INDUSTRIAL HEAT PUMP - CONTRIBUTION TO GLOBAL WARMING PREVENTION AND ITS ISSUES

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Abstract: Industrial heat pump can contribute greatly to the prevention of global warming by saving energy. In the industrialized countries, some efforts have been made to save energy by introducing industrial heat pumps during the past 30 years
.
However, its application still remains in the limited area. The objective of this presentation is to show the barriers against implementation of Heat Pumps and details of possible solution achieved in actual reference, and finally a more effective approach.
Especially, the reference of CDM projects shows important possibilities in the future.

In Chapter 1, the barriers against the implementation of heat pumps and some measures taken to overcome such barriers are analyzed in several cases. The development of heat pumps in breweries and alcohol plants in Japan during the last 30 year is shown as a typical example.

In Chapter 2, a simple process analysis tool is introduced which was developed to overcome the issues found in successful cases shown in Chapter 1 such as massive time and labour required to develop a system as well as its implementation.

In Chapter 3, implementation of CDM projects in brewery plants in Vietnam and Laos using heat pump technologies developed in Japan is introduced. In these projects, approx. 5,000t-CO_2/year each CER (Certified Emission Reduction) were achieved with the use of high efficiency (COP) heat pump system. One is MVR (Mechanical Vapour Recompression) system for Wort Kettle using screw compressor with COP of 15 and another is a heat pump system for tunnel pasteurizer using high pressure NH_3 piston compressor with COP of 9.

CDM : Clean Development Mechanism; A mechanism designated in Kyoto Protocol which enables transfer of Greenhouse Gas emission rights derived from the emission reductions achieved in developing countries to industrialized countries

Key Words: Industrial heat pump, CDM, Brewery, MVR, NH3 heat pump

1   INTRODUCTION

I made a presentation in the first Heat Pump Conference in Graz, Austria in 1983. It is my great honour to have an opportunity to present in the 10th Heat Pump Conference in Tokyo and I appreciate the support from the staff members of this conference. The agenda of my last presentation was "Screw type Steam Compression Heat Pump".

 It was the time when our country was doing every effort to develop energy conservation technologies after the serious shock of "Oil Crisis". "Screw type Steam Compression Heat Pump" presented in the agenda had been developed in cooperation with brewery companies

and subsidized by The Ministry of International Trade And Industries for a project called "Moonlight Project".

Because it was developed together with the users, we could learn a lot of essential matters required when implementing heat pumps which helped a lot to disseminate (or market) them later on.

Since then, heat pumps of this type have been installed in many Japanese brewery plants and they are still running in good condition. They have been also applied to heat recovery systems in distillers for drinking alcohol and lactic acid
.
On the other hand, various types of NH_3 heat pumps have been introduced to various industrial processes after being engaged in brewery processes deeply.

Nowadays, energy conservation plays more important role not only for economical aspects but also for the prevention of global warming. CDM is a designated market mechanism in the Kyoto Protocol and we implemented energy conservation systems in breweries in Vietnam and Laos since 2002 as a part of such projects.

In this presentation, I will summarize essential points required for the dissemination of industrial heat pumps based on our actual experience.

2   CHAPTER 1 ANALYSIS OF BARRIERS AGAINST INPLIMETATION OF HEAT PUMPS AND MEASURES TO OVERCOME SUCH BARRIERS SUCCESSFULLY.

I would like to introduce a history of heat pumps applied to wort kettles in brewery plants because it can explain the barriers against implementation and possible solutions.

2.1 First plant

The implemented heat pump system is shown in the figure below. The wort kettle receives 150m^3 of wort and evaporates 15 tons of water in 90 minutes. Therefore, evaporation rate is 10 tons per hour and discharged steam is recovered as 80 degree C hot water which is used for cleaning purposes.

