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Energy and Thermo-Economic Analysis of Crude Oil Gathering Station and Hydrocarbon Transport

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ABSTRACT

The decline in Indonesia's national crude oil production which is directly proportional to the increase in production operational costs has an impact on reducing state revenues from oil and gas revenue sharing funds. One of the efforts that can be done to eliminate losses from this sector is to conduct energy analysis and exergy analysis to determine the locations where energy and exergy losses occur which are then converted into economic costs in the upstream oil and gas business in the form of losses operating costs. Energy and exergy analysis in this study was conducted at a crude oil collection station and hydrocarbon transportation facility at CPP Blok, Riau, Indonesia. The results showed that the largest energy flow was found in the wash tank, which was 183.546 KW, the shipping pump was 240346.34 KW, and the heater was 398.4 KW. The largest exergy destruction occurred in washing tanks of 73,418 KW, shipping pumps of 0.319 KW and heaters of 0.363 KW, with a total exergy destruction cost of all equipment of 64,243.29 USD/year.

1. Introduction

Indonesia's crude oil production has continued to experience a decline in production over the last 10 years, from 346 million barrels (946 thousand barrels per day) in 2009 to 283 million barrels (778 thousand barrels per day) in 2018. The decline in crude oil production is due to aging, old facilities, new sources of oil reserves have not been discovered and high production costs, especially from energy costs, have an impact on state revenues [1-3]. Energy resource awareness is carried out by reviewing energy policies and taking effective actions to reduce waste by using energy conversion devices and developing new techniques to better utilize existing limited resources [4].

One component of routine operational costs is the enormous energy cost to drive the production pump motor and heater. Therefore, the evaluation of thermal energy systems and economic principles becomes very important for industry and researchers to reduce operating costs and increase efficiency of thermal energy systems.

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The exergy will decrease during the energy transformation due to the irreversibility process, which is proportional to the increase in the exergy-destruction cost. So that what happened has encouraged the development of a thermo-economic theory or exergy-economy, where exergy in thermodynamic units will be converted into economic quantities in the form of operational costs [5]. Exergy-economy as a method to assess the effectiveness and inefficiency of the system caused by exergy annihilation can be developed optimization techniques to reduce the cost of exergy destruction that occurs where several economic components need to be known and taken into account such as initial investment, operational costs, total energy costs of primary fuels and electricity requirement [6].

Exergy analysis can be developed to assess the exergy lost/destroyed during the process for each component of the equipment and by utilizing economic analysis to evaluate the costs incurred due to irreversible processes including investment, operation and maintenance costs, fuel costs and energy usage for each of the equipment in the process all sub-systems [7].

Research related to exergy analysis in the upstream oil and gas industry has been carried out by previous researchers, Al-Muslim *et al.,* [8], conducted an exergy analysis on a two-stage crude oil refining facility, it is known that the largest part of the irreversible energy loss in the heater is on average 71.5 MW, total energy loss of 241 1 MW on average, with an average energy efficiency of 0.315 [8]. Meanwhile, Rivero *et al.,* [9] conducted an exergy-economic analysis of crude oil facilities combined with distillation where the total energy loss was 111.08 MW and the total efficiency was 13.56% with an electrical composition of 1.4% (1.13 million USD per year), water treatment 2% (0.18 million USD per year) of the total production cost of 923.18 million USD per year [9].

Another researcher, Sajedi *et al.,* [10] conducted an energy analysis at Shazand-Arak, a crude oil collection station and refinery unit in Iran, from the largest total energy consumption of 314.94 MW which was used to heat 150.56 MW with energy loss by 6% in the pre-heat section and 24% in the main heater [10]. Voldsund *et al.,* [11] performed an exergy analysis of North Sea offshore platform operations, the largest exergy loss in the production manifold was 4600 kW, the decompression or pumping process was 4150 kW and water injection was 10,400 kW. The specific power consumption is 179±3 kWh/Sm^3 and the energy efficiency is 0.13±0.02 and by computer modeling 35-38% of the exergy loss is in the oil and gas processing facilities [11,12].

Nguyen *et al.,* [13] analyzed energy and exergy at the old facility of the Draugen offshore platform with results showing that the greatest energy losses occurred in processing (51%), recompression or pumping (12%) and production manifold (10%) [13]. DeOliveira and VanHombeeck [14] analyzed exergy at hydrocarbon collection stations and transportation facilities on offshore platforms in Brazil where exergy efficiency was 0.95, heating efficiency was 0.85 and electricity consumption was 835.3 kW and 28,190.6 kW, respectively [14].

