JELENA KESIĆ
DEJAN SKALA

Faculty of Technology and Metallurgy, University of Belgrade, Belgrade, Serbia and Montenegro

SCIENTIFIC PAPER

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ANTIFREEZE LIFE CYCLE ASSESSMENT
II. Mathematical modelling

A mathematical model based on the mass and energy balances of all the processes included in antifreeze life cycle assesment (LCA) was defined in the first part of this study [1]. The part of energy that can be transformed into some other kind of energy is called exergy in all energy processes. The concept of exergy considers the quality of different types of energy and materials. It is also a connection between energy and mass transformations where the physical meaning of exergy loss is the loss of material and energy that must be used in the process. The results of the LCA calculation are very useful for analyzing the obtained products and used processes and for determining the conditions under which this analysis was conducted. The result of this study indicated that recycling is the most satisfactory solution for the treatment of used antifreeze taking into account two parameters: material and energy consumption. The reuse of antifreeze should not be neglected as a solution of this analysis.

Key words: antifreeze, ethylene glycol, life cycle assessment, exergy, recycling, waste.

The analysis of Life Cycle Assesment (LCA) considers the identification and determination of the quantity of used raw materials, energy and the creation of wastes during the whole life cycle of some materials. The goal of such an analysis is estimation of the influence of such materials on the environment and a decrease in the generation of wastes. The derived mathematical model of LCA of antifreeze, presented in the first part of this study [1] is the basis for the calculation and determination of the optimal route for the antifreeze life cycle. A schematic presentation of both models A and B is shown in Figures 1 and 2 and all the constants and their definitions which constitute the LCA model are also described in detail in the first part of this study [1]. The models were based on the mass and energy balances of every process taken into account in the LCA (see Appendix).

Used antifreeze, after the usual manner of exploitation, can be collected and/or stored. The following coefficient of the proposed models [1] were varied in both models (A and B):

ksak,	total coefficient of collected used antifreeze (CUA)
k1sak,	coefficient of CUA which is rerefined
k1sak,	coefficient of CUA which is reused
knek,	the coefficient of uncontrolled disposal of CUA
kzem,	the coefficient of underground disposal of CUA
kkan,	the coefficient of CUA which goes into the municipal waste water system

kpkor1 and kpkor 2, distribution coefficients after antifreeze reuse (model B),

with the aim of findong the best solution of the routes for used antifreeze processing.

The coefficients were varied taking into account the following constraints:

k1sak+k2sak=1
knek+kzem+kkan=1
kpkor1+kpkor2=1

The real situation of the distribution of used antifreeze in the USA was described in a report prepared by the Union Carbide Corporation [2]. It was also taken as the basis for evaluating and testing different routes according to the proposed models A and B. The coefficients, which determine the used antifreeze disposal, were defined in the UCC report [2] by the values: kkan=0.355; kzem=0.241; knek=1–kkan–kzem =0.404.

The necessary information and a valid analysis for Serbia and Montenegro did not exist it was not possible to make a good forecast, and so, the coefficients were varied in this study assuming a real situation which was similar to those presented in the literature [2].

RESULTS AND DISCUSSION

A mass of 2.54 kg of antifreeze in exploitation was used for all the investigated cases. Three different routes of CUA were analyzed in both models (A and B, Figures 1 and 2):

1. Regeneration,
2. Reuse, and
3. Underground disposal.

The effect of the reuse of CUA was completely included in the LCA defined by model B. The results of the calculation made with model A are summarized in cases 1–10 (cases 4–9 are discussed in detail elsewere [3]), while case 11 represents a result obtained according to model B.

Case 1 (model A)

This is an unfavorable case. An uncontrolled disposal is defined by the following values of the coefficients: knek=1; kzem=kkan=0. The collection of used antifreeze (CUA) does not exist (ksak=0), so that means that rerafination also does not exist (k1sak=0), as well as the reuse of antifreeze (k2sak=0).

