, is a function of the heat loss. Obviously TX is also affected by other parameters such as depth, heat diffusivity of the ground and so on. By including all of these parameters in an interpretation model it is proposed that one may determine the amount of heat loss quantitatively and hence to draw conclusions about a potential damage to the protective casing or the pipe (Perers, 1989; Perers and Jönsson, 1990). Figure 1 illustrates this basic idea.

A more detailed analysis of the TX model was carried out within the IEA - DH&C Program - Annex III and reported by NOVEM (Jönsson,

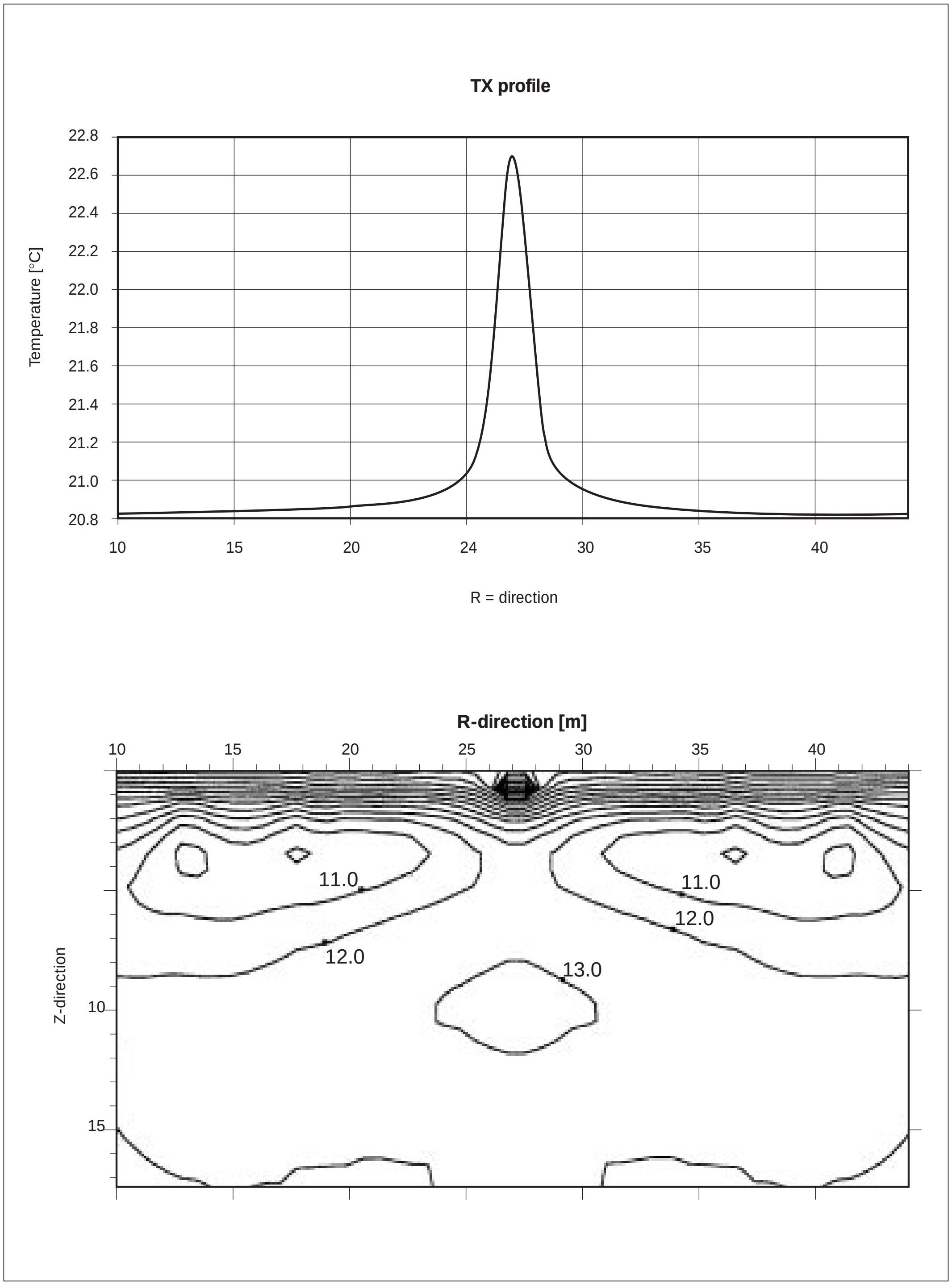


Figure 1: Thermography of buried district heating pipes and the TX-profile.

Zinko, 1992). The analysis was based on field measurements at Studsvik and on a ground simulation model that used finite difference techniques in combination with a model climate. The results were also tested in a limited field application.
In addition to a physical description of the pipe and of the surrounding ground, the finite element model includes freezing and evaporation of water in the ground and on the surface, solar radiation, snow, rain, condensation, convection, wind, and the exchange of IR radiation between the ground and the atmosphere and the surroundings, respectively. However, the interpretation model - called TX-model was derived for a limited set of conditions corresponding to variations of some of the parameters discussed above.

The objective of this phase of the project is to further develop and verify the method of IR heat loss evaluation on district heating pipes by means of the TX-model to determine its potential and limitations for determining the status of pipes and its possible use for planning service and maintenance on the network.

The work which has been carried out includes the following items:

- Installations of test sites for TX-measurements in different countries
- Modelling of test-sites with the ground model simulation program
- Experimental verification of the model with test-field results
- Refining the model by systematic sensitivity studies
- Application of the TX model in IR field surveys

Conclusions and Recommendations
The following conclusions and recommendations can be drawn from our findings:

- The proposed model for quantitative termography analyses has been shown to expand the range of applicability of conventional thermography evaluation. The TX model represents a possibility for the quantitative (instantaneous) determination of heat losses from buried pipes.
- Thermography during exposure to long wave and solar radiation is possible if the surface is uniformly exposed to the radiation and if it has a uniform emissivity within the surface area to be analyzed. The TX model can be applied under suitable conditions at both day and night.
- It has been shown that the wind has a very strong influence on the instantaneous TX factor. It is included in the Advanced TX Interpretation Model ATXIM. The ATXIM includes wind conditions during the last 7 hours before the thermography measurements. The model is verified for wind speeds up to 10 m/s.
- Rain conditions and wet and drying surfaces as well as frost in the ground are not suitable for quantitative heat loss analysis using the TX method.
- The following parameters are included in the ATXIM: Average wind speed over the last 7 hours, the thermal conductivity of the ground, the burial depth of pipes, and the integration half width X.
- Factors that can be optionally included are the changes of the surface temperature during the last 5 hours and of the pipe temperature during the last week.
- The thermal conductivity of the soil has - in contrast to a common opinion - only a relative small influence on the heat loss. The exact soil composition and the value must not be known precisely for determining the heat loss.
- Experimental verification of the model included a depth of 1.1 m and an integration width 2X up to 5 m. The burial depth of the buried pipes is an important parameter and should be known as closely as possible.

- The physical properties of the surface layer and the surface itself, as well as the irradiation, must be uniform.
- Asphalt shingles were shown to be useful as a reference cover on non uniform surfaces or surfaces with undefined physical properties.
- The TX model cannot be applied on grass surfaces and uneven surfaces.
- The error of the model should under suitable conditions be within ± 20%.
- We recommend further evaluation of the application of TX model as expressed by the ATXIM in the course of practical field thermography surveys in order to develop the procedure for a camera-integrated TX option.

