APPENDIX

Shell, Hot fluida (solar)		Tube, Cold fluida (crude oil)	
Suhu masuk T_1 (°F)	257,8	Suhu masuk t_1 (°F)	122
Suhu keluar T_2 (°F)	248	Suhu keluar t_2 (°F)	212
a. Densitas $\rho\ solar = Sg\ solar\ x\ \rho\ air$ $\rho\ solar = 0{,}832\ x\ 62{,}4\ \frac{lb}{ft^3}$ $\rho\ solar = 51{,}9168\ \frac{lb}{ft^3}$		a) Densitas $\rho\ crude\ oil = Sg\ crude\ oil\ x\ \rho\ air$ $\rho\ crude\ oil = 0{,}829\ x\ 62{,}4\ \frac{lb}{ft^3}$ $\rho\ crude\ oil = 51{,}7296\ \frac{lb}{ft^3}$	
b. Mass flow (W) Flow rate = 59629000 L/hari Mass flow = $59629000\ \frac{L}{hari}\ x\ 0{,}0008\ \frac{kg}{L}$ $x\ 2{,}205\ \frac{lb}{kg} x\ \frac{1\ hari}{24\ jam}$ $= 4558{,}0408\ \frac{lb}{jam}$		b) Mass flow (W) Flow rate = 320000000 L/hari Mass flow = $320000000 \frac{L}{hari}\ x\ 0{,}008\ \frac{kg}{L}$ $x\ 2{,}205 \frac{lb}{kg} x\ \frac{1\ hari}{24\ jam}$ $= 24372{,}6 \frac{lb}{jam}$	
c. °API $°API = \frac{141{,}5}{Sg\ \frac{60}{60°F}} - 131{,}5$ $= \frac{141{,}5}{0{,}832} - 131{,}5 = 38{,}5721$		c) °API $°API = \frac{141{,}5}{Sg\ \frac{60}{60°F}} - 131{,}5$ $= \frac{141{,}5}{0{,}829} - 131{,}5 = 39{,}1876$	

1. Menghitung heat balance
   a. Pada shell (solar)

      Diketahui :

$$T_{avg} = \frac{T_1 + T_2}{2} = \frac{357{,}8 + 248}{2} = 302{,}90\ °F$$

Cp = 0,595 $\frac{Btu}{lb°F}$ .....(Kern, figure 4)

$$\Delta T = T_1 - T_2 = 357{,}8 - 248 = 109{,}8\ °F$$

$$Q_s = W \; x \; Cp \; x \; \Delta T$$

$$= 4558{,}0408 \frac{lb}{jam} x 0{,}595 \frac{Btu}{lb°F} x 109{,}8°F = 297781{,}3609 \frac{Btu}{jam}$$

b. Pada tube (crude oil)

Diketahui :

$$t_{avg} = \frac{t_1 + t_2}{2} = \frac{212 + 122}{2} = 167°F$$

cp = $0{,}52 \frac{Btu}{lb°F}$.....(Kern, figure 4)

$$\Delta t = t_2 - t_1 = 212 - 122 = 90°F$$

$$Q_t = w \; x \; cp \; x \; \Delta t$$

$$= 24372{,}6 \frac{lb}{jam} x 0{,}52 \frac{Btu}{lb°F} x 90 \; °F = 1140637{,}68 \frac{Btu}{jam}$$

Menghitung neraca perpindahan panas :

$Q = Q_t - Q_s$

$$= 1140637{,}68 \frac{Btu}{jam} - 297781{,}3609 \frac{Btu}{jam} = 842856{,}3191 \frac{Btu}{jam}$$

$$\%Losses = \frac{Q}{Q_s} x 100\% = \frac{842856{,}3191 \frac{Btu}{jam}}{1140637{,}68 \frac{Btu}{jam}} x \; 100\% = 73{,}8934 \; \%$$

$$Q \; losses = \%Losses \; x \; Q$$

$$= 73{,}8934\% \; x \; 842856{,}3191 \frac{Btu}{jam} = 622815{,}4541 \frac{Btu}{jam}$$

$$Q \; transfer = Q - Q \; Losses$$

$$= 842856{,}3191 \frac{Btu}{jam} \; x \; 622815{,}4541 \frac{Btu}{jam} = 220040{,}865 \frac{Btu}{jam}$$

