

Online Analysis of Stirring Processes in Ladle Metallurgy

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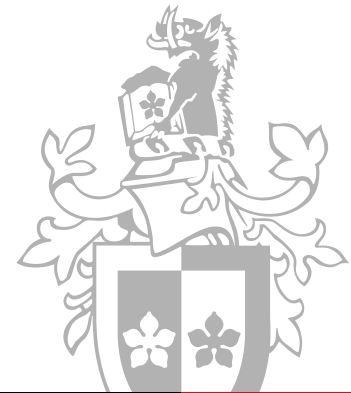
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Outline

1. Stirring Process
2. Measurement of Stirring
3. Cold Model Experiment
4. Analysis Strategy
5. Results

Stirring Process



Homogenization of temperature and chemical composition

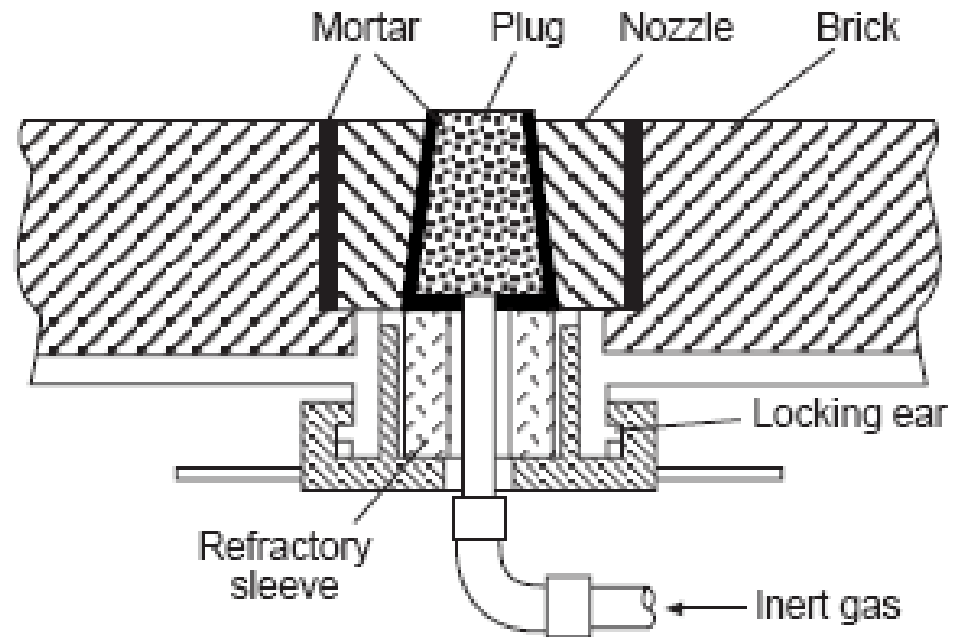
