Impact of semitrailer tyre pressure upon passive resistance and tractor unit operation economy

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Abstract: The aim of the measurement was to establish and prove the effect of the semitrailer tyre pressure on the magnitude of power losses and energy intensity in a tractor unit operation. The measured and calculated values were interlaid with the corresponding functions by means of regression analysis considering the magnitude of the determination coefficient (determination index). The values of the determination index ranged from 0.95 to 0.99 for regression functions; all the regression function were highly reliable at 0.01 relevance level. The difference of the lost power was recorded at the speed of 35 km/h, 1.82 kN between 170 kPa and 300 kPa pressures. The energy intensity of the tractor unit operated on the testing route changed as a result of increasing the semitrailer tyre pressure from 170 kPa to 240 kPa while its hourly consumption dropped by 1.9 l/h (i.e. 6.3%).

Keywords: lost power; speed; rolling; tyre pressure; fuel consumption

Transport is a necessary part of each production process, which does not change the utility value of the products but increases the production costs. In the conditions of Czech agriculture, about 35% of diesel fuel consumption is spent in handling, loading operations, storage, and transportation, and constitutes 50% to 70% of the variable costs (Syrový 2006). One possibility of increasing the competitiveness through fuel savings is to reduce the resistance that the tractor has to overcome during transportation. The user can affect the engine performance, ineffectively spent in overcoming the rolling-resistance force. During the steady motion across the plain, the rolling-resistance force is the main loss element the tractor has to overcome. Of the operation factors, the following have the greatest influence on the amount of the internal coefficient of the rolling resistance on the roadway: tyre pressure, tyre load, driving speed, and tyre temperature (Dočkal *et al.* 1998).

When pulling the tractor on the roadway, the total force needed for the steady straight movement is measured. The actual rolling resistance magnitude for wheel tractors ranges between 90–95% of the measured force (Grečenko 1963).

Agricultural transport is specific in that it takes place on surfaces of different bearing capacities. This creates conflicting requirements for the tyre pressure magnitude and hindrances arise to its optimum setting. This is why the systems for tyre pressure regulation appear on the market, depending on their technical features allowing for the pressure regulation during the operation.

This paper investigates the magnitudes of passive losses at different tyre pressures and travel speeds on the solid surface as well as that of a tractor energy intensity after changing the semitrailer tyre pressure.

MATERIAL AND METHODS

The magnitude of passive resistance was measured by pulling a tractor unit consisting of a Case IH 195 CVX tractor and an Annaburger HTS 22.79 semitrailer, steadily moving on a plain asphalt surface. The change in the passive losses was affected by the magnitude of the semitrailer tyre pressure and travel speed. The semitrailer tyres were gradually inflated to 170 kPa, 240 kPa, and 300 kPa. A tyre pressure of

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Figure 1. Measurements of the tractor unit passive losses on the flat asphalt section

240 kPa was set permanently for the tractor. A Case IH Magnum 310 was used to move the set, as shown in Figure 1. Five measurements were taken for each tyre pressure, at a constant travel speed from 4 to 35 km/h. During the measurement, the tractor spot speed and the force needed for pulling the set were recorded. The frequency of the signal sampling from sensors was 5 Hz.

The following part of the measurement focused on the effect of the semitrailer tyre pressure on the transport energy intensity. The same set was used for the measurement as that for the passive resistance measurements. A route between Hustopeče and Nikolčice, 21.86 km long, was selected for the measurement. The tractor units set out from Hustopeče and went through Velké Němčice and Křepice to Nikolčice, where they turned around in the square and came back along the same route to Hustopeče. The measured route was divided into 8 sections with different road profiles as shown in Figure 2.

Before the measurement, the whole set was weighed on a weighbridge with 20 kg weighing sections. The set for the measurement weighed 31 800 kg.

During the measurement, the following values were recorded: driving time, spot speed of the set, instantaneous hourly fuel consumption, engine speed, engine load, fuel temperature, altitude, and set position. The frequency of the signal sampling from sensors was 5 Hz.

For the individual data measurements, the data of the internal tractor sensors were used, read from the CAN-Bus.

The system of the field measurement was designed as modular and includes three main parts:
- collection of analogue quantity data read by a HBM Spider 8 measurement system,
- data collection from the CAN internal communication network via PCMCIA card made by National Instruments,
- reading of the position and other data by a Garmin GPS module.

