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Total Site Integration for Coke Oven Plant

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The process of benzene distillation and process of coal tar distillation being typical for East European countries is analyzed in this paper. The pinch analysis method was selected to perform a reconstruction project. According to principles of pinch analysis, new network diagrams are designed and capacity of heat-exchange equipment is calculated. The using of «Total Site Profiles» showed the feasibility of heat pump integration. Heat pump integration allowed to reduce the external hot utilities usage on 368 kW and cold utilities usage on 368 kW. This project let to decrease the external hot utilities usage on 23 % and cold utilities usage on 24,13 %, and also offered the way of step-by-step retrofit of the plant.

1. Introduction

Ukraine is one of the most energy-intensive countries in the region. The energy intensity of Ukraine’s GDP is higher than that of resource-rich Russia and more than three times higher that the average energy intensity of the EU. According to the results of 2006, GDP energy intensity of Ukraine was 0.5 toe. / US Dollars. GDP energy intensity of Poland was 0.21 toe. / US Dollars. In USA it was equal 0.16 toe. / US Dollars, in Russia - 0.45 toe. / US Dollars. (Ukraine policy review. 2006). The most important point is reduction of energy consumption in chemical and metallurgical industries, where energy price is a basic component of production costs. In Ukraine due to needs of extensive Metallurgical Industry 14 Coke-Oven factories have been set in operation. All of them were designed and built at the time of rather chip energy resources and now all this factories, as a rule, are working far from optimum performance. The process of benzene distillation and process of coal tar distillation, which is typical for East European countries, is analyzed in this paper.

1.1 Process description

Figures 1a and 1b illustrate a technological plan of two benzene departments of a coking plant Crude benzene is a mixture of aromatic compounds, the most important of which are benzene hydrocarbons, with content 80 - 90 %. Crude benzene contains inorganic and sulfur compounds, phenols, pyridine compounds, etc. When capturing benzene hydrocarbons from coke gas by absorption oils, crude benzene contains light distillates of absorption oil and naphthalene. Figure 1c illustrates the diagram of coal tar processing.
In Figure 1a, coke gas is supplied to benzene scrubber № 1, where it is scrubbed by absorption oil and then coke gas is removed from the scrubber. Absorption oil flows into the oil reflux exchanger № 5, where it is heated by vapors of distillation column № 4. Absorption oil flows from the oil reflux exchanger to the oil heat exchanger № 13, where it is reheated to 110 ºC by purified absorption oil supplied from the column № 4. Then, absorption oil flows into the tube furnace № 3, where it is reheated to 160 ºC and supplied to the distillation column № 4. Steam at a temperature of 200 ºC is supplied to the column № 4; refined absorption oil from the column returns to the benzene scrubber № 1, and vapors of distillation column are supplied to the oil and water reflux exchanger №5, and then they are supplied to separation column № 9. The part of vapor in the distillation column condenses and runs down into the reflux separator, from which it is returned by the pump to the column, and separator water is discharged from the separator. Narrower fractions of products are obtained in the separation column. Benzene is discharged from the column cube. Vapors from the column are supplied to the condenser № 7, where they are condensed, cooled to 30 °C and supplied to the benzene separator № 10. In the separator, condensate is separated into separator water and benzene and supplied to a warehouse.