Liu *et al.,* [15] conducted an energy and exergy analysis on a hydrocarbon transport piping system in Northeast China consisting of heating, pumping, and piping processes where the exergy losses were 18,760 MJ/hour, 2723.2 MJ/hour and 3397.1 MJ/hours, respectively. Energy lost is 24.8840 MJ/hour and the total cost of energy consumption is 16.352 yuan/hour [15].

Lu and Zhu [16] analyzed energy at the Chun Liang China gathering station where the electricity consumption was 30-40% of the total consumption, and the electricity consumption per unit was 6,581 kwh/t [16]. These results are close to the analysis of energy and exergy collection stations and transportation systems for crude oil delivery in the Zhao II Daqing oil field conducted by Kou and Yang 2012, where the percentage of exergy lost in the gathering process is 29.29%, treatment and water injection is 30.69%, and hydrocarbon transport was 27.28% of exergy is lost in the form of heat and pressure [17]. Meanwhile, Cheng *et al.,* [18] analyzed the economic exergy at a gathering station and transportation station in East China, where 579.11 yuan/GJ was the economic value of exergy lost in the form of pressure and 1,243.39 yuan/GJ was the cost of exergy heat lost [18,19].

Operating parameters such as temperature and fluid enthalpy can be varied to determine their effect on the net power output and energy wasted from the system so that with this exergy analysis new designs can be made [20]. Where in a new design it is necessary to calculate the rate of return that is adjusted to the equity of the project [21].

Exergy analysis and exergy economics can describe a number of energy losses that occur in each equipment in each operating process in the upstream oil and gas industry. The results of this analysis can be used by companies to cut the flow of exergy losses that occur so that companies can increase profits by reducing the costs of exergy annihilation losses. The current decline in the production of the upstream oil and gas industry in Indonesia will result in a decrease in company revenues so that an increase in the effective use of energy and energy and suppressing the destruction of energy that occurs will be very important for the sustainability of the company's operations by reducing the flow of operating costs losses through the implementation of efficiency in sub-processes that suffer from exergy damage and excessive energy consumption.

2. Methodology

In this study, namely by describing the object or subject according to actual conditions with the aim of describing the facts and characteristics of the object of research and quantitatively using mathematical variables. Direct observation on the object in accordance with the scope of research and theory as a supporter of research based on the scope of the discussion. Identification of energy use and waste from each sub-process of the research object including motors, pumps, tanks, pipes and electrical heaters and compared with the output performance of the equipment.

Primary data are daily average operating data for 75 days from October 1, 2021 to December 15, 2021 from each equipment in the form of exergy flow and energy consumption, operating input parameters and operating output parameters, exergy flow, and form of exergy transfer (heat, work and mass).

Data analysis was carried out through the following stages

i. The planning stage is in the form of a research proposal which is a literature study and formulating problems, designing research and action plans.
ii. The research stages are in the form of field measurements, comparing and adjusting the data obtained with the literature, processing the data and conducting data analysis.
iii. The analysis stage is to find the right optimization method based on the research results obtained.

2.1 Mathematical Analysis

Energy analysis is carried out using the principle of conservation of energy which states as follows: The net change (increase or decrease) in the total energy of the system during a process is equal to the difference between the total energy in and the total energy out. system during that time or energy balance can be written as follows [22]

$$E_{in} - E_{out} = \Delta E_{system} \tag{1}$$

Energy can be transferred in the form of heat, work, and mass, where the amount of energy transferred is equal to the difference in the amount of energy entering and leaving which is called energy balance as follows [22]

$$E_{in} - E_{out} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}) + \left(E_{mass,in} - E_{mass,out}\right) = \Delta E_{system} \quad (2)$$

Exergy balance in a control volume differs from that of a closed system in that it involves an exergy transfer mechanism, i.e., mass flow across boundaries. The general exergy balance for volume control is [22]

$$X_{heat} - X_{work} + X_{mass,in} - X_{mass,out} - X_{destroyed} = (X_2 - X_1)_{cv} \quad (3)$$

The principle of decreasing exergy is the opposite of the principle of increasing entropy or equivalent to annihilation of exergy which occurs where there is no transfer of energy and entropy in an isolated system because no heat, work, or mass crosses the boundary of the isolated system. So, the energy and entropy balance for an isolated system is expressed as [22]

Energy balance

$$E_{in}^{0} - E_{out}^{0} = \Delta E_{system} \Longrightarrow 0 = E_2 - E_1 \quad (4)$$

Exergy balance

$$S_{in}^{0} - S_{out}^{0} + S_{gen} = \Delta S_{system} \Longrightarrow S_{gen} = S_2 - S_1 - T_0 S_{gen} = E_2 - E_1 - T_0(S_2 - S_1) \quad (5)$$

