Geothermal Capacity Building Program Indonesia - Netherlands

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Low Enthalpy Geo-thermal Waste Heat Utilization for Vetiver Oil Distillation in West Java, Feasibility Study and Project Financing

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1 INTRODUCTION

1.1 OVERVIEW OF VETIVER OIL IN INDONESIA

Vetiver oil is produced from grass roots of the species *Vetiveria zizanoides* (Figure 1). The main components in the roots are vetivone alpha and beta. These components give aroma of the vetiver oil. This property allows the roots to be used as feedstock for producing the vetiver oil as main ingredient of perfumes and for aromatherapy. In perfume products, the vetiver oil is used as fixative and main aroma component (Martinez *et al.*, 2004). Therefore, the vetiver oil has high economic value.

Figure 1. Vetiver Plant
(Source : disbun.jabarprov.go.id)

***Table 1**. Data of export-import of vetiver oil.*

Year	Export		Import	
	Volume (kg)	**Price (US $)**	**Volume (kg)**	**Price (US $)**
2001	1,583,798	1,759,241	2,312	43,728
2002	79,714	1,973,451	2,572	46,312
2003	45,821	1,428,682	2,465	18,680
2004	58,444	2,445,744	2,231	51,308
2005	74,210	1,544,618	532	22,890

(Source: BPS, 2005)

In world trade, vetiver oil from Indonesia is known as "*Java Vetiver Oil*". Table 1 shows that volume of Indonesia vetiver oil export fluctuates from year to year. This is caused by inconsistency of the vetiver oil quality (Kardinan, 2005). This inconsistency makes the position of Indonesia as the largest vetiver oil producer diminish and replaced by Haiti and Bourbon. The operating conditions in refining vetiver oil is the main factor affecting the quality of the vetiver oil.

2 VETIVER OIL FACTORY

In West Java, a vetiver oil refinery factory have been in operation in the district of Samarang, Garut Regency. This factory belongs to H. Ede (Figure 2). In this factory, there are 4 distillation kettles to produce steam for steam distillation. Three kettles has been used for producing vetiver oil, while the other one is still under construction. These three kettles use fuels of diesel oil, used oil and firewood, respectively.

Figure 2. Vetiver oil factory owned by H. Ede

A distillation kettle is capable of processing grass up to 2 tons for each batch and produces approximately 6 kg of vetiver oil. Production of vetiver oil is not carried out continuously, because the plantation of the grass requires quite long time (about 8-12 months) and also the availability of vetiver root of the grass is decreasing today.

Based on field surveys conducted previously, it is known that the vetiver oil refining process in H. Ede Vetiver Oil Refinery operates at a pressure of 6 bar (temperature of approximately 158°C) and lasts for 12 hours. Steam needed to run the process is as much as 2,500 kg/hour. Steam used should not be too dry (steam quality should be under 1), because dry steam (steam quality equal to 1) inhibits vetiver oil extraction. The distillation process was done 16 times per month (or 192 times per year) per kettle. The estimated steam needed to run the process in one month is about 480,000 kg of steam or 5,760,000 kg in one year.

2.1 Pipeline Route

The nearest source of geothermal waste heat is in Kamojang. The distance between the source and the vetiver oil refinery is illustrated in the Figure 3, while elevation change between the two locations is illustrated in Figure 4.

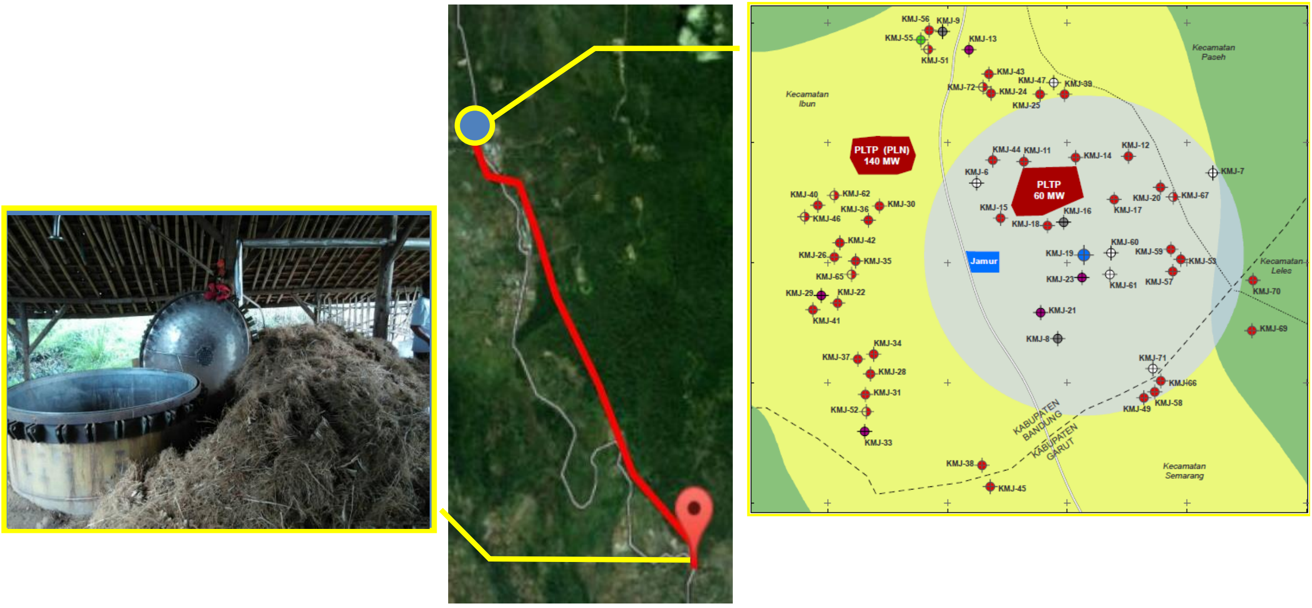

Figure 3. Distance between waste heat source with vetiver oil refinery location

Figure 3 shows the distance between heat source and the vetiver oil factory. The estimated distance is about 6 km. However, the geothermal waste heat source only provides condensate whose temperature is about 46°C, much lower than the required temperature for the distillation units, i.e. 130°C.

