Investigation of Dry and Combined Method Used for Measurement and Maintenance Control of Liquid Storage Tank Capacity

V. Uravić, Z. Car, M. Kršulja, L. Šikulec, H. Radelja

Tehničkifakultet u Rijeci, Sveučilište u Rijeci, Rijeka, Hrvatska

*Corresponding author. E-mail: Zlatan.Car@riteh.hr

Abstract
This paper presents an investigation of liquid storage tanks capacity. A measurement method used in maintenance is shown for liquid tanks manufactured by DIN6602 standard. Measurements were conducted with calibrated measurement etalon AM ET 1500 Litres. Relevant data was analysed with software TankCalc and the results of dry and combined (wet) measurement method were compared. The process and regulations for necessary calculations are shown and the results are shown graphically for better understanding. A method for calculation under the influence of inclination is shown and recommendations for error reduction are given. The emphasis is given to differentiate the advantages of geometrical towards the advantages of combined measurement method. Specifically, these two methods are most wanted by the owner of the liquid tanks and this investigation was to explore what can be expected from each method with respect to errors. Also the paper points out the importance of proper design of liquid storage tanks and an investigation of storage tank for petrol E 95 with volume 50 m^3 is shown. The importance of maintenance and measurements can be explained with the example of the propane tanks. The propane tanks are an interesting technical challenge, as the propane boils at normal room temperature. The optimum way of storing propane is in liquid form, and that propane is kept in a liquid state at room temperature, it must be kept under pressure. In order to avoid the explosion liquid tanks must not be filled beyond 80 % of full capacity (volume), as the incompressible liquid propane changes at the temperature change.
Keywords: liquid storage tanks, measurement, maintenance, storage

1. Introduction

Liquid storage tanks can be found at many places from petrol stations, ports, refineries etc., they can be horizontal or vertical and their maintenance and control requires exact law regulations and scientific procedures. Continuous measurements are conducted and used as a guideline for stockpiling optimisation and also for safety [1]. Exact scientific procedures combined with law regulations are necessary when dealing with flammable or explosive gases and wrong storage can lead to great damage or worse [2-3]. Croatian department for measurement determines rules and regulations needed for specific measurements acts as a support to local industries and facilitates control and inspection in accordance with national and international regulations. For such investigations carful measurement plans have to be made in order to follow different law and other regulations and technology innovations [4]. For measurement and control of tanks law NN 100/03 and NN 124/03 are used for length, surface and volume measurements together with law NN 47/05 that is used in order to determine control periods for measuring etalons used for control of law certified measuring devices. Specific law for measurement devices used for control of fluid level or the height of empty space in tanks is NN 111/97 it is used for measurement of total volume. For mobile tanks such as used on camions, trains etc. the regulations of law NN 35/01 is fallowed. When measuring the horizontal cylindrical tanks the law regulations NN 35/01 are used. The law prescribed in NN 26/05 is also necessary as it prescribes measuring conditions for automatic measurements of stationary tanks. And finally the law NN 2/07 is also taken in consideration as it describes the measurement and technical conditions for ship tanks. In Croatia for tanks the law certification period is every 10 years. It should be mentioned that until 2004 year for diesel tanks a period of 5 years was given and for petrol 10 years but this changed because diesel creates hard sediment of several millimetres that often gives measurements errors outside the tolerances. For the type of the size, type and placement of stamps and certification designations the law NN 113/09 is used.

