ESP Design Project (all projects have the same weight)

Student:

This project involves designing an ESP installation for a well with the following characteristics:

Well Geometry:

- Vertical well from the surface up to 6,250 ft TVDSS. Production casing of 7 5/8" 29.7 lb/ft
- At 6,250 ft a dog leg prevents running an ESP below this point. The ESP should be installed at no more than 6,100 ft of depth
- Perforations are at 7,430 ft TVDSS
- Production tubing to be used is 3 1/2" non-upset coupling 7.7 lb/ft. The tubing used in this installation is a new tubing

Fluids:

- Produced fluids are expected to be a mixture of oil and water. The oil has a specific gravity of 0.87 and the water has a specific gravity of 1.07
- GLR is expected to be small and gas effects on the pump performance can be neglected. The pressure due to a gas column on top of the dynamic liquid level MUST be considered

Reservoir conditions:

- IPR is assumed to have a linear behavior
- The field is under a strong water injection pressure maintenance program. The reservoir average pressure will remain constant at 3,500 psi throughout the life of the project.
- The water cut increase will affect the oil and water productivity indexes. This can be represented by a total liquid productivity index that will change with time
- The design assumptions include a production life of 7 years. During this time the production conditions will vary

Current production data:

- Water cut of 35%
- Total liquid productivity index of 1.13 stb/psi
- Oil-water mixture with an average viscosity of 12 cp
- Tubing relative roughness of 0.0001 (new tubing)

Future production data:

- Water cut of 80%
- Total liquid productivity index of 1.32 stb/psi
- Oil-water mixture viscosity will increase significantly due to the formation of emulsion. Expected average viscosity of 120 cp
- Tubing relative roughness will increase to 0.002 due to scale, corrosion and erosion

Other data and information

- The casing will be connected at the surface to the production line through a check valve to vent any separated gas (no packer will be used in this installation). The production line minimum pressure to carry fluids to the processing facility is assumed to be 165 psi throughout the life of the project
- A choke will be used at the wellhead to control the wellhead pressure while keeping the line pressure at 165 psi
- The location in in the desert and the temperature at the surface is 120 F and a geothermal gradient of 16 F per 1,000 ft is characteristic in this area
- The standard practice in the area recommends a minimum submergence of 300 ft at any time. This recommendation should be followed.
- Gas pressure gradient in the annulus above the liquid level assumed constant and equal to 35 psi per 1,000 ft
- Assume the liquid above the pump intake is dead oil during normal continuous uninterrupted operation

- Sand is a concern and abrasion resistant pumps should be used
- Pump with floating stages should be used
- If tandem pumps are needed you should identical housings. Do not mix housing numbers. Manufacturer only provides even pump housing numbers (#2, #4, #6, etc.)
- Do not use more than two pump housings in tandem
- No VSD is expected to be used and electricity is available at 60Hz and 12,000 V at the wellsite
- A motor lead extension should be used at the end of the round or flat cable you selected. Voltage losses in the motor extension can be neglected due to its small length. The only motor lead extension available is Powerline 450 5KV Lead Flat Cable.
- Seal or protector section will require an extra 15 HP.
- ***When determining the minimum motor horsepower use the produced water to correct the catalog pump bhp.***
- ***When determining the actual motor load and current (current and future) use the actual fluid specific gravity for those two conditions***
- When picking a motor do NOT overload the motor.

Production constraints

- No constraints are imposed by reservoir management group. This means we should pump as much as possible guided by the limitations of the equipment and design constraints or conditions
- With an increase in water cut it is desirable to select a pump capable of holding a higher flowrate in the future due to the increase in WC and increase in total fluid productivity. Flowrate should at any point be the maximum that the well can deliver given the design conditions and selected equipment.

You should design the ESP system to produce the maximum flowrate possible at current as well as future conditions. No workover is expected to be conducted during the 7 years that the installation will be expected to last.

