ANNALS of Faculty Engineering Hunedoara – International Journal of Engineering
Tome XX [2022] | Fascicule 2 [May]

[1.]Jozsef GAL, [2.]Abel SIMON

MINIMIZING THE RISK AND TRANSPORTATION COST OF ETHANOL TRANSPORTATION

[1.]University of Szeged, Faculty of Engineering, Mars ter 7, 6724 Szeged, HUNGARY
[2.]University of Szeged, Faculty of Economics and Business Administration, Kalvaria sgt. 1, 6722 Szeged, HUNGARY

Abstract: This paper presents the circumstances regarding the transportation of high purity ethanol, also mentioned as ethyl alcohol. Due to its physical or chemical properties, the ADR, also known as the International Transport of Dangerous Goods, describes the conditions under which it can be transported. The main topic in the paper is how this flammable product can be transported by tank trucks. The paper focuses on a real life logistic problem. ADR and road regulations are presented throughout a personal example in order to determine, which is the optimal tank volume for high purity ethanol transportation. It is not just a logistics problem, has environmental impacts as well.

Keywords: logistics, ethanol transport, environmental protection, cost efficiency, ADR

1. INTRODUCTION

Ethanol, also mentioned as ethyl alcohol is well known material. It is the oldest mind–altering drug, but nowadays it is also used as an additive to disinfectants, cosmetics, perfumes and fuels in addition to spirits. Due to its physical or chemical properties, the ADR, also known as the International Transport of Dangerous Goods, describes the conditions under which it can be transported and its unique identifier (UN number). It belongs to the category of excisable products in two respects as it can also be defined as an energy or alcohol product. In the course of the task we write about 100 V/V% ethanol, defined as an absolute anhydrous alcohol, the published water content can be up to 1000 ppm (0.1 m/m%) according to the pharmacopoeial regulations. The aim of the task is to determine the optimal tank capacity that allows the specific transport cost to be minimized. In other words, which is the tanker with the maximum capacity that can carry most anhydrous alcohol in one transport, taking into account the ADR and road weight restrictions. In terms of task, the shipping cost is recorded assuming we deliver to a specific "A" destination.

The goal is the minimum unit transport cost, when a company wants to buy tankers that are just suitable for transporting Dangerous Goods and to develop its own fleet of heavy vehicles. The task is to be able to deliver our own anhydrous alcohol to destination "A" at a given commercial price. The company currently has a towing vehicle of 7,500 kg. From the point of view of the task, the transport cost is fixed, assuming that we deliver to a given destination "A" (constant distance), and the market conditions are such that neither the fuel price nor the driver's wages and tolls are unchanged. The goal is to achieve maximum "profit" on the shipment, assuming that the receiver at destination "A" always has 40000 L of free storage capacity. Destination "A" is located within 1000 km and does not have the possibility of unloading by rail, air or water. We can only transport it by road, so there is no question of intermodal transport or the increased weight limits set out in Government Decree 516/2017. [1]

2. PROBLEM DESCRIPTION

According to the current regulation, the maximum permissible trailer weight on public roads is 40,000 kg. Here, the total weight of the tractor and trailer, including the driver, fuel and transported goods, is to be understood. In the case of intermodal transport, if the driver can prove that he is transporting the trailer by ship or rail, a total weight of up to 42 000 kg and 44 000 kg is permitted. In the case of intermodal shipments, we are talking about tank containers that are unloaded at the loading bay and lifted onto a railway train or hull. As the tank has to be handled separately here, so it cannot be recovered with the trailer registration number after it has been unloaded, the tank containers (Figure1) are given a unique number (container number – 4 letters + 7 number (on figure 1)) for identification, but it is also known:

Figure 1: Tank container [2]

- empty weight with frame – TARE (on figure 2)
- maximum permissible laden weight – MGW (on figure 2)
- nominal capacity – Capacity (on figure 2).

In the case of a three–axle vehicle, the maximum mass is 44 000 kg (Figure 2 right), however, if we do not have such a tractor, even in the case of a two–axle vehicle, 42,000 kg is permitted on public roads (Figure2 left) until the consignment reaches the railway or boat station.

Figure 2: Different–axle–number vehicles [3]

It is very important to comply with the ADR rules for anhydrous alcohol during the transport. When transporting ethanol, care must be taken to observe the appropriate markings. As alcohols and their solutions are to be classified as Dangerous Goods, the instructions given in the ADR must be followed for consignments. [4] [9]

The UN number [5] of the transported medium and the hazards of the transported material must be indicated in clearly defined places on the trailer and on the towing vehicle. The figure below shows where the labels and the UN number plate should be placed. The figure below shows that a sign must be placed on 2 sides and a label on all 4 sides. [6]

In the case of ethanol, the ADR plate must contain the number 33/1170. The upper number should be the hazard number, which is 33 for ethanol, as it indicates a highly flammable liquid. Below that is the 4–digit unique UN number, which is 1170 for ethanol. The label shall display Class 3 hazard, which indicates a flammable liquid with a flash point not exceeding 60°C.