Efficient Substations and Installations (1996 N5)

Summary

As part of Annex IV of the International Energy Agency's District Heating and Cooling Project (IEA-DH&CP), a project called **E**fficient **S**ubstations and **I**nstallations (**ESI**) has been performed.

The main objective of the project was to develop more efficient consumer heating systems in commercial buildings, where heating energy is supplied by district heating (DH). The need for more efficient systems has increased in recent years, as low temperature DH is considered to be favourable in a future perspective. The project strategy was to undertake a systematic, theoretical study of the design of consumer heating systems, based on thermodynamic analysis. Then some basic system configurations were chosen which make the best compromises between theoretical goals and practical limitations.

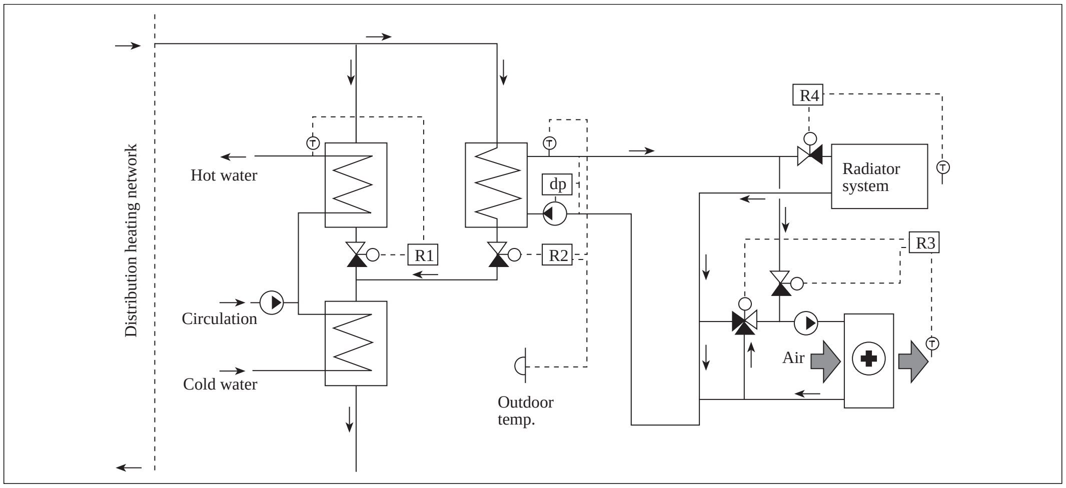
To document the performance of the chosen systems, a simulation tool was needed.
This was done with an extended and improved version of the simulation program called **CHESS** (**C**onsumer **H**eating **S**ystem **S**imulation) which was formerly developed in Annex III of the IEA-DH&CP. The extended and improved version of CHESS is called **CHESS-ESI**.

The theoretical studies lead to the conclusion that the common system, where service water is heated in two steps, has the potential to give the maximum cooling of the DH-water. This basic concept for service water heating was therefore chosen as a part of the new systems.

Three alternative principal system configurations for space heating were evaluated in CHESS-ESI:

System 1	Ventilation heating coil and radiator system connected in parallel on the secondary side of the heat exchanger (Used as "Reference system" in the documentation of the performance of the new systems since this system is common today)
System 2	Ventilation heating coil connected in series with the radiator system on the secondary side (See Figure 1)
System 3	Ventilation heating coil connected in series with the radiator heat exchanger on the primary side

Figure 1. System 2: Ventilation air heating coil connected in series with the radiator system in the secondary side.



From the theoretical studies it was deduced that there should be an optimal secondary supply temperature which would give the lowest primary outlet temperature from the space heating system's heat exchanger. From simulations, the optimal secondary supply temperatures could be found for the actual conditions, as demonstrated for System 2 in Figure 2. The overall conclusion from these simulations is that every individual space heating system in practice has its own optimal "heating curve" which normally is a nonlinear function of the outside temperature.

The simulations showed that for Systems 2 and 3 a small modification of the ventilating heating coil design could significantly increase the cooling of the primary water. Figure 3 shows the cooling of the primary water across the space heating heat exchanger by optimised heating curves and a modified ventilating heating coil design for the three principal systems in CHESS-ESI.

In these simulations we have a conventional high temperature DH-system with 120 °C design temperature and 80 °C primary supply temperature in summer.

Figure 2: Primary return temperature from space heating heat exchangers as function of secondary supply temperature for System 2

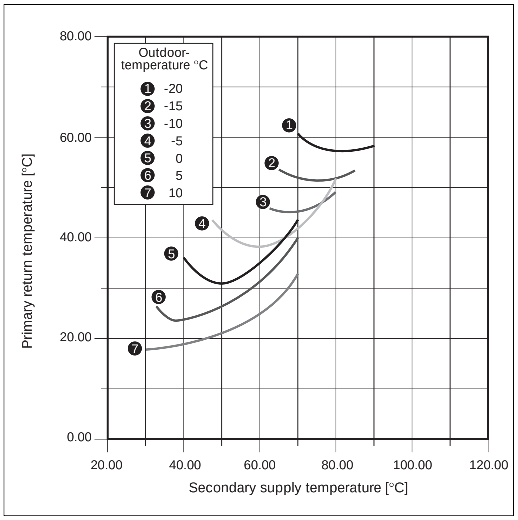
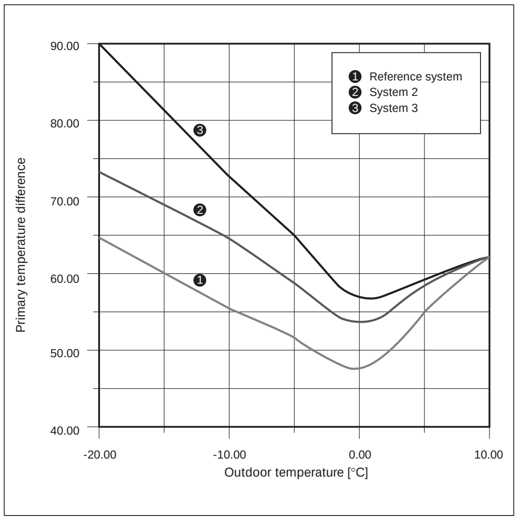


Figure 3: Primary temperature difference for space heating system with optimized heating curves, high temperature DH-system.



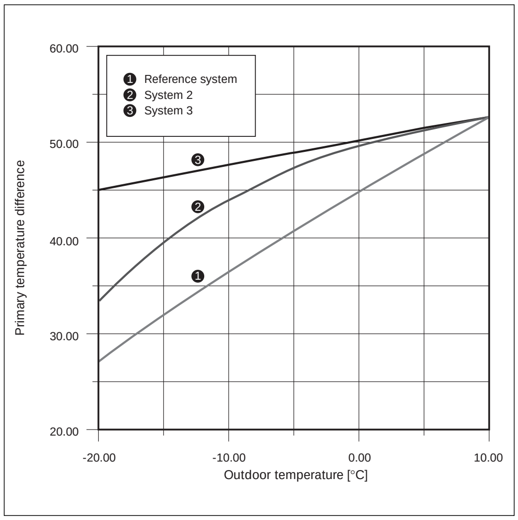


Figure 4: Primarytemperature difference for space heating system with optimized heating curves, low temperature DH-system

Modern DH-systems will normally be designed for lower primary supply temperatures compared with old systems. Figure 4 shows the results for similar conditions as in Figure 3 but now with a low temperature DH-system with a constant supply temperature of 70 °C throughout the year.