This heat pump heat recovery system is designed to suck waste vapour by a steam compressor and increase the pressure up to 0.3MPaA (133 degree C saturated temperature) and reuse energy. This is so called MVR system. COP is from 7 to 8 depending on operating conditions. MVR is a simple heat pump as shown in the figure. Evaporator is already installed inside the wort kettle and refrigerant is steam vapour discharged from the wort kettle.

Screw type was selected as a compressor due to following reasons;

● Wort boiling is a batch operation of 1 to 1.5 hours with frequent starting and stopping which is not suitable for a centrifugal compressor having ranges of surging limitations.

● Condensing pressure fluctuates greatly due to inert gasses generated in the condenser (cooker) because transportation and feeding of hops are done by air-conveyor system during boiling.

● Screw compressor with rugged construction is preferable because discharged vapour contains solid material such as hops
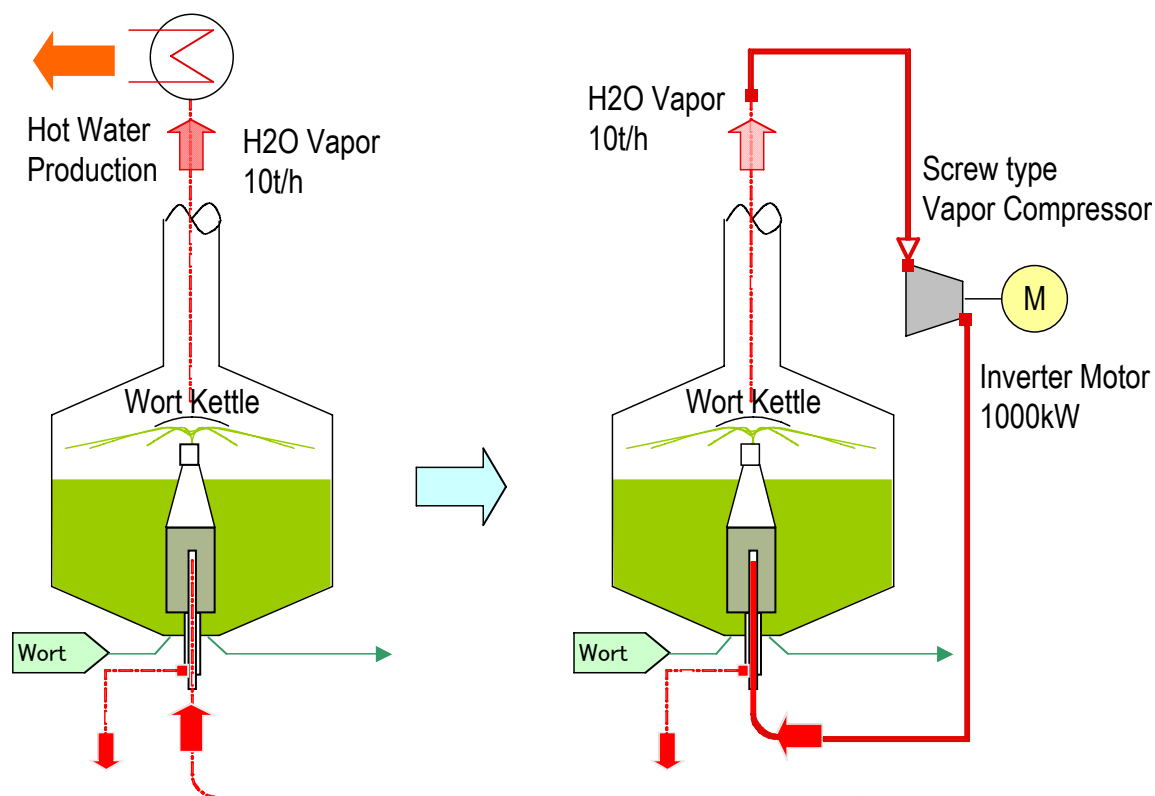
Figure 1 Simple MVR system for Wort Kettle

The function of boiling is categorized as follows:

- Flavouring by hops etc.
- Evaporation of odour contents
- Coagulation of temperature sensitive coagulable protein
- Condensation
- Colouring etc.

