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Research on Cascading Use of Waste Heat Technical Program in Heavy Oil Exploitation by SAGD Technology

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Abstract

In Du 84 block Shu 1 area in Liaohe oilfield where used SAGD technology to exploit heavy oil, the temperature of wellhead produced fluid can reach up to 170-180℃, In view of this problem of wasting large amount of thermal energy, this paper proposes a set of technical program of cascading use of waste heat with the combination of generation of electrical energy and heating. Meanwhile, the generating capacity and heating area of the program as well as its economic efficiency are also calculated and analyzed. In addition, the parameters of generating system's condenser are optimized by taking the annual total cost of the condenser as the objective function and using majorized function fminsearch in MATLAB software, and the most superior technical parameters are determined. The result can offer some reference in using of waste heat in practical project.

Keywords:low temperature waste heat; Rankine cycle; condenser; heating

1.Introduction

At present, the highest energy utilization efficiency country is Japanese (57%), the second is American (51%), the third is Western Europe Economic Community (more than 40%). But in China, according to incomplete statistics, the energy utilization efficiency is only about 30%, the others turn into waste heat to be discharged. This shows that the waste heat recovery and utilization is one of the important parts of energy saving work. Although the energy utilization efficiency in the world is different, the departments with most energy consumption and largest waste heat are basically same. They are the industry systems (steel, cement, petrochemical, building materials, etc.). China is rich in waster heat resources, especially in oil industry. Taking Du 84 block Shu 1 area in Liaohe oilfield as an example, Since 2005, it has used of Steam Assisted Gravity Draining(in short SAGD)technology to exploit heavy oil[1]. In injection stage, when the mixture is drawn out from the horizontal wells, wellhead outlet pressure>0.5MPa, outlet temperature reaches up to 170~180℃ and single well liquid production is 350~400t/d.he total liquid

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production of a project group with 40 wells is150150t/d, with water content 74%.[1] For the high temperature produced fluid, the majority of waste heat has not been utilized because heat demand of the oilfield itself is limited and large-scale of heating and cooling are difficult due to the distance of oil production sites from the urban areas.

In order to effectively recover and use the remaining heat, improve the overall economic benefits of steam flooding, this paper proposes a cascading use of waster heat technical program, calculates and analyzes generating capacity, the heating area and the economic efficiency of this plan. In addition, by using MATLAB software, this paper analysis the influence of heat exchange tube diameter and cooling water flow rate of power system condenser on its heat transfer area and pressure drop, and then optimize the condenser's parameter through taking the annual total cost of the condenser as the objective function and using Majorized function fminsearch.

2.The Propose Waste Heat Utilization Program

Du 84 block Shu 1 area in Liaohe oilfield uses SAGD technology to exploit heavy oil, causing large residual heat wasted. According to this case, considering its waste heat utilization probability and geographic characteristics, this paper proposes a set of cascading use of waste heat techn-
ocal program with the combination of waste heat electric-
ity generation and heating. The program theory figure is shown as Fig.1.

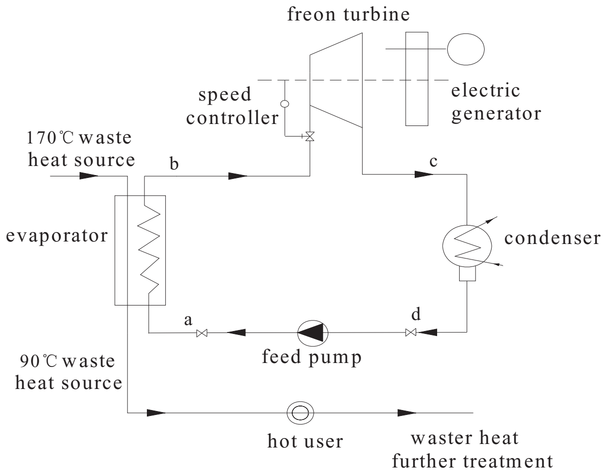

Fig.1 The program theory figure of low-temperature waste heat utilization

In the evaporator R134a refrigerant exchanges heat with heat source which is 170℃, being preheated and vaporized by heat flow, and then changes into superheated steam (a-b).The superheated steam enters into steam turbine and expand (b-c). The vapor which is discharged from the turbine is cooled by circulating water in condenser (c-d), and becomes liquid. After that, liquid R134a is delivered to the evaporator by refrigerant pump (d-a).The loop acts like this.

