Project D

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

D2 Testing of Obstacles in an Operating Heat Exchanger and Evaluation of the Overall Effect

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District heating condenser, calculated key data and heat-balances for MKS Power plant unit 3/4, Århus and Heat and Power Plant, Herning, Denmark

Preface

This report is part 2 of the project D "Improving the Heat Transmossion Properties of Tube Bundle Heat Exchangers by Installing Obstacles inside the Pipes". The previous part 1is written by Prof. Weinspach Thermische Verfahrenstechnik GmbH**.**

This part 2 contains the general introduction to the project, the reporting of the activities made in Denmark and the overall conclusion. Paragraph 3 has been written by Mr. Henning Andersen, Elsamprojekt while the other paragraphs were written by Flemming Hammer of Bruun & Sørensen Group AS.

1. Introduction

1.1 Purpose of the project

The purpose of this project was to state the effects of using turbulators in the shape of steel springs in the water tubes of tube heat exchangers applying drag reducing additives in the water - so called ”smooth water”.

Tube heat exchangers are generally used for the generation of district heating in combined heat and power plants. A previous theoretical project showed that the reduction of the heat transfer properties by the use of smooth water in such heat exchangers is very considerable and must be compensated for. It also indicated promising possibilities for the improvement by means of the springs applied in this project although increase of the pressure loss must be encountered.

Based on this knowledge, three main subjects have been focused on: Measurement of the effects on heat transfer properties and pressure loss, long time testing of metallurgic effects in a heat exchanger operating with normal water and evaluation of the overall effects on the combined generation of heat and power.

1.2 Summary

An existing test rig mainly consisting of a one tube heat exchanger and two closed loops at the University of Dortmund was modified to host the first part of this project. The additive Habon-G, developed by Hoechst AG, which has been applied successfully in three cases in Herning, was used for the tests.

Spiral springs made of 1 mm stainless steel of different pitches were used as obstacles to increase the turbulence and hence the heat transfer. The diameter of the springs was made a bit larger than the inner diameter of the tube in order to achieve the fixation of the springs.

For pure water, the increase in heat transfer was at its maximum 100 % depending on the pitch. For smooth water the behaviour strongly depends on pitch, concentration of additive and temperature. For a concentration of 250 ppm, which was successfully used in previous demonstrations in Herning, the original state of heat transfer can be reached with the 8 mm spring at water velocities normally prevailing in the CHP-plant in Herning. However, the pressure drop in this case increased to some 850 % compared to pure water.

In one of the two heat exchangers used for generating district heating in Herning since 1982, 5 spirals were installed during the scheduled summer stop in 1995. After one year of operation - with normal water - the pipes containing the spirals were dismounted during the regular revision of the plant in August 1996. regarding pipes and springs both conventional and stainless steel was used.

The spirals had caused no difficulties during operation, they showed no signs of displacement in the tubes, and the stated slight corrosion in the conventional steels were equally distributed. The stainless materials showed no sign of corrosion.

Two concrete combined heat and power plants were used as models for the calculations, so that the effects of the use of obstacles and smooth water could be quantified. The thermal couplings of these plants were slightly changed by ”installing” a pump to handle the pressure loss through the heat exchangers only. Using the results achieved from the experiments in Dortmund a number of model calculations have been carried out, and are shown in the enclosures.

1.3 Conclusion

In the previous work, the fact that the pressure loss increases disproportionally was seen as a serious drawback of the use of turbulators.

The outcome of this project has shown that due to dramatically improvement of the heat resistance on the tube inside due to the use of obstacles, the total heat transfer is so much improved, that the steam can be expanded to a lower level, implying a higher electricity generation. This higher output of electricity is generally speaking able to compensate for the increased pumping demand through the heat exchangers.

It was also found that such obstacles in the shape of simple steel springs can be manufactured, installed and operated without any significant problems.

Therefore, the overall conclusion is that in respect of changing to the use of smooth water operation almost status quo as to the tube heat exchanger in CHP-stations is achieved!

An ongoing project will make use of this and all other results achieved during 10 years of activity within demonstration and development of smooth water for district heating operation. The project will comprise a cost/benefit analysis and is planned to be terminated by the end of 1997.

1.4 Project management

The project was carried out in a co-operation among the following three partners:

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The practical tests of the springs were made in the combined heat and power plant in Herning, Denmark. The positive interest and readiness of the operational manager Mr. Bent Haurballe and his staff is highly appreciated.

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1.5 Financing

This project was co-financed by the following two programs:

IEA Advanced Transmission Fluids for District Heating and Cooling
(R&D / IEA, Annex IV) and ELSAMs R&D programme.

