INTERNAL COMBUSTION RECIPROCATING PISTON ENGINES

TYPES OF RECIPROCATING INTERNAL COMBUSTION PISTON ENGINES

Depending on the ignition pattern:

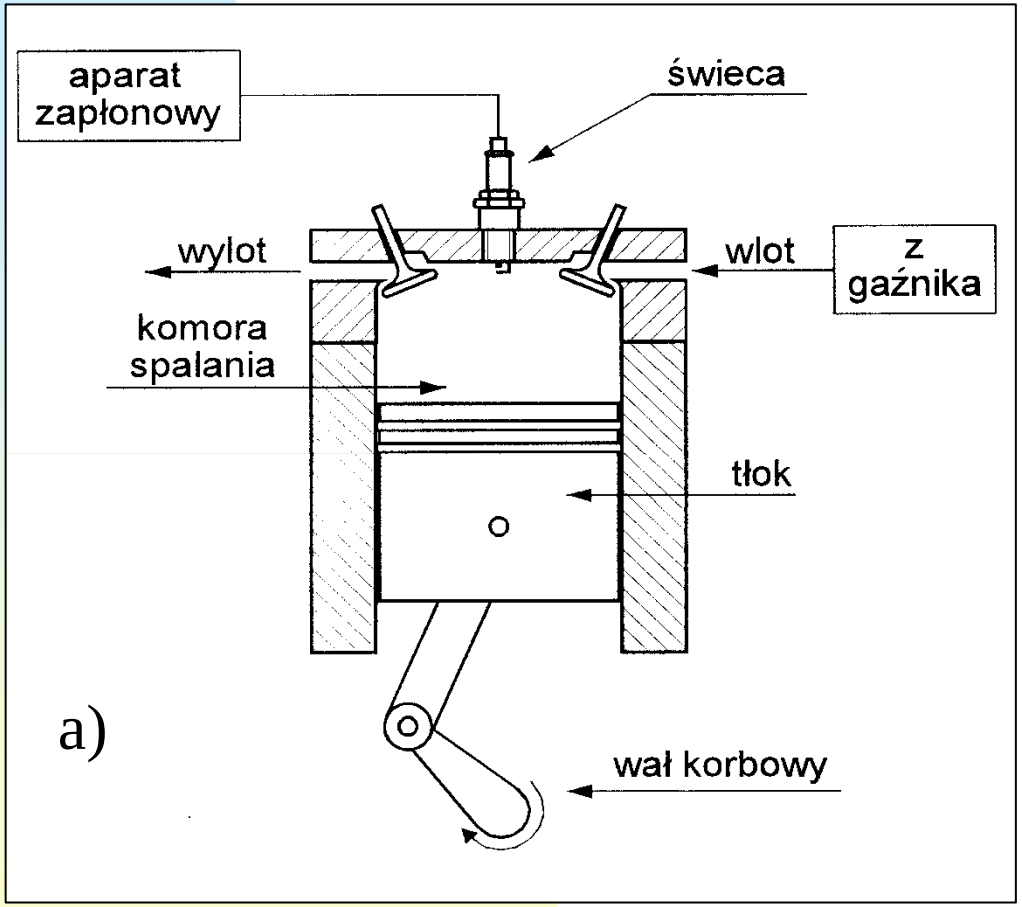
- Otto cycle (spark-ignition - SI engines),
- Diesel cycle (auto-ignition - Diesel engines).

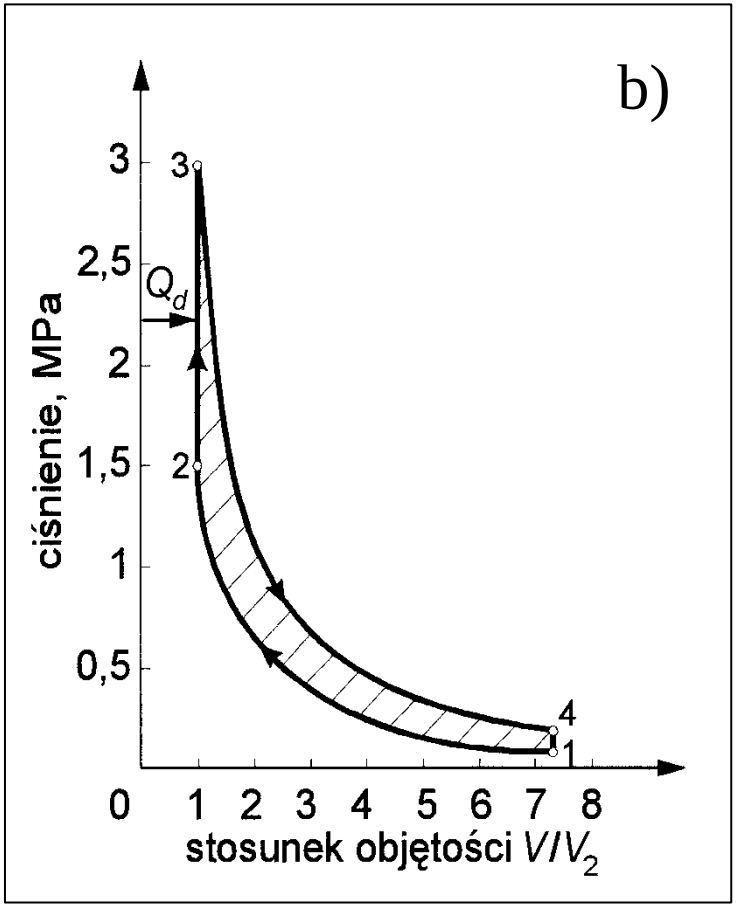
Depending on the design:

- two-stroke cycle,
- four-stroke cycle.

