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HEAT PUMPS COMPLEX FOR RECYCLING OF SECONDARY ENERGY RESOURCES OF PETROCHEMICAL PLANTS

M.A. Taimarov[1], V.K. Ilyin[1], A.L. Osipov[1], A.N. Dolgova[1,2], A.V. Akhmerov[1]
[1]Kazan State Power Engineering University, Kazan, Russia
[2]Rostov State Transport University, Rostov-on-Don, Russia

Abstract: *The created heat pump complex allows one to simultaneously utilize different types of secondary energy resources of petrochemical industries. For the developed heat pump complex the main potential for the resources used is the heat of flammable waste gases and heat of circulating water. The final received energy resources are heat of heating water of 150 °C temperature and electricity for internal and external consumption.*

Keywords*: heat pump complex, secondary energy resource, heat pump, energy potential, heat*.

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Statement of the problem

Many secondary energy resources in forms of thermal discharges of sewage treatment plants, circulating water of cooling towers, warm satellite waters, irretrievable condensate etc are formed during deep processing of petrochemical raw materials. Significant share of secondary energy resources is formed in the form of hydrocarbon and fuel gases, methane-hydrogen fractions, resins, subdimeric water, "yellow" oil and coke residue after delayed coking units [1–5].

Non-used combustible waste in the form of "yellow" oil amounted to 600 tons/year, in the form of liquid combustible sorbent A-2 amounted to 2 tons/hour, in the form of heat of waste water with a temperature of 27°C at the sewage treatment plant amounted to 50000 m^3/hour at PJSC "Nizhnekamskneftekhim" in 2016 [6–7].

According to the data from PJSC “Kazanorgsintez”, thermal secondary resources volumes in 2016 are the following: in the form of circulating water with a temperature of 25°C in cooling towers is 5000 m^3/hour, in the form of combustible waste of pyrolysis resin is 400 ton/year, in the form of waste combustible gases is 150 m^3/hour in 2016.

At PJSC "Nizhnekamskneftekhim" and PJSC "Kazanorgsintez" performance indicator of waste gas burning on flares and candles is 5 % of the total volume of the gaseous hydrocarbon raw material used in the technology in 2017.

The delayed coker unit commissioned at JSC “TANECO” in 2017 will have a raw material capacity of 2 million tons per year. Along with main commercial products such as acid gas, unstable gasoline, light and heavy gas oil, it produces a secondary fuel product: petroleum coke in the amount of 700 thousand tons/year [8–10].

The presented analysis shows that the secondary energy resources of oil refinery include fuel component in the form of liquid, gaseous, solid combustible waste and heat component in the form of heat of circulating water of cooling towers and heat of waste water of sewage treatment plants.

Therefore, the development of technology and units for complex use of secondary energy resources is the main focus of research on the energy saving potential of oil refinery enterprises.

This article discusses the use of gas turbine and heat pump units to utilize secondary energy resources of oil refinery plants.

Evaluation of power and operating parameters of a heat pump unit for disposal of secondary combustible and secondary thermal energy resources

Thermal energy characteristics of secondary energy resources of oil refinery plants are given in Table 1.

Table 1

Thermal energy characteristics of secondary energy resources of oil refinery plants

Secondary energy resources	Heat of combustion Q_h^r		Enthalpy, kJ/kg	Average energy potential of the resource, MW
	kJ/kg	kJ /m^3		
Circulating water in cooling towers at 25 °C	-	-	105	15
Wastewater from sewage treatment plants at 27 °C	-	-	114	30
Non-returnable condensate at 90 °C	-	-	377	10
Reverse heat-satellite water at 95 °C	-	-	399	20
Exhaust combustible factory gases	-	27255	-	227
Fuel gas	-	33369	-	220
Heavy pyrolysis resin with spent pyrobenzene and "yellow" oil	39300	-	-	10
Liquid combustible sorbent A-2	41636	-	-	23
Methane-hydrogen fraction	-	28526	-	200
Petroleum coke	30180	-	-	200
Reverse heat-satellite water at 70 °C	-	-	294	14,7
Condensate from polycarbonate production at 130 °C	-	-	547	11

Table 1 shows that secondary energy sources of petrochemical plants with a fuel component in the form of combustible gases have the greatest potential.

Nowadays, at petrochemical industries, fuel and waste secondary combustible gases are burned in huge quantities in flares and in process candles [8–9] besides their usage for the factory technological consumption.

