Application of gaseous fuels to heating and cooling

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Abstract: gas can realize heating and cooling by changing into thermal energy 、 mechanical energy and electric to drive heat pump、 gas turbine and electric cooler or heater, this paper analysis several ways of gas heating and cooling by energy exchange and primary energy ration , point out that should calculate the system synthesize prime energy ration as an important index to evaluate the system .

Keywords: gas heating and cooling; energy exchange; primary energy ration

Gaseous fuels include natural gas (NG), manufactured gas (MG), liquefied petroleum gas(LNG) and marsh gas , heating and cooling applications are presently limited to NG and LPG. In China , the use of electric cooling and gas heating has risen dramatically in recent years, which lead to the great peak-to-valley ration. Gas cooling can improve power load rate and make up gas consumption valley in summer[1]. It is reported that some gas companies have planned to charge by season , by then the summer user may enjoy more advantages. Gas can realize heating and cooling by the following ways:

1. Gas chemical energy ⇒ thermal energy ⇒ to heating and cooling

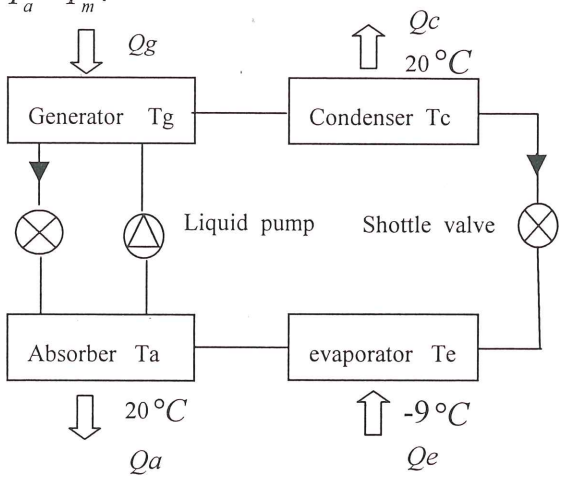
1.1 drive absorption heat pump

The gas absorption heat pump (GAHP) is illustrated in Fig.1, for ideal cycle , $T_c = T_a = T_m$ (the medium temperature). Energy addition to the system are the primary energy of gas Q_g and the liquid pump consumed energy W_p , because $W_p \ll Q_g$, we can ignore W_p . Since gas is the primary energy , the GAHP's max coefficient of heating $\varepsilon_{h,a}$ and coefficient of refrigeration $\varepsilon_{r,a}$ are equal to the primary energy ration (PER) $E_{h,a}$ 、 $E_{r,a}$:

$$E_{h,a}=\varepsilon_{h,a}=\frac{Q_c+Q_a}{Q_g}=\frac{T_m}{T_m-T_e}\cdot\frac{T_g-T_e}{T_g} \quad (1)$$

$$E_{r,a}=\varepsilon_{r,a}=\frac{Q_e}{Q_g}=\frac{T_e}{T_m-T_e}=\frac{T_g-T_m}{T_g} \quad (2)$$

The terms of T_c and T_a are condensation and absorption temperature. In ideal GAHP cycle $T_c = T_a$, since they are in the medium compared to evaporation temperature T_e and generation temperature T_g , so let $T_c = T_a = T_m$.



a: absorber ; c: condenser; e: evaporator; g: generator

Fig.1. absorption heat pump

Referred to the right part of Fig.2, in the same temperature range , the coefficient of performance (COP) of a compression counter Carnot cycle is always greater than GAHP's .

