Energy Conversion and Management 75 (2013) 498–508

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Tractor's engine performance and emission characteristics in the process of ploughing

Algirdas Janulevičius *, Antanas Juostas, Gediminas Pupinis

Institute of Power and Transport Machinery Engineering, Aleksandras Stulginskis University, Studentų str. 15, 53361 Kaunas-Akademija, Lithuania

ARTICLE INFO

Article history:
Received 27 March 2013
Accepted 29 June 2013

Keywords:
Tractor
Engine load
Fuel consumption
Exhaust emissions
Ploughing
Monitoring of performance indicators

ABSTRACT

The paper gives an overview of possibilities to determine the values of tractor‘s fuel consumption, exhaust emissions and engine load in real operating conditions by using data accumulated in electronic control units. There is ecological and economic importance for the tractors to be operated correctly: time of engine idling, operation at low and too high loads or high speeds should be shortened. To monitor tractor's operating performance, tools and techniques are necessary that would allow to determine the controlled indicators.

The paper presents research of tractor's engine load factor, fuel consumption and engine exhaust emissions during operation of ploughing. The research is conducted on the base of data accumulated in engine's electronic control units. Histograms are presented that show time intervals of the ploughing process, fuel consumption and emission components (CO_2, NO_x and CO) in engine speed and cyclic fuel injection modes. Test results are analyzed separately for the processes of technological ploughing and works at headlands. Test results showed that in the ploughing process, the main amount of fuel was consumed and CO_2 emitted during technological process of ploughing, and CO – during the work at headlands. Large quantities of NO_x were emitted during technological process of ploughing, and during the work at headlands as well.

1. Introduction

During last century the worldwide energy consumption and environmental pollution intensity showed great increase and is expected to continue its growth in future. One of the biggest problems of the current century is linked with eventual depletion of fossil fuels, growing ambient air pollution and global warming occurring because of the increased CO_2 (carbon dioxide) emissions [1–3]. Fuel consumption and environmental pollution intensity increases because of the growing number of diesel engine powered heavy-duty haulage trucks, agricultural tractors and self-propelled machines as well as personal light duty cars. Energy systems, transport and agriculture are named as the main sectors that need more attention for the appropriate measures in order to reduce high pollution and fuel consumption [2,4].

Despite global progress in reducing fuel consumption by new engines, the production of self-propelled machines is increasing and total economy of the fuel still lacks behind. Moreover, as the demand for energy has grown, so have the adverse environmental effects of its production with CO_2 (carbon dioxide), CO (carbon monoxide), NO_x (nitrogen oxides), SO_x (*sulfur* oxides), HC (hydrocarbons) and PM (particulate matter) emissions originating from fuel combustion being primary sources of atmospheric pollution [5–8].

In agriculture, tractor is the most fuel-consuming and polluting machine. Tractors are subject to various agricultural operations: ploughing, soil tillage, drilling, fertilizing, mowing, transport and other works. One of the most important indicators is usage of tractor's power for useful work. In order to reach maximum economic efficiency of works performed by agricultural equipment, tractors with higher draft are unavoidable for usage. Traction power is calculated by multiplying the speed of the tractor by traction force. When traction force of the tractor is increased, driving wheels are slipping even more [9]. Driving wheels lose sufficient grip with the ground. The result is a reduced possibility to use engine's maximum or near to maximum power [10–12]. Different results are obtained when tractor is working at higher speeds [13]. For example, when stubble is being tilled at a higher than 15 km/h speed, draft is limited by engine power. This means that almost all power of the engine can be converted into the draft (traction force of tractor) [13,14]. Variations in soil structure and surface roughness affect the variations in implement resistance and draft [9,15]. In case of tractors with manual transmission, engine torque reserve helps to

---

* Corresponding author. Tel.: +370 37 752285.

E-mail addresses: algirdas.janulevicius@asu.lt (A. Janulevičius), antanas.juostas@kesko.lt (A. Juostas), gediminas.pupinis@asu.lt (G. Pupinis).

0196-8904/$ - see front matter © 2013 Published by Elsevier Ltd.
http://dx.doi.org/10.1016/j.enconman.2013.06.052

