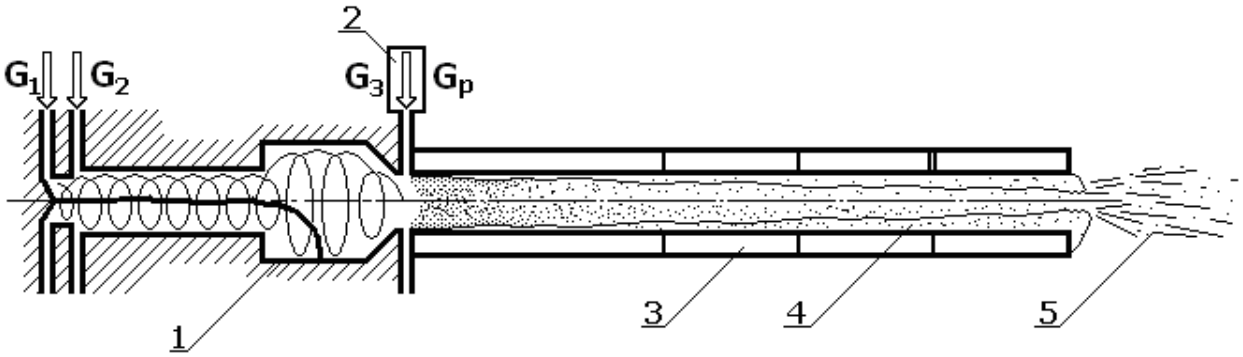
# Determination and generalization of plasma source parameters during the process of mineral fiber formation

PlasTEP Summer School and Training

Course in Vilnius/Kaunas

July 16th – July 27th, 2012

# The schematic presentation of plasma chemical reactor

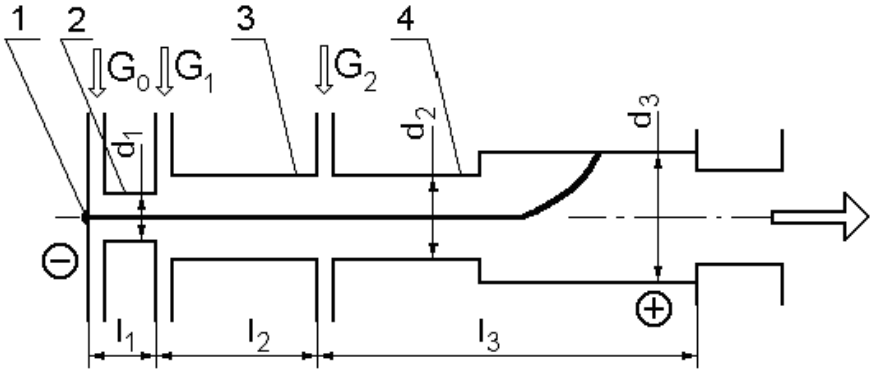



- 1 – dc plasma torch
- 2 – injection place of dispersed particles and propane-butane gas
- 3 – cooled walls
- 4 – melt flow
- 5 – fibre and granules

$G_1$, $G_2$ and $G_3$ – air flows

$G_p$ – dispersive particle flow

| | |
|---|---|
| Plasma torch power, kW | 50 – 120 |
| Air flow rate ($G_{1,2,3}$), $10^{-3}$ kg/s | 9 – 41 |
| Air flow rate at the cathode ($G_1$), $10^{-3}$ kg/s | 1,7 – 1,8 |
| Air flow rate at the anode ($G_2$), $10^{-3}$ kg/s | 7 – 24 |
| Additional air flow rate ($G_3$), $10^{-3}$ kg/s | 1 – 9 |
| Propane gas rate ($G_d$), $10^{-3}$ kg/s | up to 1,2 |
| Dispersive particle flow rate, $10^{-3}$ kg/s | up to 6 |
| Plasma flow temperature, without ($C_3H_8$), K | 1440 – 3600 |
| Plasma flow temperature, with ($C_3H_8$), K | 1950 – 4270 |
| Plasma flow velocity, m/s | 400 – 1100 |



# Experiment

| | | |
|---|---|---|
| Plasma torch current | I, A | 160 |
| Plasma torch voltage | U, V | 404 |
| Cooling water flow rate | $G_v$, kg/s | PT – 1,23<br>1st section – 0,26<br>2nd section – 0,26<br>3rd section – 0,24<br>4th section – 0,26 |
| Cooling water temperature difference | $\Delta t_v$, K | PT – 2,4<br>1st section – 3,3<br>2nd section – 2,2<br>3rd section – 2,1<br>4th section – 1,9 |
| Air flow rate | $G_a$, kg/s | $17{,}7 \cdot 10^{-3}$ |