2. Methods used in tank measurement

Methods of tanks measurement:
a) Geometrical dry method, b) Volumetric (wet) method, c) Optical determination (triangulation method), d) combined method.
Geometric method is used for determination of tank data tables and it can be used in cases when the tanks are of proper geometrical shape, without deformations, and when it is possible to calculate all geometrical and others relevant data necessary for calculation of given volume. It is also used when the application of other methods for determination of tank capacity storage is not possible. Geometrical method is typically used for control of vertical tanks as they are not practical for wet method because of the big size of such tanks.
Volumetric method or wet method is used for determination of tank table in cases when geometric method is not possible, such cases are when tanks have irregular shape, or when deformations to the tank have been determinate. Also it is used when the tank at the place of instatement has present accessories and tubes necessary for fluid management etc. Volumetric method for determination of tank volume can be used if the total volume of the tank is $V_{total} < 100\ m^3$.
Metod of triangulation it is a similar method like the geometric but with more shapes and precision and as a result it is a lot more expensive.

Combined method is use in cases when individual application of geometrical i.e. optical or volumetric method is not possible, when unused volume of the tank must be specified by volumetric method, and the rest of the tank can be selected by geometric method in similar cases.

The selection of measurement is up to the owner of the tank, and the combined method (geometric + volumetric) has been seen as the best comparison of price and precision, although all is decided by the preferences of tank owner.

Span of current measurements can be seen in table 1, and current prices for measurements range from minimum 260 euro for smallest tanks < 20 ml up to 1600 euro for > 50000 ml.

Table 1: Tanks in the shape of a roller are controlled:

Wet method	Dry method	Combined method	Optical scaling – triangulation method
< 20 ml	< 500 ml	< 500 ml	< 500 ml
20 ml - 30 ml	500 ml -5000 ml	500 ml – 5000 ml	500 ml – 5000 ml
30 ml - 50 ml	5000 ml – 50 000 ml	5000 ml - 50 000 ml	5000 ml - 50 000 ml
50 ml - 100 ml	> 50 000 ml	> 50 000 ml	> 50 000 ml

3. Problem statement

The situation of investigated tank is: the measurement place is found at 22.5 cm from the opening centre towards the closer part. The inclination is determined by height. The tank is strengthened with T-ring with dimensions 75.80.7 mm. The tank capacity is 50 m^3. And the petrol stored inside is E – 95.

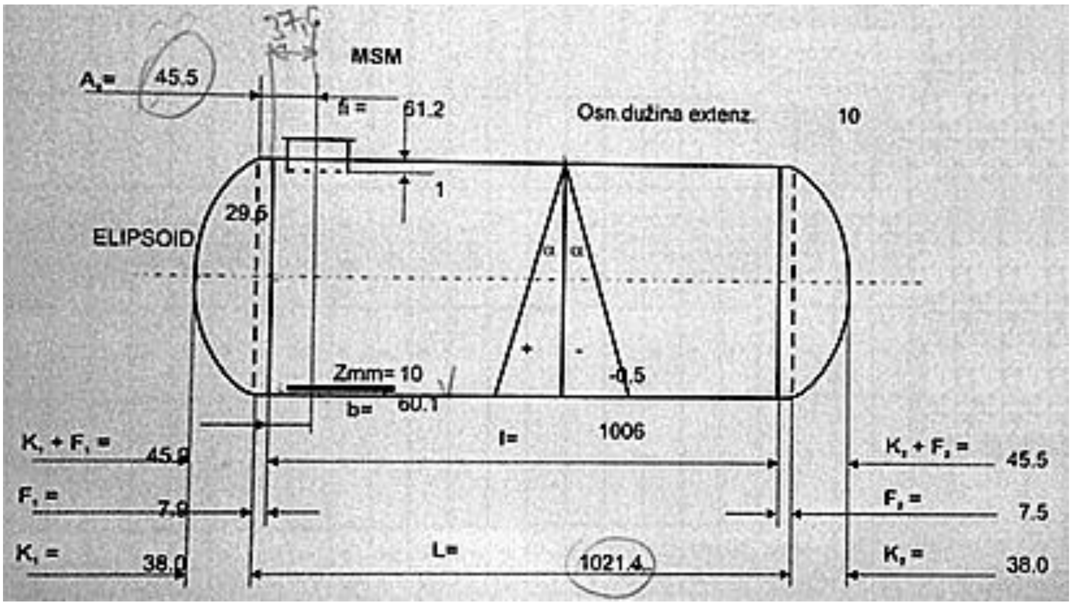

Figure 1. Tank with 50 m3 capacity used for storing petrol E-95

Figure. 1. Shows investigated tank schematics, capacity 50 m^3 used for storing petrol E – 95. The tank volume is calculated by equation for ellipsoid (1):

