COMBUSTION OF GASEOUS FUELS

COMBUSTIBLE MIXTURE

Definition:

a mixture of fuel and oxidizer is combustible when combustion is developing in it after an ignition source vanishes.

TYPES OF COMBUSTIBLE MIXTURES

COMBUSTIBLE MIXTURES		
Rich	Stoichiometric	Lean (Weak)
$\lambda < 1$	$\lambda = 1$	$\lambda > 1$

FLAMMABILITY LIMITS

FLAMMABILITY LIMITS: DEFINITION

Flame can occur only in mixture within a certain composition range: flammability limits.

Flammability limits refer to the composition range within which ignition and flame propagation can be brought by external ignition (e.g. by spark).

LEAN AND RICH FLAMMABILITY LIMITS

LFL – minimum percentage of fuel by volume in the mixture

RFL – maximum percentage of fuel by volume in the mixture

(for solid fuels could be expressed in g/m^3)

EXPLOSION LIMIT

Explosion limits mean the same as flammability limits:

LEL - lower explosion limit means the same as lean flammability limit.

UEL – upper explosion limit means the same as rich flammability limit.

FLAMMABILITY LIMITS - examples

Gas	Flammability limits			
	% in air		% in oxygen	
	LEL	UEL	LEL	UEL
Hydrogen	4.1	74.2	4.0	94.0
CO	12.5	74.2	15.5	94.0
Methane	5.3	14.0	5.1	61.0
Ethane	3.2	12.5	3.0	66.0
Propane	2.4	9.5	2.3	55.0
Butane	1.9	8.4	1.8	48.0
Acethylene	2.5	80.0	2.5	89.4
Benzene	1.41	6.75	2.6	30.0
Methanol	6.72	36.5	–	–
Ethanol	3.28	18.95	–	–

IGNITION

Definition

Ignition means local initiation of the combustion process in a combustible mixture.

IGNITION PHENOMENA

Two ignition types can be distinguished:

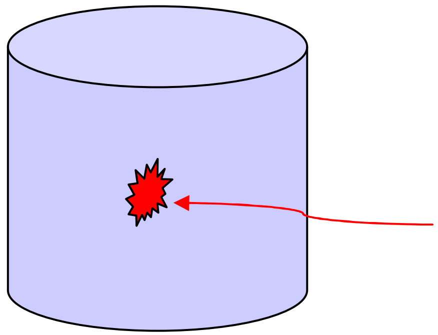
- external ignition (e.g. spark ...),
- selfignition.

MINIMUM ENERGY of IGNITION

Definition

E_{min} - is minimum of energy, which discharged in a combustible mixture causes it's ignition.

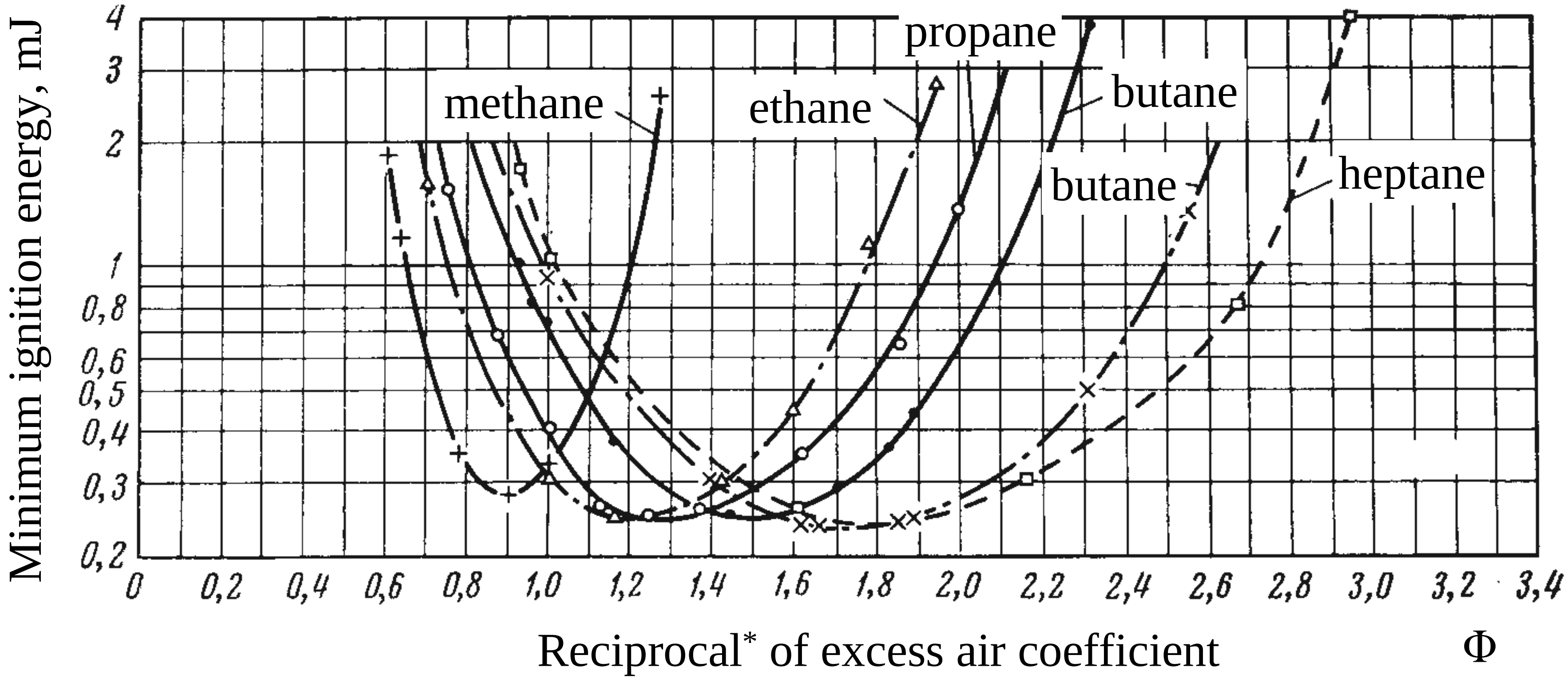
E_{min} - is measured in J.



Standard E_{min} of different fuels:

- gaseous: < 1 mJ
- liquid: 10-100 mJ
- dusts: 0.1-1.0 J

MINIMUM IGNITION ENERGY OF GASES



*odwrotność

The minimum energy of ignition depends on:

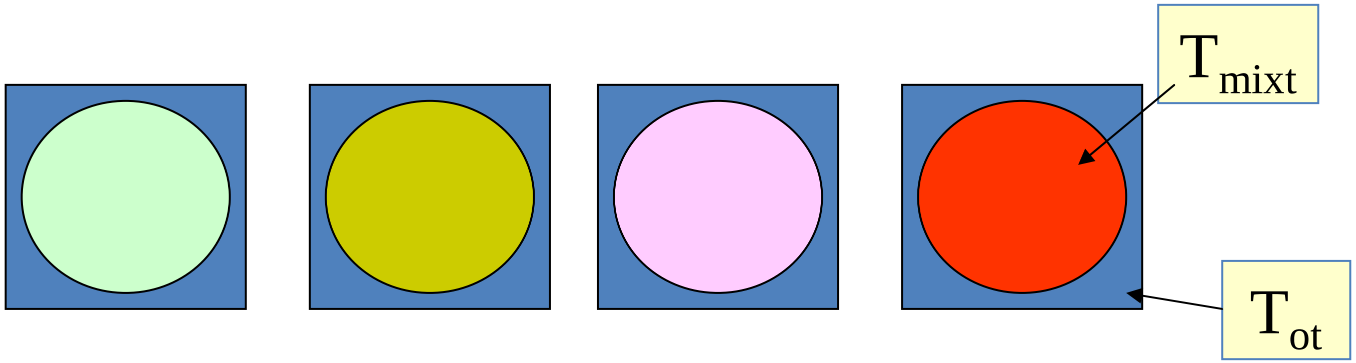
a) type of gas

b) concentration of gas in the mixture.

SELFIGNITION

<u>Definition:</u>

Selfignition is a proces of initiation of combustion in a mixture due to excess of the temperature of the mixture.



PROPAGATION OF COMBUSTION

1. Deflagration
2. Detonation
3. Glow

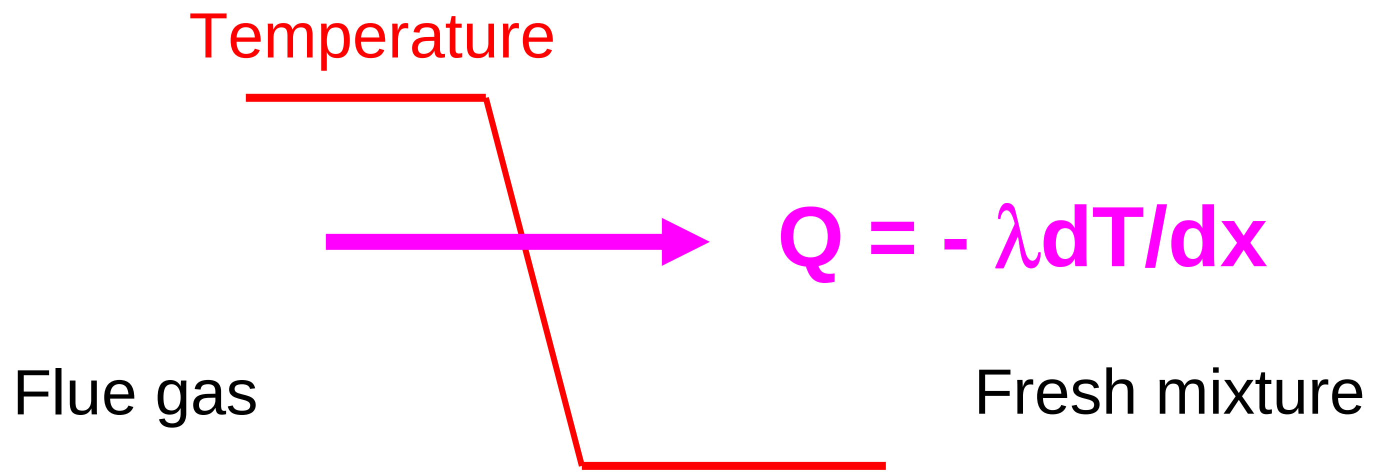
DEFLAGRATION

1. Deflagration is propagation of a combustion process by flame.
2. Mechanism of propagation has thermal character: by heat conduction.

FLAME

Definition:

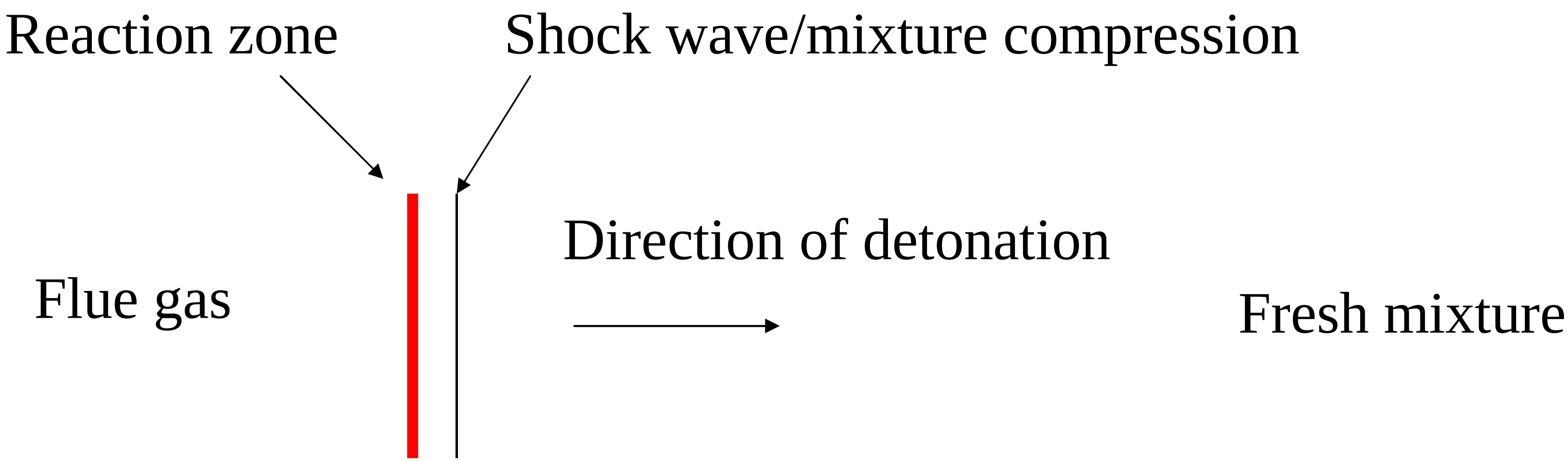
Flame is a wave of exothermic chemical reaction propagating with characteristic velocity, called flame speed u_n.



DETONATION

<u>Definition:</u>

Detonation wave is a wave of combustion preceded by the shock wave.



FLAME STRUCTURE

LAMINAR AND TURBULENT FLAMES

flames

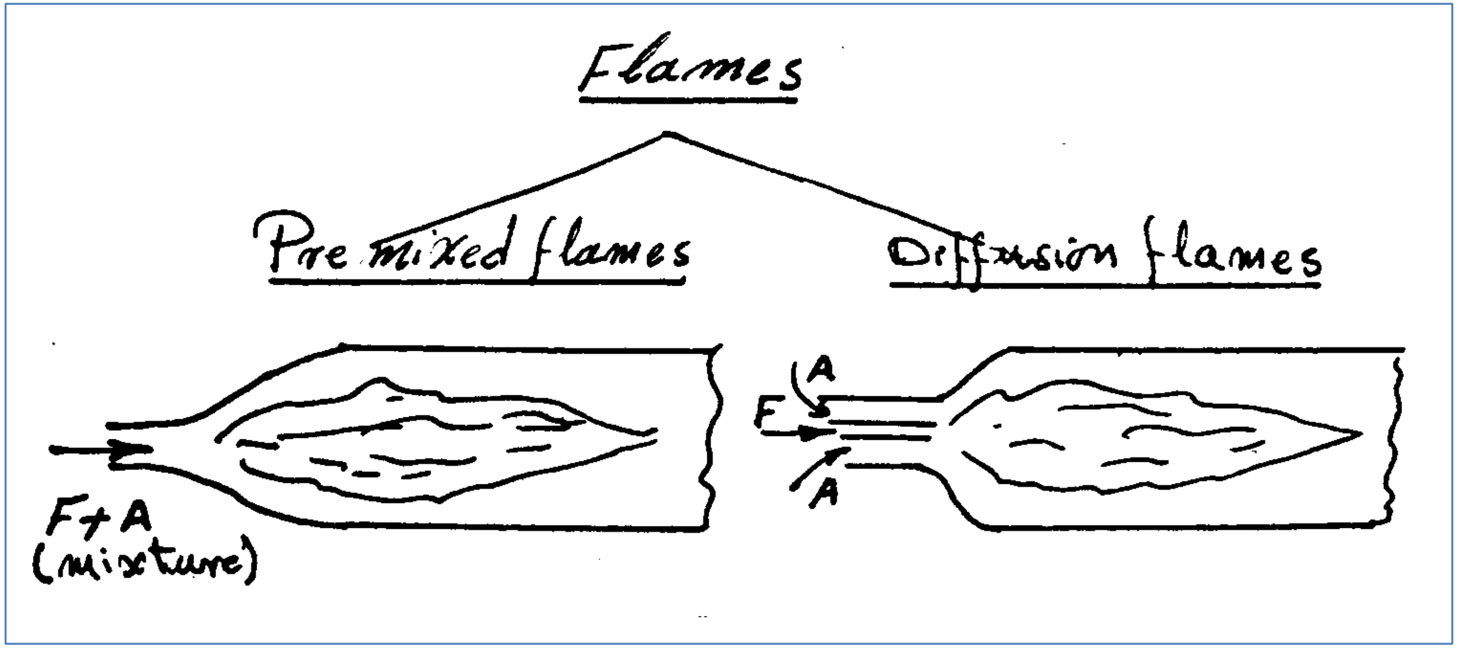
laminar

turbulent

Considering <u>character of flow</u> there are two principal types of flames :

- laminar,
- turbulent.