- Plasma torch power:

$$P = I \cdot U = 160(A) \cdot 404(V) = 64{,}6(kW)$$

- Heat losses to the cooling water:

$$Q_w = G_w \cdot \Delta t_w \cdot c_p = 1{,}23(kg/s) \cdot 2{,}4(K) \cdot 4{,}187 \cdot 10^3 (J/kgK) = 12{,}6(kW)$$

- Plasma flow heat:

$$Q_f = P - Q_v = 64{,}6(kW) - 12{,}6(kW) = 52(kW)$$

- Plasma torch efficiency:

$$\eta = \frac{Q_f}{P} = \frac{52(kW)}{64{,}6(kW)} = 0{,}8 \cdot 100\% = 80\%$$

$I$ – arc current
$U$ – arc voltage
$G_v$ – cooling water rate
$\Delta t_v$ – cooling water temperature increase
$c_p$ – specific heat of water
$G_0$ – plasma forming air flow

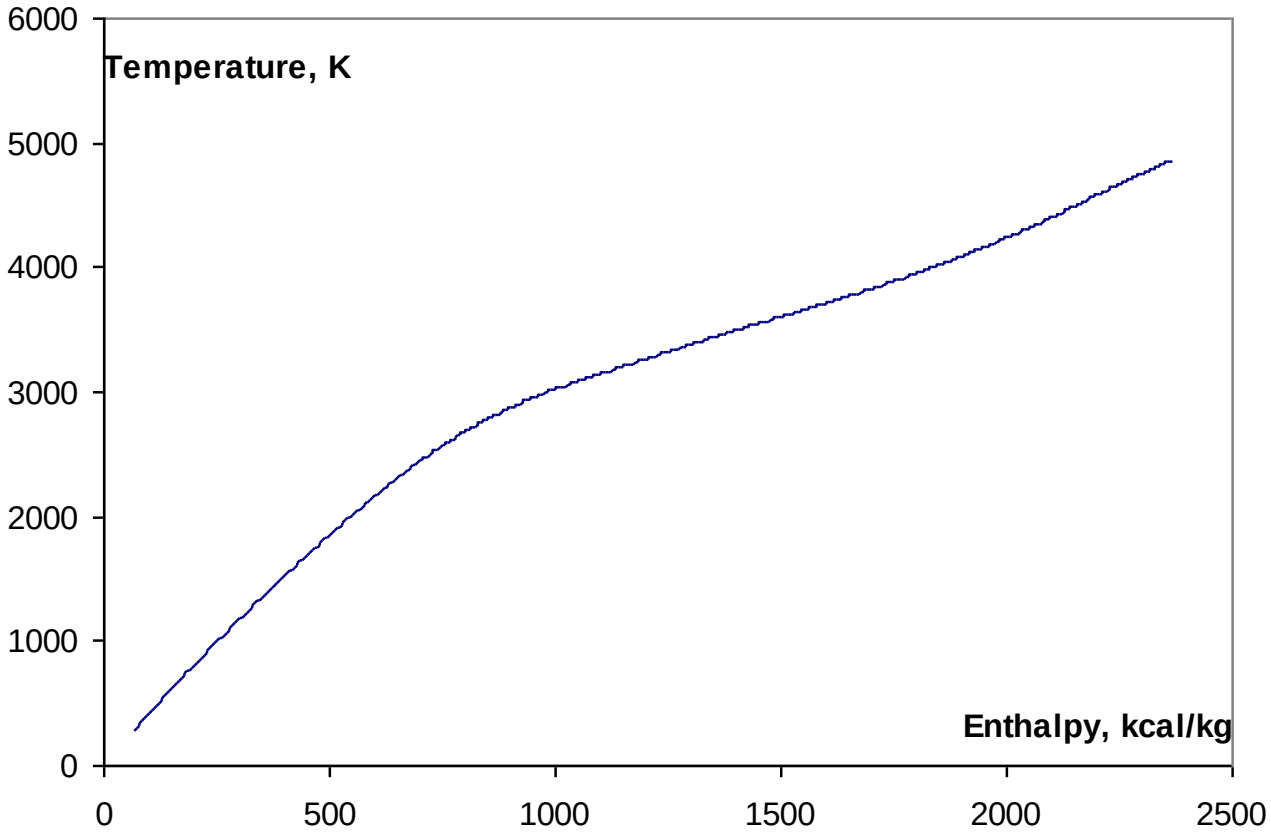
- Average flow enthalpy:

$$H_f = \frac{Q_f}{G} + H_0 = \frac{P - \sum Q_w}{G_0 + G_t} + H_0 = 238{,}8 \frac{64{,}6(kW) - 12{,}6(kW)}{17{,}8 \cdot 10^{-3}(kg/s)} + 65(kcal/kg) = 602{,}6(kcal/kg)$$