In practice, the cooling of the DH-water in consumer installations is a very important factor for the total economy of DH. It will, for instance, increase the capacity of the expensive DH-pipeline system, and reduce the cost of pumping the hot water. The total cooling of the DH-water across the consumer's installation depends to a great extent on the amount and nature of the service hot water consumption in the actual building. The CHESS-ESI simulations were carried out for typical conditions for an office building and a hospital building for the three system configurations.

For the same conditions as in Figure 3 and a two-step system for the service water heating the results for System 2 and 3 respectively show about 11% and 18% increase in the "annual volumetric mean temperature difference" for the office building compared to the traditional "Reference system". The equivalent values for the hospital building for the two systems were about 8% and 13% respectively.

For the cases above, a decrease in the "design primary flow" for System 2 and 3 respectively were found to be about 8% and 17% for the office building and about 4% and 9% for the hospital building compared to the reference system.

Simulations including service hot water were also carried out for a low temperature DH-system. The results of the simulations for the actual systems above, and a constant primary supply temperature of 70 °C, show an increase in the annual volumetric mean temperature difference of about 12% and 16% for the office building and about 8% and 10% for the hospital building, compared with the reference system.

For the low temperature case, the decrease in the design primary flow for System 1 and 2 is more significant than for the high temperature case. The results show a decrease in the design primary flow for System 1 and 2 respectively of about 9% and 21% for the office building and about 13% and 27% for the hospital building, compared with the reference system.

The simulations in this project are done with a two-step system for service water heating. The CHESS-ESI package may also simulate a one-step system for service water heating. This is achieved by setting the area of the preheat-exchanger to zero (see Figure 1). The space heating system can also be simulated with radiator system only. This is achieved by closing the heating coil control valves.

Introduction to the joint report

The main objective of the present work has been to develop more efficient consumer heating systems in buildings where the heating energy is supplied by hot water district heating (DH). The need for more efficient systems has increased in the latest years due to fact that low temperature DH is considered to be favourable in a future perspective. '

The cooling of the district heating water delivered to a building is directly affecting the capacity of the DH network and is one of the most important factors to reduce the total cost of DH. The work in this project has therefore, to a great extent, been focussing on that problem.

In the project Efficient Substation and Installations (ESI) the strategy has been to systematic, theoretical study of design of the consumer heating system based on the thermodynamical grounds. From there some basic system configurations were chosen which presumably make the best compromises between theoretical and practical goals.

To document the performance of the chosen systems a simulation tool was needed. For this purpose it was planned to use an extended and improved version of the simulation program called Consumer Heating System Simulation (CHESS) which was developed and reported in the former Annex III of the IEA-District Heating and Cooling Project.

It was considered that there was a special need for validation of the heating coil model in the CHESS program, and it was decided to do some work on that topic.

From the start it was decided that the ESI-project should be performed as a joint project between SINTEF, LTH and a work group with close connection to the University of Saskatchewan.

On this background and for technical reasons it was found appropriate to make the joint report in the following three parts:

PART I: Performance Analyses of Efficient Substations and Installations.

PART II: Discussion of Low Temperature Substations -motives, state-of-the-art and some key issues for progress.

PART III: Validation of the Heating Coil Model used in the CHESS program.

The extended and improved version of the CHESS is described in part I of the joint report, and the new simulation program is called **CHESS-ESI**.

In the appendix to the joint report you will find a brief introduction to the use of CHESS-ESI.

A diskette with the executive programmes in the CHESS-ESI package may be requested from NOVEM, the operating agent for the IEA -District Heating and Cooling Project, Annex IV.

PART I: Performance Analysis of Efficient Substations and Installations

Introduction

In the search for more efficient consumer heating systems for district heating, a tool to simulate the operation of different system configurations is useful to evaluate the performance. As mentioned previously, the CHESS simulation concept was developed in a former project under the IEA- District Heating and Cooling Project (Hjorthol and Ulseth 1992). To perform the new simulations in the IEA-Efficient Substations and Installation project, a further development of the CHESS concept was needed.

The new simulating tool that is presented and used in the present project is called CHESS-ESI. With this dynamic simulation tool we are able to simulate the complete heating system within a building connected to a district heating network on a ”standard” PC of today.

CHESS-ESI - A computer tool for analysing district heating substations and heating installations

As previously noted, the CHESS consept originated in a former IEA-District Heating and Cooling project reported in Annex III. In this project the concept has been further developed into the simulation tool, CHESS-ESI. The purpose of this development has been the need to simulate the operation of new consumer heating system configurations to test their performance.

The former version of the CHESS program

was limited to representing the space heating system with one fixed system configuration. This was partly due to settings in the source code of the CYPROS equation solver that limited the number of component models, and partly due to the speed of personal computers at the time.

The CHESS-ESI system models include both space heating and hot water preparation. Hence, the number of component models has increased. To do so the source code has been modified. Additionally, the parameter text has been adjusted as an attempt to improve the user interface.

An evaluation of the CHESS program showed that further development of the component models was required. In CHESS-ESI some models are therefore further developed and some are adjusted compared with CHESS. The heating coil model has been specially evaluated in the work by Johnson and Besant (1995), which is found in Part 3 of this report. Their suggestions for improvements have been taken into account in the heating coil model developed for CHESS-ESI.

CHESS-ESI consists of three principal system simulation models. The first is a reference system and two have been developed as attempts to improve the performance of the consumer heating system.

Conclusions

From the discussion of the case studies above it seems reasonable to draw some conclusions that are valid for these system configurations in general.

In district heating substations with indirect connection, the heating curve, which sets the secondary supply temperature should be optimized to give minimum primary return temperature. If a serial connection is used on the secondary side, like in System 2, the optimization is specially profitable due to the sharp optima.

The optimal heating curve is generally not linear. In conventional parallel systems, however, a linear heating curve can be used without any major increase in primary return temperature due to the relatively flat optima.

Due to the difference in return temperatures from the radiator system and ventilation heating coil system, the optimal heating curve will depend on the ratio between the heat loads. This is specially the case when the recirculation coupling is used on the heating coil as in System 1, 2 and 3. Since the return temperature is constant from this connection, it will favour low secondary supply temperatures.

Serial coupling of radiator system and heating coil has a potential to give a considerable increase in primary temperature difference for the space heating system. To maximize the gain from this connection the temperature levels of radiator and heating coil systems need to be harmonized.

If the serial connection is to be used on the secondary side, as in System 2, a lower design supply temperature necessitates a larger heating coil to match the system. When the heating coil is connected in series on the primary side, as in System 3, the design supply temperature for the heating coil can be allowed higher.

The improved return temperature from the heating coil coupling is more profitable for the serial coupled systems than for the conventional system in parallel. For the serial coupling on the primary side, the return temperature has direct influence on the primary return temperature. Since the marginal costs of decreasing the return temperature from the heating coil are small, the serial connection provides a cost efficient way to maximize the temperature difference.

The annual average performance of the district heating substation can be considerably improved by introducing a serial connection between radiator and ventilation air heating system.

