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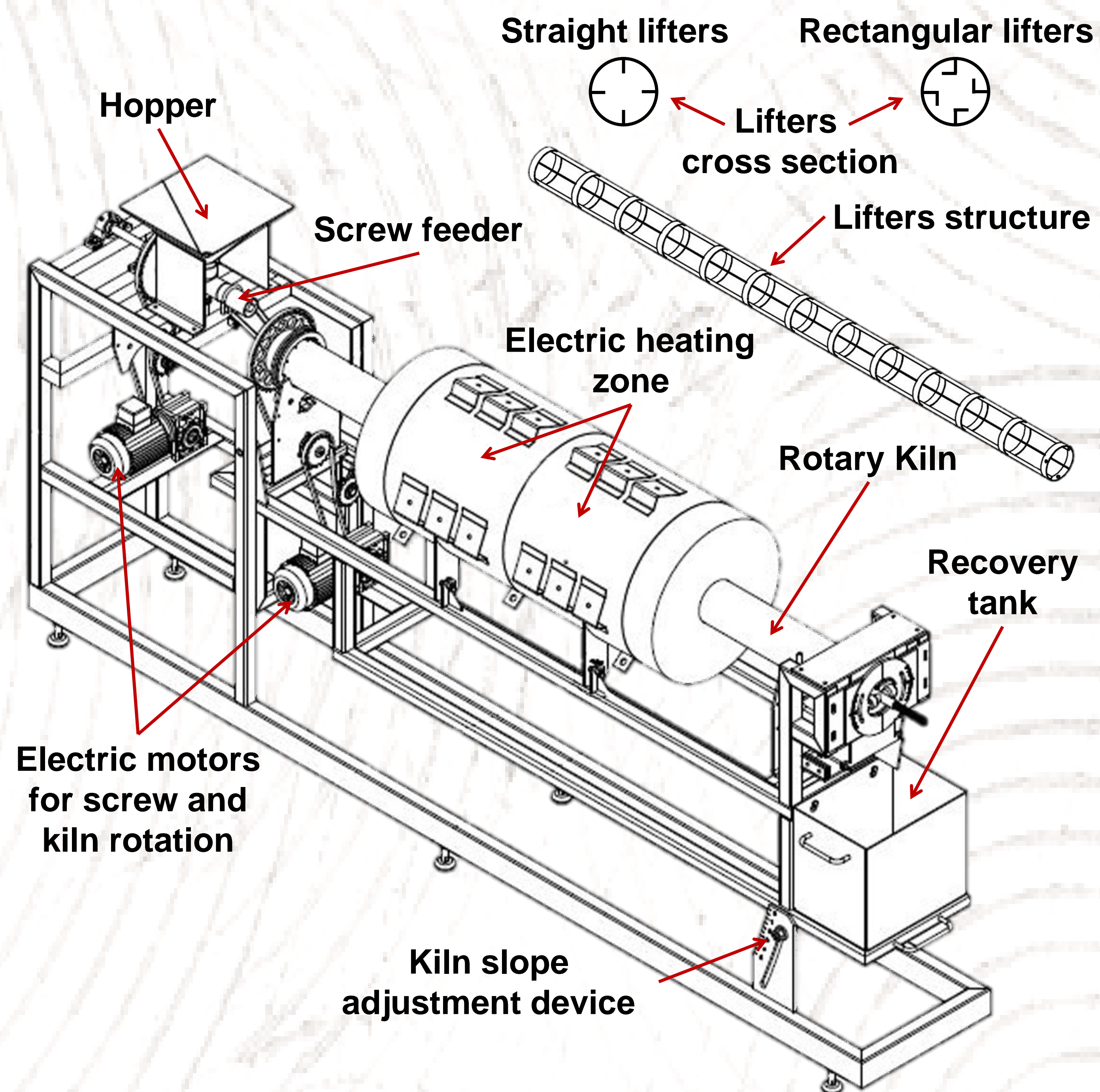
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## Introduction

Rotary kilns are **gas-solid reactors** widely used in mineral process applications (cement, lime, ore reduction) as well as solid waste pyrolysis or uranium dioxide production for the manufacture of nuclear fuel. The device is generally an inclined cylinder, which can be either directly or indirectly heated, equipped or not with lifters, and rotated axially.

Among parameters affecting the performance of a rotary kiln, one of the most important is the **mean residence time of solids (MRT)**. Hence, it is worth to characterise the influence of operational variables on this key parameter.

To achieve this goal, **residence time distribution (RTD) measurements** were operated using the tracer impulse-response technique.



## Experimental setup

RTDs and associated mean residence times were investigated in a **pilot rotary kiln** ( $L = 1.95$  m and  $D = 0.1$  m), equipped with **straight lifters (SL)** or **rectangular lifters (RL)**. The bulk material was nodular sand (angle of repose  $\theta = 39^\circ$ , density  $\rho = 1460$  kg.m<sup>-3</sup>), the tracer was sodium chloride, both within a size range of **0.4-0.8 mm**.