Measurement of forces

In the hauling rope between the two tractors, a Hottinger load cell type U2A was inserted. The sensor was calibrated before the measurement. The load cell, or the HBM Hottinger U2A weight sensor was connected to the Spider 8 frequency module with a 4.8 kHz carrier frequency. The curve of the measured values could be followed in real time on the measurement computer screen. The sensor sensitivity equalled 2 m V/V and the bridge excitation amounted to 10 V. The sensor maximum measurable force amounted to 100 kN.

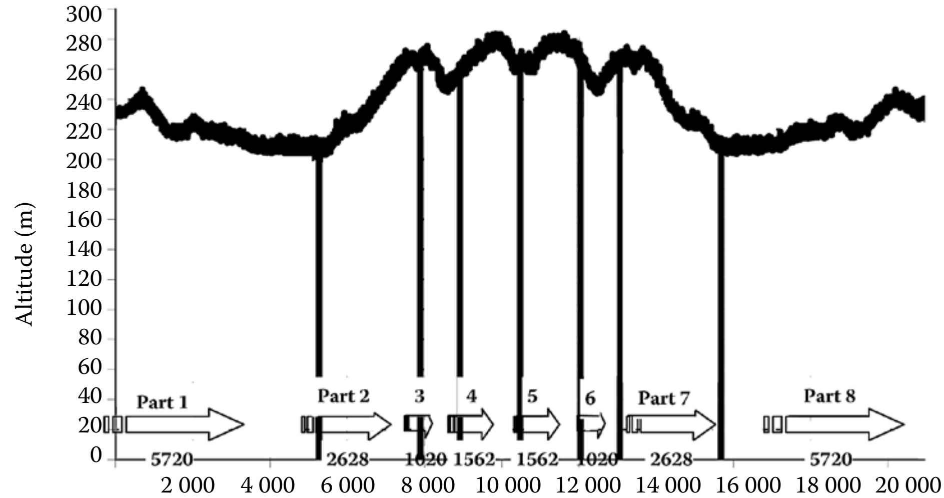

Figure 2. Altitude profile of measurement route with marked individual sections

Altitude measurement

The altitude measurement was made on an instrument working on the principle of barometric altimeters. The pressure pickup used – Motorola MPX4115 – measures from 15 kPa to 115 kPa. The output signal was linear, within the 0.2–4.8 V range. The measurement pressure accuracy was 1.5%. With calibration at a triangulation point (defined altitude), the altitude measurement uncertainty equalled 0.5 m with the assumed sampling 1000 Hz (sensor response time was 1 ms) and averaging for a period of 1 s. The signal was processed by a USB DAQ card made by National Instruments with a 14-bit resolution.

Actual speed measurement

For actual speed measurement, a RDS TGSS radar was mounted on the tractor frame. RDS TGSS radar worked on 24.125 GHz frequency with 0.5 W radiated power. The radar inclination toward the horizontal line was 37°. The output pulse signal was 128.52 pulses per 1 m of route length. The overall system accuracy ranged from 1% to 4% depending on the travel speed. The radar was connected to the frequency module of the Spider 8 data logger.

Value reading from the CAN-Bus network

The software of the measuring computer enables the sensing of values from the tractor network. The CAN-Bus of the tested tractor is fully compatible with the SAE J1939 standard in the extended ArbID (29 bit). The communication speed is 250 kbps and the relevant channels were selected through the analysis of the message frames. The engine revolutions, engine load, fuel consumption, coolant temperature, fuel temperature, and further values were deduced from the CAN-Bus network.

Tyre print measurements were made for Case IH 195 CVX tractor unit and Annaburger HTS 22.79 loaded semitrailer (Figure 3). Three prints were taken of the right back semitrailer tyre at tyre pressures of 170 kPa, 200 kPa, and 240 kPa, also used in transport. All the time, the semitrailer was coupled with the tractor. The contact patch of the semitrailer tyre was painted red and after lowering, the tyre area in contact with the surface was printed. The resulting area was measured using the Lucia-G programme for image analysis in the Faculty of Forestry and Wood Technology (LDF) biometric laboratory at the Mendel University of Agriculture and Forestry in Brno.

