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The effect of exhaust gas smokiness on air pollution in urban agglomeration

Abstract: The problem of air pollution from means of transport moving in urban agglomerations becomes more and more significant within the whole transport impact. It is particularly noticeable in case of the through traffic of automotive vehicles with large load capacity in agglomerations not having ring roads for the traffic of those vehicles. In the paper is presented the study on one of the factors inducing pollution of the air which is the exhaust gas smokiness against its general pollution in two urban agglomerations with similar through traffic pf automotive vehicles

Key words: engine, exhaust gas smokiness

Wpływ gazów spalinowych na zanieczyszczenie powietrza w aglomeracji miejskiej

Streszczenie: Problem zanieczyszczenia powietrza przez środki transportu przemieszczające się w aglomeracjach miejskich staje się coraz bardziej znaczącym w całokształtcie oddziaływania transportu. Jest on szczególnie odczuwalny w przypadku ruchu tranzytowego pojazdów samochodowych o dużej ładowności w aglomeracjach nie posiadających obwodnicy dla ruchu tych pojazdów. W artykule przedstawiono badania jednego z czynników powodujących zanieczyszczenie powietrza jakim jest zadymienie spalin ,na tle ogólnego jego skażenia w dwu różnych aglomeracjach miejskich o podobnym ruchu tranzytowym pojazdów.

Słowa kluczowe: silnik, zadymienie spalin

1. Introduction

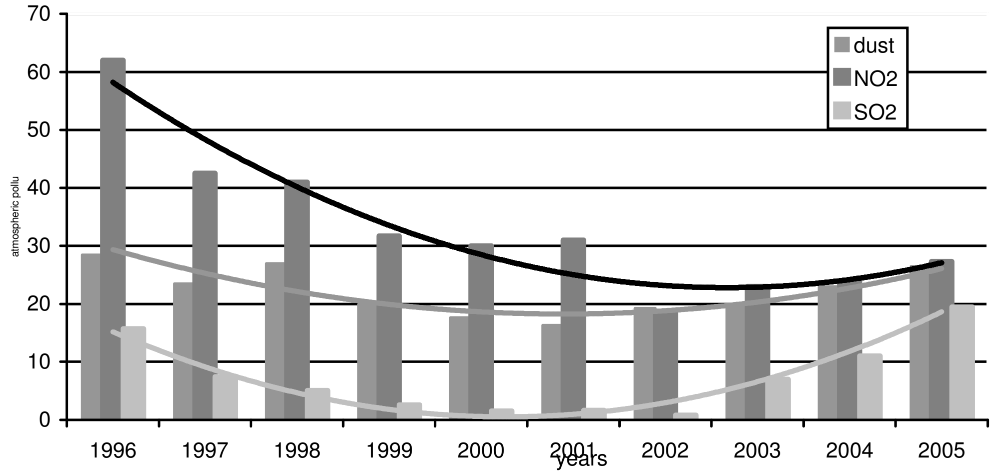
For many years, the author has examined atmospheric air pollution in two urban agglomerations with the through traffic of automotive vehicles with large load capacity taking place through city centre. Both agglomerations are situated on a main road connecting the Baltic Sea ports with the Balkans. Their size is as follows: first agglomeration (Szczecin) – about 600 thousand population, the second one (Gorzów Wielkopolski) – 125 thousand population. In both agglomerations, the air pollution was similar and limited mainly to suspended dust PM 10, nitrogen dioxide NO_2 and sulphur dioxide SO_2. Other toxic components occurring in air are present in considerably smaller percentages than the aforementioned ones. The results of studies on air pollution carried out by the author are presented in Figures 1 and 2.

Based on heretofore studies, a characteristic of average annual air pollution in 1996-2005 for larger agglomeration was made and presented in Fig. 1, while comparison of pollutions in both agglomerations in 1996-2008 in Fig. 2.

All curves representing air pollution components show a downward and then an upward trend. As far as the suspended dust is concerned, its air content decreases to 2001 when it reaches a maximum and then increases, although not reaching yet the admissible value of 40 $\mu g/m^3$. This situation is caused by the growing number of motor trucks using expressway S-3 for through traffic [1].

As it results from the author's studies, upward trends of air dustiness are similar, with dustiness build-up degree in the smaller agglomeration being larger and larger with the lapse of years, and thus dust level values in the final stage of study are equal in both agglomerations being compared.