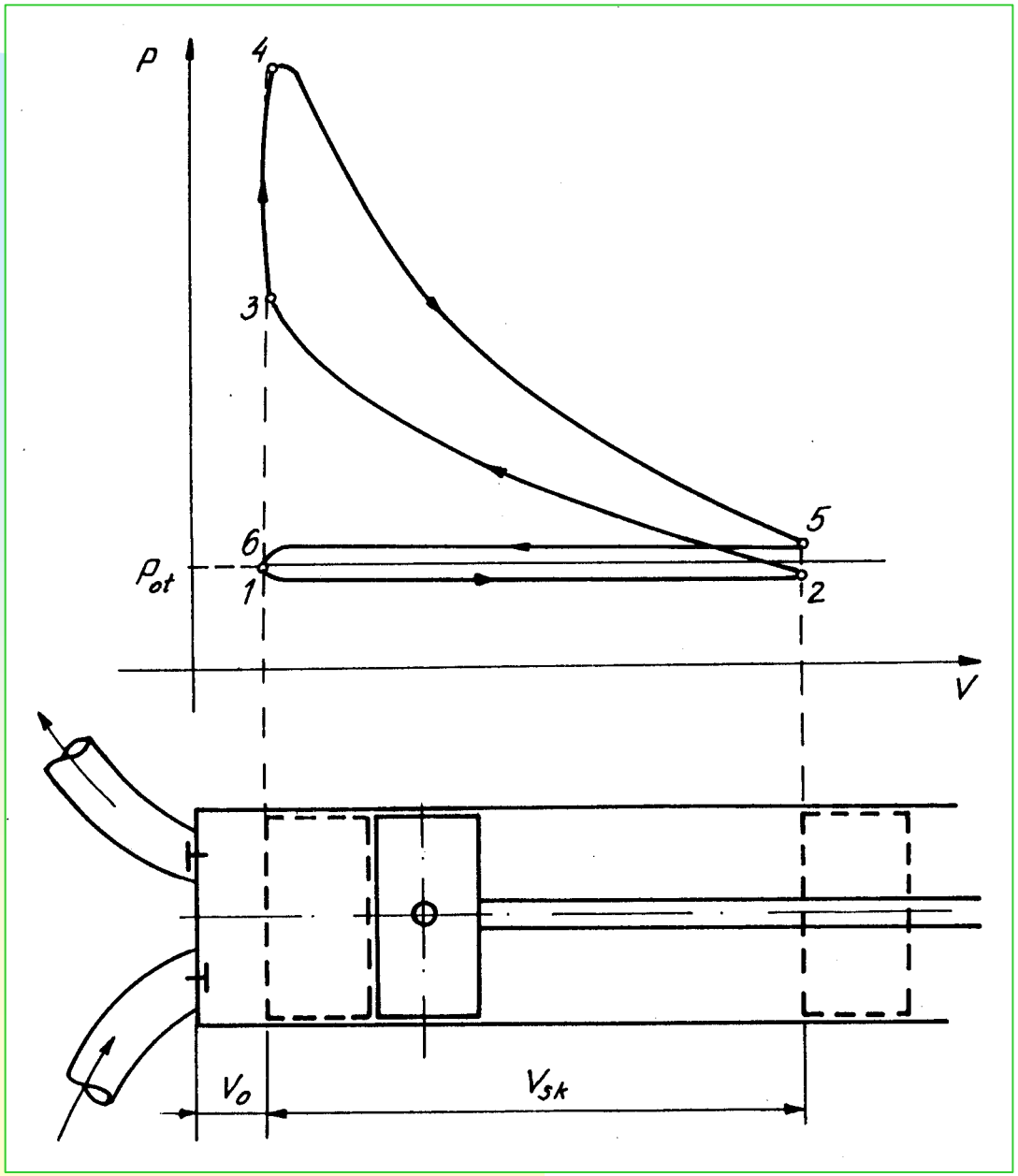
SI ENGINES

Four- stroke SI engine





4 stroke piston SI engine:
a) engine scheme, b) Otto cycle



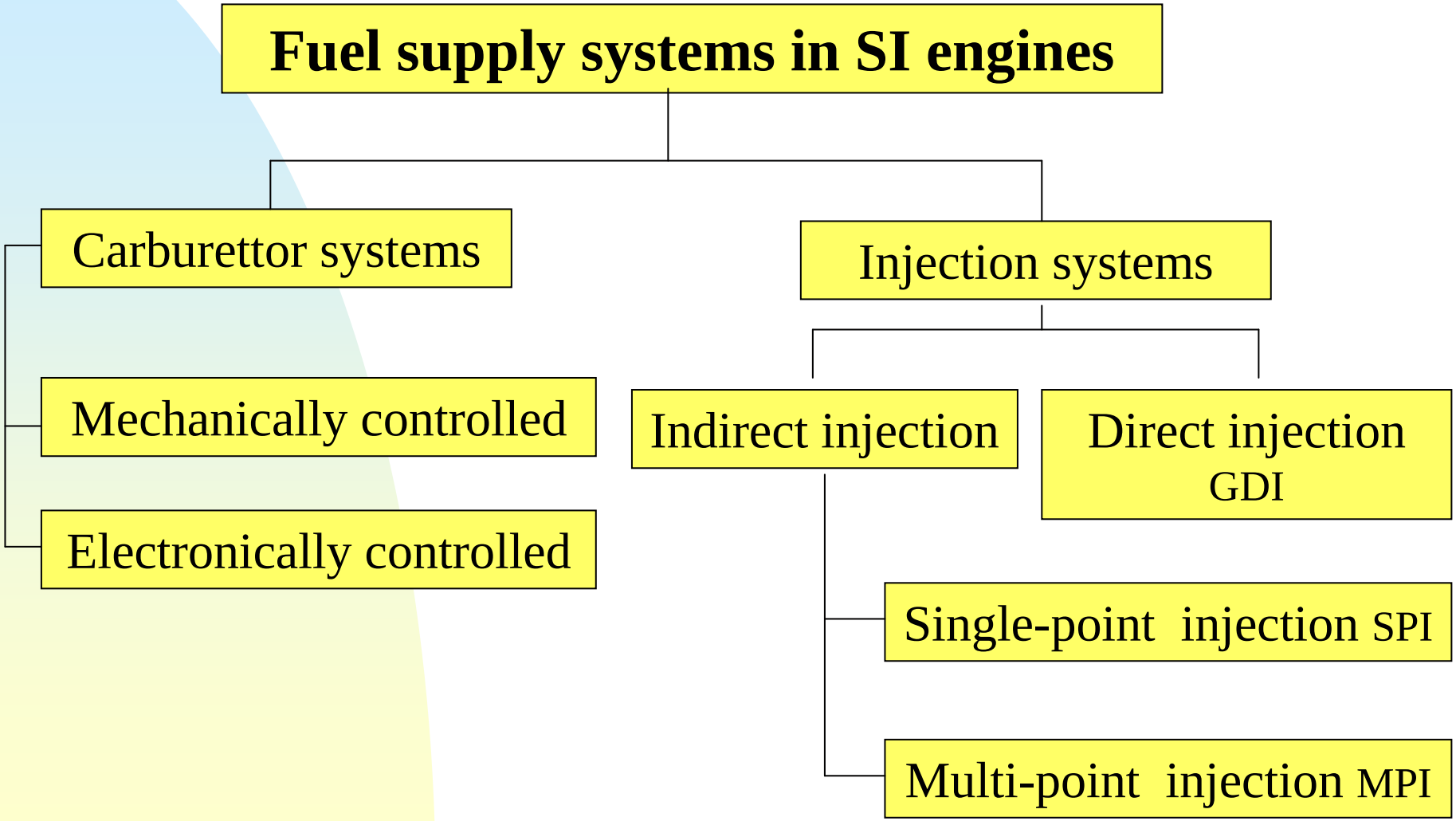
Otto cycle in real 4 - stroke SI engine

FUEL SUPPLY SYSTEMS
of
SI ENGINES

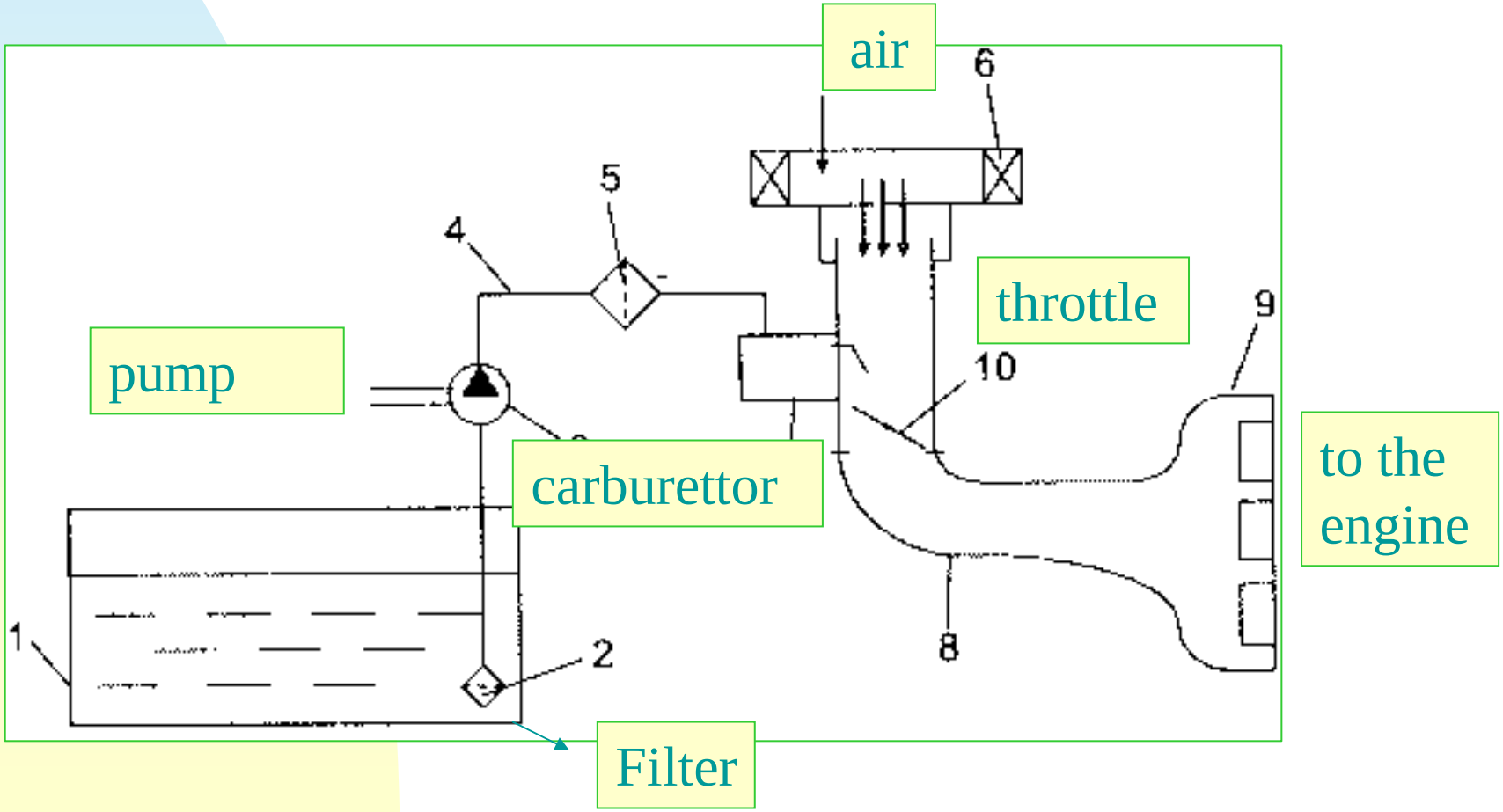
FUEL SUPPLY SYSTEMS IN SI ENGINES

- Carburettor systems
- Injection systems

Fuel supply systems in SI engines

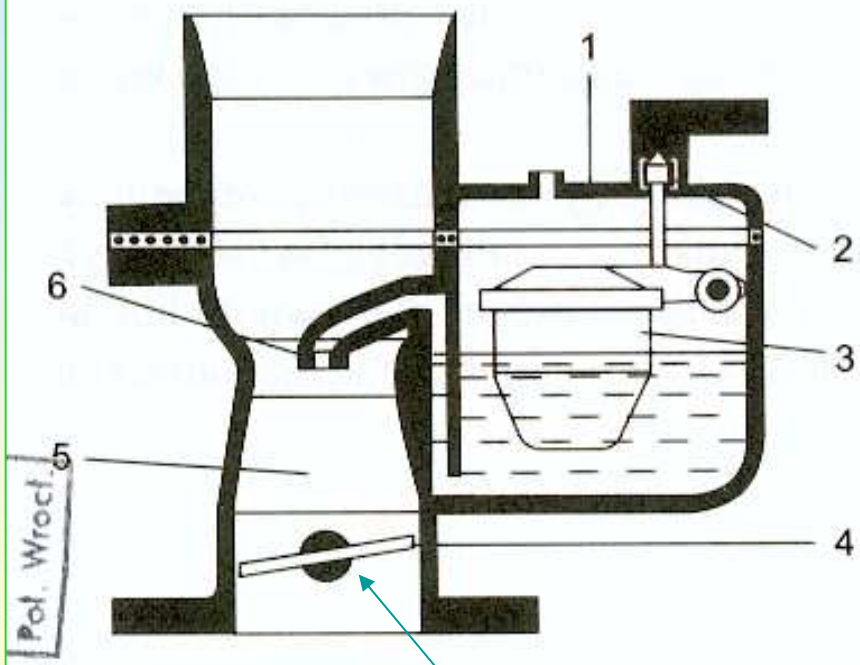


Carburettor Fuel Supply System



Carburettor

carburettor



Float chamber

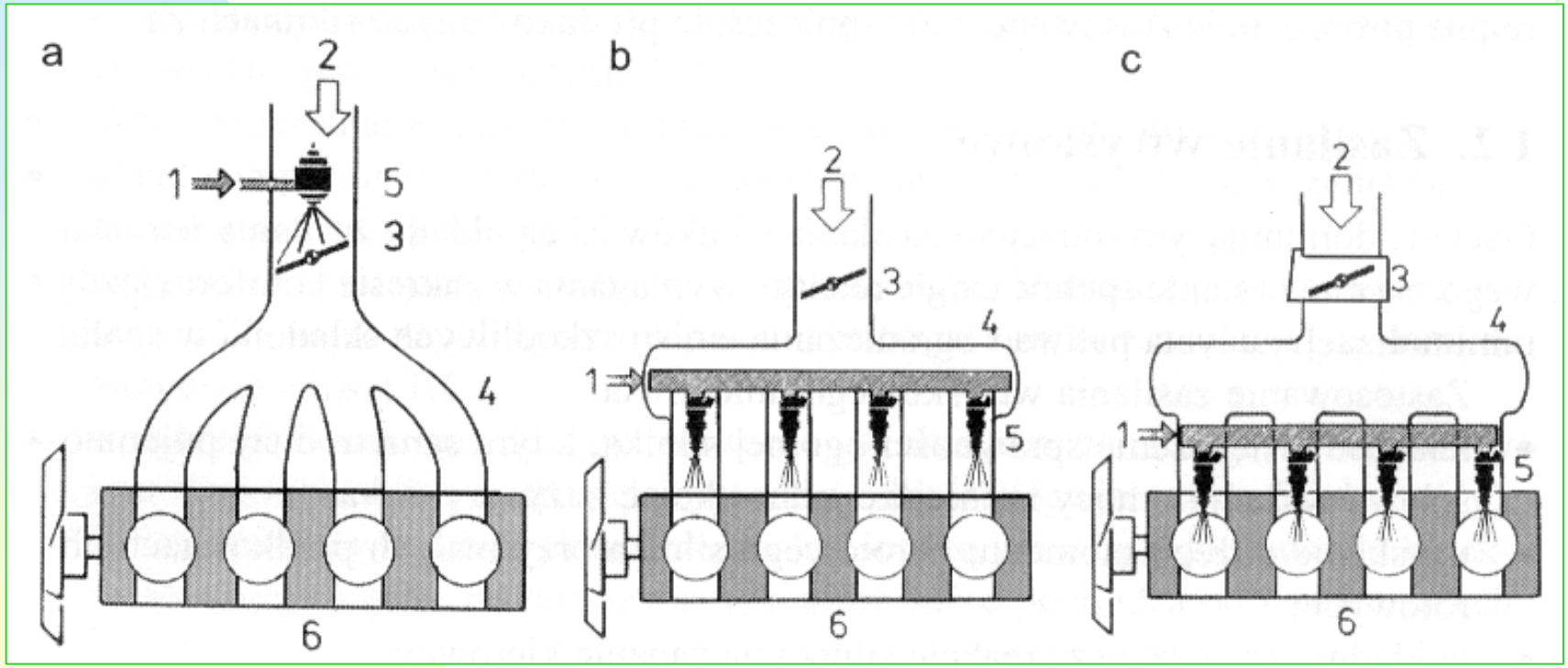