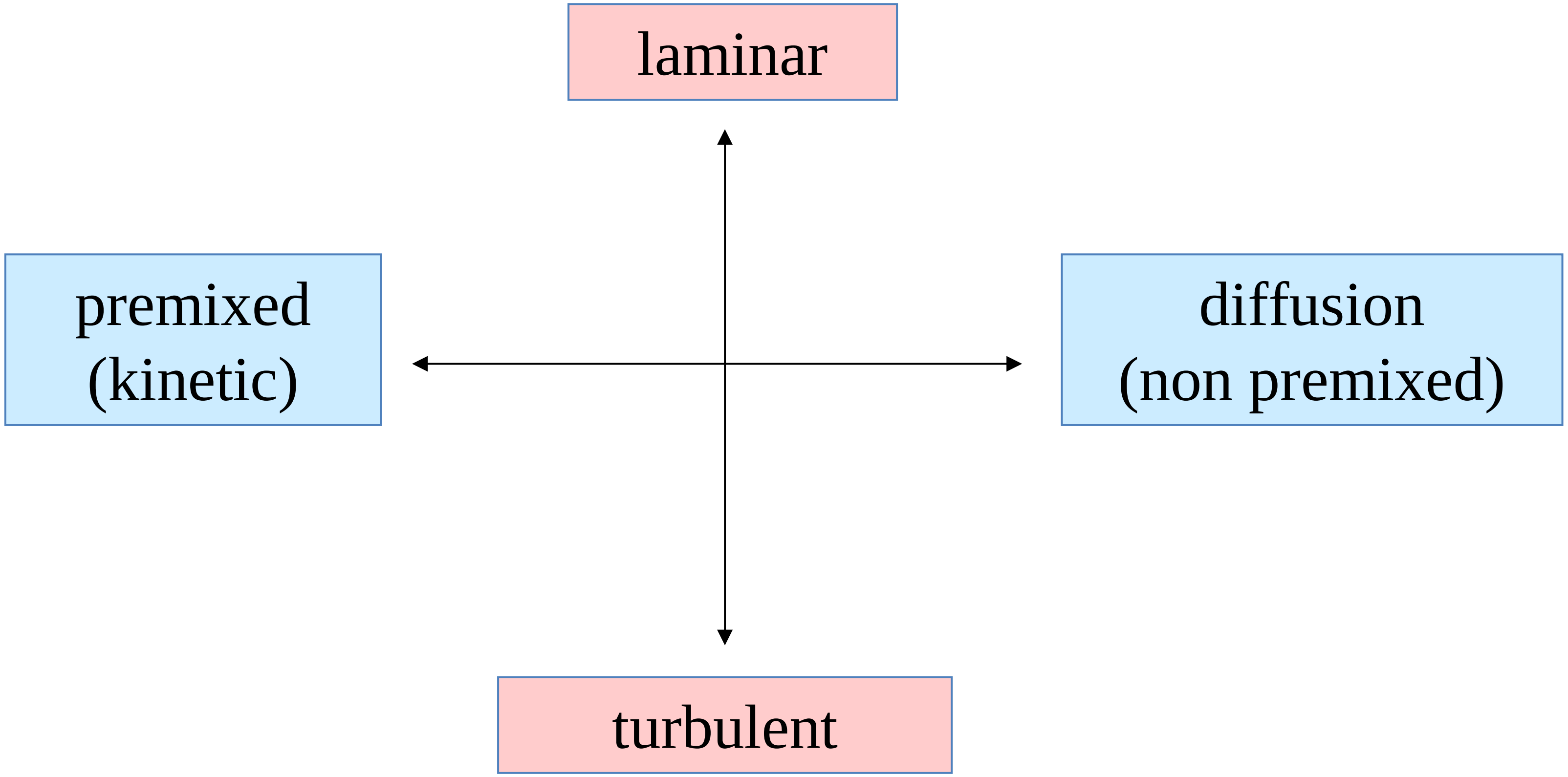
PREMIXED AND DIFFUSION FLAMES



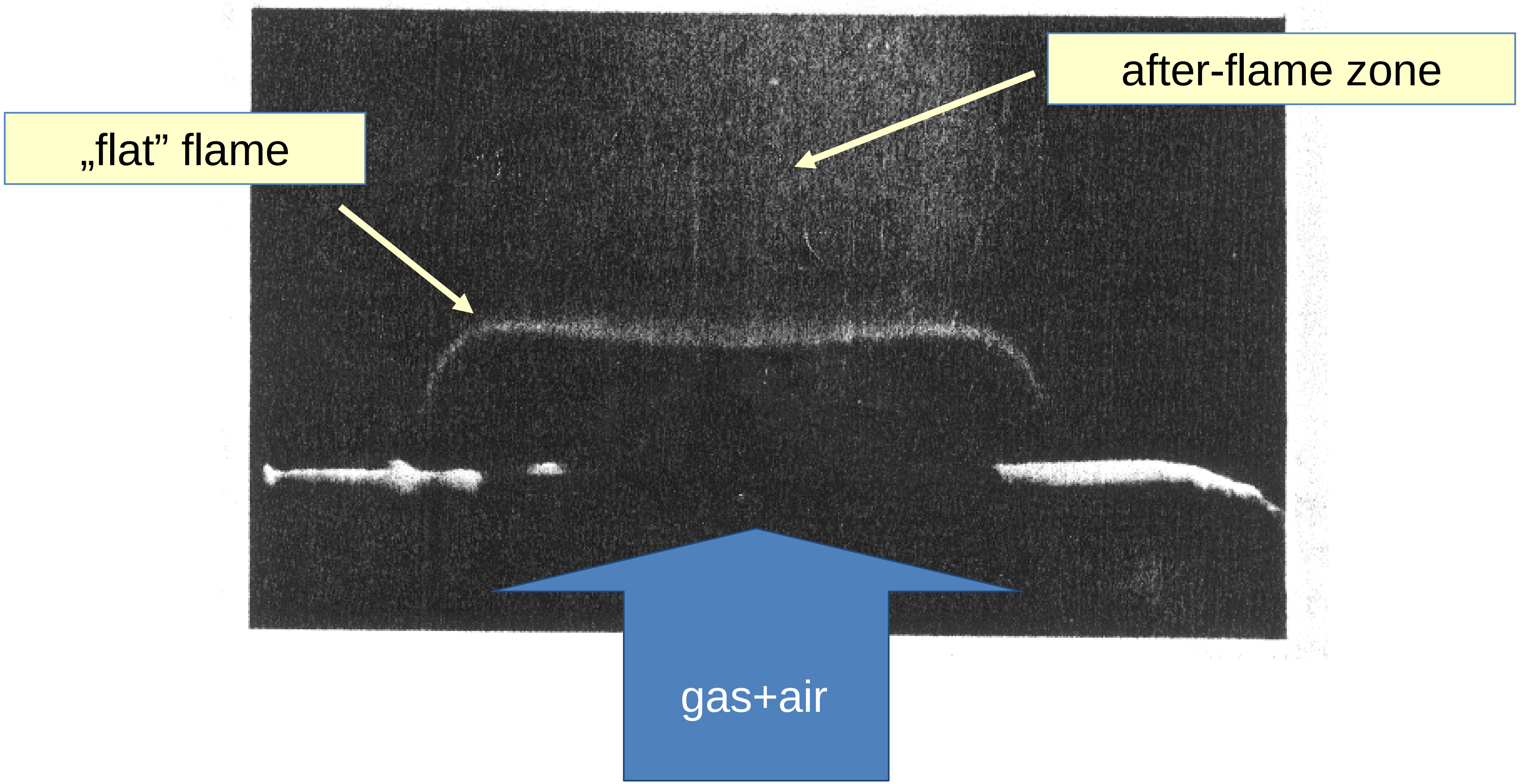
Considering preparation of combustible mixture there are two principal types of flames:

- premixed,
- diffusion flames.

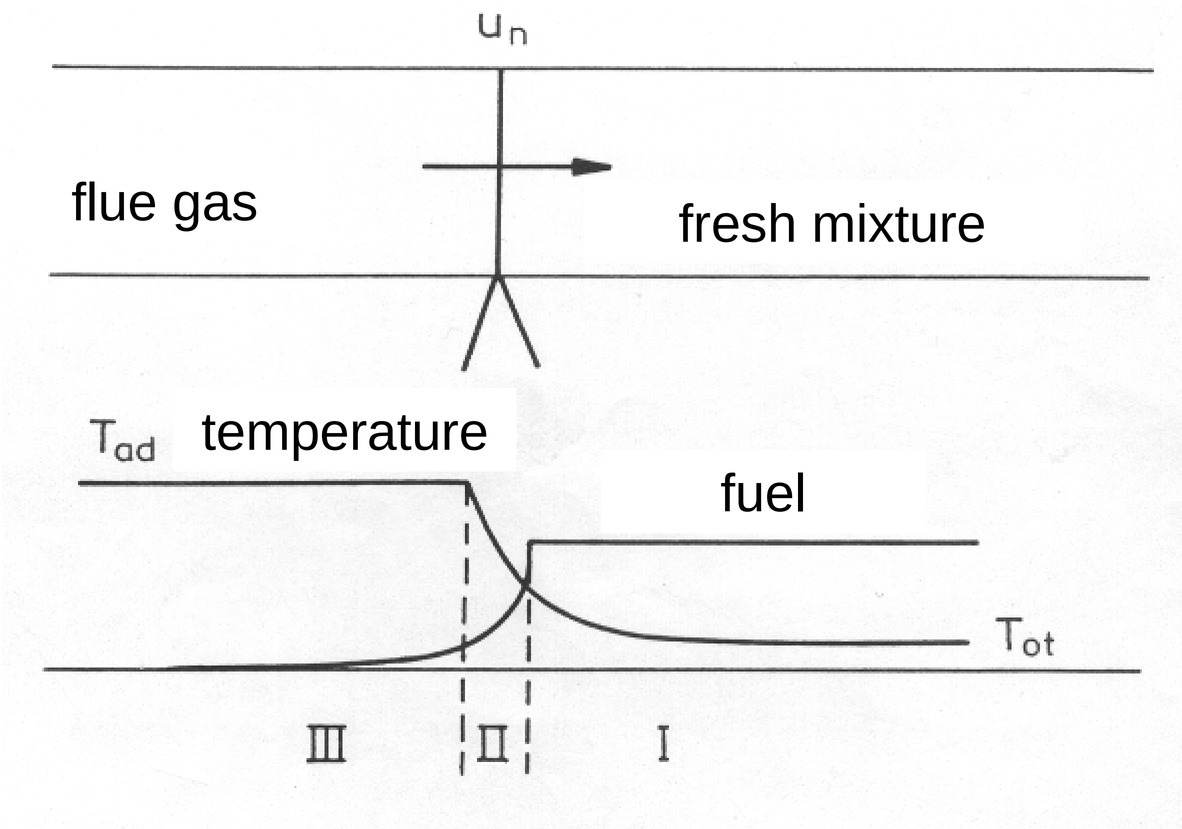
FLAMES


laminar
premixed (kinetic)
diffusion (non premixed)
turbulent

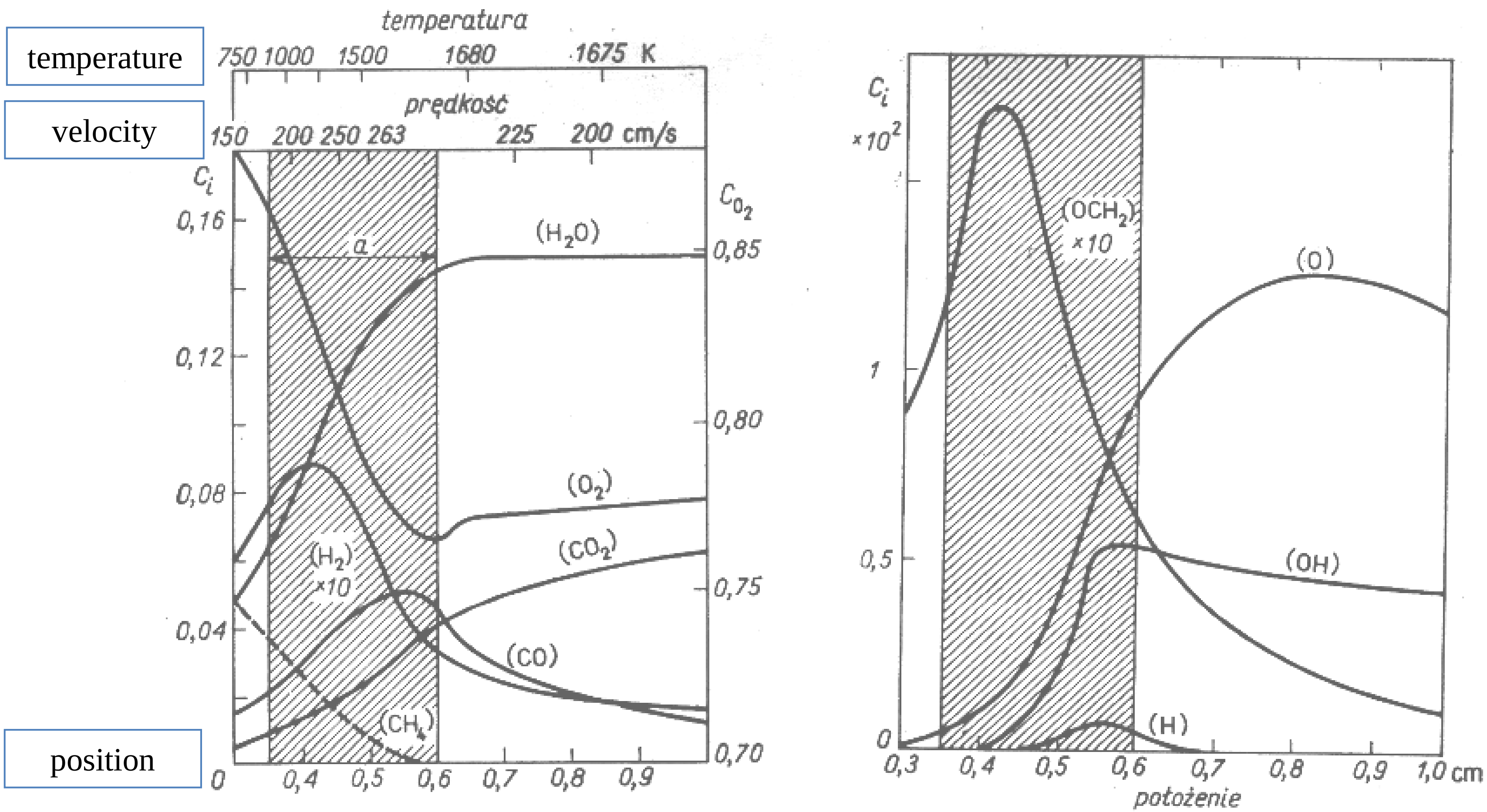
PREMIXED LAMINAR FLAME



STRUCTURE OF PREMIXED LAMINAR FLAME

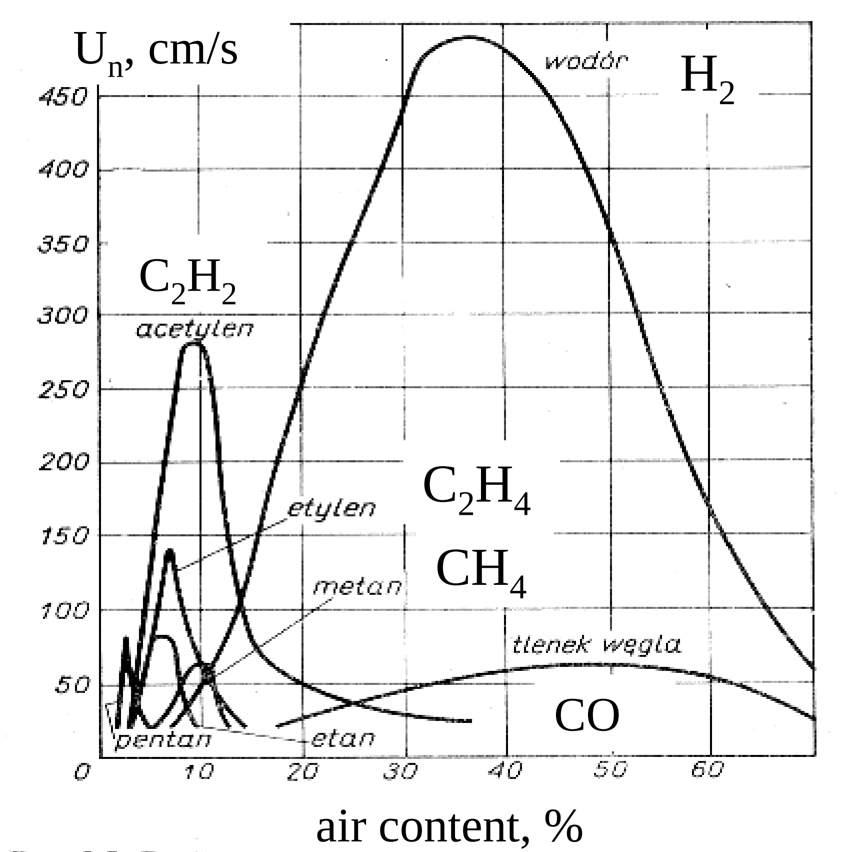


STRUCTURE OF PREMIXED LAMINAR FLAME



Rys. 2.5. Struktura laminarnego czoła płomienia ubogiej mieszanki metan-tlen. Zakreskowana strefa świecenia. Ciśnienie 0,1 atmosferycznego

