FEASABILITY STUDY OF USE OF SURPLUS HEAT FOR COLD PRODUCTION IN THE FISH INDUSTRY

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ABSTRACT

The main objective of this paper is to present results from an on-going research project funded by the Research Council of Norway called KMB CREATIV – Competence project for Reduced Energy use through Advanced Technology InnoVations. The submitted paper focuses in particular on utilisation concepts of production of cooling by use of surplus heat exploitation in the fish industry.

The seafood industry, including hatchery fish production, represents 29 % of the energy use of the food production industry in Norway. More than half of the energy use is electricity and ⅔ of total energy use is for cooling/freezing applications. Measures to reduce use of primary energy use for cooling production are therefor of major significance.

The submitted paper presents results from a feasibility study of the possibilities of production of cooling water at a low temperature (about 0°C) from surplus heat at a high temperature level (above 80°C) by the use of absorption chillers. First, possible heat sources within different types of fish industry is analysed and second, possible synergy effects from cooperation between neighbour industries are analysed. To illustrate the second part, a case study is described. The feasibility study also includes an analysis of the need for water cooling in different processes and typical fish industries. The results will indicate which conditions that has to be in place in order to make the installation of a heat driven absorption chiller profitable in the Norwegian fish industry.

1. INTRODUCTION

During the last 20 – 25 years there has been an enormous increase in production of farmed Atlantic salmon in Norway. This has also demanded great changes, development and improvements in the handling and chilling of the valuable fish. From the simple slaughter arrangement on almost every small farm in the early days, we have today large, rational and efficient slaughter plants with capacities of 200 – 400 tons per day.

Most products are sold fresh, and to preserve the high quality, the temperature should be lowered as early as possible. The development of chilling from traditional icing in boxes in the first small plants to use of containers with ice and seawater (CSW) and introduction of more efficient and rational chilling was achieved with the first continuous refrigerated sea water (RSW) units. This has led to an increased energy demand. Chilling of the common size salmon of 4 – 6 kilos takes 1.5 - 2.0 hours and is a bottleneck in processing.

2. ENERGY USE AND POSSIBLE WASTE HEAT SOURCES

2.1 Energy use

The Norwegian industry sector is very energy intensive with a high share of production of metals and basic chemicals. The food and beverage industry had an energy use of 4.5 TWh (Statistics-Norway 2011) in 2010 or approximately 7 % of energy use in industry. The fish industry, including the production of farmed fish, used approximately 1.3 TWh or 29 % of the energy use in the food industry and is one of the major energy consuming sub-sectors in the food industry. Approximately 60 % of the energy use in the fish industry is electricity and the average cost was 0.6 NOK/kWh in 2010. Cooling and freezing applications use two thirds of the energy in the fish industry and it is of great interest to reduce the use of primary energy for cooling production.

2.2 Salmon slaughterhouses

The Norwegian aquaculture industry has grown substantially since it started a few decades ago. The activity was at the highest in 2008 with an annual production of almost 900 000 tonnes of salmon and trout. At present the number of salmon slaughteries in Norway is about 15 plants, and the industry is growing.

Alevin and hatchery fish is produced under strict control in tempered fresh water tanks on land. When the hatchery fish is big enough, it is transported to net cages in the open sea where they are grown to the final size of 4-5 kg per fish.

When the fish is ready for slaughtering, the normal process steps of an industrial plant are:

1. Starving before slaughtering
2. Catching/pumping:
    a. to a well boat
    b. to a waiting net cage *or*
    c. directly to the slaughterhouse
3. Cooling/stunning
4. Killing
5. Evisceration, washing and packaging

The handling of living fish in connection to the slaughtering process will create stress response, but it is very important to find solutions that make the processes as gentle as possible. This is important both with respect to animal protection and in order to get the best product quality. Stunning is usually either by electricity or by a hit on the head.

After the fish is killed, it has to be cooled down. Cooling of living fish is more and more abandoned. The slaughtering regulation states that the fish has to be cooled down below 4°C. It is desired to cool the salmon to 0°C, but due to capacity problems this is often not reached and the final cooling is instead performed in the ice boxes used for transportation. The weight of a box is 30 kg of which approximately 6 kg is ice.