Rys. 1.3. Schemat gaźnika elementarnego
1 – komora pływakowa, 2 – zawór odcinający sprzężony z pływakiem, 3 – pływak, 4 – przepustnica, 5 – gardziel, 6 – rozpylacz

throttle

Injection fuel supply systems of SI engines

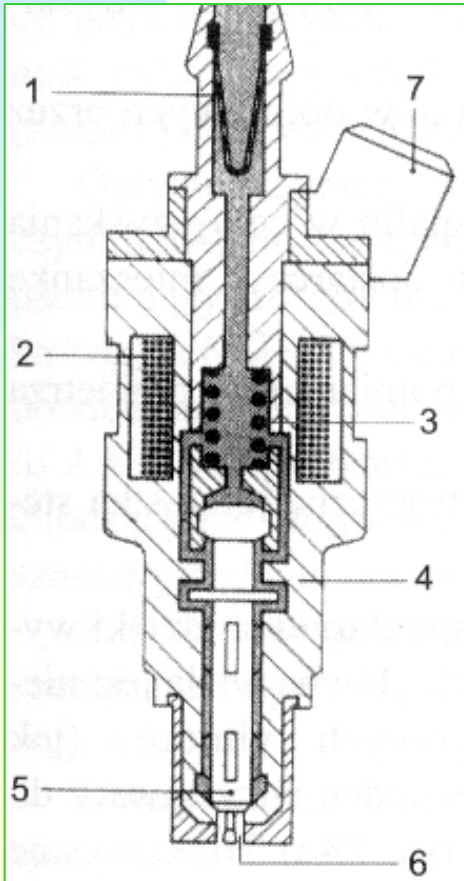
- SPI - *single-point injection* system (to the carburettor) .
- MPI – *multi-point injection* system (to the inlet channel),
- DI *direct injection* system

Types of injection systems



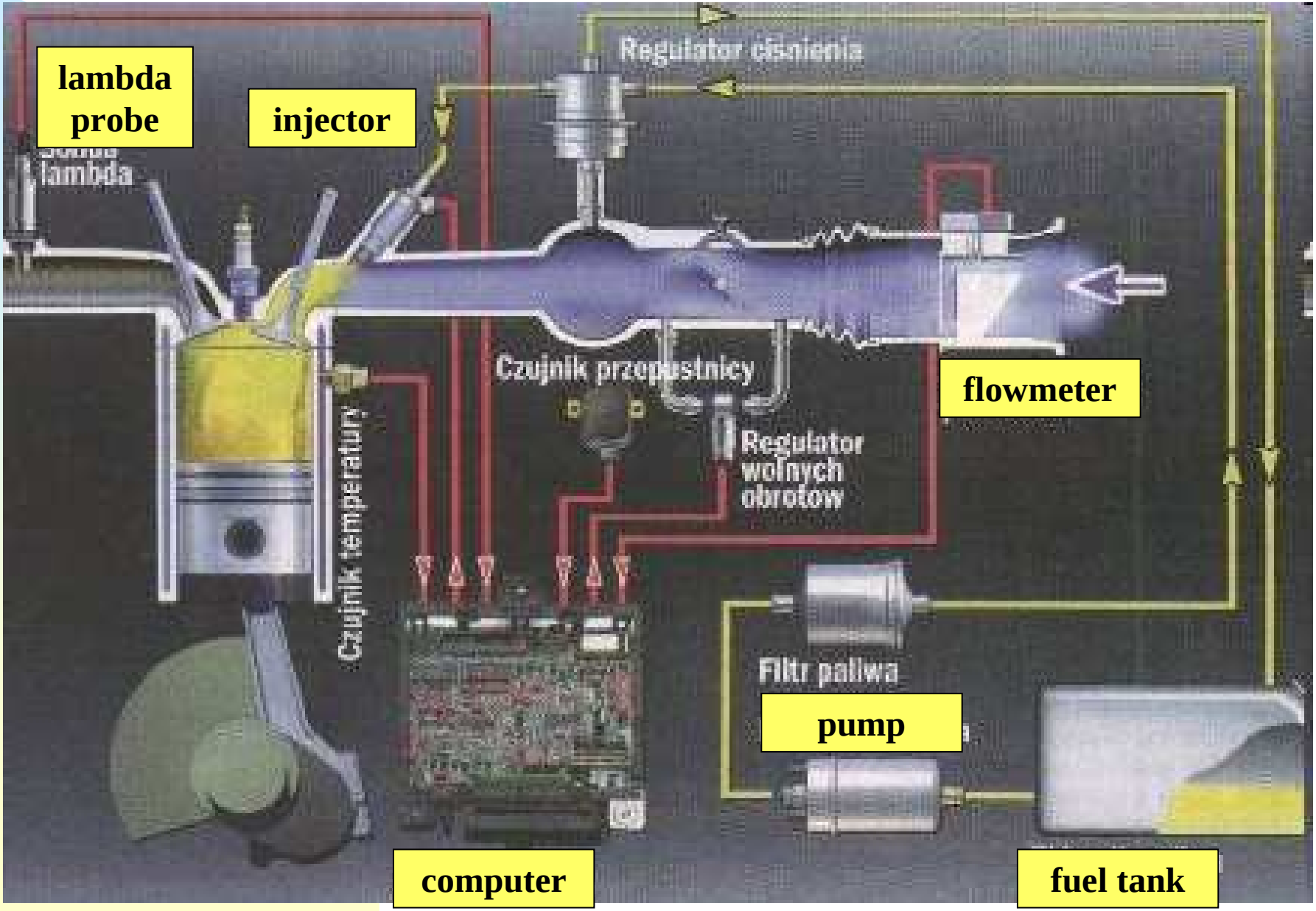
a) single-point, b) multi-point, c) direct injection