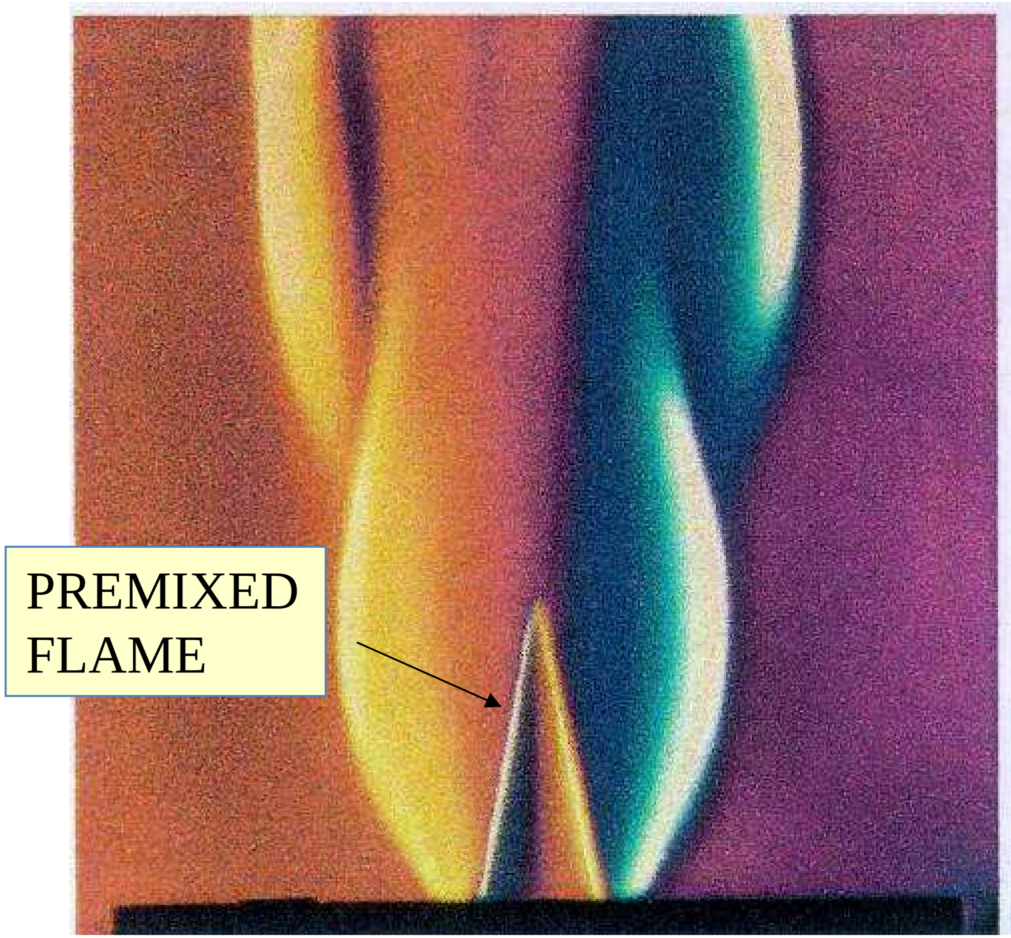
SPEED OF PREMIXED, LAMINAR FLAME

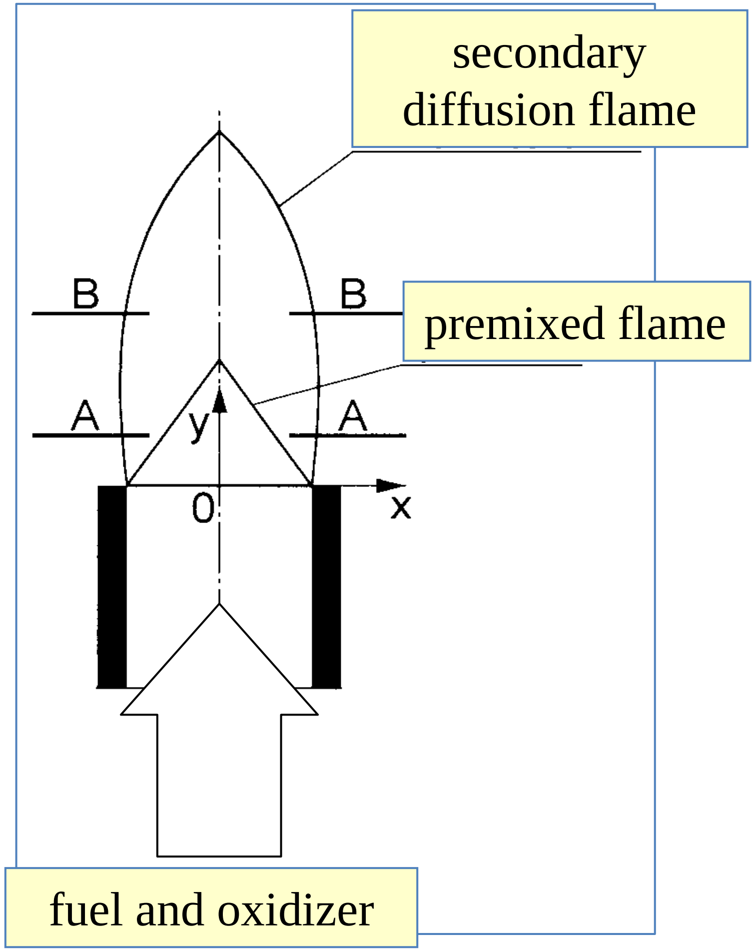


Rys. 2.7. Pręd... mieszanek

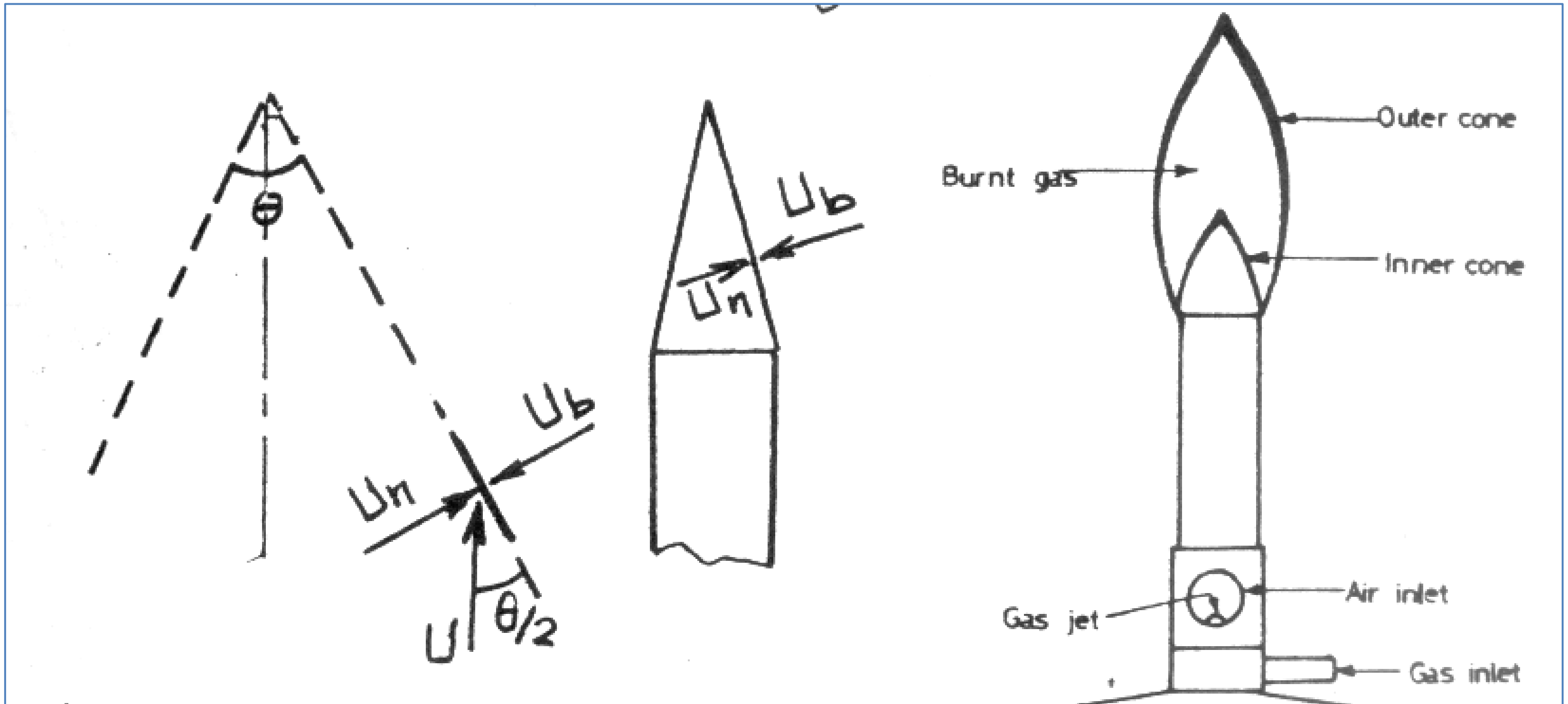
Methane: ~ 40cm/s

PREMIXED, LAMINAR FLAME ABOVE THE BUNSEN BURNER





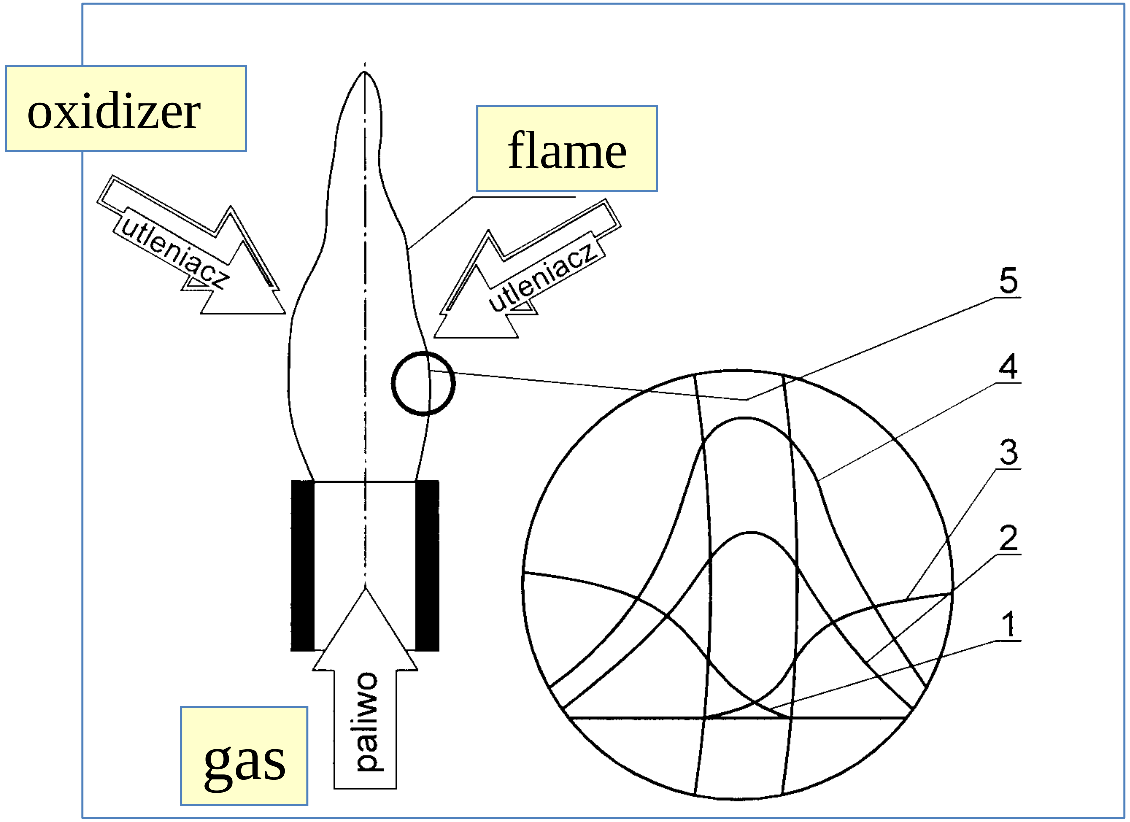
PREMIXED, LAMINAR FLAME ABOVE THE BUNSEN BURNER



$$U_b = U_n = U \sin \theta/2$$

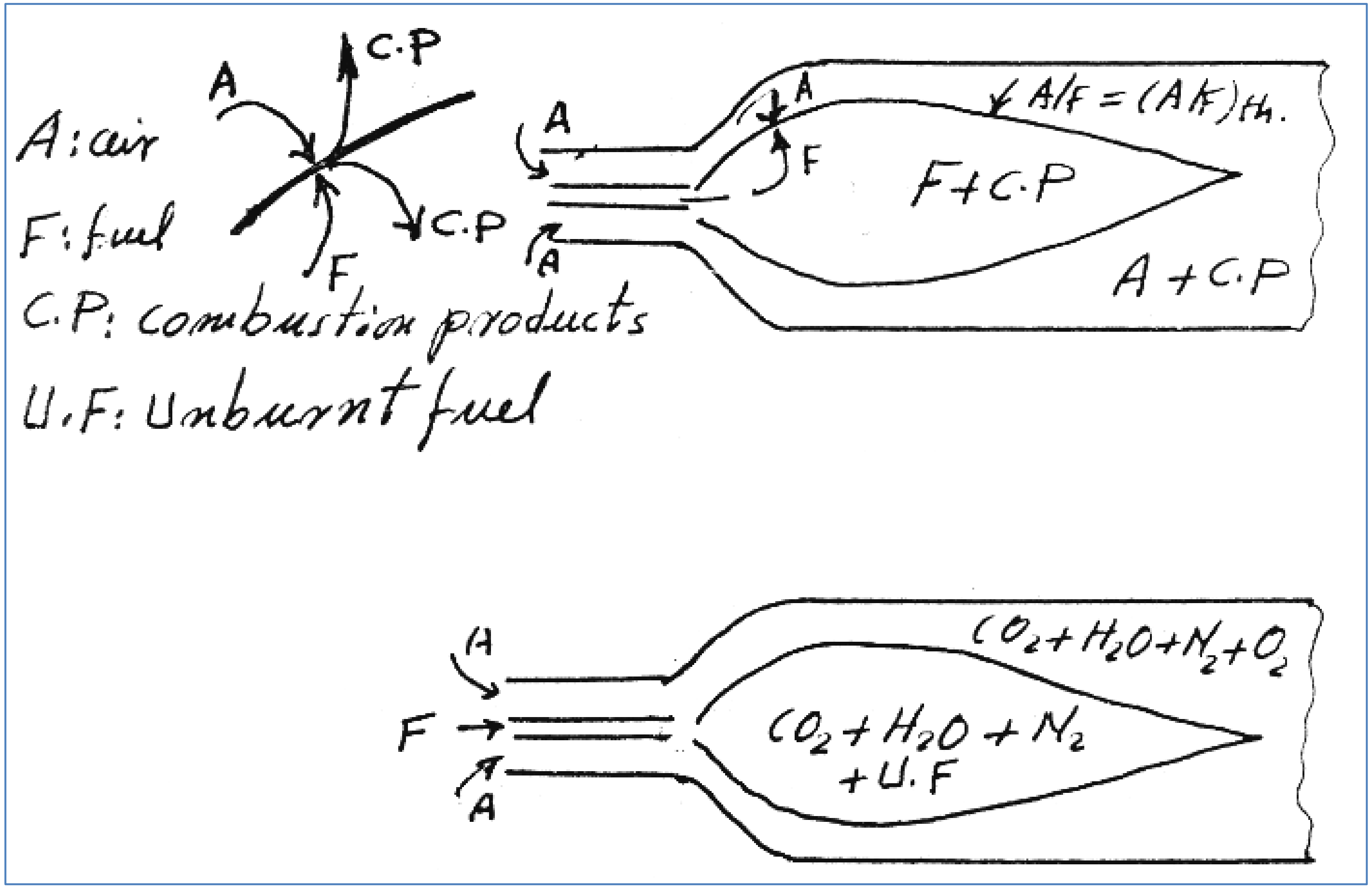
Determination of flame velocity from the angle of flame

STRUCTURE OF DIFFUSION, LAMINAR FLAME

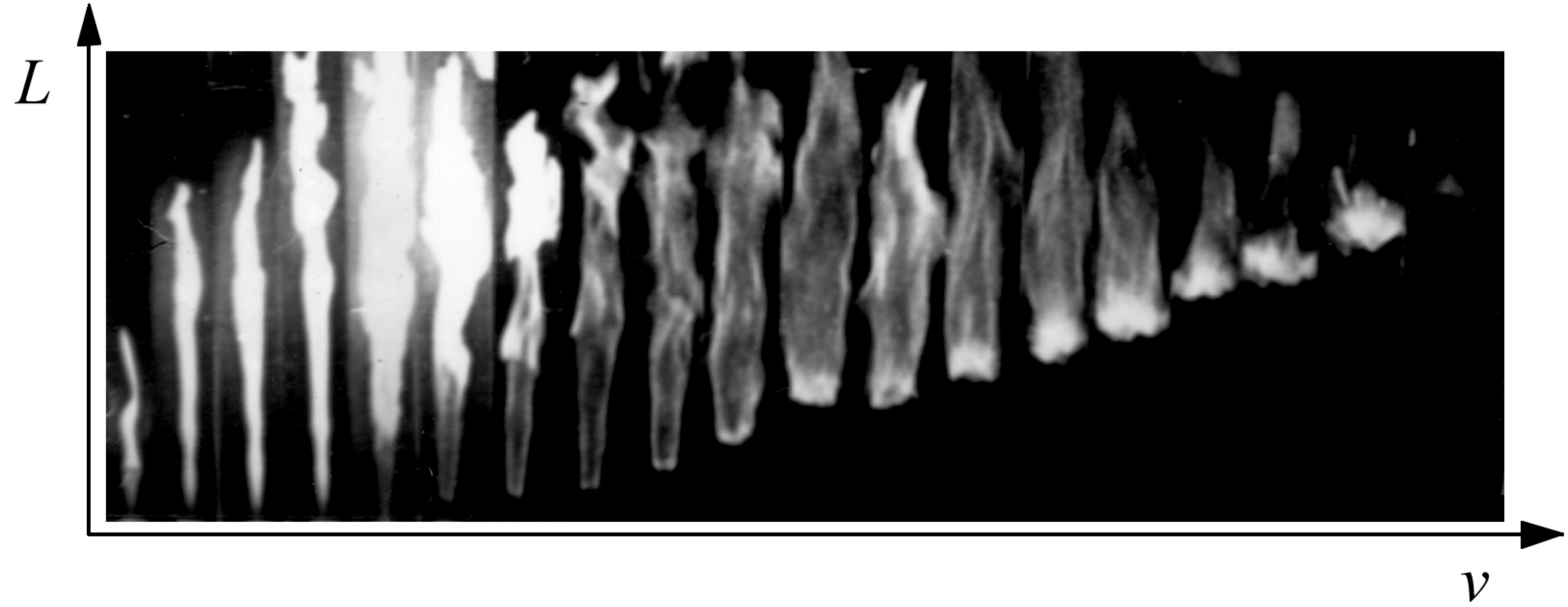


Laminar diffusion flame:
1 – gas, 2 – flue gas, 3 – air, 4 – temperature, 5 – flame

