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Cost Reduction of Cylindrical Steel Oil Storage Tanks

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ABSTRACT
With the growing demand for strategically storing bulk liquids, the cost of the storage tanks gained large importance. This cost has the greatest influence on the overall projects' cost. Hence, reducing the price of a tank is of prime importance. In this sense, the shell design, specifically the thickness of the different shell courses, play an important role along with steel plate specifications and the Manpower that it takes for construction. In this paper, parametric studies with respect to the specifications of steel plates and needed Manpower to construct the shell are performed. Different shell diameters are taken into consideration and the analysis is performed according to API 650 Standard.

***Keywords**: Cost, Manpower, Steel, Tank Shell*

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I. INTRODUCTION

In the last couple of decades, the demand for liquid storage has increased. Various economic and political activities demand the storage of different types of liquids starting from water, to oil and gas, to edible oils. Each of these aforementioned liquids demands a different type of storage tanks, like concrete tanks for water, cylindrical steel tanks for oil products, spherical for gas, stainless steel for edible oils. Hence, the storage tanks are a major component in any storage project and their cost has the highest effect on the overall project's cost. In this sense, optimizing the price of storage tanks is of prime importance. L. Roncetti [1] studied the economical optimization of welded steel tanks. He focused on the thickness of steel plates and the number of storage tanks needed for storing a specific volume. Wankhede *el al.* [2] focused on the cost optimization of concrete water storage tanks mainly studying the impact of wall thickness, the depth of the floor slab and beam on the cost. Optimal size of steel storage tanks is also an important research topic [3, 4] along with spherical storage tanks [5, 6]. Various researchers also study the optimization of labor hours in constructing steel structures [7, 8].

This paper focuses on cylindrical steel storage tanks used for oil components. These types of tanks are basically formed by a base, a shell, and a roof. On one hand, the specifications for the base and the roof are standardized and thus the cost reduction is negligible in these two parts. On the other hand, the cost of the shell which is the main component of a tank may be reduced. Furthermore, the shell is formed by a number of shell courses which can acquire different thicknesses. Thus, reducing this allowable thickness would reduce the weight of the shell which would eventually reduce its cost. Nevertheless, the thickness of a shell course, allowable to use, is linked to the steel plate specifications and to its height – equivalent to the number of used shell courses. Using higher graded steel plates would require less thickness which would lead to less shell weight. However ascending the steel grade means ascending the price. Therefore, a study should be done, in order to make the optimal choice of steel. Moreover, a higher number of shell courses might lead to a lower overall weight but it would require more work to install. Hence, the needed Manpower to construct a tank's shell also has a major influence on the cost. Taking into consideration all the above mentioned reasons, parametric studies with respect to the allowable stresses for the design and hydrostatic test conditions – S_d and S_t respectively – is performed on one hand. S_d and S_t are steel specifications that have the major influence on the shell course thickness. On the other hand, influence of the number of shell courses on the needed Manpower is also studied.

After this first introductory section, the second one deals with design of the cylindrical steel tank. The parametric studies and the results are detailed in the third section. And section 4 draws the final conclusion of the study.

II. TANK DESIGN

A cylindrical steel storage tank is mainly designed in three parts, the base, the shell, and the roof top. As stated in the introduction, the influential cost reduction can only be done in the shell's design since the base and roof designs are standardized.

A tank's shell consists of different shell courses that may vary in thickness and height (see figure 1).

Figure1: Different shell courses in a cylindrical steel tank

The cost of the steel plates in a shell is simply its mass multiplied by the price of used steel. Furthermore, the mass of the shell is sum of the mass of its courses which can be written as:

$$M_{sc} = H_{sc} \,.\, D_T \,.\, \pi \,.\, TH_{sc} \,.\, \rho_{\text{steel}} \qquad (1)$$

where, H_{sc} is the height of a shell course (in m), D_T is the diameter of the tank which is the same as the diameter of a shell course (in m), TH_{sc} is the thickness of a shell course (in mm) and $\rho_{\text{steel}} = 7.85\ g/cm^3$. Equation (1) gives the mass in Kg which is then divided by 1000 to get it in Ton.
The only variables in the previous equation are the height and thickness of the shell course. The former would be given two different values throughout the study and the latter is given by:

$$TH_{sc} = \text{roundup}[\max(t_d\,, t_t)]\ , \qquad (2)$$

where, t_d is the design shell thickness (in mm) and t_t is the hydrostatic test shell thickness (in mm). These two can be given by [9]:

$$t_d = \frac{4.9 \times D_T \times (H_{rem} - 0.3) \times G}{S_d} + CA \qquad (3)$$

$$t_t = \frac{4.9 \times D_T \times (H_{rem} - 0.3)}{S_t} \qquad (4)$$

with, H_{rem} is the design liquid level (in m) or specifically the remaining shell height above the shell course, *G* is the specific gravity of the liquid to be stored which would to be considered as 0.75, approximately the one of gasoline, *CA* is the corrosion allowance specified as 1.5mm in this study. Also S_d is the design stress (in MPa) and S_t is the hydrostatic test stress (in MPa).

It is clear from equations (3) and (4) that t_d and t_t are inversely proportional to S_d and S_t respectively. While S_d and S_t are proportional to the steel grade and hence to its price. Which means ascending the price of steel plates would require less shell course thickness and hence reducing the total mass of the shell. This is why performing a parametric study with regards to the design stress and the hydrostatic test stress is of prime importance when it comes to optimizing the cost of a tank.

III. COST OPTIMIZATION AND RESULTS

III.1 Effect of steel specifications

As state above, a parametric study is performed. In this study a shell overall height is fixed at 20m, two shell course heights are considered (2m and 2.5m) and three shell diameters are chosen (30m – 43m – 51.5m) along with three different steel specifications (check table 1).

Steel Specification	S_d (MPa)	S_t (MPa)	Notation in remainder parts of paper
A36M	160	171	*S1*
A516M (Grade 485)	173	195	*S2*
A662M (Grade C)	194	208	*S3*

Table1: Steel plates specifications

The price of 1Ton of *S1*, the cheapest among the chosen three, will be denoted Pr . Depending on the market, the price of 1Ton of *S2* is about 10% higher so it is going to be $1.1Pr$ and the price of 1Ton of *S3* is about 5% higher so it is going to be $1.05Pr$.

Tables 2, 3 and 4 illustrate the results for a tank diameter of 30m with a 2m shell course height for *S1*, *S2* and *S3* respectively.

Course #	Remaining Height	Td	Tt	Course Thickness	Mass
1	20	15.075	16.93	17	25.155
2	18	13.696	15.21	16	23.675
3	16	12.318	13.49	14	20.716
4	14	10.940	11.77	12	17.756
5	12	9.562	10.06	11	16.277
6	10	8.184	8.34	9	13.317
7	8	6.806	6.62	7	10.358
8	6	5.428	4.9	6	8.878
9	4	4.050	3.18	5	7.398
10	2	2.671	1.46	3	4.439

Table2: Results for a tank diameter of 30m with a 2m shell course height for *S1*

Course #	Remaining Height	Td	Tt	Course Thickness	Mass
1	20	14.054	14.85	15	22.195
2	18	12.780	13.34	14	20.716
3	16	11.505	11.83	12	17.756
4	14	10.231	10.33	11	16.277
5	12	8.956	8.82	9	13.317
6	10	7.682	7.31	8	11.838
7	8	6.407	5.80	7	10.358
8	6	5.133	4.29	6	8.878
9	4	3.858	2.79	4	5.919
10	2	2.583	1.28	3	4.439

Table3: Results for a tank diameter of 30m with a 2m shell course height for *S2*

Course #	Remaining Height	Td	Tt	Course Thickness	Mass
1	20	12.695	13.92	14	20.716
2	18	11.559	12.51	13	19.236
3	16	10.422	11.09	12	17.756
4	14	9.286	9.68	10	14.797
5	12	8.149	8.27	9	13.317
6	10	7.013	6.85	8	11.838
7	8	5.876	5.44	6	8.878
8	6	4.739	4.03	5	7.398
9	4	3.603	2.61	4	5.919
10	2	2.466	1.20	3	4.439

Table 4: Results for a tank diameter of 30m with a 2m shell course height for *S3*

Tables 5, 6 and 7 show the results for a tank diameter of 30m with a 2.5m shell course height for *S1*, *S2* and *S3* respectively.