Fuel injector

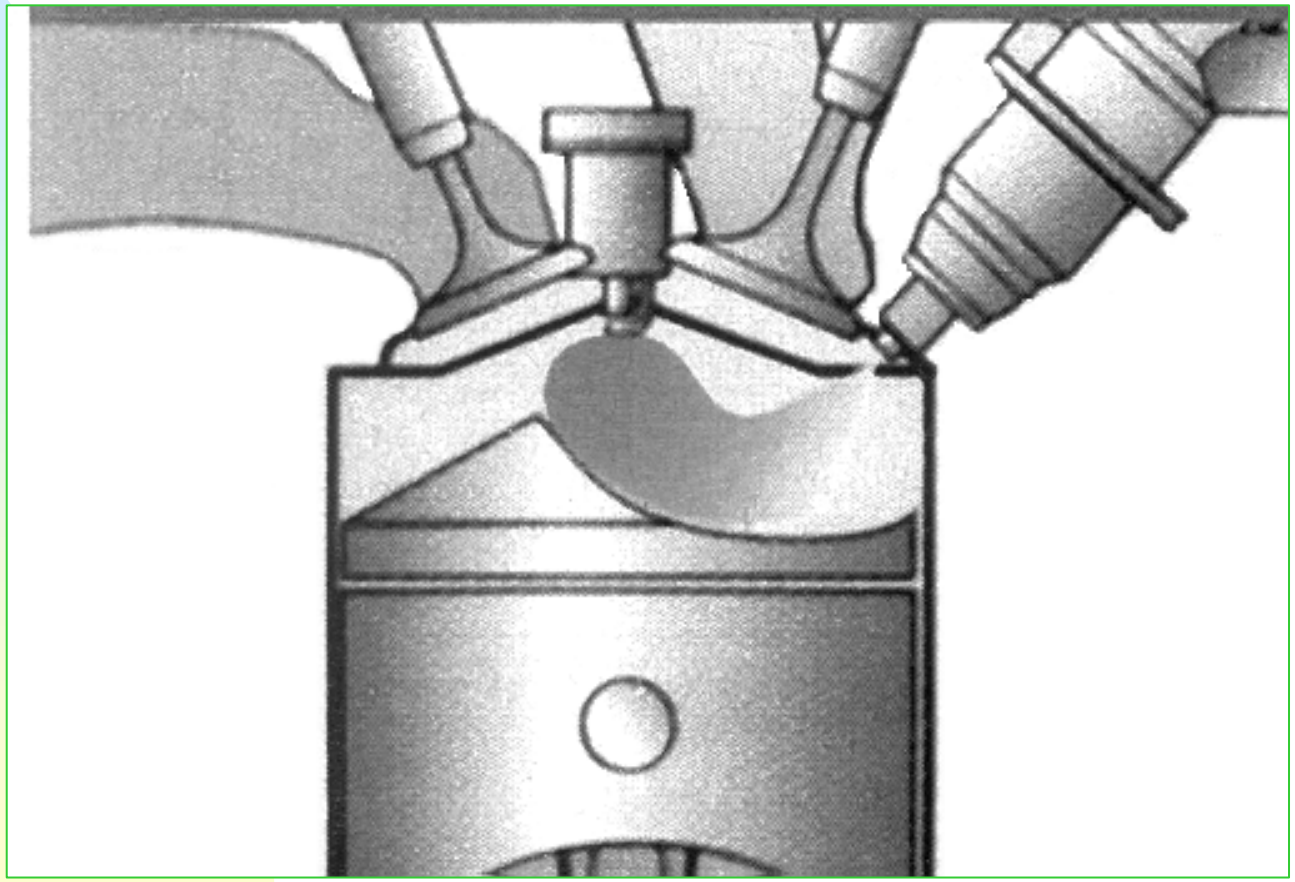


Rys. 1.7. Schemat budowy wtryskiwacza paliwa
1 – wlot paliwa z filtrem, 2 – uzwojenie elektromagnesu, 3 – sprężyna dociskowa, 4 – obudowa, 5 – iglica rozpylacza, 6 – otworek rozpylacza, 7 – złącze elektryczne

Scheme of fuel injection system

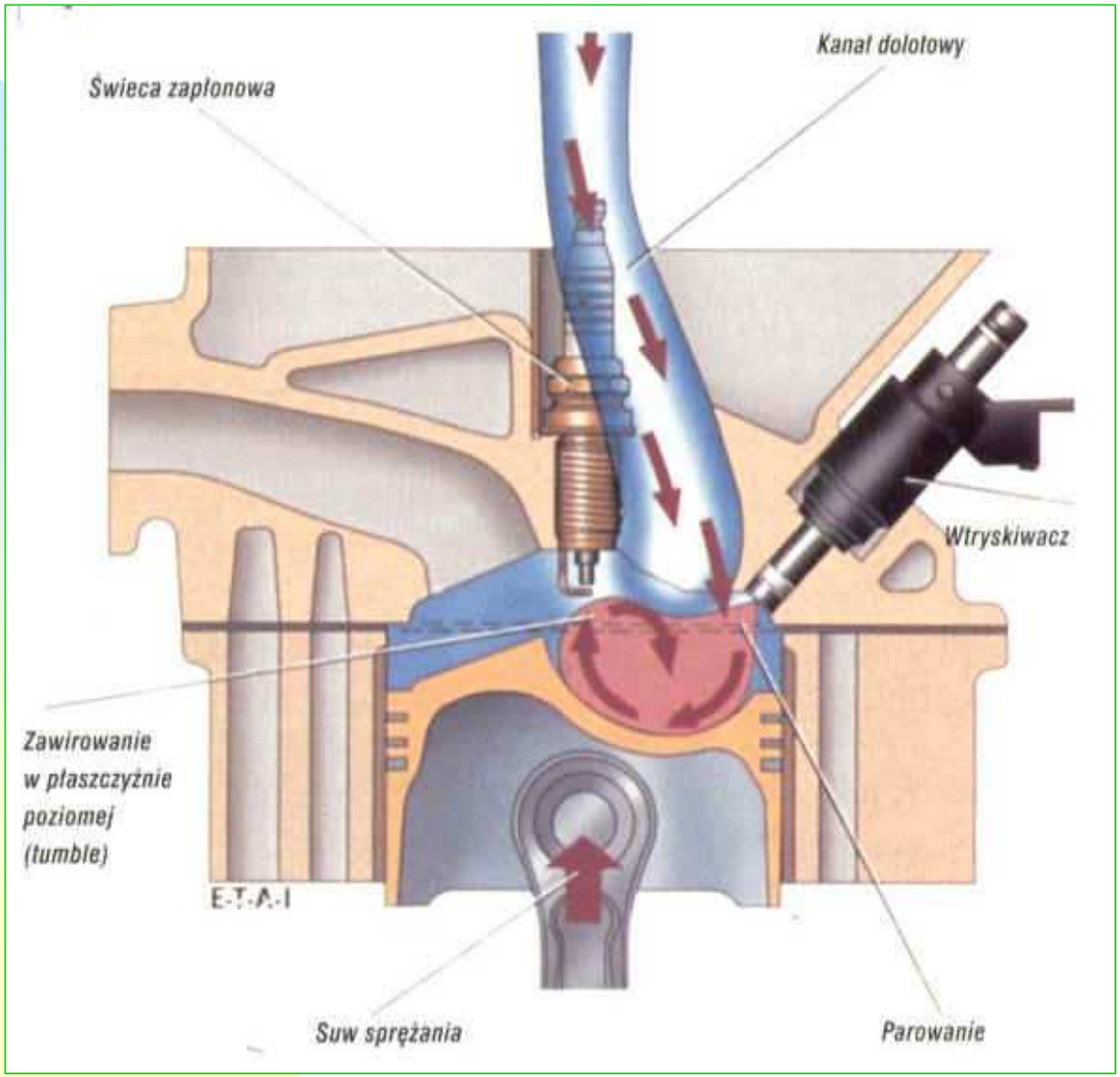


GDI system



Stratified Gasoline Direct Injection (GDI)