In presence of lifters, four other operational variables were studied: (1) the kiln rotational speed, (2) the kiln slope, (3) the height of the dam at the exit end, and (4) the feed rate of solid.

Parameters	Range
Kiln rotation speed (N)	2–12 rpm
Kiln slope (S)	1–5°
Dam height (H)	0–33.5 mm
Solid feed rate ( $\dot{M}$ )	0.5–2.5 kg.h <sup>-1</sup>
Lifters (removable)	Straight–Rectangular

## Results: RTD curves

### Rectangular Lifters

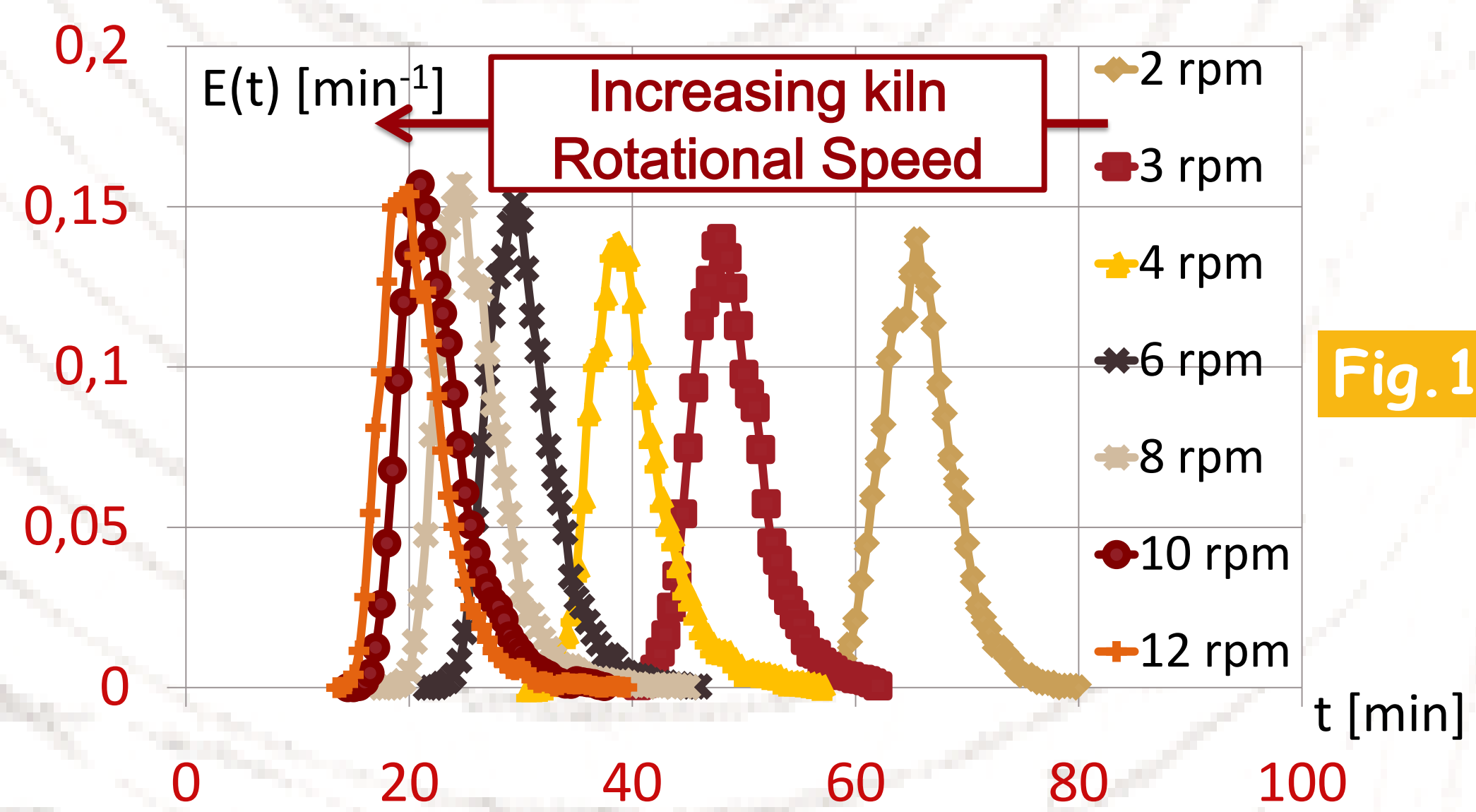


Fig. 1

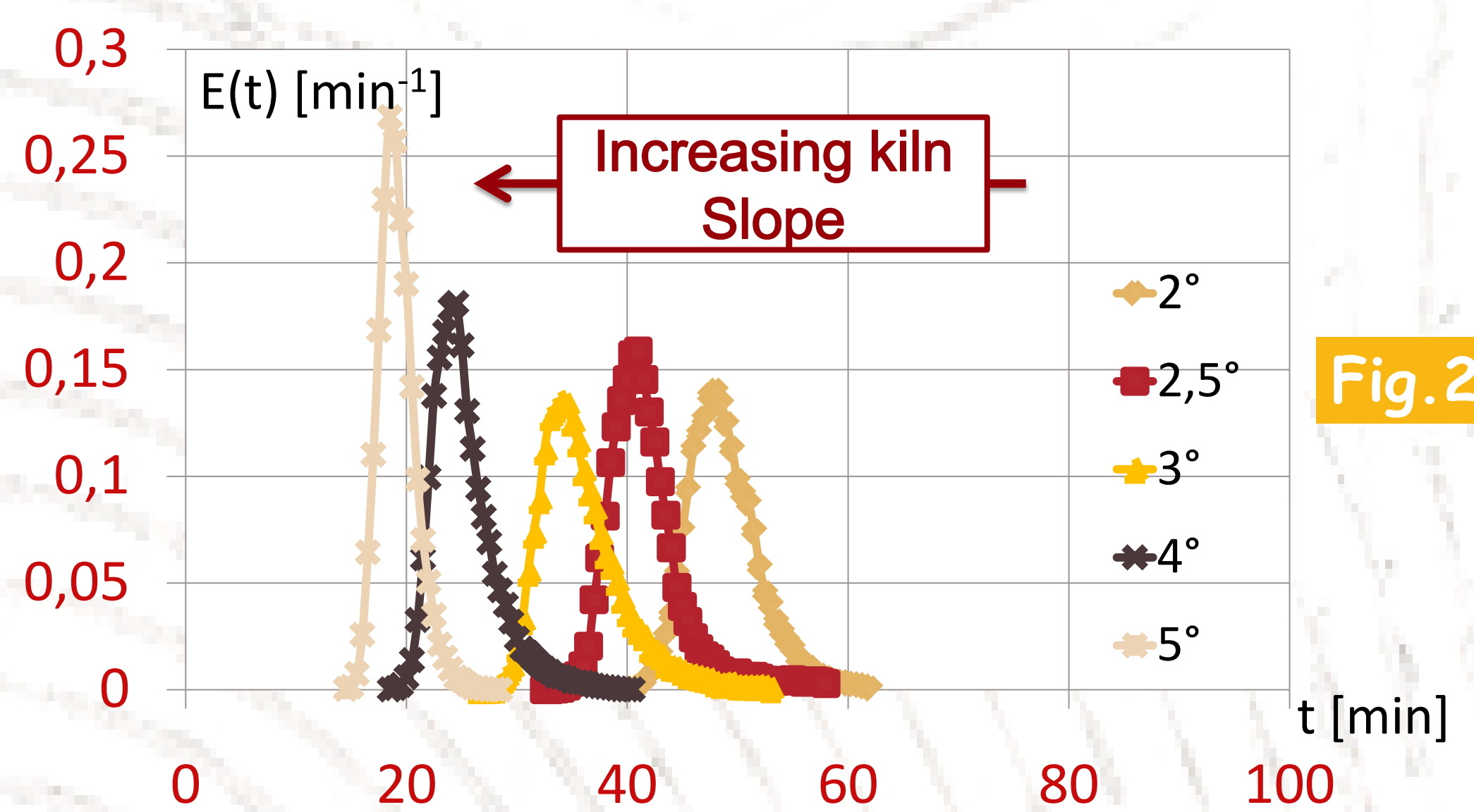


Fig. 2

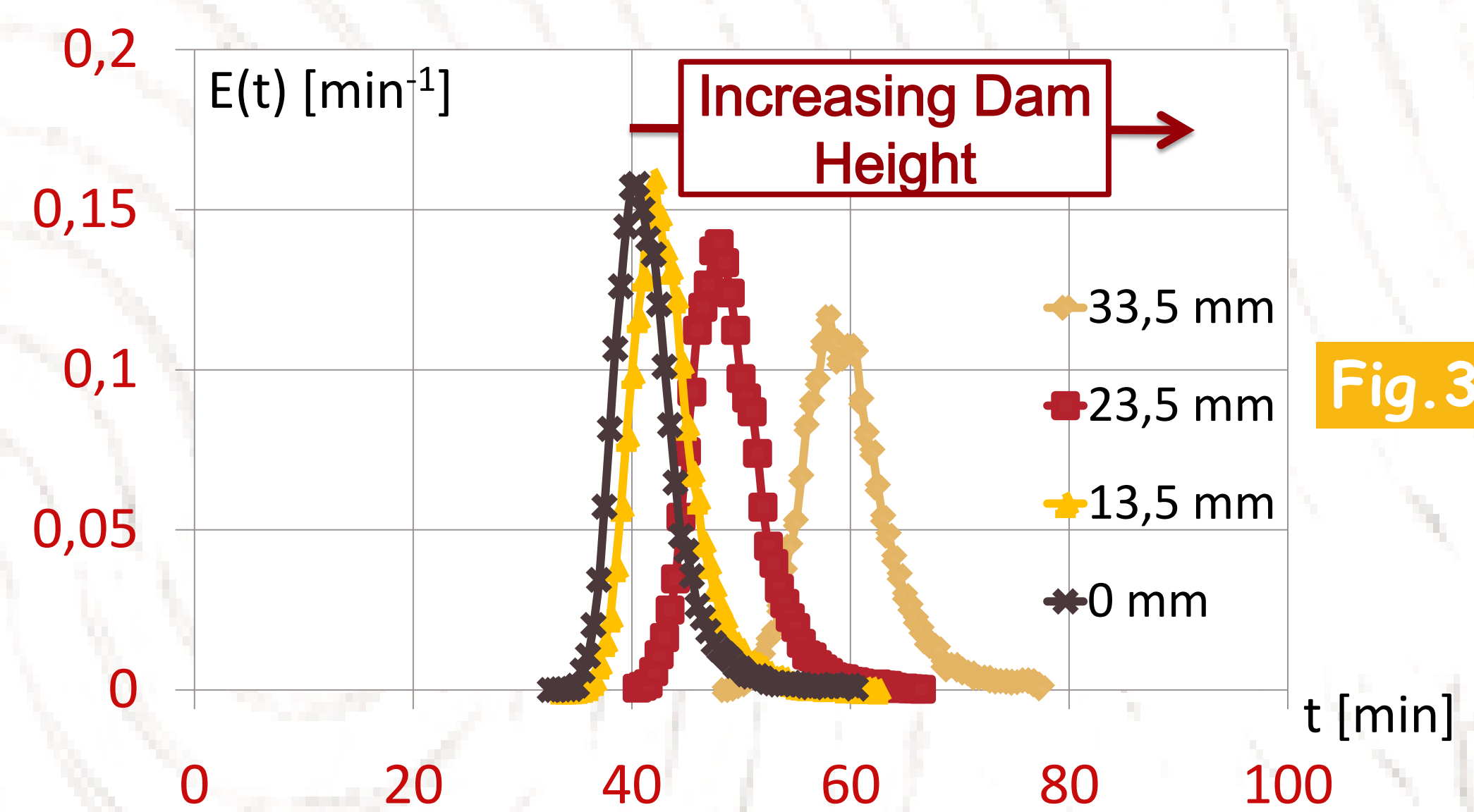


Fig. 3

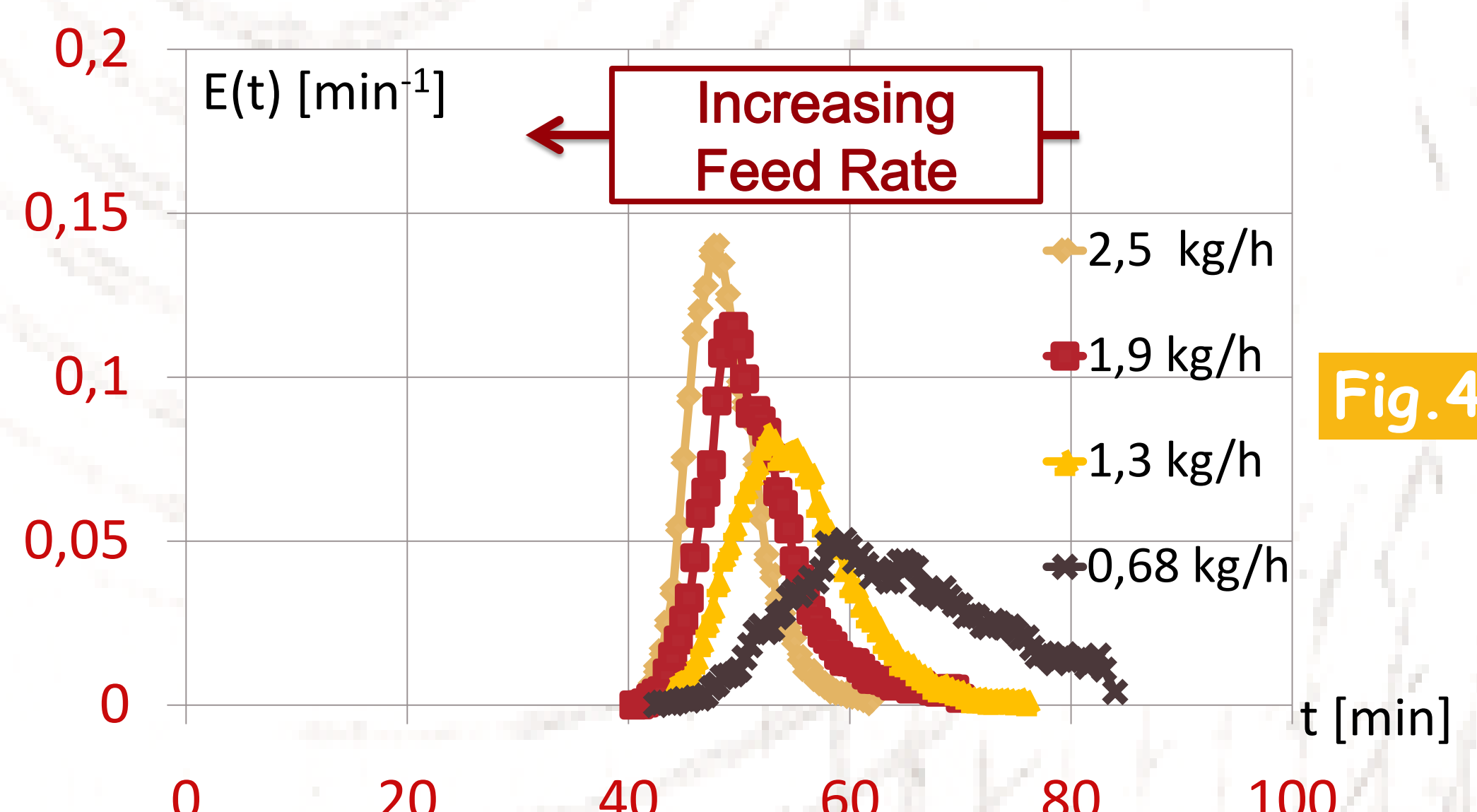


Fig. 4