Therefore, it is purposeful to compare environmental pollution conditions in both agglomerations situated by the same transit expressway S-3 (formerly known as international road E 65) [1, 2]. It is advisable inasmuch as three toxic compounds polluting the air and being found in the largest quantities in both agglomerations, i.e. suspended dust, nitrogen dioxide and sulphur dioxide, are the same.



Dust Fig. 1. The course of average annual air pollutions (μg/m^3) in the Szczecin aglomeration [3]

Y: atmospheric pollution; X: years; Pyły = Dust

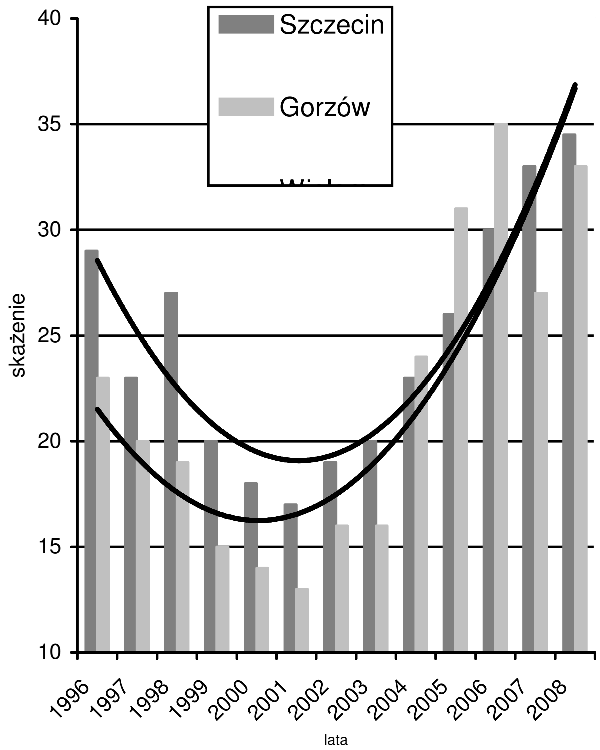


Fig. 2. Comparison of PM 10 dust pollution in the agglomerations under discussion

Y: pollution; X: years

2.Exaust gas smokiness in direct-injection engines

Despite their well-known advantages, diesel engines are a source of the emission of exhaust gas and toxic substance contained in it. In these constructions, a basic issue connected with exhaust gas emission is the smokiness level which is considered to be the most important problem as far as environmental contamination is concerned. To a large extent,particulate matter is pure carbon but due to its microscopic size and ability to bind easily to other compounds, mainly aromatic hydrocarbons of carcinogenic effect, is included into harmful and environment polluting compounds. To simplify the measurement, exhaust gas is evaluated with a Diesel smoke meter only and therefore this is an indirect method [4]. Particulate matter includes also liquid hydrocarbons, fuel and lubricating oil drops and sulphur compounds. Diesel engines emit about 50 times more these particles than petrol engines, which – in relation to increase in their applications – may contribute to a general build-up in the emission of harmful substances [2, 4, 5].

The problem of atmospheric exhaust gas pollution is particularly important in large urban agglomerations where – with a considerable intensity of traffic and specific atmospheric conditions, such as pressure, temperature and humidity – the concentration level of substances being harmful for human organism is unusually large. The hazard is the greater as a lot of the combustion products, e.g. particulate matter, fall for the most part within the direct zone of emission. The constantly growing number of automotive vehicles, their not ideal technical condition, and the lack of ring roads “taking” the road transport out of city limits makes the life within them to be more and more difficult.

Also municipal transport has a significant effect on the smokiness and the emission of exhaust gas toxic substances. The use of outdated-construction engines in suburban bus shuttles, city buses and intercity motor-coaches, not adapted to environmental protection requirements being in force at present, is a very important problem requiring implementation of new solutions.

One of such solutions is to fuel combustion engines with alternative fuels. Therefore, the effect of plant-origin fuels on exhaust gas smokiness degree in direct-injection engines was examined in the carried out study. To this end, two engines were chosen for examination, i.e. 359 Diesel engine (STAR trucks) and SW 680 Diesel engine (Leyland's licence) [6].