STRUCTURE OF DIFFUSION, LAMINAR FLAME



STRUCTURE OF DIFFUSION, LAMINAR FLAME



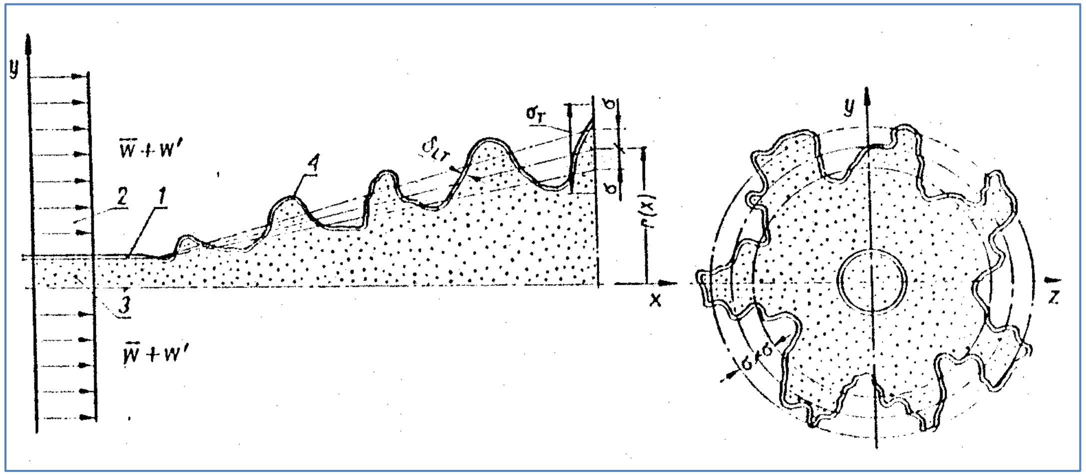
Diffusion flame height vs. gas outflow velocity

LIFTED DIFFUSION, TURBULENT FLAME

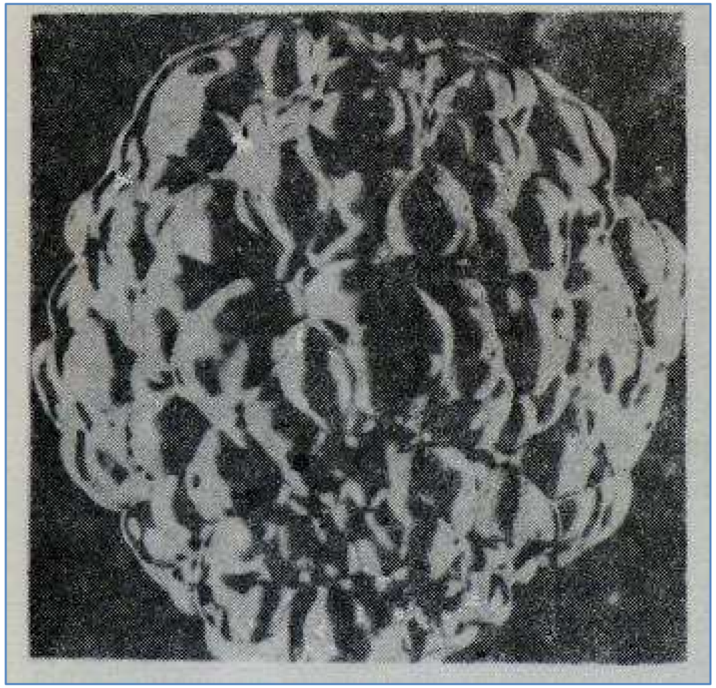
Lifted diffusion flame

a)

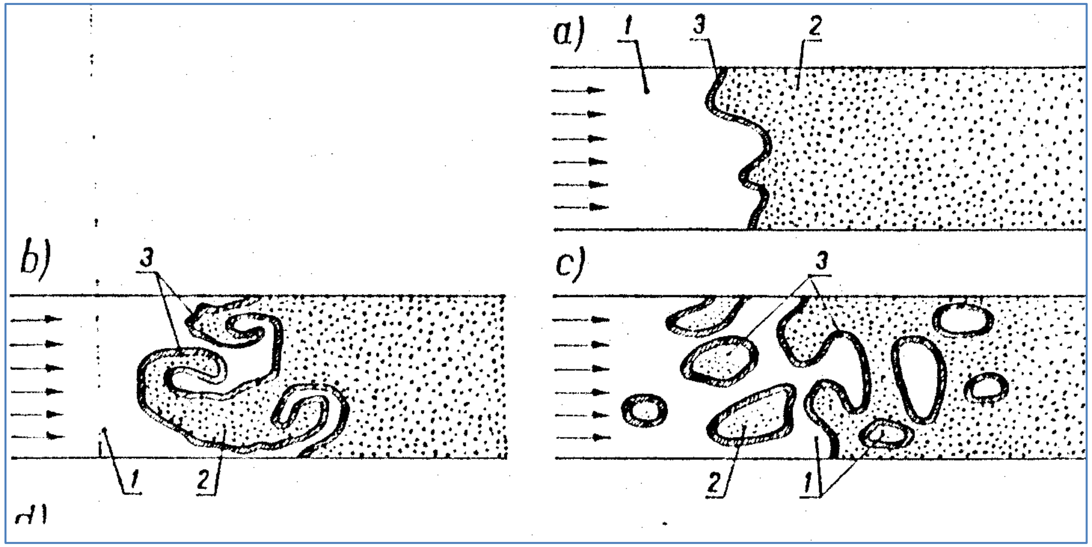
TURBULENT FLAME



Surface area of turbulent flame

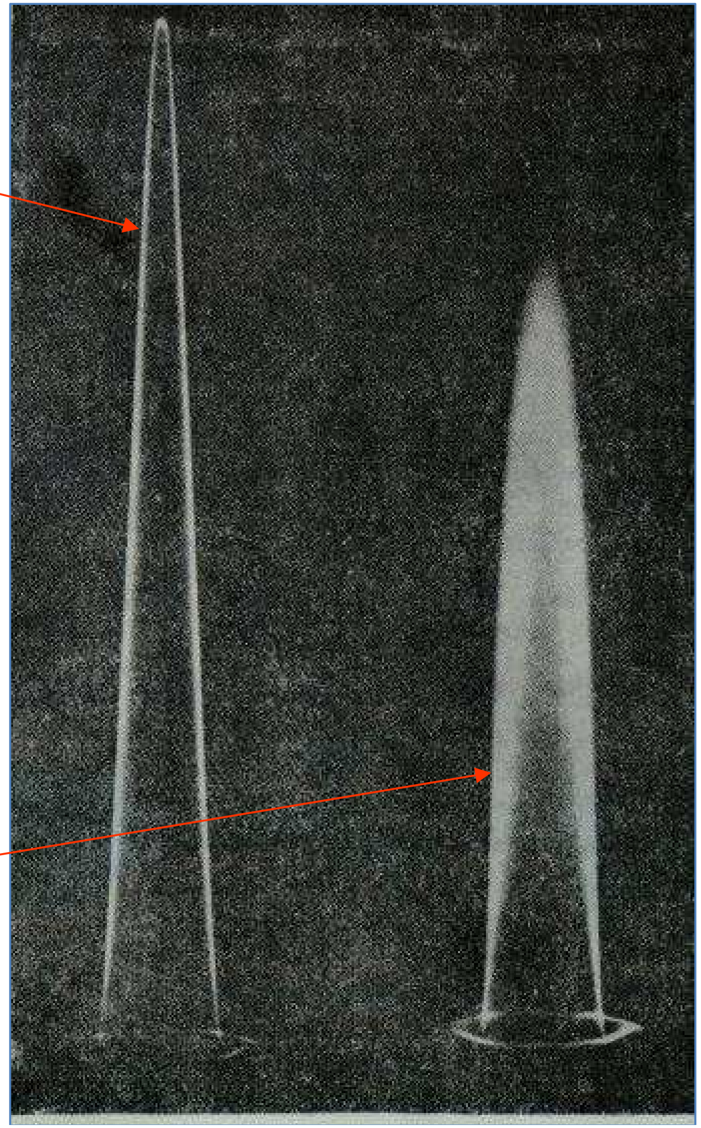


STRUCTURE OF DIFFUSION, TURBULENT FLAME

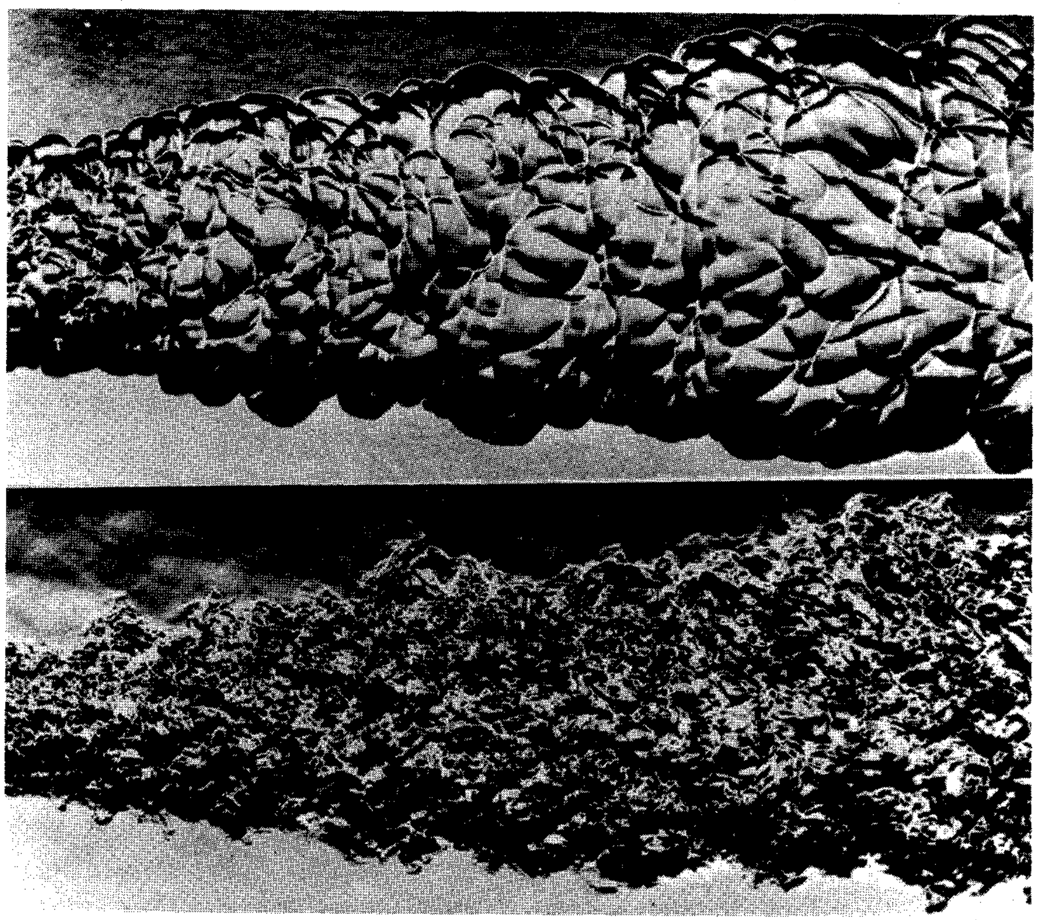


laminar

turbulent



INFLUENCE OF TURBULENCE ON FLAME STRUCTRURE

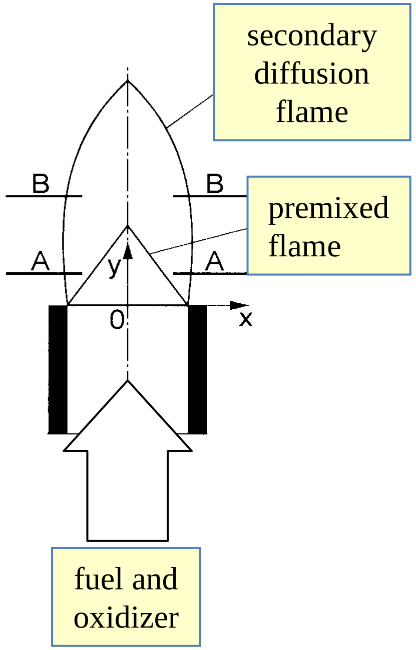


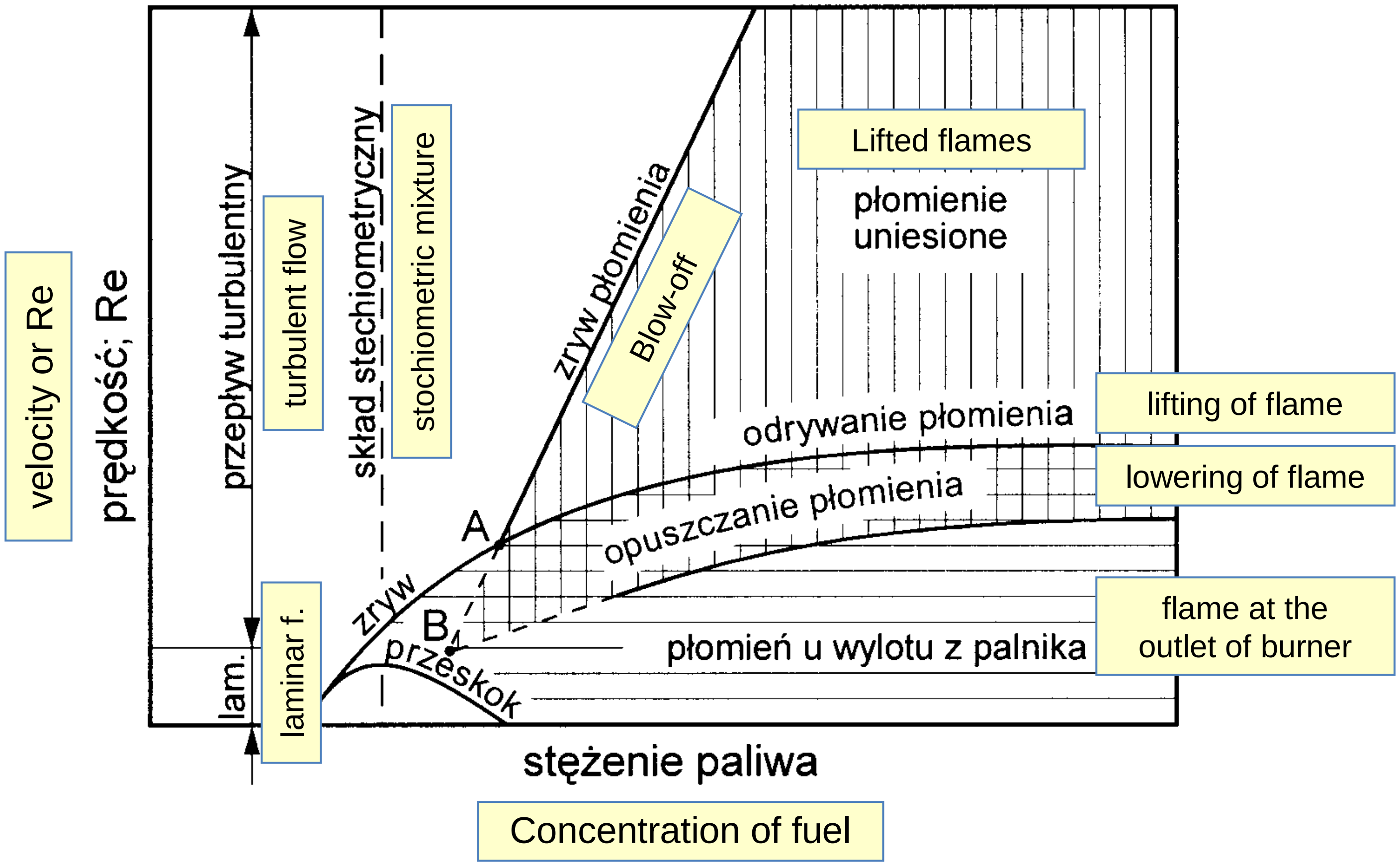
U'= 3.1 m/s

U'= 30.5 m/s

FIG. 2.9 Stoichiometric propane-air flames under conditions of low and high turbulence. Upper photograph, $u' = 3.1$ m/s. Lower photograph, $u' = 30.5$ m/s.

STABILITY OF GAS FLAMES





Stability of premixed flame in an open space

GAS BURNERS

REQUIREMETS FOR GAS BURNERS

The major requirements of a burner is to deliver air for fuel combustion and organize mixing of fuel/air to get flame of required features.

Features of good burner:

- stable and proper operation in the range of design parameters,
- low emission of pollutant,
- security of operation
- long livetime,
- low level of noise.