2. Menghitung Log Mean Temperature Difference (LMTD)

shell (Solar)			Tube (Crude Oil)			
Higher temp	T1	357,8	t2	212	Δt_h	145,8
Lower temp	T2	248	t1	122	Δt_c	126
Difference	T1 - T2	109,8	t2 - t1	90	$\Delta t_h - \Delta t_c$	19,8

$$LMTD = \frac{\Delta t_h - \Delta t_c}{ln\frac{\Delta t_h}{\Delta t_c}} = \frac{19{,}8}{ln\frac{145{,}8}{126}} = 135{,}6593\ °F$$

$$R = \frac{T_1 - T_2}{t_2 - t_1} = \frac{109{,}9}{90} = 1{,}22$$

$$S = \frac{t_2 - t_1}{T_1 - t_1} = \frac{90}{235{,}8} = 0{,}3817$$

Pada buku D.Q Kern didapatkan HE-2 menggunakan 1 shell pass and 2 or more tube pass, sehingga :

F_T = 0,88.....(Kern, figure 18)

$\Delta t = LMTD\ x\ F_T = 135{,}6593\ °F\ x\ 0{,}88 = 119{,}3802\ °F$

3. Menghitung Tc dan tc

$$\frac{\Delta t_c}{\Delta t_h} = \frac{126}{145{,}8} = 0{,}8642$$

Didapatkan :

Kc = 0,18.....(Kern, figure 17)

Fc = 0,475.....(Kern, figure 17)

Sehingga :

a. Pada shell :

$T_c = T_2 + F_c(T_1 - T_2) = 248 + 0{,}475(109{,}8) = 300{,}155\ °F$

b. Pada tube

$t_c = t_2 + F_c(t_2 - t_1) = 212 + 0{,}46(90) = 254{,}75\ °F$

Shell side, Hot fluid (Solar)	Tube side, cold fluida (crude oil)
4. Flow area (A_s) Diketahui : Diameter dalam (ID) =30,748 inchi Pitch (Pt) = 1,25 inchi Tube clearance (C") = Pt – OD = 1,25- 1 = 0,25 inc Jarak antar buffle (B) = 23,423 inchi $A_s = \frac{ID \; x \; C'' x \; B}{144 \; x \; P_t}$ $= \frac{30{,}748 \; inc \; x \; 0{,}25 \; inch \; x \; 23{,}423 inc}{\frac{144 \; inc^2}{1 \; ft^2} \; x \; 1{,}25 \; inc}$ $= 1{,}0003 \; ft^2$	4) Flow area (A_t) Diketahui : Jumlah tube (Nt) = 328 Jumlah pass (n) = 1 Diameter dalam (OD) = 1 inc , BWG 14 didapatkan nilai At'' = 0,546 inc^2.....(Kern, table 10) $A_t = \frac{Nt \; x \; At"}{144 \; x \; n}$ $= \frac{382 \; x \; 0{,}546 \; inc^2}{\frac{144 \; inc^2}{1 \; ft^2} x \; 1}$ $= 1{,}4484 ft^2$
5. Mass velocity $G_s = \frac{W}{A_s} = \frac{4558{,}0408 \; \frac{lb}{jam}}{1{,}0003 \; ft^2}$ $= 4556{,}7092 \; \frac{lb}{jam ft^2}$	5) Mass velocity $G_t = \frac{w}{A_t} = \frac{24372{,}6 \; \frac{lb}{jam}}{1{,}4484 \; ft^2}$ $= 16827{,}064 \frac{lb}{jam ft^2}$
6. Reynold Number (Res) Pada OD = 1 inc dan Pt = 1,25 inc didapatkan : D_e = 0,72 in.....(Kern, fig 28) = 0,72 : 12 = 0,06 ft $Saat \; T_c = 300{,}155$ °F $°API = 38{,}5721 \; didapatkan$: μ = 0,45 cps .....(Kern, fig 14)	6) Reynold Number (Ret) Pada OD = 1 inc dan Bwg = 14 didapatkan D = 0,834 in.....(Kern, tabel 10) = 0,834 in : 12 = 0,0695 ft $Saat \; t_c = 254{,}75$ °F °API = 39,1876 didapatkan : μ = 0,56 cps.....(Kern, fig 14) = 0,56 x 2,42 = 1,3352 $\frac{lb}{ft \; hr}$