The examination was performed on three types of fuel: regular Diesel fuel (ON), winter Diesel fuel (IZ 40), and rapeseed methyl ester (RME). These engines were successively fuelled with each of the aforementioned fuels, the selected properties of which are presented in Table 1.

Tab. 1. Comparison of the selected properties of regular Diesel fuel (ON), winter Diesel fuel (IZ 40) and rapeseed methyl ester (RME) [5]

Parameter	ON	IZ 40	RME
Density [g/cm³] at 20°C	0.81 – 0.84	0.834	0.88
Kinematic viscosity [mm²/s] at 20°C	2.8 – 5.9	2.7 – 6.0	6.9 – 8.2
Cetane number	50	40	56
Ignition temperature [°C]	60	45	168
Cold filter plugging point [°C]	0/-12	-30	-7/-12
Sulphur content [%]	0.28	0.3	0.001

The study focused for the most part on comparing exhaust gas smokiness according to the fuel type applied, using for this purpose an MDO 2 type Diesel smoke meter manufactured by MAHA (light absorption coefficient k 1/m). Exhaust gas smokiness was measured according to maximum smokiness method, being commonly used at vehicle control stations (VCS) [4]. Additionally, by changing the length of air inlet conduit, dynamic supercharging effect was obtained for the required engine rotational speed.

These fuels, in the form pf rapeseed oil or rapeseed methyl ester, were bringing about hope for a considerable improvement of some engine operation parameters.

Attention was centred on esters despite the fact that bringing them to physicochemical parameters similar to Diesel fuel required additional treatments but their advantage is that they do not contain sulphur or only in minimum quantities [5], while additional oxygen bonds allow considerable reduction of exhaust gas smokiness, the evidence of which can be the research work carried out by the author on the STAR 359 Diesel engine [3], which is presented in Fig. 3, 4 and 5.

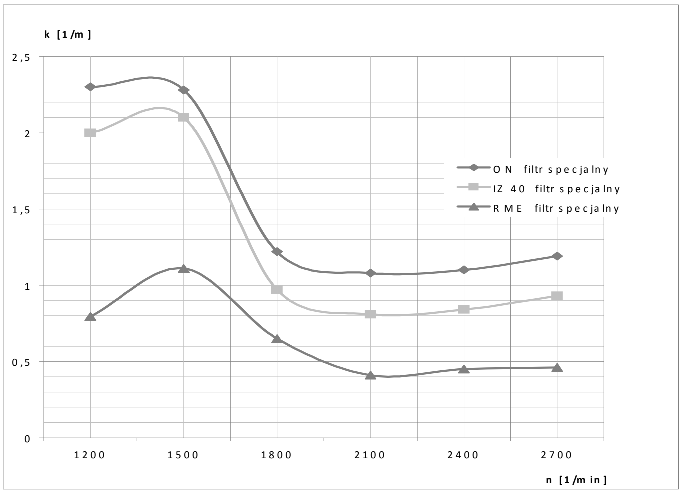


Fig. 3. The external characteristic of exhaust gas smokiness for the 359 engine fuelled with different fuels

Y: ; special filter

In Fig. 3, two groups of curves can be observed but the character of their course is very similar and they differ only in the value of absorption coefficient. Within the area of small rotational speeds (1200÷1500 min^{-1}), a difference in the smokiness between the most favourable completion (RME with special filter) and the worst one (ON with special filter) is 1.2÷1.5 1/m, whereas in the area of rotational speeds of 1800÷2700 min^{-1} it amounts barely to 0.7÷0.75 1/m. It is possible to clearly see in this figure that, starting with rotational speed of 1900 min^{-1}, exhaust gas smokiness becomes stabilised at a specific level, irrespective of the absolute value, which is evidence of the fact that only fuel physicochemical properties affect it. Within this range of rotational speeds, engine inlet system works normally and air flow speed is large enough to set it in rotational movement necessary for proper formation of air-fuel mixture and combustion of the fuel dose injected.