Author address: J. Kesić, Faculty of Technology and Metallurgy, Department of Organic Chemical Technology, University of Belgrade, Karnegijeva 4, 11000 Belgrad, Serbia and Montenegro
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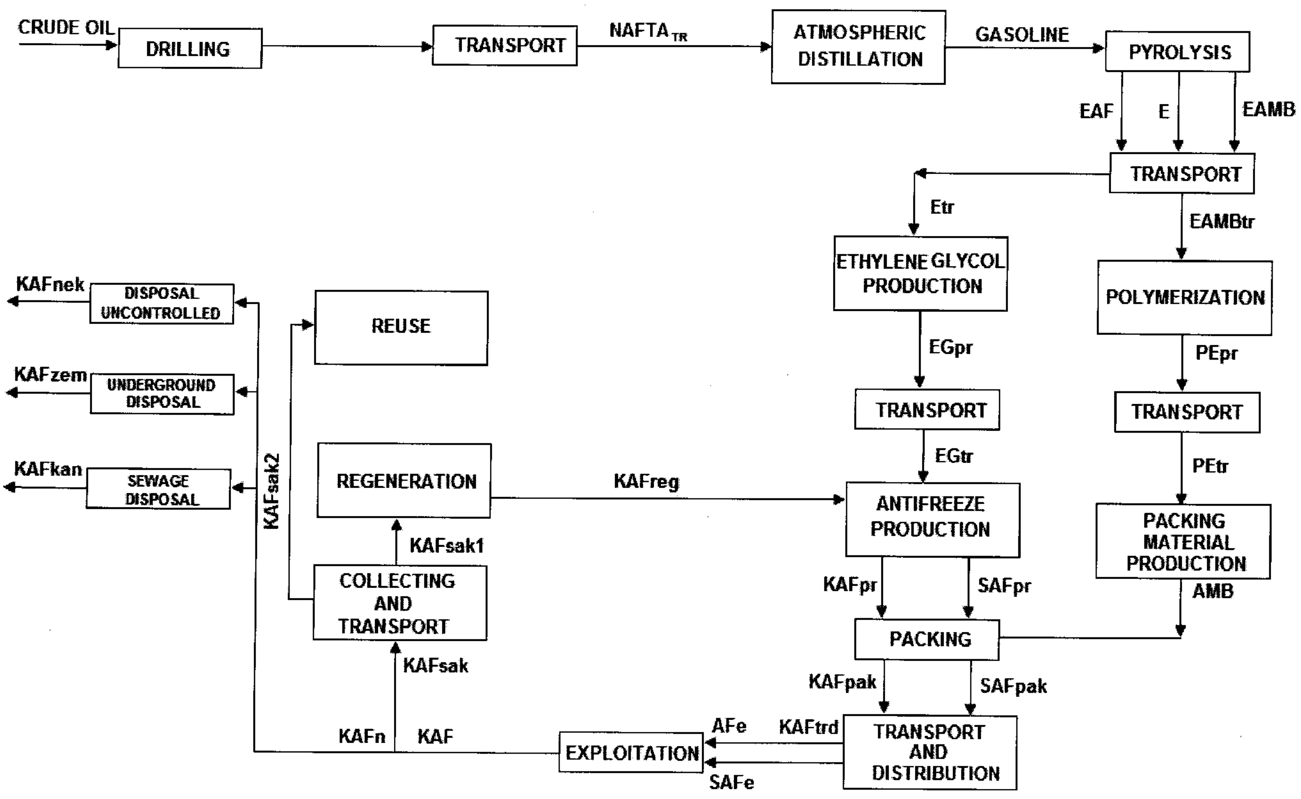

Figure 1. Scheme of antifreeze LCA according to model A [1]