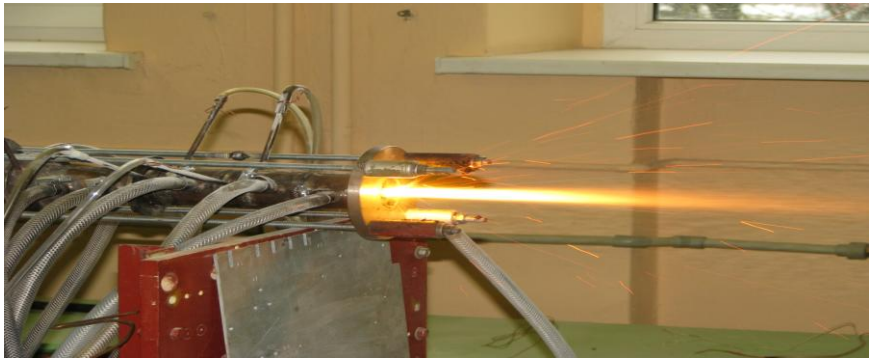
- The plasma flow velocity:

$$w = \frac{4GRT_f}{\pi d^2 p} = \frac{4 \cdot 28{,}7(J/kg/K) \cdot 17{,}8 \cdot 10^{-3}(kg/s) \cdot 2600(K)}{3{,}14 \cdot (0{,}016 \cdot 10^{-3} m)^2 \cdot 10^5 (Pa)} = 660(m/s)$$

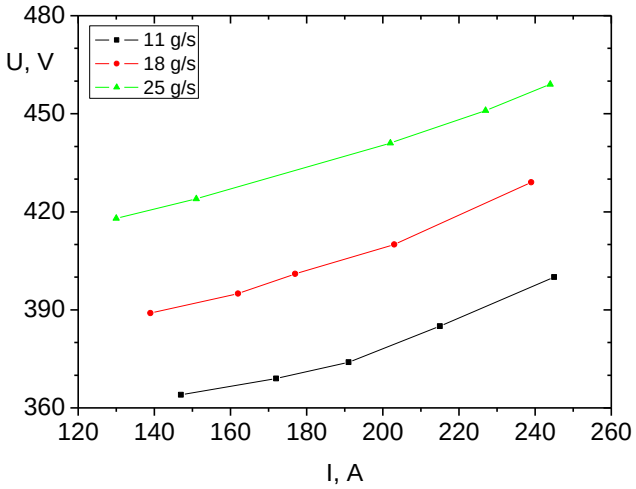
# Plasma flow enthalpy vs. temperature

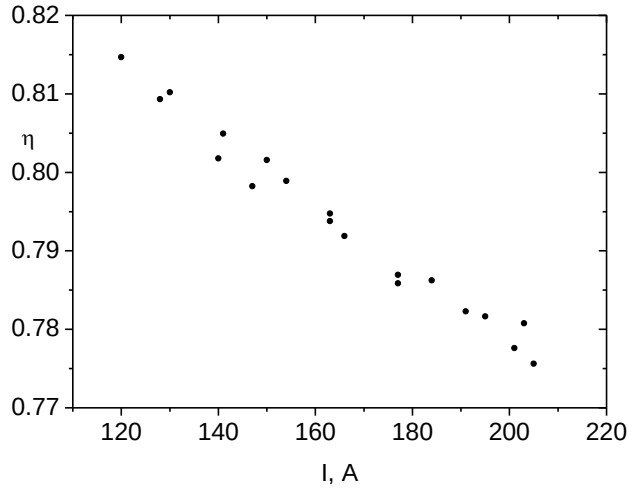


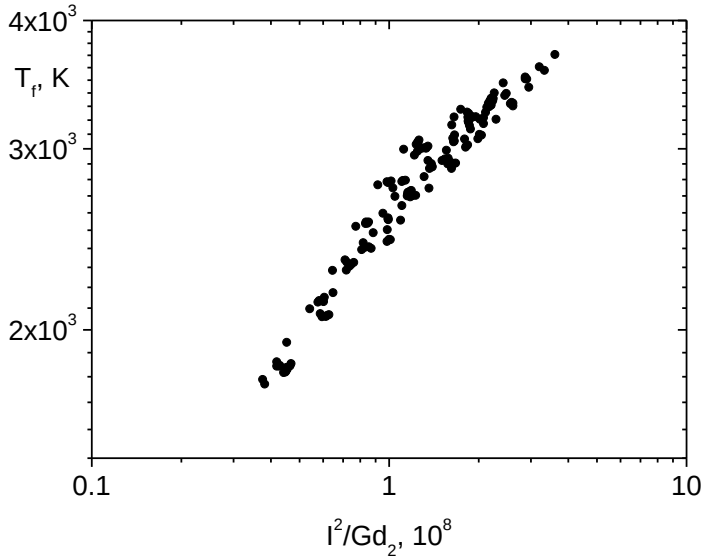
After some more identical experiments and calculations…