2. Background

In the late 1980s the first full scale demonstrations of the use of friction reducing additives in district heating systems took place in Völklingen, Germany and Herning, Denmark. The reduction of the friction was considerable. Pumping power was reduced to approx. 50% and 25% respectively in the two systems [1, 2, 3]. This was a result of the reduced turbulence of the water.

However, it was also found that the heat transfer in the applied plate heat exchangers was reduced implying a higher flow rate in order to keep up with the heat output of the system. A project was set up in order to analyse this problem and to find ways of designing such heat exchangers in order to avoid or reduce this negative effect of smooth water. It was concluded that it is possible to compensate partly or almost completely by re-shaping the plate heat exchangers [4].

Use of smooth water only has an effect of significance in large straight pipes with a high load factor. This is normally not the case in distribution systems, but certainly in superior transmission systems, conveying large amounts of base load heat from i.e. combined heat and power plants to local distribution networks. Therefore smooth water will also have to circulate through tube bundle heat exchangers normally used in CHP-plants to cool the exhaust steam from the turbines by means of district heating water being heated in this way.

In a foregoing project [5] the expected effects on heat transfer conditions applying smooth water in such exchangers were investigated. It was found that without compensation, the reduction of the heat transfer would forbid the use of smooth water. It has the effect that the necessary transfer of heat from the condensation of the steam to the district heating water cannot take place, whereby the pressure in the exhaust casing will rise to a prohibitive level.

It was found that by the introduction of turbulators in the shape of webs or springs inside the water pipes, turbulence can be created and in this way increase the heat transfer rate sufficiently. The negative effects would be, however, that the pressure loss through the water tubes would increase.

In order to have these results verified and to test whether springs can be installed and will make no harm inside the tubes, this project was proposed.

3. Activities in Denmark

3.1 Testing of obstacles at ”Herningværket”

General

Installation of built-in helical springs inside condenser tubes is a simple and economic attractive method to improve the total heat transmission of an existing shell and tube condenser. The only modifications this rebuilt implies, is the insertions of pre-stressed helical springs into the condenser tubes. That means, the original condenser design can be reestablished simply by removing the installed springs and this is an important factor for full scale testing on an operational plant.

The heat transfer resistance in condensers are often much greater on the internal waterside than on the external condensing surface. Reducing internal heat transfer resistance implies a substantial improvement of the overall heat transfer, because the thermal resistance are serial coupled.

If the internal fluid is a surfactant solution (smooth water), this internal heat transfer resistance is increased by a factor of 5-10 compared to a pure water solution. Therefore it is of utmost importance to improve the internal heat transmission to get an acceptable heat transfer performance.

The intention with this work is to demonstrate practical design possibilities and long term effects from built-in springs in a full scale test. The Heat and Power plant in Herning, Denmark has been chosen as the test plant and the built-in springs was planned to be installed in a limited number of tubes in district heating condenser no 1. The design of this condenser is shown in fig 3.1 and the tubes to be installed with helical springs are shown in fig 3.2.

All the tubes were originally made as black tubes in St 35.8, but because of wear and abrasion problems arising on the external tube surfaces, it has been necessary to replace the tubes in the two external boundary layers with tubes made of austenitic steel (Werkstoff 1.4462). With these two different tube materials it was obvious to install springs made of standard hard-drawn spring steel (Werkstoff nr 1.0600) and austenitic steel (Werkstoff nr 1.4310) to expose eventual corrosion problems in the widest sense.

The mounting and dismounting of the helical springs in full tube length (10300 mm) has to be unproblematic. The fixations of the installed springs have to be safe to avoid any operational problems caused by spring-detachment. An obvious way to solve these problems was to insert correct pre-stressed springs inside the tubes.

Spring-tube calculations

Simple calculations of pre-stressed built-in springs were initially carried out based on standard formulas for design of helical springs exposed to torsion. The pre-stressed springs have to match the condenser tube dimensions d_i x L = 12.6 x 10300 mm.

Applying material data for standard spring steel according to DIN 17223, the simple calculations gave a first-hand figure of the maximum allowable radial deflection achieved by twisting the spring. The calculations indicated, that it was possible to achieve a sufficient radial deflection to be able to mount and dismount the springs inside the tubes.

The simple helical spring calculations are only valid for small axial pitches. The spring pitch has most properly a strong influence on the internal heat transfer and pressure losses. It is possible to optimise the pre-stressing procedure by combining a twisting and a stretching of the springs simultaneously. Finally it is very important to be able to maximise the radial deflections without overloading and damaging the springs.