So that

$$X_2 - X_1 = (E_2 - E_1) - T_0(S_2 - S_1) \quad (6)$$

Exergy costing is the main idea of Thermo-economics which states that exergy is the only rational basis for assigning costs to the interaction of a thermal system with the surrounding environment and this is an inefficiency in the system. If a system has more than one product, such as a gas boot at a collection station, then by thermos-economic analysis, the cost of each product can be determined. One of the basic elements of thermo-economic principles is the cost balance, which is the cost for each transfer or change of energy. Conventional economic analysis formulates a cost balance for the entire system under stable operating conditions. The cost level relates to exergy flow, mass flow, power, or heat transfer while the investment, operation and maintenance cost variables represent all other costs is expressed as [23]

$$\sum_e \left(c_e \dot{E}_e\right)_k + c_{w,k} \dot{W}_k = c_{q,k} \dot{E}_{q,k} + \sum_i \left(c_i \dot{E}_i\right)_k + \dot{Z}_k \quad (7)$$

2. Results and Discussion

The flow of energy entering and leaving each static and rotating equipment can be described as follows

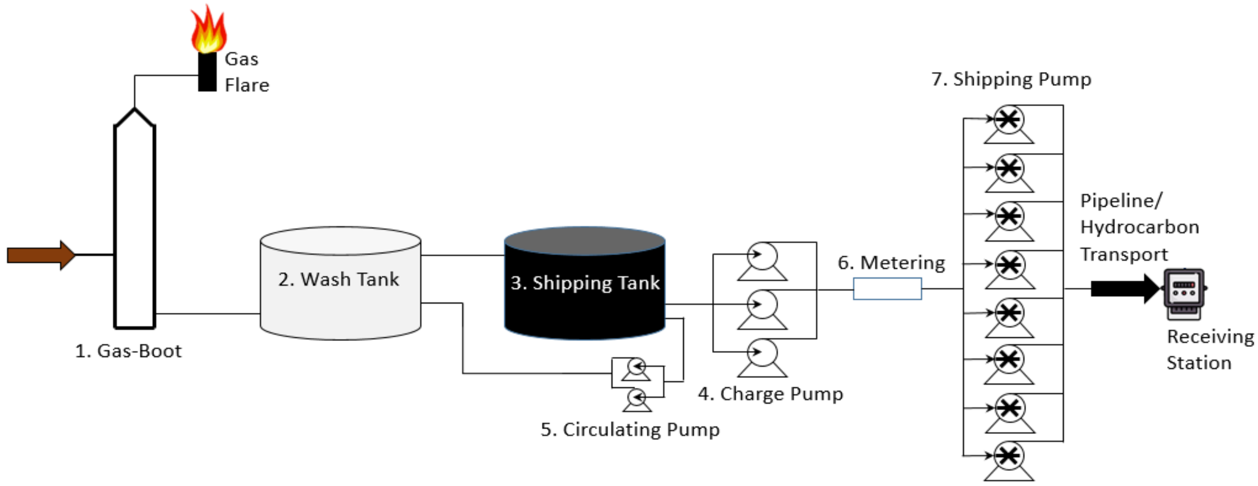

Fig. 1. Gathering station and shipping pump process flow

There is a certain amount of electrical energy consumed to drive electric motors where the daily average data for October, November and December are as follows

Table 1
Average operating data static equipment at gathering station

Month 2021	Gasboot Gs					Wash tank		Shipping tank		Metering	
	Incoming		Rate Fluida			Level (FT)	Temp. (°F)	Level (FT)	Temp. (°F)	Pressure (Psi)	Temp. (°F)
	Pressure (Psi)	Temp. (°F)	Water (Barrel/D)	Gas (Scf/D)	Crude (Barrel/D)						
Oct	29.16	183.26	226,088.35	87,006.55	4,334.19	21.18	178.15	7.80	159.06	120.03	156.75
Nov	29.50	182.37	223.429,27	86,999.83	4,367.00	21.00	176.77	8.12	151.33	120.00	148.93
Dec	29.47	181.87	223.253,73	87,005.40	4,375.47	21.00	176.53	9.93	155.73	120.00	153.33

Table 2
Average operating data rotating equipment at gathering station

Month 2021	Charge Pump					Shipping Pump				
	Suction		Discharge		Electrical	Suction		Discharge		Electrical
	Pressure (Psi)	Temp . (ºF)	Pressure (Psi)	Temp. (ºF)	Power (kW)	Pressure (Psi)	Temp. (ºF)	Pressure (Psi)	Temp. (ºF)	Power (kW)
Oct	32.0	158.1	120.0	157.7	152,120.5	118.7	156.8	137.2	157.0	260,139.0
Nov	32.0	150.3	120.0	149.9	152,120.0	118.7	148.9	122.0	165.2	230,450.0
Dec	32.0	154.7	120.0	14.3	152,120.0	118.7	153.3	125.9	165.1	230,450.0

Crude oil from the collector tank is routed to the final receiving station, where to keep the crude oil temperature above its pour point, 4 electric heating units (4 x 431 KW) are used along the pipeline every 10 kilometers (Figure 2).