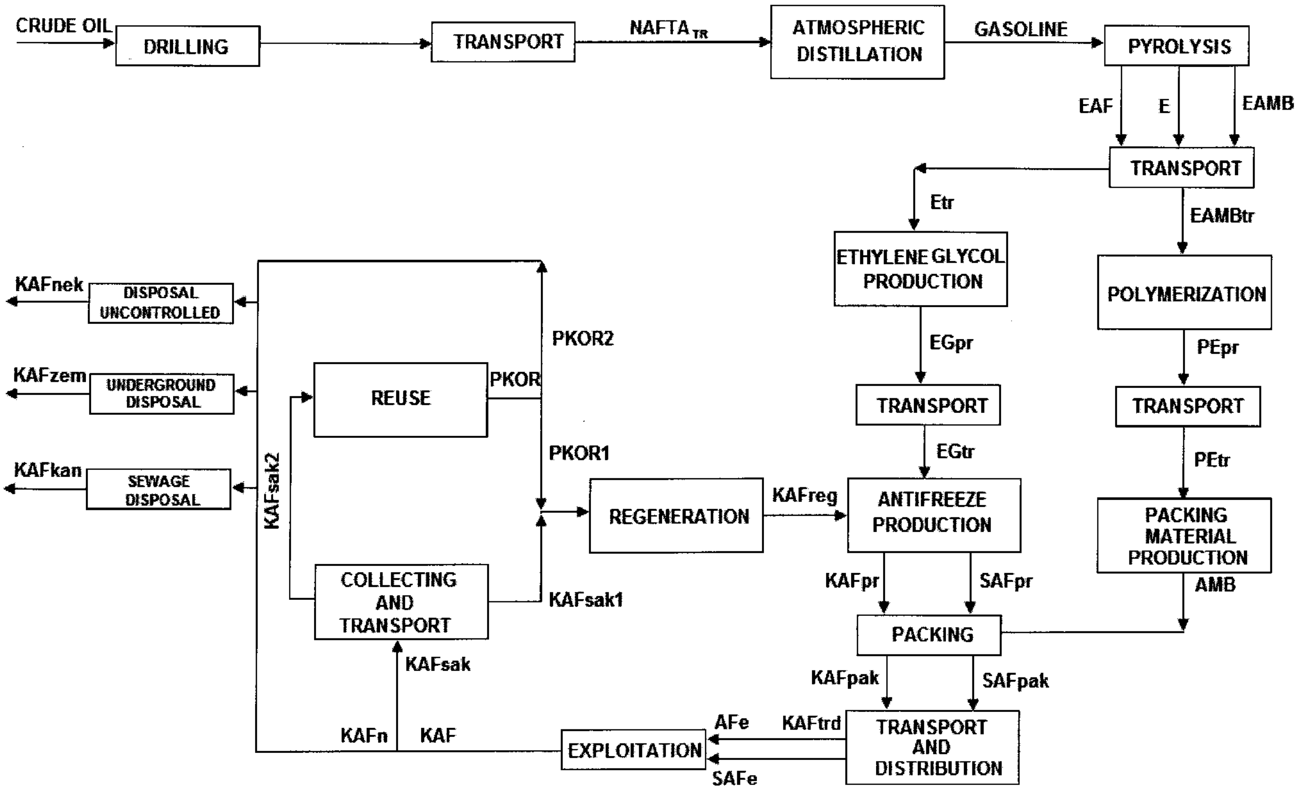

Figure 2. Scheme of antifreeze LCA according to model B [1]

Table 1. Comparison of the mass balance for cases 1 and 2, kg

	Case 1 ksak=0 knek=1.o	ksak=0.2	ksak=0.4	ksak=0.6	ksak=0.8	Case 2 ksak=1.0 knek=0
The mass of crude oil at the inlet	65.648	54.176	42.704	31.232	19.759	8.287
Ethylene necessary for antifreeze production	1.846	1.497	1.148	0.799	0.450	0.102
Styrene for packing	0.150	0.150	0.150	0.150	0.150	0.150
Regeneration	0.000	0.457	0.914	1.372	1.829	2.286
Uncontrolled disposal	2.286	1.829	1.372	0.914	0.457	0.000

Table 2. Comparison of the exergy balance for cases 1 and 2

	Case 1 ksak=0 knek=1		ksak=0.2		ksak=0.2	
	MJ	%	MJ	%	MJ	%
Exergy of crude oil	100.637	45.97	83.051	45.28	65.464	44.27
Exergy consumption in the processes	118.295	54.03	100.349	54.72	82.403	55.73
Total exergy consumption	218.932	100.00	183.400	100.00	147.868	100.00
Exergy of crude oil	47.878	42.62	30.291	39.44	12.704	30.78
Exergy consumption in the processes	64.458	57.38	46.512	60.56	28.566	69.22
Total exergy consumption	112.335	100.00	76.803	100.00	41.270	100.00

Case 2 (model A)

There is no disposal of any kind (knek=kzem==kkan=0); all of the antifreeze after exploitation was collected (ksak=1) and a further rerefinig procedure performed (k1sak=1), but without reuse (k2sak=0).

The results of cases 1 and 2 are shown in Tables 1 and 2.

A substantial decrease of the necessary mass of ethylene for ethylene glycol production was found according to the performed calculation, which means a decrease of the mass of crude oil, if the total amount (100%) of used antifreeze is going into the rerefing process. A decrease of the regeneration coefficient evidently leads to an increase of raw material (crude oil and ethylene) consumption. The mass of ethylene necessary for packing production is always constant.