Following are general subjects discussed among production engineers (brewing engineers), process engineers and heat pump engineers during the initial stage of implementation.

Brewing engineers: We believe that there will be no problem because it sucks vapour from the top of the kettle and returns it to the cooker after pressurizing. However, boiling conditions must not be changed.

Process engineers: Wort kettles are of very weak construction. It will be expanded at the static pressure of 100mmH$_2$O and shrunk at -50mmH$_2$O. How is it possible to control it within a narrow allowable range when it is directly sucking vapour at 16,700m^3/h?

Heat pump engineers: The biggest problem is the inert gas at the time of feeding hops. Is there any possibility to reduce it?

Vast time and cost were spent for mutual understanding for the first project. But, it was absolutely necessary before implementing heat pump and helped greatly to accelerate implementation in the following steps later.

2.2 Following development in brewery plants

Brewery plant is known to be a consumer of massive energy in food and beverage industry. In particular, brewing process (brewhouse) including boiling process consumes 40 to 50% of entire energy.

Brewery industries in Europe and Japan are energy conscious and have developed extensive energy conservation measures during the last 30 years. Especially, energy conservation and quality improvement have been progressed in parallel. Following is a simple explanation of improvements in wort kettles and boiling method during the last 30 years.

2.2.1 Efforts made in brewing technology

Functions and mechanism of boiling have been analyzed thoroughly. As I mentioned before, there are a lot of functions in boiling. Following mechanism and results were found after analyzing each individual function.

- The most important element of boiling capacity is the number of turns going through boiling. However, certain shape of kettle creates dead space and wort can not pass through the cooker uniformly.

- 10 to 15% of vapour evaporation ratio (80 to 90 minutes) was standard for boiling capacity at the time of initial development. It is now 6.7% to 10% (60 to 80 minutes). It may be as small as 3% in the case of a special boiling method.

2.2.2 Efforts made by process engineers

Process engineers tried to eliminate the dead space after seeing the results of brewing engineers. Following are major items studied.

- The shape of kettle eliminating dead spaces
- To increase amount of wort spraying out from the cooker
- Uniform distribution of wort sprayed out from the cooker

The shape of the kettle has been changed to be deep and longer vertically.

Cooker is a thermo-siphon heat exchanger. Water evaporated in the cooker is sprayed out upwards together with wort. Wort sprayed out changes its direction by an upper distribution plate and distributed over the surface of wort pool.
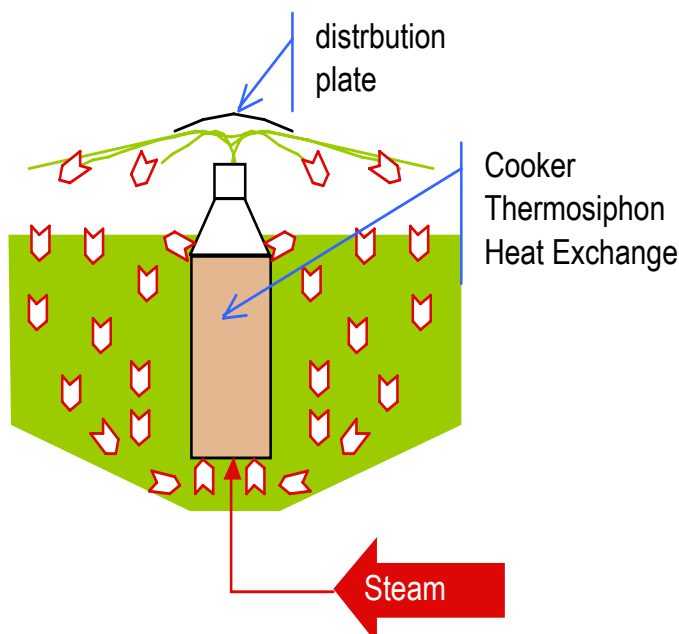

Figure 2 Wort movement

Vapour is separated in the space

where it is sprayed over and moves toward the chimney. Separated wort moves downward and is introduced to cooker from the bottom again.