3.Calculation of the Parameters of Rankine Cycle Power Generation System

The heat source temperature is 170 ℃ and the cooling water inlet temperature is 18 ℃ in the Rankine

1 General Program of Heilongjiang Provincial Education Department (11541001)

cycle power generation system. Based on the formula $T_G = \sqrt{T_{R1}T_{20}}$ and $T_{20} = T_{L1} + \delta T + \Delta T_L$, the optimum evaporation temperature is 58 ℃, and the condensing temperature is 28 ℃. Then efficiency of the Rankine cycle low-temperature waste heat power generation system is expressed as:

$$\eta = \frac{h_b - h_c - (h_a - h_d)}{h_b - h_a} \approx \frac{h_b - h_c}{h_b - h_a} \quad (1)$$

The status values of Refrigerant R134a are obtained by look-up, so the Rankine cycle efficiency is 8.7%.

3.1.Thermal calculation of steam turbine parameters

according to the intake and exhaust parameters of steam turbine, the R134a thermodynamic properties parameters are shown as follows:

Inlet enthalpy: $h_j = 426.63\text{kJ/kg}$;

Theoretical exhaust enthalpy: $h_{20} = 413.84\text{kJ/kg}$;

Ideal enthalpy loss: $h_0 = h_j - h_{20} = 12.97\text{kJ/kg}$;

The nozzle outlet theoretical flow rate:

$$c_{10} = \sqrt{2(h_j - h_{20})} = 161\text{m/s}$$

Based on the velocity triangle, leaves intake rate and absolute export rate are computed. Their values are as follows: $\omega_1 = 93.3\text{m/s}$ and $c_2 = 46.7\text{m/s}$. The loss of steam turbine consists of nozzle loss, leaf loss and over-speed loss. The turbine loss, the relative internal efficiency and the internal power of steam turbine are obtained by the formula(2) (3) (4).

$$\begin{aligned} h_s &= h_p + h_l + h_y \\ &= \frac{4.186c_{10}^2}{8380}(1-\varphi^2) + \frac{4.186\omega_1^2}{8380}(1-\varphi^2) \\ &+ \frac{4.186c_2^2}{8380} \end{aligned} \quad (2)$$

$$\eta_{ot} = \frac{h_0 - (h_p + h_l + h_y)}{h_0} \quad (3)$$

$$N_i = Gh_0\eta_{ot} \quad (4)$$

According to calculation, we know that: the steam turbine loss is 3.11kJ/kg; the relative internal efficiency is 0.76; the internal power value is 45.88kW. Assuming steam turbine mechanical efficiency to be 0.95 and generator efficiency to be 0.9, the steam turbine electric power is calculated to be 39.22 kW.

In our program, a project contains 40 well group, and the total liquid production is 150150t/d. Then the total daily power generation capacity researches up 43679kW. About 22,000 Yuan cost can also be saved in oil fields itself.

3.2.Design and calculation of condenser structural parameters

Among the waste heat recovery methods of the SAGD technology exploiting heavy oil area, the Organic Rankine Cycle (ORC) system is a favorite result with good mobility, high security and low maintenance requirements. Evaporator and condenser are the key components of the ORC system, so the condenser model selecting right or not directly affects the quality of the system model[2-3]. This paper devises a horizontal shell and tube condenser condensing R134 steam with absolute pressure 0.73MPa, flow 17210kg/h. In the past, horizontal shell and tube condenser is usually calculated by successive approximation method, which is relatively more complicated. Furthermore, its heat flux is the entire heat exchanger average heat flux and the wall temperature is the heat exchanger average wall temperature. Due to above reasons, the method has some error. By using MATLAB software, this paper calculates and optimizes the condenser structure parameters. Fig.2 shows the design flow chart of the structure parameters of shell and tube heat exchanger.

