VAPOR COMPRESSION HEAT PUMP USING LOW TEMPERATURE GEOTHERMAL WATER: A CASE STUDY OF NORTHERN THAILAND

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ABSTRACT

Experimental study on Vapor Compression Heat Pump (VCHP) is carried out with the aims to upgrade shallow depth and low temperature geothermal water to a higher temperature (at least 20 ˚C higher) suitable for use in drying facilities for agricultural products. Five working fluids, R-22 (Chlorodifluoromethane), R-290 (Propane), R-134a (1,1,1,2-Tetrafluoroethane), R-717 (Ammonia) and R-123 (2,2-Dichloro-1,1,1-trifluoroethane) have been considered and simulated. The simulation results showed that R-123 was the most suitable refrigerant for the heat pump due to its lower high-side pressure and highest coefficient of performance (COP). The R-123 VCHP is capable to upgrade supplied water temperature of 40^{O}C from the water-cooled condensers to hot water temperature of 80 ˚C.

Single stage VCHP using R123 as working fluid is equipped to a drying room of 3.3 x 4.8 x3.2 meters in dimension, at Huai Mak Liam hot spring area in Chiang Rai Province. The shallow depth well of 85 meters supplies water temperatures in and out of the heat pump as 50 ˚C and 47 ˚C, respectively. The coefficient of performance of drying room is 2.68 with the room temperature increases from 25 ˚C to 70 ˚C within 3 hours.

Keywords: Low Temperature Geothermal Water, Northern Thailand, Vapor Compression Heat Pump, Working Fluid

1.INTRODUCTION

The Department of Mineral Resources (www.dmr.go.th) reported that there are 112 hot springs in Thailand, most of them are found in the northern part of the country. Thermal water rises up from deep reservoir along steeply-dipping fractures and faults mixing with cool water and eventually exposes as the hot springs. Heat sources may be related to granite intrusion, friction along fault plane and volcanic eruption. In 2008, Chiang Mai University (CMU) assessed the potential of hot springs and classified them into three groups, i.e. high, moderate and low potential (Fig. 1). High-potential hot springs refers to those with surface water temperature higher than 80˚C and/or reservoir temperature higher than 150˚C. Moderate-potential hot springs refers to those with surface water temperature between 60-80˚C and/or reservoir temperature between 120-150˚C. Low-potential hot springs refers to those with surface water temperature between 40-60˚C and/or reservoir temperature lower than 120˚C. More than half of hot springs in Thailand are of low potential as energy source. The low-potential hot springs are usually used in direct-use application. Therefore, the Department of Alternative Energy Development and Efficiency (DEDE) provided support for Chiang Mai University to carry out a research project on the development of low potential hot springs for multi-purpose usage. The objective of the project is to promote job opportunity for local people, to increase value-added to agricultural products, and to achieve better living standard.

Northern Thailand has a wide variety of agricultural products including fruits (longan, lychee, etc.), vegetables (chili, bean, garlic, etc.) and agro-industry (coffee seed, tobacco, etc.), These products require drying system for curing to reduce moisture content and/or to preserve as dried fruits which will result in higher value added. Standard drying processes include solar dryers and electricity-powered drying facilities. The solar dryer has a drawback during the rainy season, while the electricity-powered drying facilities require higher investment cost. Hence, the idea of geothermal energy drying room may provide another alternative for cost saving. However, most of the hot springs scattering all over northern Thailand have low temperature, normally less than 60 ˚C. The temperature of drying facilities that is suitable for the agricultural products should be about 80 ˚C. The most appropriate technology is to increase the temperature of the low temperature hot spring about 20 ˚C using the heat pump concept.