TYPES OF GAS BURNERS

Gas burners:

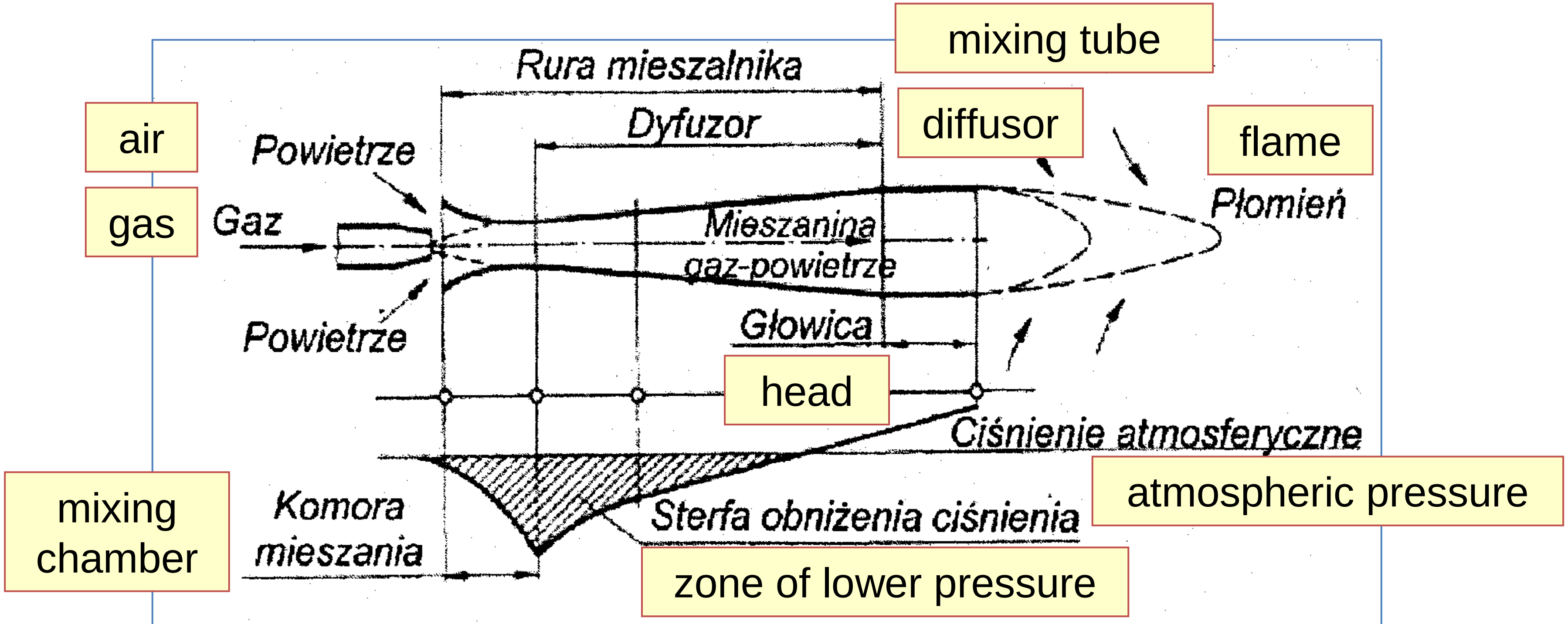
- jet ejector burners
  - Low-presssure burners
  - High-pressure burners
- compact burners
  - Jet burners
  - Swirl burners

CLASSIFICATION OF GAS BURNERS DEPENDING ON APPLICATIONS

- Compact burners (common use)
- Low- emission burners
- Start-up burners
- Pilot burners
- Special burners

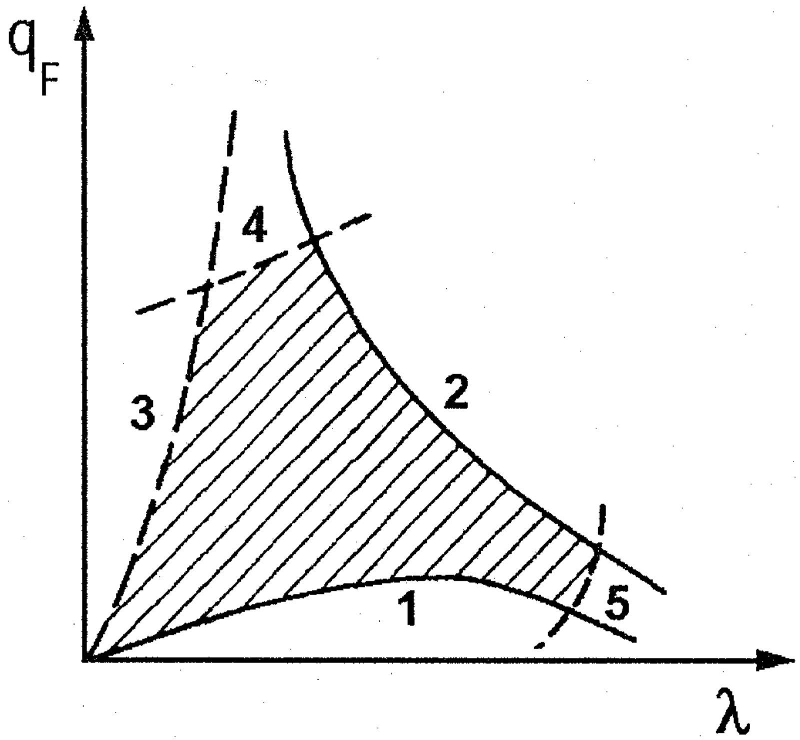
Range of power of gas burners: from kilowates to megawates

PRINCIPLE OF OPERATION OF LOW-PRESSURE JET-EJECTOR GAS BURNER



Zasada działania palnika z iniektorem gazu.

RANGE OF OPERATION LOW-PRESSURE JET-EJECTOR GAS BURNER

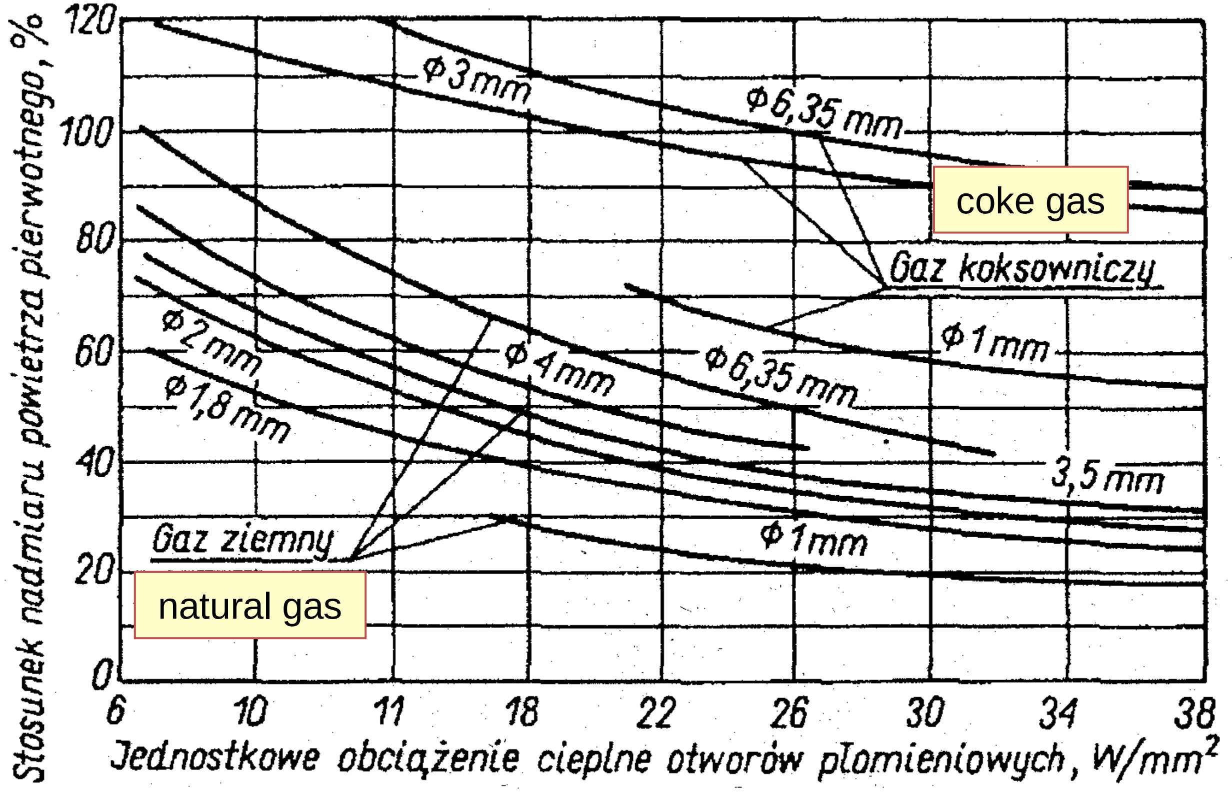


1- back-fire
2- blow-up of flame
3- yellow ends of flame
4- un-complete combustion
5- maximum of air ejection

Zakres pracy palnika inżektorowego: 1 - cofanie płomieni, 2 - odrywanie płomieni, 3 - żółte końce płomieni, 4 - niezupełne spalanie, 5 - maksymalne zassanie powietrza

SELECTION OF NOZZLES FOR LOW-PRESSURE JET-EJECTOR GAS BURNERS

excess of primary air

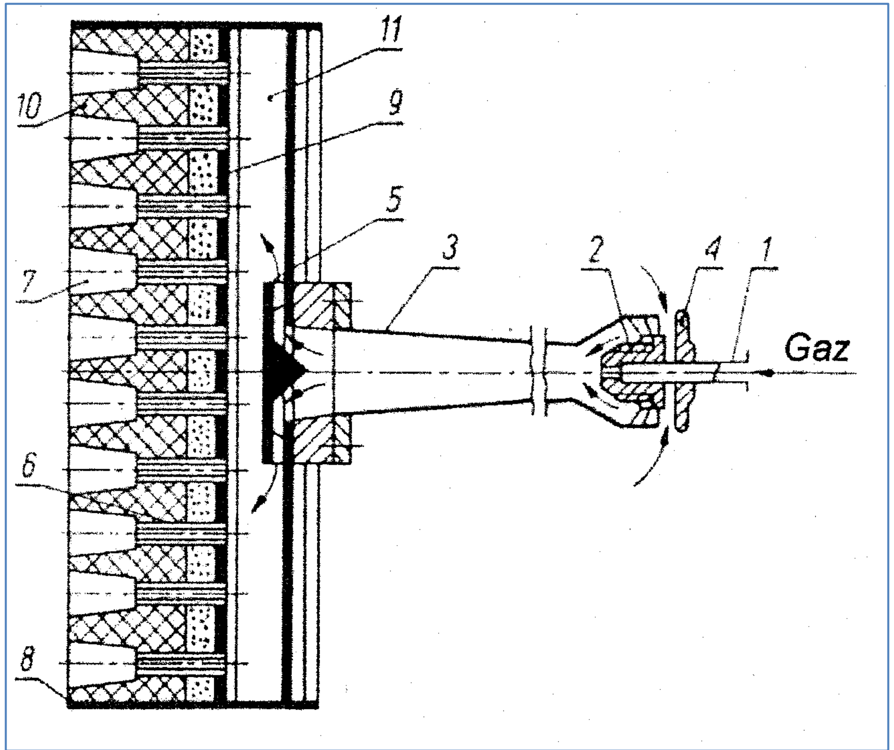


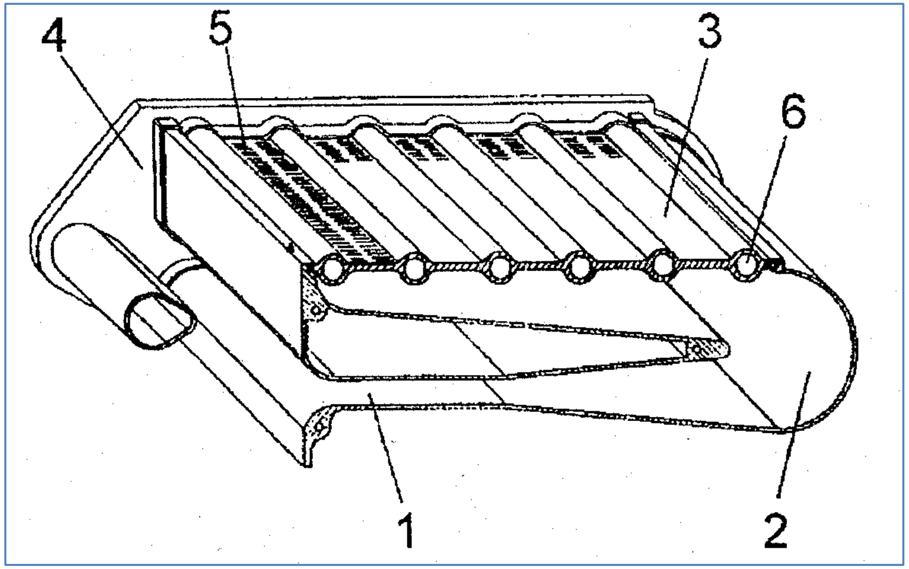
heat load of flame holes

Doświadczalne krzywe granic odrywania płomienia gazu ziemnego i koksowniczego

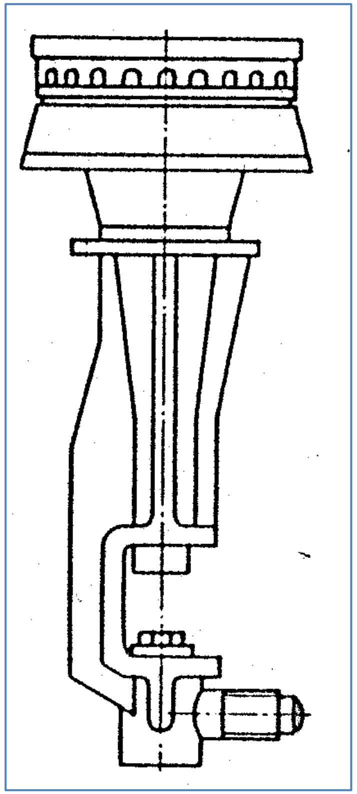
curves of flame detachment

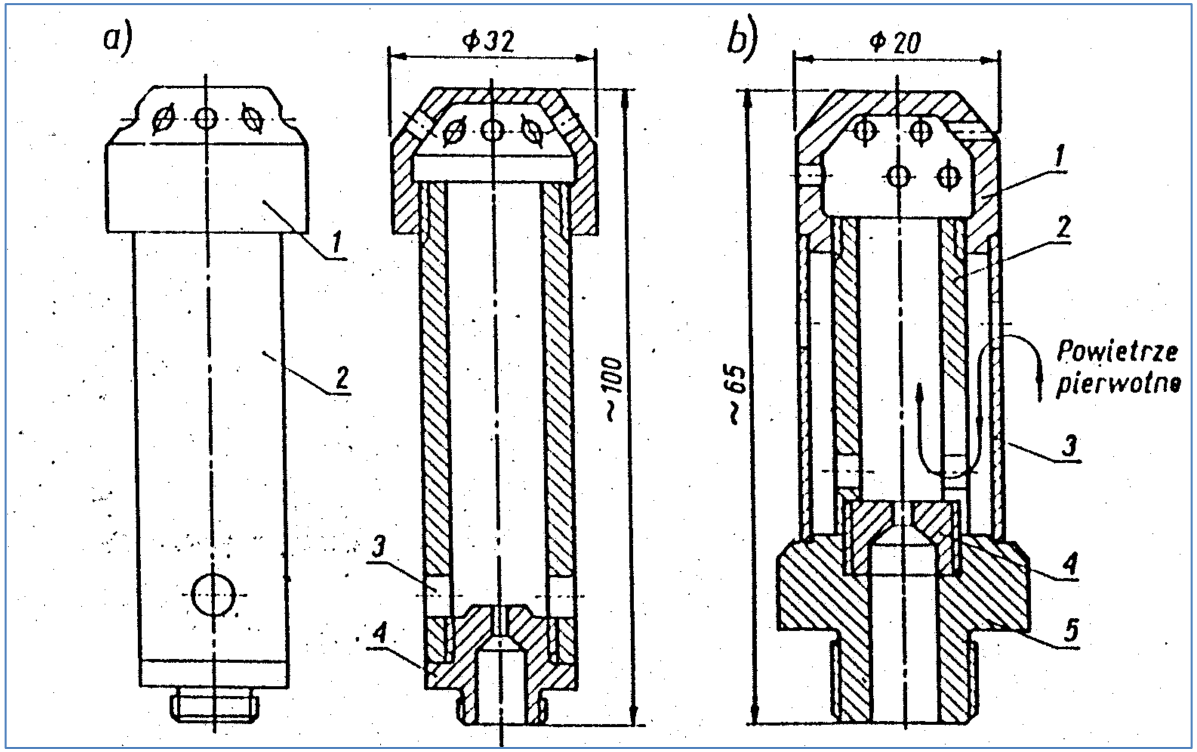
EXAMPLES OF LOW-PRESSURE JET-EJECTOR GAS BURNERS





LOW-PRESSURE JET-EJECTOR GAS BURNERS





Domestic ovens burners

HIGH-PRESSURE JET-EJECTOR GAS BURNERS

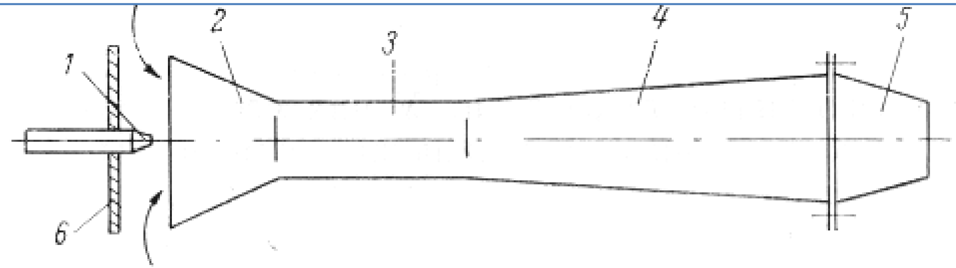
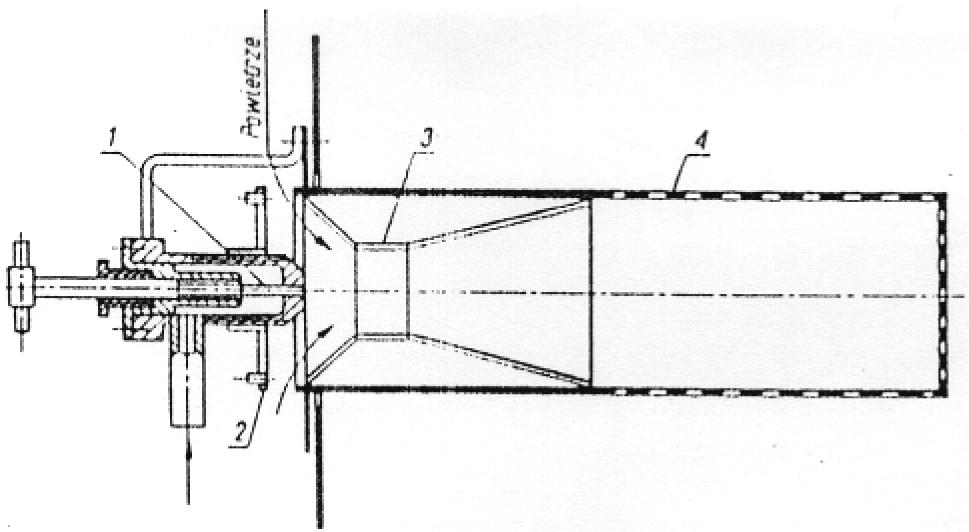