Figure 3: Sign and label [6]

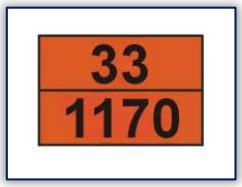

Figure 4: Ethanol sign codes [7]

Figure 5: Flammable liquid labels [7]

The ADR specifies the carriage of liquids which must be left in a liquid–free space so that, in the event of expansion of the liquid due to the temperatures reached during carriage, neither the liquid leaks nor the packaging is permanently deformed. This free space is limited by the introduction of the degree of filling by ADR. This can be given as a percentage, taking into account the physical properties of the medium.

Our medium is anhydrous ethyl alcohol. The characteristics of this medium required for the calculation are given in the table below:

Table 1: Ethanol density values [8]

Etanol 99,9 V/V%	
density at 15°C	793,8 kg/m^3
density at 50°C	758,34 kg/m^3

The ADR gives contexts for alcohol in the case of a mobile tank. (TP1), where TP1 specifies that the degree of filling can be determined as described in clause 4.2.1.9.2. [4]

$$\text{Degree of filling (\%)} = \frac{97}{1+\alpha(t_r - t_f)}$$

where: α – average cubic coefficient of thermal expansion of the medium
t_r – maximum temperature of the material during transport
t_f– is the average temperature during material loading.
According to 4.2.1.9.4, if transported and charged at ambient temperature, (t_r–t_f) is negligible and the coefficient of thermal expansion can be determined by the following formula.

$$\alpha = \frac{(d_{15} - d_{50})}{35 d_{50}}$$

where: d^{15}– is the density of the liquid at 15°C
d_{50}– density of the liquid at 50°C
Carrying out the calculation with the values given in Table 1, the value of the coefficient of thermal expansion is: α = 0,00133
Returning to the relationship described in clause 4.2.1.9.2, the maximum allowable filling level is: 96, 87%.

3. DETERMINING THE OPTIMAL TANK VOLUME

As described in the job description, the company has a 7.5 tons towing vehicle and we choose a non–intermodal solution during transport. So we have a weight of 32.5 tons. Taking into account the specified degree of loading, the following values were obtained. [10]
In the table below, the empty weight of the tank increases by 1.5% with an increase in volume of 1 m^3. The alcohol is filled and transported at 20°C, so the corresponding density is calculated. I give the unit freight cost per unit of product because the goal is to deliver as many products as possible with one shipment, so the goal is to make the divider as large as possible and therefore the specific unit as small as possible.

Table 2: Specific freight cost calculation by authors

Case	Tractor weight	Empty tank weight	Tank capacity	Degree of loading	Transported alcohol	Mass of alcohol delivered	Specific freight cost	Total weight
	[kg]	[kg]	[L]	[%]	[max L]	kg, 20°C (@789 kg/m^3)	[EUR/m^3 *10^3 alk.]	[kg]
1	7500	7500	30000	96,87	29061	22939	34,41	37939
2	7500	7613	31000	96,87	30030	23704	33,30	38816
3	7500	7727	32000	96,87	30998	24468	32,26	39695
4	7500	7843	33000	94,66	31238	24657	32,01	40000
4b	7500	7843	33000	96,87	31967	25233	31,28	40576
5	7500	7960	34000	91,44	31089	24540	32,17	40000
5b	7500	7960	34000	96,87	32936	25998	30,36	41458
6	7500	8080	35000	88,39	30938	24420	32,32	40000
7	7500	8201	36000	85,51	30784	24299	32,48	40000
8	7500	8324	37000	82,78	30628	24176	32,65	40000
9	7500	8449	38000	80,18	30470	24051	32,82	40000