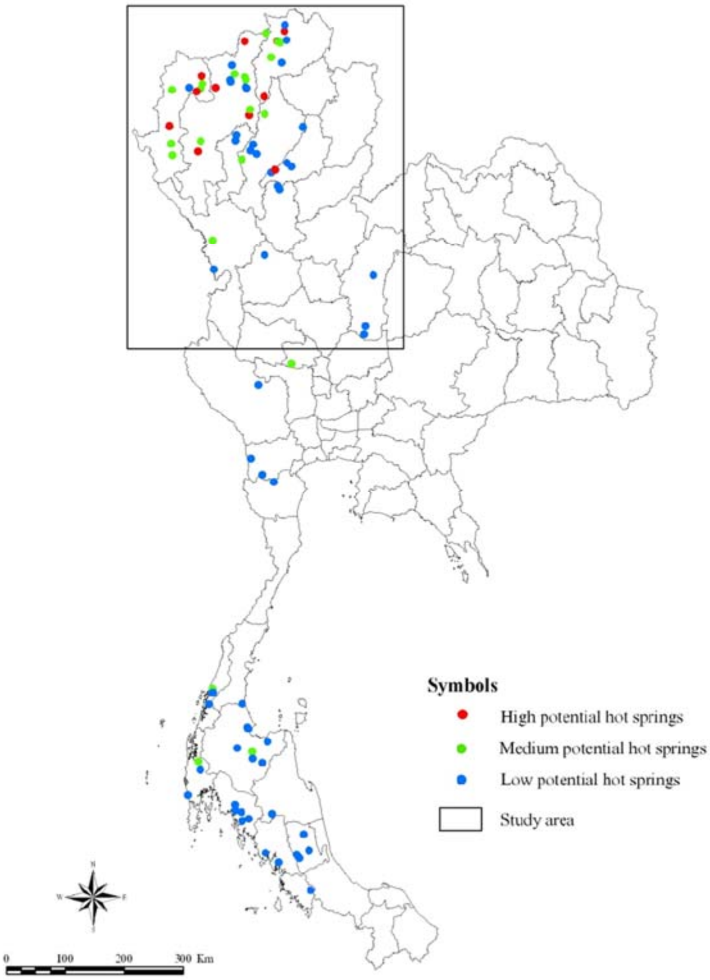


Fig. 1 Location map of hot springs in Thailand (CMU, 2008).

2. LOW POTENTIAL HOT SPRINGS SITE SELECTION

Of the 25 low potential hot springs in northern Thailand, 10 were initially selected based on geological settings, lineament pattern, water temperature at surface and flow rate, and geochemistry of hot water, which determine their potential for further development. Finally, the most appropriate hot spring to be developed as a source of water for geothermal drying room with heat pump system was selected based on (i) the availability of agricultural products all year round, (ii) the temperature used for drying not higher than 90 ˚C, and (iii) the space available for construction of the drying room. The final selection was made and the pilot project on geothermal drying room with heat pump system was carried out at Huai Mak Liam hot spring in Chiang Rai Province.

Detailed surveys on geology, hydrogeology, and geophysics (resistivity survey) were performed to identify the most suitable location for shallow well drilling. Down-the-hole hammer was used as a drilling method. Six-inch diameter casings were placed to the designed depth and cement grouting was injected around the casing. The well head was equipped with six-inch valve.

Based on the resistivity interpretation, the well LH1 was drilled at Huai Mak Liam hot spring in Chiang Rai Province (Fig. 2). Hot water was recovered from the depth of 19 m downward with a total depth of 85 m. Well temperatures range from 27.8˚C to 44.7˚C and the flow rate is about 10 m^3/hr. Logging information indicates that the rocks in the subsurface of Huai Mak Liam area were weathered granite 7.5 m depth, underlain by fresh granite with varying fracture density.

Fig. 2 Scenery of the hot spring area and hot water production well at Huai Mak Liam hot spring in Chiang Rai Province.

3. LABORATORY STUDY ON HEAT PUMP AND WORKING FLUIDS

Vapor compression heat pump (VCHP) is a standard method for upgrading low temperature heat to a higher temperature level. In a conventional VCHP, the low temperature heat is absorbed at the evaporator and the heat is delivered at the condenser at a higher temperature, as shown in Figure 3. Experimental study on VCHP with various kind of working fluids were performed to assess the suitable condition and appropriate working fluids to generate a hot water of 80-90 ˚C from a low temperature water of about 40-50˚C.

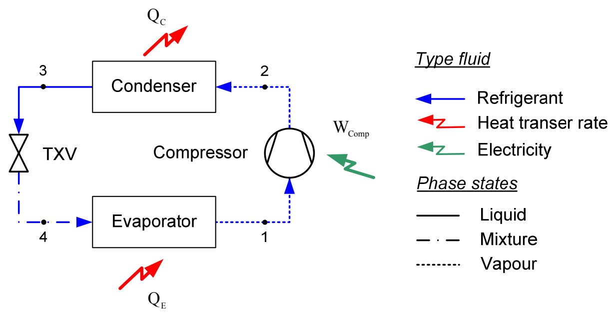


Fig. 3 A concept of a vapor compression heat pump for upgrading low temperature heat.