More favourable course of curves for the RME-fuelled engine results from the properties of this fuel containing additional oxygen bonds which induce its better combustion. Within small rotational speeds, filters with increased flow resistance cause the excess combustion air factor to be smaller, and hence there are no conditions for full and complete combustion of the fuel dose injected (ON regular Diesel fuel). This should be an explanation of a sudden drop in exhaust gas smokiness within rotational speeds 1500÷1800 min^{-1} because the engine was constructed so as to reach maximum turning moment within rotational speeds 1800÷2100 min^{-1}. Injection pump dose was selected so as to ensure the achievement of this maximum just at 1800 min^{-1}, while inlet system and timing gear system had to ensure required engine charging. Similar results were obtained during examination of this engine fuelled with Diesel fuel as a basic fuel and three types of rapeseed methyl ethyl with different composition [5].

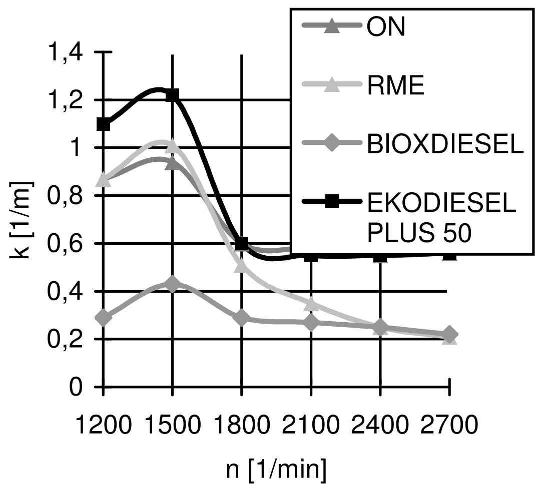


Fig 4. The characteristic of smokiness for the 359 engine fuelled with different fuels
ON – regular Diesel fuel , RME – rapeseed methyl ester, BIOXDIESEL – Diesel fuel with admixture of RME, EKODIESEL PLUS 50 – Diesel fuel with admixture of RME and alcohol

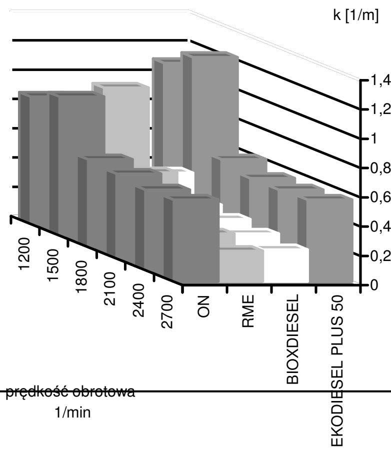


Fig. 5. The characteristic of exhaust gas smokiness time density for the 359 engine
Z: rotational speed

As it can be seen from the findings, the engine fuelled with Diesel fuel with admixture of rapeseed methyl ester looks more favourably with respect to exhaust gas smokiness.

The examination of exhaust gas smokiness was also carried out for the SW 680 engine manufactured by MIELEC-DIESEL Engine Factory. It is a direct-injection Diesel engine designed for motor trucks with large load capacity and buses [7]. It is being used in uncharged as well as supercharged version.

It results from the data presented graphically in Fig. 6 that exhaust gas smokiness degree for the SW 680 engine examined in version without supercharging differs depending on rotational speed and load but is generally large. It ranges from 0.275 1/m to 1.622 1/m, whereas admissible smokiness for the engine of that type should not exceed a value of 0.6÷0.77 1/m.

In the next figure, the characteristic of smokiness time density for the situation showed in Fig. 6 is presented. It can be seen in this figure what is the percentage of participation of respective smokiness values within the whole work area and at what parameters the engine should work to be least harmful for environment.

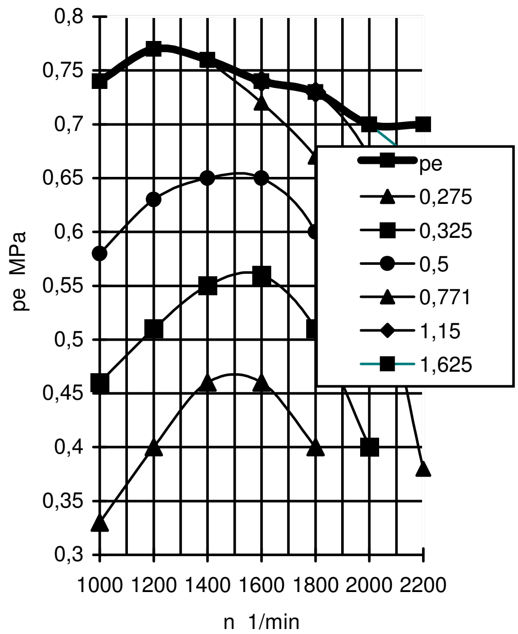


Fig. 6. The universal characteristic of smokiness for the SW 680 engine inuncharged version

