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– A REVIEW

AN INDUSTRIAL HEAT PUMP FOR STEAM AND FUEL SAVINGS

RAJNIKANT S. JADHAO[*] and TEJAY V. LANJEWAR

Department of Chemical Engineering, College of Engineering & Technology, AKOLA (M.S.) INDIA

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ABSTRACT

Currently many consumers in the India are facing with increasing shortages of electricity and petroleum gas. Prices have yet to stabilize and continue to increase as the shortages continue. What can then consumers do when facing with high heating bills and the need to stay warm and comfortable ? The answer to this may come from alternate heating systems. One such alternative to current heating systems is called a heat pump.

A heat pump is defined as an electrically driven device used to transfer heat energy from one location to another. A heat pump can be used as a heating unit, an air-conditioning unit or a water heater. Industrial heat pumps are a class of active heat-recovery equipment that allows the temperature of a waste-heat stream to be increased to a higher, more useful temperature. Consequently, heat pumps can facilitate energy savings, when conventional passive-heat recovery is not possible. The focus is on the most common applications, with guidelines for initial identification and evaluation of the opportunities being provided. Heat pump is a device that can increase the temperature of a waste-heat source to a temperature, where the waste heat becomes useful. The waste heat can then replace purchased energy and reduce energy costs. However, the increase in temperature is not achieved without cost. A heat pump requires an external mechanical- or thermal-energy source. The goal is to design a system in which the benefits of using the heat-pumped waste heat exceed the cost of driving the heat pump. Heat can be extracted from various sources such as cooling tower water or various heating sources.

Key words: Heat pump, Cooling tower water, Renewable source, Heat recovery.

INTRODUCTION

As the cost of energy continues to rise, it become imperative to save energy and improve overall energy efficiency. Improving heat pump performance, reliability, and its environmental impact has been an ongoing concern. Heat pump systems offer economical alternatives of recovering heat from different sources for use in various industrial, commercial and residential applications. At present regenerator, recuperator, economizer, waste heat boiler and thermoelectric generator are used as an alternative of heat pump. But the initial cost of heat pump is less and it is eco-friendly. In this light, the heat pump becomes a key component in an energy recovery system with great potential for energy saving. Improving heat pump performance, reliability, and its environmental impact has been an ongoing concern. Recent progresses in heat pump systems have centered upon advanced cycle designs for both heat- and work-actuated systems, improved cycle components (including choice of working fluid), and exploiting utilization in a wider range of

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Available online at www.sadgurupublications.com
[*]Author for correspondence; E-mail: rajjadhaochem@gmail.com

applications. For the heat pump to be an economical proposition, continuous efforts need to be devoted for improving its performance and reliability while discovering novel applications. Some recent research efforts have markedly improved the energy efficiency of heat pump. For example, the incorporation of a heat-driven ejector to the heat pump has improved system efficiency by more than 20%. Additionally, the development of better compressor technology has the potential to reduce energy consumption of heat pump systems by as much as 80%. The evolution of new hybrid systems has also enabled the heat pump toper form efficiently with wider applications. For example, incorporating a desiccant to a heat pump cycle allowed better humidity and temperature controls with achievable COP as high as 6. This review paper provides an update on recent developments in heat pump systems, and is intended to be a ‘‘one-stop” archive of known practical heat pump solutions.

EXPERIMENTAL

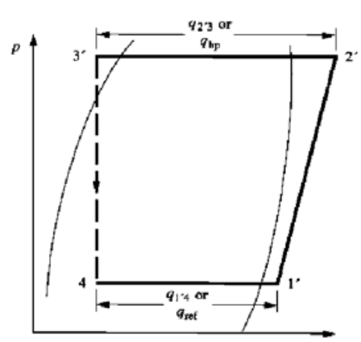
Heat pump

A heat pump is a self-contained, packaged cooling-and-heating unit with a reversible refrigeration cycle. A heat pump is basically a device that transfers heat from one substance to another substance. It has these same basic refrigeration components: compressor, condenser, evaporator, and expansion device. The difference is that it can also reverse the refrigeration cycle to perform heating, as well as cooling, by reversing the functions of the two heat exchangers. The operation of the refrigeration cycle changes depending on whether the unit is in cooling or heating mode. Heat pump is generally reserved for equipment that heats for beneficial purposes, rather than that which removes heat for cooling only. Dual-mode heat pumps alternately provide heating or cooling. Heats reclaim heat pumps provide heating only, or simultaneous heating and cooling. An applied heat pump requires competent field engineering for the specific application, in contrast to the use of a manufacturer-designed unitary product. Built-up heat pumps (field- or custom-assembled from components) and industrial process heat pumps are of two types.