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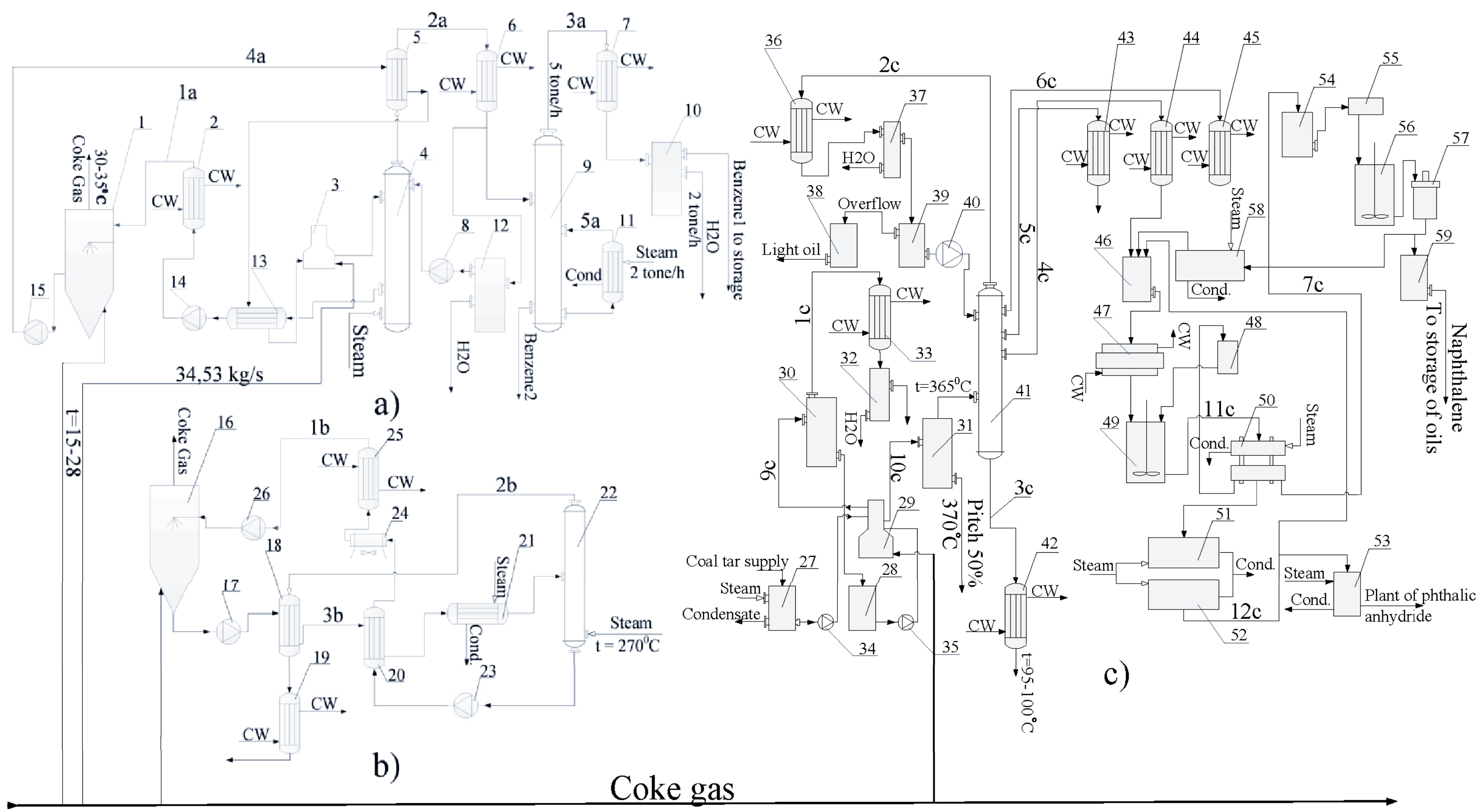


Figure 1. Technological plan of two benzene departments of a coking plant with common supply stream and diagram of coal tar processing 1, 16 – scrubber; 2, 25 – oil Cooler; 3,29 – furnace; 4 – distillation column; 5, 18 – oil reflux condenser; 6 – water reflux condenser;7 – condenser; 8, 14, 15, 16, 17 23,26, 34, 35, 40 – pumps; 9 – separation column; 10 – separator of benzene 1; 11, 21 – heater; 12 – reflux separator; 13 – heat exchanger of oil; 19 – condenser, 20 – heat exchanger, 22 – benzene column, 24 – air cooler, 27 – intermediate tank of coal-tar; 28 – water free coal tar tank; 30,31 – 1st and 2nd stages evaporation; 32, 37 –light oil separators; 33, 36 – cooling condenser of 1st stage and distillation column (stripper); 38 – light oil intermediate tank; 39 – reflux tank; 41 – distillation column (stripper); 42-45 – immersed coolers of 2nd anthracene, stripping, naphthalene and phenol fraction; 46 – gross head tank; 47, 55 – crystalliser; 48 – small head tank; 49, 56 – mixers; 50 – pressing unit; 51, 52; 58 – melting tanks; 53, 54 – naphthalene intermediate tanks; 57 – decanter; 59 – naphthalene storage tank.

