Elaboration on calculations of automobile fuel consumption

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Abstract. The existing methods of theoretical definition of automobile fuel consumption are not always correct. In particular, when we calculate fuel efficiency of the car equipped by the diesel engine, we receive some paradoxical result: the lowest fuel consumption appears to be during the movement on low gears in the gearbox. The present article tries to analyze this situation as well as to bring some mathematically proved calculations necessary to evaluate correction coefficients of the engine fuel consumption from degree of using engine power, which gives significant improving of calculation accuracy, especially for automobiles with diesel engines. Special tables for fast determination of these coefficients value are provided.

Introduction

The well-known method to theoretically evaluate automobile fuel consumption $Q_S$ at normal movement (in l/(100 km)$^{-1}$) uses the following formula [1, 2, 3, 7]

$$Q_S = g_e P_e / 36 \rho_f V,$$  \hspace{1cm} (1)

where $g_e$ – specific fuel consumption by free-piston engine in calculated movement mode, g/(kW*h)$^{-1}$; $P_e$ – power taken from the crankshaft of the engine in calculated movement mode, kW; $\rho_f$ – fuel density, kg*l$^{-1}$; $V$ – speed of the automobile movement, ms$^{-1}$.

The main difficulty in such theoretical calculations is to define the value of $g_e$, which significantly changes depending on $N$ – degree of using the engine power:

$$N_i = P_{ei} / P_{eP}^\text{max},$$ \hspace{1cm} (2)

where $P_{ei}$ – power, taken from the engine crankshaft in calculated movement mode, kW; $P_{eP}^\text{max}$ – maximum engine power in calculated movement mode, kW (evaluated according to the engine external test-bench speed characteristics).

Also, the corrected fuel consumption $g_e$ of the engine depends (but in lesser degree) on $E$ – the balance of crankshaft angle speeds:

$$E_i = \omega_{ei} / \omega_{eP},$$ \hspace{1cm} (3)

where $\omega_{ei}$ – angle speed of the crankshaft in calculated mode, s$^{-1}$; $\omega_{eP}$ – angle speed of the crankshaft in the mode of maximal power, s$^{-1}$.

Taking into consideration these special features, it is possible to recommend to evaluate the theoretical definition of size $g_e$ as per formula [1, 2, 3, 4, 6, 7]

$$g_e = g_{eP} K_N K_E = (1.05 - 1.15) g_{eP}^\text{min} K_N K_E,$$ \hspace{1cm} (4)

where $g_{eP}$ – engine corrected fuel consumption at the mode of maximal power, g/(kW*h)$^{-1}$; $K_N$ – coefficient of correction, depending on the degree of engine power using $N$; $K_E$ – coefficient of
correction, depending on balance of crankshaft angle speeds $E$; $E_{min}$ – minimum engine corrected fuel consumption according to its technical characteristics, g(kW*h)$^{1}$.

For the definition of the coefficients of correction $K_N$ and $K_E$ in technical literature [1, 2, 3, 7] the following mathematical expressions are recommended:

$$K_E = 1.25 - 0.99E + 0.98E^2 - 0.24E^3$$ (for all types of piston engines); \hspace{1cm} (5)

$$K_{NP} = 3.27 - 8.22N + 9.13N^2 - 3.18N^3$$ (for petrol engines); \hspace{1cm} (6)

$$K_{ND} = 1.2 - 0.14N + 1.8N^2 - 1.46N^3$$ (for diesel engines). \hspace{1cm} (7)

**Results**

Many calculations of automobile fuel consumption on different constant speed of movement and for different models of machines showed that for automobiles with petrol engines results of calculations correspond satisfactorily to the of dates of their operation and some special experiments (mistakes not usually exceed 15-25%). At that time for automobiles with diesel engines results of calculations on low gears of transmission give some principal mistake: fuel consumption in this situation comes out less than on high gears (Figure 1). This is not possible in real operation and contradicts laws of the automobile theory [5, 9, 10].

![Figure 1](characteristics_diesel_truck_fuel_consumption.png)

**Figure 1** Characteristics of diesel truck fuel consumption when the following expression is used (7)

$$K_{ND} = 1.2 - 0.14N + 1.8N^2 - 1.46N^3$$
Comparative analysis of the mathematical expressions (6) and (7) showed that in this case there is no correspondence between them (Figure 2). Really, it is well known from the theory of the engine, that \( g_e = 1000 \cdot G_h / P_e \) (where \( G_h \) – fuel consumption per hour, kg h\(^{-1}\)). As follows from this formula – with approach engine power to zero corrected fuel consumption \( g_e \) must tend to infinity (\( \infty \)). It is seen that widely recommended in many technical sources, for correction of \( g_e \), diesel engines mathematical expressions (7) in case of \( N = 0 \) coefficient of correction \( K_{ND} \) does not show such tending because it is equal only to 1.2. Mathematical expressions (6) in that case are more correct because the ratio of correction \( K_{NP} \) for petrol engines at \( N = 0 \) is equal to 3.27 and leads to substantial increase of corrected fuel consumption \( g_e \).