Improvements on the space heating system are most profitable for buildings with low service hot water consumption. For buildings with high hot water consumption, the primary water can be cooled against the cold service water temperature.

The design flow from the substation is decreased by using the serial connection. For low temperature systems with constant primary supply temperature, the potential decrease in design flow is considerable. For the simulated low temperature case the design flow was reduced in the range 20% to 30% compared with the Reference system.

For most systems, the return temperature from the space heating system will be sufficiently high at design conditions to give a preheating of the service hot water that reduces the design flow with a two-step hot water preparation scheme.

PART II: Discussion to Low Temperature Substations : Motives, State-of-the Art & same Key Issues.

Objective

Substations provide the interface between district heating (DH) networks and internal distribution systems in buildings. This part report indentifies some types of technological solutions which have favourable thermodynamic properties, i.e. they are in accordance with an overall move in DH practice towards operation with 1ow network temperatures.
The substation types considered here are modifications of well-established heat exchanger assembly types found in Scandinavian low-temperature hot water DH networks. This tradition has also been the starting point for an IEA-study performed at NTH/SINTEF in Trondheim, Norway, to which this work paper is related.
Before entering into the discussion of the selected technological solutions, the basic premise of low-temperature solutions is discussed, in order that the focus of interest is seen in a proper perspective.

Motives for low temperature operation

There are many arguments in favour of low DH network temperatures. As a first classification the following main arguments can be listed:

1. Improved generation plant performance
2. Reduced heat losses
3. Reduced circulating water flowrate (at lower return water temperature)
4. Cheaper pipeline technology

Low network temperatures can be achieved by a combination of various choices and measures. Some of the associated decisions may cause increased investment cost, while other decisions may result in lower network temperatures without added cost. For instance, network temperatures can be lowered by installing bigger radiators in connected buildings, a measure which clearly will increase investment costs. In contrast, more thermodyanically efficient substation connection schemes may result in lower network temperatures without necessarily calling for more expensive equipment. Ultimately, of course, investment costs will increase below certain network temperatures, so that a trade-off must be made when deciding on the appropriate temperature level.

Below, each of the 4 main attractions listed above will be commented on shortly. It will be seen that in some instances arguments pertain both to forward and return temperatures. In other cases, a certain argument is clearly linked to, either a low forward temperature, or a low return temperature.

Ad 1 (Improved plant performance):
The strongest argument in favour of low network temperatures probably is that low network temperatures can be utilized for improved CHP plant performance. In the next section this fact will be dealt with separately, along with temperature considerations for centralized heat pump plants.
Even with heat-only generation, however, there may be benefits. A particularly interesting instance of this occurs when temperatures become low enough to make recovery of latent heat from combustion gas water vapour possible. Depending on the sort of fuel and the type of generation plant, this becomes feasible at temperatures below typically 40 – 60o C. Such a facility, which is primarily made possible by a low DH return temperature, may result in a boiler efficiency in excess of 100%, based on the lower calorific value of the fuel, as is customary in Europe when specifying boiler efficiency.

Ad 2 (Reduced heat losses):
For a given DH network operating at varying water temperature level, as a first estimation it can be assumed that heat losses are proportional to the difference between the ambient temperature and the arithmic mean of the forward and return water temperatures.

When assessing variations in heat losses at different temperature levels in a design situation, things become a little more complicated, although as with differing operating temperatures the general tendency will be that lower temperatures cause reduced heat losses.

If tf is lowered at constant t, the associated increased flowrate for a given heat load requires bigger pipeline diameters to restrict pressure losses. This in turn will increase the surface area of the pipes. In the extreme, the net result could be a higher heat loss.

Ad 3 (Reduced water flowrate):
If the return temperature is lowered, e.g. due to better cooling of DH water passing substations, the circulating flowrate becomes smaller, for a given forward temperature and for a given heat load. This will reduce pumping costs, due to smaller pressure drops in pipelines.
The economic value of such reduced pumping costs will depend very much upon the type of DH network. Even in networks serving big cities the pumping power demand may be no greater than a fraction of a percentage of the heat load served, typically representing 10% of the size of the heat losses. In such a case the economic value of reduced pumping power will be only margina1.
However, in long transmission lines pumping power demand may amount to several percent of the heat load, in which case a reduced pumping power becomes more significant from an economical point of view.
Apart from reduced pumping costs there may be further benefits to achieve from reduced flowrates because of better primary water cooling. When in a given system distribution pipes are already utilized to a maximum, better primary water cooling in buildings already connected to the network can create possibilities for connecting further buildings, without installing new distribution pipeline capacity.

Ad 4 (Cheaper pipeline technology):
In classical optimization studies of DH network temperatures, specific investment network costs for pipes were usually being related only to the pipe diameter, while the temperature in itself was considered to have only minor influence on pipeline investment costs. The influence of the forward temperature on the costs would only be indirect in that a higher forward temperature for a constant return temperature would reduce the flowrate and thereby the diameter (for

given pressure losses).

This way of representing pipeline investment costs in optimization models is reasonable when the classical type of mains technology can be presupposed, i.e. pipes are installed in concrete ducts surrounded by mineral wool thermal insulation and are allowed to perform free thermal expansion.

Costs for modern plastic-shielded, bonded polyurethane insulated pipes, and other types of mains technology, in contrast tend to become lower when operating temperatures are 1owered for a given pipe dimension.

PART III: Validation of the Heating Coil model used in the Consumer Heating System Simulation Program

Summary

This report is concerned with the design and performance of typical air-heating coils used in buildings supplied by a district heating system. First the method of analysis and design for typical finned-tube heat exchanger coils is presented, and measured data is compared to simulation results. Uncertainties in the heat rate of less than 5% are expected.

Second the existing CHESS program heating coil model is reviewed and compared with the validated simulation model coil simulation results. If the CHESS model is modified to model more accurately the heat exchange processes in a typical coil, it shows good agreement with the U of S simulation program. The current assumed values of heat transfer coefficients, air side heat transfer area, and air volume are not the same as calculated using the U of S simulation model. A simulation program has been produced that will calculate the input values required in the CHESS model for a given heating coil design. It is shown that if corrected values are not introduced as input data for the CHESS program, errors of up to 50% can occur in the overall heat transfer coefficient.

Finally, an optimized heating coil design based on minimizing the Life-Cycle Cost of the heating coil has been determined.

This design has been compared to a conventional heating coil design to show the opportunities available using an optimal design. This optimized coil design resulted in a coil selection that was 65% more expensive, but the system Life-Cycle costs were more than 4 times smaller. The main benefit of using a better designed heating coil is that liquid flow rates can be reduced which is beneficial to the building owner in lower pumping costs, and beneficial to the District Heating utility which would also see the benefit of lower pumping rates.

Introduction

The purpose of this report is to validate the heating coil model in the CHESS program developed by SINTEF for the purpose of dynamic simulation of building HVAC systems connected to a district heating system. A simple 3 cell model using basic energy equations is used in the CHESS program to simulate a heating coil.

The problems involved in the incorporation of a heating coil into the dynamic program is that the input values (flow rates, temperatures, fluid and heating coil mass and volumes) must he easy to specify. Also the mathematical description of the heating coil must not be too complex in the CHESS program.

This report validates the use of the heating coil model used in the CHESS program by comparing results to a steady state simulation model developed at the University of Saskatchewan (U of S). There are four distinct steps in the validation process.