The discharged emergency and waste gases in the amount of 230 tons per hour are burned in flare No. 768 from 2009 at the block E-500 of the 3rd stage of the high pressure heater plant of PJSC “Kazanorgsintez”. The disadvantages of this technical solution are:

1. Pollution of the atmosphere and the environment.

2. Failure to save potential energy to reduce the cost of production.

Heavy flooded pyrolysis resins and combustible liquid sorbent are burned in boilers mixed with fuel gas.

At the SKI PJSC "Nizhnekamskneftekhim" there is a unit recycling liquid secondary combustible waste in the form of A-2 sorbent in the amount of 0,8 tons/hour, which are mixed with fuel gas in the amount of 12,000 m^3/hour in two steam boilers KVG-3GM with the generation of steam energy parameters in the amount of 120 tons/hour and the supply of this steam to the turbine connected to the generator.

At the plant SKI PJSC "Nizhnekamskneftekhim" the second unit of the same type for disposal of liquid waste was launched with two boilers at 75 tons of steam per hour [8].

The disadvantage of this solution is low operational reliability of combustion of liquid waste in boilers with obtaining of water steam of energy parameters and subsequent supply of this steam to the steam turbine connected with electric generator..

At the SKI PJSC "Nizhnekamskneftekhim" due to high heat of combustion of secondary combustible waste in the form of A-2 sorbent, the superheater tubes in boilers KVG-3GM are systematically destroyed. The composition of sorbent is not constant due to changes in the content of heavy resins and water and the heat of combustion varies from 16,000 kJ/kg to 40,000 kJ/kg. At low heat of combustion of liquid combustible waste, additional supply of natural gas to the furnace is necessary to generate the required amount of energy steam for the operation of the steam turbine.

The number of secondary combustible energy resources in the form of methane-hydrogen fraction obtained in PJSC "Taif-NK" is expected to be 381,4 million m^3 in 2019, and 382,5 million m^3 in 2020.

Since with growth of production capacity of petrochemical plants the need for electricity increases, so many TPS are planning to switch to mixed fuel in power boilers: natural gas in a mixture with a methane-hydrogen fraction to reduce the cost of electricity generation. The disadvantage of this technical solution is limitation of the burned amount of methane-hydrogen fraction in the fuel fraction of 12 % mixed with natural gas.

Petroleum coke is supposed to be burned in a mixture with natural gas. In the future, by 2030, Nizhnekamsk CHP-2 will use as fuel the following substances: gas – 65 %, petroleum coke – 33 %, fuel oil – 2 % [9]. The disadvantage of this solution is the need to prepare petroleum coke for chamber flaring in energy boilers and the presence of high-calorific gas fuel that is burnt together with petroleum coke.

The use of energy potential of 1,5 MW in the form of heat from the circulating water at the high pressure heater of LDPE Production Plant PJSC “Kazanorgsintez” was implemented in 2007 using the absorption refrigerating machine ABHM-1500P, i.e. single-stage thermal bromine lithium pump with steam heating. The disadvantages of this technical solution is low power of utilized heat and the need for heating steam in the amount of 4,31 tons/hour with a temperature of 115°C. The result of this technical solution is the production of cold of +7°C, used in the technology.

Design of absorption refrigerating machine (ARS) Thermax [10,11] with a capacity of 5,35 MW and with a conversion ratio of 1,4, working on burning gas or liquid fuel, producing cold water of +2°C in summer and hot water of +60 °C in winter is known. Its disadvantage is low temperature of hot water.

The steam-compression heat pump *NT*-3000 [12-15] produced by CJSC “Energia” with power of utilized water heat of 2,8 MW, temperature of +30°C and consumed electric power of 0,63 MW produces heated water of +55°C and cold water of +7°C with conversion factor of 4,45. The disadvantage is the need for electricity and low temperature of heated water.

Since 2005, the gas turbine power plant GTE-15 with an electrical capacity of 15 MW and with an efficiency of 30 % in a cogeneration cycle, using the methane-hydrogen fraction with a hydrogen content up to 26 % (vol.) has been operated at the Mozyr Oil Refinery [16]. The GTE-15 uses a ZKR-204 booster screw compressor, compressing the methane-hydrogen fraction from a pressure of 0,9 MPa to 2 MPa. The disadvantage of this scheme is the impossibility of using low-grade thermal energy of recycled and waste water.

As it can be seen from the analysis presented above, the available technical solutions for the use of secondary energy resources are not comprehensive and universal in terms of the final result, suitable for practical use with a high energy saving indicator.

The proposed scheme for the integrated use of secondary energy resources of petrochemical industries is shown in Figure 1. The energy balance of the universal module of heat pump complex for utilization of secondary energy resources of petrochemical plants, calculated taking into account the results from [12–20], is given in Table 2.