Рис. 7-1. Схема инжекционной горелки.
1 — газовое сопло; 2 — инжектор; 3 — горло; 4 — диффузор; 5 — насадок; 6 — воздушная

1 – nozzle
2 – injector
3 – throat
4 - diffuser

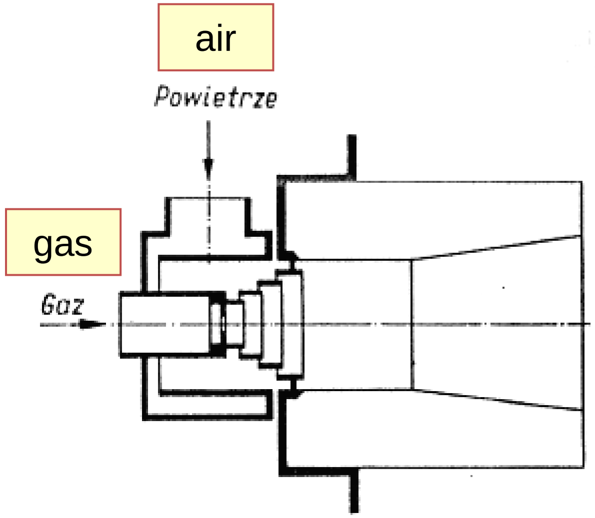


Rys. 8.8. Palnik iniektorowy wysokoprężny; 1 — dysza, 2 — regulator dopływu powietrza, 3 — gardło mieszalnika, 4 — kolektor z otworkami

1 – nozzle
2 – air flow adj.
3 – throat
4 – collector with holes

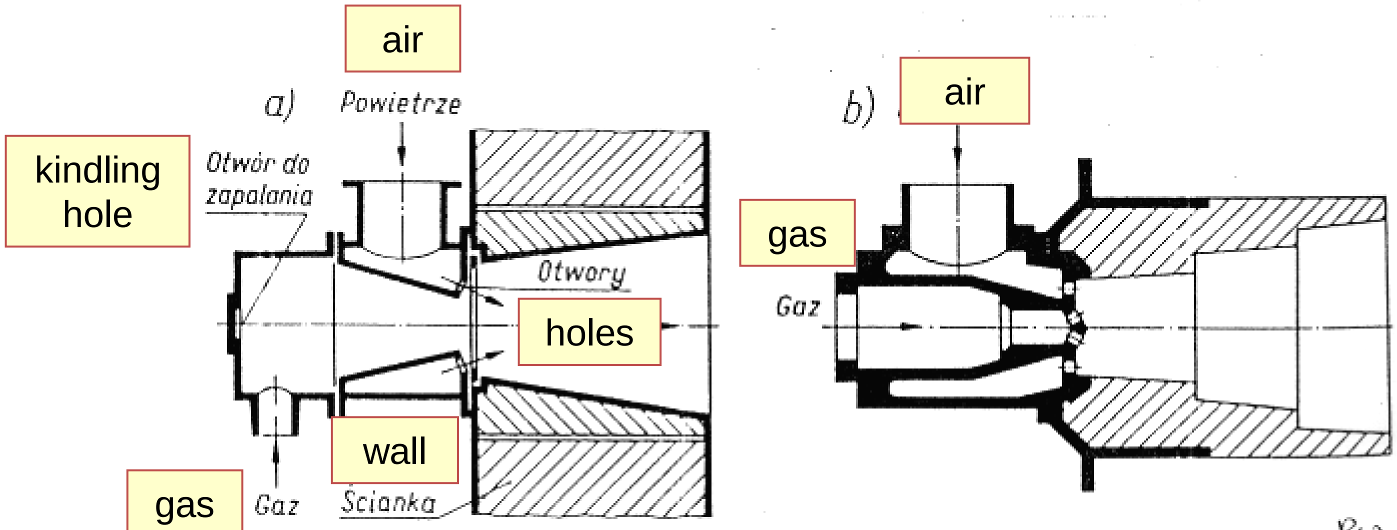
NOZZLE-MIX JET BURNERS

PALNIKI NADMUCHOWE



Rys. 8.4.
Palnik z doprowadzeniem powietrza przez dysze współśrodkowe do dysz gazu

ry 10.7



Rys. 8.5. Palniki pracujące bez wstępnego mieszania ze zbieżnym prowadzeniem strumieni powietrza i gazu: a) według dokumentacji *Meyerhofer*, b) według dokumentacji *Maxon*

NOZZLE-MIX SWIRL BURNERS

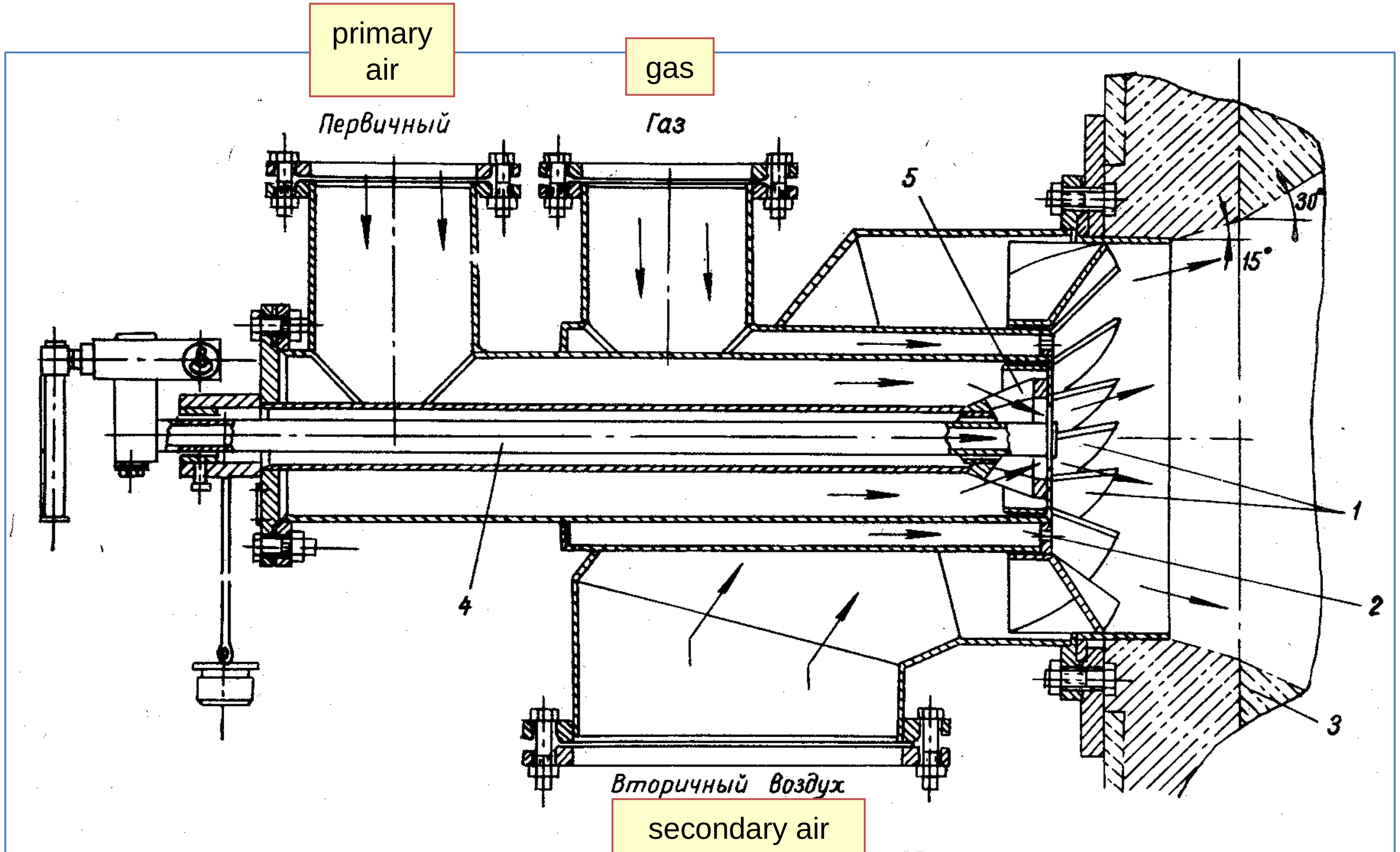
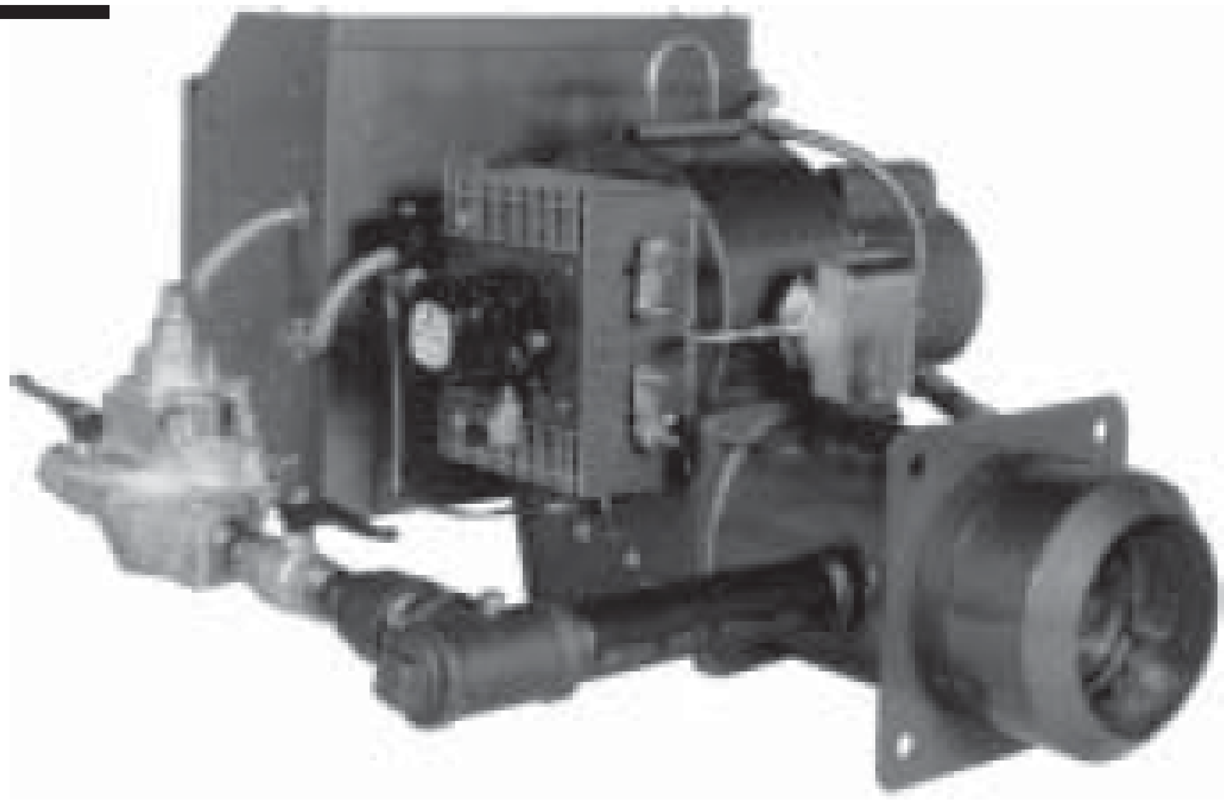


Рис. 7-11. Газомазутная горелка ГМГ-4.

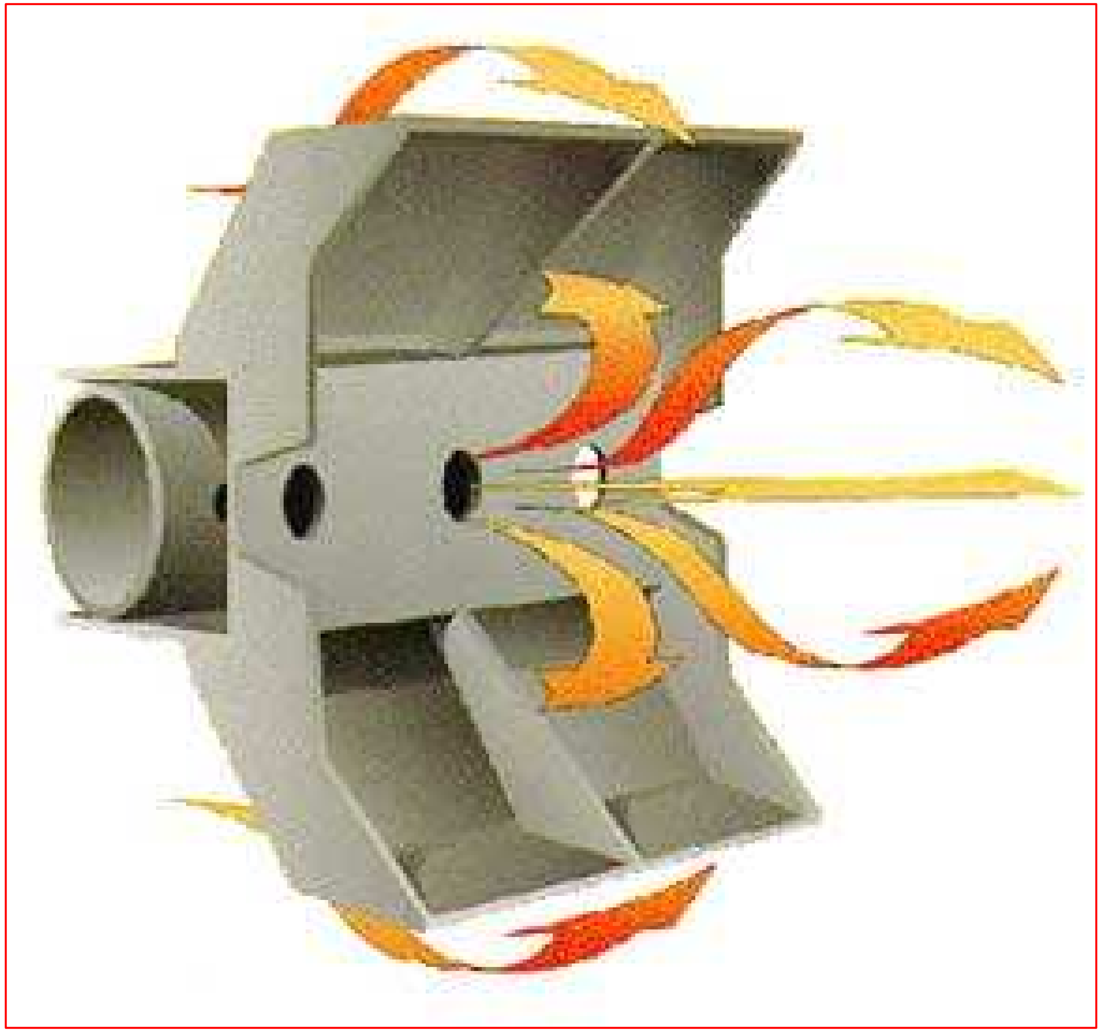
1, 5 — воздухонаправляющие устройства; *2* — газоподводящее устройство; *3* — амбразура; *4* — мазутная форсунка.

