

The performance of different APG cycles has been numerically evaluated and compared based on the following assumptions.

- APG cycles were all operated at steady-state;
- The liquid solution at the outlet of condenser was at saturated state;
- Both the vapour and liquid from the separator were at saturated state;
- Throttling process did not change the enthalpy;
- The mixing process in the mixer was an adiabatic process;
- Pressure drop and heat loss in the system were both neglected.

### KCS-11

The basic working solution is pumped from  $P_L$  to  $P_H$ , the isentropic efficiency  $\eta_{\text{pump}}$  of the solution pump is

$$\eta_{\text{pump}} = \frac{h_{2s} - h_1}{h_2 - h_1} \quad (1)$$

where  $h_{2s}$  is the solution enthalpy at the pump outlet if the pumping process is isentropic, which can be determined by the state equation considering the basic solution at pressure  $P_H$  with an entropy value of  $s_1$ . The  $\eta_{\text{pump}}$  value is pre-defined as 0.85 in the present study, then  $h_2$  can be calculated by Eq. (1). The consumed pumping power is then calculated by the following equation.

$$\dot{W}_{\text{pump}} = \dot{m}_1(h_2 - h_1) \quad (2)$$

The heat-exchange process in the recuperator is governed by the following equations.

$$\dot{Q}_{\text{re}} = \Delta T_{\text{LMTD}} \cdot UA_{\text{re}} \quad (3)$$

$$\Delta T_{\text{LMTD}} = \frac{T_5 - T_3 - (T_8 - T_2)}{\ln \left( \frac{T_5 - T_3}{T_8 - T_2} \right)} \quad (4)$$

$$\dot{Q}_{\text{re}} = \dot{m}_2(h_3 - h_2) = \dot{m}_5(h_5 - h_8) \quad (5)$$

where  $\dot{Q}_{\text{re}}$  is the heat transfer rate,  $\Delta T_{\text{LMTD}}$  is logarithmic temperature difference,  $UA_{\text{re}}$  is the multiplicative product of heat transfer coefficient and heat transfer area of the recuperator.

The consumed boiling heat is calculated by Eq. (6).

$$\dot{Q}_{\text{boi}} = \dot{m}_3(h_4 - h_3) \quad (6)$$

In the separator, the mass flow rates of the liquid ( $\dot{m}_5$ ) and vapour ( $\dot{m}_6$ ) can be calculated through the mass balance equations in the separator as given by Eqs. (7) and (8).

$$\dot{m}_4 = \dot{m}_5 + \dot{m}_6 \quad (7)$$

$$\dot{m}_4 w_4 = \dot{m}_5 w_5 + \dot{m}_6 w_6 \quad (8)$$

The power output of the turbine by the vapour expansion process (6-7) is calculated by Eq. (9), while the isentropic efficiency of the turbine is in Eq. (10).

$$\dot{W}_{\text{tur}} = \dot{m}_6(h_6 - h_7) \quad (9)$$

$$\eta_{\text{tur}} = \frac{h_6 - h_7}{h_6 - h_{7s}} \quad (10)$$

where  $h_{7s}$  is the enthalpy at turbine outlet if the expansion process is isentropic and it can be determined by considering point 7 at pressure  $P_L$  with an entropy value equal to that of point 6 ( $s_6$ ).

The throttling process does not change the fluid enthalpy as expressed in Eq. (11).

$$h_8 = h_9 \quad (11)$$

The mass balance and energy balance equations in the mixer are described by Eqs. (12) to (14) and are used to determine the solution state at point 10.

$$\dot{m}_{10} = \dot{m}_7 + \dot{m}_9 \quad (12)$$

$$\dot{m}_{10} w_{10} = \dot{m}_7 w_7 + \dot{m}_9 w_9 \quad (13)$$

$$\dot{m}_{10} h_{10} = \dot{m}_7 h_7 + \dot{m}_9 h_9 \quad (14)$$

Finally, the energy and exergy efficiencies of the cycle can be evaluated by the following equations.

$$\eta_{\text{en}} = \frac{\dot{W}_{\text{tur}} - \dot{W}_{\text{pump}}}{\dot{Q}_{\text{boi}}} \quad (15)$$

$$\eta_{\text{ex}} = \frac{\dot{W}_{\text{tur}} - \dot{W}_{\text{pump}}}{\dot{Q}_{\text{boi}} \left(1 - \frac{T_{\text{amb}}}{T_{\text{boi}}}\right)} \quad (16)$$

