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PROFESSIONAL PAPER

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ENERGY MANAGEMENT IN VACUUM DISTILLATION PROCESS

This paper deals with the technological and energy characteristics of the Vacuum Distillation Process in a typical refinery having the processing capacity of 5 million tons per year.
The cost price of medium pressure steam produced and being used in this process was calculated on the basis of the gross and net steam energy consumption. This cost price was compared to the cost prices of medium pressure steam in the Vacuum Residue Visbreaking Process, in the Fluidized Catalytic Cracking Process, as well as in the Refinery Power Plant. Also, by analyzing and comparing UE refineries, it became possible to set the target standard for energy consumption and to determine the possible money savings.

From the energy point of view, in crude oil processes, each process has its special characteristics. Because of that, they must be analyzed separately and in detail, in technoeconomic analysis.

This paper deals with the technological and energy characteristics of the Vacuum Distillation Process in a typical refinery having a processing capacity of 5 million tons per year. The procedure of determining the cost price of medium pressure steam, produced in this unit, as well as the procedure of determinig the possible money savings of energy consumption of this refinery unit, are also presented in this paper.

TECHNOLOGICAL CHARACTERISTICS OF THE PROCESS

The Vacuum Distillation Process is the second phase of crude oil processing.

Light residue from the Crude Unit is introduced into the Vacuum Distillation Process. Light residue is heated up to 390° – 410° C before entering the Vacuum Distillation. This column is under vacuum – the pressure at the top of the column is 2.67 – 4.00 kPa – which makes evaporation of some fractions possible. The temperature profile and other characteristics of the vacuum column, besides pressure, are the same as for the main column of the Crude Unit.

For an improvement of streaming and fractionation, overheated steam* is introduced to the bottom of the column (steam for stripping). The steam with the streams of light hydrocarbons is routed off the top of the column by the steam ejectors, and in that way, the necessary vacuum in the column is achieved. The steam and the steam of light hydrocarbons are condensed and separated after that in separators.

In this process, the products are: vacuum light gas oil, vacuum heavy gas oil and the non–condensing fraction. At the bottom of the column there is vacuum or heavy residue representing 35–50% of the total inlet quantity of the light residue in the vacuum distillation process.

The vacuum residue is refashioned in the Vacuum Residue Visbreaking Process and in the bitumen producing process.

All the above mentioned technological characteristics are shown in Figure 1.

ENERGY CHARACTERISTICS OF THE PROCESS

In a typical Vacuum Distillation Process, the light residue from the Crude Unit Process is preheated in heat exchangers before entering the process heater, by means of the flows of these process products.

In the process heater, gas is mainly used as the fuel and medium pressure (MP) steam is used for its preheating and dispersion in burners.

One portion of medium pressure steam is routed from the Power Plant and the other part is generated in the heat exchangers using the heat flux of the vacuum residue.

The medium pressure steam is also produced by using the heat of the flue gases in the boiler. Total steam generation is used for the ejector drive by means of the steam and the steam of light hydrocarbons is taken out of the vacuum residue and vacuum results in the vacuum column.

Besides medium pressure steam in the Vacuum Distillation Process, low pressure (LP) steam is introduced and used for stripping in the vacuum column, after preheating by the heat of the flue in the process heater.

Electric energy is used for the pump drive, fan drive (fan cooling and leadng the flue gases of the boiler) and for other equipment drive.

The main energy streams of the Vacuum Distillation Process are shown in Figure 2 which also presents all the important alternatives in meeting the energy demands of the process. Each alternative is one of the potential solutions for a process like this.

For the purpose of this process, a block energy flow scheme is shown in Figure 3 and Senky's diagram for the energy balance* in Figure 4.

*Steam means steam of water

Author address: O. Ocić, Pančevo Petroleum Refinery, Pančevo, Yugoslavia
Paper received: September 15, 1999.
Paper accepted: October 30, 1999.