- *Heat transfer area determination*

When the heat transfer coefficient is calculated based on inner surface tube basis, Condenser heat transfer area calculation is shown as formula (5).

$$F = \frac{Q}{K_i \Delta t_d} = \frac{Q}{\Delta t_d} \left(\begin{array}{l} \frac{1}{h_i} + r_{si} + \frac{\delta_w}{\lambda_w}\left(\frac{d_i}{d_m}\right) + \\ r_{so}\left(\frac{d_i}{d_o}\right) + \frac{1}{h_o}\left(\frac{d_i}{d_o}\right) \end{array} \right) \quad (5)$$

Where:

r_{si} —Fouling resistance in the inner wall, $m^2 \cdot ℃/W$; r_{so} —Fouling resistance in the outer wall, $m^2 \cdot ℃/W$;

δ_w —Wall thickness, m;

λ_w —Pipe thermal conductivity, W/(m·K);

d_m —The average diameter of pipe,

$d_m = \frac{d_o - d_i}{\ln(d_o / d_i)}$, m.

In which, the heat transfer coefficient of cooling water and the wall is calculated as formula (6).

$$h_i = 0.023\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.4}\,\lambda/d_{in} \quad (6)$$

Shell pass heat transfer coefficient is calculated as formula (7).

$$h_o = 0.729\left[\frac{\lambda^3 \rho^2 g \gamma}{\mu d_o (t_s - t_w)}\right]^{\frac{1}{4}} N_m^{-0.25} \quad (7)$$

Where: $N_m = \left(\frac{n_1 + n_2 + \ldots + n_m}{n_1^{0.75} + n_2^{0.75} + \ldots + n_m^{0.75}}\right)^4$