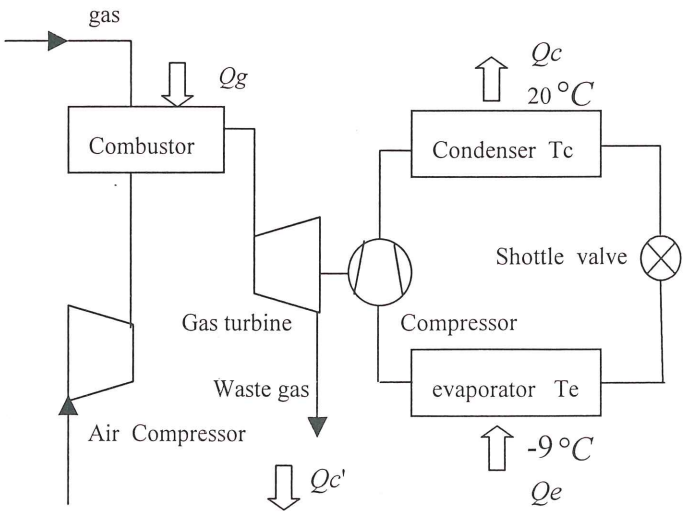


Fig.2. heat pump driven by gas turbine

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$$\varepsilon_{h,c}=\frac{T_m}{T_m-T_e}>\varepsilon_{h,a} \quad (3)$$

$$\varepsilon_{r,c}=\frac{T_e}{T_m-T_e}>\varepsilon_{r,a} \quad (4)$$

where $\varepsilon_{h,c}$, $\varepsilon_{r,c}$ are COP of counter Carnot cycle when heating and refrigeration.

However , the PER of this cycle are:

$$E_{h,c}=\varepsilon_{h,c}\cdot\eta=\frac{T_m}{T_m-T_e}\cdot\eta \quad (5)$$

$$E_{r,c}=\varepsilon_{r,c}\cdot\eta=\frac{T_e}{T_m-T_e}\cdot\eta \quad (6)$$

where $E_{h,c}$, $E_{r,c}$ are PER of the counter Carnot cycle when heating and refrigeration; η is product of power generation efficiency and power transmission efficiency. η is about 0.27 using coal to generate power and 0.46 for gas turbine.

As we know, heat transferred to the evaporator is from environment when heating .If take T_e =264K (−9℃), η =0.27, to satisfy :

$$E_{h,a}=\frac{T_m}{T_m-T_e}\cdot\frac{T_g-264}{T_g}>E_{h,c}=\frac{T_m}{T_m-T_e}\times 0.27$$

The heat source temperature T_g must be greater than 361.6 K (88.6 ℃).In other words ,If T_g > 361.6 K (88.6 ℃), the PER of ideal GAHP is greater than the electric power driven compression cycle's. When refrigeration, about the same , heat from the condenser enters environment .If take T_c = T_m = 306.2 K (33.2℃), to satisfy $E_{r,a}$ > $E_{r,c}$, T_g must be great than 419.5 K (146.5℃).

While η is 0.46, the following relationships are derived

if T_g >216℃, then $E_{h,a}>E_{h,c}$

if T_g >294℃, then $E_{r,a}>E_{r,c}$

For real GAHP, $E_{h,a}$ is greater than 1.0, and $E_{r,a}$ is 0.7, 1.1 for single and double-effect unit. It is reported that the new three-effect unit may reach 1.4~1.5. Of course, we should calculate the synthesize PER to evaluate the performance of a system if the surplus heat can be reclaimed. Without doubt, the PER will be greatly enhanced if GAHP operates with heating and cooling simultaneously. For example, provide cooling for building in Summer as well as heat for bathe or manufacture; In Winter provide heat for building, at the same time supply cold for manufacture.

1.2 Direct heating

1) district gas boiler plant: $E_h=\eta_b\cdot\eta_1\cdot\eta_2$

where : E_h is the primary energy ratio of a system when heating; η_b、η_1、η_2 is efficiency of the boiler、heat supply network and heat interchanger at the user.

2) centralized gas boiler plant: $E_h=\eta_b\cdot\eta_1$

3) direct-fired unit and gas-fired boiler、gas heater 、gas-fired infrared burner and so on ,which have no outdoor heat loss: $E_h=\eta_{\text{combustion}}$.