Design questions to ***be answered and justified***:

- Actual pump submergence throughout the life of the project
- Maximum total liquid flowrate current and in the future
- Required discharge pressure current and in the future
- Select a pump for the life span of the system that maximizes production
- Determine the number of stages required to attend the whole life of the project
- Select a proper pump housing combination if needed (use the same housing numbers).
- Verify if a shroud is needed or not and justify
- Do not use more than 2 motors in tandem. Preferably use a single motor installation.
- Verify if the motor load and efficiency are adequate for the life of the project and justify
- Since water cut and production conditions will change you must conduct the electrical design for the motor/cable at current and future conditions. Verify that the cable/motor combinations you selected will not cause problems (difficult start-up or risk of shaft failure).
- All other equipment is assumed to be available. If at the end there is more than one option for motor/cable combination, provide the complete specification for both technically adequate options so that the manager can negotiate the best economical choice when negotiating pricing with the vendor.
- Provide the complete specs for pump, protector, motor, cable, etc.
- Production conditions expected at current as well as future conditions: current, surface voltage, KVA, choke pressure losses to control production.

Nominal Size	Casing Coupling	Nominal Weight	Inside Diameter	API Drift	Bit Size	Capacity
OD (in)	OD (in)	lb/ft	ID (in)	(in)	OD (in)	bbl/100 ft
4 1/2	5.000	9.50	4.090	3.965	3 7/8	1.625
		10.50	4.052	3.927	3 7/8	1.595
		11.60	4.000	3.875	3 7/8	1.554
		13.50	3.920	3.795	3 3/4	1.493
5	5.563	11.50	4.560	4.435	3 7/8	2.020
		13.00	4.494	4.369	3 7/8	1.962
		15.00	4.408	4.283	3 7/8	1.888
		18.00	4.276	4.151	3 7/8	1.776
5 1/2	6.050	14.00	5.012	4.887	4 3/4	2.440
		15.50	4.950	4.825	4 3/4	2.380
		17.00	4.892	4.767	4 3/4	2.325
		20.00	4.778	4.653	4 1/2	2.218
		23.00	4.670	4.545	4 1/2	2.119
6 5/8	7.390	20.00	6.049	5.924	5 7/8	3.554
		24.00	5.921	5.796	4 3/4	3.406
		28.00	5.791	5.666	4 3/4	3.258
		32.00	5.675	5.550	4 3/4	3.129
7	7.656	17.00	6.538	6.413	6 1/4	4.152
		20.00	6.456	6.331	6 1/4	4.049
		23.00	6.366	6.241	6 1/8	3.937
		26.00	6.276	6.151	6 1/8	3.826
		29.00	6.184	6.059	6	3.715
		32.00	6.094	5.969	5 7/8	3.608
		35.00	6.004	5.879	5 7/8	3.502
		38.00	5.920	5.795	4 3/4	3.404
7 5/8	8.500	20.00	7.125	7.000	6 3/4	4.932
		24.00	7.025	6.900	6 3/4	4.794
		26.40	6.969	6.844	6 3/4	4.718
		29.70	6.875	6.750	6 3/4	4.592
		33.70	6.765	6.640	6 1/2	4.446
		39.00	6.625	6.500	6 1/2	4.264
8 5/8	9.625	24.00	8.097	7.972	7 7/8	6.369
		28.00	8.017	7.892	7 7/8	6.244
		32.00	7.921	7.796	6 3/4	6.095
		36.00	7.825	7.700	6 3/4	5.948
		40.00	7.725	7.600	6 3/4	5.797
		44.00	7.625	7.500	6 3/4	5.648
		49.00	7.511	7.386	6 3/4	5.480

Nominal Tubing Size	Outside Diameter	Nominal Weight		Wall Thickness	Inside Diameter	API Drift	Tubing Coupling		Capacity
		Non Upset	Upset				Non Upset	Upset	
OD (in)	OD (in)	lb/ft	lb/ft	in	ID (in)	(in)	OD (in)	OD (in)	bbl/100 ft
3/4	1.050	1.14	1.20	0.113	0.824	0.730	1.313	1.660	0.0660
1	1.315	1.70	1.80	0.133	1.049	0.955	1.660	1.900	0.1069
1 1/4	1.660	2.30	2.40	0.125	1.410	1.286	2.054	2.200	0.1931
				0.140	1.380				0.1850
1 1/2	1.900	2.75	2.90	0.125	1.650	1.516	2.200	2.500	0.2645
				0.145	1.610				0.2518
2 1/16	2.063			0.156	1.751				0.2978
2 3/8	2.375	4.00	4.70	0.167	2.041	1.947	2.875	3.063	0.4047
		4.60	4.70	0.190	1.995	1.900			0.3866
		5.80	5.95	0.254	1.867	1.773			0.3386
2 7/8	2.875	6.40	6.50	0.217	2.441	2.347	3.500	3.668	0.5788
		8.60	8.70	0.308	2.259	2.165			0.4957
3 1/2	3.500	7.70	-	0.216	3.068	2.943	4.250	4.500	0.9144
		9.20	9.30	0.254	2.992	2.867			0.8696
		10.20	-	0.289	2.922	2.797			0.8294
		12.70	12.95	0.375	2.750	2.625			0.7346
4	4.000	9.50	11.00	0.226	3.548	3.423	4.750	5.000	1.2229
				0.262	3.476	3.351			1.1737
4 1/2	4.500	12.60	12.75	0.271	3.958	3.833	5.200	5.563	1.5218