Uniform distribution can eliminate dead space so that wort can go through boiling uniformly.

The flow velocity of wort inside the tube depends on the amount of wort carried over with evaporated vapour.

Inner volume of a tube is calculated as sectional area of tube multiplied by tube length. The surface area of a tube is calculated as outer circle length multiplied by tube length.
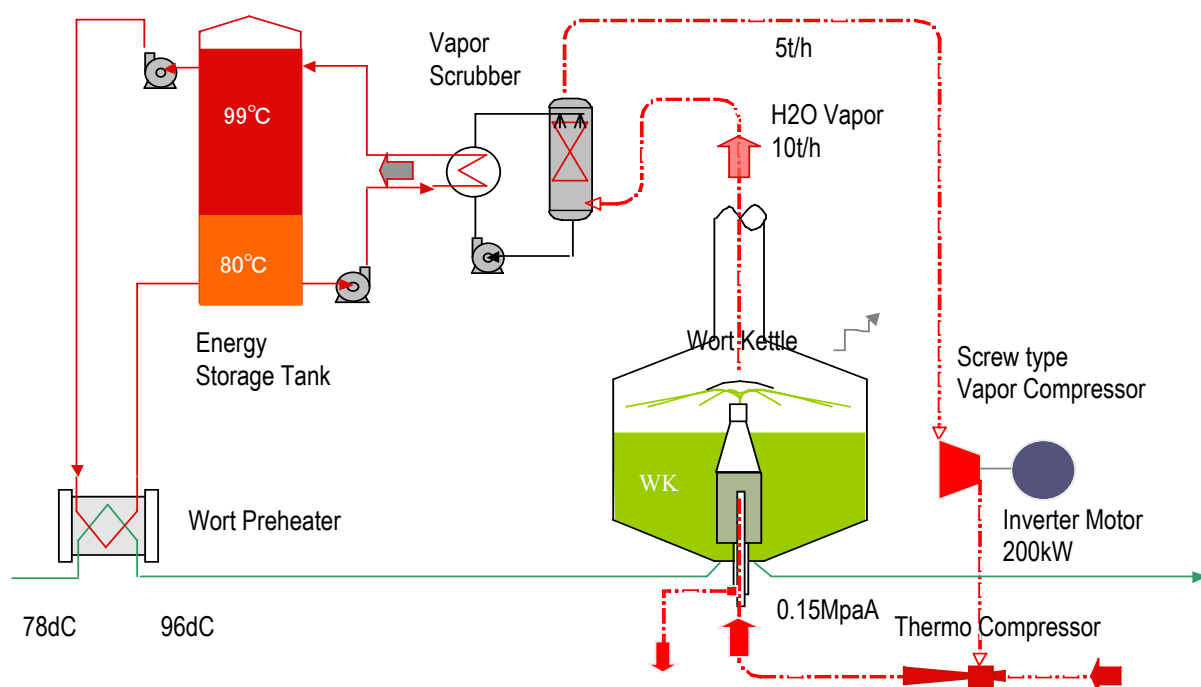
The smaller tube diameter and longer tube length make larger specific surface area and more wort carried over. Larger carry-over volume makes higher velocity inside the tube. Higher up-flow velocity improves heat transfer efficiency.

When VRC was first introduced, many cookers used 50mm inner diameter tubes. Nowadays, tubes with 20 to 25mm are used which enhanced heat transfer efficiency tremendously. The K value (overall heat transfer co-efficient) is exceeding 3,500W/m^{2}Hc. With increased velocity, it also prevents clogging caused by burns.

As a result, steam pressure (condensing pressure) can be reduced to 0.3MpaA to 0.16 MpaA. In terms of temperature differential (delta-t), it can be reduced to 13 degree C from 33 degree C that contributes to enhance COP greatly.