1. The simulation program developed at the U of S is compared to monitored results to show that the model used is accurate when compared to actual finned, staggered-tube heat exchangers.
2. A conventional designed heating coil

specified by a manufacturer to meet the requirements of the simulation example shown in Appendix A of the CHESS manual is used as the basis for comparison of the input values.

3. The CHESS program heating coil model is compared to the simulation results from the University of Saskatchewan using input values calculated from the U of S program.
4. An optimized heating coil design is found for minimum Life-Cycle Cost at the same design conditions as used by the manufacturer for a conventional heating coil design. This optimum heating coil design should provide the most economical design for the building owner.

Conclusions

It is apparent that the model used in the CHESS program is valid only if the correct heating coil input values are used. A validated simulation program has been developed that produces the required input values needed for a simulation in the CHESS program.

The geometric parameters required in the CHESS program can be calculated knowing the dimensions of the heating coil being used in the HVAC system.

The dimensions that are required are:

- Height of the heating coil,
- Width of the heating coil,
- Longitudinal tuhe spacing,
- Transverse tube spacing,
- Tube outer diameter,
- Tube inner diamter,
- Fin spacing,
- Fin thickness,
- Fin wave depth, if wavy fins are used.

The other input values that are required are:

- Air flow rate Liquid flow rate
- Glycol concentration for freeze or burst protection
- Inlet air temperature, pressure and humidity
- Inlet liquid temperature.

The CHESS program model appears to accurately simulate a heating coil at steady state conditions as long as the correct input values are used. The current assumptions used as input values in the CHESS model will lead to significant differences in the results in most cases. The calculations of air volume, and liquid and air side heat transfer coefficients are not accurate using the current assumptions and will lead to the largest errors.

Temperature Variations in preinsulated DH pipes - Low Cycle fatigue (1996 N6)

Background

Design of District Heating Pipes with Respect to Temperature

The development in construction principles for preinsulated pipes for district heating is clearly moving towards pre-heated or pre-stressed systems or systems where the cold spring effect is utilised not only in bends and curved lines but also in straight pipes (cold laying and self-induced pre- stressing).

Utilisation of the cold spring effect is not new. Most codes for design of piping systems under pressure assume that the formal yield stress in bends is approximately twice the yield stress for steel. Therefore the real stress range will be +/- the yield stress after the initial self-induced pre-stressing.

When the stress range is larger than twice the yield stress the system is said to be in the low cycle fatigue range. In the low cycle fatigue range the analysis should in principle be done based on the strain range, but in practice the calculations are normally made with a linear elastic model and formal stresses. When evaluating these formal stresses, which can be larger than twice the yield stress, a correction has to be made because in practice the strain will be lager than calculated by the elastic model. This correction can typically be included in the fatigue curve.

The use of pre-heating or pre-stressing does not increase the allowable stress range, but it reduces the forces and displacements in the system.

As this design method is based on low cycle fatigue design the number of load cycles has to be limited, and in codes for pressure piping a figure of 7000 complete load cycles is normally assumed (one full temperature cycle per day in 20 years).

For each °C a straight pipe is heated the axial stress will increase 1.2 x 2.1 = 2.52 N/mm^2/°C. The minimum yield stress for mild steel used for preinsulated pipes is typically 235 N/mm^2. This means that heating more than 93 °C can give yield over the entire cross section of the pipe.

Accepting yield over the entire cross section is quite new and unique for district heating pipes. Temperature induced axial stresses are low in most other piping systems, and therefore it is not a serious limitation in these systems to have restrictions in the codes not allowing yield over the entire cross section.

However, for preinsulated district heating pipes many designers are beginning to accept the concept of self-induced prestressing combined with very high nominal axial stress ranges.

The maximum acceptable stress range depends very much on the predicted number of complete load cycles in the lifetime of the systems, and as the design method is quite progressive the loads should on the other hand be estimated quite conservatively. Also the safety factor of the design will solely be applied on the loads.

The maximum temperatures in a systems is normally known quite well due to the safety equipment on the boilers, although peaks exceeding the maximum design temperature with up to 10 °C may happen e.g. in case of failing controls or sudden increase in combustion in waste incineration.

Another more serious problem is the variation in temperature.

The temperature in the systems will often vary during the operation in order to meet the heating demand, but the unintended variations in temperature are more difficult to estimate, and they are the most serious threat to the lifetime of the systems when speaking of low cycle fatigue.

Intended variations in the systems are typically:

- Planned variations due to normal use of the system.
- Variations at the boilers in order to vary the production.
- Variations in house connection due to e.g. night time set-back or shut-off by the consumer and other variations due to consumer behaviour.

Unintended variations are typically:

1. Cold plugs after start-up or changes in production e.g. in boiler central with cascade coupling.
2. Variation due to sudden changes in the calorific value during combustion of waste.
3. Hunting (pendling) in control equipment.
4. Hot plugs at consumers installations.

The examples show that the trend to conserve energy by more sophisticated control and operation also increases the risk of increased temperature variations.

On the other hand the number of temperature cycles should be limited when utilising prestressing or self -induced prestressing preinsulated piping systems.

Summary

In Denmark, Germany, Korea, The Netherlands and Sweden at 17 district heating sites the supply and return pipes have been fitted with temperature measuring equipment and data loggers.

There are 8 measuring sites at consumers with pipe diameters from 28 to 219 mm and 9 measuring sites at supply stations (production or heat exchanger stations) with pipe diameters from 356 mm to 1219 mm.

At each of these sites the temperature has been logged every minute for a period from 81 to 365 days - more than 5000 days or 7.6 million measurements all together.

For each site the measurements have been sorted by the so-called rainflow method forming a matrix, where the number of cycles are sorted according to range (ΔT = 1, 2, 3 …110 °C) and mean temperature. An overview of the results is given for ΔT = 5, 10, 15 …110 °C.

The matrixes have been analysed using the Palmgren-Miner cumulative damage theory, and the number of full temperature cycles, N_0, have been calculated for low cycle fatigue curves with different slope constants, b. In the calculations the measurement period of approximately 1 year have been converted into a 30-year period by simple linear progression.

The effect of different measuring frequencies is discussed together with an evaluation of the results.

For each site the measurements are graphically illustrated with:

1. A graph showing all measurements.
2. The matrix showing the number of temperature cycles in relation to mean temperature.
   The number of full temperature cycles corresponding to a 30-year period for slope constants b = 3, 4 and 5 for a common reference temperature $\Delta T = 110$ °C and for $\Delta T = T_{max} - 10$ °C where T_{max} is the maximum temperature measured at the pipe concerned.
3. A logarithmic graph showing the number of cycles as a function of the temperature range.
4. A graph showing how the different temperature ranges contribute to the cumulative damage.

Conclusion

The following conclusions can be drawn from the project:

1. The curves from the 17 measuring sites are very different.
2. There is a big difference between main lines and house service connections.
3. The largest number of full temperature cycles is at the consumers.
4. At the consumers the largest number of full temperature cycles is always at the return pipe.
5. A consumer on a high temperature system can cause more damage than one on a low

temperature system.