Motor	**T max**	**OD**	**Minimum Casing**
300 STD	200 F	3.75	4 1/2
400 STD		4.56	5 1/2
500 STD		5.40	6 5/8
700 STD		7.25	8 5/8
E4	250 F	4.56	5 1/2
E5		5.50	6 5/8
300 THD	325 F	3.75	4 1/2
400 THD		4.56	5 1/2
500 THD		5.40	6 5/8

Pressure losses are assumed to be in the fully turbulent flow regime. Friction factor is given by:

$$f_{\text{Moody}} = \frac{8}{\left(2.457\, ln\left(\frac{1}{0.27\varepsilon_r}\right)\right)^2}$$

Friction losses for single phase liquid flow with the units of psi for pressure, feet for length, inches for diameter and bpd for flowrate:

$$\left.\frac{dP}{dz}\right|_{friction} = 1.1471x10^{-5} f_{Moody} \frac{\gamma\, q^2}{d^5}$$

Motor cooling minimum flowrate with the units of bpd for flowrate and inches for diameters:

$$q_{min} = 84\left(d_{ic}^2 - d_{em}^2\right)$$

Cable temperature correction factor for voltage losses with temperature in F.

$$C_t = 0.0022\, T + 0.8517$$

Cable voltage losses per 1,000 ft at 68 F with current in amps.

$$\Delta V_{1000\,ft}^{68\,F} = a\, I$$

Cable working temperature heating equation with current in amps and temperatures in F.

$$T_c = b\, I^2 + T_{surrounding}$$

$$KVA = \frac{\sqrt{3}\, V_s\, I}{1000}$$

Values of cable constants:

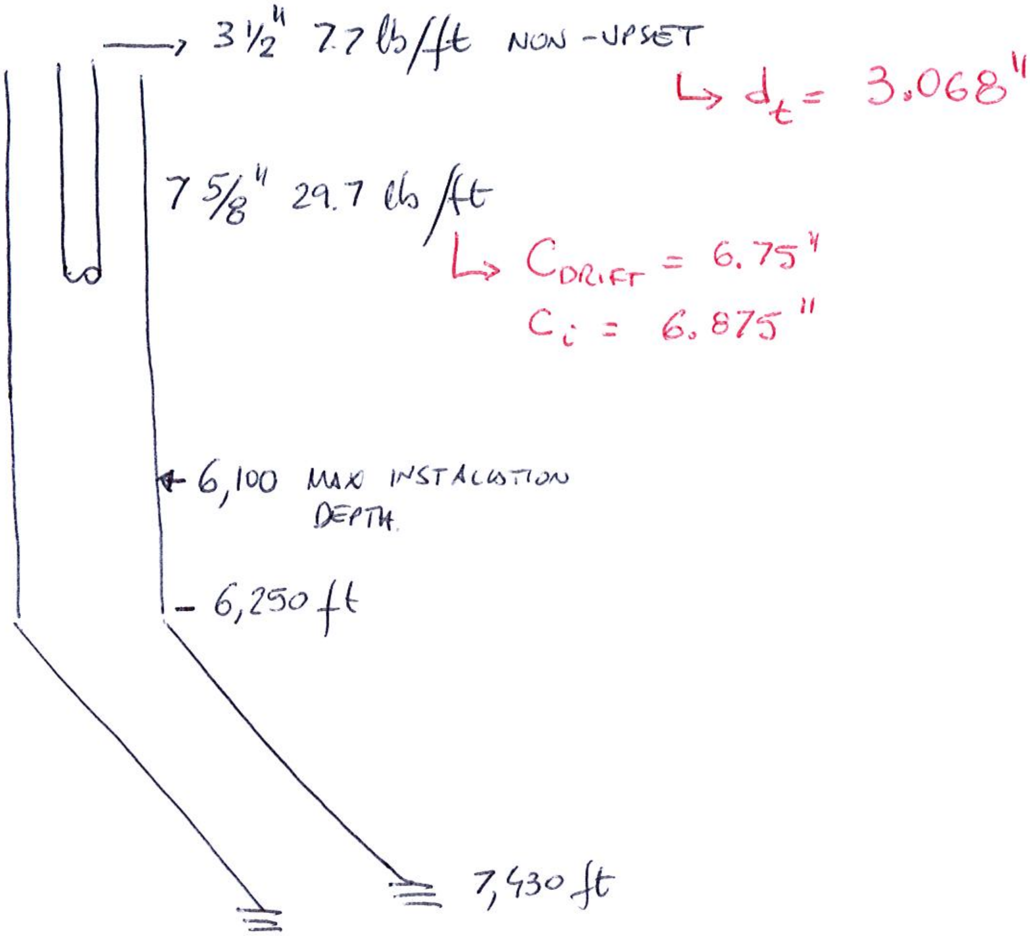
Conductor Size	*a*	*b*
#6	*0.6818*	*0.02330*
#4	*0.4545*	*0.01426*
#2	*0.2708*	*0.00749*
#1	*0.2150*	*0.00564*