Heat pump cycles

Most modern heat pumps use a vapor compression (modified Rankine) cycle or an absorption cycle. Although most heat pump compressors are powered by electric motors, limited use is also made of engine and turbine drives. Applied heat pump systems are most commonly used for heating and cooling buildings, but they are gaining popularity for efficient domestic and service water heating, pool heating, and industrial process heating. A heat pump cycle comprises the same processes and sequencing order as refrigeration cycle except that the refrigeration effect $q_{1'4}$ or q_{rf}, and the heat pump effect $q_{2'3'}$, both in J/Kg, are the useful effects.

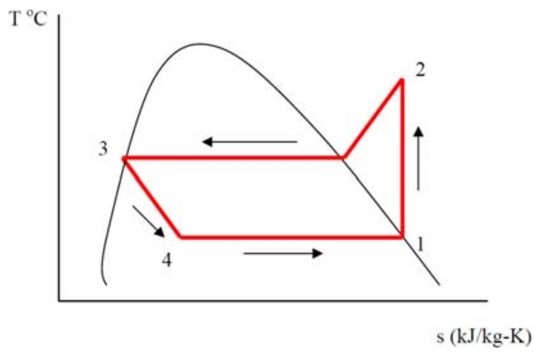
$$COP_{ref} = \frac{h_{1'} - h_4}{W} = \frac{q_{1'4}}{W_{in}}$$



$$COP_{hp} = \frac{q_{2'3'}}{W_{in}}$$

Vapor-compression refrigeration (VCR) cycle for refrigerators and heat pumps

VCR transfers heat from a low temperature reservoir to a high temperature reservoir with work input.



Characteristics

VCR cycle is comprised of three internally reversible processes.

One process is actually irreversible; however, the area enclosed by the process lines can be considered to approximately indicate the net heat transfer, and the first law for a cycle applies:

$$Q_{net} = W = Q_H + Q_L \qquad \ldots(1)$$

Where W is negative, Q_H is negative, Q_L is positive, and $|Q_H| > |Q_L|$.

Process analysis using the first law

	Process phases	Device	1st Law expression
1→2	Adiabatic and reversible (isentropic) compression input: Wcompressor Saturated vapor → Superheated vapor	Compressor	$-W_{compressor} = (h_2 - h_1)$
2→3	Isobaric compression q_H = Heat rejected to high temp. reservoir Superheated vapor → Saturated liquid	Condenser	$qH = (h_3 - h_2)$
3→4	Adiabatic expansion (Not isentropic: $S_3 \neq S_4$) Saturated liquid → Liquid-vapor mixture	Throttling valve	$h_4 = h_3$
4→1	Isothermal and isobaric expansion q_L = Heat input from low temp. reservoir Liquid-vapor mixture → Saturated vapor	Evaporator	$q_L = (h_1 - h_4)$

In general, the measure of VCR cycle performance is –

$$\text{Coefficient of performance (COP)} = \frac{\text{Desired heat transfer}}{\text{Required work input}}$$

For a refrigerator (air conditioner), desired heat transfer is cooling-transfer of heat to the evaporator from the low temperature reservoir.

$$COP_{HP} = \frac{\dot{Q}_H}{\dot{W}_{in}} = \frac{q_H}{w_{in}} = \frac{(h_2 - h_3)}{(h_2 - h_1)} = \frac{1}{\left(1 - \frac{\dot{Q}_L}{\dot{Q}_H}\right)} = \frac{1}{\left(1 - \frac{q_L}{q_H}\right)} = \frac{1}{\left(1 - \frac{(h_1 - h_4)}{(h_2 - h_3)}\right)} \quad ...(3)$$

For a heat pump, desired heat transfer is heating-transfer of heat from the condenser to the high temperature reservoir.

$$COP_{HP} = \frac{\dot{Q}_H}{\dot{W}_{in}} = \frac{q_H}{w_{in}} = \frac{(h_2 - h_3)}{(h_2 - h_1)} = \frac{1}{\left(1 - \frac{\dot{Q}_L}{\dot{Q}_H}\right)} = \frac{1}{\left(1 - \frac{q_L}{q_H}\right)} = \frac{1}{\left(1 - \frac{(h_1 - h_4)}{(h_2 - h_3)}\right)} \quad ...(4)$$