These reasons justify a refined accurate model of the pre-stressed spring-tube system. The refined model was developed based on a full 3D double curved beam element exposed to axial forces and torsion moment [7].

At present the model has been used successfully in the design phase of the spring-tube system. The model predicts accurately the necessary twisting numbers and eventually stretching measure to accomplish a specified radial gap. The model calculates the stress level and ensures that the spring is not overloaded. The model gives finally an estimate of the pre-stressed forces between the spring windings and the internal tube surface. This figure is used to evaluate the stability of the spring-tube grip under district heat operation.

Selected springs, mounting and dismounting

A parametric study encountering various spring thread diameters, pitches and thread material according to DIN 17223-17224 has been accomplished. In consultation with the helical spring manufacturer DK FJEDRE A/S, two spring systems have been selected to the planned experiments in Herning CHP-plant.

We have chosen a 1.0 mm hard-drawn spring steel wire Class D (Werkstoff nr. 1.0600) and a 1.0 mm stainless steel wire (Werkstoff nr. 1.4310) to be built in a tube with an internal diameter of 12.6 mm. The unloaded external spring diameter is 13.0 mm and the pitch is chosen to 12 mm. The external diameter of the pre-stressed spring is calculated to 11.75 mm before insertion - see fig 3.3.

A special tool was designed to pre-stress the springs correctly. The tool consists of a stiff adjoining helical spring attached to a drilling machine in one end and welded to a hold with a notch in the other end. The tool is inserted into the spring to be mounted. The spring to be installed is fixed to the notch in one end and counterbalanced in the other end at the drilling machine. The drilling machine, equipped with a revolution counter, twists the tool and thereby the installation spring in a pre-calculated number of revolutions. The installation spring has now the correct external diameter and are ready to be inserted into the condenser tube. The tool is shown in fig 3.3.. Dismounting is simple worked out in an opposite sequence.

Results from the long term tests

The springs were mounted in the summer revision 1995 and dismounted in the following summer revision 1996. After the condenser was opened the springs were found intact and correctly fixed. The springs and the related tubes were dismounted and subdivided into inlet, centre and outlet parts. The test material were marked and delivered to Mr. Knud Erik Poulsen from the Material Testing Department in the Danish Technology Institute.

The testing period was approximately 13 months with a normal district heating production. That means with reduced load in the summer period and up to max. load in the winter period (max. water velocity 2.1 m/s). The black tubes (St 38.8) have been exposed for corrosion since the start of the power plant in 1983. The austenitic tubes have first been installed in 1990.

The results from Mr K.E.Poulsen’s corrosion examination [6] are restored below.

Tube position	**Tube material**	**Spring material**
1. A inlet zone	Stainless steel W 1.4462	Stainless steel W 1.4310
2. A centre zone	Stainless steel W 1.4462	Stainless steel W 1.4310
3. C inlet zone	Steel St 35.8	Stainless steel W 1.4310
4. C centre zone	Steel St 35.8	Stainless steel W 1.4310
5. D inlet zone	Steel St 35.8	Spring steel W 1.0600
6. D centre zone	Steel St 35.8	Spring steel W 1.0600
7. D outlet zone	Steel St 35.8	No spring

The tubes have been examined for corrosions with the following results:

Tube position	**Weight of corrosion products**	**Weight of tube**
A inlet+spring	~0 g/m	425.0 g/m
A center+spring	~0 g/m	425.0 g/m
C inlet+spring	8.55 g/m	384.7 g/m
C center+spring	12.45 g/m	388.7 g/m
D inlet+spring	11.38 g/m	379.3 g/m
D center+spring	18.86 g/m	375.7 g/m
D outlet and no spring	11.41 g/m	380.1 g/m

The weight loss of black tubes made of St 35.8 corresponds to an approximate average thickness on 0.1 mm and cover existing gab-corrosions on the internal and external tube surfaces. The maximum gab-corrosion amounts 0.25 mm.

The size of corrosions on St 35.8 tubes are practical similar. It is not possible to see any significant differences of corrosions at the inlet, centre or outlet tube position. The spring materials reveal no visible differences in the corrosion pattern.

The corrosion of springs made of hard-drawn spring steel is modest.

There is not found any corrosions on the stainless springs and the stainless tubes.

Conclusion

The long term test demonstrates no operational and fixation problems. The tubes were found in exactly the same positions as they were mounted.

The results from the corrosion tests show no corrosion attacks on springs and tubes made of stainless steel. The hard-drawn spring-steel indicates a minor corrosion attack.

The black tubes show no significant corrosion pattern related to the spring assembly. The major corrosion attacks are most properly caused by the long time exposure to the water in district heating system and the extraction steam. These tubes have been installed since 1983.