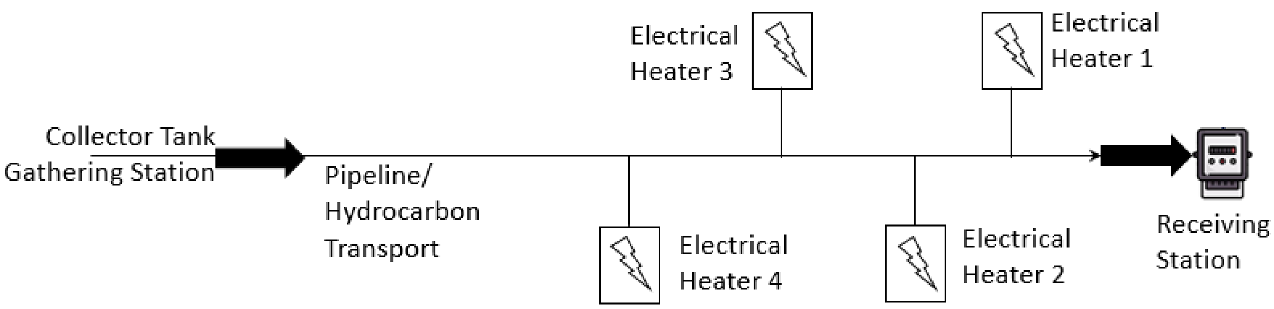

Fig. 2. Collector tank gathering station and hydrocarbon process flow

There is a certain amount of electrical energy consumed to pipe heaters (hydrocarbon sect feeding) where the daily average data for October, November and December are as follows:

Table 3
Average operating hydrocarbon transport

Month 2021	Outgoing Collector Tank GS		Hydrocarbon Pipeline Electrical Heater								Receiving Station	
	Press. (Psi)	Temp. (°F)	SF # 01		SF # 02		SF # 03		SF # 04		Press. (Psi)	Temp. (°F)
			Temp. (°F)	Electrical (kW)	Temp. (°F)	Electrical (kW)	Temp. (°F)	Electrical (kW)	Temp. (°F)	Electrical (kW)		
Oct	137.2	157.0	127.0	431.1	125.0	403.5	127.0	383.9	120.0	375.1	19.3	126.4
Nov	122.0	165.2	127.0	431.1	125.0	403.5	127.0	383.9	120.0	375.1	13.3	124.4
Dec	125.9	165.1	127.0	431.1	125.0	403.5	127.0	383.9	120.0	375.1	13.7	124.3

The operating conditions of static equipment are assumed to be stationary system with negative heat transfer direction or heat loss occurs, the volume of the equipment is statically constant and there is zero energy transfer in the form of work *($\Delta W=0$)* and without electricity power and other forms of work, so that by using Eq. (1) to Eq. (3) the following results are obtained

Table 4
Average energy and exergy destroyed static equipment at gathering station

Month 2021	Gas Boot		Wash Tank		Shipping Tank	
	Energy (Q_{out}) - kW	Exergy Destruction ($X_{Destr.}$) – kW	Energy (Q_{out}) - kW	Exergy Destruction ($X_{Destr.}$) – kW	Energy (Q_{out}) - kW	Exergy Destruction ($X_{Destr.}$) – kW
Oct	2.04	1.79	182.9	73.169	0.003	5.214
Nov	2.04	1.79	187.1	74.834	0.006	5.322
Dec	2.04	1.79	180.6	72.251	0.004	5.286
Average	2.04	1.79	183.3	73.418	0.005	5.274

Operation on the pump is a process at a constant temperature *($\Delta T=0$)* so that *$H=0$*, there is no transfer of energy in the form of heat *($\Delta Q=0$)* and work is done by the rotation of the motor shaft so that it is negative. By using Eq. (3) to Eq. (6), it is obtained as follows

Table 5
Average energy and exergy destroyed rotating equipment at gathering station