The exergy balance indicated that the largest value of exergy consumption is, in the case of the uncontrolled disposal of used antifreeze (case 1), a consequence of the exergy that the crude oil possesses. Decrease of exergy consumption is followed by increase of the regeneration coefficient. When the rerefing process is included in the LCA model, then an increase in the percentage of exergy consumption of the processes in the total exergy consumption was obtained. Thus, the value of the exergy consumption of the processes is the largest for case 2 (no disposal; all the amount of used antifreeze isgoing into the regeneration process).

Each process has some defined exergy consumption (see Appendix: Tables A1–A10). By applying mathematical model A for LCA it was observed that the changes of exergy consumption varied depending on the values of the used coefficients, for example:

Case 1 (exergy calculation is given in the Appendix, Model A)

Ethylene glycol production 52.515 MJ (44.39%)
Pyrolysis of light gasoline 40.888 MJ (34.56)
Atmospherc distillation 11.318 MJ (9.57%)

Case 2 (exergy calculation is given in the Appendix, Model A)

Packing 8.153 MJ (28.54%)
Regeneration 6.151 MJ (22.80%)
Pyrolysis of light gasoline 5.162 MJ (18.07%)

The percentages given in parantheses indicate the participation of the value of the exergy consumption of the specific process in the total exergy consumption. By increasing the coefficient of regeneration, the exergy consumption in the processes of raw material production (light gasoline, ethylene glycol, atmospheric distillation) decreases. This is reasonable because a smaller amount of raw materials is necessary for making a fresh amount of antifreeze.

THE EFFECTS OF ANTIFREEZE REUSE

Case 3 (model A)

This is a case when disposals of any kind of used antifreeze do not exist (knek=kzem=kkan=0), as well as regeneration (k1sak=0), and all the antifreeze is reused (k2sak=1). The results of this calculation are shown in Tables 3 and 4.

Table 3. Comparison of the mass balance for cases 1 and 3, kg

	Case 1 ksak=0 knek=1.o	ksak=0.2	ksak=0.4	ksak=0.6	ksak=0.8	Case 2 ksak=1.0 knek=0
The mass of crude oil at the inlet	65.648	65.648	65.648	65.648	65.648	65.648
Ethylene necessary for antifreeze production	1.846	1.846	1.846	1.846	1.846	1.846
Styrene for packing	0.150	0.150	0.150	0.150	0.150	0.150
Regeneration	0.000	0.457	0.914	1.372	1.829	2.286
Uncontrolled disposal	2.286	1.829	1.372	0.914	0.457	0.000

Table 4. Comparison of the exergy balance for cases 1 and 3

	Case 1 ksak=0 knek=1		ksak=0.2		ksak=0.2	
	MJ	%	MJ	%	MJ	%
Exergy of crude oil	100.637	45.97	100.637	47.90	100.637	49.99
Exergy of ethylene glycol (reuse)	0.000	0.00	8.944	–4.26	17.887	–8.87
Exergy consumption in the processes	118.295	54.03	118.427	56.36	118.588	58.88
Total exergy consumption	218.932	100.00	210.120	100.00	201.307	100.00
Exergy of crude oil	100.637	52.28	100.637	54.79	100.637	57.55
Exergy of ethylene glycol (reuse)	26.833	–13.94	35.777	–19.48	44.721	–25.27
Exergy consumption in the processes	118.690	61.66	118.822	64.69	118.953	68.02
Total exergy consumption	192.495	100.00	183.682	100.00	174.870	100.00

In this case, the same amount of crude oil necessary for the production of a unit mass of antifreeze exists, and so it is possible to point out, if all the quantity of collected used antifreeze is again reused, that there is no kind of saving. The total consumption of exregy in the life cycle decreases and it is smaller compared to case 1 because part of the crude oil exergy is conserved in ethylene glycol which is again reused.

The distribution of exergy consumption according to the processes included in the life cycle model is the same as that for the most unfavorable case (without collecting the used antifreeze). That means that the largest exergy consumption is present in the processes of raw material production necessary for obtaining antifreeze.

A comparative presentation of cases 2 and 3 is shown in Figure 3. It is easy to see to which extent the exergy of crude oil or exergy of other processes participate in the total exergy consumption. The striped bar area indicates (case 3) which part of the exergy is preserved if ethylene glycol is reused. From the slope of the line in Figure 3, it might be concluded that a higher saving of exergy exists when regeneration and not reuse of ethylene glycol is applied (comparison of cases 2 and 3).