It has been demonstrated that long springs in oversize (d_e = 13 mm, L = 10300 mm) can be installed into long condenser tubes (d_i = 12.6 mm, L = 10300 mm) without any serious problems.

We must conclude that stainless steel springs are the best solution, because corrosion is negligible. Even if the tubes are made of ferritic steel (St 35.8) it is still recommendable to use springs in stainless steel.

It is important that the pre-stressing of the springs before and after insertion is correctly carried out. Any operational problems caused by detached springs are unacceptable.

3.2 Application of results obtained at the test rig in Dortmund

Models

Two typical Heat and Power Plants are simulated to operate with drag reducing additives in district heating water and with helical springs installed inside tubes in district heating condensers - these systems are called modified. The original heat-balances are established, so it is possible to make comparisons and evaluations between the modified and the original systems.

Original and modified power plant systems are described below.

1. Plant: MKS unit 3/4, Århus, Denmark (Reference Plant).
   Design: Extraction type with separate seawater cooled condenser.
   District heating system: Original system applying pure water.

2. Plant: MKS unit 3/4, Århus, Denmark.
   Design: Extraction type with separate seawater cooled condenser.
   District heating system: Modified system applying drag reducing additives.
   Internal helical springs installed.

3. Plant: Herning CHP-plant, Denmark (Reference Plant).
   Design: Backpressure type (electricity and heat stiffly bound).
   District heating system: Original system applying pure water.

4. Plant: Herning CHP-plant.
   Design: Backpressure type.
   District heating system: Modified system applying drag reducing additives internal helical springs installed

The thermal couplings of the power plants are shown as heat-balances found in the appendix. The couplings are slightly changed compared to the original ones. It has been necessary to add an extra district heating pump ”PDH” to be able to compare the results. The pump ”PDH” equalises the district heating outlet pressure with the inlet one and the pump-power is then added to the internal power consumption. That means net electric powers, net efficiencies and Cm/Cv-values are direct comparable.

The results from part D1 in this report ”Investigations of heat transfer and pressure drop” have been used to describe internal heat transfer and pressure drop in the modified district heating condensers.

According to chapter 4 in part D1 it should be possible to increase the internal heat transfer coefficients of the modified district heating system with approximately 100% compared to the original systems. It is recommended to use a formula from weber [8] to compute the internal heat transfer coefficients for condensers using drag reducing additives and installed with helical springs.

The drawbacks we get by provoking turbulence inside the tubes is a substantial pressure drop. In chapter 4, part D1 it is demonstrated that the pressure drops in the modified system amounts 700 - 800% compared to the pressure drops in the original system. We have to consider these substantial pressure drops in the power plant models, so therefore we simply multiply the original pressure drop by a factor of 8. The original pressure drop is determined by means of Colebrook’s formula.

Results for Power Plant MKS unit 3/4.

Power Plant MKS unit 3/4 were originally designed for high district heating temperatures of 70-125 °C. In the meantime the tendencies have been to lower the district heating temperature level to improve efficiencies. A typical lower level district heating production is carried out at temperatures 55-115 °C.

A number of heat-balances at 100% load have been carried out for both the original and the modified model of the power plant MKS unit 3/4. The results are represented as graphical heat-balances in the appendix. The main key-data for these calculations are shown in table 3.2.1 (low district heating temperatures 55-115 °C) and in table 3.2.2 (high district heating temperatures 70-125 °C).

At high district heating temperatures the calculations show positive results. The net electrical power as function of district heating is generally improved with a max. value of 430 kW. The Cv-value (defined in the enclosure) is generally reduced with a max. value of 1%.

At low district heating temperatures the calculations show negative results. The net electrical power as function of district heating is generally reduced with a maximum value of 1280 kW. The Cv-value is generally increased with a max. value of 1.5%.

The reason to this negative shift in low temperature region is due to increased losses in the outlet ends of IP turbine. The turbine was original designed to relative high extraction pressures and temperatures to feed the district heating system. By decreasing the district heating temperature level the volume flows are increased and the last stages in the turbine are additional loaded. This tendency is increased further by using helical springs in district heaters, because of the improved heat transmissions.

It has been discussed to replace a number of the last stages in the IP turbine to meet the demand for operating with even lower district heating temperatures. In this case it is most properly, that the plant will show the same positive or neutral tendencies as we found for operating at high temperature level.

It is interesting to see that the additional pumping power caused by the great pressure drop in the modified system, is regained in an increased expansion in the turbines primary due to the improved heat transmissions in district heaters.

Results for the CHP-plant in Herning.