$COP_{HP} = COP_R + 1$ and therefore, $|q_H| > |q_L|$

Also the mass flow rate in the VCR cycle can be calculated using the relations:

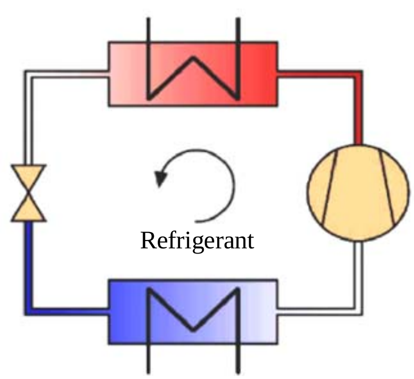
$$\dot{m} = \frac{\dot{Q}_H}{q_H} = \frac{\dot{Q}_H}{(h_3 - h_2)} = \frac{\dot{Q}_L}{q_L} = \frac{\dot{Q}_L}{(h_4 - h_1)} = \frac{\dot{Q}_L}{COP_R(h_2 - h_1)} = \frac{\dot{Q}_H}{COP_{HP}(h_2 - h_1)} \quad ...(5)$$

Where $q_H < 0$, $q_L > 0$, and $|q_L| < |q_H|$

Also, THTR is close to TLTR assuring that

$-\frac{q_H}{T_{HTR}}(\text{Positive}) > -\frac{q_L}{T_{LTR}}(\text{Negative})$ and Sgen > 0, making VCR cycle "Possible".

Working



Refrigerant enters the evaporator in the form of a cool, low-pressure mixture of liquid and vapor (I). Heat is transferred to the refrigerant from the relatively warm air or water to be cooled, causing the liquid refrigerant to boil. The resulting vapor (II) is then pumped from the evaporator by the compressor, which increases the pressure and temperature of the refrigerant vapor. The resulting hot, high-pressure refrigerant vapor (III) enters the condenser, where heat is transferred to ambient air or water, which is at a lower temperature. Inside the condenser, the refrigerant condenses into a liquid. This liquid refrigerant (IV) then flows from the condenser to the expansion device. The expansion device creates a pressure drop that reduces the pressure of the refrigerant to that of the evaporator. At this low pressure, a small portion of the refrigerant boils (or flashes), cooling the remaining liquid refrigerant to the desired evaporator temperature. The cool mixture of liquid and vapor refrigerant (I) travels to the evaporator to repeat the cycle.

Sources

Air: Outdoor air is a universal heat-source and heat-sink medium for heat pumps and is widely used in residential and light commercial systems. Extended-surface, forced-convection heat transfer coils transfer heat between the air and the refrigerant. Typically, the surface area of outdoor coils is 50 to 100% larger than that of indoor coils. The volume of outdoor air handled is also greater than the volume of indoor air handled by about the same percentage. During heating, the temperature of the evaporating refrigerant is generally 6 to 11 K less than the outdoor air temperature. Under very humid conditions, when small suspended water droplets are present in the air, the rate of frost deposit may be about three times as great as predicted from psychometric analysis.

Water: City water is seldom used because of cost and municipal restrictions. Groundwater (well water) is particularly attractive as a heat source because of its relatively high and nearly constant temperature. The water temperature is a function of source depth and climate. Frequently, sufficient water is available from wells for which the water can be re-injected into the aquifer. The use is non-consumptive and, with proper design, only the water temperature changes. The water quality should be analyzed, and the possibility of scale formation and corrosion should be considered.

Ground: The ground is used extensively as a heat source and sink, with heat transfer through buried coils. Soil composition, which varies widely from wet clay to sandy soil, has a predominant effect on thermal properties and expected overall performance. The heat transfer process in soil depends on transient heat flow. Thermal diffusivity is a dominant factor and is difficult to determine without local soil data. Thermal diffusivity is the ratio of thermal conductivity to the product of density and specific heat. The soil moisture content influences its thermal conductivity.