$$v = \frac{2}{3}\pi R^2 L. \tag{1}$$

In this investigation diagrams (figure 2) for combined and geometrical analysis method are shown for given horizontal tank. The comparison is done between geometrical (dry) and combined (geometrical +dry) method. From the diagram it can be seen that the tank filling line is adequate to standard filling diagrams. If deviations from standard filling lines are present, than results are not adequate and it is necessary to repeat the measurements.

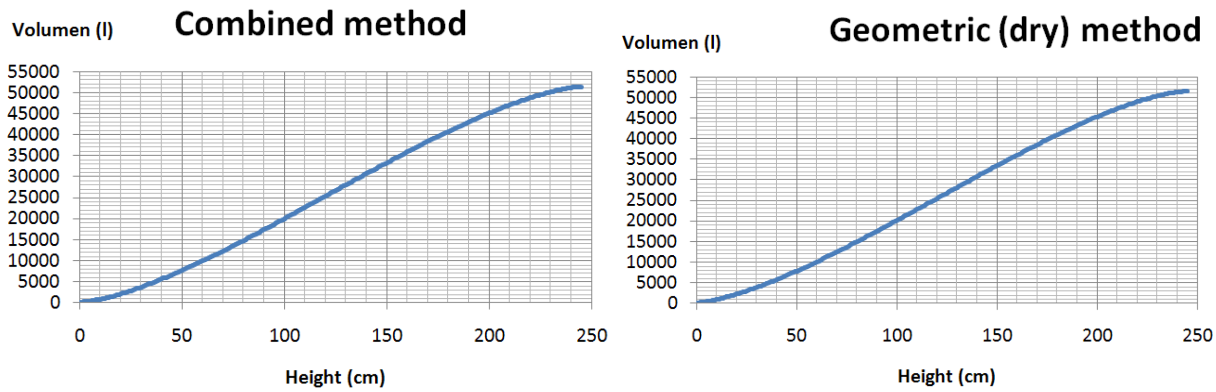

Figure 2. Diagrams show obtained characteristic lines for combined and for geometric dry method

The results in the table 2 are conducted with measurement etalon AM 1500 ET of ETRADEX company with tank capacity of 1500 l and of total measurement uncertainty of ± 0,05 % and the probability of 95 %.

Figure. 3. Shows measurement etalon AM 1500 ET with capacity of 1500 litres [1, 5]

Geometric method will be used to show the values of volume for the same heights from the filling table and compare them with errors. Program used in our investigation for geometric method is TankCalc [6], it is a free software and easily available. In the software after the necessary dimensions are introduced, the program generates table of the tank (calculation of known volume or height). It is possible to set the table in very fine segments such as 0,01 mm, 1 mm, 1 cm etc. Difference from the professional calculators is that it doesn't take temperature in consideration this can be a problem as volume changes are very important.

3. Results and analysis [7]

The measurements are done by selecting specific volumes and their heights in tanks, and by filling these volumes from designated etalons the known volume is introduced into investigated tanks. For such a volume thirty to thirty-five data are calculated. This data are then introduced into fixed data in tables of the tanks and based on that the corrections are made.
Table 2 shows measurement results for minimum, maximal and average error of geometrical method in relationship with the data for filling shown in liters (l) and percentage in relationship to total tank volume of 51032 l (% V_{total}). The columns l abs and $\%V_{total}$ abs show the data of absolute error values.