These are the cases in which only reuse and regeneration of antifreeze are considered as the limiting case and where the disposal of used antifreeze is not present. The reuse of used antifreeze is, from the environmental stand point, a better solution compared to the disposal method. However, the total exergy consumption is still high, and more compared to the case when regeneration is applied, as the second and possible solution for solving the used antifreeze problem.

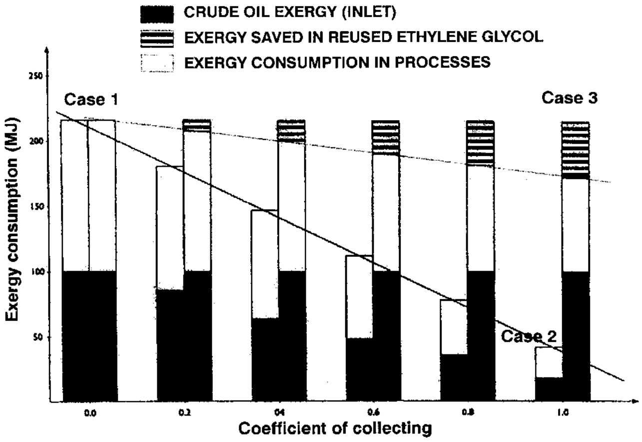

Figure 3. Diagram of exergy consumption for antifreeze reuse

EFFECTS OF UNDERGROUND DISPOSAL

The total exergy consumption in the model of LCA contains two terms indicating the exergy preserved in the saved ethylene glycol after exploitation: the first one was previously analyzed (reuse of ethylene glycol), and, the second one is related to underground disposal as a possible way for a semi–controlled type of disposal. One part of the exergy of ethylene glycol is preserved or conserved in this case as was assumed in this study.

Table 5. Balance of exergy for the cases of controlled (underground) and uncontrolled used antifreeze disposals

	kzem=0.0 knek=1.0	kzem=0.2 knek=0.8	kzem=0.4 knek=0.6	kzem=0.6 knek=0.4	kzem=0.8 knek=0.2	kzem=1.0 knek=0.0
Exergy of crude oil, MJ	100.637	100.637	100.637	100.637	100.637	100.637
Exergy of ethylene glycol (reuse), MJ	0.000	4.472	8.944	14.416	17.888	22.361
Exergy consumption in the processes, MJ	118.295	118.295	118.295	118.295	118.295	118.295
Total exergy consumption, MJ	218.932	214.460	209.988	205.516	201.044	196.572

Case 4 (model A)

There is no collection (ksak=0) which also means that the regeneration of used antifreeze does not exist (k1sak=0), as well as its reuse (k2sak=0). According to this case, the total amount of antifreeze after exploitation is disposed by: underground disposal (kzem), or uncontrolled disposal (knek). The results of the exergy consumption calculations are shown in Table 5.

There is no saving of exergy consumption in the processes if the underground disposal of used antifreeze is performed. However, the total exergy consumption in the life cycle is lower because some extent of exergy is preserved in the underground disposed ethylene glycol.

A comparative analysis of exergy consumption in the case of regeneration (case 2) as the most acceptable and underground disposal (case 4) of used antifreeze is shown in Figure 4.

The striped area presents the part of the exergy preserved by ethylene glycol which is disposed of underground. The slope of the line indicates saving of exergy. The calculation procedure resulted in less consumption of exergy if regeneration is applied which is obviously greater compared to underground disposal.

The results of LCA analysis showed that the underground disposal of used antifreeze, which is in an environmental sense more acceptable than uncontrolled disposal, in the sense of exergy consumption and exergy saving has limited possibility.

The results of the analysis of three basic procedures for used antifreeze treatment indicatively showed that the superior one was the regeneration method causing improvement of the balance of exergy for the defined antifreeze life cycle. However, it is still questionable whether some other cases, which are closer to the real situation, would give the same result, because the advantage of the regeneration route has been analyzed taking into account an ideal assumption. The results of the analysis of other cases (cases 4–10) obtained by model A were published in [3] and are valid for Serbia and Montenegro, while similar results were published in 1995 for the USA which are shown in Table 6.