Figure 3. Taking of semitrailer tyre prints

The following values were calculated according to the relevant relations:

Average instantaneous consumption per section

$$Q_p = \frac{\sum_{i=1}^{n} q_i}{t \times f} \quad \text{(l/h)} \qquad (1)$$

where:

q_1 – instantaneous fuel consumption (l/h)

t – time for passage of evaluated part of section (s)

f – sampling frequency (Hz)

Total consumption for passage of evaluated part of section

$$Q = \frac{Q_p \times t}{3\,600} \quad \text{(l)} \qquad (2)$$

Table 1. Mass of Case IH 195 CVX loaded set and Annaburger HTS 22.79 semitrailer (kg)

Tractor front axle	3 260
Tractor in total	12 520
Tractor + semitrailer	31 800
Semitrailer	19 420
Semitrailer + tractor rear axle	28 660
Tractor + front axle semitrailer	22 140

Average travel speed

$$v_p = \frac{\sum_{i=1}^{n} v_i}{t \times f} \quad \text{(km/h)} \qquad (3)$$

where:
v_1 – instantaneous driving speed of tractor unit (km/h)

Average lost force

$$F_z = \frac{\sum_{i=1}^{n} F_i}{t \times f} \quad \text{(N)} \qquad (4)$$

where:
F_z – instantaneous lost force (N)

Power losses

$$P_z = F_z \times v_p \quad \text{(W)} \qquad (5)$$

where:
P_z – power losses of front axle (W)

Coefficient of tractor unit passive losses

$$\psi_z = \frac{F_z}{G} \quad (–) \qquad (6)$$

where:
F_z – average lost force (N)
G – tractor unit weight (N)

For the calculation of the passive loss coefficients, the tractor unit had to be weighed (Table 1). The measured and calculated values used regression analysis interlaid with the corresponding functions considering the magnitude of the determination coefficient (determination index). The determination index values ranged from 0.95 to 0.99 for the regression functions. The above results proved that 95–99% of variability of the dependent variable accounted for the regressive functions. For each regressive function, the calculated function was tested for reliability and the regression parameters were also tested. The results of the completed *F*-tests are presented in Table 2. The results show that all the regressive functions are reliable at 0.01 relevance level and some of the functions are highly reliable.

RESULTS AND DISCUSSION

The aim of the measurement was to establish and prove the effect of the semitrailer tyre pressure on the magnitude of power losses and energy intensity of a tractor unit operation. Therefore, the measurement of the lost power was made, necessary for a tractor unit stable movement at semitrailer tyre pressures of 170 kPa, 240 kPa, and 300 kPa and at speeds from 4 to 35 km/h. The other group of measurements focused on a tractor unit energy intensity at the semitrailer tyre pressures of 170 kPa, 200 kPa, and 230 kPa on a 21.86 km testing route. The resulting contact patches of the semitrailer tyres includ-

Table 2. Statistical evaluation of data measured

Tractor unit	Semitrailer tyre pressure (kPa)	Regression function	R^2	Testing of function	
				F test	*p*-value
Passive losses F_z					
Case IH 195 CVX and Annaburger HTS 22.79 semitrailer	300	$F_z = 0.1592v + 3.647$	0.9582	68.6851	0.003684
	240	$F_z = 0.1698v + 4.175$	0.9937	469.4828	0.000215
	170	$F_z = 0.1489v + 6.122$	0.9928	416.0771	0.000258
Passive loss coefficient ψ_z					
Case IH 195 CVX and Annaburger HTS 22.79 semitrailer	300	$\psi_z = 0.0005v + 0.0117$	0.9582	68.6851	0.003685
	240	$\psi_z = 0.0005v + 0.0134$	0.9937	469.4828	0.000215
	170	$\psi_z = 0.0005v + 0.0196$	0.9928	416.0771	0.000258
Power losses P_z					
Case IH 195 CVX and Annaburger HTS 22.79 semitrailer	300	$P_z = 0.0458v^2 + 0.9642v$	0.9985	1725.4882	0.0000256
	240	$P_z = 0.0461v^2 + 1.1927v$	0.9988	2885.4497	0.0003460
	170	$P_z = 0.0371v^2 + 1.8285v$	0.9994	8414.7793	0.00000238

