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Garbage Truck Operation in an Urban Area

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ABSTRACT: Optimizing energy consumption, as well as the need to reduce greenhouse gas emissions, should be taken into account when building city trucks, especially heavy trucks for waste collection. The driveline is particularly important. Currently, there is a choice of possible driveline systems for a truck, but the conventional internal combustion engine is still the dominant solution. The article describes the driving characteristics of a city truck, in particular the operation of an internal combustion engine in such a truck. On the basis of data collected from several garbage trucks equipped with a compression ignition engine and compression ignition engines powered by CNG, an analysis of the load structure and engine rotational speed was presented. These vehicles operate in urban conditions and perform specific tasks. The data shows how ineffective the operation of an internal combustion engine is when operating a truck in a large city and in specific areas, e.g. a port. The reason is the very low load at low engine speed which dominates the performance characteristics of the truck. The analysis provides arguments that there is a need to change the way they are powered trucks, there is a need to replace the powertrain based on an internal combustion engine with a more efficient one.

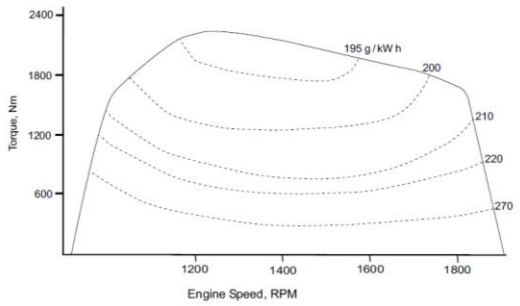
1 INTRODUCTION

In 2013, the value of waste and recycling equipment by European producers is estimated at just over $ 1 billion [3]. Alternative fuel garbage trucks are increasingly used across Europe as fleets seek to replace older diesel trucks with hybrid vehicles and cleaner burning CNG and biomethane vehicles. The share of CNG / biomethane trucks in new orders has been increasing in the last few years and is expected to continue to increase. Common reasons to choose alternative fuel vehicles are fuel efficiency, lower CO2 and particulate emissions, and quieter operation. However, one aspect of the discussion of the requirements to be considered for a garbage truck is the suitability of the driveline to the operating conditions. This is especially important in large cities, where driving conditions are very difficult and strongly affect the driving parameters of trucks. The analysis presented in the article is based on data from heavy garbage trucks operated in Warsaw. It gives the argument that it is necessary to work on an efficient way to power the garbage truck (special drive system of the garbage truck) or change the entire system of collecting waste from cities and specialized areas, such as ports. The importance of organizing waste transport, but also means of transport, is described in [1]. The author estimated and presented the values of the global warming potential (GWF), which express the potential contribution to global warming as a result of collection, transport and shipment of 1 ton of wet waste. GWFs ranged from 9.4 to 368 kg CO2 equivalent (kg CO2 equivalent) per tonne of waste, depending on collection method, capacity and choice

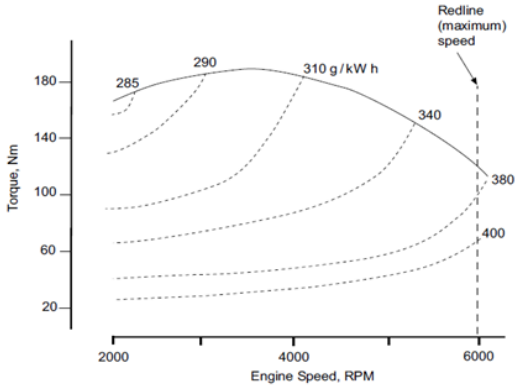
of transport equipment, and distance to be traveled. It is also an argument to analyze and work on efficient and environmentally friendly transport. Now it is still based on the IC engine. Despite some proposition of propulsion systems, such as hybrid or electric drive, the internal combustion engine is still the main source of power for such a truck, so the analysis of its functionality and efficiency, especially in the urban and specialist area, is crucial.

2 SPECIFIC FUEL CONSUMPTION AND VEHICLE TASKS

The specific fuel consumption of IC engine strongly depends on load and engine speed. Minimum specific fuel consumption will typically be seen at or near full-load and at relatively low engine speeds. As engine speed increases, the engine becomes less efficient due to the rapid rate of friction increase. At low speeds, the specific fuel consumption will again increase because of increased heat transfer losses. This phenomenon is more pronounced in diesel engines, in which the air-to-fuel ratio drops with the increased torque. This results in increased flame temperatures during combustion and minimum specific fuel consumption typically occurring between rated and peak torque speeds. As load is reduced at any speed, the specific fuel consumption again increases. This is due to a combination of increased pumping work and the fact that friction losses stay relatively constant while the brake output is dropping (Fig. 1a). The specific fuel consumption increases more rapidly as load is reduced with the spark-ignition engine than with the diesel (Fig. 1b). This is due to the increased pumping work associated with the throttled intake on the spark-ignition engine [1].



a)



b)

Figure 1. Typical operating map, showing lines of specific fuel consumption for: a) diesel engine; b) spark ignition engine