COMPACT BURNER

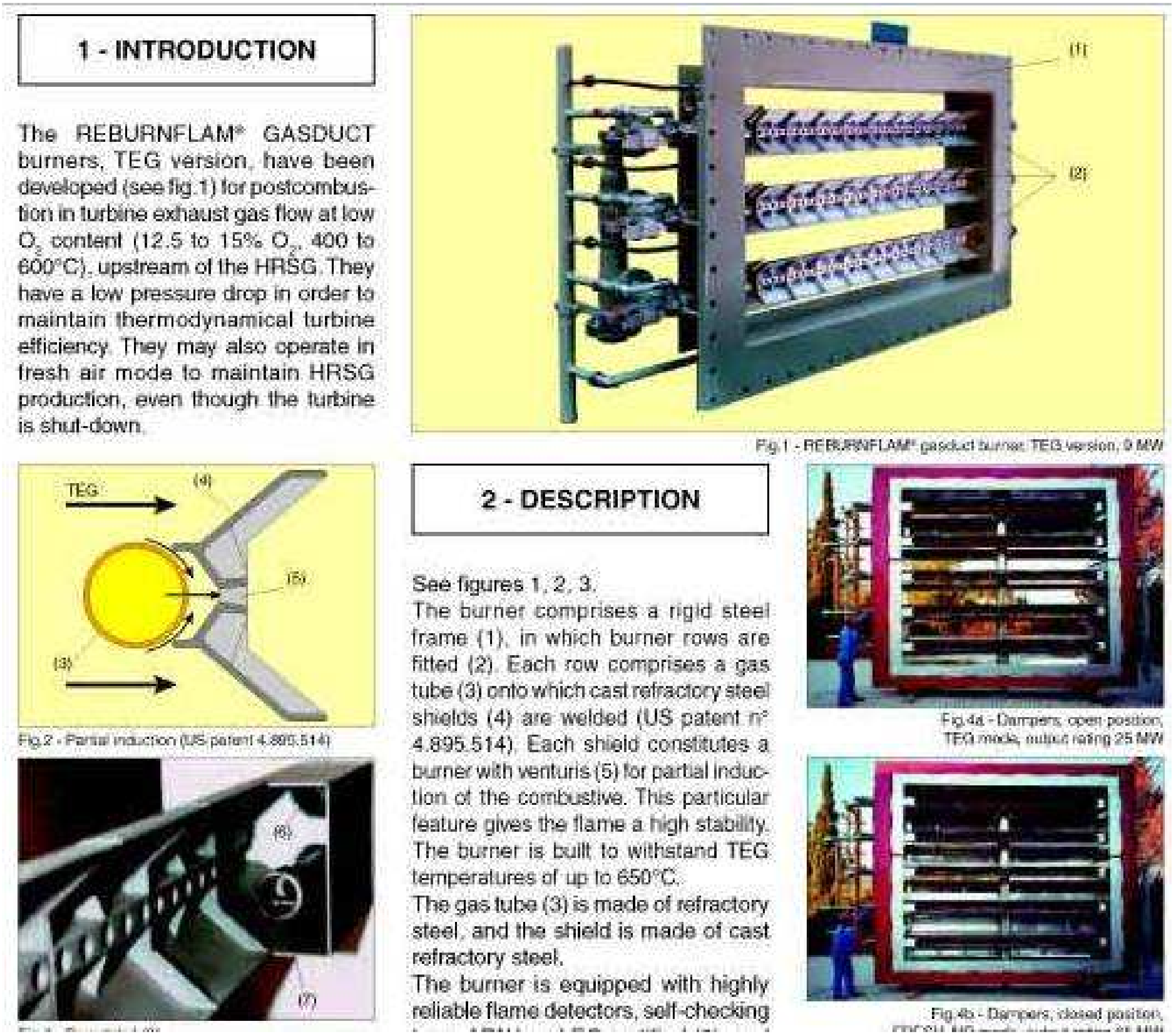


Power flame

DUCT BURNER - IDEA



DUCT BURNERS - SOLUTIONS



1 - INTRODUCTION

The REBURNFLAM® GASDUCT burners, TEG version, have been developed (see fig.1) for postcombustion in turbine exhaust gas flow at low O_2 content (12.5 to 15% O_2, 400 to 600°C), upstream of the HRSG. They have a low pressure drop in order to maintain thermodynamical turbine efficiency. They may also operate in fresh air mode to maintain HRSG production, even though the turbine is shut-down.

Fig.1 - REBURNFLAM® gasduct burner, TEG version, 9 MW

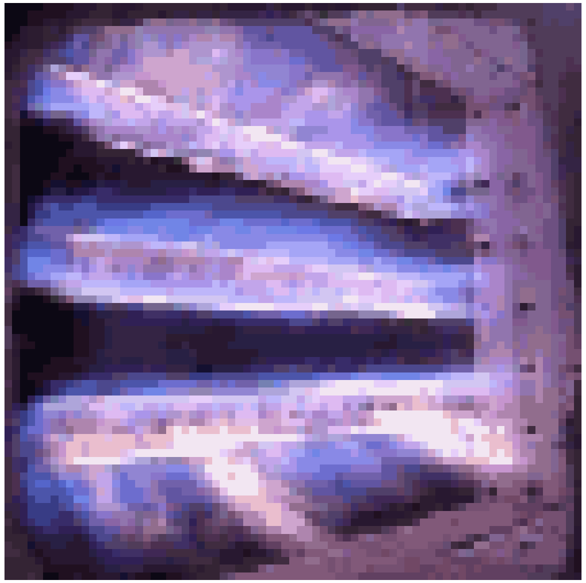
Fig.2 - Partial induction (US patent 4.895.514)

2 - DESCRIPTION

See figures 1, 2, 3.
The burner comprises a rigid steel frame (1), in which burner rows are fitted (2). Each row comprises a gas tube (3) onto which cast refractory steel shields (4) are welded (US patent n° 4.895.514). Each shield constitutes a burner with venturis (5) for partial induction of the combustive. This particular feature gives the flame a high stability. The burner is built to withstand TEG temperatures of up to 650°C.
The gas tube (3) is made of refractory steel, and the shield is made of cast refractory steel.
The burner is equipped with highly reliable flame detectors, self-checking

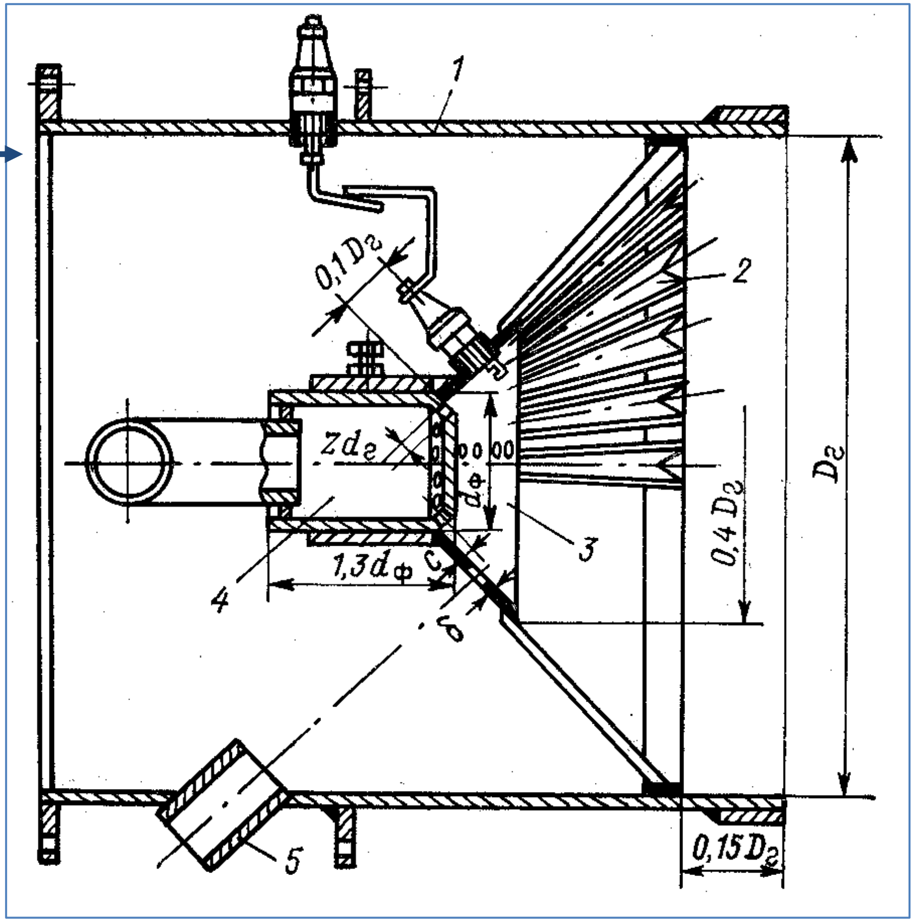
Fig.4a - Dampers, open position, TEG mode, output rating 25 MW

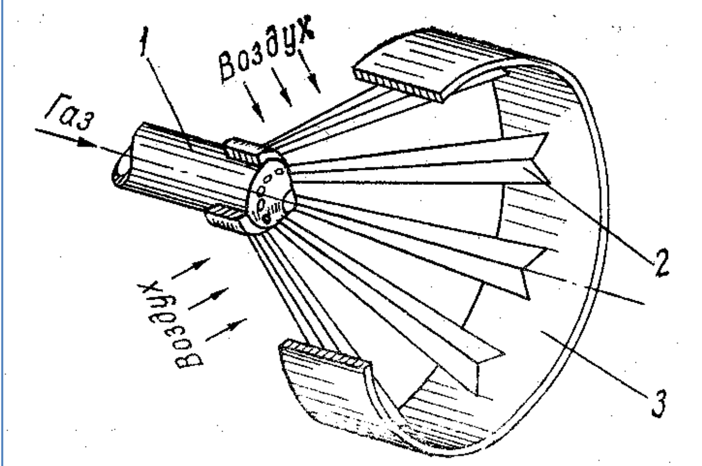
Fig.4b - Dampers, closed position,



WASTE GAS BURNER

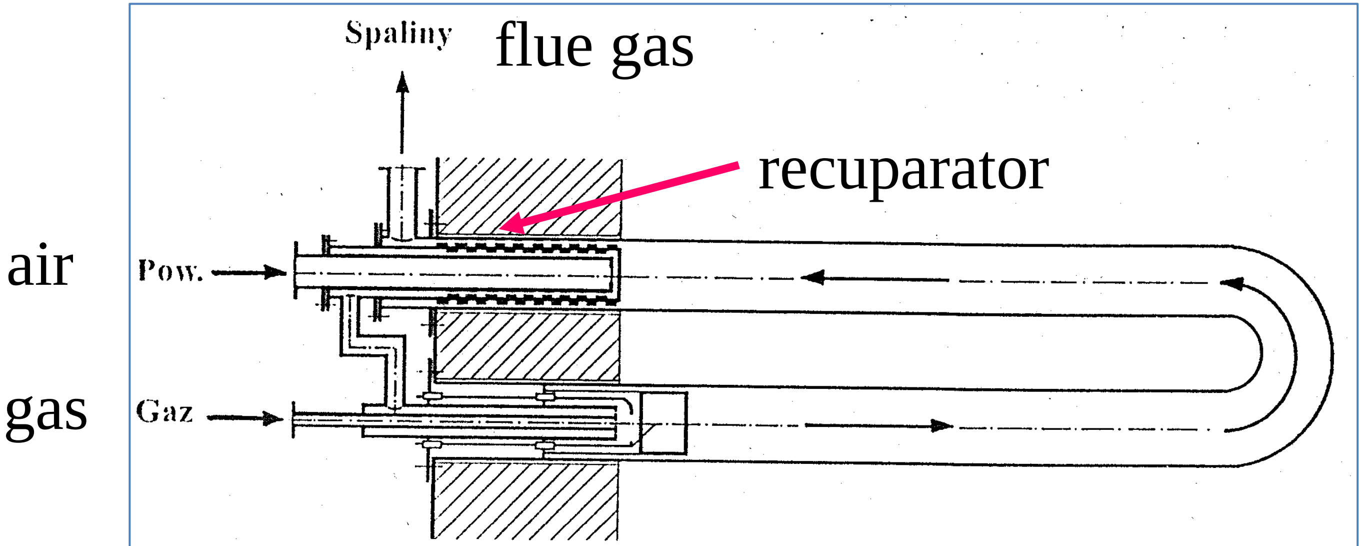
Design





Idea

RADIATING TUBES

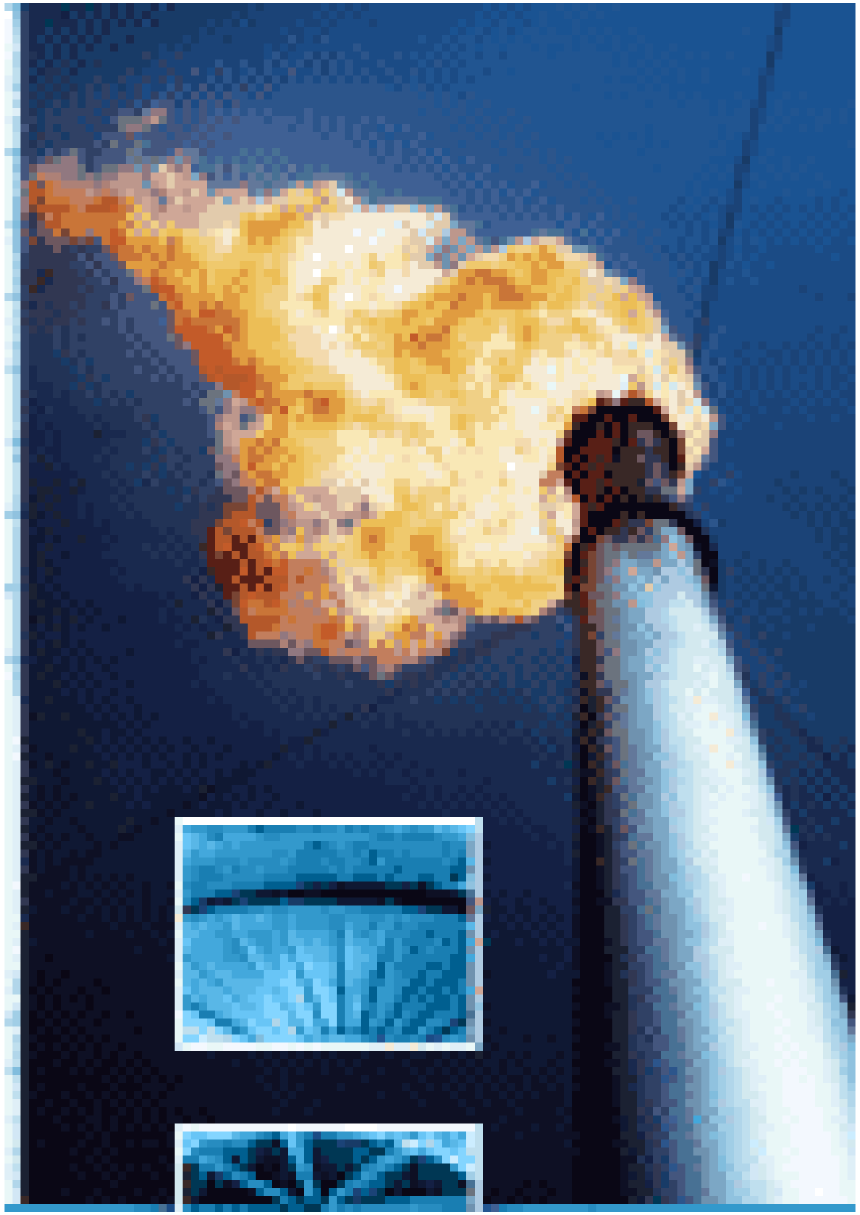


Niskoemisyjne palniki gazowe:

Moc cieplna	- 20 kW, 30 kW,
Nadmiar powietrza	- 1.1,
Sprawność	- 80%,
NO_x	< 30 ppm,
CO	< 25 ppm,

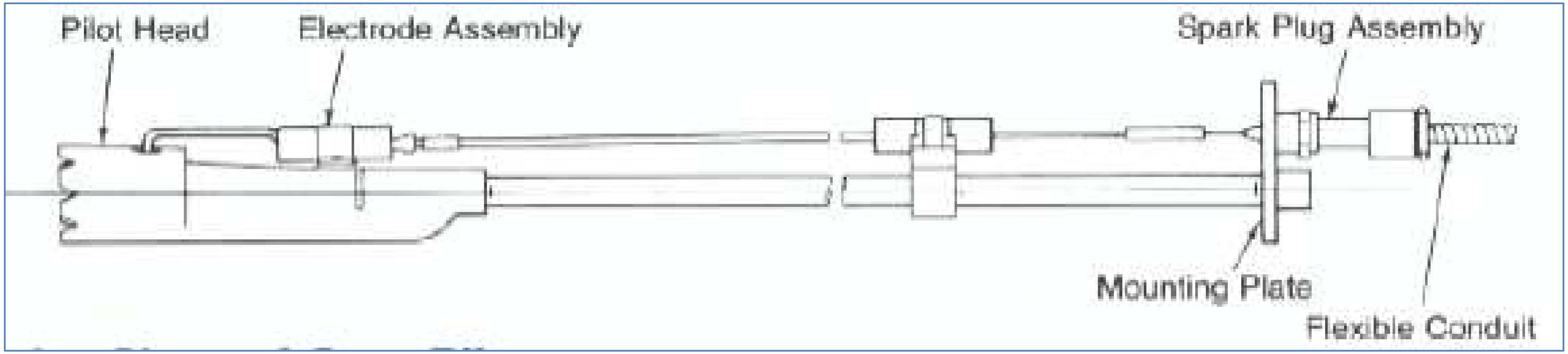
Oszczędność paliwa, wysoka jakość grzania,
Precyzyjne sterowanie rozkładem temperatury,
Bezpieczna eksploatacja pieca,
Detekcja płomienia, automatyczny zapłon.