$= 0{,}45 \times 2{,}42 = 1{,}089 \frac{lb}{ft\ hr}$ $R_{es} = \frac{D_e \times G_s}{\mu}$ $= \frac{0{,}06\ ft \times 4556{,}7092 \frac{lb}{hr\ ft^2}}{1{,}089 \frac{lb}{ft\ hr}}$ $= 251{,}0584$	$R_{et} = \frac{D \times G_t}{\mu}$ $= \frac{0{,}0695 ft \times 16827{,}0604 \frac{lb}{hr ft^2}}{1{,}3552 \frac{lb}{ft\ hr}}$ $= 862{,}9582$
7. Factor for heat transfer *Pada* $R_{es} = 251{,}0584$ *didapatkan* : $j_H = 8{,}25$.....(Kern, fig 28)	7) Factor for heat transfer L = 10 ft D = 0,0695 ft $\frac{L}{D} = \frac{10\ ft}{0{,}0695\ ft} = 143{,}8849$ Didapatkan : $j_H = 15$ .....(Kern, fig 24)
8. Bilangan Prandtl *Saat* $T_c = 300{,}155°F$ $°API = 38{,}5721$ *didapatkan* : c = 0,595 $\frac{Btu}{lb\ °F}$ .....(Kern, fig 4) k = 0,0755 $\frac{Btu}{ft^2 hr(°F/ft)}$ .....(Kern, fig 1) $\mu = 1{,}089 \frac{lb}{ft\ hr}$ $P_r = \left[\frac{c \times \mu}{K}\right]^{\frac{1}{3}}$ $= \left[\frac{0{,}595 \frac{Btu}{lb\ °F} \times 1{,}089 \frac{lb}{ft\ hr}}{0{,}0755 \frac{Btu}{ft^2 hr \left(\frac{°F}{ft}\right)}}\right]^{\frac{1}{3}}$ $= 2{,}0474$	8) Bilangan Prandtl *Saat* $t_c = 254{,}75$ °F °API = 39,1876 didapatkan : c = 0,57 $\frac{Btu}{lb\ °F}$ ....(Kern, fig 4) k = 0,0765 $\frac{Btu}{ft^2 hr(°F/ft)}$ .....(Kern, fig 1) $\mu = 1{,}3552 \frac{lb}{ft\ hr}$ $P_r = \left[\frac{c \times \mu}{K}\right]^{\frac{1}{3}}$ $= \left[\frac{0{,}57 \frac{Btu}{lb\ °F} \times 1{,}3552 \frac{lb}{ft\ hr}}{0{,}0765 \frac{Btu}{ft^2 hr \left(\frac{°F}{ft}\right)}}\right]^{\frac{1}{3}}$ $= 2{,}1614$
9. Koefisien perpindahan panas fluida	9) Koefisien perpindahan panas

