STUDIA UNIVERSITATIS BABEȘ-BOLYAI, CHEMIA, XLVII, 1-2, 2002

Dedicated to Professor Ionel Haiduc
on the occasion of his 65th birthday

HYDROGEN GAS SEPARATION SYSTEM OPTIMISATION IN HYDROTREATING PLANTS

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ABSTRACT. Actual study reffers to the eficiency of main four separating systems from the most new high performance hydrotreaters.The principal performance criterions are: purity of hydrogen separated, eficient heat integration, lower overall costs due to savings heat exchanger surface, separator investment and operation costs.The data are processed with two important simulation programs: PRO II 3.3, CHEMCAD 5.0.The results of the study show that the design for reactor effluent separation into gas and liquid streams has major impacts on plant operability and economics for both new and revamped units.

1. GENERAL CONSIDERATIONS ABOUT HYDROGEN RICH GAS MAIN SEPARATION SYSTEMS FROM HYDROTREATING PLANTS

Hydrotreating of oil cuts represents a catalytic process to eliminate compounds like: sulphur, oxigen and nitrogen which are transformed in water, hydrogen sulphide and ammonia. The application of this process in oil industry was stimulated by the sources of hydrogen from the catalytic reforming process in the reffinery.

The hydrotreating process includes the next three steps (fig. 1): reaction, phases separation and stripper column step.In this process between reactor and stripper column an important role have phases separators which ensure the separation of hydrogen rich gas, gas that with the completion hydrogen becomes recycle in process.

The literature recommend four separation systems of the phases from effluent reactor.

♦ System 1 (fig. 2) includes a cold low pressure separator (CLPS) (pressure: 39 bar, temperature: 52^0C). The reactor effluent is cooled through 2 heat exchangers before entering in the separator. The first cooling step of effluent is ensured by heat exchanger E1, cooling agent is the liquid fraction from the separator F1 which is heated to 255^0 C, stripper column entering temperature. In heat exchanger E2 the effluent reactor is cooled using untreated diesel oil (feed of the reactor) like cooling agent, which is preheated before entering the fired heater. The gas phase which result from separator F1 is compressed with C1 compressor to the desulphurization system with MEA and becomes recycle in process.

- System 2 (fig. 3) includes 2 separators: a hot high pressure separator (HHPS) F1 (pressure:41 bar, temperature:191^0C) followed by a cold low pressure separator (CLPS) F2 (pressure:39 bar, temperature: 52^0C). The reactor effluent is cooled through 2 heat exchangers before entering in the first separator F1. The first cooling step of effluent is ensured by the heatexchanger E1, cooling agent is the total liquid fraction from separators F1, F2 which is heated to 255^0C, stripper column entering temperature. In heat exchanger E2 the effluent reactor is cooled using untreated diesel oil (feed of the reactor) like cooling agent, which is preheated before entering the fired heater. Between separators F1 and F2 the gas phase resulted from F1 is cooled in aircooler E3. The hydrogen rich gas separated from F2 is compressed with C1 compressor to the desulphurization system with MEA and becomes recycle in process.