Enhance chemical reactions

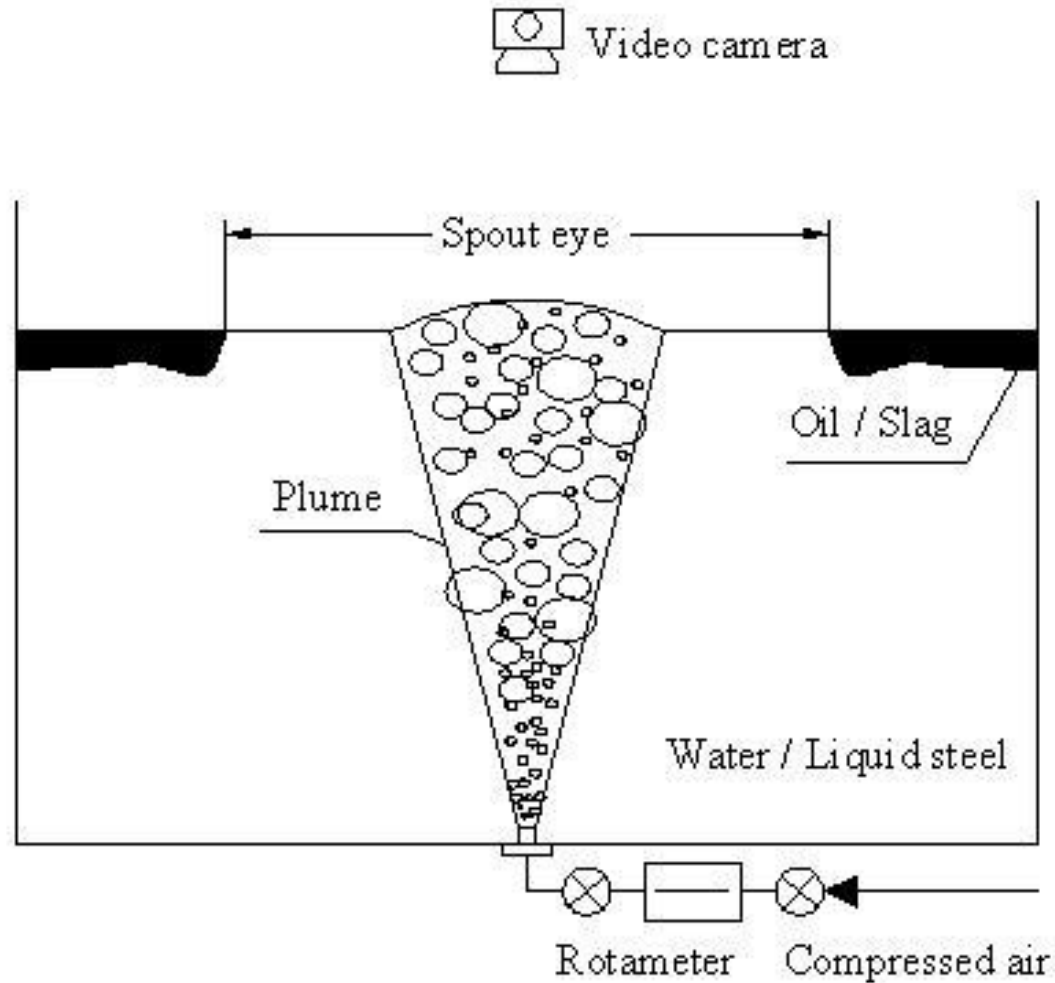


Measurement of stirring process

Current method: $P_{Gas-line}$ \dot{V}

- o Erosion
- o Leakage
- o Partially plugged

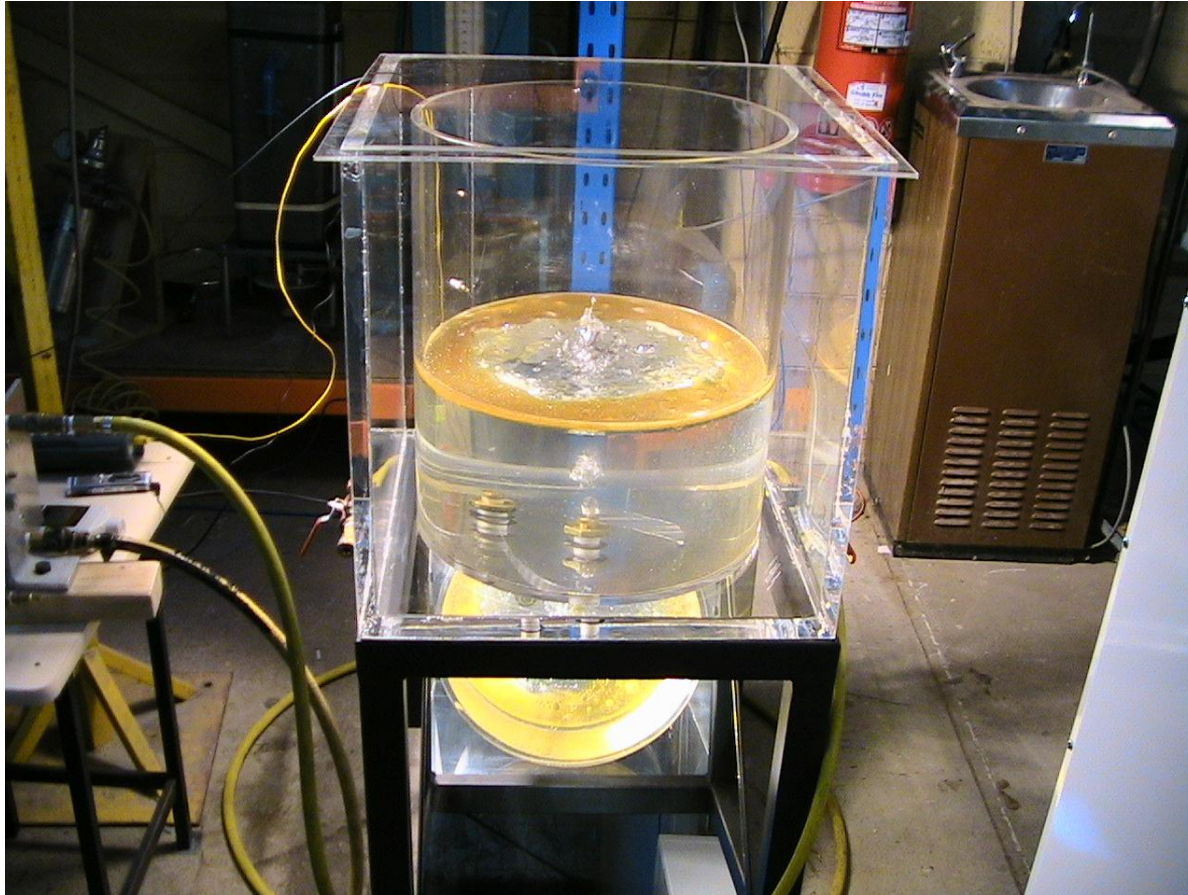




Schematic diagram of the cold modelling apparatus (Krishnakumar, and Irons)

Cold model rig

($H=500\text{mm}$, $D=420\text{mm}$, $Q=2\text{ lpm}-20\text{ lpm}$)