The universal module of heat pump complex for utilization of secondary energy resources of petrochemical plants (Fig. 1) consists of three blocks: gas-turbine unit 1 based on GTE-2,5 with an electric power of 2,5 MW with a steam heat recovery boiler, a steam-compression heat pump unit based on two heat pumps NT-3000 with a unit capacity of up to 2,8 MW, absorption heat pump unit of two Thermax ARS with a unit capacity of up to 5,35 MW.

The power of the resource Q_e obtained in the evaporator of the heat pump NT-3000 is determined by the formula, MW

$$Q_e = G\left(i_{w2} - i_{w1}\right), \tag{1}$$

where G is flow rate of circulating water, kg/s; i_{w2}, i_{w1} is enthalpy of circulating water at the outlet and inlet of the evaporator (kJ / kg), respectively.

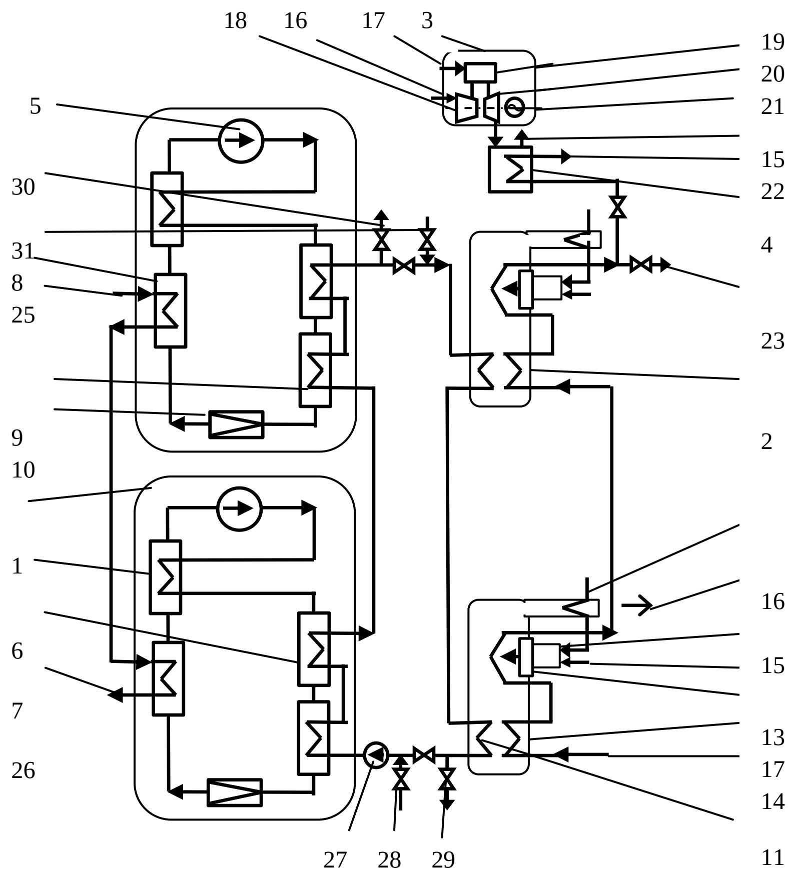

Fig. 1. Scheme of the universal module of heat pump complex for utilization of secondary energy resources of petrochemical plants: *1* – steam compression heat pump; *2* – absorption bromine-lithium heat pump; *3* – gas turbine unit; *4* – water recovery boiler; *5* – electrically driven compressor; *6* – regenerative heat exchanger; *7* – condenser; *8* – evaporator; *9* – subcooler; *10* – throttle; *11* – absorber; *12* – evaporating heat exchanger; *13* – generator; *14* – condenser; *15* – combustion products; *16* – air intake; *17* – fuel; *18* – compressor; 19 – combustion chamber; *20* – gas turbine; *21* – electric generator; *22* – superheated heating water of 150 °C; *23* – heating water of 130 °C; *24* – circulating water of 70 °C; *25* – circulating water of 25 °C; *26* – circulating water of 5 °C; *27* – circulation pump; *28* – water being cooled of 40 °C; *29* – cooled water of 10 °C; *30* – heated water of 70°C; *31* – circulating water of 30°C

Table 2

Energy balance of the universal module of the heat pump complex for utilization of secondary energy resources of oil refinery plants