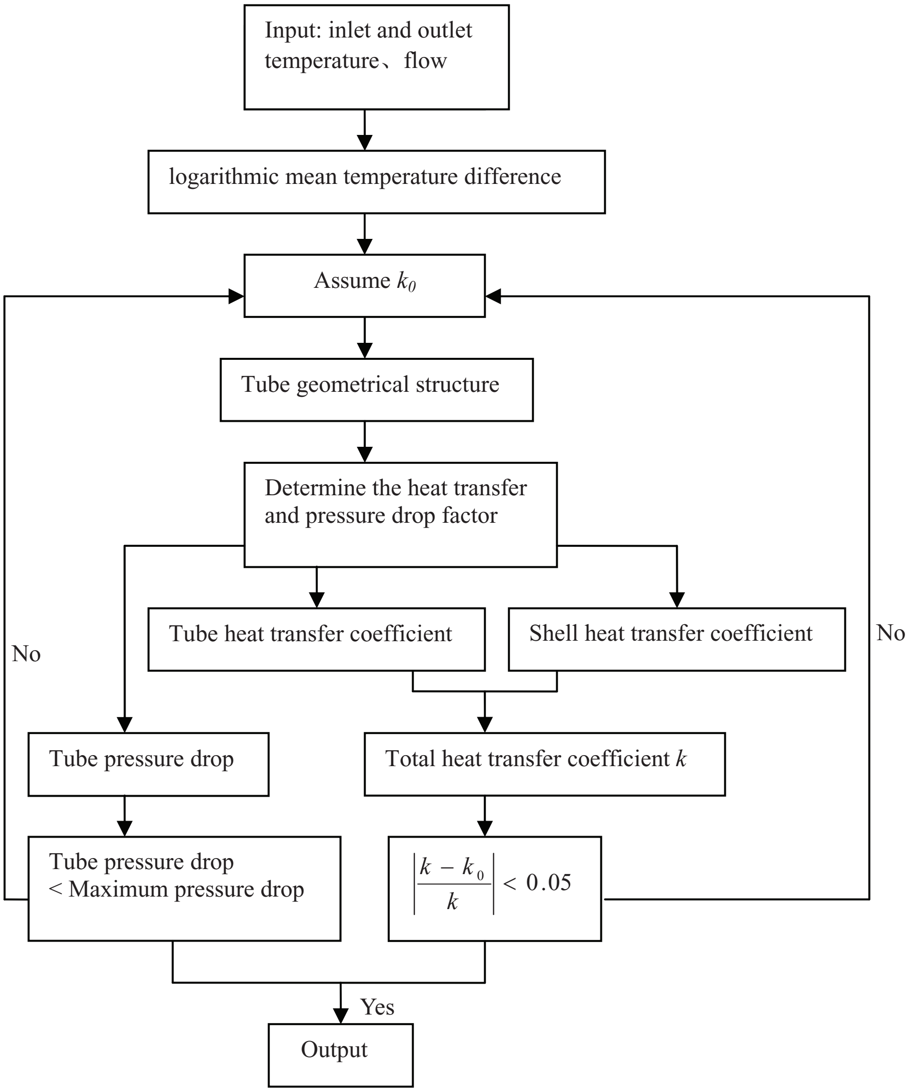

Fig.2 The design flow chart of structure parameters of shell and tube heat exchanger.

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$n_1 \ldots\ n_m$ is the pipe number of layers

- *The Pressure Drop Calculation*

Condenser pressure drop caused by flow resistance is an important indicator to measure the running economic effects. Tube and shell pressure drops of the shell and tube heat exchanger are calculated separately. The shell pressure drop is much smaller than the tube pressure drop, so the pressure drop of the shell is ignored. Tube pressure drop includes the pressure drop along way, the back drop pressure drop and import and export connecting pipe pressure drop[4].

$$\Delta P_t = \Delta P_i + \Delta P_r + \Delta P_n = 4 f_{\mathrm{i}} \frac{L}{d_i} \frac{\rho v_t^2}{2} \phi_i + 4 \frac{\rho v_t^2}{2} Z_t + 1.5 \frac{\rho v_t^2}{2} \tag{8}$$

Where:

f_i—Fanning friction coefficient;

L—The tube overall length, m;

d_i—Pipe inner diameter, m;

v_t—Flow velocity in pipe, m/s;

Z_t—The tube number.

ϕ_i—Tube fluid viscosity correction factor，

when Re>2100， $\phi_i = (\mu / \mu_w)^{-0.14}$,

Re<2100， $\phi_i = (\mu / \mu_w)^{-0.25}$.

a) The Total annual costs Calculation

The condenser annual fixed costs are calculated by formula (9) [5].

$$W_1 = AF\eta \tag{9}$$

Where:

η—The annual depreciation rate, 1/y;

A—Investment costs of unit heat transfer area, yuan/ m^2;

F—heat transfer area, m^2.

The condenser annual operating costs like this.

$$W_2 = \frac{BM\tau}{1000} + \frac{M\Delta P\tau}{1000\eta} s \tag{10}$$

Where:

B—the a unit mass of cooling water cost, Yuan/t;

M—Amount of cooling water, kg/h;

τ—Running time of year, h;

ΔP—pressure drop, Pa;

s—electric bill, Yuan/ (kW·h).

The total cost of the condenser like this.

$$W = W_1 + W_2 = AF\eta + \frac{BM\tau}{1000} + \frac{M\Delta P\tau}{1000\eta} s \tag{11}$$

Put the expression (5) and (8) into equation (11), then we know that the total cost of heat exchanger is only a function of diameter and flow. When W is the minimal value, the corresponding diameter and flow rate are the optimal diameter and flow.

b) Parameter optimization results

R134a (28℃) vapor discharged from the steam turbine is cooled to be liquid in condenser. Cooling water initial temperature is 18 ℃. The investment costs of condenser unit heat transfer area is 800yuan; the annual depreciation rate is 15 %; the condenser running time of a year is 7900h; a unit mass of cooling water cost is 0.1yuan/t; charges of electricity is 0.5Yuan/ (kW·h).

A MATLAB program is compiled to calculate the shell and tube heat exchanger structure parameter, in which LMTD is used to calculate logarithmic temperature difference, Water properties are used to calculate the 0 to 100 ℃the cooling water physical parameters.