In Figure 1b, coke gas is supplied to the scrubber № 11, where benzene hydrocarbons are extracted from coke gas using absorption oil. Then, absorption oil from the scrubber passes through the reflux exchanger № 18, the recuperative heat exchanger № 20 and steam heater № 21, and then runs into rectification column № 22. In the process of rectification, benzene hydrocarbons are extracted form the oil and supplied, in the form of vapor at the top of column, to the reflux exchanger № 18, and then - to the final condenser № 19 and, being condensed, are discharged to the storage. Refined absorption oil from the column, having a cooling cycle, is supplied to the scrubber again and the process is repeated.

Figure 1c – the coal tar distillation the distribution of the vaporized part of coal tar is performed in the single shell. In this case the water free tar heated in the furnace is supplied to 2nd stage vaporiser № 31 for one-step evaporation. From the bottom the liquid tar residue with temperature about 370 ^{0}C outputs. From the top the vapours of fractions with temperature 365 ^{0}C are supplied to distillation column № 41 for fractional condensation. Vapor fractions from this column are: phenol fraction, naphthalene fraction, stripping fraction and 2nd entrance fraction. The vapors of these fractions are condensed with cooling water in immersed condensers and are supplied to intermediate tanks.

The flowsheet of naphthalene fraction treatment unit is shown on figure too. From head tank № 46 the fraction is supplied to bath of drum crystallizer № 47 that is fed with cooling water. The naphthalene crystallized is supplied to mixers № 49 and then to hot pressing to press tool № 50. The tablets of pressed naphthalene are transported to melters 51, 52 and then to naphthalene tank 53. The part of melted naphthalene is returned to process recycle.

Heat engineering characteristics streams that have been submitted in technological scheme (Fig. 1a - c) are presented in Tables 1 – 3.

Table 1. Stream data for flowsheet (Figure 1a)

№	Stream	Type of stream	T_S, °C	T_T, °C	*W*, kg/s	*r* kJ/kg	*C*, kJ/ (kg·^{0}C)	*CP* kW/^{0}C	Δ*H*, kW	*α*, kW/ (m^2·^{0}C)
1	Refined absorption oil from the column	Hot	145	30	48.25	-	2.01	96.97	-11,152	0.3
2,1	Condensation of steam	Hot	100	100	5.55	1,908	-	-	-10,589	9
2,2	Steam cooling	Hot	130	100	5.55	-	2.1	11.65	-349.65	0.56
3,1	Condensation of steam	Hot	74	74	1.38	1,816	-	-	-2,506	8
3,2	Condensate from the column	Hot	74	30	1.38	-	3.23	4.45	-196	0.8
4,1	Absorption oil from the scrubber	Cold	32	160	50.98	-	2.03	103.5	13,246.6	0.3
4,2	Evaporation	Cold	160	160	2.78	1,920	-	-	5,337.6	9
5,1	Hot jet	Cold	90	115	3.93	-	1.97	7.73	193.55	0.3
5,2	Evaporation	Cold	115	115	1.38	1,910	-	-	2.635.8	9

Table 2. Stream data for flowsheet (Figure 1b)

№	Stream	Type of stream	T_S,° C	T_T,° C	*W*, kg/s	*r* kJ/kg	*C*, kJ/ (kg·^{0}C)	CP kW/ ^{0}C	Δ*H*, kW	*α*, kW/ (m^2·^{0}C))
1	Refined absorption oil from the column	Hot	120	30	66.9	-	2.01	134.6	-12,115	0.9
2.1	Steam Cooling	Hot	170	90	5.36	-	1.70	9.14	-731.1	0.56
2.2	Condensation of steam	Hot	90	90	5.36	1908	-	-	-10,227	9
2.3	Steam Cooling	Hot	90	30	5.36	-	3.23	17.32	-1,039.4	0.56
3,1	Absorption oil from the scrubber	Cold	32	150	69.33	-	2.03	140.74	16,607.2	0.3
3,2	Evaporation	Cold	150	150	5.36	1850	-	-	9916	9

2. Reconstruction of two benzene departments and the tar distilling shop with common supply stream

2.1 Design of Heat Exchanger Networks

The pinch analysis method was selected to perform a reconstruction project, which effectiveness was demonstrated in previous studies (Tovazhnyansky et al., 2011). Optimal ΔT_{min} values obtained using the «Hint» programme are: 10 ºC for Table 1, 10 ºC for Table 2, and 12 ºC for Table 3. According to principles of pinch analysis, new network diagrams were designed for the new ΔT_{min} value, and capacity of heat-exchange equipment was calculated. The scheme of reconstruction of coal tar processing (Figure 1c), and a way to simplify a heat exchange system have been published previously (Tovazshneanski et al., 2001).