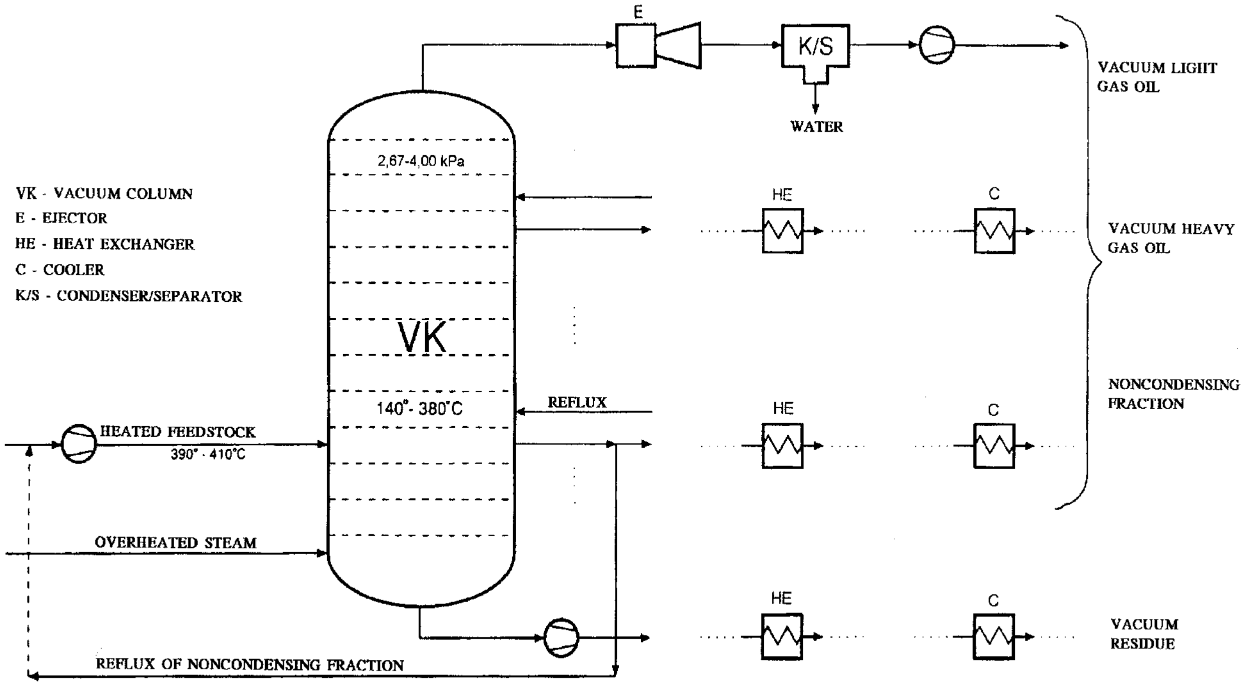

Figure 1. Technological characteristics of the Vacuum Distillation Process

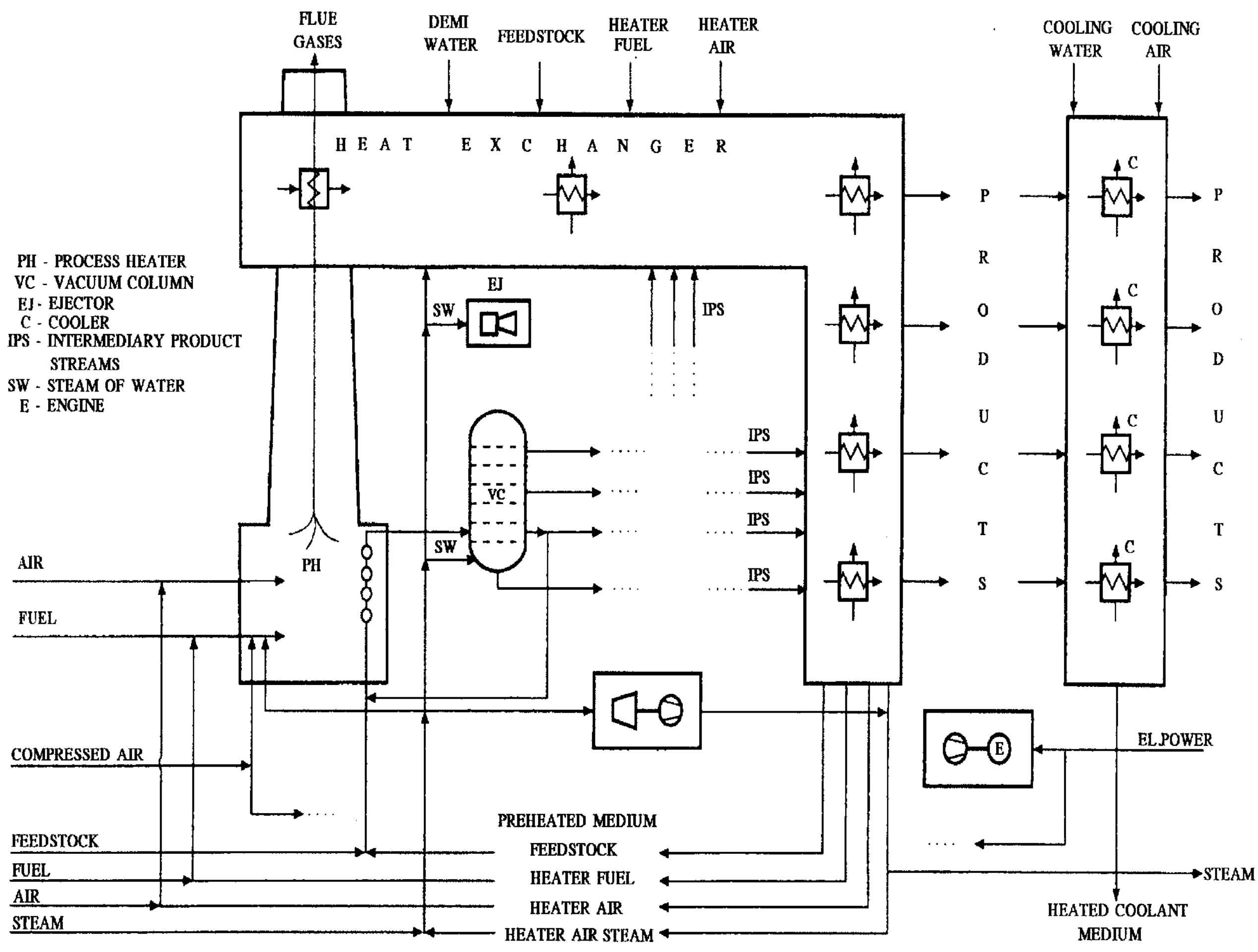

Figure 2. Energy characteristics of the Vacuum Distillation Process

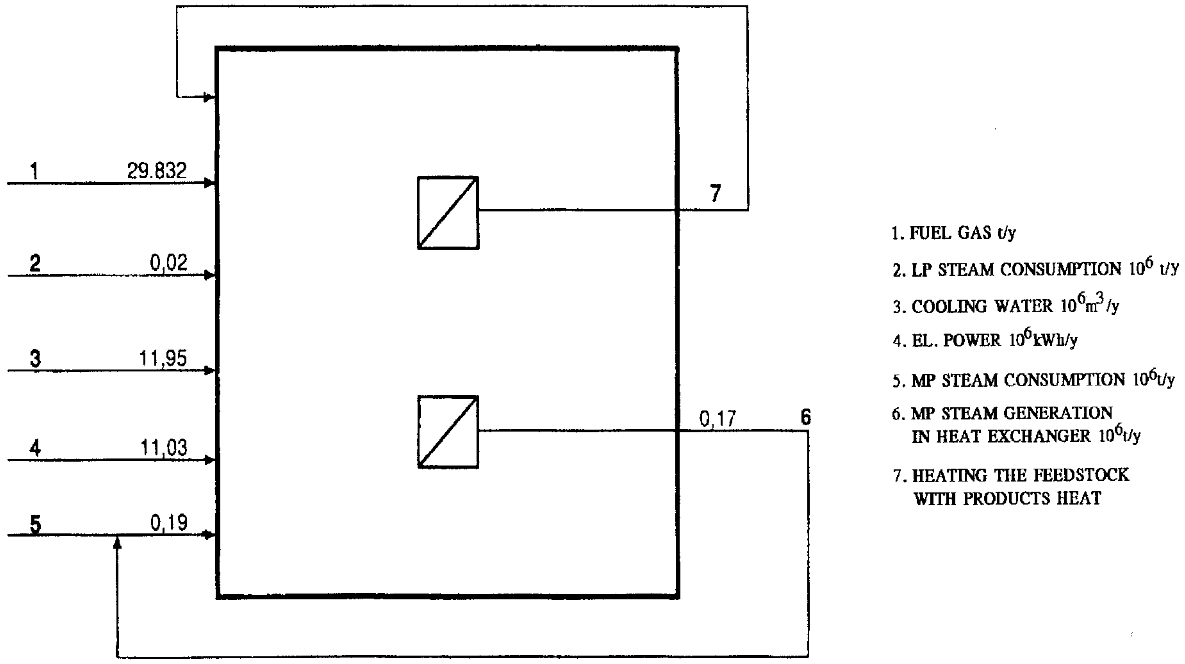

Figure 3. Energy flows of the Vacuum Distillation Process

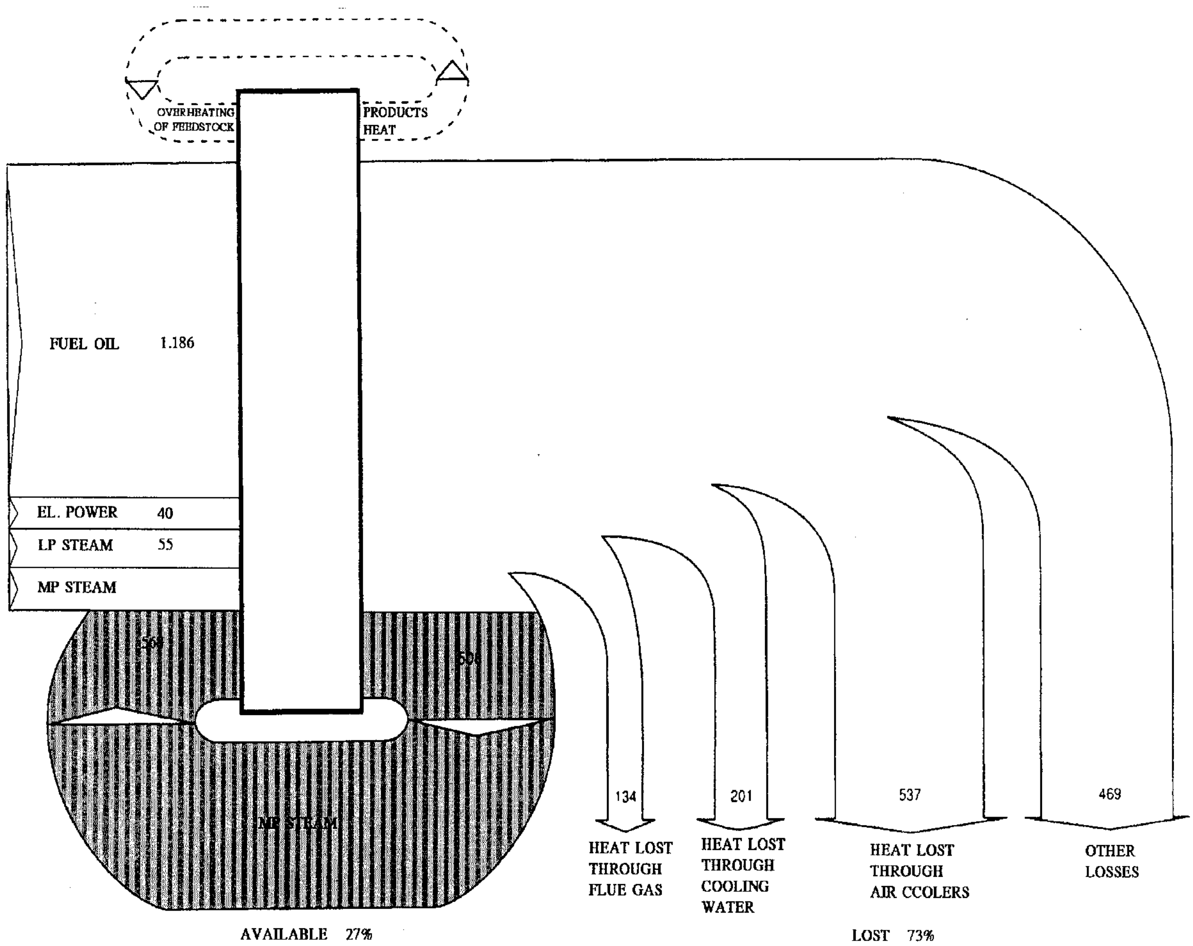

Figure 4. Senky diagram of energy flows of the Vacuum Distillation Process in a typical oil refinery in TJ/y

Table 1. Cost price of medium pressure (MP) steam

Item No.	Elements for calculation	Annual quantity t	Cost price US$/t	Total MP steam production in US$	MP steam consumption for Vacuum Distillation
1	2	3	4	5	6
1	MP steam supply from Refinery Power Plant	20 000	9.66	193 200	193 200
2	MP steam production	170 000	0.439	74 636	74 636
	2.1. Demineralized water 2.2. Depreciation 2.3. Current and investment maintenance 2.4. Insurance premium for equipment	170 000	0.165	28 050 38 821 4 659 3 106	28 050 38 821 4 659 3 106
3.	Total (1 + 2)	190 000	1.41	267 836	267 836
4.	Quantity in t				190 000
5.	Cost price in US$/t		1.41		

The difference between the gross and net power consumption appears with medium pressure steam due to the generation of this bearer of energy in the same process. The gross consumption of medium pressure steam is 190 000 t or 568 TJ or 29.308 GJ/t, the net consumption is 20 000 t or 60 TJ or 42.000 GJ/t, and the steam generation is 170 000 t or 508 TJ or 27.809 GJ/t.