Rapid image analysis

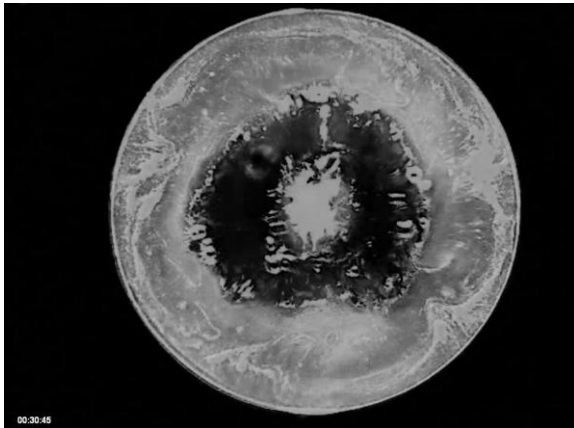


Image of Red channel

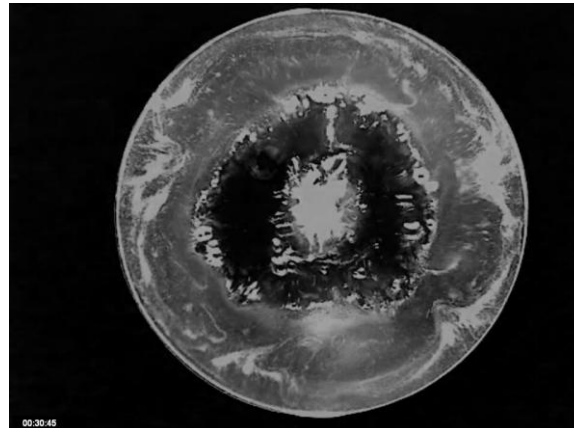


Image of Green channel

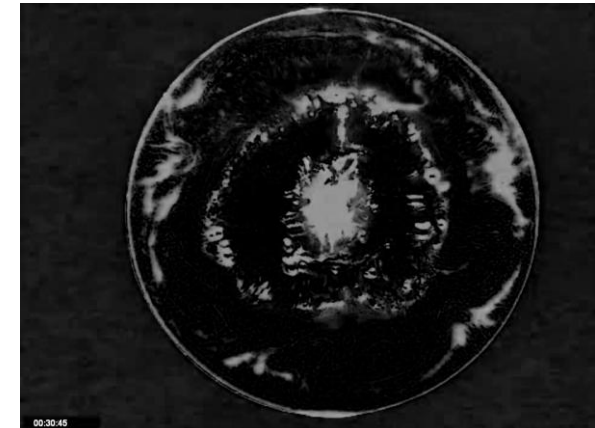