The data presented in the literature indicated that from the uncollected amount of used antifreeze, about 35% was disposed as waste in the sewage system, 24% was disposed of underground, and the rest was disposed without any control. The results of cases a–e were obtained by calculating with different values of the coefficient of collection (k1sak) and, for each of these cases, the value of the coefficient for regeneration (k1sak) and reuse (ksak2) were freely varied. The determined saving of total exergy of materials varied from 5 to 87%; the exergy of case a (reuse of collected used antifreeze) was unchanged, while for other cases (b–e) the values of the saved exergy of the processes varied from 1 to 76%.

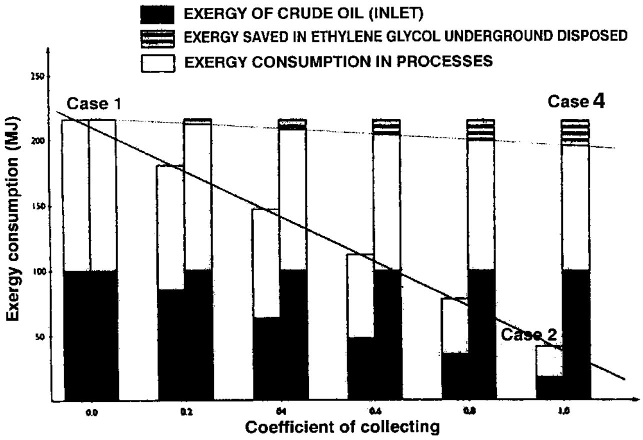

Figure 4. Diagram of exergy consumption for underground antifreeze disposal

Table 6. Total saving of exergy (in %)

Case	ksak					
	0	0.2	0.4	0.6	0.8	1.0
a	2.46	5.99	9.53	13.06	16.59	20.13
b	2.46	7.21	11.97	16.72	21.47	26.23
c	2.46	9.66	16.85	24.04	31.24	38.43
d	2.46	12.10	21.73	31.37	41.00	50.64
e	2.46	18.20	33.94	49.67	65.41	81.15

There are no valid data for our country, and so, in this study an assumption that underground disposal does not exist, and only uncontrolled and disposal into the sewage system are presented in the same proportion (cases 10 and 11) were assumed. The organized collection of used antifreeze is realized only in the Army, and such practice led to about 6% of the used antifreeze being rerefined in the past in the unit for vacuum distillation installed at the NIS–Oil Refinery "Belgrade".

Case 10 was analysed according to model A (without reuse), while case 11 represents the solution obtained by model B taking into account the reuse of used antifreeze. The influence of the reuse procedure on the LCA of antifreeze was considered using model B.

After the reuse of antifreeze the coefficients of distribution are:

Case 11a: kpkor1=1.0 and kpkor2=0
(regeneration without disposal)
Case 11b: kpkor1= kpkor2=0.5
(50% of the total amount goes to regeneration)
Case 11c: kpkor1=0 and kpkor2=1.0
(disposal without regeneration)

For the production of a unit mass of antifreeze, a more crude oil is necessary, if only the reuse method is proposed into the LCA model (kpkor1=1.0), compared to the quantity of crude oil necessary for the same production in case 10. Apart from case 3, where the same amount of crude oil was necessary and did not depend on the coefficient of used antifreeze collection, the simulation performed in case 11 showed that the decrease of crude oil consumption was followed by increase of the coefficient of collection. The decrease is more expressed if part of the antifreeze, after reuse, is rerefined in the new (second) cycle of antifreeze exploitation.

The total exergy consumption in the life cycle is a smaller compared to the most favorable situation (case 1) but is larger compared to the case of regeneration (case 10).

Increase of the coefficient which determines the used antifreeze collection decreases the total exergy consumption, because part of the exergy of the system is preserved by ethylene glycol which could again be reused.

Obviously that a reasonable question could be posed: "Does reuse make sense compared to the case (case 10) where collected used antifreeze goes directly to the regeneration procedure?". Namely, investigations performed in this study showed that, for the cases when reused antifreeze in the second cycle went into the rerefing process (without disposal), the total exergy consumption increased. Such increase of the total exergy is shown in Table 7 where only a small difference of exergy consumption was determined in case 11a compared to case 10, so one can conclude that such a case (11a) could not be neglected.