6. Low temperature systems will other things being equal have smaller cycles than a high temperature systems.
7. At the production sites there is a tendency that the largest number of full temperature cycles is at the supply pipe.
8. The number of full temperature cycles depends on b. (b is the slope of the fatigue curve).
9. The large peaks have the greatest influence (specially for b = 5).
10. The small peaks have greater influence for b = 3.
11. A sampling frequency of 1 min. is acceptable.
12. A measuring period of one year is acceptable in the assessment of the stress from temperature over a 30-year period.

A summary of the calculated number of full temperature cycles is given in the tables below for the reference temperature $\Delta T_{ref} = 110$ °C.

It shall be noticed that the greatest values is at the consumers return pipe and the smallest at the return pipe at the productions sites. The difference is significant.

The largest values of full temperature cycles calculated for b = 3 are within the range specified in the guideline in the Danish Standard for DH pipes, see chapter 3.
These values are for b = 3 :

- 100 - 250 full temperature cycles for large main pipelines
- 250 - 500 full temperature cycles for ordinary distribution pipelines
- 500 - 2500 full temperature cycles for house service connections

For the time being there is therefore no basis for changing these recommendations. The same recommendations are used in a draft European Standard for design and installation of preinsulated bonded pipes for district heating, though the lower limit for house service connection are set at 1000 instead of 500.

Supply Maximum	Minimum	Average	Production
b = 3	17	136	365
b = 4	4	42	102
b = 5	1	18	37

Return Production	Minimum	Average	Maximum
b = 3	2	7	14
b = 4	0	1	1
b = 5	0	0	1

Supply Consumer	Minimum	Average	Maximum
b = 3	7	139	578
b = 4	2	55	308
b = 5	1	31	197

Return Consumer	Minimum	Average	Maximum
b = 3	35	429	1050
b = 4	4	111	379
b = 5	1	37	157

Table 1.1: Numbers of full temperature cycles for ΔT_{ref} = 110 °C and b = 3, 4 and 5.

Lower figures should only be used, if the designer has a firm knowledge of the temperature history to which the system in question will be subject. Even if such knowledge is available conservatism is advisable, because there might be suspicion that the expectations of the operating personnel are not in accordance with the realities. Furthermore it is important to be aware of systems with irregular operational conditions.

The information on where the largest number of full cycles occur should cause that more attention is paid to details like the fatigue life of branch connections to consumers, especially the tee where the branch is connected to the main pipe.

The operating personnel should use the results to evaluate the mode of operation and especially the impacts on the DH system from the consumers. Some temperature variations are due to energy saving measures and the systems should of course be designed to withstand these variations. However, many of the temperature curves more than indicate that many of the large temperature variations occur due to inexpedient instrumentation at the consumers, thus causing an unnecessary wear of the system.

Finally, it must be mentioned that although the Palmgren-Miner cumulative damage theory is a generally accepted theory for fatigue analysis there is a strong suspicion that a temperature history with few large temperature cycles is more harmful than a temperature history with many small variations, which give the same number of full temperature cycles.

This is especially true for preinsulated bonded pipes. If for example a change of direction is designed with foam cushions in order to absorb the expansion of e.g. $\Delta T = 110$ °C, it is more or less evident that the construction detail better can absorb a large number of small temperature variations than a limited number of very big variations.

When the project originally was described it was expected that after processing the temperature measurements would give figures for full temperature cycles, which, without any further consideration, could be used as a design basis when designing bends, tee and other district heating components in the low cycle fatigue range.

However, even though the project has added considerably to the knowledge of temperature variations it has not given the final answer, but raised a number of new questions.

The most important question is the choice of SN-curve. It is very important that the same SN-curve is used for calculation of the number of full temperature cycles and as limit state for the fatigue analysis, but which curve is most relevant for buried preinsulated pipes, $b = 3$, 4 or 5?

The second question is the conversion into full temperature cycles. From many of the temperature spectra it is seen that very many of the temperature cycles must be in the high cycle fatigue range and it might therefore not be correct to convert them into few cycles in the low cycle fatigue range.

A third question is the assumption that the stress differences are proportional to the temperature differences.

These questions can probably be answered by applying the measured temperature histories to elasto-plastic models of buried preinsulated pipes using “real” fatigue curves, and it is among other things the intention to examine these questions in an expected continuation of the project under the IEA District Heating and Cooling Project, Annex V.

The measured and processed data make up close to 450 Mb and will be burned on CD-ROM so that it is available for further studies.

Managing a hydraulic system in district heating (1996 N7)

Introduction
The International Energy Agency, IEA, District Heating and Cooling Implementing Agreement, in its efforts to point to ways to reduce the use of energy, has produced a number of publications dealing with various aspects of implementing and improving district heating and cooling systems. This brochure highlights the management of using low temperatures in a direct district heating system in the Netherlands.

More and more low-temperature systems are in operation in district heating. The advantages are obvious, especially when operating a direct system and a STAG (STeam And Gasturbine combined cycle), combined heat- and powerplant. Low temperatures allow for the cooling of condensers at temperature levels comparable with cooling towers at attractive electricity generating efficiency.
Return temperatures from consumers may be as low as 25-30 °C and may even be cooled down further by partially wasting heat.

If at the same time sufficient storage capacity of heat is included, a STAG powerplant may be operated almost at will, regardless of the discrepancy in demand for electricity and heating.
A STAG plant of limited capacity may be incorporated in a regional or national electricity grid, located near consumers and operated to follow heat demand if and when it occurs at optimum conditions for generating electricity. Such a plant, or several strategically located plants, could be regarded as stand-by capacity replacing older, less efficient powerplants.

When heat storage tanks are located near clusters of consumers, a reduction in piping and pumps will result. Allowing for a lower capital layout and reduced pumping costs.

This report looks at a system where all the above advantages were eventually taken into consideration.

Although some of the advantages were lost in the late implementation of the proper heat source, the overall picture will be of interest to all concerned with planning, operating and implementing district heating systems.

Apart from the obvious advantages in reducing the effect of heating upon the environment, the overall cost of heating could be reduced dramatically by generating electricity at the best possible efficiency, paying for the plant and the necessary adaptions to produce heat. Even more advantageous when governments find ways and means to allow consumption of energy used for heating only at consumer prices in order to force the optimal use of combined heat and power generation.

Summary
Purmerend is a town with presently 60,000 inhabitants growing to 100,000. The town is located 20 km north of Amsterdam, the Netherlands.

In 1980 the town council of the municipality of Purmerend decided to implement a district heating system.

A municipal department was created to build, run and manage the system. At the same time the provincial electricity board decided to build a combined heat and power station (CHPS) from which heat would be sold to the municipal heating scheme at cost.

The present municipal heating system serves 20,400 housing equivalents through a 32 km transport pipeline and 165 km distribution pipelines. The system is equipped with 47 substations. Heat is supplied by a combined heat and power station, capacity 68 MWe and 65 MWth, an auxiliary boiler house (ABH) containing 4 boilers of 16 MW each, four mobile boilers of 3.5 MW for temporary or emergency duties and three decentralized storage tanks of a combined capacity of

550 MWh. The transport pipelines have a storage capacity of 70 MWh.

The system may be expanded to serve 30.000 housing-equivalents. Re-organisation of the power industry brought the CHPS in hands of the regional power company UNA (NV Energieproduktiebedrijf UNA, the energy production company of the provinces of Utrecht and North Holland and the city of Amsterdam).