Nomenclature

B_d	hourly fuel consumption, kg/h
B_m	fuel consumption at particular mode, kg
b_c	cyclic fuel injection quantity, mg
b_{cm}	cyclic fuel injection quantity at particular mode, mg
b_{em}	specific fuel consumption for operating mode, g/kW h
$E_{(e)}$	emission of engine exhaust gas component (e, i.e., CO_2, CO or NO_x), (g/kW h)
$E_{(x)}$	emission of engine exhaust gas component, during the work (x, i.e., CO_2, CO or NO_x), g
$E_{(x,PPM)}$	emission of engine operating mode component (i.e., CO_2, CO or NO_x), ppm
i_c	number of the engine cylinders
K_m	engine load factor for operating mode (according to power)
l	length of a ploughed field stretch, m
m	engine operating mode
M_m	engine torque for operating mode, Nm
$M_{\max}$	engine maximum torque, Nm
n	engine speed, rpm
n_m	engine speed at particular mode, rpm
P_m	engine power for operating mode, kW
$P_{\max}$	engine maximum power, kW
t	engine operational time, s
t_m	engine operational time at particular mode, s
w	width of the headland (edge of the field for tractor unit turn around) , m
ε	factor for assessing changes in engine load at operating mode
σ_E	gas flow, m^3/h
ρ_E	gas density, kg/kmol
υ_e	engine capacity, cm^{-3}
CO	carbon monoxide (engine exhaust gas component)
CO_2	carbon dioxide (engine exhaust gas component)
NO_x	nitrogen oxides (engine exhaust gas components)
HC	hydrocarbons (engine exhaust gas components)
PM	particulate matter (engine exhaust gas components)
SO_x	*sulfur* oxides (engine exhaust gas components)
EEM	Electronic Engine Management
ECU	Electronic Control Unit
4WD	four-wheel drive
PTO	power take-off

overcome the increased resistance to draft. In order not to overload the engine and let it operate normally, work is usually done by not utilizing the full load. When draft increases and engine speed becomes slower, it works in a range of higher torque, so greater traction is ensured even without switching gears. Power reserve in the conditions of agricultural production varies in the range from 6% to 18% of total engine power. During their whole lifecycle most of the tractors are running at 60–70% of max. load [16–18]. Many researchers of tractors argue that in the field works, when tractors are loaded partially, work should be done at a reduced engine speed. When it is necessary to reach full engine force, it is recommended to run the engine in constant power mode. Rakopoulos and Giakoumis [19] made a review of factors having influence on sudden changes to engine load and speed. In modern tractors, reserve for engine torque reaches 40–50%, but anyway it is not enough, because resistance to traction varies more. Therefore, bigger variation of torque shall be compensated by using transmission. Stepless and automatic speed adjustment allows engine to run in steady mode or close to it. During tractor operation in stepless speed adjustment mode, maximum load can be applied on engine in order to develop highest or close to it output. [15,16,20–22]. However, during soil cultivation and other field operations, the choice of gear by the driver plays a rather important part in fuel consumption and emission amounts [15,23].

Speed of soil cultivation equipment is limited (generally not exceeding 10–12 km/h). For example, in case of faster ploughing, dynamic effect on soil highly increases, soil is strongly thrown and too much energy is used [9,15]. Tractor engine power may be used more economically by increasing working width of plough [15] instead of increasing a speed. Fuel consumption, and amount of emissions that arise from a specific operation, depend on engine load characteristics. The connection between fuel consumption and emissions strongly depends on engine utilization [23–26] An et al. [25] study shows that the engine idle speed and partial load condition have a vital influence on the behavior of engine combustion and exhaust emissions. Experimental studies [7,25] show that the low engine speed and partial load condition significantly affected the CO emission formation processes. It also shows that the high engine speed and full load condition affects the NO_x emission formation processes. The NO_x emissions are very sensitive to the combustion temperature which generally increases with the increase of engine speed and engine load [7,25,27,28]. An et al. [25] study shows that the engine idle speed of 800 rpm may also have a significant affect on the NO_x emission formation processes. A reduction in fuel consumption can also reduce emissions [23,26,29,30].

Fuel consumption and emission quantities during particular in-field operations depend on engine speed and load characteristics. Engine load may be influenced by the use of agricultural equipment of different efficiency, its design and alternative control methods [29–31]. Engineers and farmers must be aware of what values of efficiency are associated with each elementary process and make the right decisions towards the best possible overall energy and pollution balance.

Most today's information on fuel consumption and emissions [5–8,29,30] is obtained from testing engine that is running in settled mode. In field operations, parameters of engine speed and load vary from time to time. Sudden variations in engine load or speed influence performance parameters of tractors [19]. In scientific literature research information is available where performance parameters of tractors during real operational period are analyzed [23,32–36]. One example of such research results is supplied in Appendix A, Fig. A1. Recorded are all tractor engine load values, which came into evidence during operational process, idling, turning at headlands, etc. From such results it is possible to determine the complexity of works that were performed, i.e. how engine power was exploited, how torque and rotation frequency changed.

Engine torque is directly proportional to tractor draft, and the crankshaft revolutions are directly proportional to the tractor motion speed. Therefore, engine operational characteristics to some degree represent operation of the whole tractor [13,37–39].

The relationship between draft and fuel consumption is given in Appendix A Fig. A2 and shows significant high *oscillation* frequency for both draft and fuel consumption. This high frequency component is normal for field operations. General trends from the low frequency component of the graphs are readily apparent and are due to spatial variability in soil physical parameters. Analysis of test portions has shown that less consolidated sandy soils exhibit much