Course #	Remaining Height	Td	Tt	Course Thickness	Mass
1	20	14.054	14.85	15	31.443
2	17.5	12.461	12.97	13	27.744
3	15	10.868	11.08	12	24.045
4	12.5	9.275	9.19	10	20.346
5	10	7.682	7.31	8	16.647
6	7.5	6.088	5.43	7	12.947
7	5	4.495	3.54	5	9.248
8	2.5	2.902	1.66	3	7.398

Table5: Results for a tank diameter of 30m with a 2.5m shell course height for *S1*

Course #	Remaining Height	Td	Tt	Course Thickness	Mass
1	20	14.054	14.85	15	27.744
2	17.5	12.461	12.97	13	24.045
3	15	10.868	11.08	12	22.195
4	12.5	9.275	9.19	10	18.496
5	10	7.682	7.31	8	14.797
6	7.5	6.088	5.43	7	12.947
7	5	4.495	3.54	5	9.248
8	2.5	2.902	1.66	3	5.549

Table6: Results for a tank diameter of 30m with a 2.5m shell course height for *S2*

Course #	Remaining Height	Td	Tt	Course Thickness	Mass
1	20	12.695	13.92	14	25.895
2	17.5	11.275	12.97	13	24.045
3	15	9.854	11.08	12	22.195
4	12.5	8.433	9.19	10	18.496
5	10	7.013	7.31	8	14.797
6	7.5	5.592	5.43	6	11.098
7	5	4.171	3.54	5	9.248
8	2.5	2.750	1.66	3	5.549

Table7: Results for a tank diameter of 30m with a 2.5m shell course height for *S3*

The overall mass of the tank's shell along with the total price of the shell are illustrated in table 8, which basically summarizes the important results of all six previous tables.

(H of course ; type of steel)	Mass of Tank Shell (Ton)	Price of Tank Shell
(2m ; S1)	147.97	$147.97 \times Pr$
(2m ; S2)	131.69	$144.86 \times Pr$
(2m ; S3)	124.29	$130.51 \times Pr$
(2.5m ; S1)	149.82	$149.82 \times Pr$
(2.5m ; S2)	135.02	$148.52 \times Pr$
(2.5m ; S3)	131.32	$144.45 \times Pr$

Table8: Mass and Prices for a tank shell of diameter 30m

It is clear from table 8 that, for a 30m-diameter steel tank, of height 20m, choosing shell courses of height 2m of steel type *S3* (A662M (Grade C)) costs less than the other choices.
For clearer visuals and for minimizing the number of tables, only two tables, similar to table 8, illustrate the results for the other two tank diameters (see tables 9 and 10).

(H of course ; type of steel)	Mass of Tank Shell (Ton)	Price of Tank Shell
(2m ; S1)	294.80	$294.80 \times Pr$
(2m ; S2)	260.87	$286.96 \times Pr$
(2m ; S3)	239.66	$251.64 \times Pr$
(2.5m ; S1)	302.23	$302.23 \times Pr$
(2.5m ; S2)	267.76	$294.54 \times Pr$
(2.5m ; S3)	259.81	$285.79 \times Pr$

Table9: Mass and Prices for a tank shell of diameter 43m

(H of course ; type of steel)	Mass of Tank Shell (Ton)	Price of Tank Shell
(2m ; S1)	421.66	421.66 × *Pr*
(2m ; S2)	368.32	405.15 × *Pr*
(2m ; S3)	350.54	368.07 × *Pr*
(2.5m ; S1)	431.82	431.82 × *Pr*
(2.5m ; S2)	377.84	415.63 × *Pr*
(2.5m ; S3)	371.49	408.64 × *Pr*