By means of well protected modem, public telephone and portable computer, the functioning of the entire system may be called up at any time, any place. Flow-charts and diagrams may be consulted and, whenever required, autonomous controls adjusted.

Overall control depends on the type of users served: one family housing, flats, major users. The controls are adjusted to demand for heating and individual supply of hot water. Heat consumption is measured individually by energy meters.

The entire transport, distribution and storage system is protected against six potential calamities: high pressure in pumping stations, high pressure in substations and distribution grids, high pressure in return pipelines, overflow of storage tanks, draining of storage tanks and uncontrolled flow into one another. Moreover, the entire system is monitored, data are collected and stored at 10-minute intervals. Faultfindings are sorted according to importance, registered and, where necessary action taken by calling up service personnel till satisfied.

Conclusion

As was the case for many a heating system, the project Purmerend was originally designed and partly laid-out in far too grand a fashion allowing for far greater demand, as well per connection (housing-equivalent) as for the entire system (simultaneity), then would be ultimately required.
This made it possible to change the planned indirect system to a direct system. The indirect system started from a 90/70 regime, i.e. 90 °C input into house connections and 70 °C return. This to be realized through transport pipelines wherein water at a temperature of 125 °C would be delivered.

At the time the first part of the system was completed, it became evident that a direct low-temperature heating system was possible, e.g. at a 90/50 regime. This would allow an equal transport capacity in the same pipelines and at the same pump pressures. Costs in layout, maintenance and heat losses would be considerably lower. Also, this regime corresponds well with the implementation within the system of a CHPS at the highest possible electricity generating efficiency.
In addition, direct operation will reduce power required by pumps through upgrading of pump efficiency and consequent reduction of pressure.

The general conclusion drawn means that application of a direct system requires 15 % less capital investment than an indirect system. Additionally, heat losses and maintenance costs will be lower, upkeep and operation will be simplified.

Further reduction of pumping power may be obtained by installing booster pumps. Hereby all required pressure does not need to be supplied at source, giving the opportunity to either reduce pressure or reduce pipe sizes.
Optimising of heat supply may be gained by optimal application of auxiliary heat sources and heat storage tanks.

Heat storage tanks have two functions. The first function is that they allow the CHPS to run at full capacity (or not at all) allowing for optimal efficiency. Additionally, this will reduce the number of starts, especially in

summertime whereby the plant may only be required to run once every two or three days.
The second function is that storage tanks may deliver heat at times of peak demand, thus reducing the maximum size of heat source required. The obtainable savings in relation to the cost of installing heat storage tanks is so dramatic that consideration will be limited to optimisation.
To increase the effect to its maximum, tanks should be situated where their capacity meets demand.

An autonomous control system was designed, incorporating the entire system. When the CHPS produces heat, transport pumps will take hot water out of the storage tank into which the CHPS delivers, and deliver hot water to the transport grid at a pressure of maximum 6 bar. The water level of the storage tank nearest to the CHPS is controlled by a control valve, all other storage tanks by flow balancing. Control of storage tanks and auxiliary boilers is autonomous. All sorts of situations may occur, depending on conditions in the grid.
The controls automatically take care of heat storage. Pumps are directed by a compilation of signals found in the grid, pumps located at the CHPS and at the ABH have key-functions.

By use of telecommunication and a central computer, control may be gained by means of altering parameters of the autonomous controls and reactivating local control systems.
Through conditioned parameters, storage tanks may be switched on or off by means of altering values intended for automatic functioning.
Pressure rising, and thus the outgoing flow to the grid, may be changed by altering the relating factor.

By this a state of the art district heating system was designed, implemented and managed for the municipality of Pumerend, the Netherlands.

A review of European and North American water treatment practices (1996 N8)

Summary

This report outlines the European approach to water treatment and corrosion prevention in hot water district heating systems, specifically the approach advocated by Nordvärme, the district heating association of Nordic countries in Europe. The intent of this report is to make information and operating experiences on the Nordvärme approach available to North American system operators as well as to describe common North American water treatment methods.

An interest in the European approach to water treatment has grown recently because of developments in advanced fluids for district heating and cooling systems. New additives are sometimes incompatible with chemicals traditionally added in North America to prevent corrosion in hot and cold water systems. In particular, some corrosion inhibitors have been shown to be incompatible with the use of friction reducing additives.

Friction or drag reducing additives reduce the frictional losses from water in turbulent flow by suppressing the formation of turbulent eddies. This results in lower pumping energy requirements and costs. Interest in these additives has grown over the last few years and the additives have been successfully demonstrated in several systems, including a transmission system in Herning, Denmark in which pumping energy requirements were reduced by 70% and overall operating costs were reduced by 40%.

In North America, corrosion of steel district heating pipes has traditionally been prevented by adding corrosion inhibitors which protect the pipe by forming a protective passivating film on the internal surfaces.

Most corrosion inhibitors are inorganic oxidizing substances which passivate the metal surface by forming an impervious film which interferes with the anodic or cathodic corrosion reactions. These inhibitors work with metals that exhibit active-passive transitions such as iron, nickel, chromium and alloys containing these metals.

As well, chemicals are sometimes added which react with and remove dissolved oxygen. This limits corrosion by limiting the oxygen reducing cathodic reaction. Restricting either the cathodic or anodic reactions will limit the overall corrosion rate since these processes are dependent on one another. The electrochemical mechanisms of corrosion are explained in more detail in the first paper in this report, “Corrosion and Water Treatment in Nordic District Heating Systems, Experience and Practice”.

The overall treatment strategy also includes filtering and demineralizing (or softening) system water and raising the pH. The second paper in this report describes chemical additives which are currently used to prevent corrosion in North American closed cold and hot water distribution systems and explains some of the advantages and disadvantages of each.

Common chemical additives for corrosion prevention in North America

Passivators:
  chromate
  borate nitrite
  silicate
  molybdate
Oxygen scavengers:
  hydrazine morpholine
  sulphite caustic soda/soda ash

The strategy recommended by Nordvärme is simply to maintain high quality water in the system through continual filtering, deaeration and demineralization (or softening) and to maintain the pH between 9.5-10 by adding sodium hydroxide. The procedure requires careful monitoring of the chemistry of the system water. The corrosion rate must also be monitored through the use of corrosion coupons or piping samples inserted in the flow. Demineralization is preferable to softening because it reduces the total ionic concentration.

Summary of Nordvärme water treatment method

- filter
- demineralize or soften
- deaerate
- raise pH to 9.5-10 by adding sodium hydroxide (NaOH)
- monitor corrosion rate and concentrations

The first paper in this report is an English translation of the Nordvärme water treatment manual for district heating system operators. This manual was prepared by expert representatives from five member countries of the Nordvärme working group on water treatment. In it, Nordvärme gives recommended ceiling concentrations for chemicals in the system water.

Summary of guideline values of dissolved species in district heating water

pH at 25 °C	9.5-10.0
Oxygen concentration	< 0.02 mg O_2/kg
Ammonia concentration	< 10 mg NH_3/kg
Total iron concentration	< 0.1 mg Fe/kg
Total copper concentration	< 0.02 mg Cu/kg

The Nordvärme approach has been successfully applied in the two district heating systems in Prince Edward Island, Canada. In these systems raw water entering the network is filtered, softened and deaerated. Water in the system is continually filtered. The pH is maintained between 9 and 9.5 by adding sodium hydroxide.