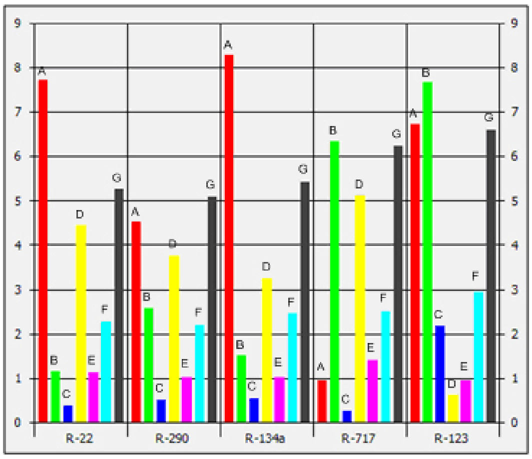
Five working fluids, R-22 (Chlorodifluoromethane), R-290 (Propane), R-134a (1,1,1,2-Tetrafluoroethane), R-717 (Ammonia) and R-123 (2,2-Dichloro-1,1,1-trifluoroethane) have been used in the simulation. Table 1 shows physical properties of the working fluids (NIST, 2000). The working conditions for the evaluation are:

- The VCHP evaporator temperature (T_{Er}) is at 40 ˚C.
- Total cooling capacity (Q_{Er}) is 10 kW.
- Required hot water temperature ($T_{HW,o}$) is 80-85 ˚C. (the VCHP condenser temperature (T_{Cr}) is at 90 ˚C.)
- No pressure drops at the VCHP condenser and the VCHP evaporator.
- Isentropic efficiency of compressor (η_{Comp}) is 80%.
- Degree of superheating (SH) is 5.0 ˚C.
- Degree of subcooling (SC) is 5.0 ˚C.
- The properties of working fluids are based upon REFPROP (NIST, 2000).

The indicators used to identify the appropriate working fluid are mass of refrigerant per unit heat output, volume flow rate of refrigerant, high-side pressure, refrigerant temperature at the compressor outlet, pressure ratio and heating COP. Figure 4 shows the results of the selected refrigerants. From the figure, it is clearly seen that R-123 gives the suitable refrigerant in terms of energy consumption for generating heat at about 80-85 ˚C due to its low maximum pressure for the heat pump compressor, and highest COP is obtained.

Table 1. Physical properties of working fluids.

Working Fluid	R-22	R-290	R-134a	R-717	R-123
Chemical formulae	$CHClF_2$	C_3H_8	CF_3CH_2F	NH_3	$CHCl_2CF_3$
Molecular mass (kg/kmol)	86.46	44.10	102.03	17.03	152.93
Critical temperature ˚C	96.14	96.68	101.06	132.25	183.68
Critical pressure (MPa)	4.99	4.25	4.06	11.33	3.66
Critical density (kg/m^3)	523.84	218.50	511.90	225.00	550.00
Boiling point ˚C	-40.81	-42.09	-26.07	-33.33	27.82
Latent heat of vaporization at 40 ˚C (kJ/kg)	164.24	302.30	160.88	1089.82	164.04
Flammability	NO	YES	NO	YES	NO
Toxicity	NO	NO	NO	YES	YES
ALT (Year, Atmosphere Life Time)	13.3	< 1	14	< 1	1.4
ODP (CO_2-related, Ozone Depletion Potential)	0.034	~0	0.0015	~0	0.02
GWP (100 Years, Global Warming Potential)	1780	0	1320	0	76



A) Mass of refrigerant per unit heat output, (g/kJ)
B) Vapor volume flow rate, (10-2 m^3/kg)
C) Displacement volume, (10 m^3/h)
D) Discharge pressure, (10 bar)
E) Discharge temperature, (102 °C)
F) Pressure ratio, (-)
G) COPhp, (-)

Fig. 4 The results for the selected refrigerants.

4. HEAT PUMP SYSTEM DESCRIPTION

The main components of VCHP are compressor, condenser, evaporator and expansion valve as shown in Figure 5. At the VCHP evaporator, the working fluid in liquid phase is boiled at a low pressure and temperature to be vapor. After that, the fluid in vapor phase is compressed in the compressor and the vapor condenses in the VCHP condenser at a high pressure and temperature to be liquid. The liquid is then throttled to a low pressure and the temperature drops down thus the fluid could absorbed low temperature heat at the VCHP evaporator again and the new cycle restarts.