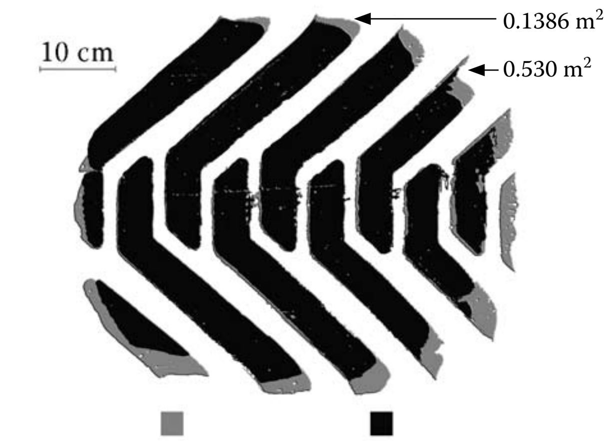

Figure 4. Contact patch of Aliance 600/55 R22.5 left tyre at Annaburger HTS 22.79 semitrailer rear axle

ing the size of area are given in Figure 4. Since the complete characteristics of the tested tractor engine were measured, the energy intensity of the tractor unit at 35 km/h speed can be established. Within the complete characteristics shown in Figure 5, points 1 and 2 were plotted at 1650 1/min engine revs based on the supply magnitudes measured at the tyre pressures of 170 kPa and 300 kPa:

– point 1 – tyre pressure 170 kPa, supply 108 kW, speed 35 km/h,
– point 2 – tyre pressure 300 kPa, supply 89 kW, speed 35 km/h.

At 825 kg/m^3 specific weight of diesel oil, the difference in consumption was 4.2 l per 1 h of operation. The testing route was divided into 8 sections, of which in section 1, the smallest difference in altitude was achieved, so the tyre pressure effect on the fuel consumption can be evaluated only in this relatively flat section. When comparing the measured values during the transport in the same tractor unit between the semitrailer tyre pressures of 70 kPa and 230 kPa in section 1, the difference in the consumption equalled 2.52 l per 1 h of operation during an average travel speed of 40.3 km/h.

The results of the lost power measurements show that the resulting power required for the tractor unit movement increased in the speed range of 4 to 35 km/h, linearly to the travel speed and falling tyre pressures. The difference of the lost powers was at 35 km/h speed 1.82 kN between 170 kPa and 300 kPa pressures. If the lost power at 170 kPa is taken as the basis, then the increase amounts to 19.6%. The greatest power amounting to 11.1 kN was identified at 35 km/h speed and 170 kPa tyre pressure. The development of the regression functions indicates that their directions shown in Figure 6 come close to each other. An average value of the directions of three regression equations used in Figure 6 reached 0.1593 at a variance coefficient of 6.57%. From that we may infer that the regression parameter changes with the tyre pressure change. Resulting from that,