The relationship between specific fuel consumption and engine overall efficiency is described by the formula:

$$\eta_e = \frac{1}{q_e \cdot W_u}$$

q_e - specific fuel consumption [g/kWh]
W_u – fuel calorific value [kJ/kg] or [kJ/m^3]

The maximum overall engine efficiency of contemporary IC engine reaches 43-45% (especially CI engine) but as it was described it is the only one point of minimum specific fuel consumption from engine operating map. Variety of loads and engine speeds makes the engine far less efficient. The art of vehicle design also includes an appropriate fitting of the size and power of IC engine to the vehicle tasks. Sometimes it is very difficult to chose the right engine characteristic to ensure vehicle functionality and minimize the fuel consumption, especially specific fuel consumption. The good example of this is typical heavy garbage truck operates in urban conditions. A vehicle for urban transport should ensure low operating costs but primarily must comply with restrictions on emissions and noise. The process of garbage collection creates specific requirements. At the start the truck is empty and its load increases during the collection process. The dump of the garbage is often connected with the drive on a slope, miry road.

3 HEAVY GARBAGE TRUCK IN THE URBAN ENVIRONMENT

The refuse collection industry faces various issues that determine the choice of type of heavy garbage truck and its powertrain. Heavy-duty engine strict emissions standards impose the use of EURO 6 engines. Despite of mentioned in the introduction alternatives of engine fuelling, in practice there is very limited choice. Typical IC engine for three axles urban garbage truck is 280 - 340 HP (maximum torque 1400 – 1800 Nm) engine. One could choose EURO 6 compression ignition engine fuelled with diesel oil or alternatively it's possible to use spark ignition engine fuelled with CNG or far less frequently biomethane to power the truck. The choice of CNG seems to be attractive from the point of view of a cost of the fuel but limited millage between refueling and the volume of the tanks is a drawback. Engine and vehicle manufacturers are pursuing different compliance strategies that will affect fuel efficiency and emission differently but still there is impossible to fit the engine characteristic to the conditions which impose urban environment and the character of the task. The truck has a lot of stops and starts, and its ride consist of acceleration, deceleration and limited stretches of the road where the truck moves with low, constant speed. Additionally during the stay and loading of the garbage the engine provides power to the body equipment by the use of power take off. This issue was discussed, among others, in the extensive material Characterization of Municipal Solid Waste Collection Operations by Megan K. Jaunich. The influence of numbers of starts and stops of the heavy

truck equipped with IC engine on a fuel consumption was examined and described illustrates Fig. 2.

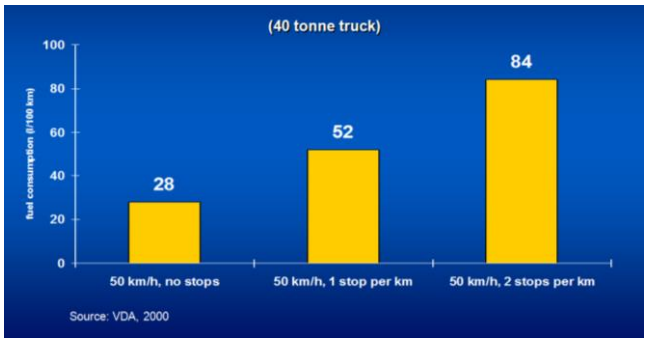


Figure 2. The influence of number of stops per 1 km on heavy truck fuel consumption

Even that the levels of fuel consumption are now lower than in year 2000 when the tests presented in Fig 2 were carried out its results show the phenomenon which strongly influences contemporary urban garbage trucks equipped with IC engines. A lot of stops of the trucks are caused not only by the points of collecting wastes but also by traffic, especially by traffic lights.

4 THE WORK DATA OF SELECTED URBAN TRUCKS

The data taken from the heavy garbage trucks operating in Warsaw includes the structure of trucks speed as well as the structure engine load and speed which is the most interesting from the point of view of efficient way of its run.

The data are divided into two groups of trucks equipped with:
1. CI engine fuelled with standard diesel oil,
2. SI engine fuelled with CNG.

4.1 *Garbage truck speed in urban area*

The structure of trucks speed is presented in the Fig. 3. but Fig. 4 presents the average garbage truck speed calculated for 10 trucks which was calculated according to the formula 1:

$$vx_{av} = \frac{\sum_{i=1}^{n}(vx_i\ m_i)}{\sum_{i=1}^{n} m_i} \qquad (1)$$

where:
n – number of the truck,
vx_{av} – the average share of truck speed in the chosen range (eg. 0-10 km/h) in the whole range of average truck speed [%],
vx_i – the share of single truck speed in the chosen range (eg. 0-10 km/h) in the whole range of single truck speed [%],
m_i – examined single truck millage [km],

