Water As A Refrigerant

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Abstract

Water is one of nature's most powerful refrigerant. Evaporating water at a rate of 1 L/h generates 695 W of cooling power. Compared to conventional vapor compression air conditioning technology, evaporative cooling technology reduces the electricity consumption and CO_2 emission rate by about 98%. Although evaporative cooling technology inherently requires water, in an indirect way, existing conventional air conditioning systems already consume significant amounts of water themselves.

1 Introduction

1.1 Company overview

Oxycom is a Dutch company specialized in the development and production of products and components for adiabatic cooling, indirect evaporative cooling, dew point cooling, air humidification and heat recovery.

Oxycom developed, engineered and manufactures the Oxycell Indirect Evaporative Heat Exchanger and the Oxyvap Direct Evaporative Cooling pad.

The Oxycell is the base of highly efficient all season fresh air systems that provide dew point cooling, indirect evaporative cooling, heat recovery and ventilation. The Oxyvap is the base of highly efficient cooling-only systems that provide direct evaporative cooling, humidification and ventilation.

1.2 Scope of the paper

Conventional air conditioning technology is used for cooling in residential, commercial and industrial systems worldwide. Although capable of achieving an efficiency, expressed in Coefficient of Performance (COP) or Energy Efficiency Ratio (EER), of over 100%, exponential growth of the cooling demand dramatically increases electricity consumption worldwide [1].

To be able to meet future cooling demand, many alternative sustainable technologies are emerging, of which evaporative cooling may be the most promising. This paper shows the power of water as a refrigerant and its modest environmental impact compared to conventional vapor compression air conditioning technology.

2 Refrigerants

2.1 Introduction

Refrigerants function as the working fluids in air conditioners, heat pumps and refrigeration systems by absorbing and releasing heat as they undergo continuous phase transitions between the gaseous state and the liquid state in a closed refrigeration cycle.

2.2 Common refrigerants

R-22 (a hydrochlorofluorocarbon or HCFC) has long been the most widely used refrigerant in air conditioning systems, but is increasingly being phased out because of its ozone-depleting behaviour [2]. Instead, chlorine-free replacements have gained popularity, most notably the following hydrofluorocarbons (HFCs):

- R-410A.
- R-407C.
- R-134a.

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2.3 Water

In conventional air conditioning systems, water is one of the many available refrigerants, having its own unique properties and refrigerant number (R718) [3]. Strictly speaking, evaporative cooling technology also uses water as a refrigerant, but instead of being evaporated and condensed in a closed-cycle system, it is continuously being evaporated.

Water is highly suitable for this purpose, as it is one of nature's most powerful refrigerant, with an exceptionally high latent heat of vaporisation (2501 kJ/kg at 0 °C) [4]. As such, evaporating water at a rate of 1 L/h generates 695 W of cooling power.

3 Cooling technologies

3.1 Introduction

Vapor compression air conditioning is one of many possible refrigeration cycles and is the most widely used technology for air conditioning, heat pump and refrigeration systems used for residential, commercial and industrial purposes.

3.2 Vapor compression air conditioning technology

Conventional vapor compression air conditioning systems consist of four main components through which the refrigerant is pumped in a closed cycle: [5]

- The compressor adiabatically compresses the gaseous refrigerant, hereby increasing its pressure and temperature.
- The condenser coil allows the gaseous refrigerant to condense to the liquid state at constant pressure, hereby releasing heat to its surroundings.
- The expansion valve causes the liquid refrigerant to expand, hereby lowering its pressure and temperature.
- The evaporator coil allows the liquid refrigerant to evaporate to the gaseous state at constant pressure, hereby absorbing heat from its surroundings.

3.3 Evaporative cooling

In evaporative cooling, a stream of unsaturated air is brought in direct contact with a wet surface. The boundary layer around the wet surface is naturally saturated with water vapor. As unsaturated air travels along the boundary layer, water vapor will diffuse into the airstream, driven by a difference in vapor concentration. The water vapor content in the boundary layer is then restored to its natural saturated state by the adiabatic evaporation of water. The required latent heat for the phase change of water is taken from the sensible heat of the airstream, resulting in a lower air temperature.

The lowest possible temperature that can be achieved is the wet bulb temperature of the intake air, but is in practice somewhat higher due to a limited efficiency. The saturation efficiency or wet bulb efficiency is defined as the ratio of the actually achieved temperature drop to the maximum possible temperature drop.