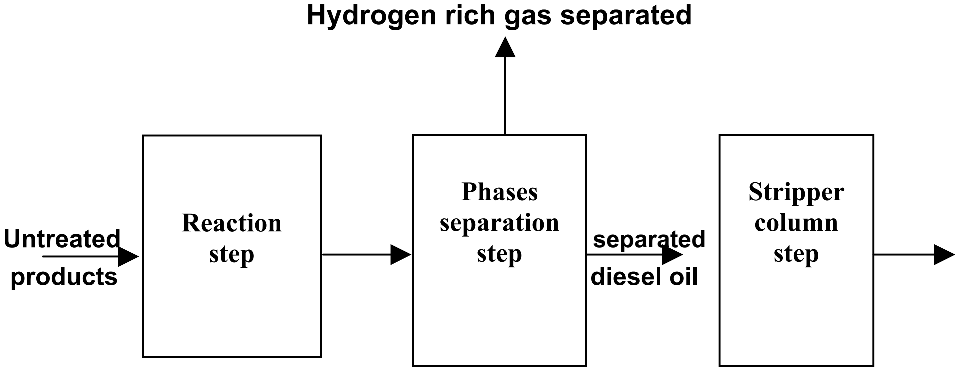

Fig. 1. Main steps of hydrotreating process

- System nr 3 (fig.4) includes 2 separators: a cold high pressure separator (CHPS) F1 (pressure: 39 bar, temperature: 52^0 C) followed by a cold low pressure separator F2 (CLPS) (pressure: 4.5 bar, temperature: 52^0 C). The reactor effluent is cooled through 2 heat exchangers before entering in the separator F1. The first cooling step of effluent is ensured by the heat exchanger E1, cooling agent is the total liquid fraction from separator F2 which is heated to 255^0C, stripper column entering temperature. In heat exchanger E2 the effluent reactor is cooled using untreated diesel oil (feed of the reactor) like cooling agent which is preheated before entering the fired heater. Hydrogen rich gas separated from F1 is compressed with C1 compressor to the desulphurization system with MEA and after that becomes recycle in process. The gas separated from separator F2 is used like fuel gas.
- System 4 (fig.5) includes 4 separators: a hot high pressure separator (HHPS) F1(pressure: 41 bar, temperature: 191^0C) followed by a cold low pressure separator (CLPS) F2 (pressure 39 bar, temperature: 52^0C), a

hot high pressure separator (HHPS) F3 (pressure: 6 bar, temperature: 191^0C), followed by a cold low pressure separator (CLPS) F4 (pressure: 4.5 bar, temperature: 52^0C). The reactor effluent is cooled through 2 heat exchangers before entering the first separator F1. The first cooling step of effluent is ensured by the heatexchanger E1, cooling agent is the total liquid fraction from separator F3 which is heated to 255^0C, stripper column entering temperature. In heat exchanger E2 the effluent reactor is cooled using untreated diesel oil (feed of the reactor) like cooling agent, which is preheated before entering the fired heater.Between separators F1 and F2 the gas phase resulted from F1 is cooled in aircooler E3 and between separators F3 and F4 the gas phase from F3 is cooled in the aircooler E4. Hydrogen rich gas separated from F2 is compressed with C1 compressor to the desulphurization system and becomes recycle in process. The gas phase from F4 separator is used like fuel gas. [1, 2, 3]

2. SIMULATION OF SEPARATION SYSTEMS TO GET THE OPTIMUM VARIANT

The aim of the present study is the technical and economic analysis of the four hydrogen separation systems to identify the optimum variant. In order to simulate the four separation systems were used two important simulation programs: PRO II 3.3 and CHEMCAD 5.0 and data from industrial process of diesel oil hydrotreating. The properties of untreated cycle oil and products resulted from the hydrotreating process are presented in tables nr: 1, 2 and 3. Other input data about the streams of the reactor are presented in the table nr 4.

Table nr. 1

ASTM D86 curve for untreated diesel oil

T, ^{0} C	180	215	240	264	285	321	360
% vol	0	10	30	50	70	90	97
d_4^{20}=0.835 g/cm^3							

Table nr. 2

ASTM D86 curve for hydrotreated diesel oil

T, ^{0}C	179	213	244	260	284	324	362
% vol	0	10	30	50	70	90	97
d_4^{20}=0.827 g/cm^3							

Table nr. 3

ASTM D86 curve for gasoline

T, C	47	118	157
% vol	0	50	97
d_4^{20}=0.827 g/cm^3			

Table nr. 4

Input and output reactor flow rates

Compounds	Diesel oil	Hydrogen rich gas from R.C	Input reactor flow rate	Output reactor flow rate
	kg/h	kg/h	kg/h	kg/h
H_2		6422	6422	5622
H_2S				2211
C1		10580	10580	10660
C2		5801	5801	6551
C3		3649	3649	4489
iC4-nC4		1626	1626	2130
iC5-nC5		3428	3428	2886
GASOLINE				8257
DIESEL OIL	138800		138800	127500
TOTAL	138800	31506	170306	170306
REACTOR PARAMETERS : PRESSURE: 66 bar TEMPERATURE: 326^0C				

The main data from the simulation used to identify the optimum variant of separation system are:

- Separators costs
- Heat exchangers duty
- The flowrate and purity of hydrogen rich gas separated
- Liquid flowrate before entering into stripper column
- Temperature of cycle oil (feed of the reactor) preheated, with influence to fired heat duty

All this data are presented in tables nr. 5 and nr. 6.

Analysing the data from table nr 5 comes out the next conclusions:

- From the viewpoint of separators costs, system nr 1 is the most advantageous and system nr 4 the most expensive, price diference between system nr 1 and nr. 4 is 170000 USD.
- Analysing the heat exchangers surfaces, system nr 4 is the most advantageous using the smallest total heat exchanger surface, being followed by the system nr 2 due to savings of heat exchanger total surfaces. System nr.4 has an efficient heat integration due to elimination of excessive cooling and lower overall costs due to savings in heat exchanger surfaces.