For comparison, exhaust gas smokiness was examined for the SW 680 engine supercharged dynamically, which is presented in Figures 7 and 8.
The application of dynamic (without compressor) supercharging does not require any additional equipment apart from changing geometric dimensions of the inlet system. This is because the engine inlet system is adapted to the induction of wave phenomena at rotational speeds corresponding to maximum turning moment velocity. At present, this charging is being commonly used in spark-ignition engines with petrol injection as well as in Diesel engines in motor-cars and motor trucks as a combined supercharging in conjunction with turbocharging [6]. Its effect on ecological parameters is presented based on the SW 680 engine examination.

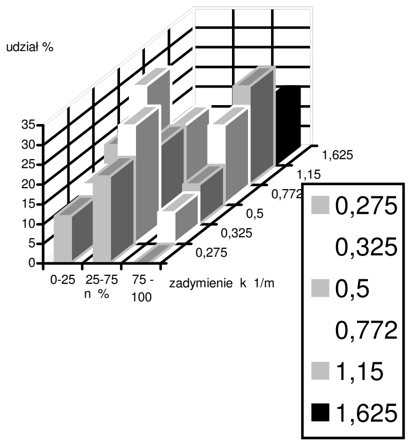


Fig. 7. The characteristic of time density for the SW 680 uncharged engine

Y: participation Z - smokiness

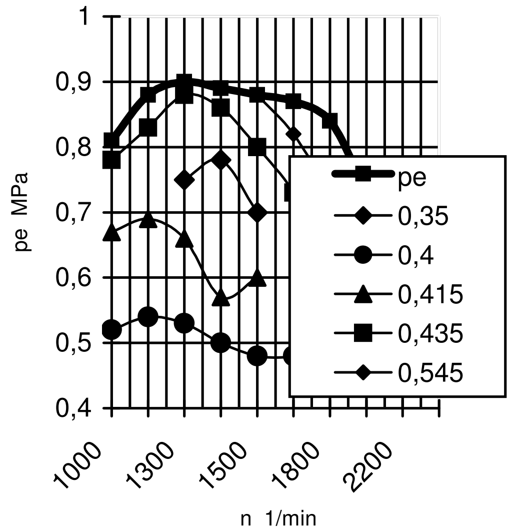


Fig. 8. The universal characteristic of smokiness for the SW 680 engine charged dynamically

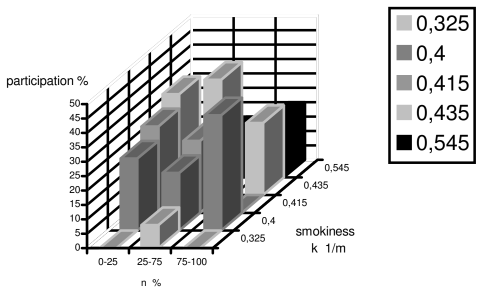


Fig. 9. The characteristic of exhaust gas smokiness time density for the SW 680 engine charged dynamically

The value of exhaust gas smokiness for dynamically supercharged engine is decidedly smaller as they range from 0.325 to 0.545 1/m, while the area of characteristic with relatively small smokiness is big for respective rotational speed ranges. In per cent, the largest values of exhaust gas smokiness, i.e. 0.4 1/m and 0.435, occurred at 25-75 % of engine rotational speed.

According to the standard PN-ISO 9178-3:1997, the admissible exhaust gas smokiness for uncharged engines is 2.5 1/m and 3.0 1/m for the supercharged ones [4].

Based on the quoted findings, it is clearly seen why modern combustion engines designed for driving motor-cars are characterised by a trend towards supercharging, in particular towards combined supercharging which is a combination of dynamic supercharging and turbocharging. In relation to motor truck engines, this phenomenon occurred considerably earlier since it was connected with a significant reduction of fuel consumption.

In this way, one of the problems related to the improvement of combustion engine environmental impact is presented in short.