### Double-effect APG cycle

This double-effect APG system can also use Eqs. (1) to (16) to solve each state point of the High-T and Low-T cycle; it additionally requires the thermal balance in the coupling component, i.e. the L-Boiler/H-Condenser, as expressed in Eq. (17).

$$\dot{m}_{20}(h_{20} - h_{11}) = \dot{m}_3(h_4 - h_3) \quad (17)$$

### Half-effect APG cycle

A rectifier as illustrated in Fig. 6 must be used instead of a separator to enlarge the mass fraction of ammonia-water vapour from the L-Boiler, leading to the mass balance described as Eqs. (18) to (20).

$$\dot{m}_{4v} = \dot{m}_{6l} + \dot{m}_6 \quad (18)$$

$$\dot{m}_{4v}w_{4v} = \dot{m}_{6l}w_{6l} + \dot{m}_6w_6 \quad (19)$$

$$\dot{m}_4w_4 = \dot{m}_{4v}w_{4v} + (\dot{m}_4 - \dot{m}_{4v})w_{4l} \quad (20)$$

where the subscripts *v* and *l* indicate the vapour phase and liquid phase, respectively. Further, the energy balance within the rectifier is expressed as Eq. (21), where  $\dot{Q}_{\text{rec}}$  is the condensation heat released by rectification.

$$\dot{m}_{4v}h_{4v} = \dot{m}_{6l}h_{6l} + \dot{m}_6h_6 + \dot{Q}_{\text{rec}} \quad (21)$$

### Ejector-combined APG cycle

The analysis of the ejector as schematised in Fig. 9 was based on the following assumptions

- The properties and velocities were constant over the cross section of the ejector therefore the analysis was one-dimensional;
- The working fluid was in thermodynamic quasi-equilibrium all the time;
- Viscous pressure drop inside the ejector was negligible;
- The flow velocities outside the ejector in the cycle were negligible compared to the velocities within the ejector;

- Constant pressure in the mixing section was assumed, which should be lower than the pressure of the secondary flow;
- The deviation of the ejection process from the isentropic process could be expressed in terms of non-isentropic efficiencies.

In the suction section, the energy balance equations for the primary and secondary fluid flows are

$$h_8 = h_b + \frac{V_b^2}{2} \quad (22)$$

$$h_7 = h_a + \frac{V_a^2}{2} \quad (23)$$

The efficiency of the nozzle,  $\eta_n$ , and the efficiency of the suction of the secondary fluid,  $\eta_s$ , are given as Eq. (24) and Eq. (25), which are set as 0.75 and 0.9, respectively according to the literature [26-27].

$$\eta_n = \frac{h_b - h_8}{h_{bs} - h_8} \quad (24)$$

$$\eta_s = \frac{h_a - h_7}{h_{as} - h_7} \quad (25)$$

where  $h_{as}$  and  $h_{bs}$  are the enthalpies at points a and b, respectively in isentropic processes, and they can be calculated based on the pre-defined pressure at mixing section,  $P_c$  ( $P_a = P_b = P_c$ ), and the entropies at points 7 and 8.

In the mixing section, the velocity and enthalpy at point c,  $V_c$  and  $h_c$ , can be determined through the momentum and energy balance equations as Eqs. (26) to (27).

$$(\dot{m}_7 + \dot{m}_8)V_c = \dot{m}_7V_a + \dot{m}_8V_b \quad (26)$$

$$(\dot{m}_7 + \dot{m}_8)\left(h_c + \frac{V_c^2}{2}\right) = \dot{m}_7h_7 + \dot{m}_8h_8 \quad (27)$$

The energy balance equation of the diffusion process is given as Eq. (28).

$$h_9 = h_c + \frac{V_c^2}{2} \quad (28)$$

Once the enthalpy value at point 9 is identified, the isentropic enthalpy at point 9,  $h_{9s}$ , can be calculated by the Eq. (29) based on the pre-defined diffusion efficiency,  $\eta_d$ , at 0.9 [26-27].

$$\eta_d = \frac{h_{9s} - h_c}{h_9 - h_c} \quad (29)$$

Finally the pressure at point 9, i.e. the  $P_M$  in this APG cycle, can be determined by  $h_{9s}$  and the entropy at point c.