# Plasma torch characteristics

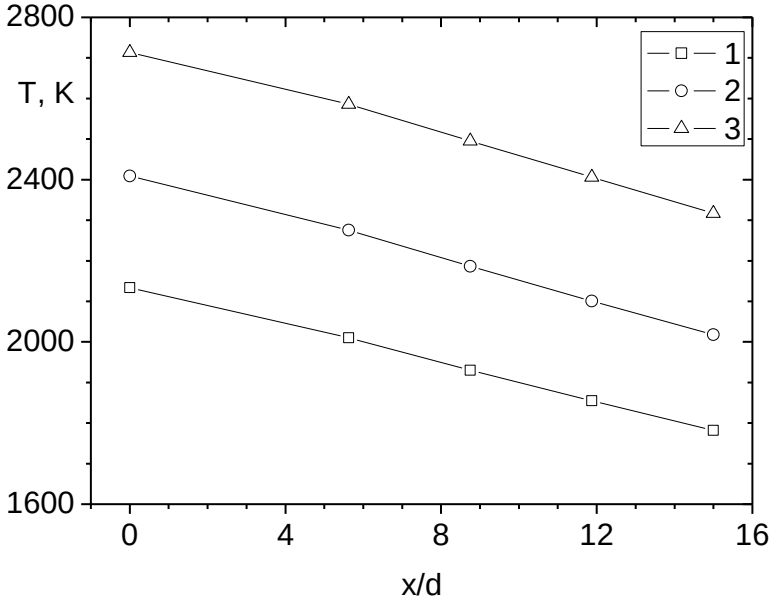


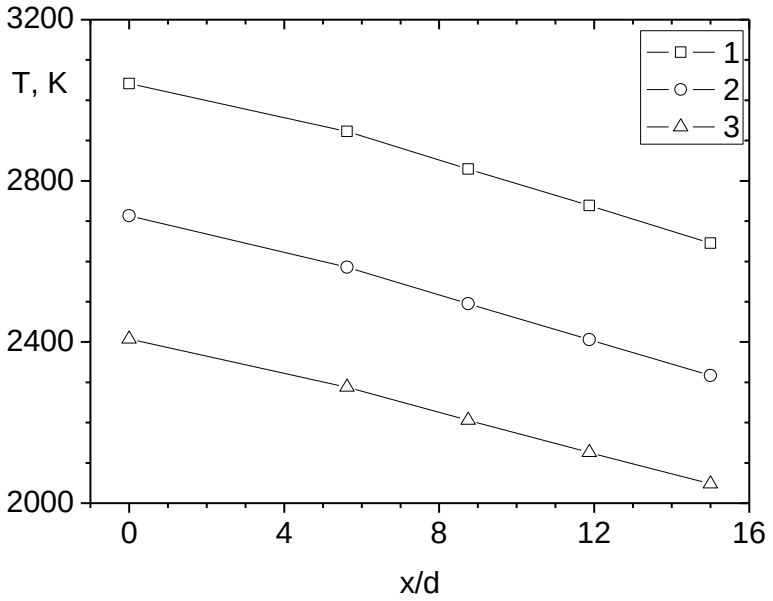

$$T_f = 5\left(\frac{I^2}{Gd_2}\right)^{0,34}$$

# Plasma flow temperature distribution in the plasma-chemical reactor




PT power: 1 – 56 kW, 2 – 66 kW, 3 – 81 kW.

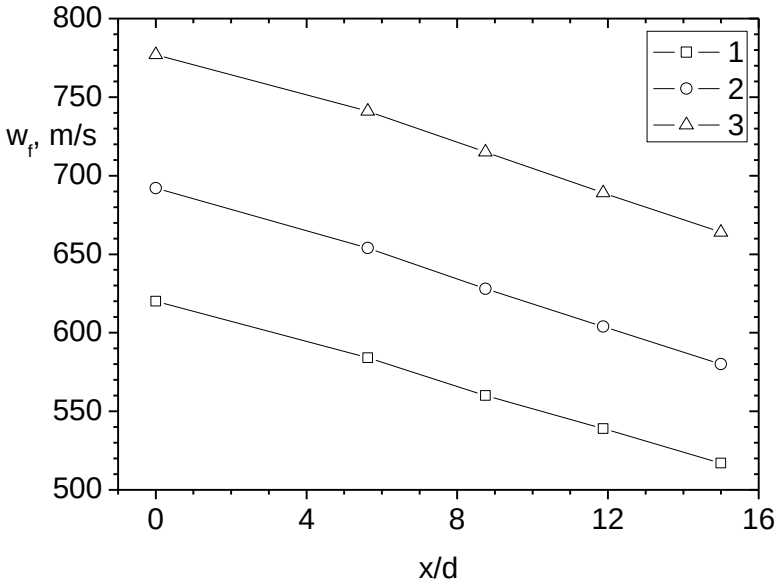
$G_{1.2}$ - $20 \cdot 10^{-3}$ kg/s




$G_{1.2}$ : 1 – $16 \cdot 10^{-3}$ kg/s, 2 – $20 \cdot 10^{-3}$ kg/s, 3 – $25 \cdot 10^{-3}$ kg/s