Table 2. Relevant data for geometrical measurement

	l	l abs	$\%V_{total}$	$\%V_{total}$ abs
min	-277,6	13,8	-0,543972409	0,027042
max	150,1	277,6	0,294129174	0,543972
average	-136,838	157,3676	-0,268142019	0,308371
Standard deviation ja	111,7112	79,09795	0,218904158	0,154997

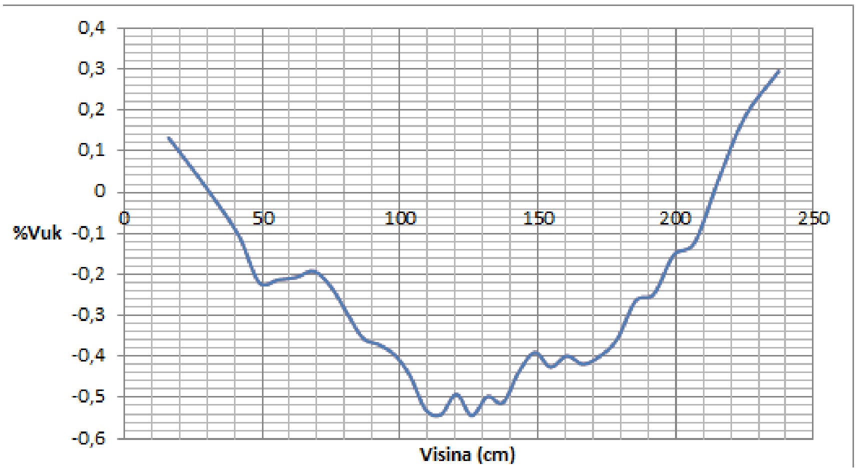

Figure 4. Show filling data errors in relationship to the total volume tank

Figure 4 shows error of geometric method in relationship to the data of filling in relationship to the total volume in the tank expressed in percentage. Figure 4 demonstrate that the largest volume quantities are located in centre of the tank which is logical considering it is a horizontal tank and therefore it has a big horizontal surface. In order to gain full insight into the state of the errors their frequency is analysed and shown in a combined Pareto diagram.

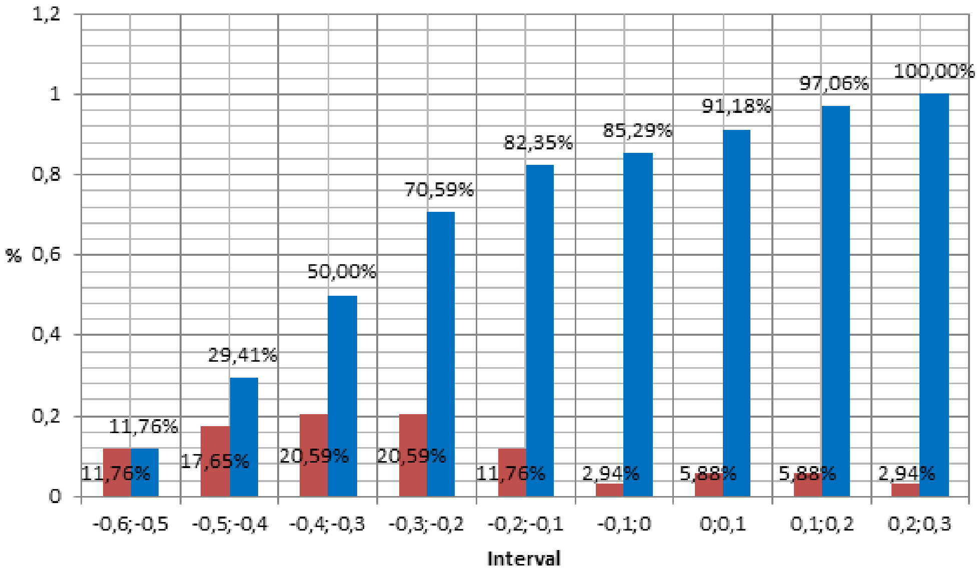

Figure 5. Frequency of errors in relationship to filling data

Figure 5 shows the frequency of errors for geometric method in relationship to the data of filling considering the total tank volume. Figure b demonstrates relative and cumulative frequencies.