Clearance Check

$$\delta = smallest\begin{cases} C_{drift} - \left[\dfrac{OD_{motor}}{2} + \dfrac{OD_{tub\,coup}}{2} + d_{cable} + h_{band} + h_{guard}\right] \\ C_{drift} - \left[\dfrac{OD_{motor}}{2} + \dfrac{OD_{pump}}{2} + d_{cable} + h_{band} + h_{guard}\right] \\ C_{drift} - \left[\dfrac{OD_{motor}}{2} + \dfrac{OD_{seal}}{2} + d_{cable} + h_{band} + h_{guard}\right] \end{cases}$$

$$h_{guard} = 0.08''$$

$$h_{band} = 0.08''$$



$\gamma_w = 1.07$; $\gamma_o = 0.87$; $\bar{P} = 3{,}500$ psi ; $T = 7$ YEARS

CURRENT CONDITIONS

$WC = 0.35$

$J = 1.13$

$\mu = 12$ cp

$\varepsilon/d = 0.0001$

FUTURE CONDITIONS

$WC = 0.8$

$J = 1.32$

$\mu = 120$ cp

$\varepsilon/d = 0.002$

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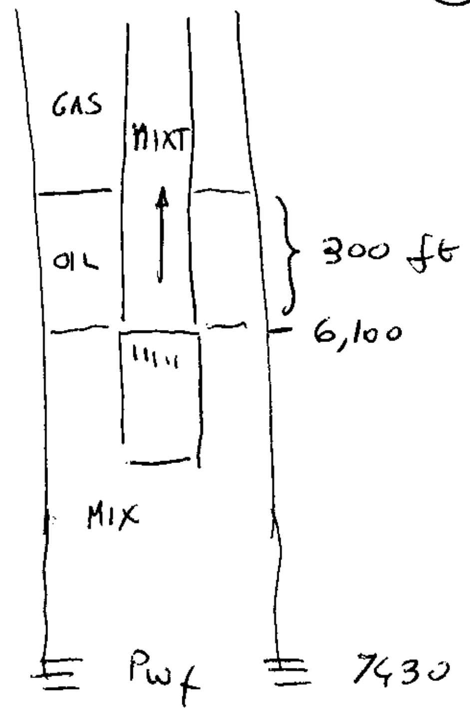
$\gamma_m = 0.35(1.07) + 0.65(0.87) = 0.94$

$\gamma_m = 0.8(1.07) + 0.2(0.87) = 1.03$

$P_{WH} = 165$ psi ; $L_{SUB} = 300$ ft ; $\left.\frac{dP}{dZ}\right|_{GAS} = 0.035$ psi/ft

(A) PUMP WILL BE SET @ 6,100 ft

(B) $L_{SUB} = 300$ ft (DATA)