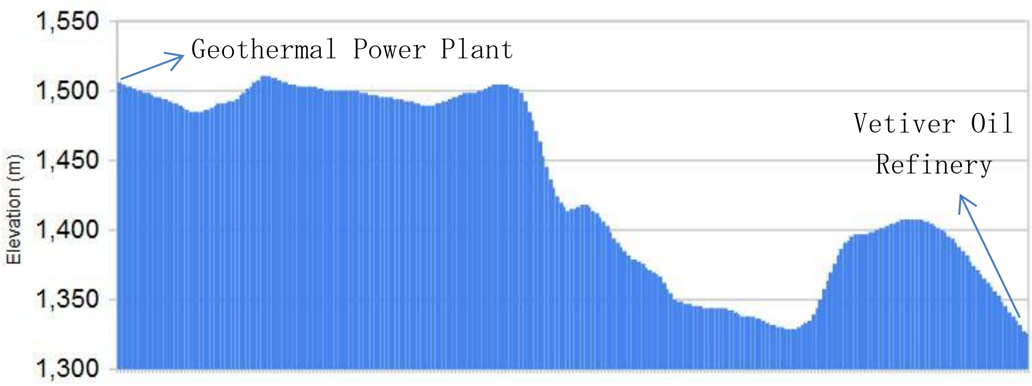

Figure 4. Elevation change between heat source with vetiver oil refinery

Referring to the map of geothermal wells in the area of Kamojang, there are some abandoned wells (monitoring wells) that can be taken into consideration. The data of steam conditions were obtained from the previous workshop held in ITB. Based on the data, it is found that the steam is at a temperature of approximately 180°C.

2.2 DISTILLATION PROCESS

Extraction of oil contained in grass may be carried out in different methods. In general, there are 5 methods, i.e. *expression*, water distillation, water and steam distillation, steam distillation and solvent extraction. Among those methods, the steam distillation is generally used to extract vetiver oil. In this method, the steam is contacted directly with grass either in batch or continuous operation because this method is considered to be less costly and easy in operation. The schematics of the steam distillation units is shown in Figure 5.

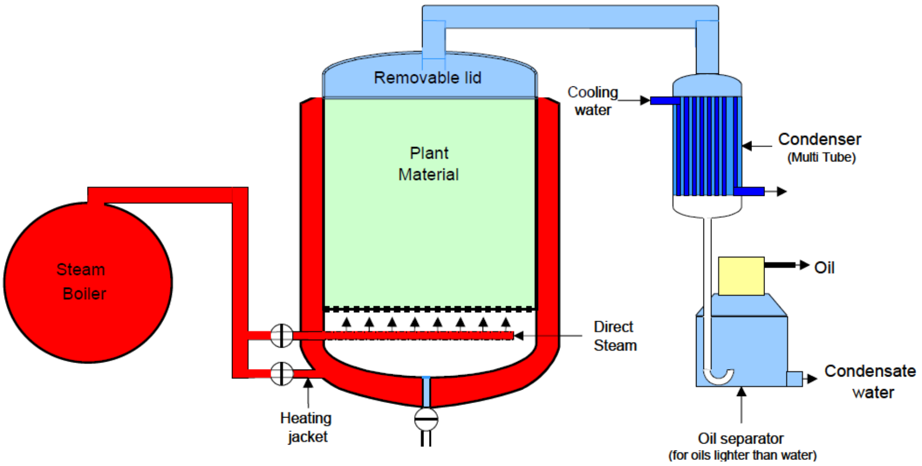

Figure 5. *Schematics of equipment used in distillation method*

(Source: UNIDO and FAO, 2005)

In the steam distillation method, the grass roots are loaded on a perforated grate below which a steam boiler lies. In the steam boiler, the water temperature slowly increases when the fuel is ignited until it produces wet steam. The resulting steam will pass through the grate and stack of the grass, vaporizing the essential oil within the grass. The valve located at the top of the refinery unit is closed for 7 hours so that the steam does not flow out of the unit. The steam diffuses into the inside of the grass root material to allow the vetiver oil contained in the plant material to be evaporated. After 7 hours, the valve is opened for 5 hours to allow the vapour containing steam and vetiver oil vapour to flow through a series of condensers before being condensed as a mixture of vetiver oil and water. The total time required for each batch therefore is 12 hours. After passing through the condensers, the mixture of water and vetiver oil is separated in a screen cloth based on their density difference. Figure 6 shows the process equipment used during the process.

Figure 6. Process equiptment of steam distillation used in H. Ede refinery

In the direct use of geothermal energy, heat supplied by geothermal fluid is used to generate steam in the steam distillation process. The proposed schematics of equipment in vetiver oil refining process utilizing geothermal fluid is shown in Figure 7. A boiler is proposed to be constructed in the vetiver oil refining system to increase the steam temperature to that required by vetiver oil refinery, i.e. 130 ˚C if this temperature is not achieved by the heat exchanger alone. Otherwise, the boiler is not needed.

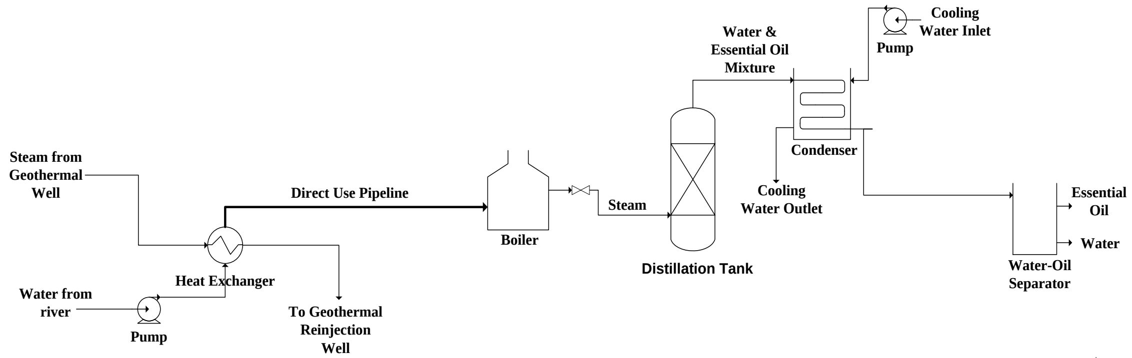

Figure 7. Process flow diagram for geothermal direct use to the vetiver oil refining process

2.3 Simulation of Vetiver Oil Production with Geothermal Utilization

Simulation of the process has been divided into three schemes. Those schemes are the BAU (Business As Usual) scheme, the condensate scheme and the geothermal steam scheme. The results of three simulation schemes are shown in the discussion below.