Gasoline Direct Injection



FSI
Fuel
Stratified
Injection

SPARK IGNITION

Ignition of the mixture in SI engines

WHEN THE MIXTURE COULD BE IGNITED:

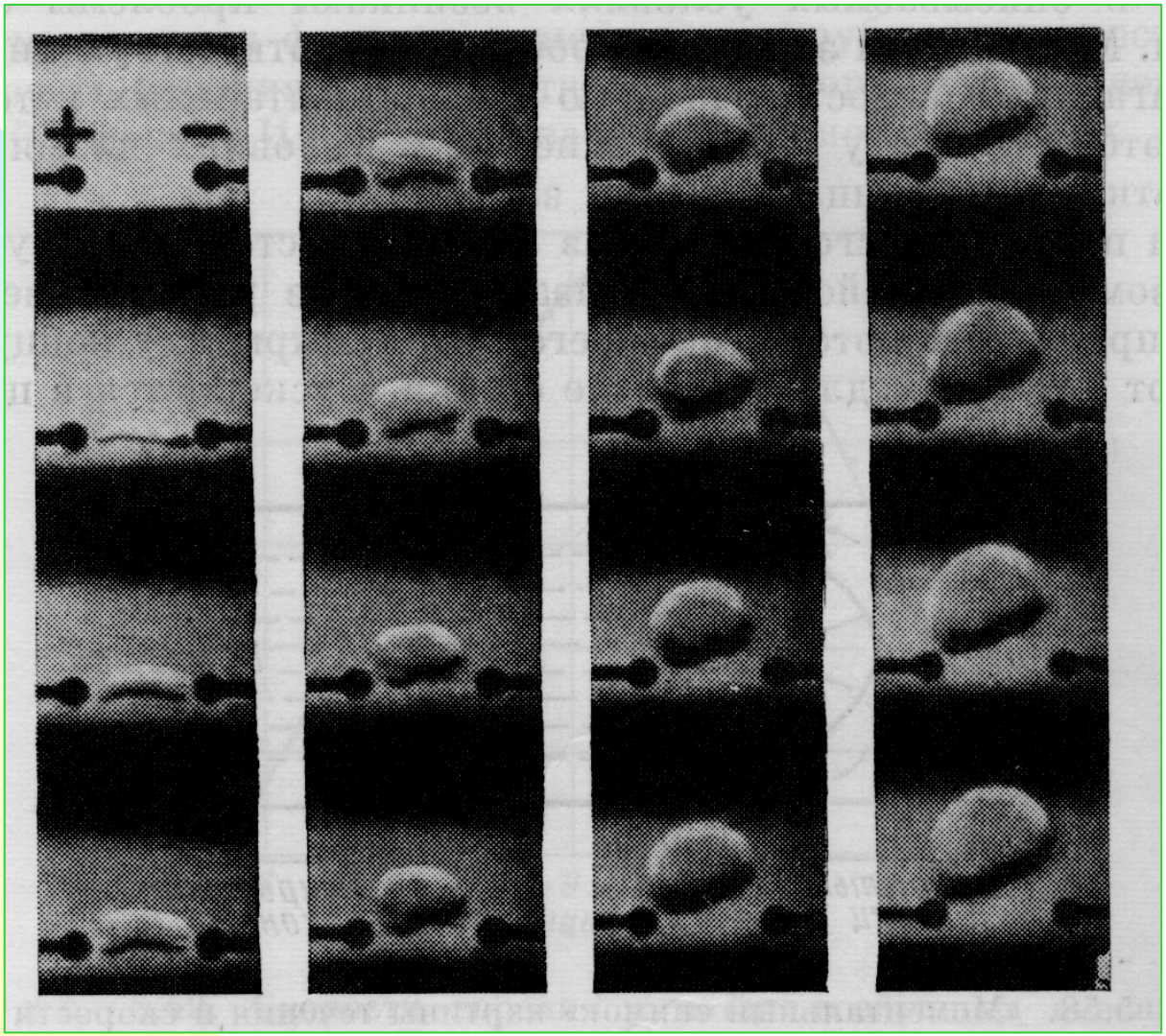
a) spark energy must be higher than the minimum energy of ignition of the mixture,

b) distance between electrodes is larger than the extinguishing distance for a given mixture,

c) local gradient of velocity is smaller than the critical for a given mixture.

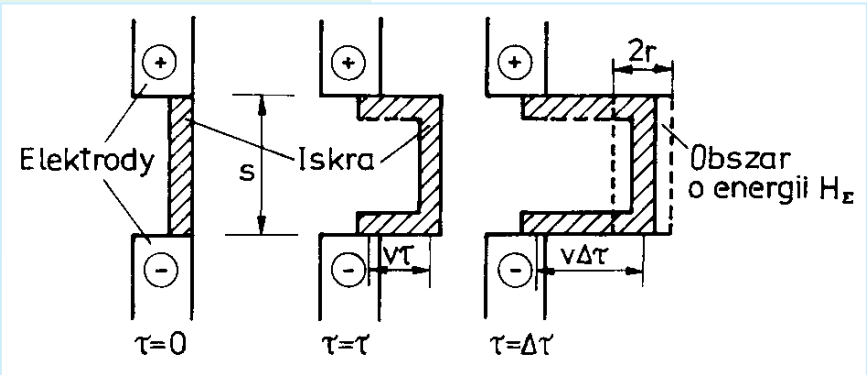
Comment: in the cylinder the mixture is moving, which makes ignition difficult.

Spark ignition of the mixture

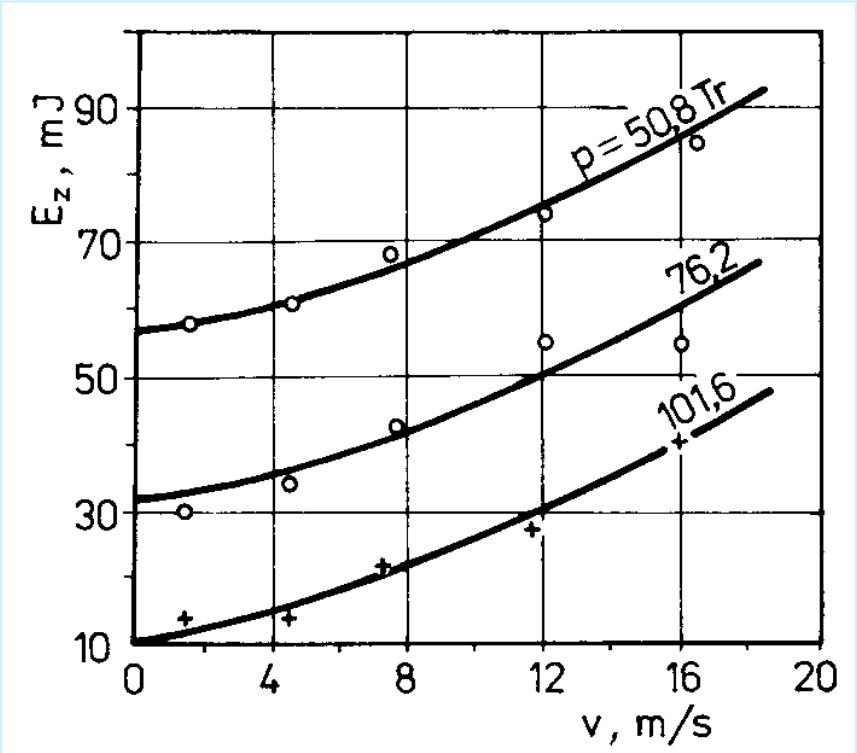


Effect of velocity on spark ignition

Remark: when the mixture is moving ignition is more difficult



Model of spark ignition in flow.



Effect of velocity

Improvement of spark ignition effectiveness

1. Energy of spark generated by spark-plug is in the range of : 50-100 mJ. This is enough for ignition of stoichiometric mixture, but it could be not enough for the lean mixtures.

2. To improve the effectiveness of spark ignition of lean mixtures a few modifications of SI engines ignition systems have been proposed:

   - 2- spark-plug systems (twin-spark),
   - increase of ignition energy by:
     - increase of spark energy,
     - plasma ignition,
     - laser ignition
   - Increase the distance between electrodes.