In the St. Paul, Minnesota district heating system in the United States, water is pretreated by filtering and softening and a corrosion inhibitor is added to the system. The cost of this treatment is $0.12 per gallon of makeup water compared with $0.05 per gallon of makeup water in the P.E.I. systems. The cost of water treatment in the P.E.I. systems however, is dependent on the cost of laboratory analyses. In the St. Paul system, testing is included as a service with the purchase of the corrosion inhibitor.

The experiences in the P.E.I and St. Paul systems are outlined in the paper beginning on p. 44 of this report. This paper was presented at the annual conference of the International District Energy Association in Indianapolis in June 1995, and again at the IDEA's distribution workshop in St. Paul in November 1995.

Feedback from the audience at the IDEA conferences indicated that many North American operators were more comfortable contracting out water treatment activities. Even if there are savings to be made, operators prefer a complete treatment "service", where providing the chemicals and monitoring the system are both the responsibility of the chemical company. Water treatment activities sometimes require both time and a level of expertise that plant staff do not have.

Conversations with plant staff have indicated that in busy seasons, water treatment monitoring is sometimes the first activity put on hold although it is vital to the long-term health of the system. The assumption is sometimes made that if a given method has worked well in the past, it will continue to work. Stopping monitoring, however, can lead to unexpected problems.
A number of conditions in the system can change such as the chemistry of the makeup water, and the operation of the deaeration and deionization equipment and chemical feed equipment.

Comparison of Nordvärme approach and the use of corrosion inhibitors

Nordvärme approach
(Carried out by plant staff)

Advantages
- avoids the need to add corrosion inhibitors
- if corrosion rate increases, corrosion inhibitors
- can be added later
- can be cheaper

Disadvantages
- requires careful monitoring

Corrosion inhibitors (chemical supply and monitoring by chemical company)

Advantages
- will protect pipe surfaces regardless of rate of oxygen infiltration
- addition and monitoring are the responsibility of the chemical company

Disadvantages
- once corrosion inhibitors are being used in a system it is difficult to stop
- in the future, use of some common corrosion inhibitors may be restricted because of environmental impact and regulations

Conclusions

The low corrosion rates seen in the PEI systems indicate that the European approach for water treatment in hot water systems as described in reference 1 can be effective in North American situations. In this treatment strategy the risk of corrosion is minimized by removing oxygen from the feed water through chemical or thermal deaeration, by raising the pH to at least 9 and by decreasing the hardness by softening. Good water quality monitoring and leak detection systems are important elements of this type of water treatment program.

Operators of new hot water systems might want to consider simple pH control as an alternative to the more common North American approaches. The treatment strategy is suitable when there is a slow rate of makeup and when leakage into or from the system is small. This strategy might be especially suitable for systems considering the use of friction reducing additives, since some corrosion inhibitors have been shown to lower their drag reducing capabilities.

For the cases examined, the simpler approach to water treatment is less expensive. The cost of maintaining corrosion inhibitors in the St. Paul system exceeded the cost of the simpler approach in the Charlottetown system. Other considerations which should be taken into account include the amount of makeup required in the system, availability of steam for deaeration, and the availability of staff to operate the equipment and monitor the water quality.

The authors would like to thank John Davey and John te Raa of the PEI Energy Corporation and Ron Cackoski of District Energy St. Paul for their help in preparing this paper.

Appendix I: List of publications

List of publications Annex I

1986: R9	IEA District Heating Small-Scale Combined Heat and Power Plants
1986: R10	IEA District Heating Cost Analysis of District Heating Networks
1987: R4	IEA District Heating Temperature Levels in District and Local Heating Systems in Sweden
1987: R6	IEA District Heating Technical and Economic Assessment of New Distribution Technology
1988: R12	IEA District Heating Small Heat Meters
1988: R13	IEA District Heating State-of-the-art Review of Coal Combustors for Small District Heating Plants
1988: R16	IEA District Heating Summary of Research Activities 1983 - 1987

List of publications Annex II

Number	**Title**	**ISBN nummer**
1989: R1	District Heating & Cooling R&D Project Review	90-72130-07-3
1989: R2	Advanced District Heating Production Technologies	90-9002876-5
1989: R3	Static problems in the laying of plasticjacket pipes	90-7213-09-X
1989: R4	Fittings in plastic jacket pipelines	90-72130-08-1
1990: R5	Welded Sleeves Technique for Plastic Jacket Pipes	90-72130-17-0
1990: R6	New Methods in Underground Engineering and Installing of District Heating Pipelines	90-72130-16-2
1990: R7	A technology assessment of potential telemetry technologies for district heating	90-72130-10-3
1990: R8	Guidelines for converting building heating systems for hot water district heating	90-72130-12-X
1990: R9	Advanced Energy Transmission Fluids Final report of research	90-72130-11-1

List of publications Annex II (Cont.)

Number	**Title**	**ISBN nummer**
1990: R10	Heat Meters - Report of research Activities - Annex II	90-72130-15-5
1990: R11	Thermal Energy from Refuse Analysis Computer Program	90-72130-18-9
1990: R12	Summary of research activities 1987 - 1990	90-72130-19-7

Publications Annex III

Reports	**Title**	**ISBN nummer**
1992: P1	The environmental benefits of District Heating and Cooling	90-72130-36-7
1992: P1.1	DETECT Consequence model for Assessing the environmental benefits of District Heating and Cooling in a well defined area	
1992: P2	CFC-Free Plastic Jacked Pipes	90-72130-28-6
1992: P3	District Heating Piping with plastic medium pipes, status of the development and laying costs	90-72130-29-4
1992: P4	Bends for Plastic Jacket Pipe Systems, able to withstand high transverse loadings	90-72130-30-8
1992: P5	Consumer Heating System Simulation	90-72130-32-4
1992: P6	R&D Project Review	90-72130-33-2
1993: P7	Advanced Energy Transmission Fluids Final Report of Research, annex III	90-72130-34-0
1993:P7.1	The design and Operation of Ice-Slurry Based District Cooling Systems	90-72130-50-2
1993: P8	Supervision of District Heating Networks	90-72130-35-9
1993: P9	Promotion Manual for District Energy Systems	90-72130-39-1
Brochure	‘A Clean Solution? It is also your responsibility	

Publications Annex IV

Reports	**Title**	**ISBN nummer**
1996: N1	Integrating District Cooling with Combined Heat and Power	90-72130-87-1

Publications Annex IV (Cont.)

Reports	Title	ISBN nummer
1996:N2	Advanced Energy Transmission Fluids for District Heating and Cooling	90-72130-94-4
1996: N3.1	Guideline to Planning and Building of District Heating Networks	90-72130-84-7
1996: N3.2	Bend Pipes	90-72130-83-9
1996: N3.3	Execution of Connections to Pipelines in Operation	90-72130-82-0
1996: N4	Quantitative Heat Loss Determination by Means of Infrared Thermography -the TX Model	90-72130-95-2
1996: N5	Efficient Substations and Installations	90-72130-88-X
1996: N6	Temperature Variations in Preinsulated DH Pipes Low Cycle Fatigue	90-72130-97-9
1996: N7	Managing a Hydraulic System in District Heating	90-72130-86-3
1996: N8	A review of European and North American water treatment practices	90-72130-93-6

Appendix II: List of participating countries and their Ordinary Members of the Executive Committee

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