BAU (Business As Usual) Scheme

In the BAU scheme, simulation of distillation process is carried out in accordance with the conditions that exist in H. Ede Kadarusman vetiver oil refinery (classified as small & medium industry) in Garut, West Java. In accordance with existing conditions, the simulation process does not involve the use of heat coming from the nearest geothermal power plant. Instead, process equipment used in the simulation was equipment present at H. Ede's vetiver oil refinery. The flowsheet of simulation conducted in Unisim program is shown in Figure 8.

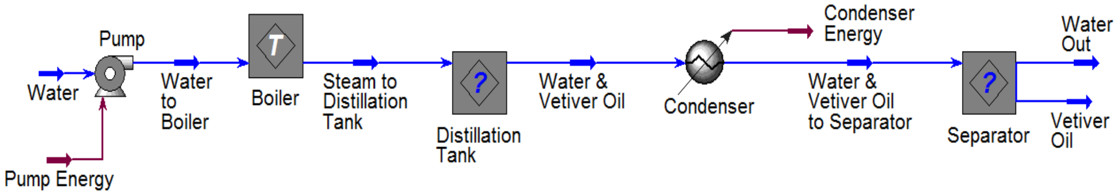

Figure 8. Flowsheet of BAU scheme

The result of BAU scheme process simulation is shown in Table 2.

Table 2. Result of BAU scheme simulation

Parameter	Value
T (°C)	158
P (bar)	6
t (hour)	12
Steam flow rate (kg/jam)	2500
Steam quality at the inlet of distillation tank	0.85
Fuel Consumption (litre)	525.93
Raw vetiver root (kg)	2000
Vetiver oil produced (kg)	6
CO_2 production (kg)	1482.71

Condensate Scheme

In the condensate scheme, process simulation is done similar to the BAU scheme. However, in the condensate scheme, the process water is preheated first by the condensate heat generated by the Kamojang geothermal power plant. The flow rate of the condensate produced by Kamojang geothermal power plant is 100 kg/s at a temperature of 46°C (Geocap report, 2015). The flowsheet of the condensate scheme process simulation conducted is shown in Figure 9.

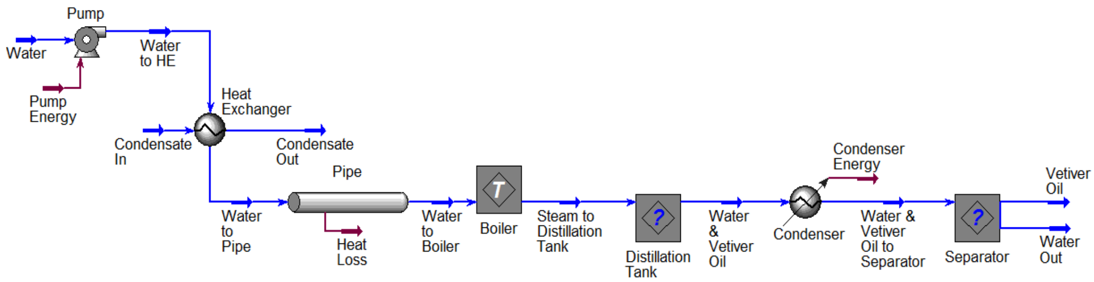

Figure 9. Flowsheet of condensate scheme

Based on the simulation results, the required condensate flow rate is 2 kg/s or about 2% of the capacity of Kamojang power plant condensate. It is used to raise the water temperature from 25°C to 41°C. The results of the condensate scheme process simulation is shown in Table 3.

Table 3. Result of condensate scheme simulation

Parameter	Value
T (°C)	158
P (bar)	6
t (hour)	12
Steam flow rate (kg/hour)	3000
Condensate flow rate (kg/hour)	7200
Steam quality at the inlet of pipe	0
Steam quality at the inlet of distillation tank	0,85
Fuel consumption (l)	494,92
Raw vetiver root (kg)	2000
Vetiver oil produced (kg)	6
CO_2 production (kg)	1396,68

Geothermal Steam Scheme

Process equipment used in the geothermal steam scheme is similar to that used in the condensate scheme. However, in the geothermal steam (abandoned/monitoring wells) scheme, a heat exchanger instead of boiler is used to produce saturated vapor with a pressure of 6 bar. Steam produced from the heat exchanger is then transported through a pipeline to the vetiver oil refinery.

Based on the placement of the heat exchanger in the process flow, the geothermal steam scheme is divided into two cases, namely geothermal steam scheme 1 and geothermal steam scheme 2. In geothermal steam scheme 1, the heat exchanger is placed upstream of the pipe inlet. The fluid flowing in the pipe is steam obtained from the heat exchange process between water and geothermal steam in the heat exchanger. Meanwhile, in the geothermal steam scheme 2, the heat exchanger is placed after the pipe outlet. The fluid flowing in the pipe is the geothermal steam. After flowing through the pipe, heat exchange between geothermal steam and water takes place to produce steam used in the refining process (steam distillation).

The simulation flowsheet of geothermal steam scheme 1 and 2 are shown in Figures 10 and 11.