Month 2021	Gas Boot				Shipping Tank			
	W_{out} (kW)	$W(rev_{out,1})$ - (kW)	η_{pump} (%)	Exergy Destruction ($X_{Destr.}$) – kW	W_{out} (kW)	$W(rev_{out,1})$ - (kW)	η_{pump} (%)	Exergy Destruction ($X_{Destr.}$) – kW
Oct	21.09	68.80	0.31	47.72	21.09	0.60	5.24	21.68
Nov	21.09	75.39	0.46	54.30	21.09	3.89	5.42	24.97
Dec	21.09	67.01	0.31	45.92	21.09	2.99	7.05	24.08
Average	21.09	60.43	0.36	39.34	21.09	2.49	5.90	23.58

By using Eq. (3) and Eq. (6) where the height $z_1 = z_2 = 1$ meter where this subsystem is a steady flow process as the control volume, *$EP = 0$*. So that the calculation of the monthly average is obtained as follows

Table 6
Average energy and exergy pipeline hydrocarbon transport

Month 2021	Electrical Heater (Sect Feeding)								Q_{out} (kW)	Exergy Destruction ($X_{Destr.}$) – kW
	$X_{in,4}$ (SF # 01)		$X_{in,3}$ (SF # 02)		$X_{in,2}$ (SF # 03)		$X_{in,1}$ (SF # 04)			
	$W_{rev,in,1}$ (kW)	I_{in} (kW)	$W_{rev,in,1}$ (kW)	I_{in} (kW)	$W_{rev,in,1}$ (kW)	I_{in} (kW)	$W_{rev,in,1}$ (kW)	I_{in} (kW)		
Oct	32.99	398.11	34.87	368.63	34.46	349.44	28.70	346.40	0.02	0.36
Nov	32.99	398.11	34.87	368.63	34.46	349.44	28.70	346.40	0.03	0.36
Dec	32.99	398.11	34.87	368.63	34.46	349.44	28.70	346.40	0.03	0.36
Average	32.99	398.11	34.87	368.63	34.46	349.44	28.70	346.40	0.03	0.36

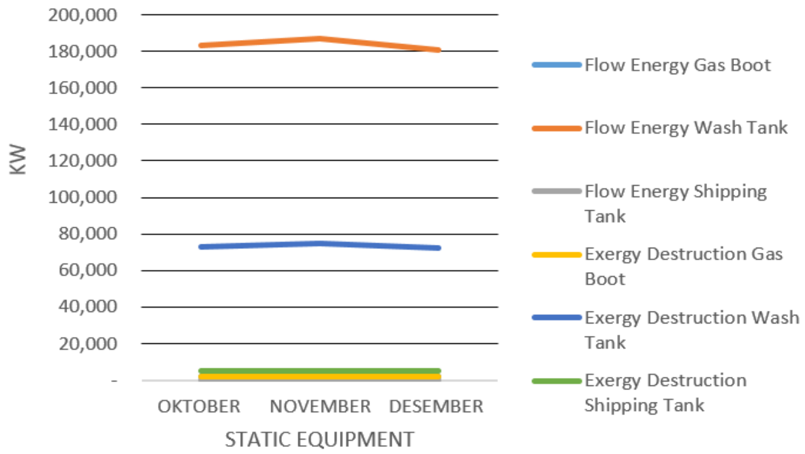

Fig. 3. Static equipment energy and exergy destruction charts (October-December 2021)

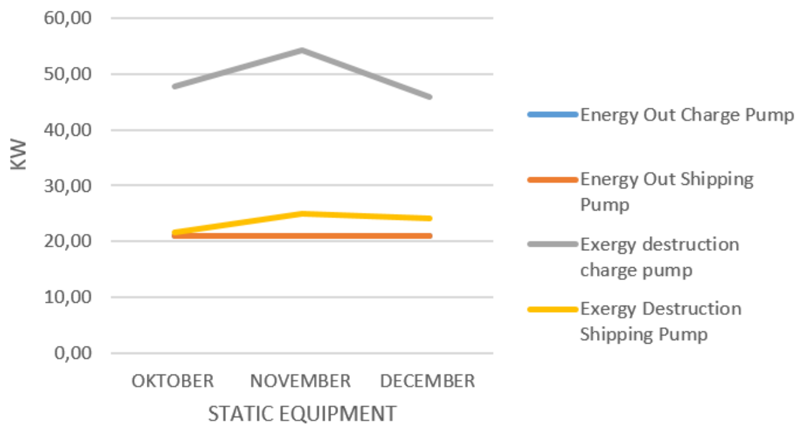

Fig. 4. Rotating equipment energy and exergy destruction chart (October-December 2021)