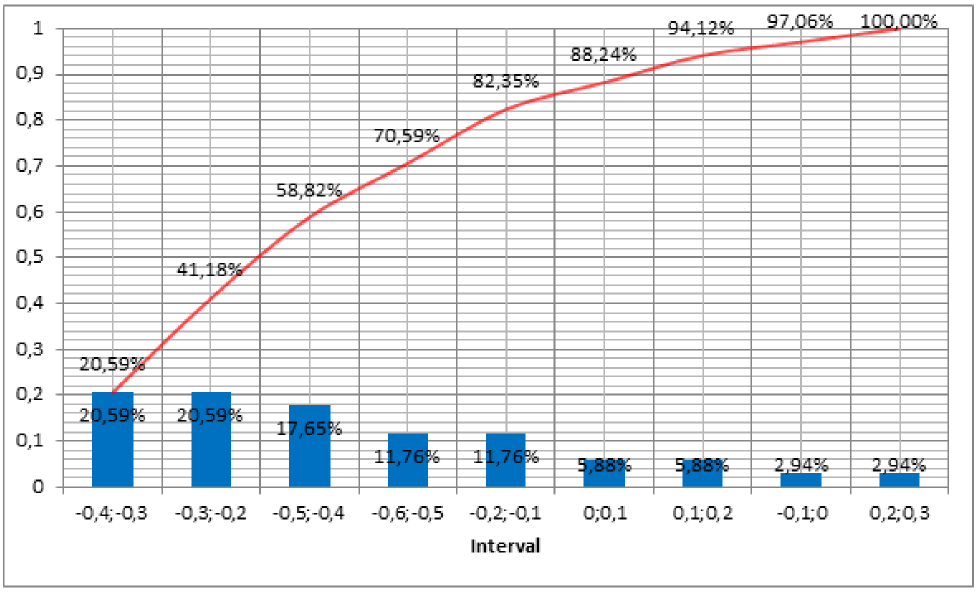

Figure 6. Pareto diagram

Figure 6 shows Pareto diagram for obtained filling frequencies. Pareto Diagram shows that 58,82 % errors can be found within 3 interval from total 9, and 82.35 % of errors within 5 intervals from the total of 9. We can also conclude which intervals are the most common for errors.

Table 3 shows relative errors of data obtained by geometric method by submerging. It can be seen that with the increase of the height the relative error drops. This is understandable when taking into the account that the total volume increases.

Table 3. Relative errors of data obtained by geometric method by submerging

	Relative error u %	Absolute relative error u %
min	-1,49373	0,028733
max	4,518454	4,518454
average	-0,50661	0,84944
Stand. Dev.	1,016674	0,744747

Figure 7 shows relative error of geometrical error in relationship with wet method.

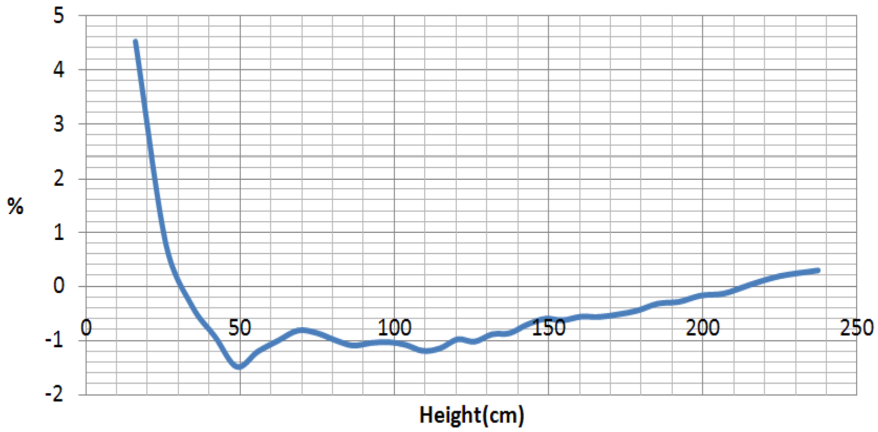

Figure 7. Diagram shows error of wet method and diagram

4. Comparison of combined and dry method

Errors of dry method in comparison to the combined method in % in relationship to total volume are shown in figure 8 and relative data is shown in table 4.