Heat pump engineers tried to utilize heat more effectively and design a most appropriate system. The general system currently used is shown in Figure 3.

Discharged steam from the kettle is condensed partly (about half) by a scrubber and produces 99 degree C hot water by a plate heat exchanger installed in the re-circulating circuit. Remaining half is compressed by a steam compressor. 99 degree C hot water generated is stored in a thermal storage tank and utilized for wort pre-heating in the next boiling session.

Figure 3 Latest MVR for Wort kettle

As almost half of vapour is already condensed by a scrubber, remaining portion of steam after recompression by a compressor is not sufficient for boiling wort. Additional boiler steam is required to match the capacity used for pre-heating as recovered hot water.

This system is using a thermo-compressor driven by steam for this purpose and decreases discharge pressure of steam compressor. This system is designed to recover and reuse discharged steam 100% while reducing required compressor capacity to below half. Required driving power of the compressor can be reduced to below 1/5th while achieving COP exceeding 15.

As a side effect, because of higher wort feeding temperature, decrease of heat transfer efficiency caused by burns in cooker is eliminated. Burns could happen when evaporation rate is small at lower temperature. It also helped to stop rising discharge pressure and reduced the frequency of cleaning greatly.

It is essential to understand minimum temperature differential and required heating and cooling capacity. For this purpose, we require cooperation between production engineers and process engineers.

3 CHAPTER 2 – PROCESS ANALYSIS TOOLS

It requires a vast time to develop an economically efficient heat pump system involving production engineers, process engineers and heat pump engineers. We developed a tool to show the process simply in order to reduce project procedures of working team and obtain mutual understanding in a short time. This is a simple write-in software based on Microsoft Excel. Below is a reference of a brewery plant.

This software accepts data entries for material balance and energy balance of entire processes following production flow. The figure shows an example of wort boiling process in the brewing process.

This software covers the entire plant in the same way. We call it "Virtual Factory". Following are features of "Virtual Factory".