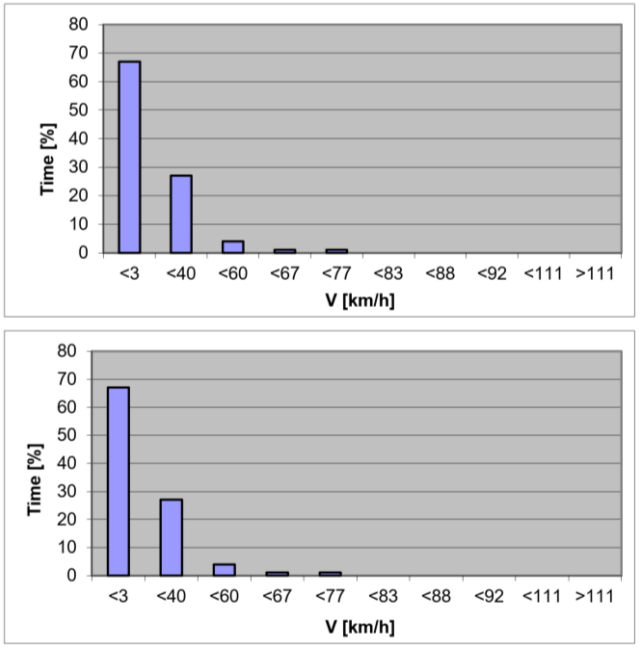


Figure 3. Garbage truck speed structure
a) the truck equipped with CI engine
b) the truck equipped with SI engine

4.2 *The garbage truck IC engine speed and load in urban environment*

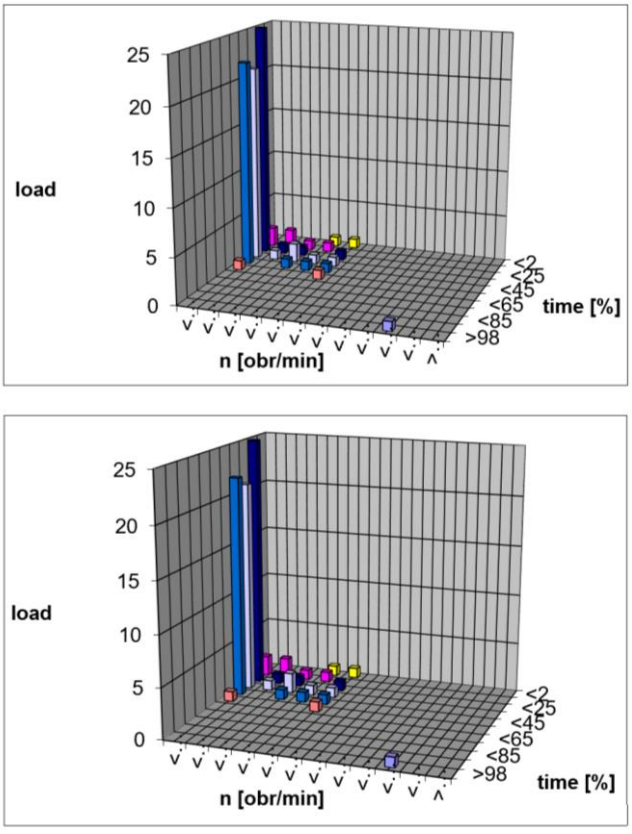


Figure 4. The load and engine speed structure for single examined truck (for average truck)
a) the truck equipped with CI engine
b) the truck equipped with SI engine

5 CONCLUSIONS

Heavy garbage trucks that work in urban conditions perform specific tasks. The data shows how inefficient the operation of an internal combustion engine is when a truck is operated in a large city. The reason is the very low load at low engine speed which dominates the performance characteristics of the truck. Figure X1 shows areas on operational maps that are very ineffective. The area corresponds to the operating points of the analyzed trucks. Heavy garbage trucks that work in urban conditions and in closed areas such as ports perform specific tasks. The data shows how inefficient the operation of an internal combustion engine is when a truck is operated in a large city. The reason is the very low load at low engine speed which dominates the performance characteristics of the truck. Figure X1 shows areas on operational maps that are very ineffective. The area corresponds to the operating points of the analyzed trucks.

The analysis provides arguments that there is a need to change the method of powering such a truck, especially since there is a need to replace the powertrain based on an internal combustion engine with a more efficient one. A good solution is to use two motors. The hybrid driveline appears to be effective because of the two engines (internal combustion engine and electric motor) that can be used separately and together when a truck needs maximum power.

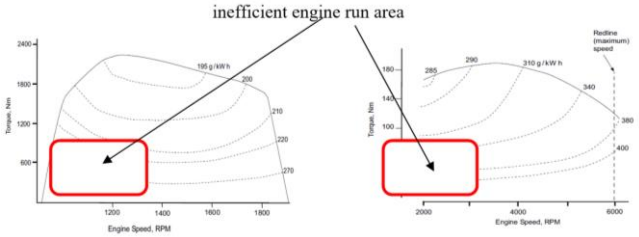


Figure 5. X1 Schematic engine map with inefficient engine run area

For a garbage company, the most important thing is the cost of buying a truck and the cost of maintaining it. The data presented in the article are an argument for a thorough analysis of the costs of a truck with only an internal combustion engine and a hybrid truck.

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