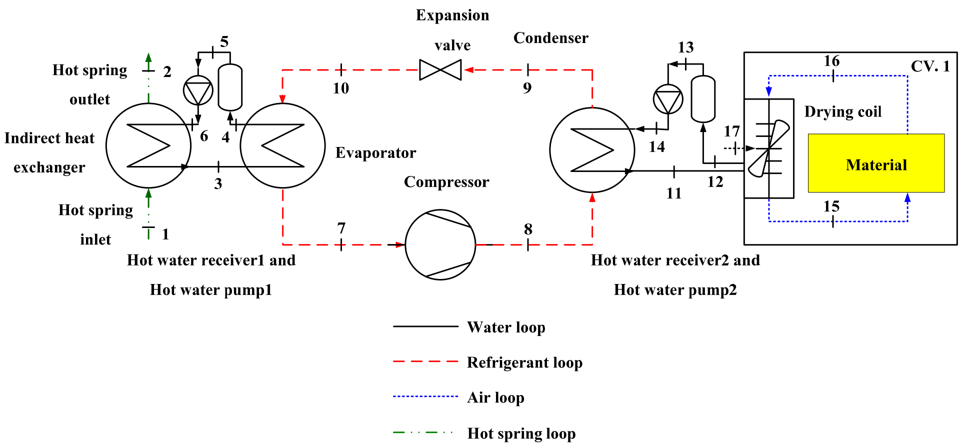


Fig. 5 Single diagram geothermal heat pump.

5. DRYING ROOM WITH A HEAT PUMP SYSTEM

Continuing research suggested that the most effective technology for the enhancement of low-temperature hot springs in Thailand is the heat pump system. The reasons supporting the suitability of system are as follows:

- Components of the system can be acquired at reasonable prices, and this technology is widely used in Thailand.
- Consist of a small number of separate components that can be easily maintained, and maintenance service is available in various parts of the country.
- Suitable to apply with hot springs of liquid nature, and the scales in the system can be easily removed.
- No adverse environmental impact.

The drying room was constructed with a dimension of 3.30m x 4.80m x 3.20m giving an intake capacity of about three tons (3,000 kg) of agricultural products. It generates room temperatures between 40 ˚C and 85 ˚C. The working steps of the drying room with heat pump system (Fig. 6 and Fig. 7) start with the hot water enters the system. The hot water transfers the heat to the working fluid, which evaporates accordingly. The resultant vapor is then pressurized by a compressor and sent into the heating coil in the drying room. The air inside the room is then heated by the heating coil. Efficiency test of the empty drying room showed that the room temperature increased from 25 ˚C to 70 ˚C within 3 hours. The coefficient of performance (COP) of drying room is 2.68 with the water temperature in and out of the system as 50 ˚C and 47 ˚C, respectively.

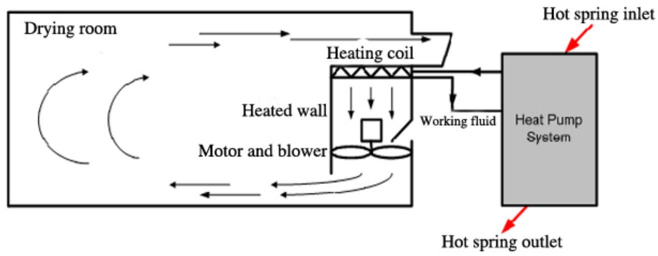


Fig. 6 Working steps of drying room with heat pump system.

Economic evaluation is also carried out with 15 sets of drying per month, 24 hours per drying set. At the time of assessment with the construction budget of about USD 25,000, the payback period is 16 months.

Fig. 7 Drying room with the heat pump system.

6. CONCLUSIONS

The concept of drying room with a heat pump system is the best direct-use of low temperature or low potential hot spring, especially in northern Thailand. The VCHP using R-123 as the working fluid can upgrade the hot water to 80 ˚C from 40 ˚C of the water-cooled condenser. The payback period is 16 months for the set of drying room with a heat pump system, excluding the cost of well drilling and pipe installation.

7. ACKNOWLEDGEMENTS

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