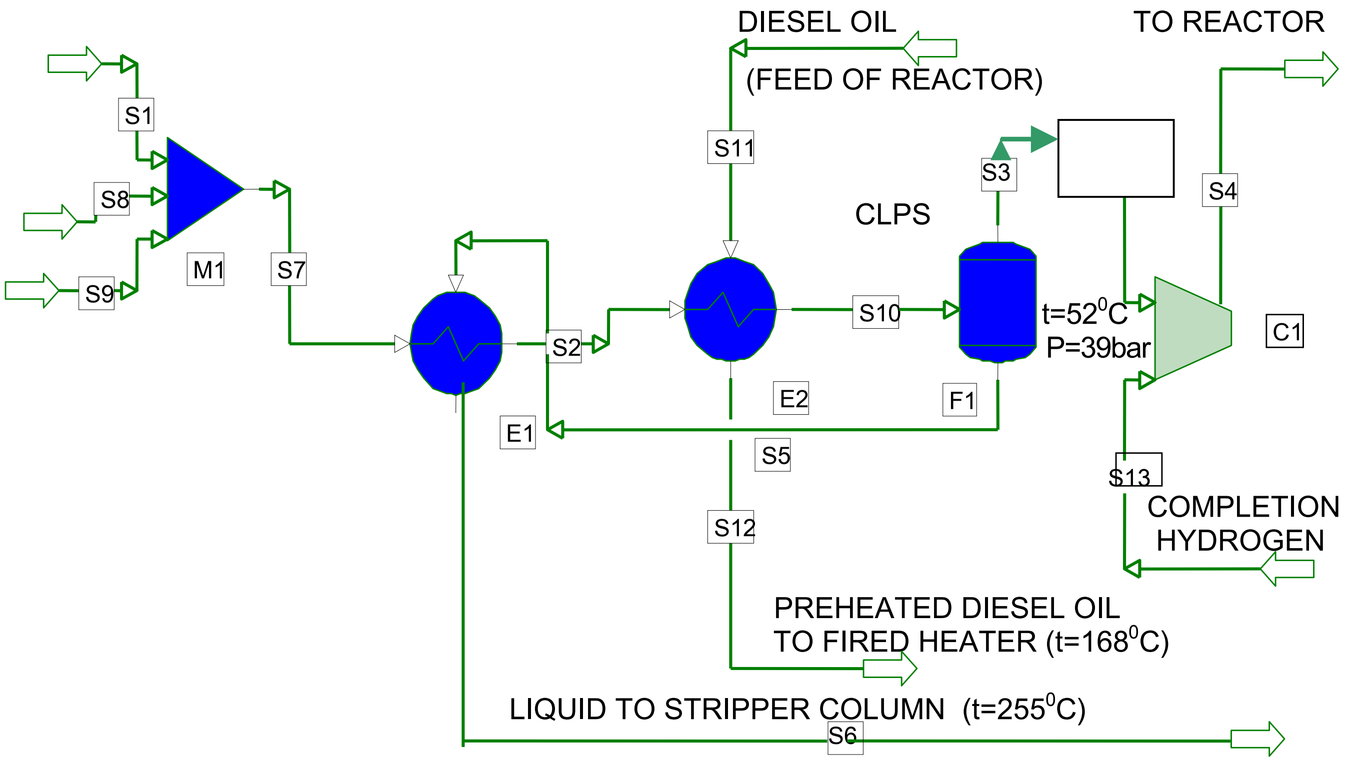

Fig. 2 SEPARATION SYSTEM NR. 1

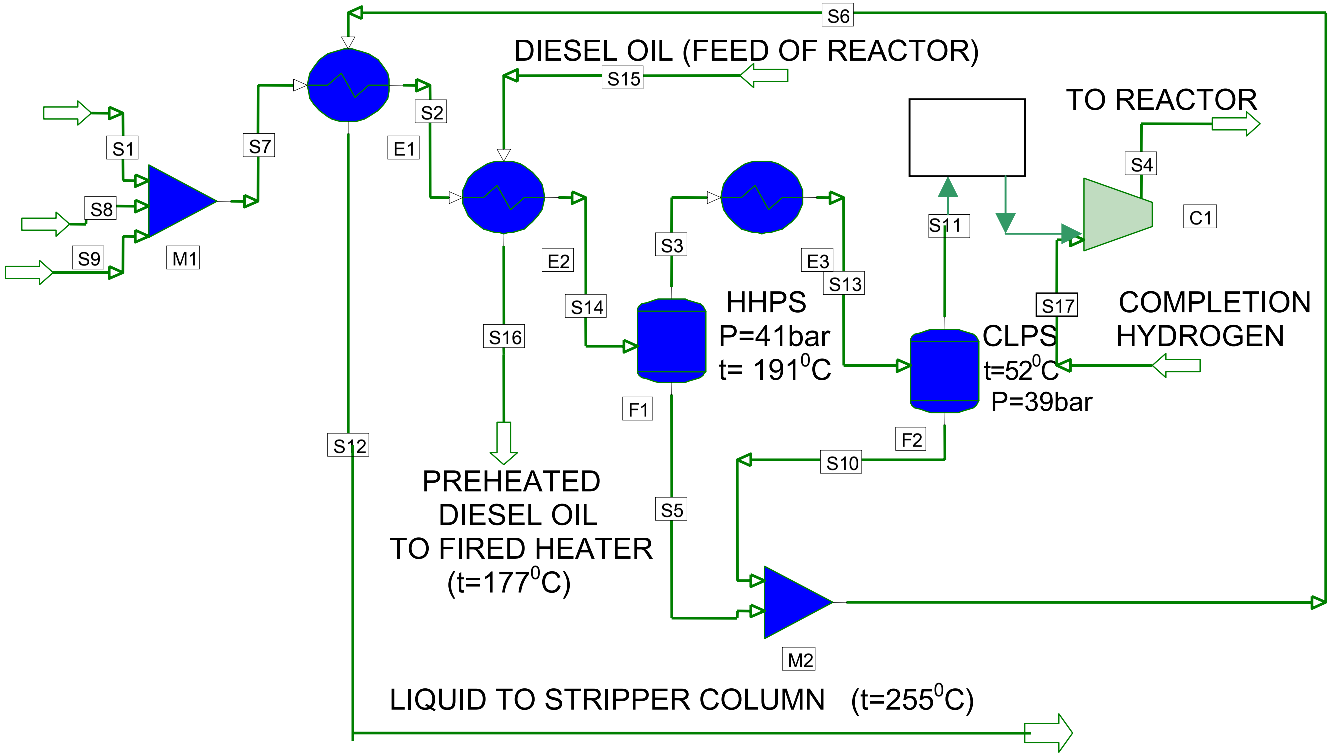

Fig. 3 SEPARATION SYSTEM NR. 2

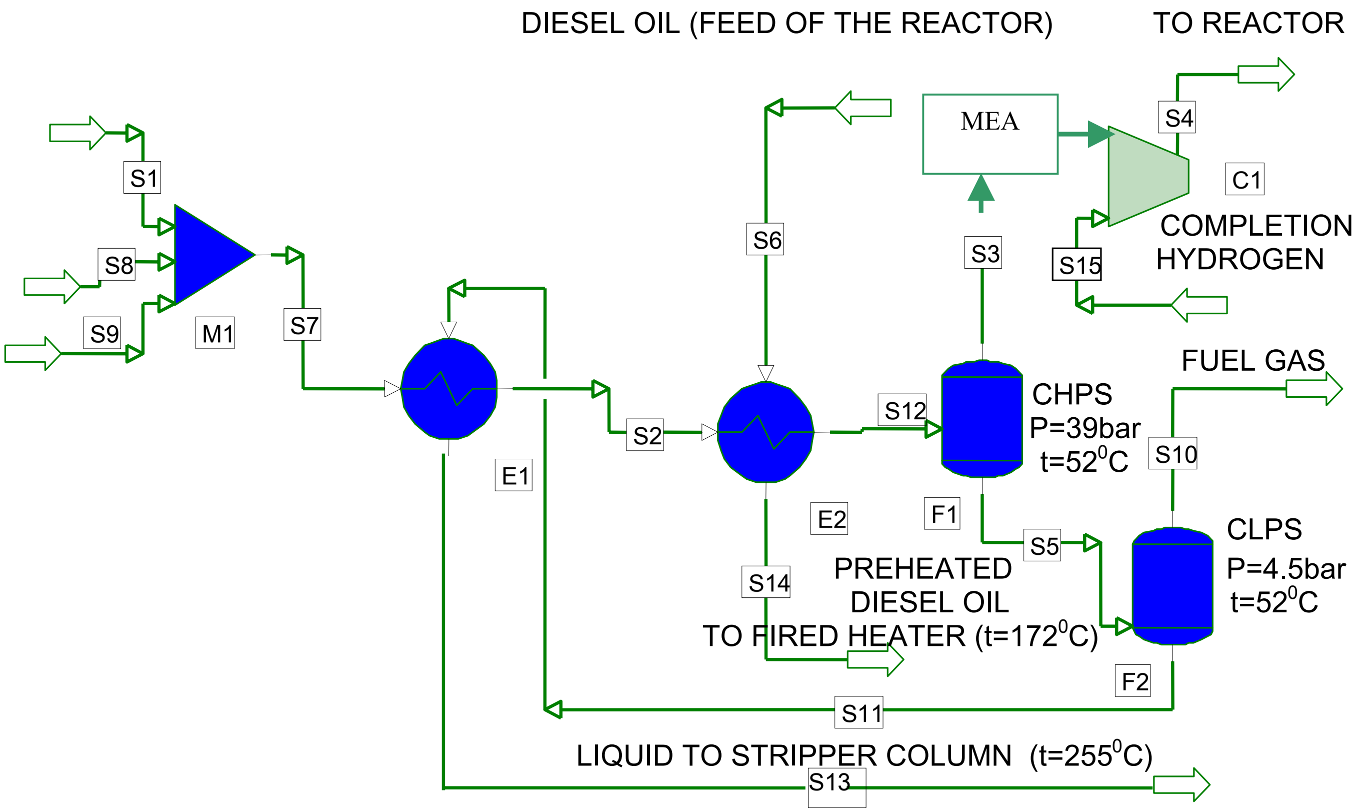

Fig.4 SEPARATION SYSTEM NR. 3

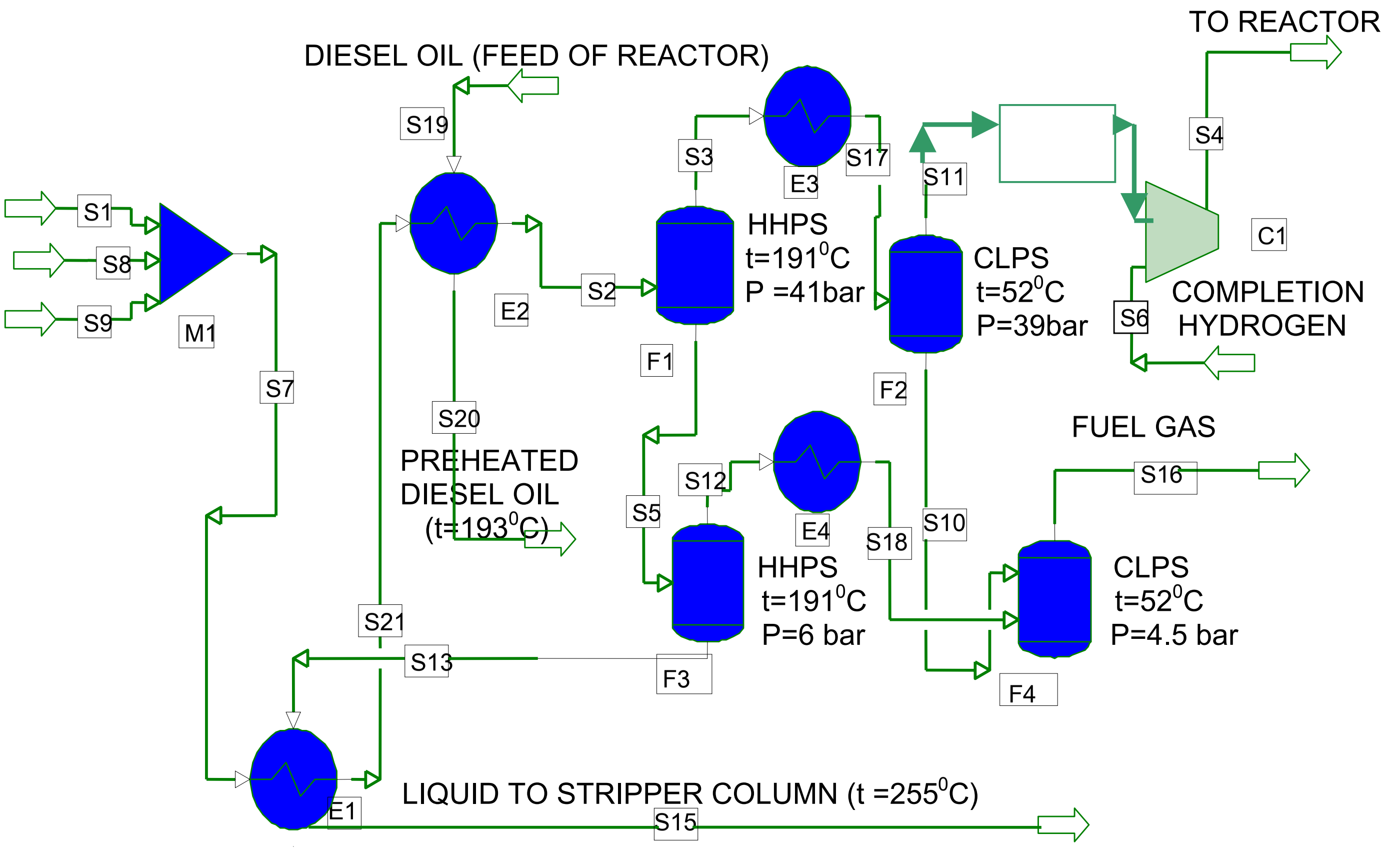

Fig.5. SEPARATION SYSTEM NR. 4

Table nr. 5

Separators costs, duty and total surfaces of heat exchangers (simulation output data)

Separation system	Separators costs, USD	Ratio separators costs to system 1	Heat exchanger		Total heat exchangers surfaces, m^2	Ratio heat exchangers total surfaces to system 4
			Duty, $W*10^{-5}$	Surfaces, m^2		
1	208826	1	E1:198	724	1663	1.67
			E2:182.23	939		
2	200256	1.26	E1:76	364	1004	1.01
	63026		E2:122	336		
	Total:263282		E3:73	304		
3	208826	1.4	E1:190.69	775	1784	1.79
	84364					