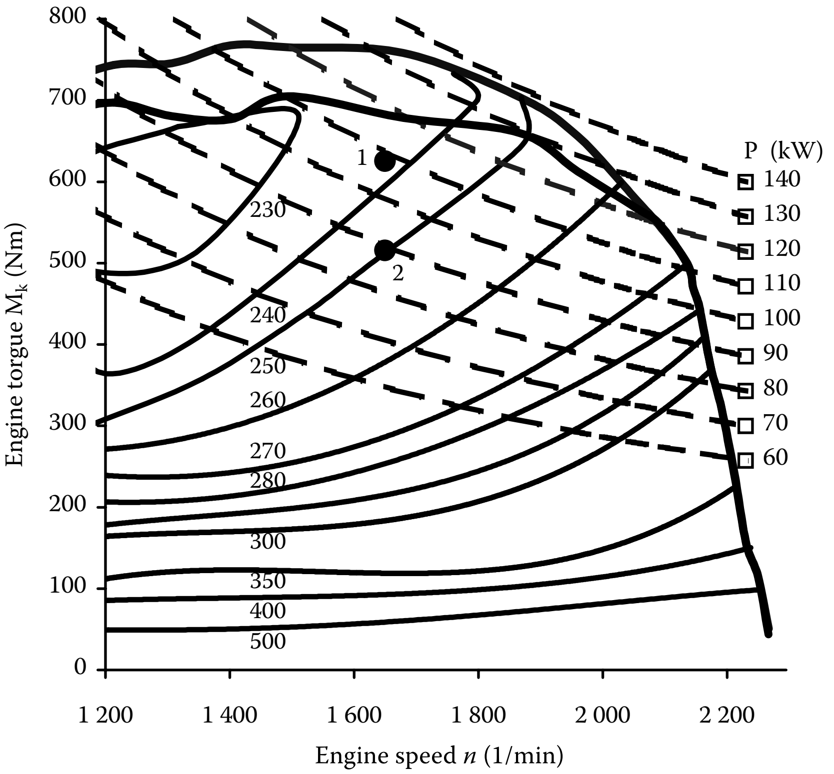

Figure 5. CASE IH 195 CVX tractor – complete characteristics

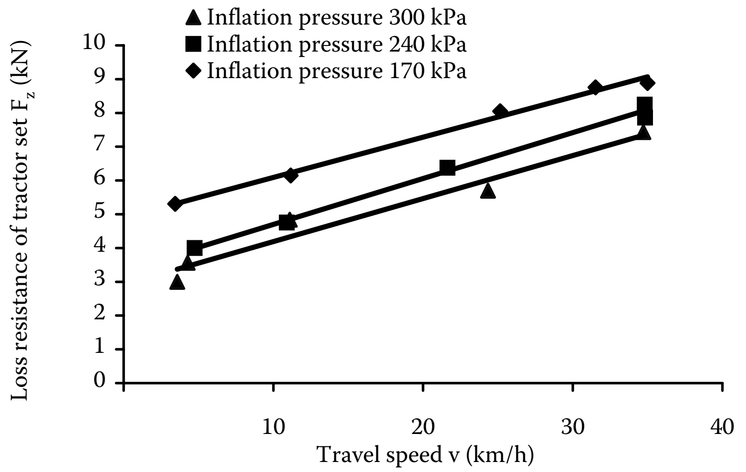

Figure 6. Relation of force necessary for the tractor unit movement to travel speed at different semitrailer tyre pressures

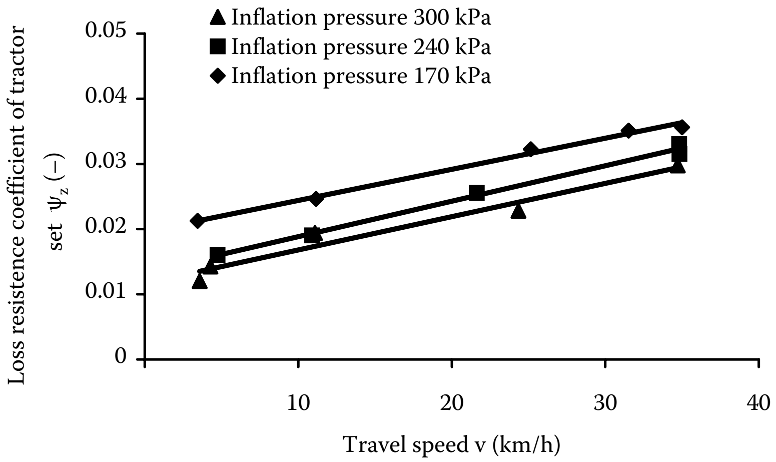

Figure 7. Power loss curves during tractor unit movement and different semitrailer tyre pressures

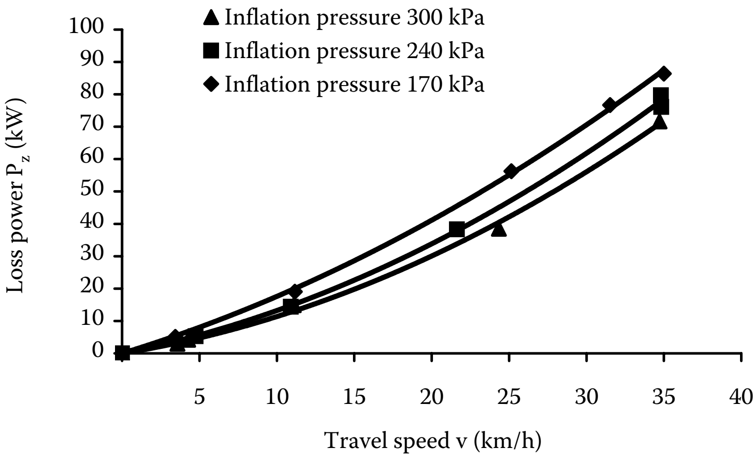

Figure 8. Dependence of tractor unit passive loss coefficients on travel speed at different tyre pressures