Come in		Come out	
Energy resource	Value	Energy resource	Value
Gas Turbine Unit			
Heat of combustible fuel gas, MW	10	Electric power for two steam compression heat pumps, MW	1,26
Heat supplied with water at 130 °C for heating, MW	7,0	Electricity to consumers, MW	1,24
		Heat output with water heated to 150 °C, MW	13,9
		Heat loss with outgoing gases, MW	0,6
Total energy received, MW	17,0	Total energy consumed, MW	17,0
Unit of two steam compression heat pumps			
Electric power for two steam compression heat pumps, MW	1,26	Energy resource given to circulating water for heating up to 70 °C, MW	7,0
Heat of circulating water at 25 °C, MW	5,74		
Total energy received, MW	7,0	Total energy consumed, MW	7,0
Unit of two absorption heat pumps			
Heat of combustion of waste gas in the heat pump generator, MW	5	Heat given to water when it is heated to 130 °C, MW	7,0
Energy resource brought with circulating water with a temperature of 70 °C, MW	2,3	Heat loss with outgoing gases, MW	0,3
Total energy received, MW	7,3	Total energy consumed, MW	7,3
Total come in, MW	**31,3**	**Total come out, MW**	**31,3**

The power spent in steam compression heat pump to transfer heat from the circulating water to the heated water, MW:

$$N_s = Q_e \cdot \eta / \varphi_s \quad (2)$$

where η =0,8 is coefficient taking into account the degree of perfection of thermodynamic cycle of steam-compression heat pump [1–5]; φ_s =4,45 is the energy conversion factor for the steam compression heat pump NT-3000.

For absorption heat pump, the power consumed for burning secondary fuel Q_f (MW) is calculated as:

$$Q_f = Q_a / \varphi_a, \quad (3)$$

where Q_a is power received by the consumer from absorption heat pump, MW; φ_a =1,4 is conversion coefficient for the absorption heat pump Thermax [10,11].

Discussion of results

The results presented in table. 2 show that for operation of a universal module consisting of GTE-2,5, two NT-3000 and two ARM Thermax, the main share of secondary energy source belongs to waste and fuel gases in the amount of 15 MW. The heat capacity of circulating water of 25°C consumed for operation of heat pump complex is 5,74 MW. The module of the heat pump complex has a thermal power according to the secondary energy resources used at the input Q_{in} =15,74 MW. The final product of operation of heat pump complex is heat Q_{out} =13,9 MW in the form of water heated to 150°C and electricity in the form of 2,5 MW power of.

Energy efficiency of energy resources usage in the heat pump complex module $\eta_{e.u.} = Q_{out} \cdot 100 / Q_{in} = 88,3\%$.

Compared with the known existing and discussed above technical solutions, the proposed module of the heat pump complex is universal both in terms of the potential of the secondary energy resources used in it and in their types. The complex operation does not require external supply of electricity.

The conventional structural formula of the module: 1 Gas Turbine Unit + 1 boiler + 2 steam compression heat pumps +2 absorption heat pumps Thermax allows, according to the nomenclature and type of equipment available in the industry, to create units and, on their basis, heat pump modules for utilization of secondary resources in oil refinery with a wide range of used capacities.

Conclusion

1. The created heat pump complex allows simultaneously utilizing various types of secondary energy resources of oil refinery plants.

2. The main potential for the resources used for the developed heat pump complex is the heat of combustible waste gases and heat of recycled water, and the final energy resources obtained are heat of heating water with a temperature of 150°C and electricity for internal and external consumption.

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Authors of the publication

Mikhail A .Taimarov – Professor of the Department «Energy supply of manufactures and energy resources saving technology» Kazan State Power Engineering University; doct. sci. (techn.); E-mail: taimarovma@yandex.ru.

Vladimir K. Ilin – Professor of the Department of the Department «Energy supply of manufactures and energy resources saving technology», Pro-vice-chancellor for academic affairs of Kazan State Power Engineering University; doct. sci. (techn.); E-mail: ilinwk@rambler.ru.

Ayrat L. Osipov – Associate Professor of the Department «Energy supply of manufactures and energy resources saving technology» Kazan State Power Engineering University; cand. sci. (techn.); E-mail: nord7077@yandex.ru.

Anastasia N. Dolgova –Associate Professor of the Department «Energy supply of manufactures and energy resources saving technology» Kazan State Power Engineering University; Associate Professor of the Department «Energy supply of manufactures and energy resources saving technology»; Rostov State Transport University; cand. sci. (techn.); E-mail: dolgova.an@list.ru.

Artem V. Akhmerov –Associate Professor of the Department «Energy supply of manufactures and energy resources saving technology» Kazan State Power Engineering University; cand. sci. (chem.); E-mail: akhm@mail.ru.

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