Table 7. Influence of the used oil collection procedure on the total exergy consumption in MJ. Comparison of different cases (1, 10 and 11)

Case (X/Y)	ksak		
	0.06	0.3	1.0
11a/10	0.53	2.69	8.98
1/11c	2.64	13.21	44.06
11b/10	4.29	21.49	71.63
1/11b	6.40	32.01	106.71
11c/10	8.05	40.28	134.29
1/11a	10.16	50.81	169.37
1/10	10.70	53.50	178.35

A decrease of the positive effect of antifreeze reuse is a consequence of the decreased amount of used antifreeze which was rerefined. If collected antifreeze goes to disposal after the second cycle of its reuse, the difference of the total exergy consumption is determined only by the exergy saved with ethylene glycol used again for antifreeze production.

The data presented in Table 7 show that only in the case of very small coefficients of collecting (<10%) does any kind of treatment of the used antifreeze not influence exergy saving. However, re–reuse in the case of ksak<0,1 has practical importance representing extended exploitation of the antifreeze. Moreover, the present situation in Serbia and Montenegro could be represented by this case (ksak=0.6) and thus, regeneration after reuse has advantages to rerefing immediately after collection of the used antifreze.

Namely, by performing the regeneration process of 6% used antifreeze, the following savings could be obtained:

less exergy consumption in the raw materials: 5.25%
less exergy consumption in the processes: 4.59%
less total exergy consumption: 4.89%.

CONCLUSION

The performed LCA analysis of antifreeze using the proposed models A and B showed that:

a. An increase of the collection of used antifreeze also needs aserious analysis of the different manners of distribution of these quantities governed by maximizing the saving of exergy consumption;

b. Only the regeneration of used antifreeze leads to significant saving of the total exergy in the LCA of antifreeze.

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APPENDIX
Catalogue of different processes

Table A1. Atmosferic distillation – a mass balance [4–7]

Raw materials and products	t/t of light gasoline
Crude oil (URAL REB/Kirkuk)	–10.718
LNG (C3–C4)	0.103
Light gasoline (C5 70)	0.261
Stabilized gasoline (C5 70–175)	0.975
Primary gasoline (C5 175)	1.000
Petroleum (175–225)	0.944
LGO	2.024
HGO	0.653
Atmospheric residue	4.686
Normatives per 1 t of primary gasoline	
Fuel gas	0.083 t
Fuel oil	0.139 t
Steam (LP, 4 bar)	0.509 t
Superheated steam (LP, 4 bar)	0.351 t
Steam (MP, 16 bar)	0.478 t
Processing water	0.728 t
Air for fuel combustion	2.582 t
Electricity	78.46 kWh
Exergy consumption	19742 MJ/t

Table A2. Exploitation (driling) and desalination of crude oil [7,8]

Assumption	
Capacity of crude oil hole	50 t
Hole depth	1500 m
Average velocity of drilling	2 m/h
Only every third hole is successful for exploiting crude oil	0.975
Power of drilling equipment	368 kW
Ratio of crude oil:water from the hole	1:1
Rate of pumping	10 m^3/h
Crude oil transport by pipe (for 45.9 t/d is enough 4410 kW)	1913 t/h
Calculated values (for 1 t of crude oil)	
Drilling	16.56 kWh
Pumping	12.00 kWh
Transportation	2.30 kWh
Exergy consumption	111.1 MJ/t

Table A3. Packing [9]

Capacity of unit	0.247 t/h
Normatives per 1 t of the final product	
Electricity	276.44 kWh
Exergy consumption	3210 MJ/t

Table A4. Ethylene polymerization [10]

Raw materials and products	t/t of PEVG
Ethylene	–1.040
PEVG	1.000
Normatives per 1 t of PEVG	
Steam (LP, 3.5 bar)	0.620 t
Steam (MP, 10.5 bar)	1.340 t
Steam (HP, 33.5 bar)	0.056 t
Electricity	685 kWh
Exergy consumption	14330 MJ/t

Table A5. Pyrolysis of primary gasoline [10,11]

Raw materials and products	t/t of ethylene
Primary gasoline	–3.060
Ethylene	1.000
Propylene	0.425
C4 fraction	0.225
Pyrolitic oil	0.190
Pyrolitic gasoline	0.690
Normatives per 1 t of ethylene	
Fuel (heavy oil)	0.377 t
Steam (HP, 33.5 bar)	1.855 t
Processing water	12.778 t
Electricity	174.4 kWh
Exergy consumption	51810 MJ/t

Table A6. Antifreeze production [9]