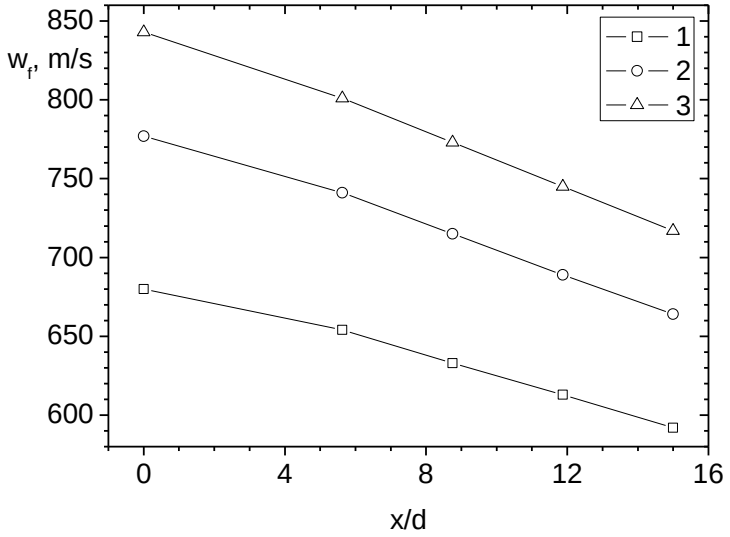
PT power: 81 kW.

# Plasma flow velocity distribution in the plasma-chemical reactor




PT power: 1 – 56 kW, 2 – 66 kW, 3 – 81 kW.

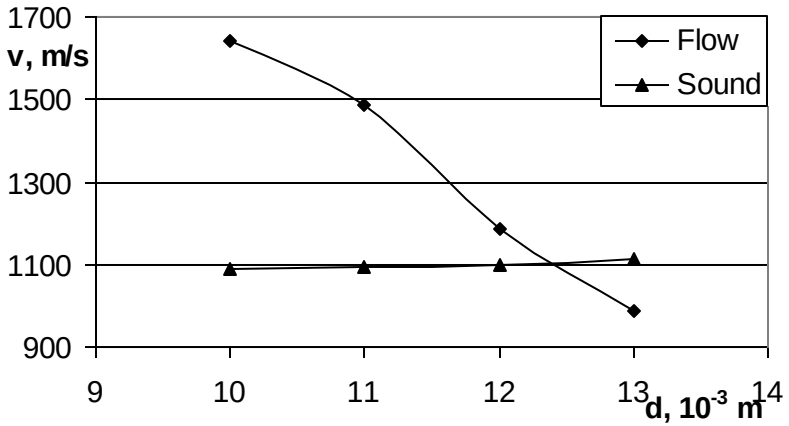
$G_{1.2}$ - $20 \cdot 10^{-3}$ kg/s

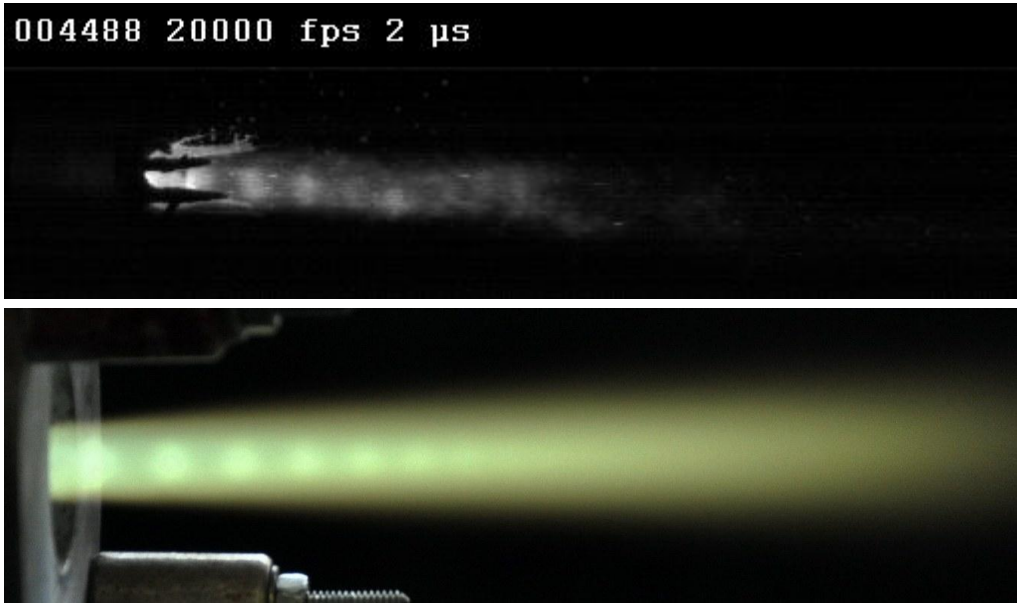



$G_{1.2}$ : 1 – $16 \cdot 10^{-3}$ kg/s, 2 – $20 \cdot 10^{-3}$ kg/s, 3 – $25 \cdot 10^{-3}$ kg/s