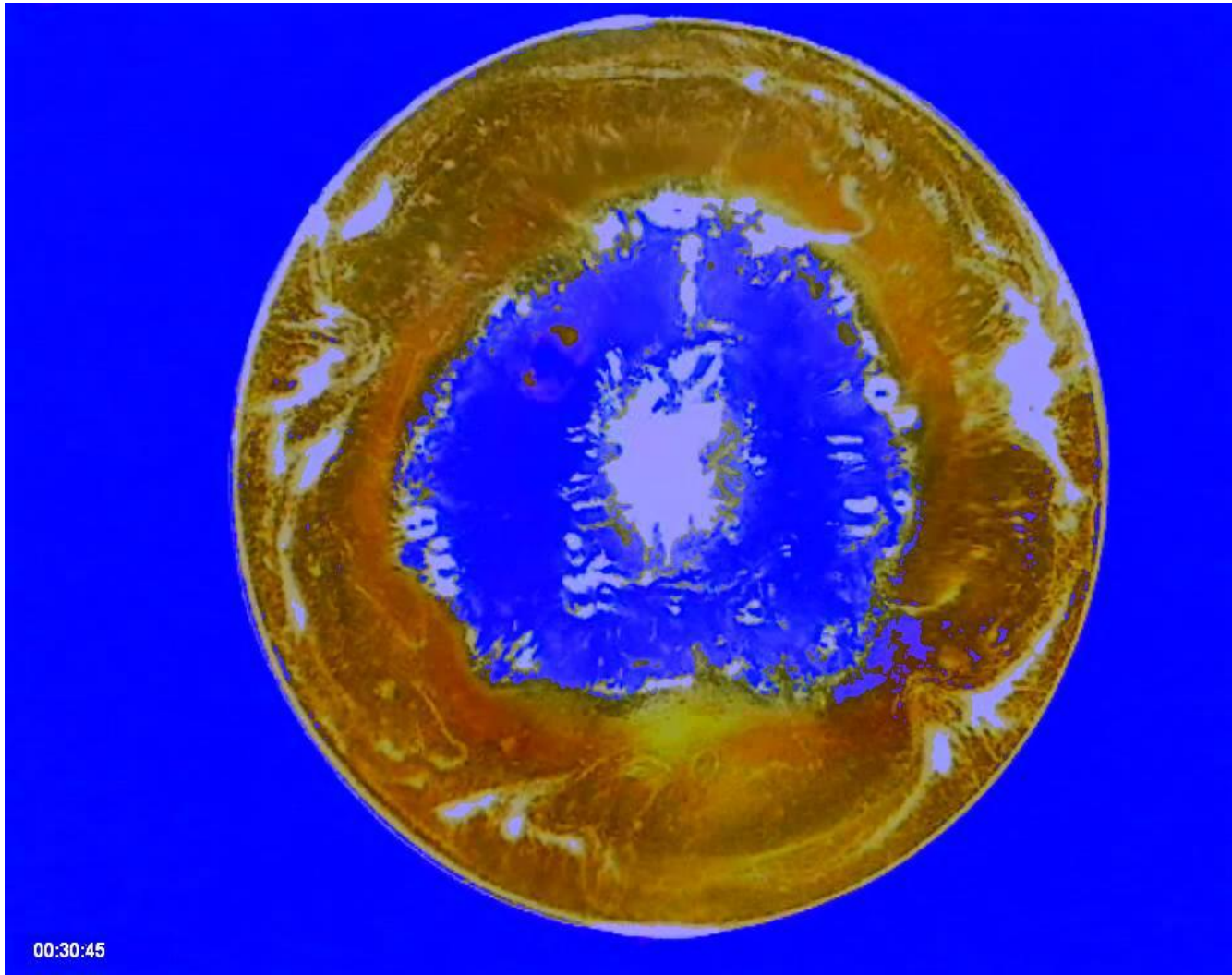
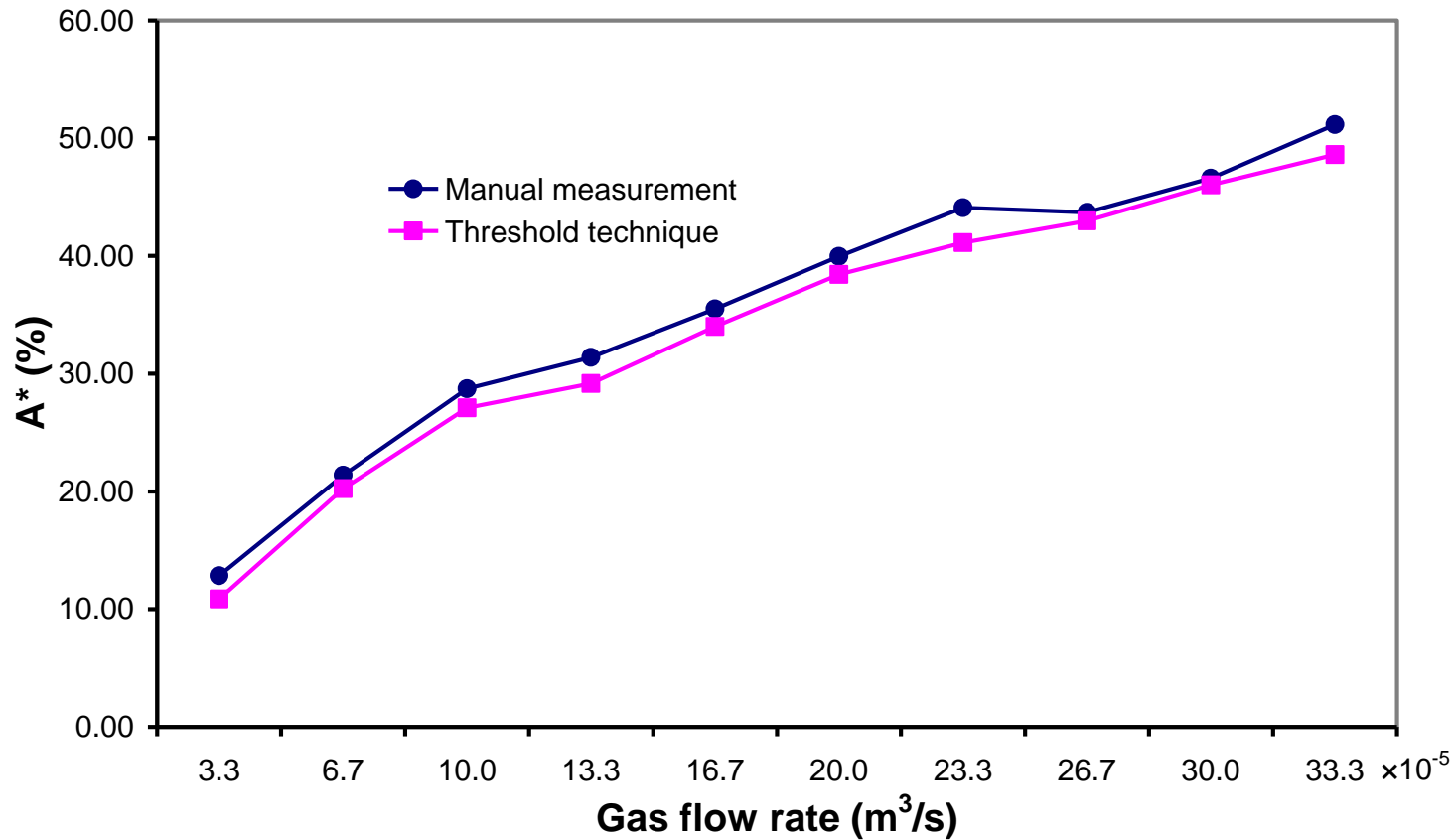
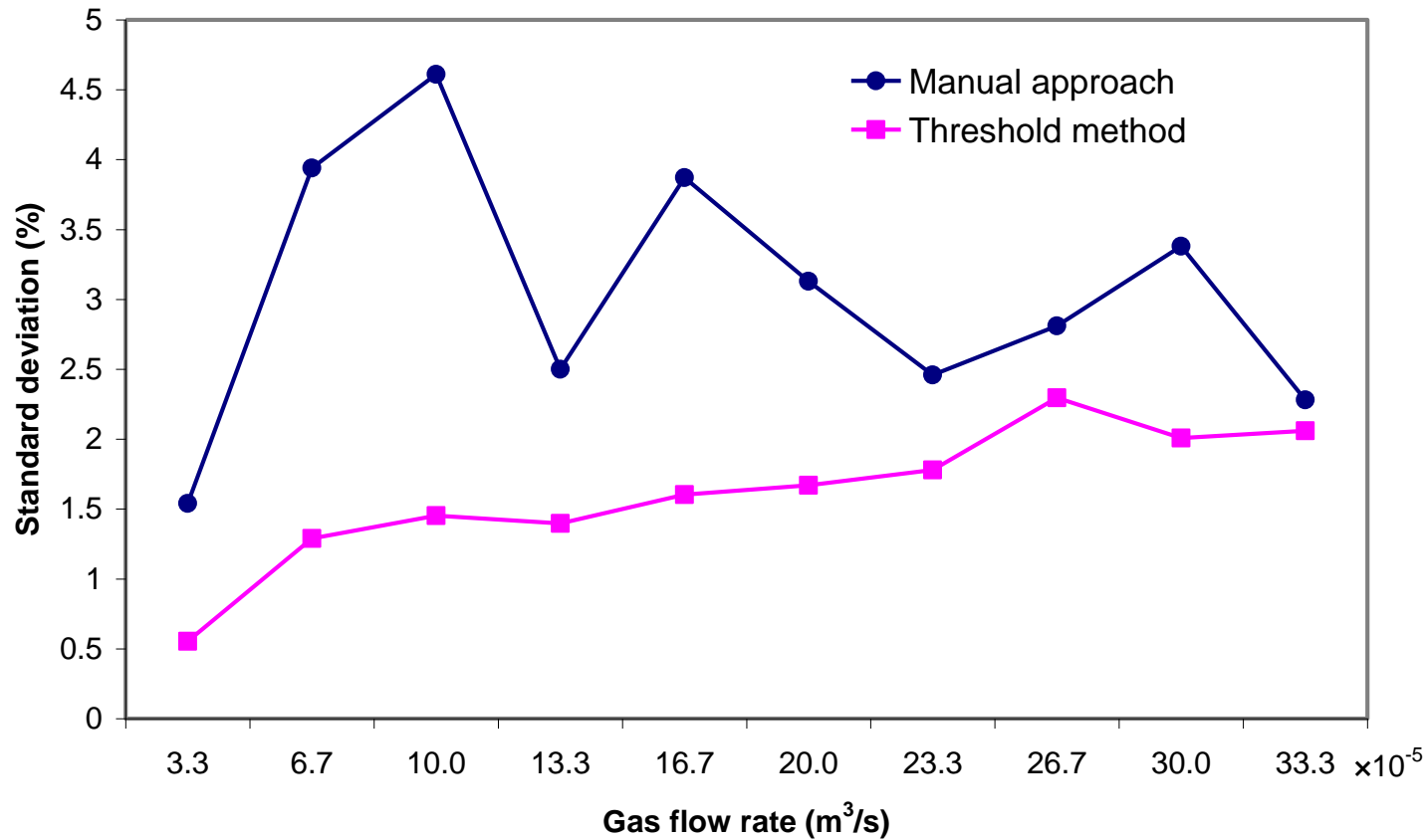