Table 4. Shows relevant data for error of dry method in relationship to combined method when compared to total volume tank in percentage

Minimal error (%)	0,007838
Maximal error (%)	0,431102
Average error (%)	0,263401
Median (%)	0,039191
Standard deviation (%)	0,082497

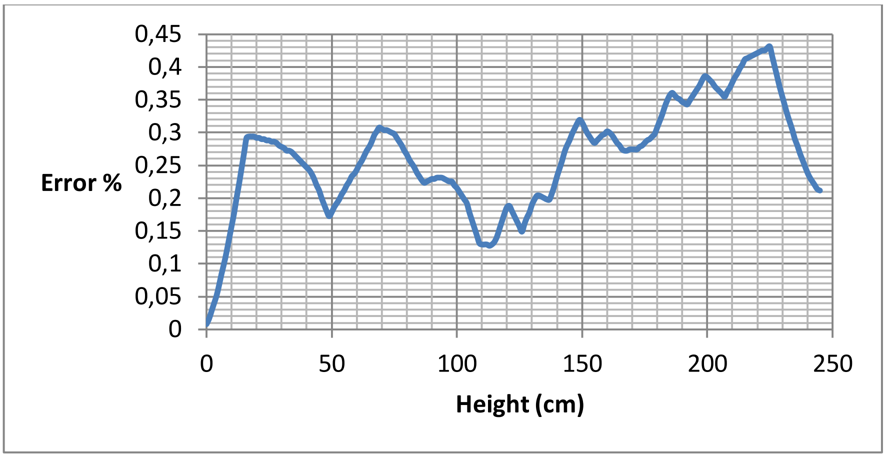

Figure 8. Errors of dry method in comparison to the combined method in % in relationship to total volume

In relationship to total volume the maximal error is 0,43 %, and the average 0,26 % which is acceptable. Data from the diagram is also shown as frequency of intervals in which the errors occur.

Table 5. Shows data used for calculation of Pareto frequency diagrams.

INTERVAL	FREQ..	REL. FREQ.	CUMMULATIVE FREQ.
0,05	4	1,62601626	1,62601626
0,1	4	1,62601626	3,25203252
0,15	12	4,87804878	8,130081301
0,2	33	13,41463415	21,54471545
0,25	49	19,91869919	41,46341463
0,3	77	31,30081301	72,76422764
0,35	25	10,16260163	82,92682927
0,4	29	11,78861789	94,71544715
0,45	13	5,284552846	100

Diagram shown in figure 9, clearly shows intervals in which the errors are most common. It also demonstrates that over 86,59 % is contained in 5 from 9 intervals. Also it can be seen that errors within 0-0,1 % rarely occur. Since the combined method is more accurate than geometrical, the diagram shows the error of dry method in relationship to the combined method in percentages. It can be seen that the biggest error is at the beginning which is understandable considering that it is the case of relative error, and that the size of the volume is small at the beginning, in such a way even a small error can result as a big relative error. It must be remembered that the relative error is used only in order to compare methods of measurement. Figure 10 and table 6 show the comparison of results and relative data of error comparison between geometrical and combined method.