2.3 Waste heat sources in fish slaughterhouses

The available waste heat sources in the salmon slaughterhouse are limited. One possible waste heat source is the heat from oil of the compressor of the cooling machine. The temperature is approximately 60-70 °C and the energy content can be calculated as 10-20 % of the compressor output.

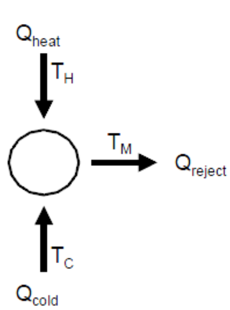
2.4 Waste heat sources in neighbour plants

With limited waste heat sources in the slaughterhouse, another interesting solution might be cooperation between neighbours. The production of fish packaging boxes is often located in direct connection to salmon slaughterhouses. The boxes are produced continuously by casting of balls of expanded polystyrene. In producing molded parts heat can be recovered as condensate and cooling water from the molding machines and exhaust steam from pre-expanders (BASF 1998). The temperature of the cooling water leaving the molding machines is generally 60-80 °C. The exhaust flow from the pre-expanders is a mixture of steam, air and pentane at a temperature of approximately 95°C. These might be interesting waste heat sources for an absorption chiller.

Other possible waste heat sources with a high temperature that might be located close to a salmon slaughterhouse are plants producing primary aluminium or gas power plants. The flue gas from the pot furnaces of a primary aluminium smelter is often equipped with a heat recovery unit and from this unit waste water with a temperature of approximately 80-90°C might be available as a waste heat source for a neighbouring plant. The energy content of the waste water is much more than the amount needed producing chilled water in a typical fish slaughterhouse and will not be the limiting factor. In the case of a gas power plant, flue gases with a temperature of approximately 80°C will be available. The energy content of the flue gases will also in this case not be the limiting factor if considered use as waste heat source for an absorption chiller for production of chilled water to a fish slaughterhouse.

3. ABSORPTION CHILLERS

Thermally driven chillers may be characterized by three temperature levels: a high temperature level at which the driving temperature of the process is provided (T_H), a low temperature level at which the chilling process is operated (T_C), and a medium temperature level (T_M) at which both, the heat rejected from the chilled water cycle and the driving heat, have to be removed. For this heat removal, in most cases a wet cooling tower is used.



Figur 1: Basic process scheme of a thermally driven chiller

The temperatures in an absorption cooling machine may not be chosen independently of each other. When an evaporator temperature and a heat rejection temperature have been chosen, the lowest temperature at which drive heat may be supplied to the machine has also been determined. The performance of an absorption chiller is always dependent of the chosen operating conditions.

Absorption cooling technology is a well proven technology and the absorption machines that are commercially available are powered by steam, by hot water or by combustion gases. The main market for absorption technology is the production of chilled water in comfort cooling of buildings. The dominant refrigerant-solution pairs are water/LiBr and ammonia/water. The water/LiBr pair is restricted to temperatures above 0 °C, while ammonia/water can be used both in comfort cooling and in freezing applications.

Ammonia/water absorption chillers are available from 18kW to MW sizes. The cooling coefficient of performance for a single-effect ammonia/water absorption chiller is around 0.5-0.6 (IEA 2000).

4. CASE STUDY

As a case this paper will discuss the potential of using surplus heat to cover the chilling demand in a salmon slaughterhouse with use of an absorption chiller.

All the salmon in a salmon slaughterhouse have to be cooled down from the sea water temperature to 0°C. Normally, the cooling of salmon is done after the fish is killed and bleeded. The fish is cooled down in a tank with circulating cold sea water. The sea water is cooled from approximately 6°C to approximately -1°C and is recirculated in the tanks. Approximately 10 % fresh seawater is added. A normal size of a salmon slaughterhouse is 200 to 400 tonnes of slaughtered salmon per day. This case study is based on a typical slaughterhouse with a capacity of 250 tons a day. If the sea temperature is approximately 6°C and the specific heat capacity of salmon is 3.4 kJ/kgK, then 5.1 GJ has to be removed per day in order to cool down the fish to 0°C. With an operation time of 8 hours per day, the necessary cooling effect is approximately 180 kW. The annual number of production days is usually 250-300. In this case study, the slaughterhouse is assumed to be in operation 295 days per year and the annual need of cooling is then 1.5 TJ/year.