Table10: Mass and Prices for a tank shell of diameter 51.5m

Tables 9 and 10 also show that choosing shell courses of height 2m of steel type *S3* (A662M (Grade C)) costs less than the other choices. These last three tables show that ascending the grade of steel plate would lead to using less steel which would cost less. Moreover, even when choosing to work with shell courses of height 2.5m, the *S3* steel costs the least but more than the 2m shell courses. Nevertheless, ten 2m-courses are needed for a shell of height 20m while eight 2.5m-courses are needed. This means that installing 2m-courses requires more time and work than that of 2.5m-courses. Hence, studying the effect of Manpower required for this task on the overall cost of the tank is of prime importance.

III.2 Effect of steel manpower

As stated above, the difference between installing ten 2m-courses and eight 2.5m-courses with regards to manpower should be studied for the three chosen tank diameters. But first of all, it has to be noted that since we are focusing on the shell's design, the installation of other parts (such as the base, annular plates, roof plates, etc) are not taken into consideration. Moreover the installation of these parts is independent of the height of used shell courses. Second of all, based on past field experience, some approximations/assumptions regarding the required working days should be made. And third of all, indirect manpower, such as project managers, quality inspectors etc…, will not be taken into consideration. And only direct manpower and used equipment will be considered. The first of these assumptions is that, for a 30m-diameter tank, 6 days are needed to install a shell course regardless of its height. While 8 days are needed for the 43m and 51.5m tanks. Hence, the total days needed for shell installation are summarized in table 11.

Tank diameter (m)	**51.5**	**43**	**30**
Duration of Installation of a Shell course (Days)	8	8	6
Total Duration for Option of 10 Shell Courses	80	80	60
Total Duration for Option of 8 Shell Courses	64	64	48
Difference in Duration	16	16	12

Table11: Days needed for shell installation

Furthermore, the needed manpower and equipment for installing a shell course are detailed in table 12.

	51.5	**43**	**30**
Direct Manpower (Quantity)			
Mechanical Engineer	1	1	1
Foreman	1	1	1
Tank Welder	5	4	3
Tank Erector/Fitter	10	8	6
Semiskilled assistant	5	4	3
Helper	10	8	6
Equipment (Quantity)			
Jacking System	65	55	38
Welding Machines	10	8	6
Generators	2	2	1
50-Ton Crane	1	1	1

Table12: Required manpower and equipment to install one shell course

In order to be more realistic and to avoid having idle time, the above quantities can be used for working on two tanks simultaneously since most the manpower and equipment cannot be put on the same tank at once. Therefore, the following realistic daily rates should be divided by two.

The shell cost highly depends on labor and equipment rates hence it depends on the country where the tank are being constructed. Therefore, two countries – Sudan and Cyprus, where TETCO® had already constructed tanks, will be used as benchmarks for quasi-realistic total shell costs. These two countries, Sudan and Cyprus, are chosen since the former has cheap labor and the latter has a high manpower cost.

III.3 On ground cases

As stated above, two work locations are chosen as benchmarks. The steel price is not affected by the location, neglecting the fact that the shipping might affect it, thus the price of a Ton of A36M (referred to above as S1) will be *Pr = 700$*. Surely this number depends on the market price, however for the purpose of this study we can assume a price of 700$. As for the manpower and equipment daily rates, they are summarized in table 13 for both Cyprus and Sudan.

	Monthly Rates Cyprus ($)	Daily Rates Cyprus ($)	Monthly Rates Sudan ($)	Daily Rates Sudan ($)
Direct Manpower				
Mechanical Engineer	8500.00	326.92	4500.00	173.08
Foreman	2750.00	105.77	2500.00	96.15
Tank Welder	2350.00	90.38	950.00	36.54
Tank Erector/Fitter	2250.00	86.54	850.00	32.69
Semiskilled assistant	1960.00	75.38	650.00	25.00
Helper	1640.00	63.08	250.00	9.62
Equipment				
50-Ton Crane	13500.00	519.23	7500.00	288.46
Jacking System	85.00	3.27	85.00	3.27
Welding Machines	125.00	4.81	125.00	4.81
Generators	1500.00	57.69	1500.00	57.69

Table13: Monthly and Daily rates in Sudan and Cyprus

Furthermore the total manpower cost for all three tank diameters and two course heights are illustrated in table14.