(C) PUMP INTAKE PRESSURE

$$PIP = P_c + \left.\frac{dP}{dz}\right|_g (L_P - L_{SUB}) + 0.433\, \gamma_o\, L_{SUB}$$

$$= 165 + 0.035\,(6{,}100 - 300) + 0.433\,(0.87)\,300$$

$$= \underline{481 \text{ psi}}$$

(D) $P_{wf} = PIP + 0.433\, \gamma_M\, (7430 - 6{,}100)$

CURRENT

$481 + 0.433\,(0.94)\,(7430 - 6{,}100)$

$P_{wf} = 1{,}022$ psi

FUTURE

$481 + 0.433\,(1.03)\,(7430 - 6100)$

$P_{wf} = 1{,}074$ psi

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(E) FLOWRATES $q_L = J\,(\bar{P} - P_{wf})$

CURRENT

$1.13\,(3500 - 1022)$

$q_L = 2800$ bpd

FUTURE

$1.32\,(3500 - 1074)$

$q_L = 3{,}200$ bpd

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(F) FROM CATALOG THE LARGES PUMP SERIES THAT FITS IS THE "TE"

HOWEVER, BASED ON THE FLOWRATE RANGE OF 2,800 bpd – 3,200 bpd ONLY THE TG 3,100 IS A GOOD CHOICE

THE TD - 3,000 IS A "BACK-UP" CHOICE

G FRICTION FACTOR

$$f = \frac{8}{\left(2.457 \ln \frac{1}{0.27\varepsilon_r}\right)^2}$$

CURRENT

$$\frac{8}{\left(2.457 \ln\left(\frac{1}{0.27(0.0001)}\right)\right)^2}$$

$$f = 0.012$$

FUTURE

$$\frac{8}{\left(2.457 \ln\left(\frac{1}{0.27(0.002)}\right)\right)^2}$$

$$f = 0.0234$$

H PUMP DISCHARGE PRESSURE

$$PDP = P_{WH} + L_p \gamma_m \left(0.433 + 1.1471 \times 10^{-5} f \frac{q_L^2}{d_t^5}\right)$$

CURRENT

$$PDP = 165 + (6{,}100)(0.94) \times$$
$$\times \left(0.433 + 1.1471 \times 10^{-5} (0.012) \frac{2800^2}{3.068^5}\right)$$

$$PDP = 2670 \text{ psi}$$

FUTURE

$$PDP = 165 + (6{,}100)(1.03) \times$$
$$\times \left(0.433 + 1.1471 \times 10^{-5} (0.0234) \frac{3200^2}{3.068^5}\right)$$

$$PDP = 2949 \text{ psi}$$

I HEAD NEEDED

$$H = \frac{\Delta P}{0.433\ \gamma_m}$$

CURRENT

$$= (2670 - 481)/0.433\ 0.94$$

$$H = 5378 \text{ ft}$$

FUTURE

$$(2949 - 481)/0.433\ (1.03)$$

$$H = 5534 \text{ ft}$$

(4)

(J) PUMP CATALOG CURVE

TG 3,100 @ 60 Hz $\Rightarrow$ { q = 2800 H = 40 // HP = 1.4 //
q = 3200 H = 33 // HP = 1.4 //

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(K) STAGES NEEDED

$$N = \frac{H_{NEED}}{H_{PUMP}}$$

CURRENT

$$N = \frac{5378}{40} = 134$$ //

FUTURE

$$N = \frac{5534}{33} = 168$$ //

WE NEED 168 STAGES MINIMUM //

—n—

(L) HOUSING SELECTION $\Rightarrow$ ABRASION RESISTANT FLOATING STAGES

2 HOUSINGS # 8 WITH 86 STGS EACH = 172 TOTAL STAGES //

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(M) PUMP SPECS

TG 3,100 2 HOUSINGS # 8 (172 STAGES)
ABRASION RESISTANT – FLOATING STAGES
STANDARD SHAFT (LIMIT OF 179 STGS)
STANDARD HOUSING (LIMIT OF 214 STGS)
STD OR HIGH-LOAD THRUST BEARINGS (AT THE LIMIT) //
TR-5 SEAL