Table 3. Stream data for flowsheet (Figure 1c).

№	Stream	Type of stream	T_S, °C	T_T, °C	W, kg/s	r kJ/kg	C,kJ/ (kg·^{0}C)	CP, kW/^{0}C	ΔH, kW	α,kW/ (m^{2}·^{0}C)
1.1	Stream of vaporizer water	Hot	130	100	0.160	-	1.89	0.302	9.063	1.0
1.2	Condensation of vaporizer water stream	Hot	100	100	0.160	2257	-	-	360.759	10.0
1.3	Condensate of vaporizer water	Hot	100	50	0.160	-	4.19	0.670	33.486	0.8
2.1	Stream of light oil	Hot	135	100	0.043	-	2.03	0.087	3.041	0.5
2.2	Condensation of light oil stream	Hot	100	100	0.043	379	-	-	16.222	10.0
2.3	Condensate of light oil	Hot	100	45	0.043	-	2.03	0.087	4.779	0.5
3	2nd anthracene fraction	Hot	310	100	0.856	-	1.739	1.489	312.587	0.3
4	Stripping fraction	Hot	265	80	0.642	-	1.567	1.006	186.127	0.3
5	Naphthalene fraction	Hot	210	95	0.428	-	1.785	0.764	87.858	0.3
6	Phenol fraction	Hot	185	50	0.171	-	1.823	0.312	42.127	0.3
7.1	Naphthalene in crystallizer	Hot	90	78	0.750	-	1.787	1.340	16.083	0.1
7.2	Crystallization of naphthalene	Hot	78	78	0.750	149.16	-	-	111.873	0.1
7.3	Naphthalene in crystallizer	Hot	78	60	0.750	-	1.787	1.340	24.125	0.1
8	Pitch	Hot	370	170	2.140	-	2.000	4.280	856.032	0.3
9	Crude coal-tar	Cold	75	130	4.44	-	1.800	9.324	512.820	0.3
9.1	Evaporation of coal tar	Cold	130	130	0.160	2,300	-	-	368	10
10	Dry coal-tar	Cold	130	400	4.280	-	2.331	11.556	3120.24	0.3
11.1	Naphthalene in press	Cold	60	78	0.833	-	1.787	1.489	26.805	0.1
11.2	Melting of naphthalene	Cold	78	78	0.833	149.16	-	-	124.303	0.1
11.3	Naphthalene in press	Cold	78	100	0.833	-	1.787	1.489	32.762	0.1
12.1	Naphthalene in melting chamber	Cold	45	78	0.417	-	1.787	0.745	24.571	0.1
12.2	Melting of naphthalene	Cold	78	78	0.417	149.16	-	-	62.152	0.1
12.3	Naphthalene in melting chamber	Cold	78	105	0.417	-	1.787	0.745	20.104	0.1

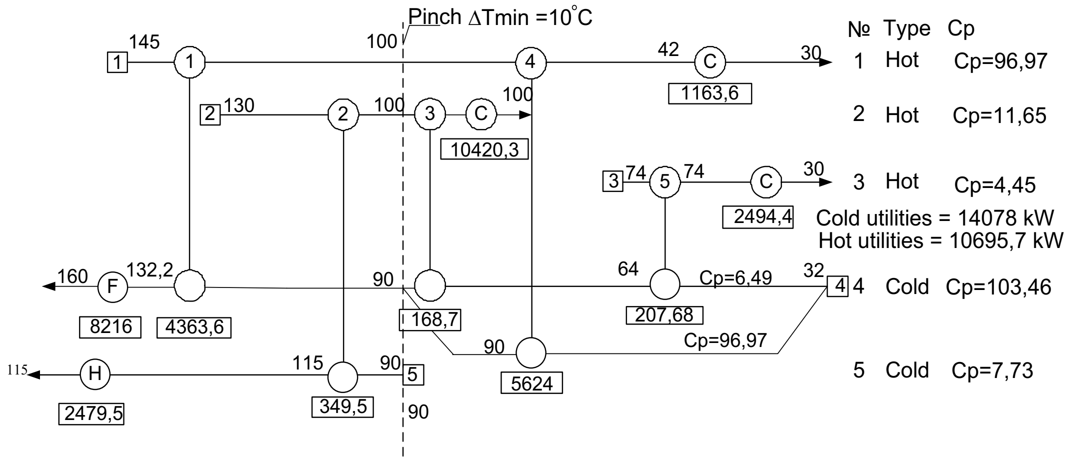


Figure .2 Project of heat network for Table 1. H – heaters, C – coolers, F – furnace