Solar energy

Solar energy may be used either as the primary heat source or in combination with other sources. Air, surface water, shallow groundwater, and shallow ground-source systems all use solar energy indirectly. Using solar energy directly as a heat source for heat pumps can provide heat at a higher temperature than the indirect sources, resulting in an increase in the heating coefficient of performance. Compared to solar heating without a heat pump, the collector efficiency and capacity are increased because a lower collector temperature is required.

The heat pump (HP) has evolved to become a mature technology over the past two decades. However, it is not applied as widely as it should or could be. Initial costs, system design and integration remain to be challenging problems, since few major vendor so refrigeration systems offer large-scale heat pumps. Efficient use of energy in such energy-intensive operations as district cooling/heating, drying and cogeneration is crucial to the reduction of net energy consumption and hence, emissions of greenhouse gases. Heat pumps offer one of the most practicable solutions to the greenhouse effect. It is the only known process that recirculates environmental and waste heat back into a heat production process; offering energy efficient and environmentally friendly heating and cooling in applications ranging from domestic and commercial buildings to process industries. Practical studies have shown the potential of heat pumps to drastically reduce greenhouse gases, in particular CO_2 emissions, in space heating and heat generation. The positive impact on environment depends on the type of heat pump and the energy-mix and efficiency of driving power used. One key approach to improving the energy efficiency of many industrial operations is to recover every possible sources of waste heat and turn them to useful outputs. To facilitate this approach, the

HP becomes a critical heat system as it possesses the capacity to recover thermal energy, otherwise exhausted to environment, and channel it to places, where this heat energy can be converted to produce useful outcomes such as producing hot water to provide heat to occupants in buildings or even for the noble purpose of desalination.

Novel application

Geothermal

A geothermal heat pump or ground-source heat pump (GSHP) is a central heating and/or cooling system that pumps heat to or from the ground to provide heating, air conditioning and, in most cases, hot water. They are ideally suited to tap the ubiquitous shallow geothermal resources. GSHPs include those in which heating/cooling coils are placed in horizontal and vertical configurations, under a building or parking lot as shown in Figure. Geothermal HP heating and cooling systems operate as follow: During winter period, they move the heat from the earth into buildings and pump the heat from buildings and discharge it into the ground during summer season. Studies have shown that approximately 70 percent of the energy used in a geothermal heat pump system is renewable energy from the ground. The earth's constant temperature is what makes geothermal heat pumps one of the most efficient, comfortable, and quiet heating and cooling technologies available today. Researchers have developed new mechanical compression heat pumps using organic fluids to upgrade the heat and increase the temperature to a level, which can run a thermochemical or hybrid cycle. Their heat pumps have demonstrated favourable efficiency in applications with a temperature difference of about 50^{o}C and where available constant heat source is available, as in the case of the ground-source. As a renewable energy technology, the GSHP's high energy efficiency and low environmental impact characteristics have already drawn a fair amount of attention in huge energy-consuming nation like China. GSHP can employ both the earth and buried underground water as potential heat sources/sinks.

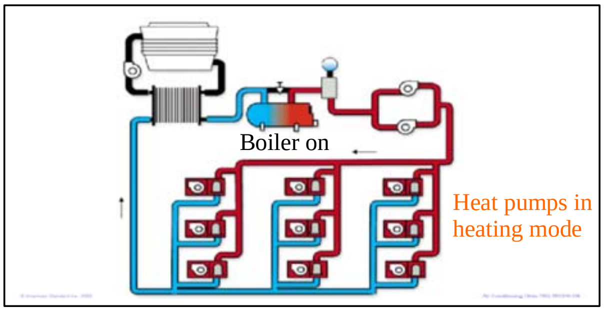
The water below the ground level can be the waste water from power plants (e.g. chemical, fossil fuel, etc.) to the wastewater treatment plant. The primary advantage of the GSHP technology is that the both the earth and water stream provides a relatively constant temperature for heat transfer, thereby, improving the energy efficiency (COP) over that of conventional air systems. Work has also been carried out to integrate ground-coupled heat pump (GCHP) system with a fluid cooler, a cooling tower or surface heat rejecters in cooling-dominated buildings. The operation principle of the GCHP system with a cooling tower involves the cooling tower being connected in series with the ground heat exchanger loop and is isolated from the building and ground loops with a plate heat exchanger. The ground loop is judiciously sized to meet the building heating load and the cooling load in excess of the heating load is met through the supplemental heat rejection. Recent studies have focused on the evaluating the effectiveness of GCHP for heating/cooling applications in buildings while resolving related technical problems. One devices for drying applications. The energy efficiency of HPD can be reflected by the higher SMER values and drying efficiency, when compared to other drying systems. Consequently, higher SMER would then be translated to lower operating cost, making the pay-back period for initial capital considerably shorter. The key advantages of the heat pump dryer[2]:

(i) Heat pump drying (HPD) offers one of the highest Specific Moisture Extraction Ratio (SMER), often in the range of 1.0-4.0, since heat can be recovered from the moisture-laden air;

(ii) Heat pump dryers can significantly improve product quality via drying at low temperatures. At low temperatures, the drying potential of the air can be maintained by further reduction of the air humidity.

With cooling tower and boiler

It can be used with the cooling tower and the boiler by using the heat pump with the boiler and the cooling tower, we can cut down the running cost of the cooling tower and boiler, so that we can save the lot of fuel.



Benifits of water to water heat pump

In the heat recovery mode, it saves energy by reducing the operating time of the cooling tower and boiler. Allowing different space temperature in many spaces with dissimilar cooling and heating requirements (each independently controlled space is served by its own heat pump and own thermostat), the same piece of equipment is used to provide both cooling and heating to the space. Even though a separate cooling tower and boiler may be included in the system, only one set of water pipes is required. This can reduce the system installation cost. A water-source heat pump system typically requires less mechanical floor space than centralized systems. This increases the rentable space and revenue in tenant-occupied buildings. If one heat pump fails and must be replaced, it does not affect the operation of the rest of the system.

RESULTS AND DISCUSSION

Comparison with boiler

Conventional steam boiler

Heat capacity 5,0 MW

Operating hours 7.000 h/a

Annual heat quantity for stem generation 35.000 MWh/a

Heat price = Fuel price x (Hs/Hi)/generation 5000 Rs/MWh

Annual steam costs 171500.00 Rs/a

Steam generation with Heat pump

Performance factor of the steam generation 2,8

Annual electricity generation for steam generation 12.500 MWh/a

Electricity price 8000 Rs./MWh

Annual steam costs 100000.00 Rs/MWh

Annual cost savings x 71500.00 Rs.

Net saving of 71500 Rs

System	Primary energy efficiency (%)	Specific CO_2 emissions (Kg CO_2/kWh heat)
Oil fired boiler	60-65	0.45-0.48
Gas fired boiler	70-80	0.26-0.31
Condensing gas boiler + Low temp. system	100	0.21
Electric heating (eff. 40%)[1]	36	0.90
Conventional electricity (eff. 40%)1 + GSHP	120[2] (160)[3]	0.27 (0.20)
Green electricity (100% eff.) + GSHP	300 (400)	0.00 (0.00)

Environmental benefits

Reduced carbon emissions by 2,484 tons annually reduced Buck's carbon footprint by 53% equivalent to: Taking 9,738 cars off the road not driving 5,620,159 miles every year potential for annual revenue stream in the form of "Carbon Credits" which, based on the current European Carbon Credit market, can have significant financial value (if a carbon credit system is implemented locally or nationally).

Advantages

(a) Improved energy efficiency

(b) Water is a better heat transfer medium

(c) Heat or cool on demand, during or after hours,

(d) Heats water economically

(e) Saves chemical treatment

(f) Reduces blow down & sewer charges

(g) Improves chiller efficiency

(h) Recovers waste heat

(i) Ecofriendly

Disadvantages

(a) Initial cost is more

(b) Creates noise pollution

(c) Water quality may decrease the efficiency

(d) Electricity is used

Application

(a) Hill stations

(b) Mass housing complex

(c) Swimming pool heating

(d) Process industry

(e) Laundry

(f) Dairy

(g) Poultry

(h) Slaughter house

(i) Boiler feed water

(j) Beverage

(k) Pharmaceutical

(l) Automobile/

(m) Auto Ancillary

(n) Food processing

And at all places, where hot water requirement is critical by using heat pump, we can save the environment as well as society.

CONCLUSION

As the there is constant increase in the price of the fuel, it is very necessary to save the low waste heat that can be used for various purposes, and that will also save the environment by reducing the CO_2 gas in the atmosphere that is responsible for the global warming. The effects of the global warming we have seen recently in Uttrakhand. By using heat pump, we can save lot of energy that will be beneficial for both human and the environment.

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