COMBUSTION IN SI ENGINES

Conditions of combustion in SI engines

The angular speed in SI engines is in the range of 500-5000 min^{-1}, so the whole cycle is 10-100 ms. During this time the mixture must be ignited, burnt and reburnt.

Laminar flame is too slow, however the mixture in the cylinder is turbulized and flame is turbulent, which makes the rate of combustion very high.

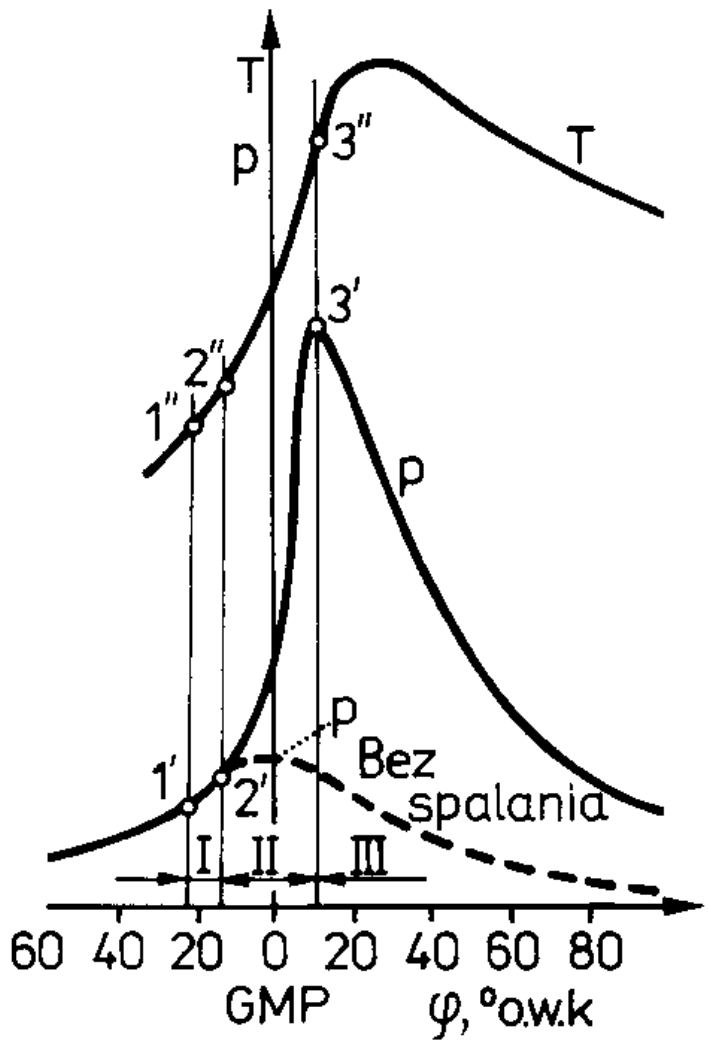
In the process of combustion in SI can be divided into three phases :

a) **ignition,**

b) **combustion,**

c) **reburning**.

Phases of combustion in SI engines



Changes of the pressure in the cylinder of SI engine

Phases of combustion:

I – ignition,

II – combustion,

III – reburning.

1 – ignition, 2 – start of combustion, 3 –maximum of pressure (end of combustion)

Optimisation of combustion in SI engines

There is a dominating tendency to burn lean mixtures ($\lambda >> 1$), because it improves efficiency of the engine and reduces pollutant emission.

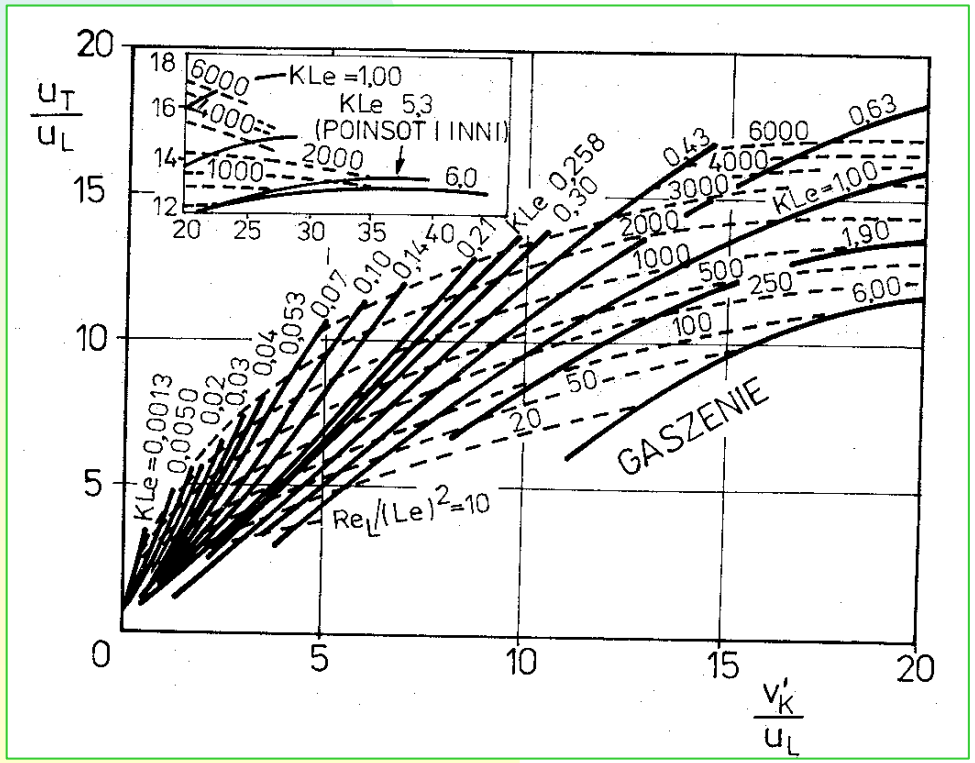
Combustion of lean mixtures in SI engines causes some problems:

a) Speed of laminar flame propagation is lower,

b) Ignition is more difficult.

Intensification of combustion in SI engines

Enhancement of rate of burning is done by turbulization of charge at the inlet valve of the cylinder. Rate of turbulent combustion is approximately proportional to the intensity of turbulence.



Restriction: too intensive turbulence can extinguish flame, due to the phenomenon of flame stretching (K>1).

Air stoichiometry in SI engines

AFR (Air to Fuel Ratio)

$$\mathbf{AFR = m_{pow}/m_{pal}}$$

for gasoline

$$\mathbf{AFR = 14{,}7}$$

AFR	Content
14,7	Stoichiometric
> 14,7	Lean (λ = 1)
> 14,7	Rich(λ = 1)

Charge preparation

Type of combustible charge

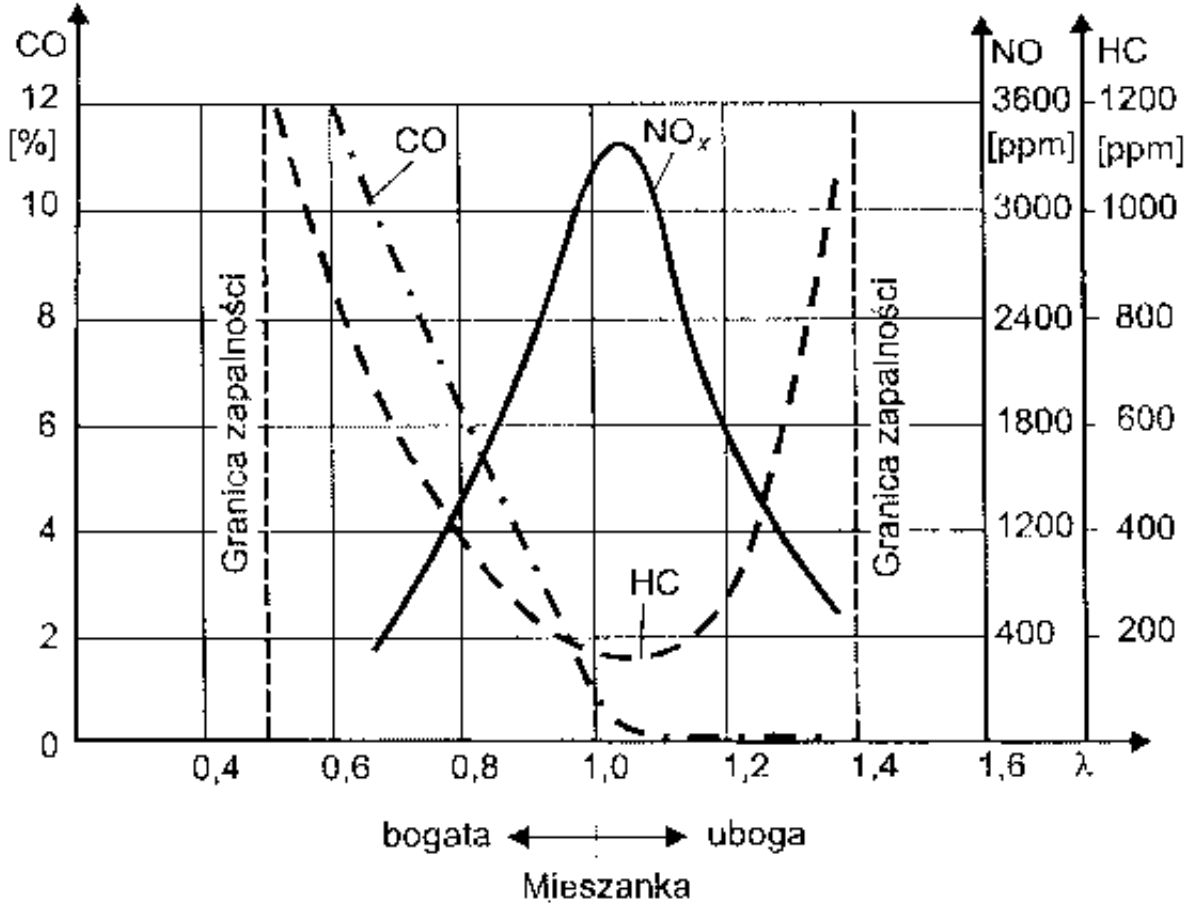
- Uniform charge (homogeneous)
- Heterogeneous charge (two-phase)
- Stratified charge

