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Original Article

EMISSION OF POLLUTANTS AND ENERGY CONSUMPTION IN LIFE CYCLE OF DIESEL OIL

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ABSTRACT
The following article is an analysis of designed processes of the life cycle of the most popular fuel for Diesel engines: diesel oil. This fuel is produced from petroleum, which is a non-renewable source of energy. Analysis was carried out with the assumptions of Life Cycle Assessment, which is a tool to test the environmental impact of the product. The life cycle of diesel was divided into five unit processes: petroleum extraction, transport of petroleum to the refinery, refining petroleum to diesel, transport of diesel to the recipient and utilization of delivered fuel by transport company. For every process the energy consumption and emission of carbon monoxide, nitrogen oxides and sulphursulphur oxides was calculated, with assumption of probable data, that could occur in real processes. The analysis has shown, that the process of refining petroleum is highly pollution-intensive. Also the combustion of diesel generates a significant amount of pollutants' emission, which is why it is necessary to develop technologies that could contribute to the reduction of emission.

Keywords: diesel, petroleum, Life Cycle Assessment, pollution, energy.

INTRODUCTION

The demand for fuel increases annually. It is associated with economic development, growing trade volume and mobility of societies. The most popular fuel for Diesel engines is diesel oil, which is produced from petroleum and its combustion causes emission of a lot of pollutants. Conventional fuel comes from non-renewable sources, whose supplies are running low. Prices of petroleum are increasing and are highly dependent on politics in countries of its production. Therefore, it is inevitable to develop alternative and renewable fuel, which could replace diesel. But before, the awareness of amount of pollutants emitted while production and combustion of fuel may lead to take various actions in order to reduce them.

The subject of the following analysis is a designed process of production, transportation and combustion of diesel oil.

LIFE CYCLE ASSESSMENT METHOD

In the following article, the assumptions of Life Cycle Assessment were used. LCA provides information about the whole life cycle of product, including obtaining raw materials, processing, packaging, transportation, use and disposal. In the analysis, the whole process is divided into unit processes. The important elements of analysis are energy consumption and greenhouse gases emission [Thorn at al. 2011].

It is used to assess the environmental impact of all processes belonging to the life cycle of the product, in order to compare and select products or improve unit processes.

UNIT PROCESSES

Designed life cycle of diesel oil has been divided into five unit processes, which are: petro-

leum extraction, transport of petroleum to the refinery, refining petroleum to diesel, transport of diesel to the recipient and utilization of delivered fuel by transport company from Wroclaw, Poland. For each process, energy consumption and emission of pollutants were calculated. The analysis was carried out for 10 000 litres of fuel.

Petroleum extraction

The whole life cycle of diesel begins with petroleum extraction. In the designed process, the extraction takes place in Russia, where the most of petroleum used in Poland comes from [Albrycht at al. 2011]. To remove petroleum from earth, submerged centrifugal pump may be used. The engine of pump is located in the wellbore.

Only 17% of petroleum is refined into diesel oil, so in order to produce 10 000 liters of diesel, 58.8 m^3 of crude oil is necessary.

$$n = 10\,000\ l / 0.17 = 58\,800\ l = 58.8\ m^3$$

In designed process it is assumed, that the wellbore is 1000 m deep and the pump efficiency is 170 m^3 of petroleum per 24 hours, which is 0.002 m^3 per second. Therefore, to deliver 58.8 m^3 of petroleum, the pump will run for 29 400 s, which is 8.16 h.

$$t = 58.8\ m^3 / 0.002\ m^3/s = 29\,400\ s$$

The calculated power of pump is 37 863 W. Therefore, energy consumption during the process will be 309 kWh.

$$E = 37.863\ kW \times 8.16\ h = 309\ kWh$$

The whole process requires 1.113 GJ of energy.

While providing 1 kWh of energy, the pump's engine emits 0.022 g of carbon monoxide, 0.053 g of nitrogen oxides and 0.288 g of sulphur oxides. Therefore, process of extraction of 58.8 m^3 of petroleum causes the emission of 6.8 g of carbon monoxide, 16.4 g of nitrogen oxides and 89 g of sulphur oxides.

Transport of petroleum to the refinery

Next unit process is the transport of extracted petroleum to the refinery, which is located in Plock, Poland. Most of petroleum supplies from Russia is transported by Druhzba pipeline [Overview … 2005], so it is also in the designed process. Pipelines are a relatively environmentally-friendly form of petroleum transportation. They do not require the provision of big amounts of energy, which is why they do not cause emission of a lot of pollutants and also are a relatively cheap form. Also environmental risk is relatively low, leaks and ruptures are rare [Williams 2012].

Annual capacity of the pipeline is 47 727 272 m^3, which is 1.513 m^3 per second. Therefore, force-pomp of 5 157.246 kW runs for 39 s to transport 58.8 m^3 of petroleum, so the whole process requires only 55.7 kWh.

$$t = 58.8\ m^3 / 1.513\ m^3/s = 39\ s$$

$$E = 5\,157.246\ kW \times 0.0108\ h = 55.7\ kWh$$

The energy consumption of transport is 201.1 MJ. It was assumed, that the amount of pollutants emitted per 1 kWh by force-pomp is the same as the amount emitted by submerged centrifugal pomp, used during petroleum extraction. Therefore, designed process of transport 58.8 m^3 of petroleum will cause an emission of 1.22 g of carbon monoxide, 2.95 g of nitrogen oxides and 16.04 g of sulphur oxides.