## Experimental rotary kiln layout

### Effect of operational variables

#### Influence of kiln rotation speed:

As the rotation speed increases from 2 to 12 rpm, RTD curves shift towards lower residence time region (Fig. 1) so that the MRT decreases significantly by 69% (Fig. 5).

#### Influence of kiln slope:

By increasing the kiln slope from 2 to 4°, the MRT significantly decreases (Fig. 6) and RTD curves show a gradual change in shape (Fig. 2).

#### Influence of exit dam height:

The MRT slowly increases with increasing the dam height (Fig. 7), sidewise the spread of corresponding RTD curves decreases (Fig. 4).

#### Influence of solid feed rate:

When the solid feed rate decreases, RTD curves gradually spread and flatten (Fig. 4) while slowly moving forward so that the MRT increases (Fig. 8).

#### Influence of lifters:

Rectangular lifters can lift a volume of solid material 3 times bigger than straight lifters. From Fig. 5-8, it is apparent that the MRT decreases by 3 to 4 min when replacing rectangular lifters by straight lifters.

## Correlation

On the basis of the experimental data, the following semi-empirical equation was obtained to determine the mean residence time in rotary kiln equipped with lifters:

$$MRT = 0,0111375 \times \frac{L^3}{V_m} \times \left(\frac{\omega^2 D}{2g}\right)^{-0,366} \times \left(\exp\left(\frac{2H}{D}\right)\right)^{0,463} \times \left(\frac{\theta}{S}\right)^{0,943} \times \left(\frac{L^3 \omega}{V_s}\right)^{0,7945} \times \left(\exp\left(\frac{V_L}{V_T}\right)\right)^{7,5}$$

Where

- MRT = the mean residence time, min
- L = the length of the kiln, m
- D = the internal diameter of the kiln, m
- $\dot{V}_m, \dot{V}_s$  = the volumetric bulk material feed rate, m<sup>3</sup>.min<sup>-1</sup>, m<sup>3</sup>.s<sup>-1</sup>
- $\omega$  = the angular rotation speed, s<sup>-1</sup>
- g = the gravitational acceleration, m.s<sup>-2</sup>
- H = the exit dam height, m
- $\theta$  = the bulk material angle of repose, degrees
- S = the kiln slope, degrees
- $V_L$  = the maximum volume capacity of a lifter at horizontal position, m<sup>3</sup>
- $V_T$  = the kiln total volume, m<sup>3</sup>