The plant in Herning was designed for district heating temperatures of 55-90 °C. Today the plant operates at lower temperature levels - typical 42.6-85.6 °C.

A number of heat-balances have been carried out for both the original and the modified model of the plant. The results are represented as graphical heat-balances in the appendix. The main key-data for these calculations are shown in table 3.2.3 (low district heating temperatures 42.6-85.6 °C) and in table 3.2.4 (high district heating temperatures 55-90 °C).

At high district heating temperatures the calculations show positive results at 25%, 50% and 75% boiler-load. At 100% boiler-load the results are negative. The net electrical power as function of gross boiler-load shifts between 200 kW extra and 350 kW lesser power. The Cm-value (defined in the enclosure) shifts between +0.7% and -0.6%. The pressure drop is increased from 1.1 bar to 8.6 bar at 100% boiler-load.

At low district heating temperatures the calculations show exclusively positive results. The net electrical power as function of gross boiler-load is improved at all gross boiler-loads. The max. increase of net electrical power amounts 363 kW. The Cm-value is raised to a maximum of 1.1%. The pressure drop is increased from 0.7 bar to 5.5 bar.

The success here is due to the increased temperature difference and thereby reduced massflow in district heating condensers. The pressure difference over the modified condensers are reduced from 8.6 bar at high temperature operation to 5.5 bar at low temperature operation at 100% boiler-load.

A thorough study of heat-balances shows modest flow-losses in the Herning Plant. This indicates a greater robustness against improved condenser capacity.

The turbine has no symmetric cylinders and is exclusively balanced by means of an axial piston. If the pressures in the turbine are changed perceptible it is necessary to consult the turbine manufacturer.

Conclusions

Despite the great pressure drops and thereby extra pumping power we experience, when helical springs are installed into the district heating condenser tubes, it is surprising that the improved heat transmission causes such an extra expansion in the turbines, that the overall effects are practical neutral. The calculations demonstrate increased efficiencies at low temperature district heating and especially here we have to consider the turbines carefully if we try to expand the steam fur-ther.

The calculations are based on the work described in part D1. The experiments here deal with a single helical spring with fixed geometrical measures. It is most likely that the heat transmissions and pressure drops can be optimised by choosing another geometry of the obstacle.

The results from the present investigation indicates, that it should be possible to improve power plant efficiency, if we use an optimized obstacle inside the district heating condenser tubes. Anyway if we neutralize the power plant efficiency as demonstrated here, we still reduce the district heating transmission losses with 70-80% compared to traditional district heating systems.

Finally if the pressure drop becomes too great, it is obvious to check the possibility for raising the district heating temperature difference and thereby reduce the massflow and then the pressure drop. This step can very well improve the efficiency as indicated under ”Results for Heat and Power Plant Herning”.

4. Outlook

The most conspicuous effect of smooth water is the reduced demand for pumping energy.

However, it has to be assumed to be even more important that the capacity of existing networks can be increased due to the possibility of increasing the flow rate. This is a valuable alternative to the building of new expensive networks in those cities having a fully utilized network and being in need of increased capacity demand.

Another aspect is the possible reduction of the forward temperature in order to reduce heat loss from the network and to improve the efficiency of power production from CHP-plants. The water velocity in the network, which necessarily has to be increased if the mean temperature difference falls will be a limiting factor. The application of smooth water has the potential of solving this particular problem.

In case of building new networks, savings may be obtained by using smaller pipe dimensions.

In connection with restructuring of old systems and implementation of CHP on regional levels, it will be likely to build new transmission systems to replace old distribution systems. Also in these cases - which will be relevant in many Central and Eastern European city areas - the utilization of smooth water is an obvious chance of reducing initial costs.

A number of R&D and demonstration projects have taken place during the past 10 years aiming at the goal that friction reducing additives should be applied in hydraulically separated heat transmission networks in order to save energy for pumping.

In a co-operation between Herning Kommunale Værkert (the public utilities of Herning), CTR (the Metropolitan Copenhagen Heating Transmission Company) and Bruun & Sørensen Group AS a project is now under development, which will apply the results of previous projects and set up models for the application of smooth water in the transmission networks of Herning and Copenhagen respectively. In Herning a reduction of pumping costs is aimed at, while in Copenhagen an extension of the output of the present network is the objective. It is the intention to set up a feasibility study in the two cases and also discuss the effects as to energy consumption and advantages / risks to the environment. This project is co-financed by the participants and the R&D-programme of the Danish Ministry of Energy.

This project will be terminated by the end of 1997.

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6. Appendix

(District heating condenser, calculated key data and heat-balances for MKS Power plant unit 3/4, Århus and Heat and Power Plant, Herning, Denmark)