If the coefficient of performance (COP) of the chiller is 4, the electricity use will be 104 MWh per year. With an electricity price of 78.3 €/MWh, the annual electricity cost is approximately 8143 €.

The electricity use of the ammonia/water absorption chiller is between 2 to 4% (http://www.ago.ag 2011) of the rated chilling power, giving an electricity demand of 16.67 MWh per year. The annual electricity cost will then be approximately 1305 €. If the cooling COP for the absorption chiller is 0.5, the required heat for driving the chiller is 360kW, and the annual heat demand is 850MWh.

A slaughter house with a capacity of 250 tons salmon per day requires 12.500 boxes a day based on that the boxes stores 20 kg each. The annual demand for transport boxes are nearly 3.7 million, making the amount of surplus heat sufficient for driving an absorption chiller.

The cost of refrigeration plants depends on various parameters as refrigeration capacity, heating medium temperature, re-cooling temperature or cooling water temperature etc. A rough economic comparison of a standard RSW chiller and an ammonia/water absorption chiller is given in Table 1. The comparison is for a cooling capacity of 180kW. The specific investment costs of a standard RSW(refrigerated sea water) chiller is estimated to 520€/$kW_{cooling}$ (Helle 2012). The specific investment cost of an ammonia/water absorption chiller adapted to the same application is estimated based on the assumption that the specific investment costs of an absorption chiller is approximately 50% higher than the specific investment costs of a vapor compression chiller for the same duty.

An evaluation of the benefits of absorption chillers based on the simple payback, defined as the period after which the cumulative cost savings equal the capital cost of a project, do not give a good base for comparison of conventional vapor compression and absorption cooling. The differential payback, the net present value (NPV) and the internal rate of return (IRR) give better measures of the benefits of competing technologies. The differential payback method uses the difference between the capital and operating costs of competing technologies to justify additional expenditure if additional savings are available.

Table 1 Net present value and Investment Rate of Return (life time =15 years, discount rate = 20%)

Case#	**A**	**B**
Annual operational hours [h]	2360	2920
Difference in investment costs [€]	46800	46800
Annual savings in electricity costs with absorption chiller [€]	6838	8460
Differential payback [years]	6.8	5.5
Net present value, NPV [€]	-14829	-7246
Investment rate of return, IRR [%]	12	16

The calculation of the differential payback, the NPV and the IRR assuming a life time of 15 years, a discount rate of 20% and electricity costs of 7.82 Eurocents per kWh show that an absorption chiller is not competitive in the case studied. The calculations are sensitive to the electricity costs, the coefficient of performance (COP) of the vapor compression chiller and the annual operational hours. Increasing the annual number of production days up to 365 with 8 working hours daily does not make the investment profitable. The operational hours will increased if the plant is exploited more intensively by working two shifts.

The high investment costs of absorption chillers, the relatively few annual operational hours and the low electricity costs are the main reasons for the absorption chillers not being competitive in this case study.

5. CONCLUSIONS

The feasibility of using waste heat driven absorption chillers to provide chilled water for cooling of salmon in the fish industry has been explored. Several possible waste heat sources have been identified, of which the waste heat of neighbouring plant are most promising as there are limited waste heat sources in the slaughterhouse.

A case study based on a slaughterhouse with a capacity of 250 tons per day, 8 hours of operation per day, an electricity cost of 7.82 Eurocents/kWh and a cooling demand of 180kW revealed that the absorption chiller is not profitable compared to a standard vapour compression RSW unit.

The high investment costs of absorption chillers, the relatively few annual operational hours and the low electricity costs are the main reasons for the absorption chillers not being competitive in this case study.

ACKNOWLEDGEMENTS

This publication forms a part of the CREATIV project, performed under the strategic Norwegian research program RENERGI. The author acknowledge the Research Council of Norway (195182/S60) and the industry partners Danfoss, Hydro Aluminum, John Bean Technology Cooperation, Norske Skog, the Norwegian Seafood Federation (FHL/FHF), TINE BA , Systemair and REMA 1000 for their support.

NOMENCLATURE

COP	coefficient of performance
CSW	ice and sea water
RSW	refrigerated sea water

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