Image of Blue channel

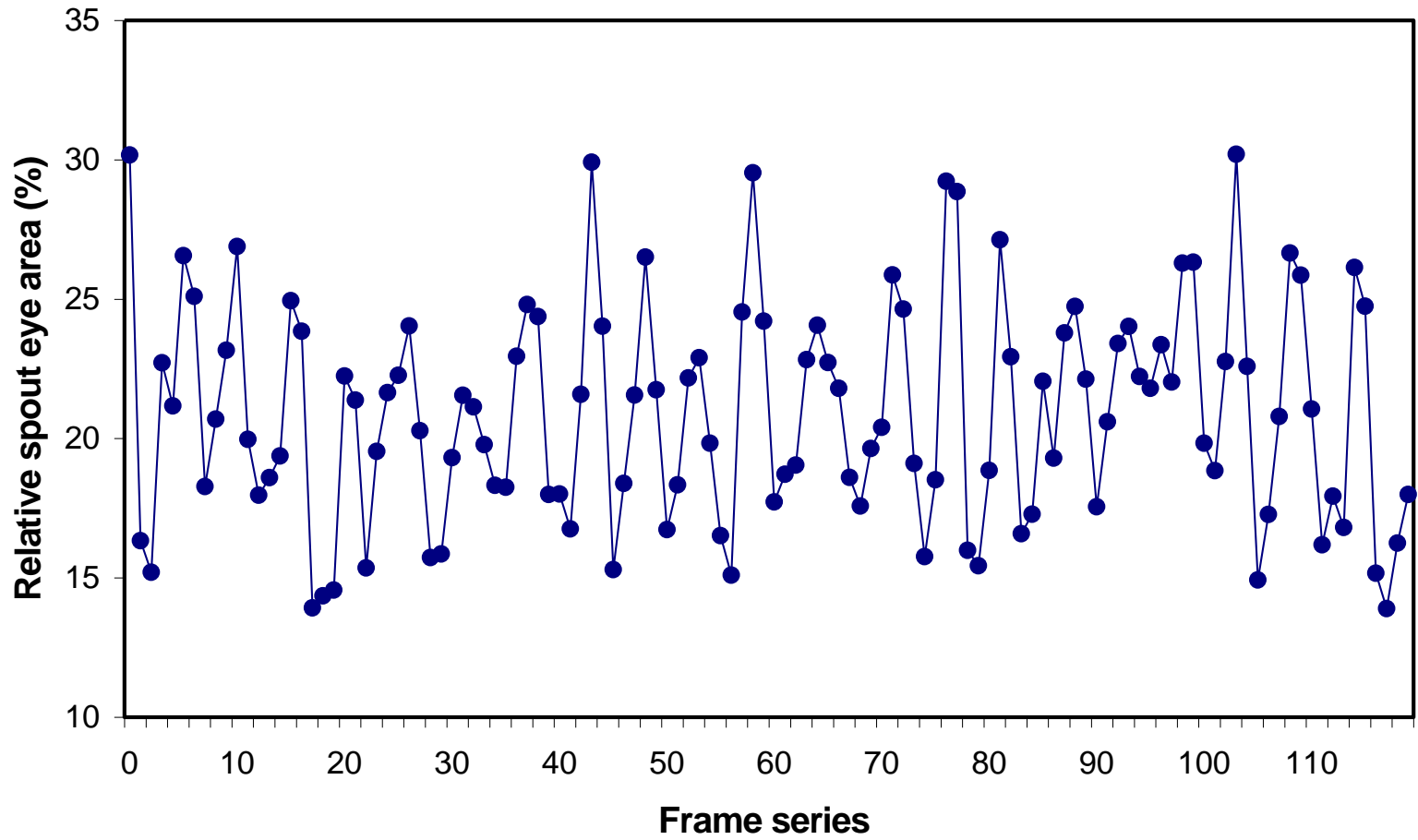


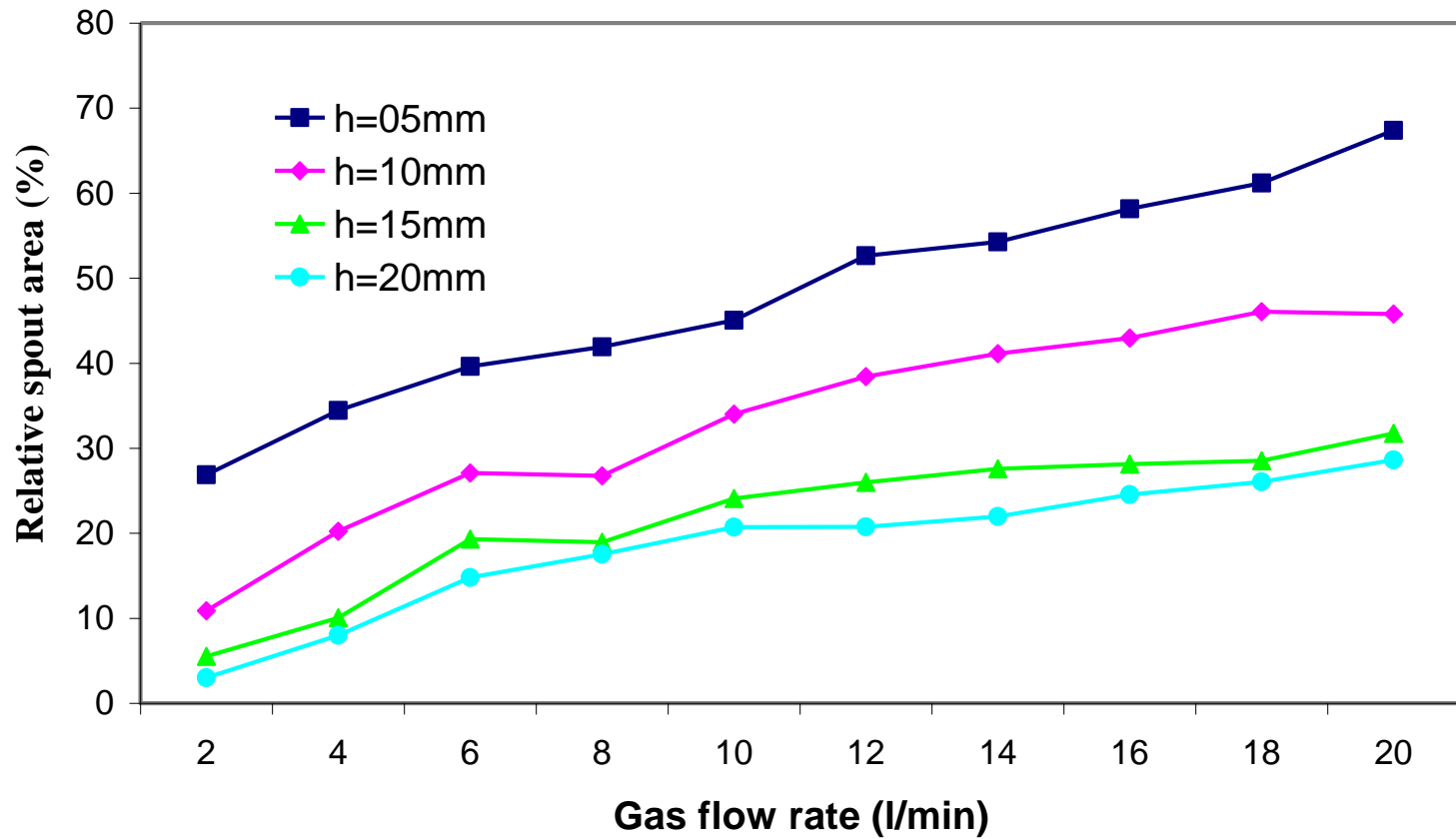