DETERMINING THE COST PRICE OF MEDIUM PRESSURE STEAM PRODUCED IN THE VACUUM DISTILLATION PROCESS

The procedure of determining the cost price of medium pressure steam, produced in the Vacuum Distillation Process, is given in Table 1.

From Table 1, it can be seen that the cost price of MP steam generated in the Vacuum Distillation Unit is 0.44 US$/t.

The basic explanation for such cost lies in the fact that, in this particular plant, steam is obtained as a by–product by utilizing the heat of the flue gases in the boiler and the heat flux of the vacuum residue in the heat exchangers, thus offsetting the consumption of engine fuel (fuel oil or fuel gas). By its own generation of medium pressure steam, the Vacuum Distillation ensures 170 000 t or 508 TJ, i.e. about 90% of its own gross consumption which is 190 000 t or 568 TJ. The difference to the mentioned gross consumption of 20 000 t or 60 TJ is compensated by the refinery's Power Plant at a cost price of 9.66 US$/t.

By calculating the mentioned supplied quantity of medium pressure steam, the average cost price of medium pressure steam used for the consumption of Vacuum Distillation is 1.41 US$/t.

Significant differences between the cost prices can be seen (see Table 2) when comparing the cost price of medium pressure steam produced in the units: Vacuum Distillation, Vacuum Residue Visbreaking, Fluidized Catalytic Cracking and the Refinery Power Plant.

Table 2. Comparison between the cost prices of medium pressure steam produced in Vacuum Distillation, Vacuum Residue Visbreaking, Fluidized Catalytic Cracking and the Refinery Power Plant

Item No.	Type of steam	Cost price of steam produced in the refinery units			
		Vacuum Distillation	Visbre-aking	Catalytic Cracking	Power Plant
		US$/t	US$/t	US$/t	US$/t
1	Medium pressure steam	0.44	0.22	2.53	9.66

With the same level of plant depreciation, the basic reason of such cost price trends lies in the savings of fuel, as the most important element in the cost price calculation (Vacuum Distillation, Vacuum Residue Visbreaking and Fluidized Catalytic Cracking), and in the production of surplus steam supplied to other users (Vacuum Residue Visbreaking and Fluidized Catalytic Cracking). Therefore, in the Vacuum Distillation Unit and the Vacuum Residue Visbreaking Unit, for example, fuel consumption is completely eliminated, in the Fluidized Catalytic Cracking Unit partially eliminated, while in the cost calculation for steam obtained in the Power Plant, the fuel consumption share in the total cost price is approximately 80%.

This analysis is outlined in Table 3.

DETERMINING THE POSSIBLE MONEY SAVINGS OF ENERGY CONSUMPTION IN THE VACUUM DISTILLATION UNIT

Possible money savings which can be realized by eliminating the differences between the target standard (average energy consumption standard of UE refineries)

Table 3. Cost price and consumption of fuel in Vacuum Distillation, Vacuum Residue Visbreaking, Fluidized Catalytic Cracking and the Refinery Power Plant

Item No.	Type of steam	Vaccum Distillatior		Visbreaking		FCC		Power Plant	
		cost price	fuel cons.	cost price	fuel cons.	cost price	fuel cons.	cost price	fuel cons.
1	Medium pressure steam	0.44	–	0.22	–	2.53	2.4	9.66	8.09

Table 4. Target standard of energy net consumption and specific energy consumption in a typical Vacuum Distillation Unit (quantity of energy per one ton of feedstock)