Refining petroleum to diesel

Oil refining is one of the most pollution-intensive industries. It also consumes a lot of energy. Refinery in Plock needs 0.8 GJ per 1000 kg of petroleum processed. Density of petroleum is 880 kg/m^3.

$$m = 58.8\ m^3 \times 880\ kg/m^3 = 51\,744\ kg$$

$$E = 0.0008\ GJ \times 51\,744\ kg = 41.4\ GJ$$

Therefore, refining of 58.8 m^3 of petroleum delivered requires 41.4 GJ. The process causes a big amount of pollutants emitted. In order to produce 10 000 liters of diesel, 5150 g of carbon monoxide, 20 600 g of nitrogen oxides and even 50 000 g of sulphur oxides are emitted.

Transport of diesel to recipient

In designed process, after refining diesel is transported to the recipient, which is a transport company in Wroclaw. The distance between Plock and Wroclaw is 276 km. It was assumed that diesel is transported by truck Mercedes-Benz Actros with tank trailer NPA-33.

Energy consumption depends on many factors. It was calculated, that for a vehicle of total mass 21 200 kg and average speed 16.6 m/s, the energy consumption will be 2.954 GJ. Average fuel consumption for Mercedes-Benz Actros is 32 l per 100 km. Therefore, on the route of 276 km vehicle will combust 88.32 liters of diesel. For aver-

age speed 60 km/h, process will last 4.6 h. Engine power is 335.6 kW, so energy consumption will be 1 544 kWh.

$$G = 0.32 \text{ l/km} \times 276 \text{ km} = 88.32 \text{ l}$$

$$t = 276 \text{ km} / 60 \text{ km/h} = 4.6 \text{ h}$$

$$E = 335.6 \text{ kW} \times 4.6 \text{ h} = 1\,544 \text{ kWh}$$

While combusting diesel, pollutants are also emitted. Per 1 kWh emission is 1.63 g of carbon monoxide, 6.54 g of nitrogen oxides and 0.235 g of sulphur oxides. Therefore, during the transportation of 10 000 l of diesel from refinery to recipient in Wroclaw, 2 516 g of carbon monoxide, 10 098 g of nitrogen oxides and 363 g of sulphur oxides will be emitted.

Utilization of diesel by transport company

Last unit process in the life cycle of diesel is its combustion in vehicles of the transport company. It is assumed that company uses also truck Mercedes-Benz Actros with a trailer, with 335 kW power engine. Energy value of diesel is 43 MJ/l, therefore 10 000 liters of fuel provides 430 GJ.

Assuming average speed of vehicle 75 km/h and fuel consumption 32 l/km, delivered fuel is sufficient to drive 31 250 km at the time of 417 h. Total energy provided is 139 695 kWh.

$$L = 10\,000 \text{ l} / 0.32 \text{ l/km} = 31\,250 \text{ km}$$

$$t = 31\,250 \text{ km} / 75 \text{ km/h} = 417 \text{ h}$$

$$E = 335 \text{ kW} \times 417 \text{ h} = 139\,695 \text{ kWh}$$

During the combustion of 10 000 liters of fuel, engine emits 227 703 g of carbon monoxide, 913 605 g of nitrogen oxides and 32 828 g of sulphur oxides.

RESULTS, DISCUSSION AND CONCLUSIONS

The analysis was carried out for each unit process in designed life cycle of diesel. As a result, the amount of total energy consumption and emission of pollutants was calculated.

Table 1 presents the amount of energy consumed in each of single processes of diesel production and transportation. It was calculated that the production and delivery of 10 000 litres of diesel requires 45.7 GJ. That fuel provides 430 GJ for a transport company.

Refining petroleum was the most energy-intensive of all designed processes. It is also this process that caused the biggest amount of pollutants emitted among the processes of production and transportation. The levels of emission are presented in Table 2.

Designed process of manufacturing, transportation and utilization of diesel caused the emission of 235 377 g of carbon monoxide, 944 322 g of nitrogen oxides and 38 294 g of sulphur oxides.

The awareness of the amount of pollutants emitted by transport companies and, first of all, produced during petroleum extraction and refin-

Table 1. Energy result for diesel life cycle

Parameters		Energy consumption [GJ]	Energy production [GJ]
1	Petroleum extraction	1.113	–
2	Transport of petroleum to the refinery	0.2011	–
3	Refining petroleum to diesel	41.4	–
4	Transport of diesel to recipient	2.954	–
5	Utilization of diesel by transport company	–	430
Sum		45.6681	430

Table 2. Amount of pollutants emitted during life cycle of diesel

Parameters		Emission [g]		
		CO	NO_x	SO_x
1	Petroleum extraction	6.8	16.4	89
2	Transport of petroleum to the refinery	1.22	2.95	16.04
3	Refining petroleum to diesel	5 150	20 600	50 000
4	Transport of diesel to recipient	2 516	10 098	363
5	Utilization of diesel by transport company	227 703	913 605	32 828
Sum		235 377.02	944 322.35	83 296.04

ing, may contribute to its reduction. The analysis has shown, that there is a necessity of solutions that may cause lower emission, for example installing filters or improving technologies, so that less energy was consumed.

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