(h_o) $h_o = j_H \, x \, \frac{K}{D_e} x \left[\frac{c \, x \, \mu}{K}\right]^{1/3} x \, \emptyset_s$ $\frac{h_o}{\emptyset_s}$ $= 8{,}25 \, x \, \frac{0{,}0755 \frac{Btu}{ft^2 hr(\frac{°F}{ft})}}{0{,}06 \, ft} x2{,}0474$ $= 34{,}5466 \frac{Btu}{ft^2 hr \, °F}$	fluida (h_i) $h_i = j_H \, x \, \frac{K}{D} x \left[\frac{c \, x \, \mu}{K}\right]^{1/3} x \, \emptyset_s$ $\frac{h_i}{\emptyset_t} = 15 \, x \, \frac{0{,}0765 \frac{Btu}{ft^2 hr(\frac{°F}{ft})}}{0{,}0695 \, ft} x2{,}1614$ $= 35{,}6867 \frac{Btu}{ft^2 hr \, °F}$
10. Tube wall temperature $T_c = 300{,}155°F$ $t_c = 254{,}75 \, °F$ $T_c - t_c = 45{,}405 \, °F$ $t_w = t_c + \frac{\frac{h_o}{\emptyset_s}}{\frac{h_o}{\emptyset_s} + \frac{h_{io}}{\emptyset_t}} x \, (T_c - t_c)$ $= 254{,}75 + \frac{21{,}254}{(21{,}254 + 29{,}7627)} x \, 45{,}41$ $= 273{,}6663 \, °F$	10) Menghitung $\frac{h_{io}}{\emptyset_t}$ ID = 0,834 in OD = 1 inc $\frac{h_{io}}{\emptyset_t} = \frac{h_i}{\emptyset_t} x \, \frac{ID}{OD}$ $= 35{,}6867 \frac{Btu}{ft^2 hr°F} x \frac{0{,}834 \, inc}{1 \, inc}$ $= 29{,}7627 \frac{Btu}{ft^2 hr°F}$
11. Saat $t_w = 273{,}6663$ °F didapatkan : $\mu_w = 0{,}49 \, cps$.....(Kern, fig 14) = 0,49 x 2,42 = 1,186 lb/ft hr $\emptyset_s = \left[\frac{\mu}{\mu_w}\right]^{0{,}14}$ $= \left[\frac{1{,}089 \frac{lb}{ft \, hr}}{1{,}186 \frac{lb}{ft \, hr}}\right]^{0{,}14} = 0{,}9881$	11) Saat $t_w = 273{,}6663°F$ didapatkan $\mu_w = 0{,}45 \, cps$.....(Kern, fig 14) = 0,45 x 2,42 = 1,089 lb/ft hr $\emptyset_t = \left[\frac{\mu}{\mu_w}\right]^{0{,}14} = \left[\frac{1{,}3552 \frac{lb}{ft \, hr}}{1{,}089 \frac{lb}{ft \, hr}}\right]^{0{,}14}$ $= 1{,}0311$
12. h_o terkoreksi	12) h_i terkoreksi

$h_o = \frac{h_o}{\emptyset_s} x\, \emptyset_s$	$h_{io} = \frac{h_{io}}{\emptyset_t} x\, \emptyset_t$
$= 21{,}2544 \frac{Btu}{ft^2 hr\,°F} x\, 0{,}9881$	$= 29{,}7627 \frac{Btu}{ft^2 hr°F} x\, 1{,}0311$
$= 21{,}0025 \frac{Btu}{ft^2 hr\,°F}$	$= 30{,}6881 \frac{Btu}{ft^2 hr°F}$

13) Menghitung Uc

$$U_c = \frac{h_{io} h_o}{h_{io} + h_o} = \frac{30{,}6881 \frac{Btu}{ft^2 hr°F} x\, 21{,}0025 \frac{Btu}{ft^2 hr°F}}{(30{,}6881 + 21{,}0025) \frac{Btu}{ft^2 hr°F}} = 12{,}4689 \frac{Btu}{ft^2 hr°F}$$

14) Menghitung Ud

OD = 1 inc dan BWG = 14 didapatkan a" = 0,2618 ft^2/ft.....(Kern, tabel 10)