Content	Stoichiometry coefficient, λ
Homogeneous normal Homogeneous lean	0,85 –1,2 1,4 – 1,6
Stratified	< 3

Pollutant emission from SI engines

Flue gas			
Non-toxic compounds		Toxic compounds	
Water	H_2O	Carbon monoxide	CO
Carbon dioxide	CO_2	Hydrocarbons	HC
Nitrogen	N_2	Nitrogen oxides	NO_x
Hydrogen	H_2	Aldehydes	CHO
Noble gases		Solids	PM
		Others	SO_x, Pb

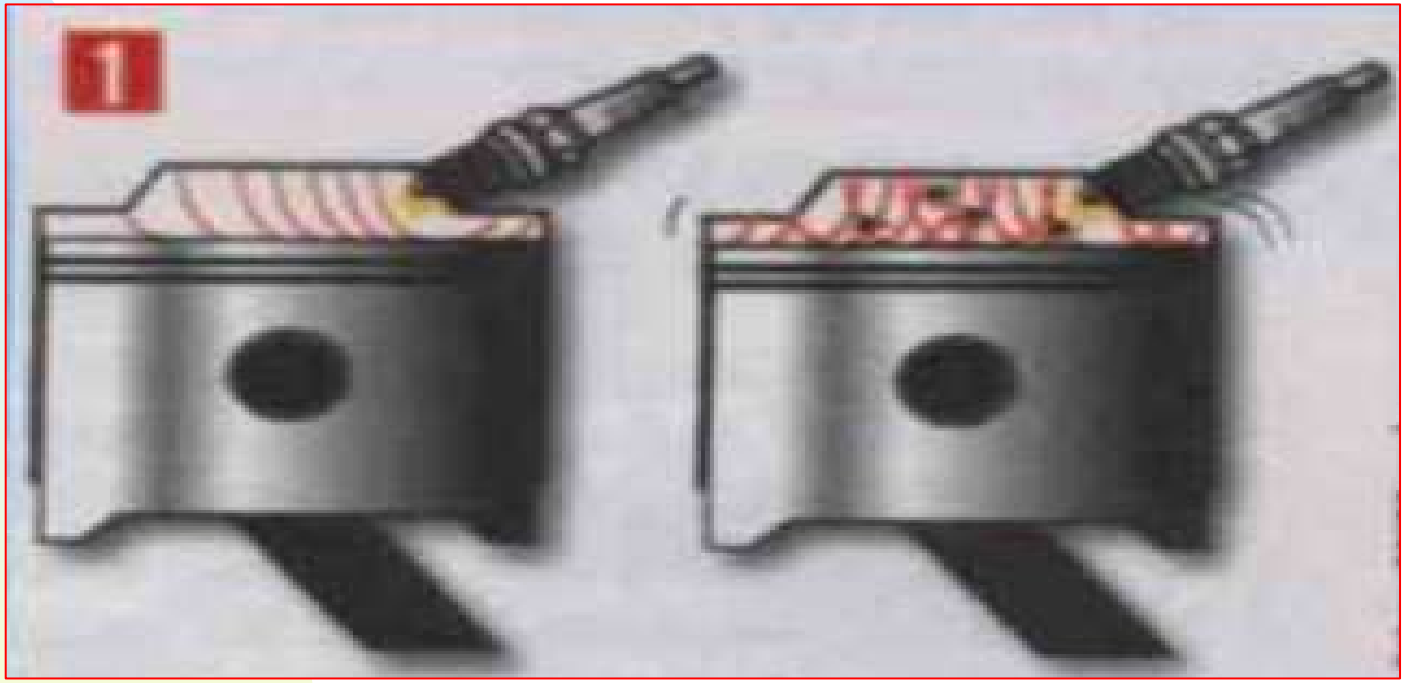
Effect of stoichiometry on pollutant emission



Rys. 2.2. Wpływ współczynnika nadmiaru powietrza λ na stężenie głównych składników toksycznych w spalinach silnika ZI

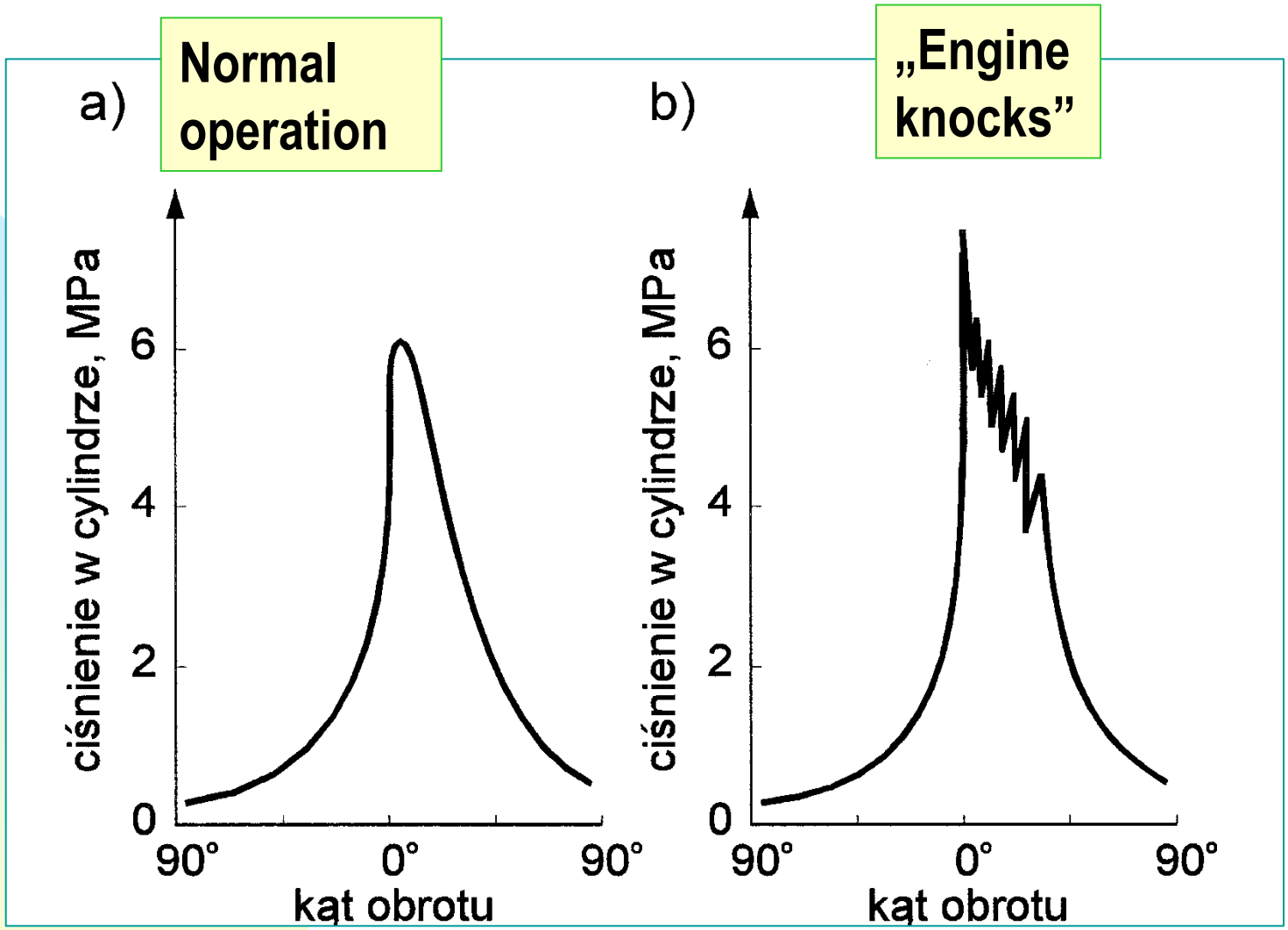
„ENGINE KNOCK" AND FUELS

„Engine knocks”