4 Generation of electricity and water

4.1 Electricity

There are various types of fuel available which power plants can use to generate electricity. In 2012, about 78% of the world's electricity production originated from the following sources: [6]

- Coal (40%).
- Natural gas (23%).
- Nuclear (11%).
- Oil (4%).

However, it strongly varies per region. The Middle East, for example, predominantly uses oil and natural gas, whereas about half of Europe's electricity production originates from coal and nuclear power; North America, Asia and Oceania use coal as the main fuel.

Power plants require water for the generation of electricity, where it is predominantly used for cooling [7], and also emit CO_2 [8].

Table 1 – Water consumption and CO_2 emission for electricity generation

Source	Water consumption [L/kWh]	CO_2 emission [kg/kWh]
Coal	2.91	0.97
Natural gas	2.31	0.55
Nuclear	3.16	0.02*
Oil	2.33	0.76

*Indirect CO_2 emission only [9].

4.2 Water

Water intended to be used in evaporative coolers should be of potable quality to prevent the risk on scale formation [10]. Various industrial processes can be used to desalinate seawater, such as:

- Multi-stage flash distillation (MSF).
- Multi-effect distillation (MED).
- Multi-effect distillation with thermal vapor compression (MED-TVC).
- Mechanical vapor compression (MVC).
- Reverse osmosis (RO).

Typically, and rather process-independent, desalination requires about 4 kWh of electrical energy per m^3 of water [11].

5 Comparison

5.1 Introduction

Evaporative cooling with an abritrary evaporation rate of 1 litre of water per hour has been chosen as the baseline. Comparative calculations have been performed for both technologies having equal cooling power, i.e. 695 W.

5.2 Evaporative cooling

- Evaporation rate: 1 L/h.
- Cooling power: 695 W.
- Electrical power consumption for the desalination of water: 4 W.
- CO_2 emission rate when using coal to generate electricity: 4 g/h.
- CO_2 emission rate when using natural gas to generate electricity: 2 g/h.
- CO_2 emission rate when using nuclear power to generate electricity: 0.08 g/h.
- CO_2 emission rate when using oil to generate electricity: 3 g/h.

5.3 Conventional air conditioning

- Cooling power: 695 W.
- Typical EER: 2.8 [12].
- Electrical power consumption: 250 W.
- Water consumption when using coal to generate electricity: 0.73 L/h.
- CO_2 emission rate when using coal to generate electricity: 243 g/h.
- Water consumption when using natural gas to generate electricity: 0.58 L/h.
- CO_2 emission rate when using natural gas to generate electricity: 138 g/h.
- Water consumption when using nuclear power to generate electricity: 0.79 L/h.
- CO_2 emission rate when using nuclear power to generate electricity: 5 g/h.
- Water consumption when using oil to generate electricity: 0.58 L/h.
- CO_2 emission rate when using oil to generate electricity: 189 g/h.

6 Summary

Table 2 – Results for coal

	Evaporative cooling	Conventional cooling
Cooling power	695 W	695 W
Electricity consumption	4 W	250 W
Water consumption	1 L/h	0.73 L/h
CO_2 emission rate	4 g/h	243 g/h

Table 3 – Results for natural gas

	Evaporative cooling	Conventional cooling
Cooling power	695 W	695 W
Electricity consumption	4 W	250 W
Water consumption	1 L/h	0.58 L/h
CO_2 emission rate	2 g/h	138 g/h

Table 4 — Results for nuclear power

	Evaporative cooling	Conventional cooling
Cooling power	695 W	695 W
Electricity consumption	4 W	250 W
Water consumption	1 L/h	0.79 L/h
CO_2 emission rate	0.08 g/h	5 g/h

Table 5 — Results for oil

	Evaporative cooling	Conventional cooling
Cooling power	695 W	695 W
Electricity consumption	4 W	250 W
Water consumption	1 L/h	0.58 L/h
CO_2 emission rate	3 g/h	189 g/h

7 Conclusion

- Using evaporative cooling technology instead of conventional vapor compression air conditioning technology reduces the electricity consumption and CO_2 emission by about 98%, virtually independent of the fuel source that has been used for the generation of electricity.
- Evaporative cooling technology inherently requires water to evaporate, but, although in an indirect way, existing conventional vapor compression air conditioning systems already consume significant amounts of water themselves. Therefore, increasing adoption of evaporative cooling technology will have less impact on the global water consumption than one may expect.

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