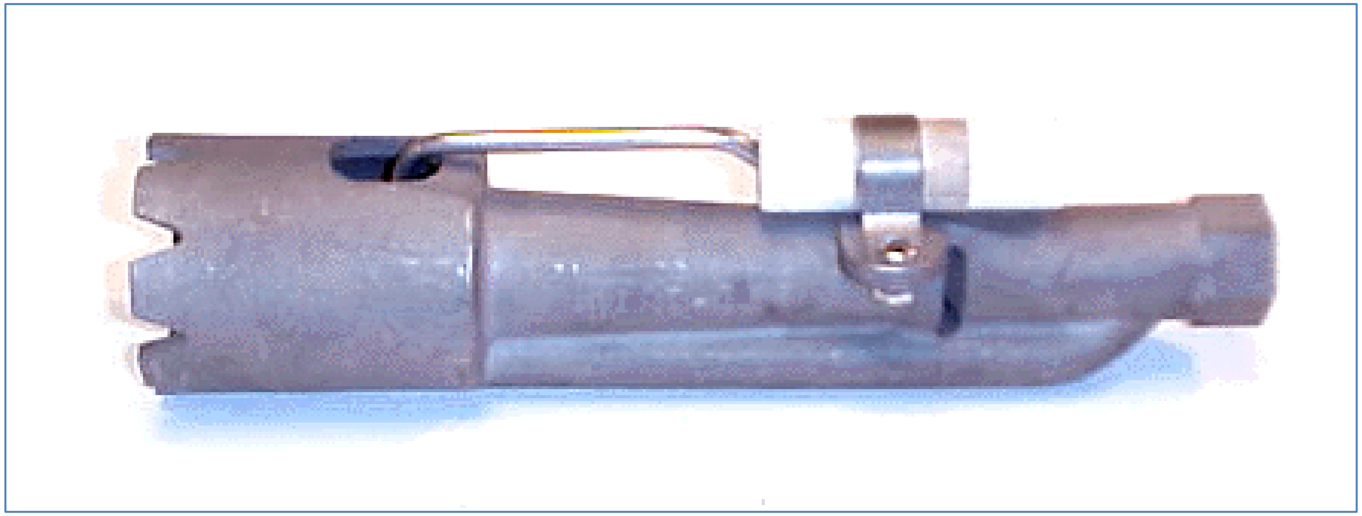
GAS FLARES



John Zink

PILOT BURNERS



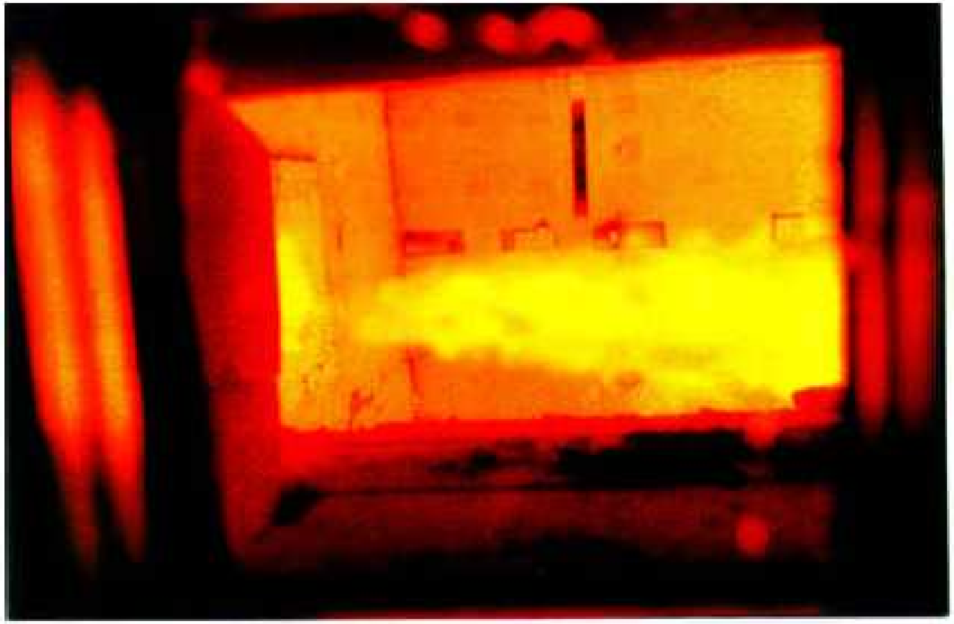


GAS LAMPS

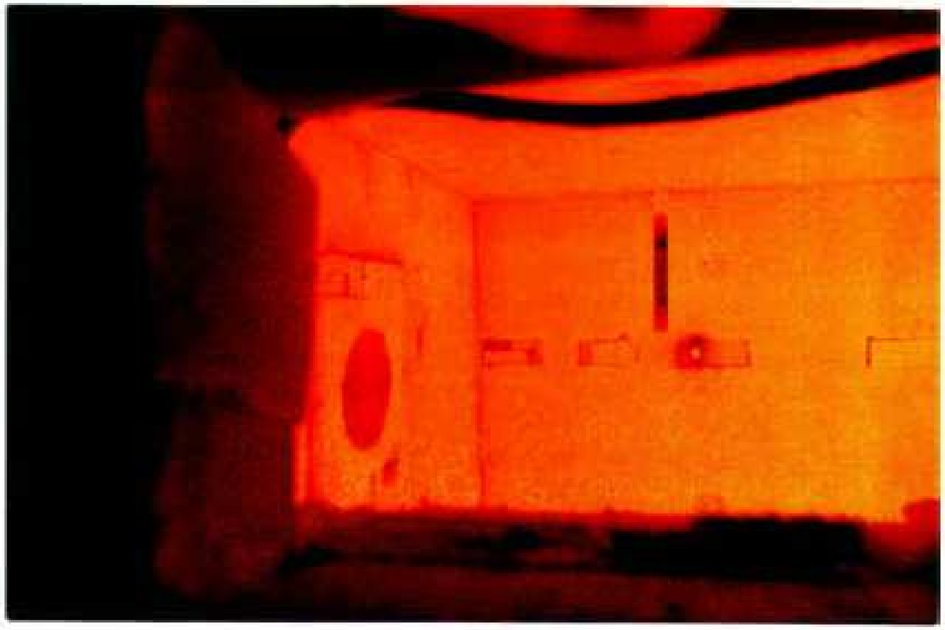
NEW COMBUSTION TECHNOLOGIES: FLAMELESS COMBUSTION

- Diluted combustion
- Highly preheated combustion

FLAMELESS COMBUSTION



flame combustion

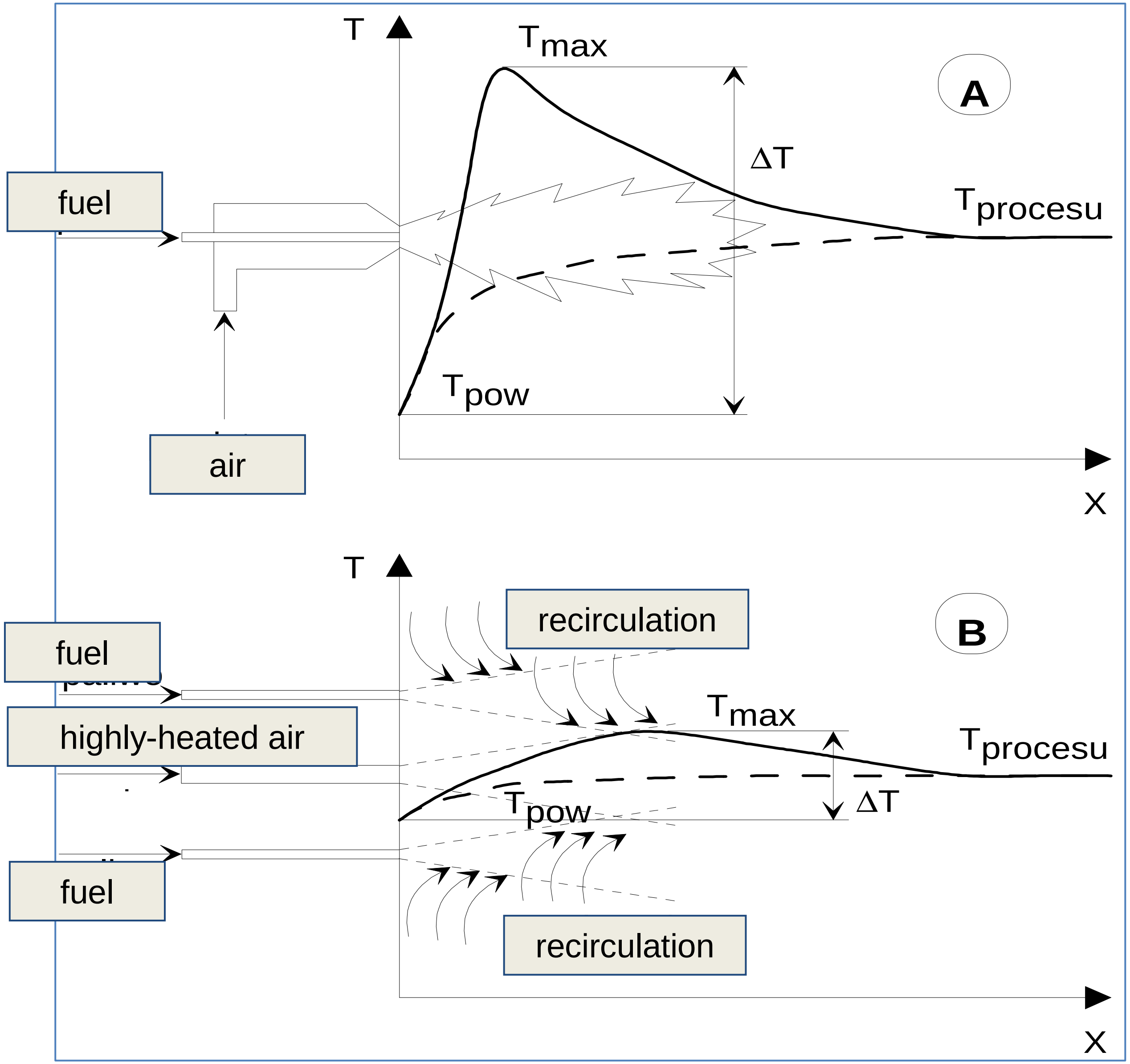


flameless combustion

CONDITIONS OF FLAMELESS COMBUSTION

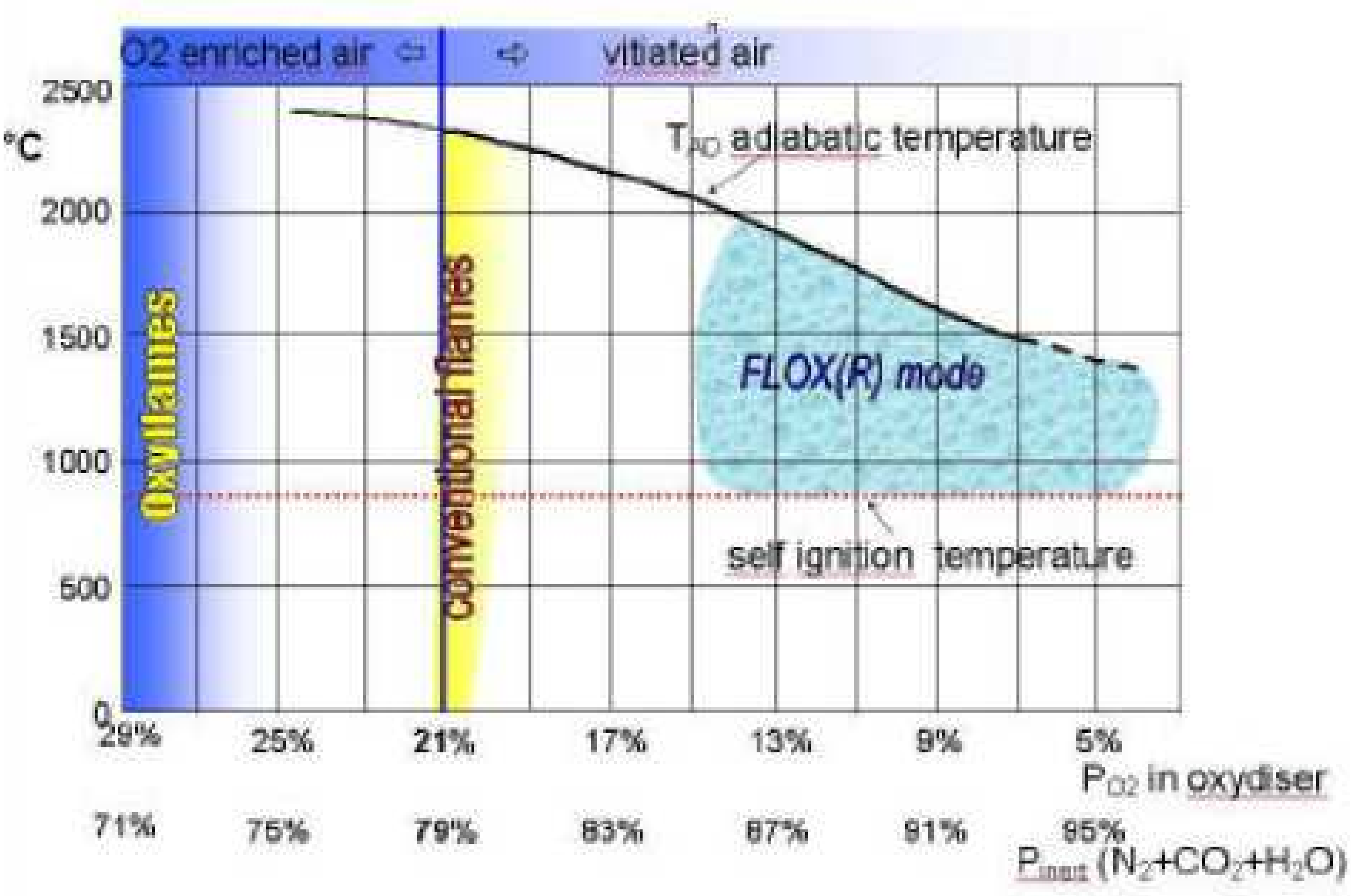
- temperature of air must be higher than selfignition temperature (800-1000 ^oC),
- intensive recirculation in flame region should secured,
- burning at low oxygen concentration, below 2-5 % vol.,
- system of air and gas nozzles should allow to extend the combustion process on the whole furnace.

RULES OF FLAMELESS COMBUSTION



T_{pow} – air temp.
$T_{procesu}$ – process temp.

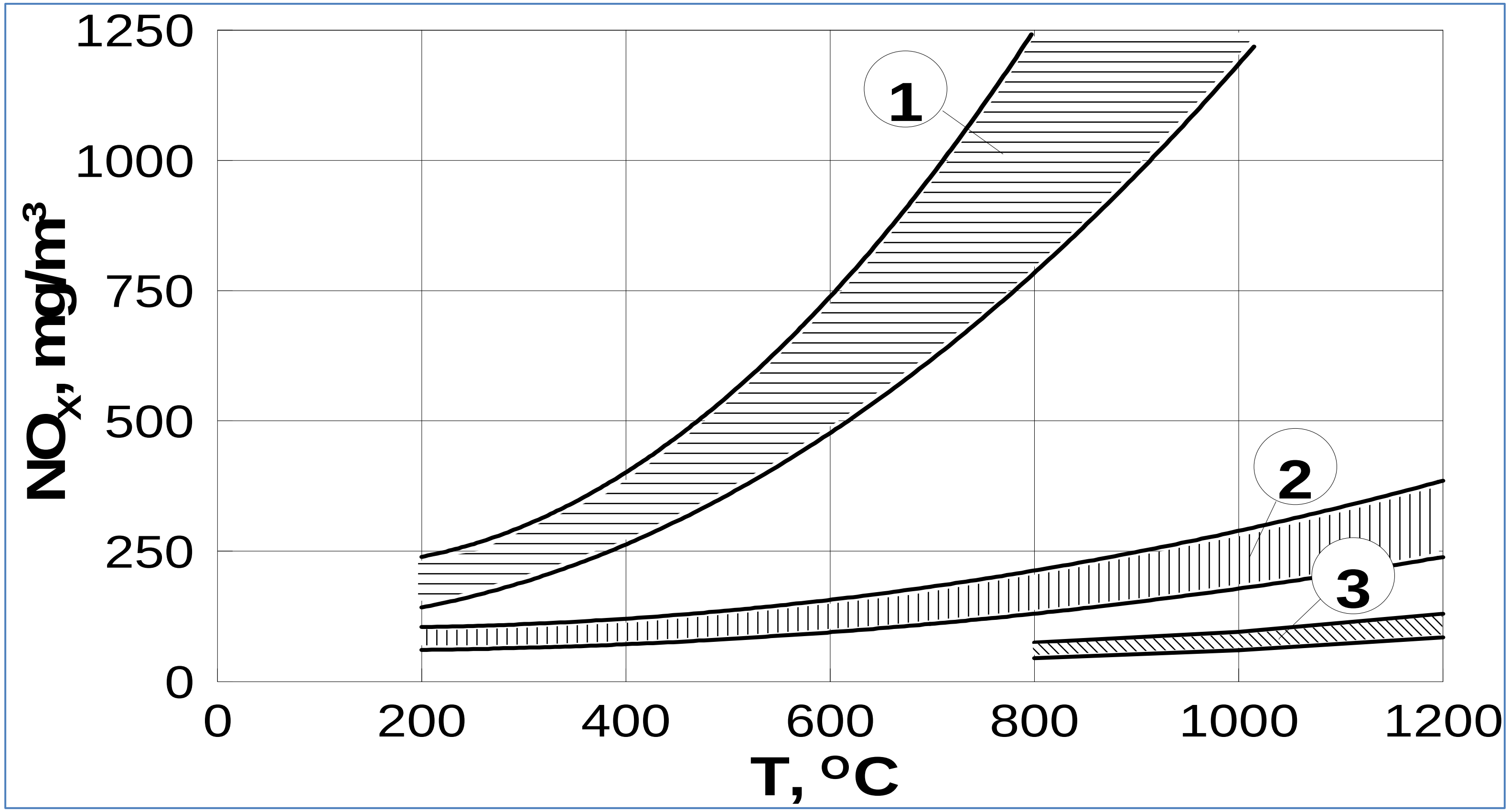
RANGE OF FLAMELESS COMBUSTION



EFECTS OF FLAMELESS COMBUSTION

- increase of thermal efficiency,
  - saving of fuel: 15-30%,
  - increase of furnace capacity: 25%,
- uniform temperature distribution in the furnace,
- low NO_x concentration in flue gas
  - an order lower than using low-NO_x combustion systems,
  - two orders lower than using conventional burners.

NOX CONCENTRATION IN FLUE GAS DEPENDING ON THE TEMPERATURE



1- conventional burner, 2- air staging, 3- flameless combustion

APPLICATION OF FLAMELES COMBUSTION TECHNOLOGY

At present:

- ➢In glass industry (burners of 200-300kW),
- ➢In ceramic industry (burners of 200-300kW),
- ➢In metallurgy (burners of 6-8 MW),
- ➢In petrochemistry.

In the future:

- ✓In power plants (PF boilers),
- ✓In the waste incinerators.