N) MINIMUM MOTOR SPECS

$$BHP = 172\,(1.07)\,(1.4) = 258 \text{ HP}$$

$$BHP_{MINIMUM} = 258 + 15 = \underline{273 \text{ HP}}$$

— n —

O) CHOKE PRESSURE DROP

$$\Delta P_c = 0.433\ H/_{STG}\,(N_{INST} - N_{NEEDED})\,\gamma_m$$

CURRENT

$$0.433\,(40)\,(172 - 134)\,(0.94)$$

$$\Delta P_c = \underline{618} \text{ psi}$$

FUTURE

$$0.433\,(33)\,(172 - 168)\,(1.03)$$

$$\Delta P_c = \underline{59} \text{ psi}$$

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P) MOTOR TEMPERATURE CLASS

$$T_M = 120 + \frac{16}{1000}\,6100 = 217\,^\circ F \Rightarrow \underline{\text{MOTOR "E" SERIES}}$$

E-5 FITS ~~TABLE~~

MOTOR E-5 1 SECTION WITH 280 HP; 1920 V; 87 AMPS

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$$d_M = 5.5''$$

Q COOLING CONDITIONS.

$$q_{MIN} = 84\left(6.875^2 - 5.5^2\right) = 1430 \text{ bpd}$$

NO SHROUD NEEDED

R HP MOTOR LOAD

$$\text{LOAD} = \frac{N \; HP/_{STG} \; \gamma_M + 15}{HP_N}$$

CURRENT

$$\text{LOAD} = \frac{172(1.4)\,0.94 + 15}{280} = 86\%$$

FUTURE

$$\frac{172(1.4)(1.03) + 15}{280}$$

93%

GOOD MOTOR EFFICIENCY RANGE !

S MOTOR ACTUAL CURRENT.

CURRENT

$87(0.86) = 75$ AMPS

FUTURE

$87(0.93) = 81$ AMPS

7

VOLTAGE = 1,920 V

CURRENT

CABLE	i	T_{CMAX}	T_{ABLE}	C_T	ΔV_c	V_S	$\Delta V_c / V_M$	
6	75	349	300	1.511	471	2391	0.25	
4	75	298	249	1.399	291	2211	0.15	
2	75	260	211	1.316	163	2083	0.08	OK
1	75	249	201	1.293	127	2047	0.07	OK
FUTURE								
6	81	370	322	1.559	525	2445	0.27	
4	81	311	262	1.429	321	2241	0.17	
2	81	267	218	1.3311	178	2098	0.09	OK
1	81	255	206	1.305	139	2059	0.07	OK

CABLES # 1 AND # 2 <u>WORK</u> !
MUST BE 300 TEMPERATURE CLASS !
MUST BE OR CAN BE 3 KV CLASS !

(T) CLEARANCE

$OD_{MOTOR} = 5.5"$ $C_{DRIFT} = 6.75"$

$OD_{SEAL} = 5.13"$ $h_{GUARD} = 0.08$

$OD_{PUMP} = 5.13"$ $h_{BAND} = 0.08$

$OD_{COUP} = 4.25"$

$$\delta = C_{DRIFT} - \left[\frac{OD_M}{2} + \frac{OD_P}{2} + d_c + 0.08 + 0.08 \right]$$

$$\text{IF } \delta = 0 \Rightarrow 0 = \left[6.75 - \left(\frac{5.5}{2} + \frac{5.13}{2} + d_c + 0.16 \right) \right]$$

$d_{C\,MAX} = 1.275"$ TO CLEAR PUMP/SEAL!

$$\text{IF } \delta = 0 \Rightarrow 0 = \left[6.75 - \left(\frac{5.5}{2} + \frac{4.25}{2} + d_c + 0.16 \right) \right)$$

$d_{C\,MAX} = 1.715"$ TO CLEAR COUPLING!

(U) CABLE POWERLINE 300 3KV ROUND CABLE!

$\#1 \Rightarrow d_c = 1.319"$

$\#2 \Rightarrow d_c = 1.248"$

BOTH #1 AND #2 CAN BE USED AROUND THE TUBING!

(V) MOTOR LEAD EXTENSION

#1 POWERLINE 450 5KV $d_c = 0.67$

#2 POWERLINE 480 5KV $d_c = 0.64$

BOTH MOTOR LEAD EXTENSION CAN BE INSTALLED AROUND THE ESP SYSTEM !

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(W) . KVA

$$KVA \cong \frac{\sqrt{3}\,(3000)\,87}{1000} \cong 452\ KVA$$