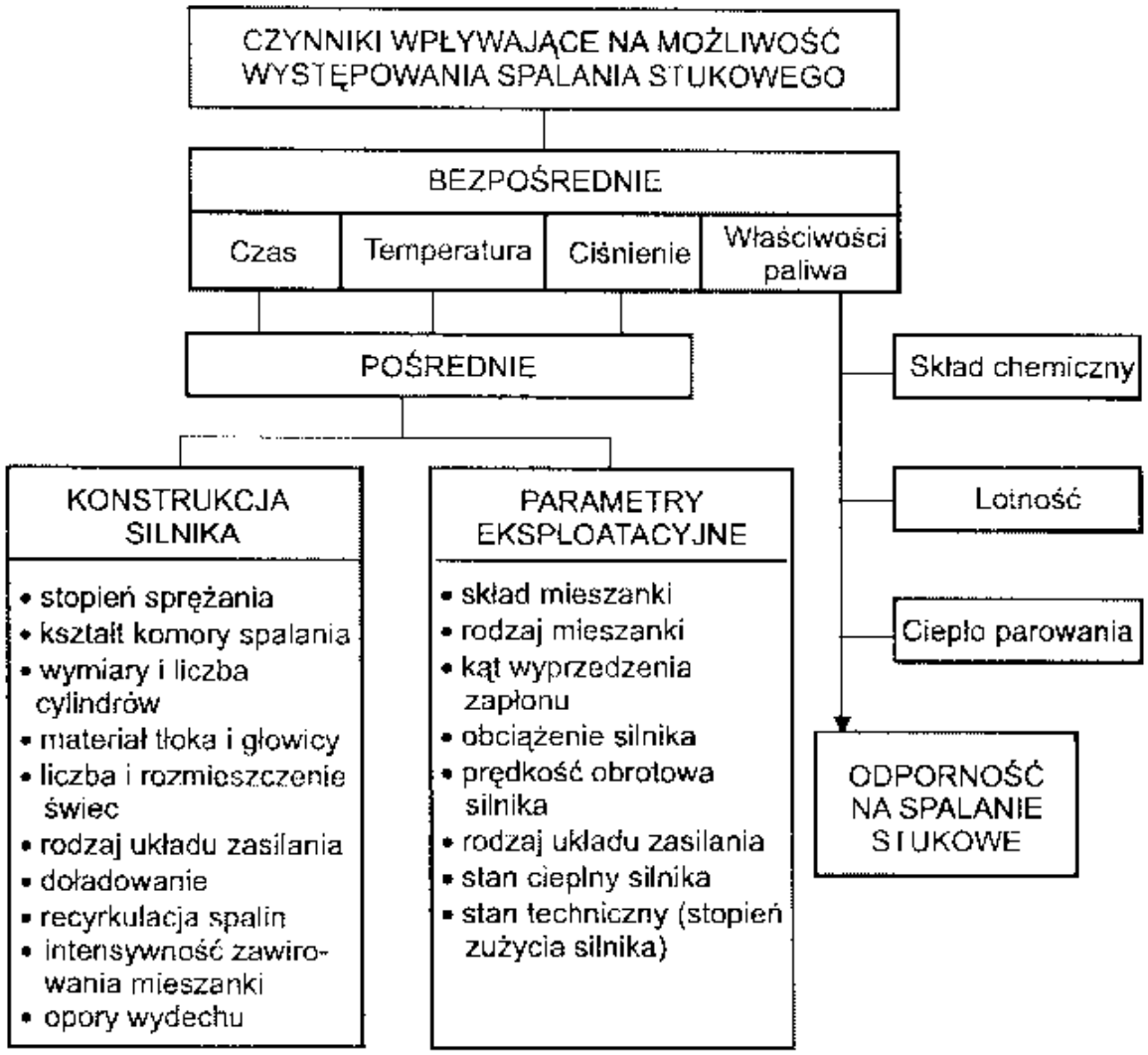
Normal operation

„Engine knocks”



History of pressure in the cylinder for: a) normal operation, b) „engine knocks”

Major factors influencing „engine knocks”



Rys. 2.4. Podział i rodzaje czynników wpływających na spalanie stukowe w silnikach ZI

Anti-knocks additives

- ethyl tetrachloride (TEO) $Pb(C_2H_5)_4$
- Ethyl alcohol (ethanol)
- Methyl alcohol (methanol)
- *Tetra*-butyl alcohol (TBA)
- Ester methyl-*tetra*-butyl (MTBE)
- Ester *tetra*-amyl-methyl (TAME)

SI ENGINE FUELS

Major requirements

- high LCV
- easiness of air-fuel charge preparation,
- small content of incombustible components,
- easy and safe transport.

SI engine fuels

- Convenional (gasoline, gas, petrol)
- Non-conventional fuels

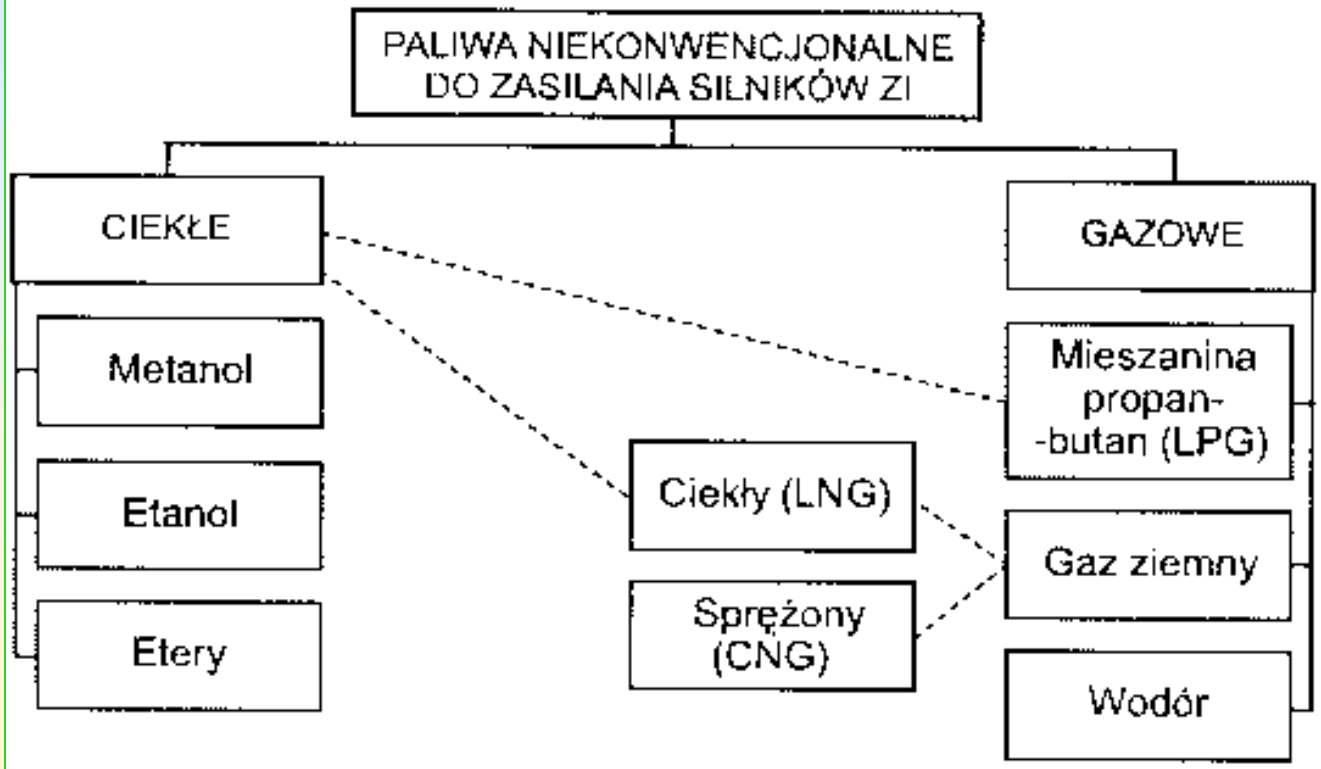
SI fuels – petrol

Gasoline is basic SI engine fuel. It is a mixture of hydrocarbons of the boiling temperature in the range of 30-200 ^{o}C.

Gasoline is obtained by distillation of crude oil or synthesised from coal, natural gas and from oil shale or oil sand.

In order to increase octane No. in the required range gasoline is blended by anti-knocks additives: 4-ethyl of lead $(C_2H_6)_4Pb$ (leaded gasoline) or some organic compounds (un-leaded gasoline).

Non-conventional SI engine fuels



Rys. 6.1. Podział paliw niekonwencjonalnych do silników ZI