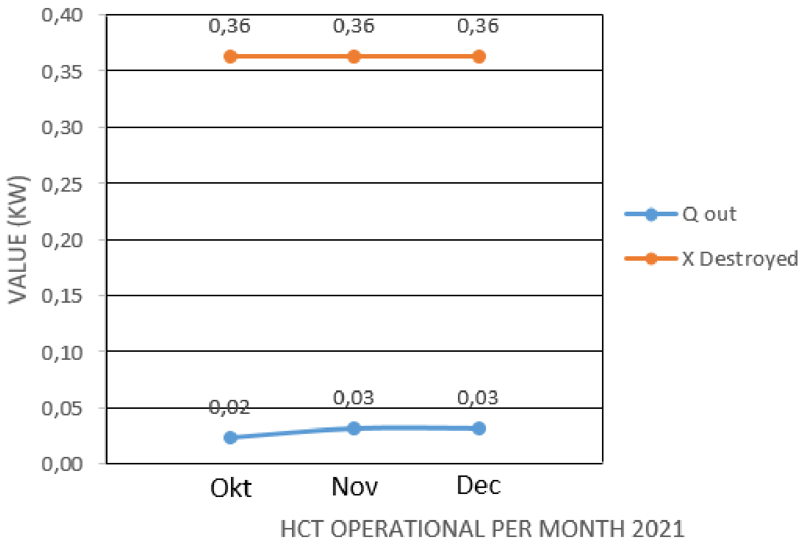

Fig. 5. HCT energy and exergy destruction Charts (October-December 2021)

By using the Grassman-diagram for exergy flow, the largest daily average for static equipment in the wash tank is 73.42 KW, on rotating equipment it occurs at the charge pump of 39.3 KW and shipping pump of 53.58 and hydrocarbon transportation of 0, 36 kW. The total daily exergy crushing is 171, 9727 KW, which is as follows

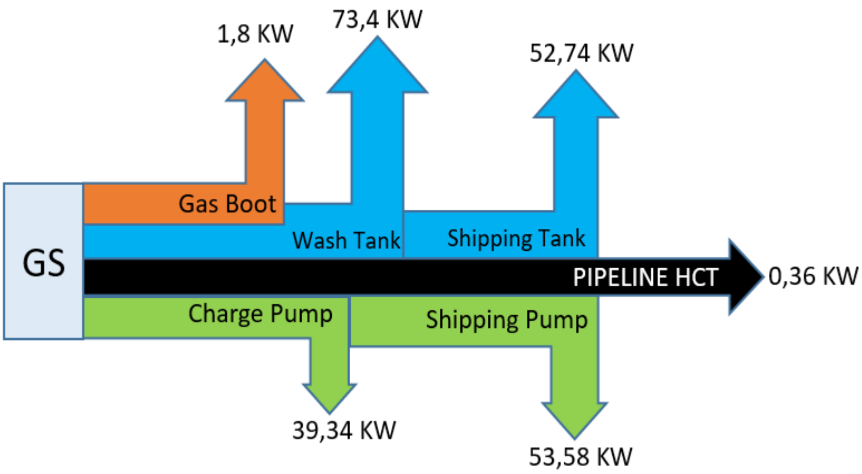

Fig. 6. HCT energy and exergy destruction charts for October-December 2021

From the calculation of exergy of destruction obtained, then converted into economic value, then obtained a number of costs that can be considered as operating losses due to energy that is not absorbed by the production equipment system, namely as follows

Table 7
Exergy-economic or thermos-economic equipment operated at GS & HCT

Components	Exergy Destruction (kW)	Exergy Destruction Cost Per Hour ($/h)	Exergy Destruction Cost Per Day ($/d)	Exergy Destruction Cost Per Year ($/y)
Gas Boot GS	1.79	0,16	3.86	1,408.96
Wash Tank GS	73.42	6.61	158.58	57,882.94
Shipping Tank GS	52.74	4.75	113.92	41,580.22
CHARGE PUMP GS	39.34	3.54	84.97	31,015.66
Shipping Pump GS	53.58	4.82	115.73	42,242.47
HCT Heater SF	0.36	0.03	0.78	283.82
Total	221.23	19.88	477.07	174,414.07

The biggest energy of static equipment on gas-boot of 104,654.92 kJ/day, rotating equipment on transfer pump of 571,95 KW and filter charge pump of 745,95 KW and sect feeding pipe heater of 2,948 kJ/s. There was some exergy destruction, the largest on static equipment occurred in wash tank 73,418 kwh, on rotating equipment on shipping pump 15,90 kwh and sect feeding pipe heaters 131.01 kwh. 3. The total value of losses due to exergy destruction is 174,414.97 USD/year where the cost of exergy destruction for static equipment in the wash tank is 57,882.94 USD/year, rotating equipment for shipping pump 42,242.475 USD/year and HCT pipe heaters 283.82 USD/year.