Nt = 382

L = 10 ft

$$U_d = \frac{Q}{Nt\ x\ a"\ x\ L\ x\ LMTD}$$

$$= \frac{1140637{,}68\ Btu/hr}{382\ x\ 0{,}2618\ ft^2/ft\ x\ 10\ ft\ x\ 135{,}6593\ °F} = 8{,}4075 \frac{Btu}{hr ft^2 °F}$$

15) Menghitung Rd

$$R_d = \frac{U_c - U_d}{U_c\ x\ U_d} = \frac{(12{,}4689 - 8{,}4075) \frac{Btu}{hr ft^2 °F}}{12{,}4689 \frac{Btu}{ft^2 hr°F} x\, 8{,}4075 \frac{Btu}{hr ft^2 °F}} = 0{,}0387 \frac{Btu}{hr ft^2 °F}$$

16) Menghitung efisiensi efektivitas

$$\eta = \frac{220040{,}865\ Btu/jam}{842856{,}3191\ Btu/jam} x\ 100\% = 26{,}1066\ \%$$

Pressure Drop	
Shell side, Hot fluid (Solar)	Tube side, cold fluida (crude oil)
1. Factor friksi (f) R_{es} = 251,0584 f = 0,0042 ft^2/in^2.....(Kern,fig 29) Sg = 0,832 $Ds = 30{,}748\ in$ = 30,748 in : 12 = 2,5623 ft	1) Factor friksi (f) R_{et} = 862,9582 f = 0,0034 ft^2/in^2.. .(Kern,fig 29) Sg = 0,829
2. Jumlah crosses L = 10 ft B = 23,423 in $N+1 = \frac{12\,L}{B} = \frac{12\,x\,10}{23{,}423}$ = 5,1232	2) Pressure Drop (ΔPt) L = 10 ft n = 1 $\Delta Pt = \frac{f.(Gt)^2.L.n}{5{,}22.10^{10}.D.Sg.\emptyset t}$ $= \frac{0{,}0034\ x\ (16827{,}064)^2 x\ 10\ x\ 1}{5{,}22.10^{10} x\ 0{,}0695 x\ 0{,}829 x 1{,}031}$ = 0,0031 psi

3. Pressure Drop (ΔPs)

$$\Delta Ps = \frac{f.(Gs)^2.Ds.(N+1)}{5{,}22.10^{10}.De.Sg.\emptyset s}$$

$$= \frac{0{,}0042x\ (4556{,}7092)^2x5{,}12317\ x\ 2{,}56}{5{,}22.10^{10}x\ 0{,}06\ x\ 0{,}832\ x\ 0{,}9881}$$

= 0,0004 psi

3) Menghitung (ΔPr)

$$Gt = 16827{,}064\ \frac{lb}{jam\,ft^2}$$

$$v = \frac{Gt}{\rho t}$$

$$v = \frac{16827{,}064\ \frac{lb}{jam\ ft^2}}{51{,}7296\ \frac{lb}{jam\ ft^3}} x\ \frac{1\ jam}{3600\ detik}$$

v = 0,0904 ft/s

$$\Delta Pr = \frac{4n}{Sg} x \frac{v^2}{2g}$$

$$= \frac{4x1}{0{,}829} x\ \frac{0{,}0904^2}{2x32{,}2}$$

$$= 0{,}0006\ psi$$

4) Menghitung Tekanan Total

$$\Delta P_{tot} = \Delta Pt + \Delta Pr$$

= 0,0031 psi + 0,0006 *psi*

= 0,0037 psi

Data Hasil Evaluasi

Uc (Clean Overall Heat Transfer Coeficient)	12,4689	Btu/ft^2 jam◦F
Ud (Dirt Overall Heat Transfer Coeficient)	8,4075	Btu/ft^2 jam◦F
Rd (Fouling Factor)	0,0387	Btu/ft^2 jam◦F
ΔP Shell	0,0004	psi
ΔP Tube	0,0037	psi