Raw materials and products	t/t of commercial product*
Ethylene glycol	–0.920
Demi water	–0.030
Additives	–0.050
C4 fraction	0.225
Product (Korsantin 100)	1.000
Normatives per 1 t of commercial product	
Steam (LP, 6 bar)	0.044 t
Electricity	8.77 kWh
Exergy consumption	203.5 MJ/t

*Commercial product Korsantin 100 produced by NIS–Refinery of "Belgrade", Beograd

Table A7. Transport [12]

Assumption	
Vehicles (railway and truck)	
Average distance	100 km
Calculated value (per 1 t of product)	
Vehicle 16 t	288 MJ
Vehicle 28 t	192 MJ
Vehicle 40 t	117 MJ

Table A8. Production of ethylene glycol from ethylene [*11,13,14*]

Raw materials and products	t/t of ethylene
Ethylene	–0.727
Oxygen	–0.879
Methane	–0.014
Ethylene glycol	1.000
Di–ethylene glycol	0.103
Tri–ethylene glycol	0.027
CO_2	0.485
Normatives per 1 t of ethylene glycol	
Steam (MP, 13 bar)	2.900 t
Processing water	0.324 t
Electricity	265 kWh
Exergy consumption	23362 MJ/t

Table A9. The production of packaging materials [*9,15,16*]

Extruder capacity	0.275 t/h
Normatives per 1 t of package material	
Electricity	429.09 kWh
Exergy consumption	1545 MJ/t

Table A10. Used antifreeze regeneration by vacuum distillation [*9*]

Unit capacity	0.214 t/h
Normatives per 1 t of rerefined antifreeze	
Electricity	233.64 kWh
Exergy consumption	2713 MJ/t

The total exergy consumption (MJ) in the life cycle of antifreeze was determined by the equation:

$$dE=E_{\text{crude oil, in}}-E_{EG1}-0.5E_{EG2}+\Sigma\Delta E_{\text{processes}}$$

where: $E_{\text{crude oil}}$ is the exergy of crude oil at the inlet into the life cycle; the exergy preserved in reused ethylene glycol; the exergy of ethylene glycol which is disposed of underground (with 0.5 probability that this exergy will be reused). The calculation of exergy for different processes was given in the first part of this study [1]. Different products are the result of crude oil distillation under atmospheric pressure, the pyrolysis of primary gasoline and ethylene glycol synthesis, and for that reason, the total exergy consumption for these processes was calculated taking into account the corresponding coefficients of mass balances, i.e. the yields for each of the formed products [1,17].

IZVOD

ŽIVOTNI CIKLUS ANTIFRIZA II. Rezultati matematičkog modelovanja

(Naučni rad)

Jelena Kesić, Dejan Skala
Tehnološko–metalurški fakultet, Katedra za organsku hemijsku tehnologiju, Univerzitet u Beogradu,
Beograd, Srbija i Crna Gora

Analiza životnog ciklusa (LCA) podrazumeva identifikaciju i kvantitativno razmatranje upotrebljenih sirovina, energije i stvorenih otpadnih materijala tokom celog životnog ciklusa ispitivanog proizvoda. U ovom radu je cilj bio da se ispita procena uticaja antifriza na okolinu i poboljšanje procesa kako bi se sprečilo i/ili umanjilo nastajanje štetnog otpada. U prvom članku su definisani matematički modeli (A i B, Hemijska industrija 59(5–6)(2005)xxxx) na osnovu odgovarajućih bilansa mase i energije svih procesa životnog ciklusa. Kako je za sve procese potrebna određena energija koja se može pretvoriti u druge oblike energije, modeli A i B su zasnovani na konceptu definisanja kvaliteta različitih vidova energije i kvaliteta različitih materija, odnosno definišu promene eksergije kojim se najbolje može opisati proces transformacije sirovina i energije. Ceo životni ciklus antifriza (LCA) je okarakterisan ukupnim gubtikom (utroškom) eksergije tj. gubitkom upotrebljive materije i energije.
Rezltati analize životnog ciklusa antifriza u ovom radu ukazuju da je regeneracija antifriza najpovoljnija mogućnost tretmana korišćenog antifriza, kako sa stanovišta utroška materijala tako i korišćenja energije, mada ne treba zanemariti ni efekat ponovnog korišćenja antifriza.

Ključne reči: antifriz, etilenglikol, životni ciklus procesa, LCA, eksergija, modelovanje.