Based on the measurements and calculations as well as the results obtained from previous studies, it is necessary to re-examine to analyze the causes of temperature loss and pressure drop in each equipment. Inspection and measurement of insulation need to be considered considering the age of use of insulation is 40 years.

Based on measurement data and calculation of exergy analysis, the loss of a certain amount of exergy in the wash tank was caused by the loss of a certain amount of heat due to damage to a number of insulation tanks and a leak in the insulation plate which caused water to flow into the gap of the exergy insulation tank in a number of rotating equipment facilities caused by malfunction/damage check valve in the discharge position and the gate valve in the suction position due to corrosion due to long operating life.

Meanwhile, energy losses in shipping lanes are caused by the size of the pump design which is not proportional to the amount of crude oil produced, so that the pump operation is not stable due to the adjustment of the amount of crude oil collected in the collector tank so that some of the heat lost is absorbed by the pipes automatically by convection heat transfer because there will be a certain amount of fluid in the idle position (not flowing) when the pump is turned off.

3. Conclusions and Suggestions

The greatest energy in static equipment in the wash tank is 183.546 KW, in rotating equipment it is almost the same, namely 240346.3 KW and sect feeding pipe heaters 398.4 KW. There is some exergy destruction, the largest on static equipment occurs in wash tank 73.418 KW, on rotating equipment it is also relatively the same 0.319 KW and sect feeding pipe heaters 0.363 KW.

The total value of losses due to exergy crushing is 64,243.29 USD/year wherein exergy crushing costs for static equipment in the washing tank are 57,882.94 USD/year, rotating equipment 251 USD/year and HCT pipe heaters 290.29 USD/year.

This research can be developed in the future by conducting exergy-environment studies, namely the effect of exergy loss on the surrounding environment and combined with cost studies for remediation of polluted environments.