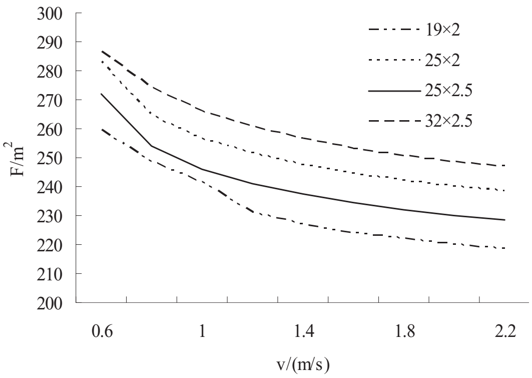

Figure.3 The influence of velocity on heat transfer area in different diameters

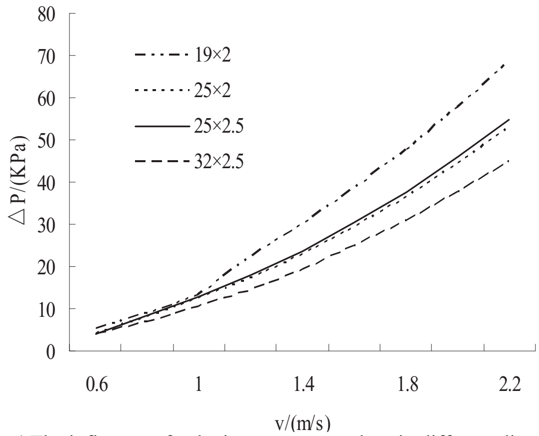

Figure.4 The influence of velocity on pressure drop in different diameters

From the chart 3 and chart 4, we know: condenser heat transfer area of different diameters decreases with the increasing velocity value; Pressure Drop increases with the increasing velocity value. When velocity remains unchanged, heat transfer area increases with the increasing pipe inner diameter value. Pressure Drop decreases with the increasing pipe inner diameter value. Under different velocity， condenser with 32 × 2.5 (mm × mm) pipe diameter has the largest heat transfer area and the smallest pressure drop; Condenser with 19 × 2 (mm × mm) pipe diameter has the smallest heat transfer area and the largest pressure drop. Taking the annual total cost of the condenser as the objective function, using MATLAB optimization function fminsearch () to optimize the velocity and diameter. Function Area (), pressure loss () are used to calculate heat transfer area and pressure drop based on equation (5), (8). According to known conditions, the parameter is optimized. The optimization results are shown in Table 1.

TABLE 1 THE CONDENSER OPTIMIZATION RESULTS

Parameter	**Optimal value**
Diameter (mm×mm)	19×2
Velocity (m/s)	0.899
Heat transfer area (m^2)	244.72
Pressure drop (kPa)	10.97

The total cost (yuan)	31636.4

4.Secondary Heat Heating Feasibility and Benefit Analysis

After the exchange heat with R134a, waste hot water is exhausted with 90℃, so it can still be used as district heating and domestic hot water heat source. In some areas, there are 90,000 square meters buildings need to be heated. When the heating network unit energy consumption is assumed to be 272kJ/m^2·h, the 90,000 square meters heating area requires 2.45 × 107kJ. In Du 84 block Shu 1 area in Liaohe oilfield, waste hot water after the first use as power generation resource can be 323t/h with temperature 90℃. If these water are used for heating with 90℃ of discharge temperature, the total energy is 2.58 × 10^7kJ. It can replace others heat source to meet architectural complex demand.

In the second heating program, 8 sets of steam boiler and 1,500 small coal stoves are replaced, saving 8,062 tons of coal, 282500 degrees of electricity power, 90 man labor and 230,000 yuan of funds with a environmental friend way.

5.Conclusions

- In the SAGD technology exploits heavy oil area, a set of cascading use of waste heat technical program (combined with Rankine cycle power generation and heating) is put forward in this article.
- Du 84 block Shu 1 area in Liaohe oilfield, has 40 well group, with the total liquid production 150150t/d, then the total daily capacity researches up 43679kW by calculation. About 22,000 Yuan cost can be saved if the capacity used in oil fields themselves.
- By using MATLAB software, the influence of diameter and flow rate on the condenser heat transfer area and pressure drop is analyzed. The result shows that: Condenser heat transfer area of different diameters decreases with the increasing velocity value, Pressure Drop increases with the increasing velocity value; In addition, the most optimal condenser parameters and total cost are obtained by using MATLAB optimization functions.
- Waste heat after the first use as power generation resource can still be utilized as a resource for heating and domestic hot water. In our heating program, 9 sets of steam boiler, 1,500 small coal stoves and 230,000 yuan can be replaced.

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