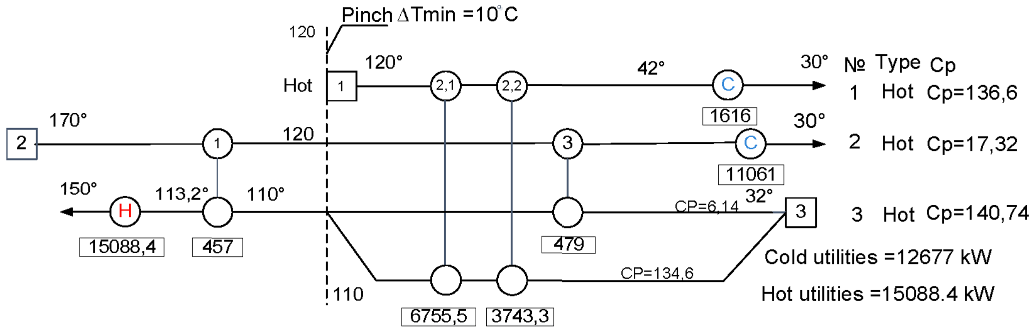


Figure 3. Project of heat network for Table 2.

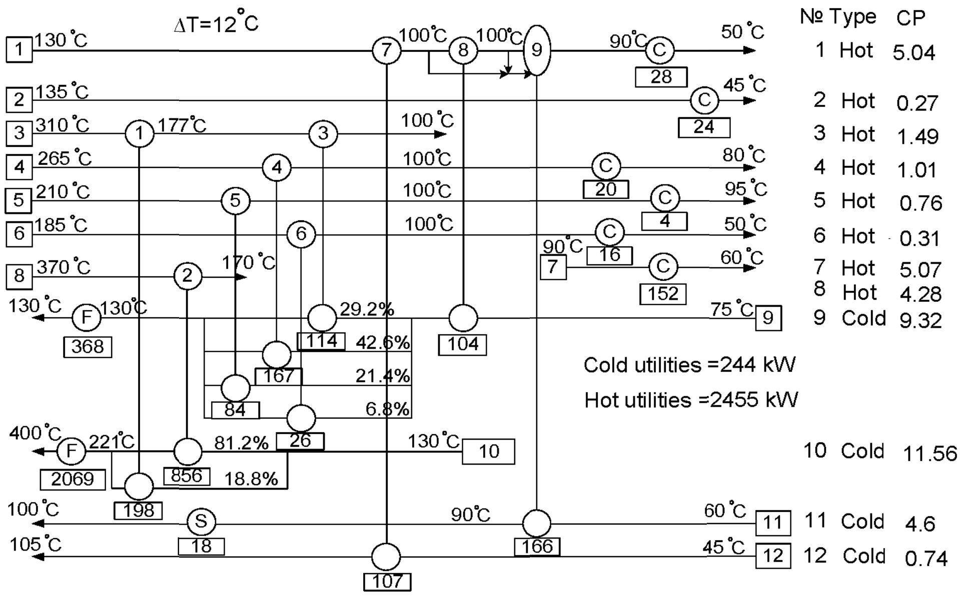


Figure 4. Project of heat network for Table 3.