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References
[1] Purwatiningsih, Annisa. "Eksplorasi dan Eksploitasi Pertambangan Minyak dan Gas Bumi di Laut Natuna Bagian Utara Laut Yuridiksi Nasional Untuk Meningkatkan Kesejahteraan Masyarakat di Kepulauan Natuna." *Reformasi* 2, no. 2 (2012): 59-67.
[2] Suharyati, Suharyati, Sadmoko Hesti Pambudi, Jamaludin Lastiko Wibowo, and Nurina Indah Pratiwi. "Indonesia Energy Outlook 2019." *Secretary General of the National Energy Council* (2019).
[3] Sidemen, I Gusti Suarnaya. "Direktorat Jenderal Minyak Minyak dan Gas Bumi: Pangkas Regulasi Tingkatkan Investasi." *Jurnal Migas*, 2018. www.migas.esdm.go.id.
[4] Martin, Awaludin, Hamdani Wahab, and Mohammad Barbarosa. "Coalbed methane as a new source of energy in Indonesia and some developed countries; a review." *Journal of Ocean, Mechanical and Aerospace-Science and Engineering* 65, no. 2 (2021): 40-60. https://doi.org/10.36842/jomase.v65i2.242
[5] Yan, Chenglei, Liping Lv, Ali Eslamimanesh, and Weifeng Shen. "Application of retrofitted design and optimization framework based on the exergy analysis to a crude oil distillation plant." *Applied Thermal Engineering* 154 (2019): 637-649. https://doi.org/10.1016/j.applthermaleng.2019.03.128
[6] Ghafoor, A., and A. Munir. "Thermo-Economic Optimization of Solar Assisted Heating and Cooling (SAHC) System." *International Journal of Renewable Energy Development* 3, no. 3 (2014): 217-227. https://doi.org/10.14710/ijred.3.3.217-227
[7] Martin, Awaludin, Nur Indah Rivai, Rahmat Dian Amir, and Nasruddin Nasruddin. "Exergoeconomic Analysis of 21.6 MW Gas Turbine Power Plant in Riau, Indonesia." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 84, no. 1 (2021): 126-134. https://doi.org/10.37934/arfmts.84.1.126134
[8] Al-Muslim, H., I. Dincer, and S. M. Zubair. "Effect of reference state on exergy efficiencies of one-and two-stage crude oil distillation plants." *International Journal of Thermal Sciences* 44, no. 1 (2005): 65-73. https://doi.org/10.1016/j.ijthermalsci.2004.04.015
[9] Rivero, Ricardo, Consuelo Rendón, and Salvador Gallegos. "Exergy and exergoeconomic analysis of a crude oil combined distillation unit." *Energy* 29, no. 12-15 (2004): 1909-1927. https://doi.org/10.1016/j.energy.2004.03.094
[10] Sajedi, Syed Navid, Mir Esmaeil Masoumi, and Kamyar Movagharnejad. "Exergetic improvement and environmental impact assessment of crude oil distillation unit of Shazand-Arak oil refinery." *International Journal of Exergy* 16, no. 4 (2015): 464-480. https://doi.org/10.1504/IJEX.2015.069116
[11] Voldsund, Mari, Tuong-Van Nguyen, Brian Elmegaard, Ivar S. Ertesvåg, Audun Røsjorde, Knut Jøssang, and Signe Kjelstrup. "Exergy destruction and losses on four North Sea offshore platforms: A comparative study of the oil and gas processing plants." *Energy* 74 (2014): 45-58. https://doi.org/10.1016/j.energy.2014.02.080
[12] Nguyen, Tuong-Van, Tomasz Jacyno, Peter Breuhaus, Mari Voldsund, and Brian Elmegaard. "Thermodynamic analysis of an upstream petroleum plant operated on a mature field." *Energy* 68 (2014): 454-469. https://doi.org/10.1016/j.energy.2014.02.040
[13] Nguyen, Tuong-Van, Leonardo Pierobon, Brian Elmegaard, Fredrik Haglind, Peter Breuhaus, and Mari Voldsund. "Exergetic assessment of energy systems on North Sea oil and gas platforms." *Energy* 62 (2013): 23-36. https://doi.org/10.1016/j.energy.2013.03.011
[14] de Oliveira, Silvio, and Marco VanHombeeck. "Exergy analysis of petroleum separation processes in offshore platforms." *Energy Conversion and Management* 38, no. 15-17 (1997): 1577-1584. https://doi.org/10.1016/S0196-8904(96)00219-1
[15] Liu, Yang, Qinglin Cheng, Yifan Gan, Yuxin Wang, Zhidong Li, and Jian Zhao. "Multi-objective optimization of energy consumption in crude oil pipeline transportation system operation based on exergy loss analysis." *Neurocomputing* 332 (2019): 100-110. https://doi.org/10.1016/j.neucom.2018.12.022
[16] Lu, Meng Mei, and Jiao Zhu. "Study of Energy Optimization Technical Program of Zhao II Oil Transfer Station Gathering and Transportation System." In *Advanced Materials Research*, vol. 765, pp. 295-299. Trans Tech Publications Ltd, 2013. https://doi.org/10.4028/www.scientific.net/AMR.765-767.295
[17] Kou, Jie, and Wen Yang. "Study on Energy Consumption Analysis and Application of Oil Gathering Station." In *Advanced Materials Research*, vol. 524, pp. 1899-1904. Trans Tech Publications Ltd, 2012. https://doi.org/10.4028/www.scientific.net/AMR.524-527.1899

[18] Cheng, Qinglin, Zhidong Li, Chunguang Yu, Hao Wu, Lili Lv, Hongjun Xie, and Guoyu Ma. "Exergoeconomic analysis for crude oil gathering and transportation system in matrix pattern." *Energy Science & Engineering* 7, no. 5 (2019): 1557-1571. https://doi.org/10.1002/ese3.363

[19] Cheng, Qinglin, JinWei Yang, Anbo Zheng, Lu Yang, Yifan Gan, and Yang Liu. "Unavoidable destroyed exergy in crude oil pipelines due to wax precipitation." *Entropy* 21, no. 1 (2019): 58. https://doi.org/10.3390/e21010058

[20] Nazari, Navid, and Soheil Porkhial. "Energetic and Exergetic Improvement of Geothermal Single Flash Cycle." *International Journal of Renewable Energy Development* 5, no. 2 (2016): 129-138. https://doi.org/10.14710/ijred.5.2.129-138

[21] Bamisile, Olusola, Foyin Olubiyo, Mustafa Dagbasi, Humphrey Adun, and Ifeoluwa Wole-Osho. "Economic Analysis and Performance of PV Plants: An Application in Kurdistan Region of Iraq." *International Journal of Renewable Energy Development* 8, no. 3 (2019): 293-301. https://doi.org/10.14710/ijred.8.3.293-301

[22] Cengel, Yunus A., Michael A. Boles, and Mehmet Kanoğlu. *Thermodynamics: an engineering approach*. 9th Ed. New York: McGraw-hill, 2011.

[23] Jaluria, Yogesh. *Design and optimization of thermal systems*. CRC press, 2007. https://doi.org/10.1201/9781420019483