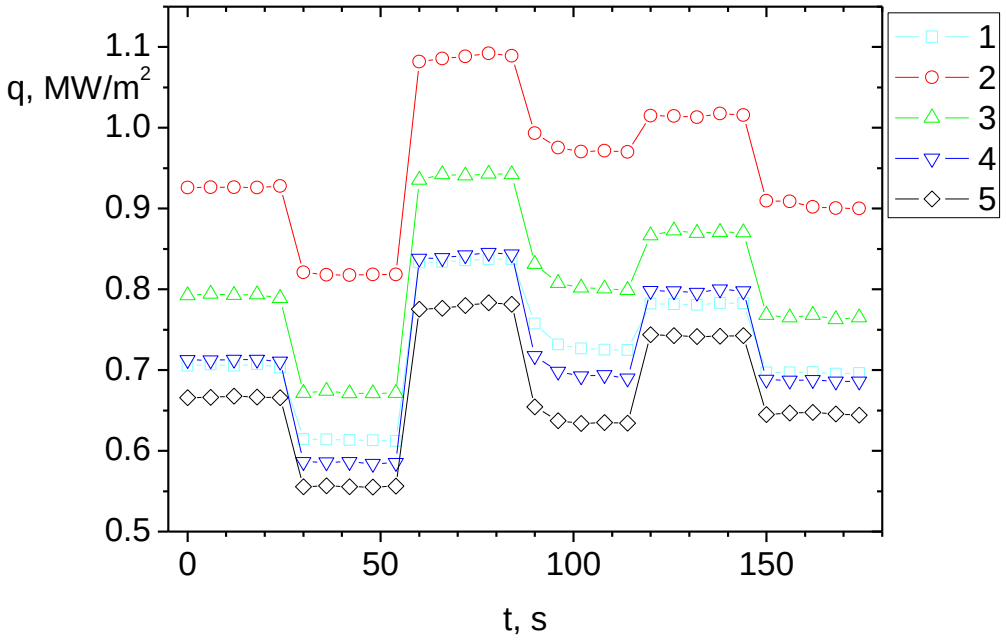
PT power: 81 kW.

# The supersonic plasma flow



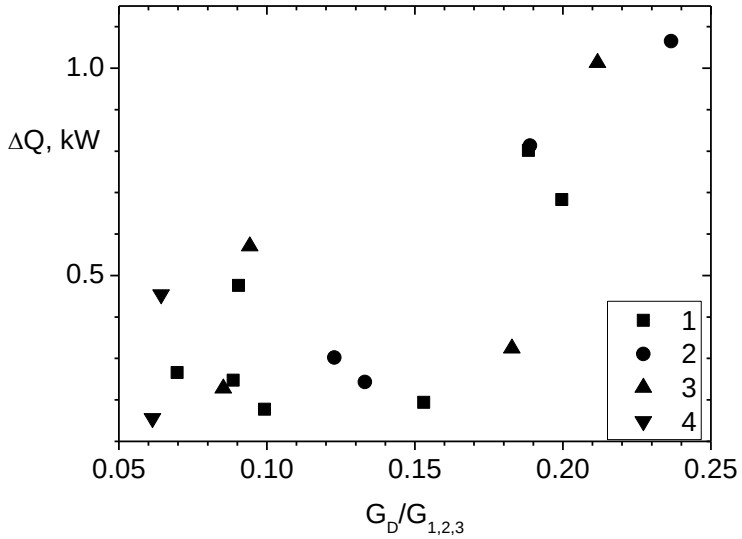
# Interaction between plasma flow and dispersive particles

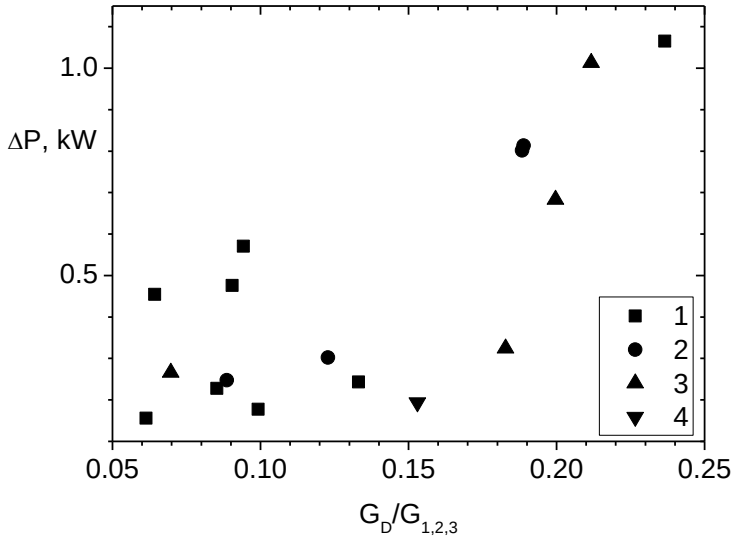



$Al_2O_3$
3,3 g/s
0,04 – 0,06 mm

| P, kW | 53 | 62 | 62 |
|---|---|---|---|
| $G_{1,2}$, g/s | 12 | 12 | 16 |
| $G_3$, g/s | 1,5 | 1,5 | 1,5 |