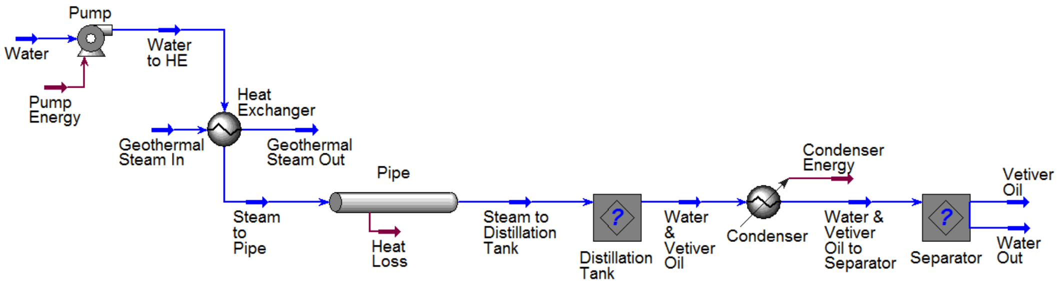

Figure 10. Flowsheet of geothermal steam scheme 1

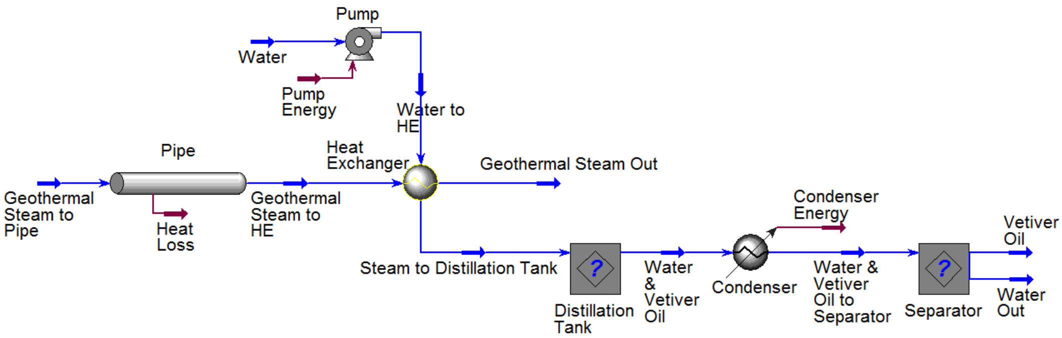

Figure 11. Flowsheet of geothermal steam scheme 2

The results of the geothermal schemes process simulation are shown in Table 4.

Table 4. Result of geothermal schemes simulation

Parameter	Value	
	Scheme 1	Scheme 2
T (°C)	158	158
P (bar)	6	6
t (hour)	12	12
Steam flow rate (kg/hour)	2500	2500
Geothermal steam flow rate (kg/hour)	3148	3700
Steam quality at the inlet of pipe	1	0.92
Steam quality at the inlet of distillation tank	0.73	0.73
Fuel consumption (l)	-	-
Raw vetiver root (kg)	2000	2000
Vetiver oil produced (kg)	6	6
CO_2 production (kg)	-	-

Figures 12 and 13 show the comparison of fuel consumption and carbon dioxide production of every scheme. Fuel consumption and carbon dioxide production of the condensate and the geothermal steam schemes are lower than BAU scheme. Fuel consumption and CO_2 production of the condensate scheme is 6% lower compared to the BAU scheme. Meanwhile, the geothermal steam scheme does not require fuel and does not produce CO_2 (pump electricity is small and is neglected). The absence of CO_2 gas production could be an interesting point to attract investors or obtain supports from the environmental agencies, because by using the geothermal steam scheme, the process becomes much cleaner without generating CO_2 emissions.

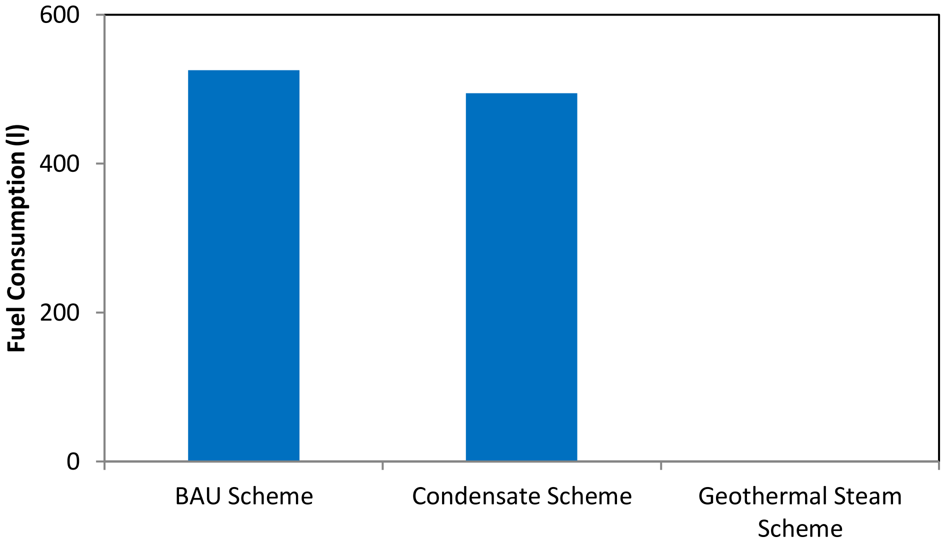

Figure 12. Comparison of fuel consumption between three schemes

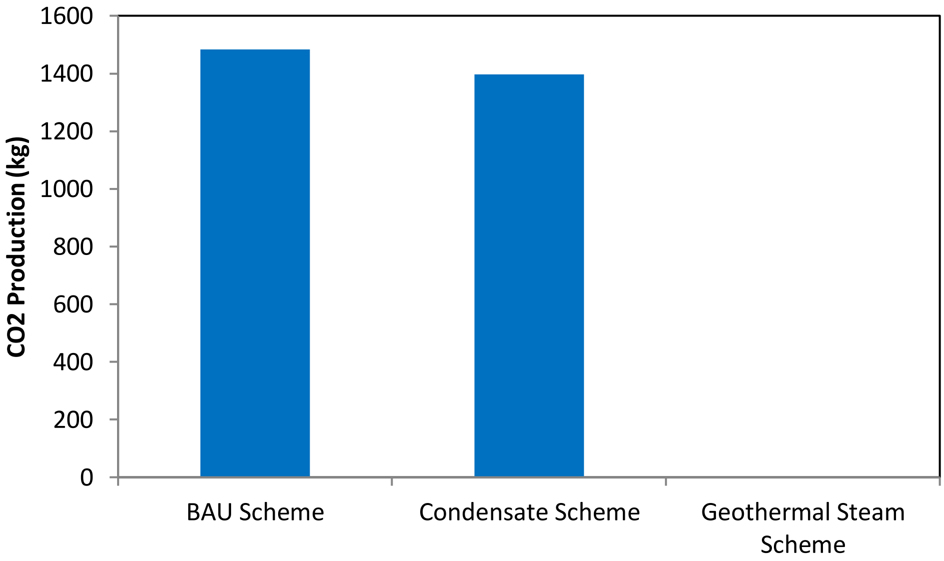

Figure 13. Comparison of CO_2 production between three schemes

2.4 PROCESS EQUIPMENT SIZING

Sizing of the process equipment was made for the condensate and the geothermal steam schemes. The process equipment units are pumps, heat exchangers and piping. The results of the process equipment sizing are shown below.

Pump

The flow rate of the process water to be pumped in the condensate scheme is the same as the geothermal steam scheme, i.e. 2,500 kg/hour. Process water at the pump inlet is assumed to be at a condition of 1 bar and 20°C. The pressure of process water is increased from 1 bar to 6 bar. Table 5 shows the result of pump sizing used in both schemes.