Tank Diameter (m)	**51.5**	**43**	**30**
Cyprus			
Direct daily rate for one shell course ($)	2757.69	2292.69	1827.69
Equipment daily rate for one shell course ($)	895.19	852.88	730.00
Total manpower cost for whole shell (10 courses) ($)	146115.38	125823.08	76730.77
Total manpower cost for whole shell (8 courses) ($)	116892.31	100658.46	61384.62
Sudan			
Direct daily rate for one shell course ($)	1000.00	853.85	707.69
Equipment daily rate for one shell course ($)	664.42	622.12	499.23
Total manpower cost for whole shell (10 courses) ($)	66576.92	59038.46	36207.69
Total manpower cost for whole shell (8 courses) ($)	53261.54	47230.77	28966.15

Table14: Total manpower cost for all three chosen diameters

Adding the price of the steel plates to table 14 gives the following final total cost results in US dollars (see table 15). These results are for all three tank diameters and steel grades and for the two chosen course heights in Sudan and Cyprus. Also the lowest total costs are highlighted in bold.

	51.5 (m)	**43 (m)**	**30 (m)**
Sudan			
(H of course ; type of steel)			
(2m ; S1)	361738.92	265398.46	139786.69
(2m ; S2)	350181.92	259910.46	137609.69
(2m ; S3)	**324225.92**	**235186.46**	**127564.69**
(2.5m ; S1)	355535.54	258791.77	133840.15
(2.5m ; S2)	344202.54	253408.77	132930.15
(2.5m ; S3)	339316.54	247283.77	130081.15
Cyprus			
(H of course ; type of steel)			
(2m ; S1)	441277.38	332183.08	180309.77
(2m ; S2)	429720.38	326695.08	178132.77
(2m ; S3)	403764.38	301971.08	168087.77
(2.5m ; S1)	419166.31	312219.46	166258.62
(2.5m ; S2)	407833.31	306836.46	165348.62
(2.5m ; S3)	**402947.31**	**300711.46**	**162499.62**

Table15: Total shell cost for all cases

Many observations can be drawn from table 15. Firstly, using the steel of type *S3*, which is 5% more expensive than *S1*, will lead to a cheaper tank's shell for all three diameters and for both course heights. This just is just a confirmation of what was obtained in section 3.1. Secondly, using 10 shell courses is cheaper than using 8 in a country with lower man-day rates such as Sudan since working more days will not lead to drastic increase in cost. Thirdly, using 10 shell courses is more expensive than using 8 in a country with high man-day rates such as Cyprus since it would lead to high increase in payments. Lastly, this study is performed for only one tank which is never the case in a construction site. Hence, when the cost reduction is multiplied by the effective number on constructed tanks, it would imply major cost optimization.

IV. CONCLUSION

This paper dealt with cost reduction of cylindrical steel tanks for storing oil derivatives. It focused on the tank's shell where major optimization can be made. Two parameters were studied: the steel plate specifications used for the shell and the manpower needed to install it. It was concluded that using steel specifications higher than the allowable ones by the API standards (in terms of design stress and hydrostatic test stress) would reduce the steel cost since thinner shell courses might be used. Furthermore, using more shell courses in in a lower man-day costcountry reduces the overall shell cost in opposition to a highly-paid labor country. Furthermore, reducing the cost of a storage tank would reduce the produced steel which would have a small impact on energy saving.

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BIOGRAPHIES

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[3]. Assad Tahhan has a bachelor in mechanical engineering from the American University of Beirut. He is currently a project manager at TETCO®, a leading company in the construction of steel storage tanks in the MENA region. He has more than ten years experience in the field of oil and gas and worked in many countries including Lebanon, UAE, Sudan, Cyprus and Qatar. This paper represents his first written research study. Previous work involved site and cost studies in the work field.

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