Energy bearers	Target standard of net energy consumption		Specific energy consumption in the plant					
			Specific gross energy consumption			Specific net energy consumption		
			(kg/t) (kwh/t)[1]	per unit	total	(kg/t) (kwh/t)[1]	per unit	total
	(MJ/t)	(kwh/t)		(MJ/t)			(MJ/t)	
Fuels Fuel oil	*	–	14.1	558.9	558.9	14.1	558.9	558.9
Heat bearers LP steam MP steam	 * *	 – –	 9.0 89.0	 25.1 266.1	291.1	 9.0 9.5	 25 28.3	53.3
Sources of heat	432	–	–	–	850.0	–	–	612.2
Electric energy	18	5.0	5.2[1]	18.7	18.7	5.2[1]	18.7	18.7
Energy bearers	450	–	–	–	868.7	–	–	630.9

and the specific gross and net energy consumption of this refinery unit are very important and were determined as follows:

The specific consumption of medium pressure steam related by the quantity of light residue is:

$$\text{gross: } \frac{89\text{kg (steam)}}{\text{t(entering feedstock)}} \text{ or } 266{,}1 \frac{\text{MJ}}{\text{t(entering feedstock)}}$$

$$\text{net: } \frac{9{,}5\text{kg (steam)}}{\text{t(entering feedstock)}} \text{ or } 28{,}3 \frac{\text{MJ}}{\text{t(entering feedstock)}}$$

The target standard of net energy consumption and the specific gross and net energy consumption, in a typical Vacuum Distillation Unit, are outlined in Table 4.

Through the target standards presenting the average energy consumption standards in UE refineries, it is possible to compare the energy consumption standard of the plant analyzed.

If the specific net energy consumption of a typical plant is compared with the target standard, the following conclusion can be drawn:

1. The specific electric energy consumption (for mechanical necessities) is close to the target standard.

2. The specific net consumption of process and thermal energy (fuel and steam) amounts to 612.2 MJ/t exceeding the target standard (432 MJ/t) by 42%.

3. The total specific net energy consumption is 630.9 MJ/t which is 40% higher than the target standard (450 MJ/t).

Compared with the net energy consumption the target standard of a typical plant has an efficiency/inefficiency index of 140.

By eliminating the difference between the target standard (the average energy consumption standards of UE refineries) and the specific gross and net energy consumption of this refinery unit, significant money savings can be achieved, about 1.3 million US dollars (see Table 5).

From Tables 4 and 5, it can be concluded that the money savings which could be achieved by eliminating the differences between the specific net energy consumption and the target standards are 1273240 US$/y (2 122 065 t x 0.60 US$/t).

It can be concluded that the mentioned money savings are important, but at the same time, important money savings could be realized at the other refinery units as well, for example: at the Crude Unit the inefficiency index of which is 137, possible money savings are 4.7 million dollars per year, at the Vacuum Residue Visbreaking Unit the inefficiency index of which is 110, possible money savings are 0.4 million dollars per year, at the Fluidized Catalytic Cracking unit the inefficiency index of which is 116, possible money savings are 0,5 million dollars etc.(see Table 6).

From Table 6 it can be concluded that the important savings are possible in most crude oil processing units.

By observing the total refinery complex, it can be seen that possible money savings are 9.2 million dollars (see Table 7).

Table 5. Financial presentation of energy consumption and money savings in a typical Vacuum Distillation Unit (in US$)

Specific gross energy consumption			US$
Energy bearers	Quantity of entering feedstock (light residue)		
Fuel oil	2 122 065 t	(558.9 MJ/t x 0.00305 US$/MJ) =	3 617 367
Low pressure steam	2 122 065 t	(25.1 MJ/t x 0.003378 US$/MJ) =	179 926
Medium pressure steam	2 122 065 t	(266.1 MJ/t x 0.000472 US$/MJ) =	266 531
Sources of heat	2 122 065 t	**(850.1 MJ/t x 0.002253 US$/MJ) =**	4 063 824
Power energy	2 122 065 t	(18.7 MJ/t x 0.0167 US$/MJ) =	662 700
Energy bearers	2 122 065 t	**(868.8 MJ/t x 0.002564 US$/MJ) =**	**4 726 524**
Specific net energy consumption			US$/t
Fuel oil		(558.9 MJ/t x 0.00305 US$/MJ) =	1,704645
Low pressure steam		(25.0 MJ/t x 0.003378 US$/MJ) =	0,084450
Medium pressure steam		(28.3 MJ/t x 0.000472 US$/MJ) =	0,013358
Sources of heat		**(612.2 MJ/t x 0.002944 US$/MJ) =**	1,802453
Power energy		(18.7 MJ/t x 0.0167 US$/MJ) =	0,312290
Energy bearers		**(630.9 MJ/t x 0.003352 US$/MJ) =**	**2,114743**
Sources of heat			
Own net energy consumption		(612.2 MJ/t x 0.002944 US$/MJ) =	1.80
Target net energy consumption		(432 MJ/t x 0.002944 US$/MJ) =	1.27
Difference:			0.53
Energy bearers			
Own net energy consumption		(630.9 MJ/t x 0.003352 US$/MJ) =	2.11
Target net energy consumption		(450 MJ/t x 0.003352 US$/MJ) =	1.51
Difference:			**0.60**