1.3 Electric heat pump whose condenser is heated by gas to enhance heating performance

$$E_h=\frac{Q_c}{\frac{W}{\eta}+Q_g}$$

2. Gas chemical energy ⇒ thermal ⇒ mechanical ⇒ to drive heat pump

2.1 heat pump driven by steam driven turbine

Referred to Fig.2 , gas-fired boiler produce vapor to drive turbine , then turbine drive heat pump to heating and cooling.

$$E_h=\frac{Q_c+Q_c'}{Q_g}=\frac{Q_c+Q_c'}{W}\cdot\eta_{tur} \quad (7)$$

$$E_r=\frac{Q_e}{Q_g}=\frac{Q_e}{W}\cdot\eta_{tur}=\varepsilon_r\cdot\eta_{tur} \quad (8)$$

2.2 direct combustion driven domestic heat pump

This is indicated in Fig.3. we can see that the obtained heat is the sum of gas primary energy consumed by liquid heater and evaporator absorbed heat from outdoor. E_r is the same as Eq. (8),and

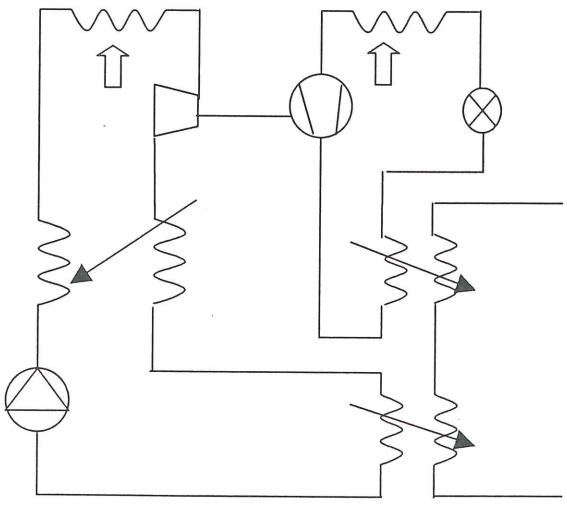

Fig.3. direct combustion driven domestic heat pump

$$E_h=\frac{Q_c+Q_c'}{Q_g}=\frac{Q_g+Q_e}{Q_g}=\frac{Q_c+Q_c'}{W}\cdot\eta_{tur}$$

E_h can reach 1.45 [2].

2.3 heat pump driven by gas engine

Gas engine can be categorized into either gas turbine (see Fig.2) or gas diesel engine

We also can use Eqs.(7), (8) to get the PER of this system, here η_{tur} is 0.37 to 0.42 and η_{diesdl} is o.25~0.45. In practical engineering situation , E_h is 0.9~1.0 and may be higher with heat reclaim by jacket cooling. If heating and cooling simultaneously, E_h can reach 1.74 [3].

3. Gas chemical energy ⇒ electric ⇒ to heating and cooling

1) As mentioned above , both gas engine and steam turbine driven by gas fired boiler can generate electric energy. Besides these, gas cell and turbine can also realize combined cycle power generation. Usually, combined cycle power in small has higher PER[4].

2) Electric can be used to heat directly by electric air heater, electric infrared heater etc. Provided we know the power generation efficiency and power transform efficiency, COP of electric heating and cooling, the use of surplus heat, the synthesize PER of the system can be obtained.

4. Conclusions

1) In many methods of gas heating and cooling, gas transformed to electric and then heat directly has the minimum PER. Next is gas direct combustion for heating, both of their PER is less than 1.0. Gas driven heat pump have higher PER and is beneficial to energy saving.

2) Heating and cooling simultaneously has the max PER and should consider first. A gas driven turbine can be combined with absorption chiller and heat excess boiler to realize combined cycle power generation in domestic district, which will enhance PER greatly. This may prove economically attractive to quite a wide range of users.

3) Should calculate the system synthesize PER as an important index to evaluate a system.

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