	Total:293190		E2: 206.73	1009		
4	200258	1.83	E1: 137.67	394	997	1
	63026		E2: 59.84	289		
	84096		E3: 72.66	304		
	34379		E4: 2.46	10		
	Total: 381759					

Table nr. 6

Flowrate and purity of hydrogen rich gas; flowrate of the liquid to stripper column and temperature of preheated diesel oil (simulation output data):

Separation system	Hydrogen rich gas separated flowrate (to desulphurization), kg/h	Purity of hydrogen rich gas separated, mol. fr.	Hydrogen rich gas flowrate without hydrogen sulphide, (ecycle), kg/h	Purity of hydrogen rich gas (recycle), mol. fr.	Flowrate of hydrogen rich gas(feed of the reactor, H_2 recycle+ completion) kg/h	Purity of hydrogen rich gas (feed of the reactor), mol. fr.	Liquid product flowrate to stripper column, kg/h	Liquid product flowrate ratio to system 4	Preheated diesel oil temperature, ^0C
1	28434	0.738	26223	0.745	27057	0.769	141872	1.14	168
2	32941	0.720	30730	0.736	31582	0.762	137365	1.1	177
3	28434	0.738	26223	0.745	27057	0.769	140397	1.12	172
4	32941	0.720	30370	0.736	31582	0.762	124874	1	193

From the data presented in table nr 6 comes out the next conclusions:

- System nr 4 is the most advantageous from the viewpoint of diesel oil preheated .The temperature of diesel oil resulted from system nr 4 is higher than in other 3 system cases .The fired heater duty is lowest.
- The flowrate of liquid which enter into stripper column is the lowest at system nr 4 because of the oportunity to flash off light fractions from the liquid phase whithout going into column .This offloads the column and the overhead compressor system significantly. [4]

- From the viewpoint of hydrogen gas purity the differences between all four systems are not important.

As results, it is obvious that system nr 4 although is more complicated like design and require a higher cost for the separators with 83%, (170000 USD) more than system 1 case, the savings due to heat exchangers total surfaces; offloading the columns and the overhead compressor and especially lower overall fired heater duty (because of preheated cycle oil temperature); it reduces the fired heater duty with 2 400 000 Kcal/hour, that represents 230 kg fuel less (for fired heater)/hour with value 230 000 USD/ year, recommend system nr. 4 as the optimum variant for both new and revamped hydrotreating plants. [5]

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