- Each process is shown as an integration of individual components with a single function. (Such as condenser, kettle, dryer, fermenter and so on). We break them down as much as possible and show them in a simple manner.
- In the same way, we can show various plants by composing each process as an integration of single functions.
- We calculate material balance in all processes and required amount of energy based on such material balance. By taking overall heat balance, we can design much more effective utilization of waste heat and so on.
- Energy and utility plants can be shown in the same way.
- Wastewater treatment and waste disposal can be shown in the same way.
- Equipment is shown in figures so that more staffs involved in production can handle it as much as possible.
- Calculation of heat pump and cooling plant is done in a simple way using Carnot efficiency. It is rather better to evaluate expected COP by temperature differential in the process.
- Types of heat exchangers (shell & tube) and formula of heat exchange (thermo-siphon, falling film, etc.) are to be described together with expected K value (overall heat transfer efficiency) and temperature differential against process fluid.
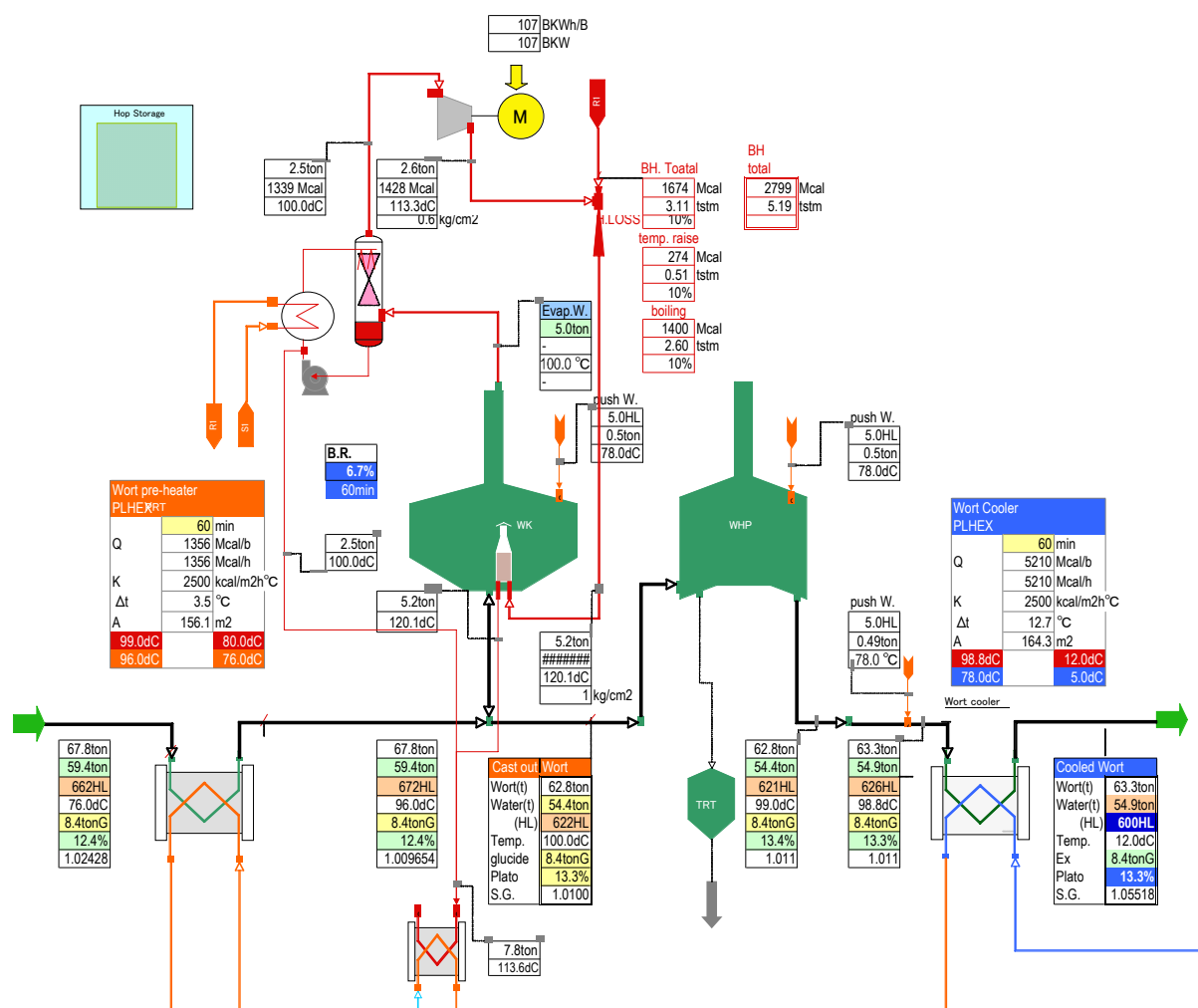
Figure 4 Part of Virtual Brewery

With "Virtual Factory", it is now possible to carry out following things.

- It is possible to study an appropriate production process, heat utilization and utilization of heat pump in a short time.
- It is easy to simulate replacement of equipment and modification of processes in the virtual factory, so that it is possible to calculate energy consumption after the modification precisely.
- It is possible to analyze and evaluate energy consumption of the plant in operation.

Up to now, "Virtual Factory" has been used in factories in Japan for energy audit and energy conservation in operation. It is also used to support energy conservation in various food plants in Southeast Asia (brewery, beverage, meat, processed fruit and sugar plants)

4 CHAPTER 3 ENERGY SAVING WITH HEAT PUMP TECHNOLOGY AND CDM

In Laos and Vietnam, some projects were implemented as CDM (Clean Development Mechanism) projects for energy efficiency improvement with heat pump. The case for Laos is a brewery plant and it is the first CDM project for brewery. It is also a rare energy efficiency improvement CDM project.