Table 5. Result of Pump Sizing

Parameter	Value
Pump Type	Reciprocating
Inlet Pressure (bar)	1
Outlet Pressure (bar)	6
Flow Rate (kg/hour)	2500
Power (kW)	2.77
Head (m)	372

Heat Exchanger

Sizing of heat exchanger was performed using HTRI software. Tubular Exchanger Manufacturers Association (TEMA) types of heat exchanger used in the condensate scheme is AES (see TEMA for more details), whereas for the geothermal steam scheme is AKT type (see TEMA for more details). The result of heat exchanger sizing is shown in Figures 14 through 17.

Process Conditions		Cold Shellside		Hot Tubeside	
Fluid name					
Flow rate	(kg/s)		0,6944		0,8806
Inlet/Outlet Y	(Wt. frac vap.)	0,000	1,000	0,922	0,000
Inlet/Outlet T	(Deg C)	25,00	165,00	181,25	120,00
Inlet P/Avg	(kPa)	600,009	599,309	1032,02	1031,13
dP/Allow.	(kPa)	1,399	0,000	1,763	0,000
Fouling	(m2-K/W)		0,000000		0,000000

Exchanger Performance					
Shell h	(W/m2-K)	7317,38	Actual U	(W/m2-K)	1700,93
Tube h	(W/m2-K)	2469,14	Required U	(W/m2-K)	1594,00
Hot regime	(--)	Sens Liq	Duty	(MegaWatts)	1,8588
Cold regime	(--)	Flow	Area	(m2)	71,854
EMTD	(Deg C)	16,2	Overdesign	(%)	6,71

Shell Geometry			Baffle Geometry		
TEMA type	(--)	AKT	Baffle type	(--)	Support
Shell ID	(mm)	720,000	Baffle cut	(Pct Dia.)	
Series	(--)	1	Baffle orientation	(--)	
Parallel	(--)	1	Central spacing	(mm)	1186,39
Orientation	(deg)	0,00	Crosspasses	(--)	1

Tube Geometry			Nozzles		
Tube type	(--)	Plain	Shell inlet	(mm)	26,645
Tube OD	(mm)	19,050	Shell outlet	(mm)	102,261
Length	(m)	2,438	Inlet height	(mm)	57,169
Pitch ratio	(--)	1,2992	Outlet height	(mm)	311,279
Layout	(deg)	30	Tube inlet	(mm)	102,261
Tubecount	(--)	506	Tube outlet	(mm)	26,645
Tube Pass	(--)	1			

Thermal Resistance; %		Velocities; m/s		Flow Fractions	
Shell	23,25	Shellside	0,38	A	0,000
Tube	74,44	Tubeside	1,136e-2	B	1,000
Fouling	0,00	Crossflow	0,17	C	0,000
Metal	2,31	Window	0,00	E	0,000
				F	0,000

Figure 14. Sizing of heat exchanger for the geothermal steam scheme

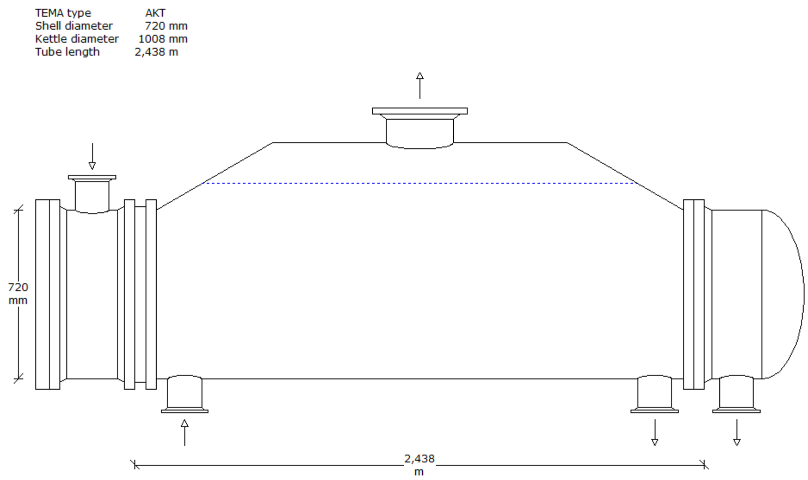

Figure 15. Illustration of heat exchanger for the geothermal steam scheme

Process Conditions		Cold Shellside		Hot Tubeside	
Fluid name			Water		Kondensat
Flow rate	(kg/s)		0,6944		2,0000
Inlet/Outlet Y	(Wt. frac vap.)	0,000	0,000	0,000	0,000
Inlet/Outlet T	(Deg C)	25,00	41,00	46,00	39,33
Inlet P/Avg	(kPa)	600,009	599,130	111,302	110,954
dP/Allow.	(kPa)	1,758	0,000	0,695	0,000
Fouling	(m2-K/W)		0,000000		0,000000

Exchanger Performance					
Shell h	(W/m2-K)	157,18	Actual U	(W/m2-K)	115,43
Tube h	(W/m2-K)	513,76	Required U	(W/m2-K)	107,55
Hot regime	(--)	Sens. Liquid	Duty	(MegaWatts)	0,0511
Cold regime	(--)	Sens. Liquid	Area	(m2)	133,105
EMTD	(Deg C)	3,6	Overdesign	(%)	7,33

Shell Geometry			Baffle Geometry		
TEMA type	(--)	AES	Baffle type	(--)	None
Shell ID	(mm)	700,000	Baffle cut	(Pct Dia.)	
Series	(--)	1	Baffle orientation	(--)	
Parallel	(--)	1	Central spacing	(mm)	1764,44
Orientation	(deg)	0,00	Crosspasses	(--)	1

Tube Geometry			Nozzles		
Tube type	(--)	Plain	Shell inlet	(mm)	26,645
Tube OD	(mm)	9,525	Shell outlet	(mm)	26,645
Length	(m)	1,829	Inlet height	(mm)	23,517
Pitch ratio	(--)	1,3001	Outlet height	(mm)	23,518
Layout	(deg)	30	Tube inlet	(mm)	52,553
Tubecount	(--)	2521	Tube outlet	(mm)	52,553
Tube Pass	(--)	1			