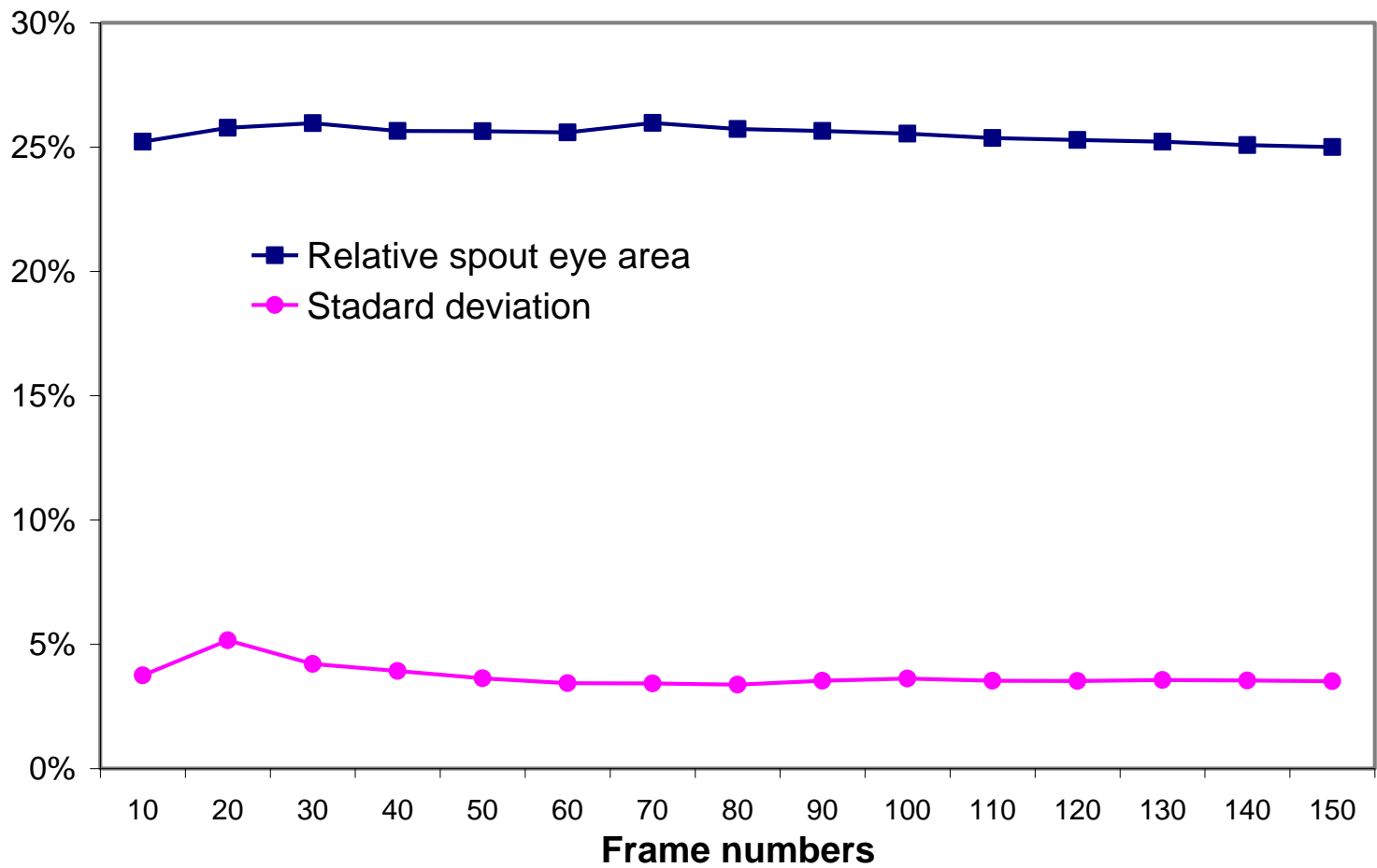
Comparison of results between manual measurement and threshold technique (h=10mm)