Simple description of project

Implemented plant: Lao Brewery Co., Ltd. Vientiane Brewery
Production capacity: 120,000kL/year
Applied technology:
- MVR for Wort Kettle (Vapour compression: 2 tons/h, Motor: 110kW)
- NH_3 Heat pump for Pasteurizer (Heat recovery: 120,000kcal, motor 37kW
- Biogas Boiler from Anaerobic Wastewater Treatment system: Boiler 1ton/h x 2 sets

GHG emission reduction (CER): 5,000ton-CO_2/year
Methodology: Small Scale CDM II.D. Energy efficiency and fuel switching measures for industrial facilities

Production is 120,000kL/year that is a medium size brewery but the quality is highly appreciated.

This project started in 2003, an energy conservation project based on CDM and was completed 4 years later in December 2006.

CDM project registration was completed in April 2007. At present, around 5000 tons of CER is generated.

Applied technologies are MVR, NH_3 Heat Pump and Biogas Boiler as mentioned before.

I have already explained about MVR in detail in Chapter 1. So, I will explain about NH_3 Heat Pump for Pasteurizer in this Chapter.

Figure 5 Site Map

This heat pump is quite informative about dissemination of industrial heat pump.
The concept of pasteurizer and heat pump is shown in Figure 6.

Pasteurizer is a device to sterilize beer after bottling. Sterilizing temperature is higher than 60 degree C. The beer entering at 6 degree C is heated to above 60 degree C and cooled down to below 40 degree C for desirable quality. As the figure shows, it is already designed to reduce energy consumption as much as possible.

Water sprayed over the bath at inlet heats up beer there. After that it cools down beer in the final bath, then, it is sprayed in heating bath again. It is cross-flow type heat exchanging. The figure shows 2 heating baths and 2 cooling baths which can recover a lot of heat capacity. Steam consumption is limited to sterilizing baths and other baths to maintain temperature for sterilization. However, energy consumption is still large.

In these days, brewing process became energy efficient and energy consumption in packaging shares rather bigger portion. In the packaging line, most energy is consumed by pasteurizer.

NH_3 heat pump cools down water in the final cooling bath and supply condensing heat to the first heating bath. It is possible to increase temperature differential by 10 degree C more compared to a conventional system and it contributes to energy conservation. Evaporating temperature is 20 degree C and condensing temperature is 38 degree C. It achieves COP from 8 up to 10.

This Heat Pump also achieved more benefits other than high COP as follows.

- It is possible to maintain constant cooling temperature in the final bath. This enables precise control of beer temperature and better beer quality is achieved. In the conventional system, it is controlled by the quantity of fresh water supply and is unstable.
- Beer outlet temperature is controllable and pressure inside the bottle becomes more stable later, so that the number of broken bottle became almost none and no beer lost. It means a big economical advantage.
- The final bath is forced to be cooled down that enables the use of 80 degree C hot water instead of steam. 80 degree C hot water is easily and abundantly available from waste heat recovery in a brewery plant. In the case of conventional pasteurizer, it is not possible maintain constant final temperature because of imbalanced heat caused by the supply of hot water.