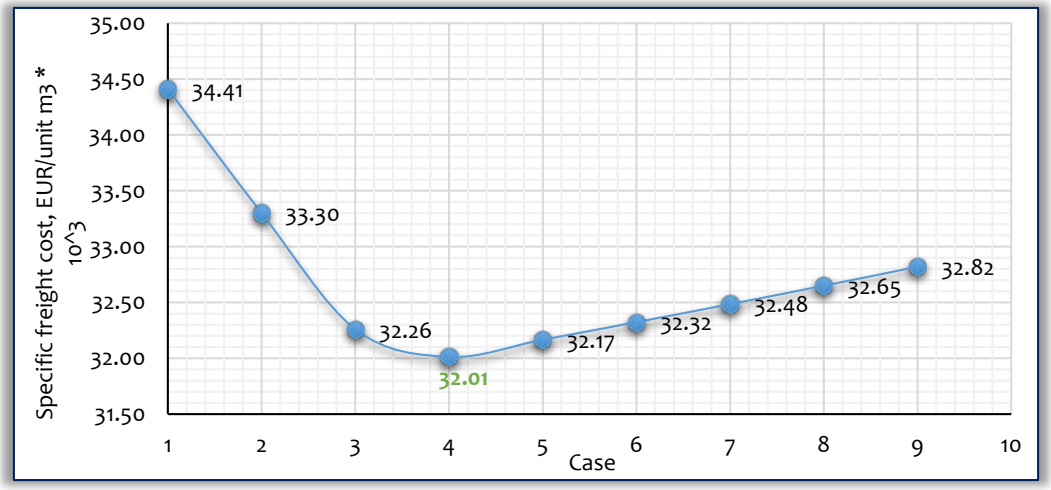

Figure 6: Variation in specific freight costs depending on the cases. Minimum score in case 4 (with a value of 32.01) based on calculation and Table 2

It is clear from the values in the table that the weight limit is above the tank above 32 m^3. On the other hand, if we can buy a tanker one size larger, we can deliver more products, only with a lower degree of filling, to stay

within the weight limit. Determined by target value search, a specific freight cost of 32.01 can be achieved for a 33 m^3 tank with a filling degree of 94.66% (4 cases), but by utilizing a filling degree of 96.87%, the weight limit would be exceeded (case 4b). The purchase of a tank of 34 m^3 or more does not make sense for the conditions described in the task, as we will not be able to fully utilize it, or with the increase in weight due to the increase in volume, we will lose product volumes and specific freight costs will increase (see Figure 6).

4. CONCLUSIONS

As a solution to the above problem, it is justified to buy tank wagons with a capacity of 33000 L if we deliver ethyl alcohol with a maximum water content of 1000 ppm to destination "A". During the task, it was important to know the ADR so that we were aware of the restrictive parameters for the delivery of our product. It can be concluded that by carefully circulating the topic during a high–value purchase, a decision can be made that will increase the company's profits. In the optimization task, it was a mistake to be able to achieve a better specific freight cost by releasing the filling level between cases 3 and 4, even if we do not use the maximum loadable capacity.

Note: This paper was presented at ICOSTEE 2022 – International Conference on Science, Technology, Engineering and Economy, organized by University of Szeged, Faculty of Engineering (HUNGARY) and Hungarian Academy of Sciencies – Regional Commettee in Szeged (HUNGARY), in Szeged, HUNGARY, in 24th of March, 2022.

References

[1] 516/2017. (XII. 29.) Korm. rendelet az egyes közlekedési tárgyú kormányrendeletek módosításáról (2017), https://net.jogtar.hu/jogszabaly
[2] Tank container, https://mccontainers.com/product/20–iso–tank–container–chemicals/ download 19.03.2022
[3] Types of vehicles https://www.tankformator.com/ download 15.03.2022
[4] A veszélyes áruk nemzetközi közúti szállításáról szóló európai megállapodás (ADR) (2020) http://www.kozlonyok.hu/nkonline/MKPDF/hiteles/MK17108–4R.pdf download 15.03.2022
[5] UN számok https://en.wikipedia.org/wiki/List_of_UN_numbers_1101_to_1200 sownload 05.03.2022
[6] Signes and labels http://sklep.fireshop.pl/tablice–adr/1097–tablica–adr–001–3–cyfrowa–33–1170–300x400–al.html download 15.03–2022
[7] Ž. Zadnik; M. Karakašić, M. Kljajin, J. Duhovnik (2009): *Function and functionality in the conceptual design process*. Strojniški vestnik – Journal of Mechanical Engineering, 55, 7–8
[8] Ethanol Water Mixtures – Densities vs. Temperature, https://www.engineeringtoolbox.com/ethanol–water–mixture–density–d_2162.html download 19.03.2022
[9] ADR categories https://www.gkicenter.hu/kisaru/az_adr_ruosztlyai.html download 18.03.2022
[10] Rixer Attila (1996): A közút–vasút, Közlekedés–tudományi szemle 8. 1996 augusztus XLVI. évfolyam, Budapest


ISSN 1584 – 2665 (printed version); ISSN 2601 – 2332 (online); ISSN-L 1584 – 2665