# Interaction between plasma flow and dispersive particles



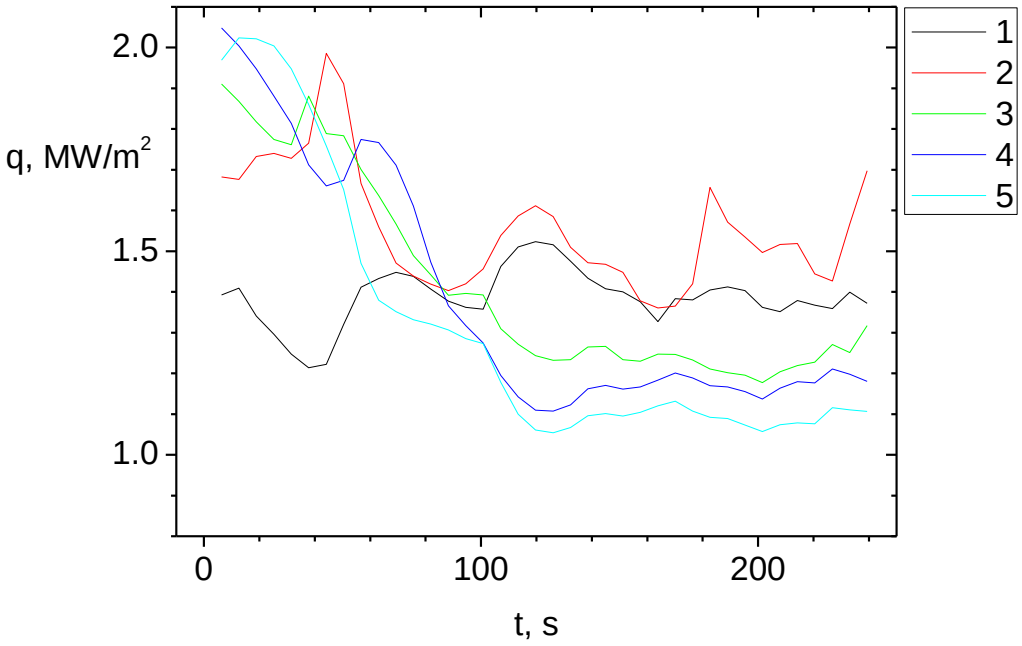




- 1 – $SiO_2$,
- 2 – $Al_2O_3$,
- 3 – $Al(OH)_3$,
- 4 – zeolite.

- 1 – 0.04-0.06 mm,
- 2 – 0.06-0.16 mm,
- 3 – 0.16-0.2 mm,
- 4 – 0.2-0.25 mm.