In laboratory on special motor stand some tests of different diesel engines at were held- all at different angle speeds of crankshafts and different brake moments with measuring fuel consumption per hour (\( G_h \)) and calculations \( g_e \) and \( K_{ND} \) by using received dates. Experiments showed, that dependence \( K_{ND} \) from \( N \) for diesel engines has distinct expressed tending to infinity at \( N = 0 \), as it showed from \( K_{NP} \) for petrol engine. As a result of experimental material study we received new mathematical approximation for dependence \( K_{ND} = f (N) \) for diesel engines as polynom of fifth degree [5, 8, 9]:

\[
K_{ND} = 3.52 - 17.24N + 44.85N^2 - 55.28N^3 + 31.23N^4 - 6.08N^5
\]  

(8)

Similar experiments were hold with petrol engines, and basing on its results we received new mathematical approximation of dependence coefficient of correction \( K_{NP} = f (N) \) for petrol engines with distribute injection, also as polynom of fifth degree [5, 8, 9]:

\[
K_{NP} = 4.32 - 24.21N + 71.87N^2 - 107.21N^3 + 78.73N^4 - 22.5N^5
\]  

(9)

Good results were given by calculations of traveling fuel consumptions of diesel equipped automobiles when mathematical expression (8) for definition of \( K_{ND} \) was used. For example, received fuel characteristics for truck KamAZ-5320 (figure 3) fully correspond to theoretical ideas about dependence on fuel consumptions from using gear in gearbox and movement speed of automobile.

Figure 2 Difference in the character of expressions (6 and 7)
(compare figure 3 and figure 1) [9, 10]. For this model truck we received exact correspondence of calculation result of traveling fuel consumptions on direct gear in the gearbox at movement speed of 40 km/h and control fuel consumptions of real truck in a similar movement mode in case of its full load (24 l/(100 km))

Results, better corresponding to real fuel consumptions in operation were also received for cars with petrol engines, when we used expression (9) for definition of $K_{NP}$.

\[
K_{ND} = 3.52 - 17.24N + 44.85N^2 - 55.28N^3 + 31.23N^4 - 6.08N^5
\]

Figure 3 Characteristics of diesel truck fuel consumption when the following expression is used

To simplify calculations of $K_{ND}$ and $K_{NP}$ the authors worked out special tables. With the help of these tables the process of definition coefficients of correction becomes easy. High precision of definition $K_{ND}$ and $K_{NP}$ is providing also at intermediate meanings of $N$. For example, if is necessary to define $K_{NP}$ for $N = 0.415$, which is absent in table 2, you should take the average meaning of $K_{NP}$ between $N = 0.41$ and $N = 0.42$ (it is 1.0464). The mistake with the exact size (1.046282), received from expression (9), will be only 0.03% and consequently may be ignored.

Conclusion

Thus, we may conclude that the improved method of calculation of fuel consumption with the use of a polynom of the fifth degree has been worked out. This method is aimed at finding more exact correction coefficients $K_{ND}$ and $K_{NP}$ which significantly improves the accuracy of calculation of engine corrected fuel consumption $g_e$, especially for the cars with diesel engines [5, 8, 10]. This improving excludes contradiction, when calculations using expression (7) of fuel consumptions of automobiles with diesel engines give the wrong conclusion about less fuel usage during the movement of the car on low gears. Introducing such calculations, basing on special tables, worked out by the authors according to mathematical expressions (8) and (9) and which are aimed at correcting coefficients $K_{ND}$ and $K_{NP}$ will simplify and accelerate the calculation process.
Table 1 \( K_{ND} = f(N) \) for diesel engines according to polynomial of V I Peskov; \( K_{ND} = 3.52 – 17.24N + 44.85N^2 – 55.28N^3 + 31.23N^4 – 6.08N^5 \)