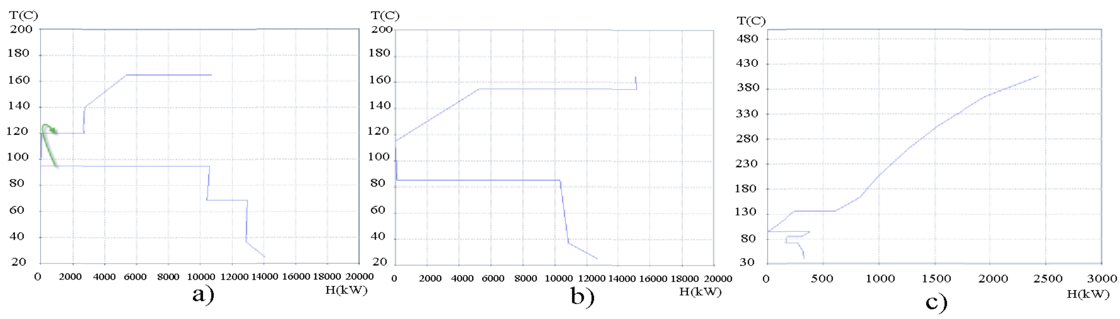
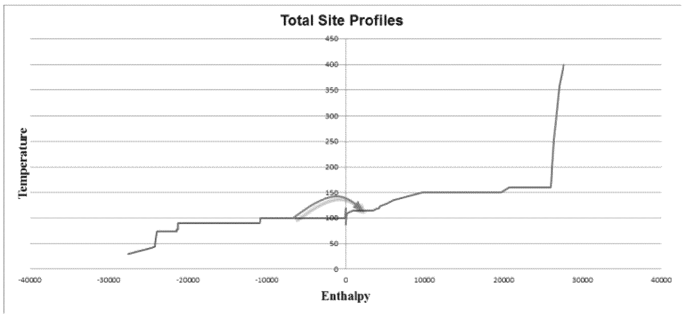


Figure 5. Grand composite curve a) Grand composite curve for (Fig. 2), b) Grand composite curve for (Figure 3) c) Grand composite curve for (Figure 4)

2.2 Heat pump integration

The ability of install the heat pump was shown in Figure 5a. Coefficient of performance for the heat pump has been obtained by using UniSim Design programme: ε=3.46. Installation of the heat pump allowed to reduce the external hot utilities usage by 2,597.15 kW and cold utilities usage by 2,597.15. Compressor cost has been obtained from previously published studies (Gorshkov, 2004). Recent pinch-analysis researches allow to identify target energy values within a large industrial complex. (Gorsek et al., 2006). Total Site Profiles are used for this purpose. These profiles are formed from grand compound curves of individual processes included into the industrial complex (Smith et al., 2000). Creation of the complex temperature profile for two processes illustrates is Figure 6. Wiring diagram for heat pump was shown in Figure 7.



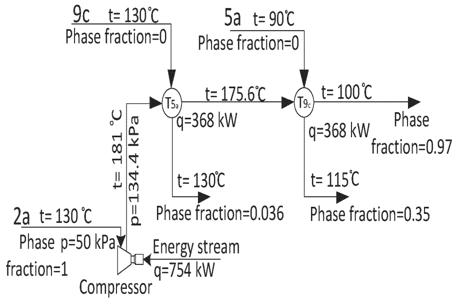


Figure 6. Total Site Profiles

Figure 7. Wiring diagram for heat pump

Total Site Profilies shows the possibility for heat pump integration. As can be seen from the calculations, in order to achieve targets values compressor capacity should be increased by 3.1 kW.
The payback period for heat pump was defined (Eq(1)):

$$P = \frac{C}{Qhot \cdot Shot + Qcold \cdot Scold - Wcompressor \cdot Selec} \tag{1}$$

P - payback period; C - capital costs; S - cost of energy; Q - external utilities.

P=3.5 year; C=91,739 USD; Q_{hot}=2,965.15 kW; S_{hot}=172 USD per 1 kW year; Q_{cold}=2,965.15 kW; S_{cold}=24.5 USD per 1 kW year; $W_{compressor}$=754 kW; S_{elec}=736 USD per 1 kW year.

Notation

ΔH – change of enthalpy, C – heat capacity, CP – heat transferred, Q_{Cmin} – requirement for cold utility, Q_{Hmin} – requirement for hot utility, α – heat transfer coefficient, W - flow rate, r - heat of vaporization.

3. Conclusions

The retrofit project for the coal tar distillation plant was suggested using the pinch-analysis technique. This project allows to decrease the external hot utilities usage by 23 % and cold utilities usage by 24.13 %, and also offered the way of step-by-step retrofit of the plant. The using of «Total Site Profiles» showed the feasibility of heat pump integration. Heat pump integration allowed to reduce the external hot utilities usage by 368 kW and cold utilities usage by 368 kW. Capital costs – 666,230 US Dollars, Present Value –635,124.5 US Dollars / year, Pay-Back Period - 1.04 year.

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