Thermal Resistance; %		Velocities; m/s		Flow Fractions	
Shell	73,44	Shellside	1,212e-3	A	
Tube	26,41	Tubeside	1,553e-2	B	0,283
Fouling	0,00	Crossflow	0,00	C	0,717
Metal	0,15	Window	3,404e-3	E	
				F	

Figure 16. Sizing of heat exchanger for the condensate scheme

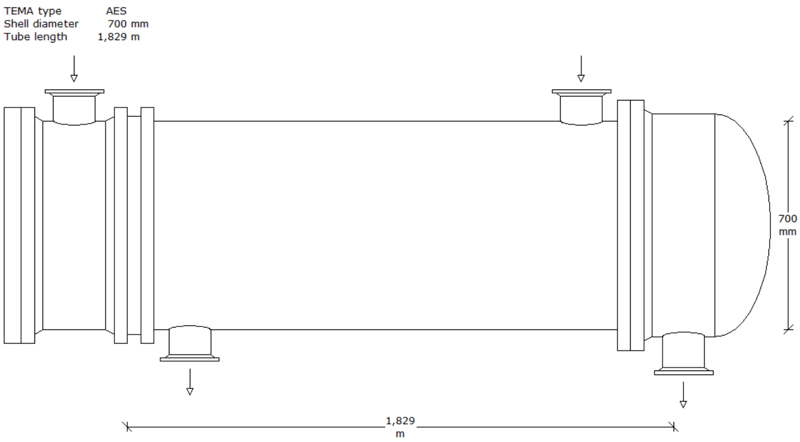

Figure 17. Illustration of heat exchanger for the condensate scheme

Steam Pipe

The steam pipe has a length of 6000 m which is the distance between the source of waste heat and the vetiver oil refinery. Routes of pipe and elevation change between the two locations are shown in Figure 9 and 10.

Results of steam pipe sizing for the condensate and the geothermal steam scheme are shown in Table 6.

Table 6. Result of steam pipe sizing

Parameter	Condensate Scheme	Geothermal Steam Scheme 1	Geothermal Steam Scheme 2
Length (m)	6000	6000	6000
ID (inch)	6.065	10.02	6.065
OD (inch)	6.625	10.75	6.625
Material	*Carbon Steel*	*Carbon Steel*	*Carbon Steel*
Insulation Thickness (inch)	4	6	1.5
Insulation Material	Silicate Calcium	Silicate Calcium	Silicate Calcium
Heat Loss (kW)	29.03 (0.3%)	409.2 (4.5%)	804.1 (5.9%)

2.5 Steam Distillation Modelling

The steam distillation process used in the distillation of vetiver oil is modeled using equation 1 (McKetta, 1992).

$$\theta = \frac{N_i}{S_i}\left[\frac{\pi}{EP}\times\left(\ln\frac{X_f}{X_s}\right)+\left(\frac{\pi}{EP}-1\right)\left(X_f-X_s\right)\right] \qquad (1)$$

where

S_i = Steam flow rate (mole/hour)
θ = Distillation time (hour)
N_i = mole of inert (mole)
π = Pressure of system (mmHg)
E = Vaporization efficiency
X_f = Mole of feed per mole of inert
X_s = Mole of residue per mole of inert
P = Vapor pressure of volatile (mmHg)

From the previous study (Tutuarima 2009), it is known that the steam distillation process can be carried out at lower pressures (1-3 bar) compared to the distillation process at a pressure of 6 bar that took place at H. Ede vetiver oil refinery. Based on this information, the steam distillation process simulation is conducted under pressures of 1-3 bar with a steam flow rate variation of 2000-4000 kg/hour within 24 hours. The weight of the raw material used is 2000 kg, the same as the amount of raw materials used in refining scale of H. Ede. The simulation results are shown in Figures 18 to 20.

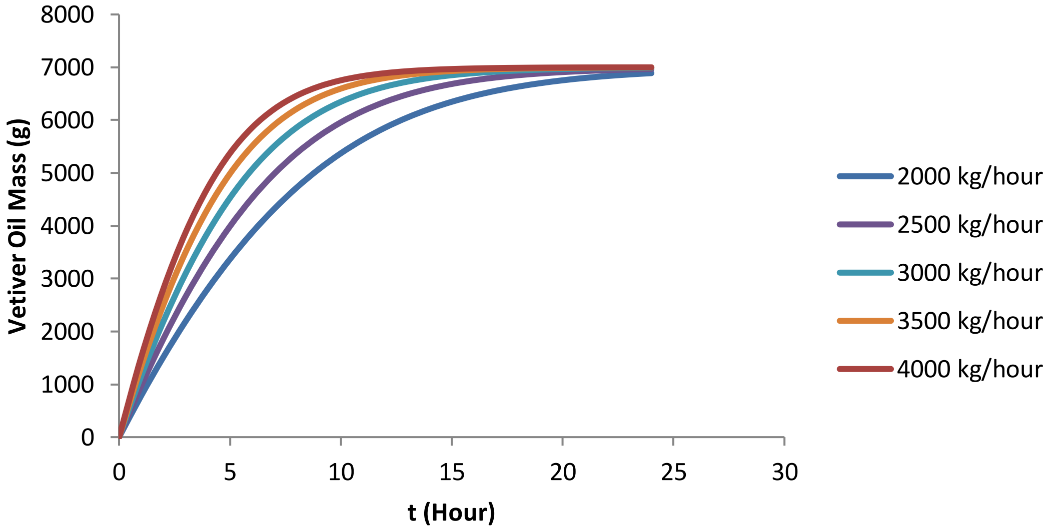

Figure 18. Profile of produced vetiver oil at 3 bar with steam flow rate variation