| N   | \( K_{ND} \) | N   | \( K_{ND} \) | N   | \( K_{ND} \) |
|-----|--------------|-----|--------------|-----|--------------|
| 0.005 | 3.434914    | 0.24 | 1.300342    | 0.55 | 0.959658    |
| 0.01  | 3.352030    | 0.245 | 1.282521    | 0.56 | 0.958976    |
| 0.015 | 3.271506    | 0.25  | 1.265430    | 0.57 | 0.958306    |
| 0.02  | 3.192703    | 0.255 | 1.249046    | 0.58 | 0.957625    |
| 0.025 | 3.116180    | 0.26  | 1.233348    | 0.59 | 0.956912    |
| 0.03  | 3.041698    | 0.265 | 1.218318    | 0.6  | 0.956147    |
| 0.035 | 2.969218    | 0.27  | 1.203934    | 0.61 | 0.955317    |
| 0.04  | 2.898701    | 0.275 | 1.190176    | 0.62 | 0.954409    |
| 0.045 | 2.830111    | 0.28  | 1.177027    | 0.63 | 0.953415    |
| 0.05  | 2.763408    | 0.285 | 1.164465    | 0.64 | 0.952329    |
| 0.055 | 2.698557    | 0.29  | 1.152474    | 0.65 | 0.951148    |
| 0.06  | 2.635520    | 0.295 | 1.141035    | 0.66 | 0.949873    |
| 0.065 | 2.574260    | 0.3   | 1.130129    | 0.67 | 0.948505    |
| 0.07  | 2.514744    | 0.305 | 1.119739    | 0.68 | 0.947051    |
| 0.075 | 2.456934    | 0.31  | 1.109848    | 0.69 | 0.945518    |
| 0.08  | 2.400796    | 0.315 | 1.100438    | 0.7  | 0.943917    |
| 0.085 | 2.346296    | 0.32  | 1.091494    | 0.71 | 0.942261    |
| 0.09  | 2.293399    | 0.325 | 1.082999    | 0.72 | 0.940566    |
| 0.095 | 2.242072    | 0.33  | 1.074936    | 0.73 | 0.938848    |
| 0.1   | 2.192282    | 0.335 | 1.067290    | 0.74 | 0.937129    |
| 0.105 | 2.143996    | 0.34  | 1.060048    | 0.75 | 0.935430    |
| 0.11  | 2.097182    | 0.345 | 1.053191    | 0.76 | 0.933775    |
| 0.115 | 2.051807    | 0.35  | 1.046707    | 0.77 | 0.932191    |
| 0.12  | 2.007841    | 0.355 | 1.040580    | 0.78 | 0.930705    |
| 0.125 | 1.965251    | 0.36  | 1.034797    | 0.79 | 0.929349    |
| 0.13  | 1.924009    | 0.365 | 1.029344    | 0.8  | 0.928154    |
| 0.135 | 1.884082    | 0.37  | 1.024207    | 0.81 | 0.927153    |
| 0.14  | 1.845442    | 0.375 | 1.019373    | 0.82 | 0.926381    |
| 0.145 | 1.808059    | 0.38  | 1.014829    | 0.83 | 0.925877    |
| 0.15  | 1.771903    | 0.385 | 1.010563    | 0.84 | 0.925677    |
| 0.155 | 1.736947    | 0.39  | 1.006562    | 0.85 | 0.925822    |
| 0.16  | 1.703162    | 0.395 | 1.002815    | 0.86 | 0.926353    |
| 0.165 | 1.670521    | 0.4   | 0.999309    | 0.87 | 0.927312    |
| 0.17  | 1.638995    | 0.41  | 0.992977    | 0.88 | 0.928744    |
| 0.175 | 1.608557    | 0.42  | 0.987478    | 0.89 | 0.930692    |
| 0.18  | 1.579182    | 0.43  | 0.982728    | 0.9  | 0.933204    |
| 0.185 | 1.550843    | 0.44  | 0.978650    | 0.91 | 0.936325    |
| 0.19  | 1.523513    | 0.45  | 0.975167    | 0.92 | 0.940104    |
| 0.195 | 1.497168    | 0.46  | 0.972210    | 0.93 | 0.944589    |
| 0.2   | 1.471782    | 0.47  | 0.969712    | 0.94 | 0.949830    |
| 0.205 | 1.447331    | 0.48  | 0.967612    | 0.95 | 0.955877    |
| 0.21  | 1.423790    | 0.49  | 0.965851    | 0.96 | 0.962781    |
| 0.215 | 1.401135    | 0.5   | 0.964375    | 0.97 | 0.970593    |
| 0.22  | 1.379343    | 0.51  | 0.963135    | 0.98 | 0.979365    |
| 0.225 | 1.358391    | 0.52  | 0.962083    | 0.99 | 0.989150    |
| 0.23  | 1.338254    | 0.53  | 0.961179    | 1.0  | 1.0          |
Table 2 $K_{NP} = f(N)$ for petrol engines with distribute injection accordance to polynom of V I Peskov:

$K_{NP} = 4.32 - 24.21N + 71.87N^2 - 107.21N^3 + 78.73N^4 - 22.5N^5$

| N   | $K_{NP}$ | N   | $K_{NP}$ | N   | $K_{NP}$ |
|-----|---------|-----|---------|-----|---------|
| 0.005 | 4.200733 | 0.24 | 1.410532 | 0.55 | 0.980008 |
| 0.01 | 4.084981 | 0.245 | 1.389706 | 0.56 | 0.976393 |
| 0.015 | 3.972663 | 0.25 | 1.369755 | 0.57 | 0.973254 |
| 0.02 | 3.863703 | 0.255 | 1.350738 | 0.58 | 0.969985 |
| 0.025 | 3.758024 | 0.26 | 1.332533 | 0.59 | 0.966783 |
| 0.03 | 3.655552 | 0.265 | 1.315139 | 0.6 | 0.963648 |
| 0.035 | 3.556211 | 0.27 | 1.298527 | 0.61 | 0.960583 |
| 0.04 | 3.459930 | 0.275 | 1.282667 | 0.62 | 0.957594 |
| 0.045 | 3.366636 | 0.28 | 1.267529 | 0.63 | 0.954688 |
| 0.05 | 3.276259 | 0.285 | 1.253088 | 0.64 | 0.951877 |
| 0.055 | 3.188729 | 0.29 | 1.239315 | 0.65 | 0.949172 |
| 0.06 | 3.103977 | 0.295 | 1.226183 | 0.66 | 0.946587 |
| 0.065 | 3.021937 | 0.3 | 1.213668 | 0.67 | 0.944138 |
| 0.07 | 2.942542 | 0.305 | 1.201744 | 0.68 | 0.941840 |
| 0.075 | 2.865727 | 0.31 | 1.190386 | 0.69 | 0.939711 |
| 0.08 | 2.791428 | 0.315 | 1.179572 | 0.7 | 0.937768 |
| 0.085 | 2.719580 | 0.32 | 1.169277 | 0.71 | 0.936029 |
| 0.09 | 2.650124 | 0.325 | 1.159480 | 0.72 | 0.934512 |
| 0.095 | 2.582996 | 0.33 | 1.150158 | 0.73 | 0.933234 |
| 0.1 | 2.518138 | 0.335 | 1.141291 | 0.74 | 0.932213 |
| 0.105 | 2.455490 | 0.34 | 1.132858 | 0.75 | 0.931465 |
| 0.11 | 2.394995 | 0.345 | 1.124839 | 0.76 | 0.931004 |
| 0.115 | 2.336595 | 0.35 | 1.117214 | 0.77 | 0.930845 |
| 0.12 | 2.280235 | 0.355 | 1.109966 | 0.78 | 0.930799 |
| 0.125 | 2.225859 | 0.36 | 1.103075 | 0.79 | 0.931478 |
| 0.13 | 2.173413 | 0.365 | 1.096525 | 0.8 | 0.932288 |
| 0.135 | 2.122845 | 0.37 | 1.090298 | 0.81 | 0.933436 |
| 0.14 | 2.074103 | 0.375 | 1.084378 | 0.82 | 0.934924 |
| 0.145 | 2.027134 | 0.38 | 1.078749 | 0.83 | 0.936753 |
| 0.15 | 1.981890 | 0.385 | 1.073396 | 0.84 | 0.938920 |
| 0.155 | 1.938320 | 0.39 | 1.068305 | 0.85 | 0.941416 |
| 0.16 | 1.896377 | 0.395 | 1.063640 | 0.86 | 0.944233 |
| 0.165 | 1.856013 | 0.4 | 1.058848 | 0.87 | 0.947354 |
| 0.17 | 1.817172 | 0.41 | 1.050272 | 0.88 | 0.950762 |
| 0.175 | 1.779837 | 0.42 | 1.042477 | 0.89 | 0.954433 |
| 0.18 | 1.743935 | 0.43 | 1.035371 | 0.9 | 0.958338 |
| 0.185 | 1.709432 | 0.44 | 1.028870 | 0.91 | 0.962444 |
| 0.19 | 1.676284 | 0.45 | 1.022898 | 0.92 | 0.966711 |
| 0.195 | 1.644450 | 0.46 | 1.017384 | 0.93 | 0.971095 |
| 0.2 | 1.613888 | 0.47 | 1.012266 | 0.94 | 0.975546 |
| 0.205 | 1.584558 | 0.48 | 1.007487 | 0.95 | 0.980007 |
| 0.21 | 1.556421 | 0.49 | 1.002996 | 0.96 | 0.984414 |
| 0.215 | 1.529437 | 0.5 | 0.998750 | 0.97 | 0.988698 |
| 0.22 | 1.503570 | 0.51 | 0.994709 | 0.98 | 0.992781 |
| 0.225 | 1.477882 | 0.52 | 0.990841 | 0.99 | 0.996579 |
| 0.23 | 1.455036 | 0.53 | 0.987116 | 1.0 | 1.0 |
| 0.235 | 1.432298 | 0.54 | 0.983511 | | |
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