the dependence of the regression parameters on the tyre pressure $k_2 = f(p)$ may be created and parameter k_2 for the selected tyre pressure calculated from the regression of this dependence:

$$F_z = k_1 v + k_2$$

$$k_2 = f(p)$$

The passive loss coefficient includes the losses of the inner rolling resistance, but also the forces required for spinning the gears linked with the traveling wheels. The results indicate that the passive loss coefficient is impacted on by the tyre pressure and travel speed. The measured values ranged from 0.012 to 0.035 (Figure 7). In the speed range of 4 to 35 km/h, the coefficient increased by 97% on average. The coefficient magnitude is within the range defined in literature Semetko *et al.* (1986), Grečenko (1994) and Bygdén *et al.* (2004).

The power required for the tractor unit movement was calculated from the known speed and lost power,

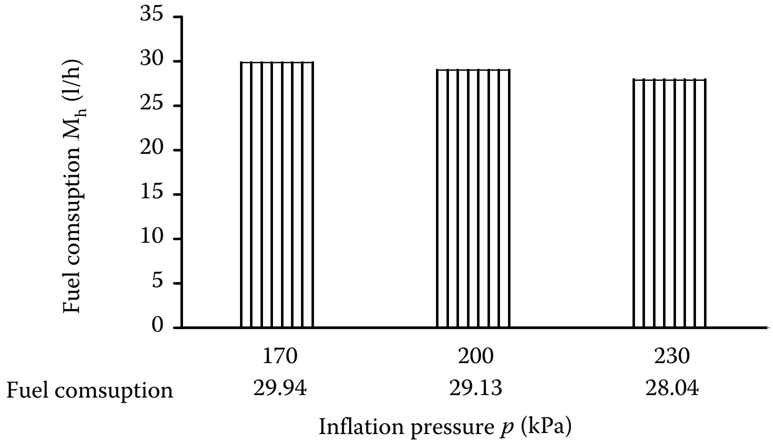

Figure 9. Hourly fuel consumption of the tractor unit on a circuit at different semitrailer tyre pressures

Figure 8. The greatest difference of the lost powers was between pressures of 170 kPa and 300 kPa at the highest travel speed. Here the difference in the lost power reached 18.42 kW. The supply necessary for the tractor unit movement thus increased by 20.56%, although the print area in one semitrailer tyre increased by 10.3% between the pressures of 170 kPa and 240 kPa.

The energy intensity of the tractor unit operated on the testing route changed through increasing the semitrailer tyre pressure from 170 kPa to 240 kPa in the way that the hourly consumption fell from 29.94 to 28.04 l/h, which represents a difference of 1.9 l/h (i.e. 6.3%), Figure 9.

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Abstrakt

Novák P., Šmerda T., Čupera J. (2009): **Vliv tlaku huštění pneumatik návěsu na pasivní ztráty a ekonomiku provozu traktorové soupravy**. Res. Agr. Eng., **55**: 129–135.

Cílem měření bylo zjistit a prokázat vliv tlaku huštění pneumatik návěsu na velikost ztrátových sil a energetickou náročnost provozu traktorové soupravy. Naměřené a vypočtené hodnoty byly pomocí regresní analýzy proloženy odpovídajícími funkcemi s ohledem na velikost koeficientu determinace (indexu determinace). Hodnoty indexu determinace se u regresních funkcí pohybují od 0,95 do 0,99 a všechny regresní funkce jsou vysoce průkazné na hladině významnosti 0,01. Rozdíl ztrátových sil byl při rychlosti 35 km/h a 1,82 kN mezi tlaky 170 kPa a 300 kPa. Energetická náročnost soupravy provozované na zkušební trase se v důsledku zvýšení tlaku huštění pneumatik návěsu ze 170 kPa na 240 kPa projevila snížením hodinové spotřeby o 1,9 l/h (6,3%).

Klíčová slova: ztrátový výkon, rychlost, valení, tlak huštění, spotřeba paliva

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