Table 6. Total specific net energy consumption and target standard of net energy consumption in crude oil processing

Crude oil processing	Total specific net energy consumption MJ/t	Target standard of net energy consumption MJ/t	Index (in)efficiency (2:3)
1	2	3	4
Crude Unit	1095.5	800	137
Vacuum Distillation Unit	630.9	450	140
Vacuum Residue Visbreaking Unit	1325.2	1200	110
Bitumen	1626.7	1300	125
Catalytic Reforming	3232.2	2800	115
Fluidized Catalytic Cracking	1508.7	1300	116
Hydrodesulphurisation of jet fuel	1471.8	900	164
Hydrodesulphurisation of gas oil	11 30.4	800	141
Alkylation	11595.6	6000	193
Total processing complex	2384.9	1824.3	131

Table 7. Savings which can be realized by eliminating the differences between the target standard and self consumption (capacity of crude oil processing 5 000 000 t)

Item No.	Refinery units	Quantity of entering feedstock (t)	Difference target and self consumption (US$/t)	Possible money savings (US$)
1	2	3	4	5
1	Crude Unit	5 000 000	0.94	4 700 000
2	Vacuum Distillation Unit	2 122 065	0.60	1 273 239
3	Vacuum Residue Visbreaking Unit	973 085	0.40	389 234
4	Bitumen	94 314	1.16	109 404
5	Catalytic Reforming	380 605	1.44	548 071
6	Fluidized Catalytic Cracking	821 239	0.62	509 168
7	Hydrodesulphurisation of jet fuel	141 471	2.11	298 504
8	Hydrodesulphurisation of gas oil	244 419	1.24	303 080
9	Alkylation	59 053	19.30	1 139 723
10	Possible money savings			9 270 423

The mentioned money savings can be realized by using more efficient technological, energy and organizational solutions.

Namely, important possibilities for the rationalization of energy consumption exist because refineries were built at a time when energy was cheap and when investors did not devote more attention to the cost of energy.

These possibilities are:

1. Continually following energy costs,
2. Identify the places of non–rational energy consumption and make projects of energy savings,
3. The modernization of equipment and the introduction of computing management,
4. The reconstruction of existing equipment and intensification the maintenance process,
5. Continual expert instruction of operators and increasing the motivation and responsibility of workers,
6. Improve process management and direct engagement in the rationalization of energy consumption.

Such outlined possibilities present an important step in the rationalization of energy consumption and that is why they have an important role in strategic business management.

CONCLUSION

This technical/economic analysis of the Vacuum Distillation Process, from an energy point of view, outlines plant operation possibilities under optimal energy conditions, which are proportional to its economic aspects.

Also, by analyzing and comparing the UE refineries, it became possible to set a target standard for energy consumption and to determine possible savings.

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IZVOD

TEHNOLOŠKE I ENERGETSKE KARAKTERISTIKE PROCESA VAKUUM DESTILACIJE NAFTE

(Stručni rad)

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U radu su date tehnološke i energetske karakteristike procesa vakuum–destilacije za odabranu tipsku rafineriju nafte kapaciteta primarne prerade pet miliona tona godišnje.

Na osnovu neto i bruto potrošnje energije vodene pare, izračunata je cena koštanja vodene pare srednjeg pritiska koja se troši u procesu vakuum–destilacije. Dato je i poređenje ove cene koštanja sa cenama koštanja vodene pare u procesima termičkog razređivanja vakuum ostatka, katalitičkog krekovanja i u rafinerijskoj energani.

Takođe, data je mogućnost upoređivanja normativa potrošnje energije analiziranog postrojenja sa ciljnim normativima.

Key words: Energy management • cost • target standard • steam • money • energy savings • Vacuum distilation • crude oil • refining.

Ključne reči: potrošnja energije • cena • standardi • ušteda • vakuum destilacija.