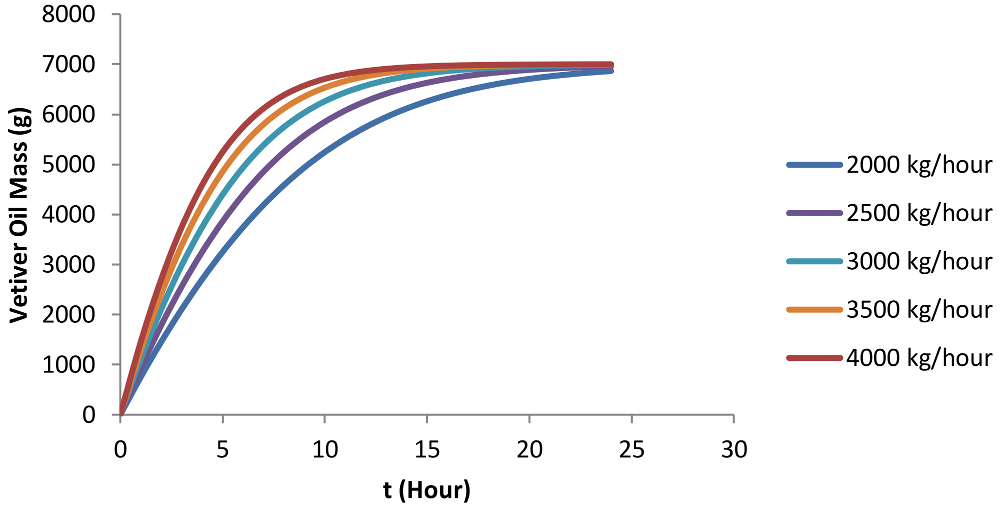

Figure 19 Profile of produced vetiver oil at 2 bar with steam flow rate variation

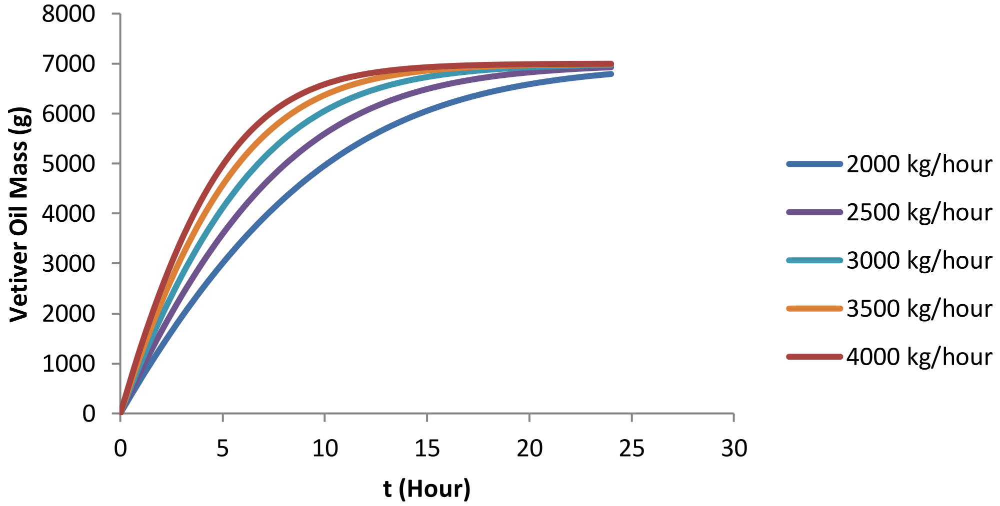

Figure 20. Profile of produced vetiver oil at 1 bar with steam flow rate variation

Based on the simulations, the use of steam flow rate of 3000 kg/hour at a pressure of 3 bar can produce as much as 6.8 kg vetiver oil within 14 hours. This value is greater than H. Ede vetiver oil refinery that produces 6 kg of vetiver oil at a higher pressure, which is 6 bar, within 12 hours.

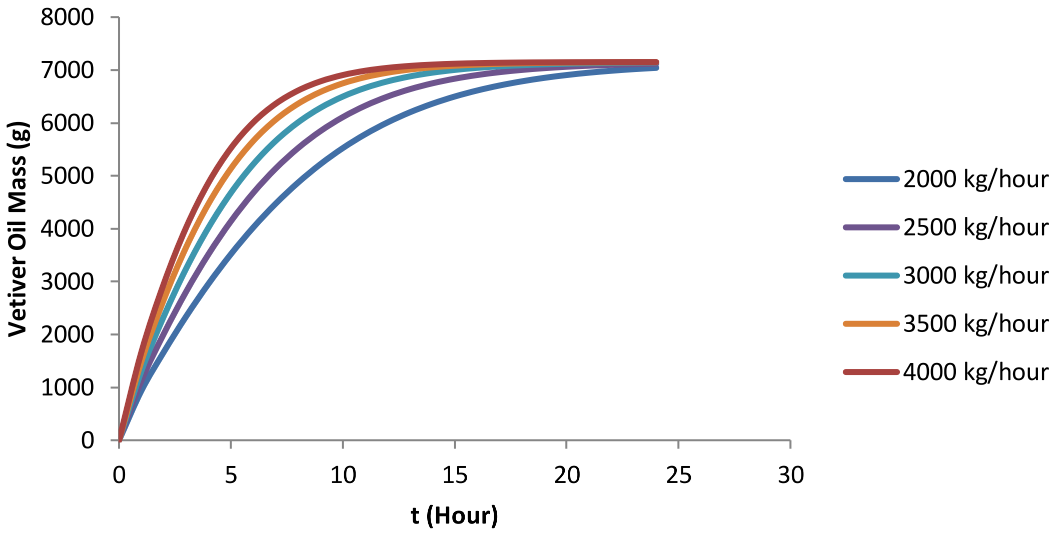

Figure 21. Profile of produced vetiver oil at 6 bar with steam flow rate variation

The result is then justified with the simulation of steam distillation operating at 6 bar as shown in Figure 21. The results of a simulation at 6 bar shows that vetiver oil obtained with the same operating condition as H. Ede vetiver oil refinery, i.e. 6 bar & 2500 kg/hour of steam for 12 hours, is about 6.5 kg. The value of the simulation, i.e. 6.5 kg of vetiver oil, is greater than the real value which is only 6 kg of vetiver oil. The difference is caused by some simplification used in the modelling. Thus, the operating condition of steam distillation proposed for the improvement of the BAU scheme (H.Ede vetiver oil refinery) can be summarized in Table 7.

Table 7. Comparison between BAU scheme with 6 bar simulation result and proposed operating condition

Parameter	BAU Scheme	6 bar Simulation	Proposed Operating Condition
Pressure	6 bar	6 bar	3 bar
Temperature	160°C	160°C	130°C
Steam flow rate*	2500 kg/hour	2500 kg/hour	3000 kg/hour
Time	12 hours	12 hours	14 hours
Vetiver oil obtained	6 kg	6.5 kg	6.8 kg

*Total running time

3 Economical Aspect

This section will provide the capital and operational cost that are required to implement waste heat utilization. After that, the profitability of this investment can be shown by calculating economic parameters such as the Internal Rate of Return (IRR), Net Present Value (NPV) and Payback Period (PBP).