In this plant, Green House Gas emission reduction of 3000 tons per year was achieved by implementing MVR, NH_3 Heat Pump for Pasteurizer and Biogas Boilers. Fuel reduction was 1200 tons per year and the payback period of initial investment was 2 years, good economic efficiency. Lao Brewery invested the whole installation and all of generated CER (Certified Emission Reduction) is transferred to Japan. Lao Brewery gets the benefit of the sale of credit.
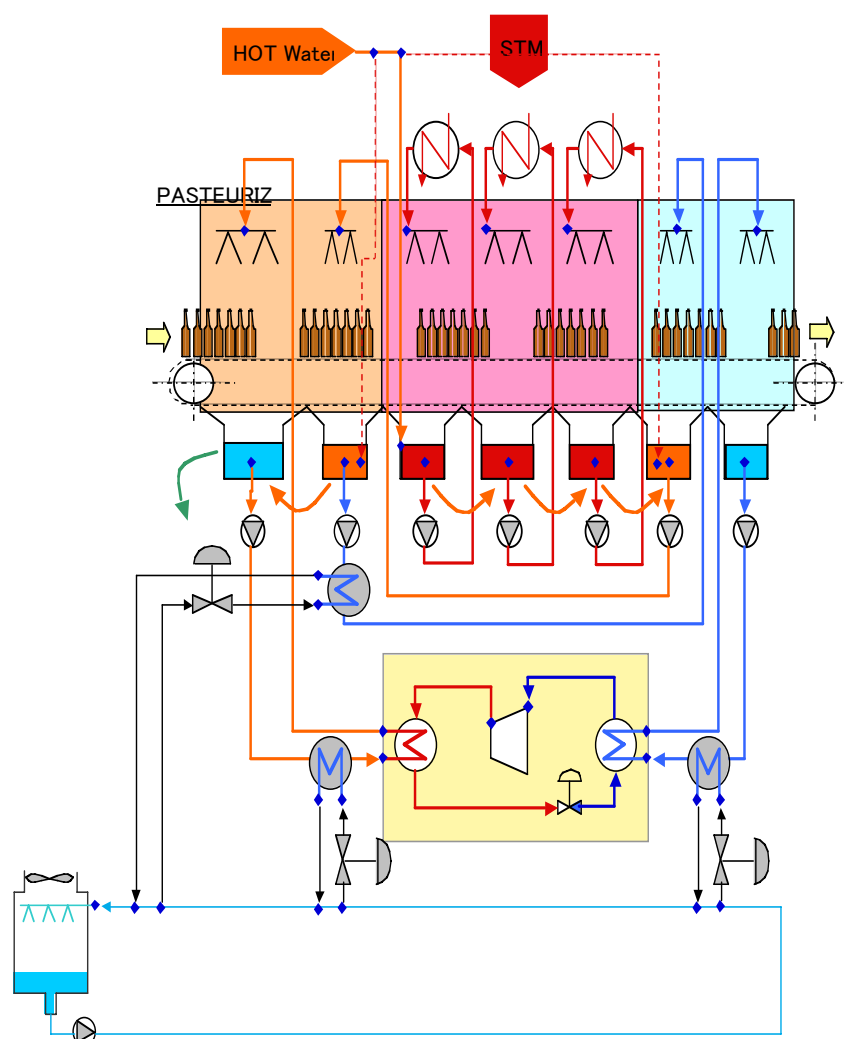

Figure 6 NH3 Heat Pump for Pasteurizer

5 CLOSING

40 years have already passed since Roma Club presented "Limitation of Growth". Energy crisis is becoming more realistic. Oil price has be regulated traditionally by political initiative rather than balance between demand and supply. It looks that increasing demand from developing countries with their economic growth is causing price increase.

The issue of global warming also becomes realistic. Energy conservation is a most realistic measure to solve these issues and the role of industrial heat pump becomes more important.

In order to disseminate industrial heat pump, it is most important to enhance its economic performance. The essence of industrial heat pump is its economic performance and high COP is required obviously.

As a measure to develop more economically efficient heat pump, I have pointed out following items based on the reference of brewery plants.

- Energy conserving activities as a cooperative work among production engineers, process engineers and heat pump engineers. In other words, economically efficient heat pumps can be produced after meeting requirements for product quality, production process improvement and application technology of heat pump.

- Economically efficient heat pumps can be produced by pursuing minimum temperature differential in order to achieve high COP.

- An effective utilization of heat pump can be realized by handling heat utilization in the entire plant.

As a tool to accelerate dissemination, I introduced "Virtual Factory" that can show the production process in a simple way. Such a common tool to analyze the process is required. It does not make sense to develop a heat pump with unnecessarily higher temperature differential. It is better to study the process and pursue minimum temperature differential in order to develop economically efficient heat pump.