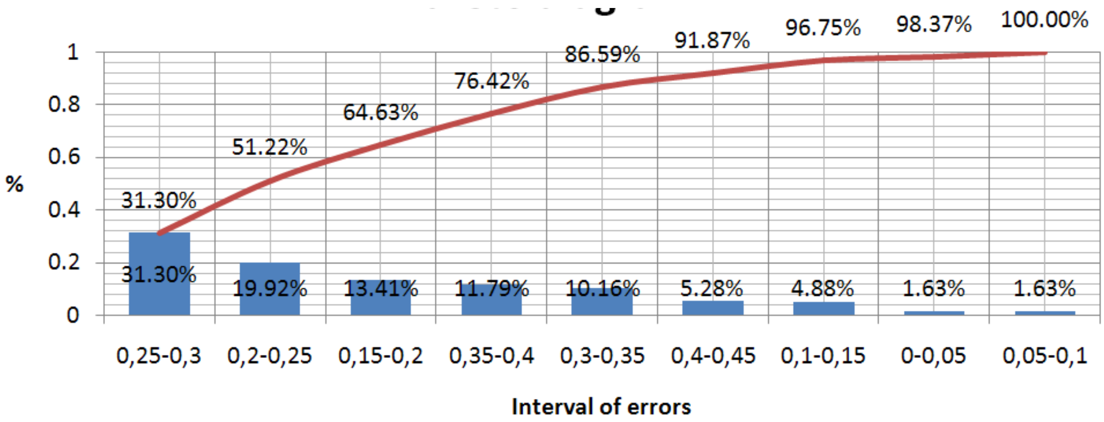

Figure 9. Pareto diagram of combined method

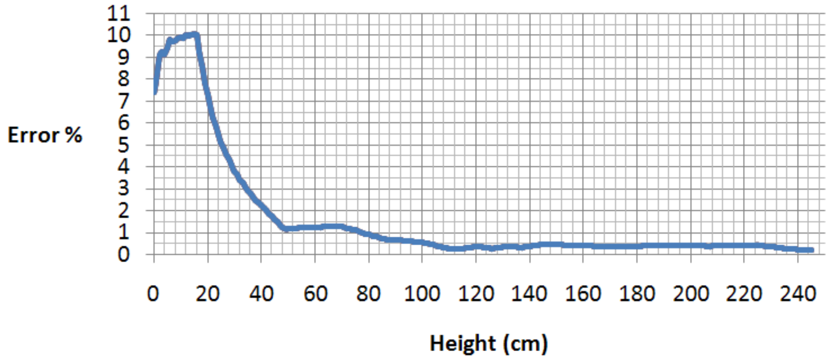

Figure 10. Error of geometrical in comparison to the combined method in %

Table 6. Shows relevant data used in comparison of dry with combined method in %

Minimal error (%)	0,209917
Maximal error (%)	10,04399
Average error (%)	1,605886
Median (%)	0,439108
Standard deviation (%)	2,582269

4. Conclusion

In this paper the investigation of investigation of storage tank for petrol E 95 with volume 50 m^3 is shown [7]. Several diagrams are shown in order to demonstrate typical measurement method, comparisons of used methods have been made and recommendations were given. In relationship to total volume for investigated tank the maximal error is 0,43 %, and the average 0,26 % which is acceptable accuracy by Croatian law. Measurements shown in this investigation are compatible with Croatian laws and they have been addressed in introduction chapter. Average errors that occur in geometrical method in comparison to the wet method have been determined. Both method geometric and combined have been conducted and results shown. The recommendation is to use more accurate geometric method; however this method requires more exact measurement and more expensive equipment and in the event of tank deformations the error will be greater than the wet method. Further investigation will be focused on measurement plans and implementation of European norms and time periods necessary for accurate measurements of different fluids and tank capacities.

Acknowledgement

This investigation was conducted in joint cooperation between Croatian department for measurement Rijeka, Project Financed by Ministry Of Science, Education and Sports 069-1201787-1754 ''Numerical modelling, simulation and optimization in plate forming'', Laboratory of intelligent machines and machining systems of Technical faculty Rijeka.

6. Literature

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