There are four financing schemes that have been made in this study. The four schemes used to fund this project are as follows :

Scheme 1: Capital (investment) is 100% funded by a bank loan. The interest rate on this loan is set at 10%, which is common for Indonesian banks. Meanwhile, the tax component used in the calculation is the income tax (25%).

Scheme 2: The source of the capital is the same as in scheme 1. However, the tax component used in the calculation is adjusted to the regulation of Finance Ministry (PMK No. 21/PMK.011/2010). Under the regulation, government provides an income tax facility for activities exploiting renewable energy sources in the form of net income reduction by as much as 30% of the amount of investment which is charged for 6 years at 5% per year.

Scheme 3: The total investment cost of the poject is charged to the producer (waste heat provider), which means that the capital is obtained from the producer by as much as 100% of the total capital cost as a form of CSR funding without interest rate. The tax component used in the calculation is the income tax (25%).

Scheme 4: Capital is obtained from international institutions that provide funding in the form of green funds for any projects that utilize renewable energy. An example of an institution is the International Finance Corporation (IFC). The loans obtained from IFC are limited to 25% of the total "greenfield" project cost up to maximum of $100 million. The interest rate on the loan is 0.75% (LIBOR). Tax component used in the calculation is the same as the previous schemes.

3.1 Capital Cost

The capital cost is mainly used for the investment of process equipments. The process equipment are a pump, a heat exchanger and also piping. Process equipment investment costs are estimated by using Seider, *et al* (2003) and Ulrich & Vasudevan (2006). The details of the estimated process equipment costs are shown in Table 8.

Tabel 8. Process equipments investment cost

Equipment	Cost ($)		
	Condensate Scheme	Geothermal Steam Scheme 1	Geothermal Steam Scheme 2
Pump[1]	40,392	40,392	40,392
Heat Exchanger[2]	331,519	331,170	331,170
Pipe[3]	1,242,200	2,250,600	1,241,710
Total	1,614,111	2,622,162	1,613,272

References : [1,2] (Seider, *et al*, 2003) ; [3](Ulrich & Vasudevan, 2006)

In addition to the process equipments cost, other capital cost components are the costs for the installation of equipments in the field. It is comprised of fees for pipe ROW (Right of Way), contingencies and wage contractors, startup and working capital. Details of the cost of each component can be seen in Table 9.

Tabel 9. Components of capital cost

Component	Cost ($)		
	Condensate Scheme	Geothermal Steam Scheme 1	Geothermal Steam Scheme 2
Total of process equipments Cost	1,614,111	2,622,162	1,613,272
Pipe ROW (Right of Way)[1]	124,220	262,216	161,327
Contingency and constructor fees[2]	166,253	270,083	166,167
Startup cost[3]	27,432	44,564	27,418
Working capital [4]	37,124	60,309	37,105
Total of Capital Cost	**1,969,140**	**3,259,334**	**2,005,289**

[1] 10% of pipe investement cost; [2] 10% of direct investment; [3] 2% of total direct cost; [4] 5% of total direct investment. References : (Seider, *et al*, 2003)

3.2 Operational Expenditure

Based on the rule of thumb, the operational expenditure per year is amounted as much as 2% of the total of capital cost. The amount of operational expenditure of each scheme can be seen in Table 10.

Tabel 10. OPEX for each scheme

Scheme	OPEX ($)
Condensate	40,106
Geothermal Steam 1	65,187
Geothermal Steam 2	40,106

3.3 Profitability

The economic viability of the project was determined by calculating three economic parameters for all four the financing schemes. The three parameters are NPV, IRR and PBP (Payback Period). The assumptions used in this economic calculation are as follows:

- The production of vetiver oil is performed 16 times per month or 192 times per year.
- The revenue comes from the amount of fuel that is saved on each waste heat recovery scheme. The fuel saving for condensate scheme, according to the results of the technical analysis, is 5,953.92 l per year. Meanwhile, the fuel saving for both of the geothermal steam scheme 1 and 2 is 100,978.56 l per year.
- The price of fuel (Industrial Diesel Oil) is Rp 6,500 / liter.
- The lifetime of the project is 15 years.

The results of the economic calculation are shown in Tables 11-13.

Tabel 11. The result of NPV calculation for each scheme

Financing Scheme	Condensate Scheme	Geothermal Scheme 1	Geothermal Scheme 2
1	-$ 2,701,837	-$ 4,215,549	-$ 2,484,212
2	-$ 2,701,837	-$ 4,215,549	-$ 2,484,212
3	-$ 216,390	-$ 162,062	$ 9,676
4	-$ 2,632,636	-$ 4,101,008	-$ 2,407,109

Tabel 12. The result of IRR calculation for each scheme

<table>
<tr><th>Financing Scheme</th><th>Condensate Scheme</th><th>Geothermal Scheme 1</th><th>Geothermal Scheme 2</th></tr>
<tr><td>1</td><td rowspan="4">N/A*</td><td rowspan="4">N/A*</td><td>-27.24%</td></tr>
<tr><td>2</td><td>-27.24%</td></tr>
<tr><td>3</td><td>20%</td></tr>
<tr><td>4</td><td>-26.80%</td></tr>
</table>

Tabel 13. The result of PBP calculation for each scheme

<table>
<tr><th>Financing Scheme</th><th>Condensate Scheme</th><th>Geothermal Scheme 1</th><th>Geothermal Scheme 2</th></tr>
<tr><td>1</td><td rowspan="4">N/A*</td><td rowspan="4">N/A*</td><td>>15 years</td></tr>
<tr><td>2</td><td>>15 years</td></tr>
<tr><td>3</td><td>5 years</td></tr>
<tr><td>4</td><td>>15 years</td></tr>
</table>

*N/A means that IRR and PBP can not be calculated because of negative cash flow in every year.

Geothermal waste heat is feasible to be used for vetiver oil production when the capital cost for infrastructure is financed by the geothermal operator through CSR (Scheme

3). Due to on-off (batch) utilization of steam (low load factor), other users need to be found for a cascading approach.

4 CONCLUSIONS

Geothermal waste heat is feasible to be used for vetiver oil production when the investment cost for infrastructure is financed by the geothermal operator through CSR. To achieve PBP of 5 years, as much as 100% of the total capital cost as a form of CSR fund without interest rate is needed. Due to intermittent operation of utilization of steam at a low load factor, it is suggested to find other users for a cascading approach.

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