## Results: MRT

### Straight & Rectangular Lifters

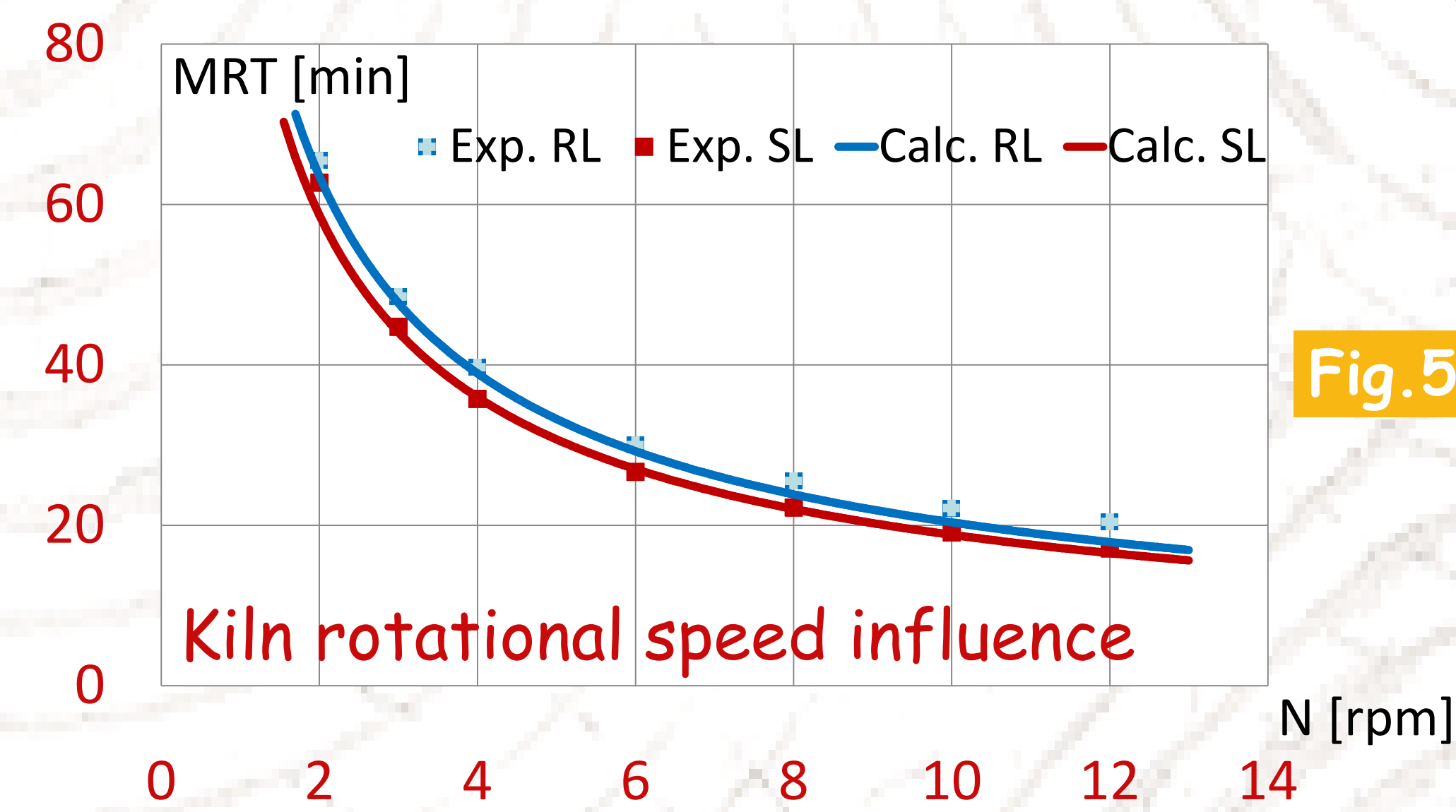


Fig. 5

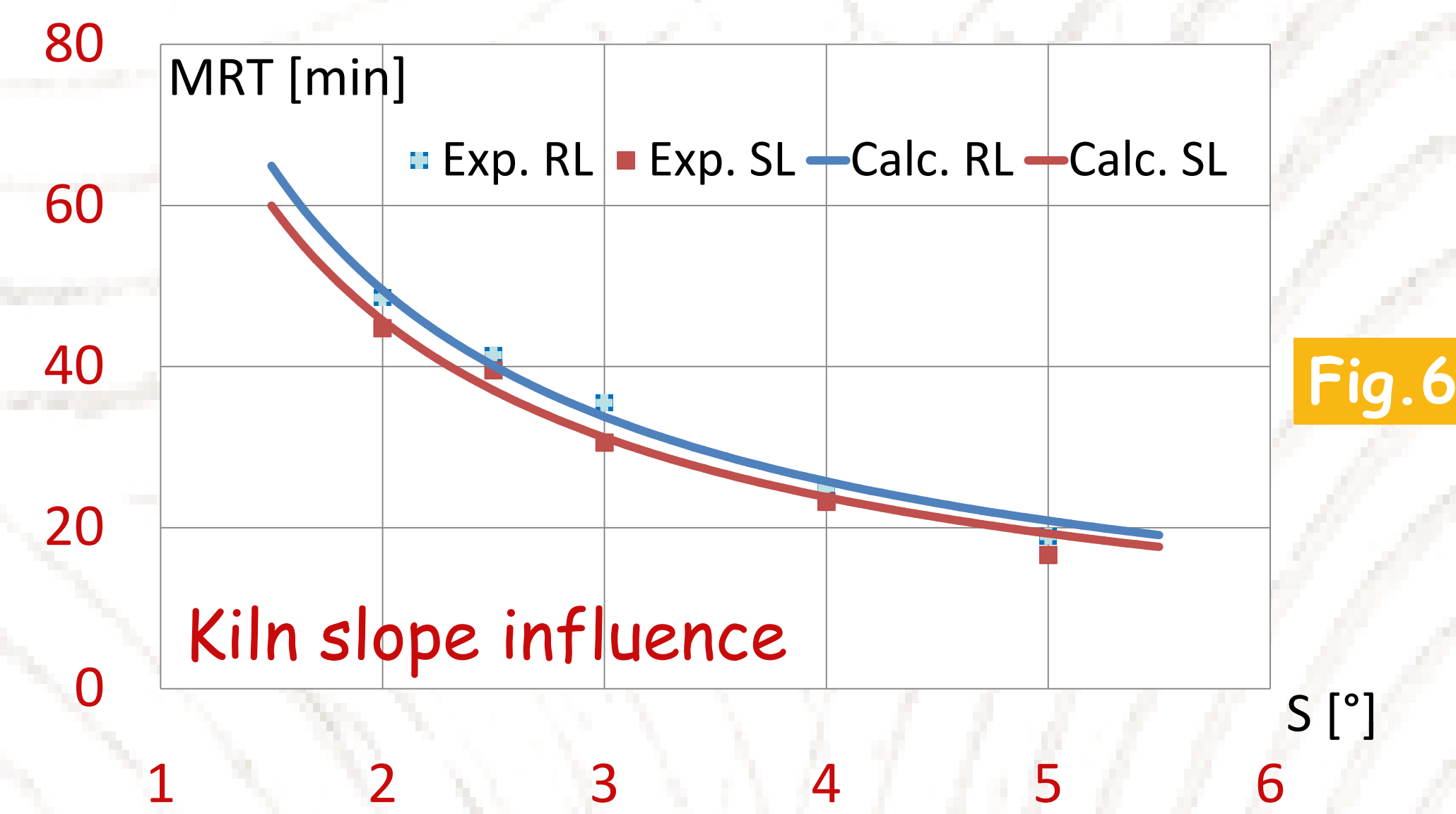


Fig. 6

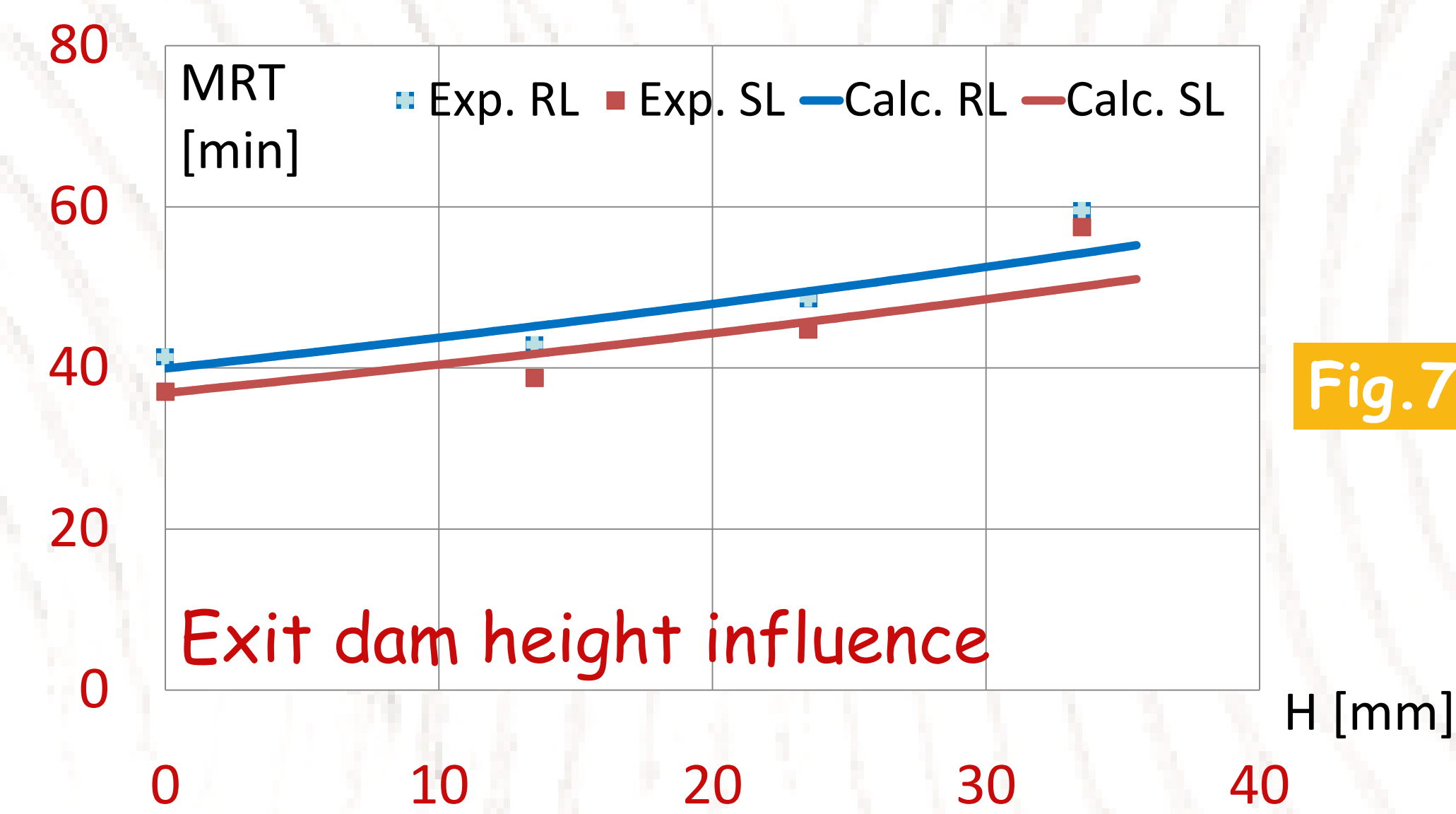


Fig. 7

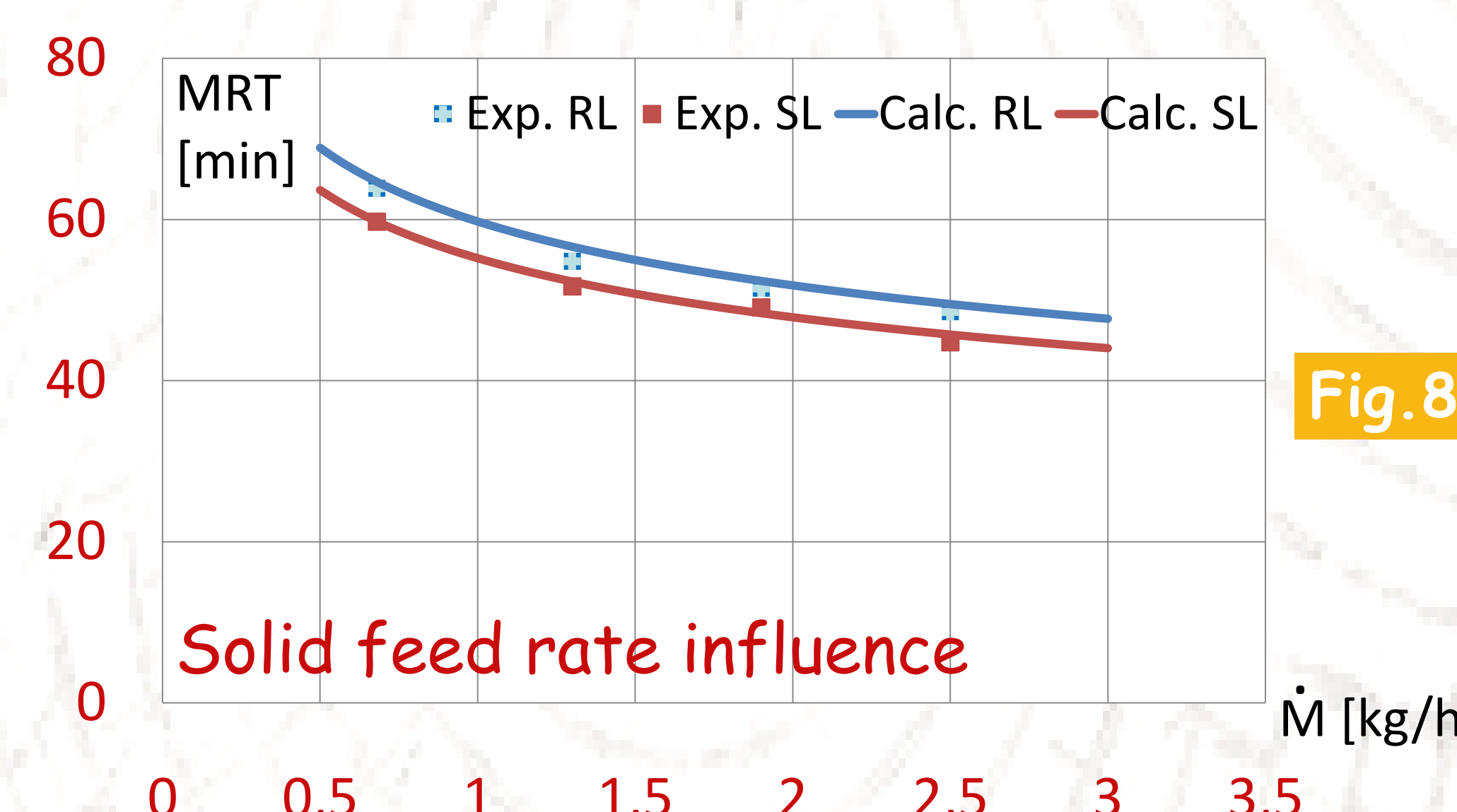


Fig. 8

## Conclusion

In a rotary kiln having longitudinally disposed lifters and using sand as bulk material, it was found that the mean residence time increases with the exit dam height. Conversely the mean residence time decreases with the increase in either rotational speed or slope of the kiln, or the bulk material feed rate. These results are consistent with previous research on rotary kilns without lifters.

From experimental data computation, the mean residence time could be correlated in term of operating parameters and physical characteristics of the rotary kiln. Good agreement is found between predicted and experimental results.

Future work will focus on determining effect of the particle size, the total number of lifters and the kiln scaling-up on the mean residence time.