The examination of exhaust gas smokiness, as mentioned above, was carried on three types of Diesel engines with direct injection designed for driving motor trucks with medium and large load capacity. For this group of engines, using Spearman's rank correlation coefficients R_{xy} (i.e. a measure of ordered correspondence) [8, 9], the author determined the relationship between exhaust gas smokiness and air pollution by suspended dust PM 10. This measure of the accuracy of relationship between two traits is used when the traits are measurable but the simplicity of calculation is preferred. The variants of each trait are given a rank, i.e. a number given in the sequence of changes of that trait arranged in the ascending order.

The total correlation was determined, i.e. a relationship between two random variables, apart from values of other random variables.

This coefficient has the following properties:

1. It is a measure of correlation strength;
2. It assumes values within the range of < -1, 1>,
   - $R_{xy} = 0$ – means no correlation,
   - $R_{xy} < 0$ – means that correlation is negative, i.e. when one trait increases its intensity degree (growth), it induces a decrease in the intensity of another trait (drop),
   - $R_{xy} > 0$ – means that correlation is positive, i.e. changes are unidirectional and an increase in the intensity of one trait induces an increase in the intensity of another one,
   - $|R_{xy}| = 1$ – correlation is functional;
3. It is symmetrical $R_{xy} = R_{yx}$;
4. It is applied when at least one trait is measurable;
5. As a rule, it is used when the number of observations is small.

Tab. 2. Relationship between exhaust gas smokiness and air dust content

Item	Engine	Smokiness k 1/m	PM 10 content $\mu g/m^3$	Coefficient of correlation
1.	STAR - 359	0.55	18	
2.		0.56	17	0.964912
3.		0.58	19	
4.		0.6	20	
5.		0.87	23	
6.		0.95	26	
1.	SW 680/1	0.275	18	
2.		0.325	17	
3.		0.5	19	
4.		0.771	20	0.955309
5.		1.15	23	
6.		1.625	26	
1.	SW 680/17	0.35	18	
2.		0.4	17	0.903167
3.		0.415	19	
4.		0.435	20	
5.		0.545	23	
6.		0.545	26	

SW 680/1 engine – uncharged engine
SW 680/17 engine – supercharged engine

As it can be seen from the results presented in Table 2, the value of correlation coefficients for different versions of motor truck engines ranges from 0.903167 to 0.964912 and is very high but the difference between them does not exceed 3.2 %.

3.Exhaust gas smokiness in indirect-injection engines

This problem looks slightly different in relation to Diesel engines with indirect injection designed for driving motor-cars.

Diesel engines with indirect injection have higher values of exhaust gas smokiness [4, 7]; nevertheless, the trends accompanying combustion process results in the form of exhaust gas smokiness are similar as in direct-injection engines. The comparison of exhaust gas smokiness for VW 16 engine in JK uncharged version and CY supercharged one is presented in Table 3.

Tab. 3. Relationship between exhaust gas smokiness and air dust content for indirect-injection engine

Item.	Engine	Smokiness k 1/m	PM 10 content $\mu g/m^3$	Coefficient of correlation
1.	JK	0.283	18	
2.		0.292	17	
3.		0.3	19	0.955085
4.		0.301	20	
5.		0.301	23	
6.		0.318	26	
1.	CY	1.374	18	
2.		1.4	17	
3.		1.678	19	
4.		1.901	20	0.870627
5.		2.14	23	
6.		2.3	26	

Based on the results presented in Table 3, it is possible to state that also in case of indirect-injection engines there is a large correlation between exhaust gas smokiness and air pollution, the evidence of which is correlation coefficient values ranging from 0.870627 to 0.955085.

CONCLUSION

Most Diesel engines manufactured and sold at present and driving motor-cars are direct-injection engines, and thus these observations refer to a considerable group of engines under operation. The studies carried out by the author clearly indicate that exhaust gas smokiness is a factor significantly affecting the air pollution in urban agglomerations, in particular where there is a through traffic of motor trucks with large load capacity which, as a rule, are driven by Diesel engines with direct injection, which as the study objective.

Nomenclature/*Skróty i oznaczenia*

RME – rapeseed methyl ester,
BIOXDIESEL – Diesel fuel with admixture of RME,
EKODIESEL PLUS 50 – Diesel fuel with admixture of RME and alcohol

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