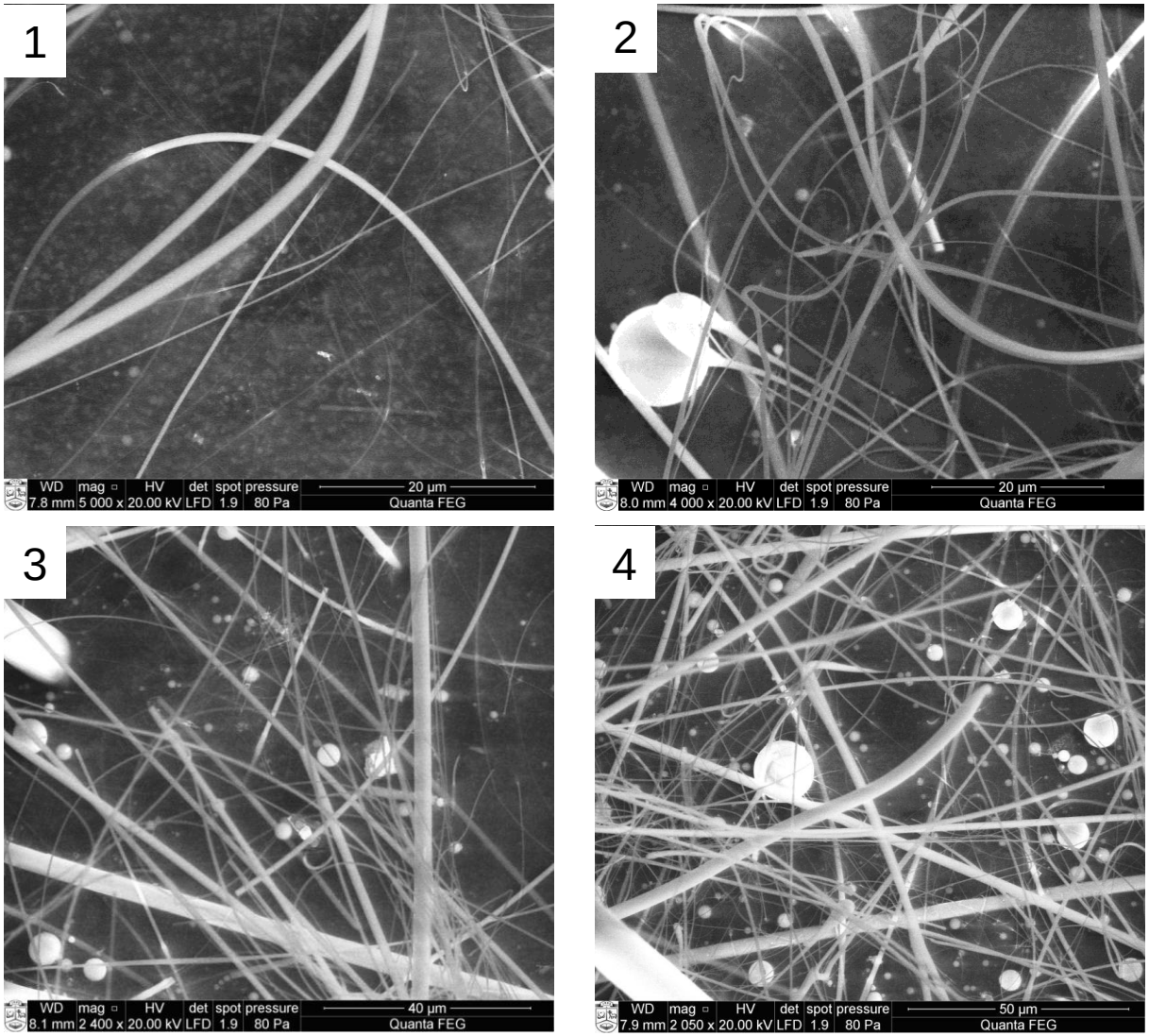
| P, kW | $G_{12}$, g/s | $G_3$, g/s |
|---|---|---|
| 65 | 16 | 1.6 |

# Interaction between plasma flow and dispersive particles



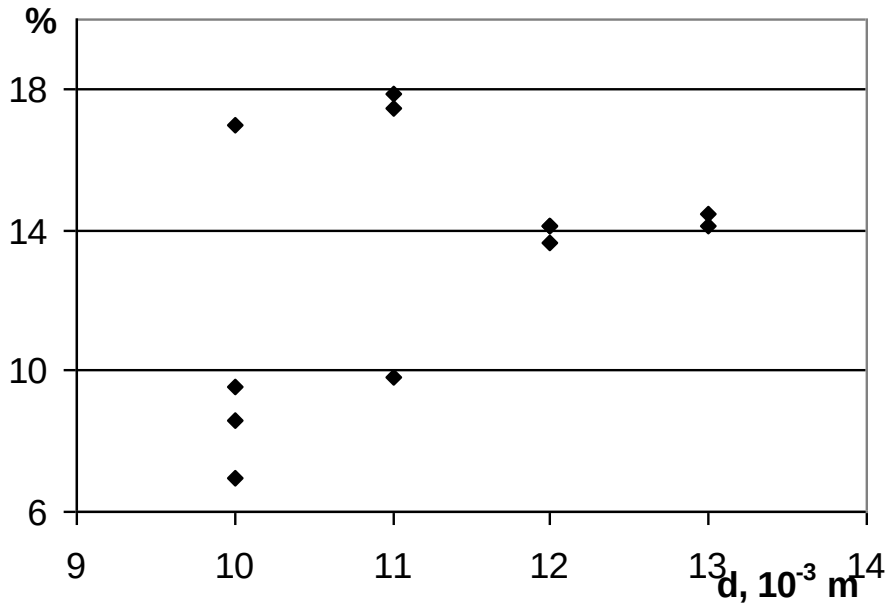

| P, kW | $G_{12}$, g/s | $G_3$, g/s | $G_d$, g/s |
|---|---|---|---|
| 78 | 12 | 1 | 0.8 |

Zeolite
1,2 g/s
0,04 – 0,06 mm




SEM images of zeolite fibre morphology dependence on outlet diameter:
1 – 0.01 m, 2 – 0.011 m, 3 – 0.012 m, 4 – 0.013 m

# Mineral fibre output




Fibre output dependence on outlet nozzle diameter


Thank You for Attention!