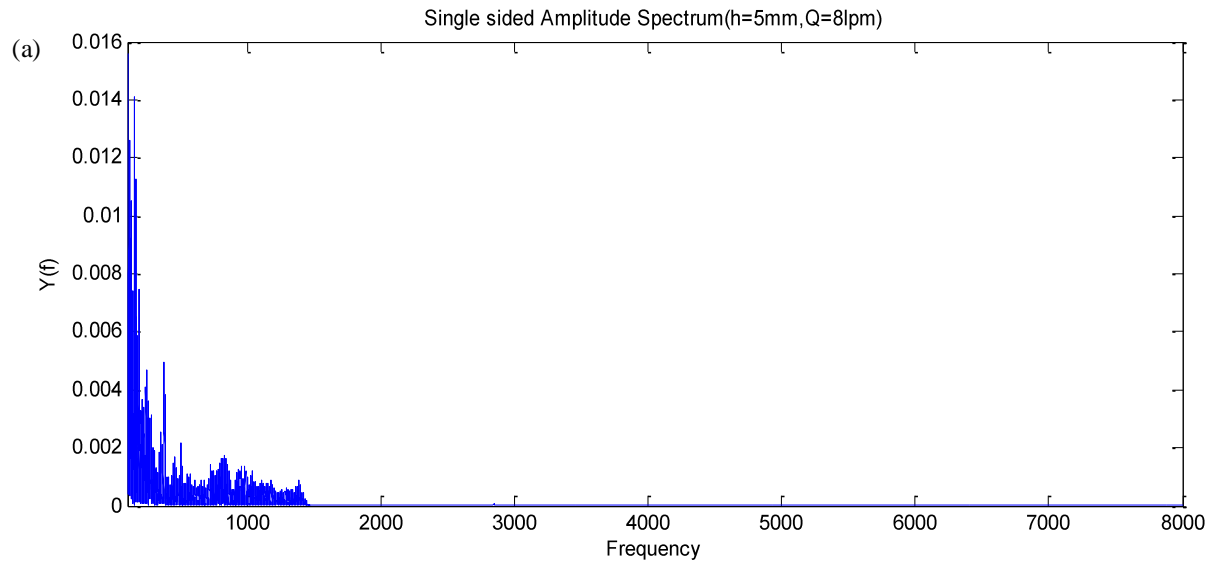
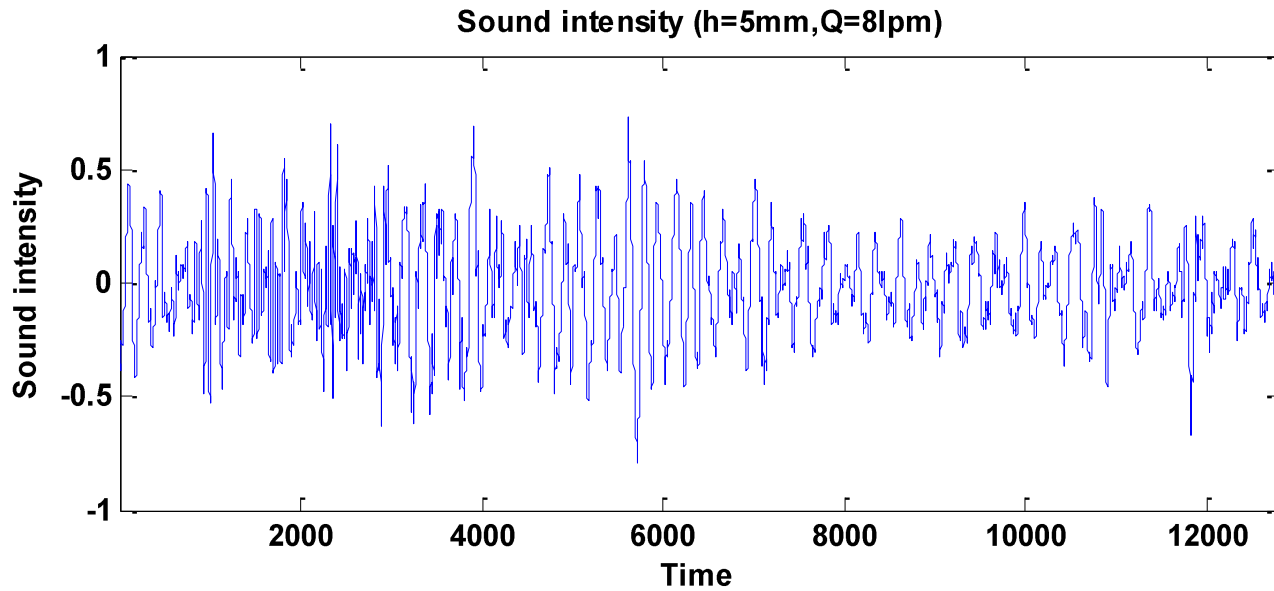


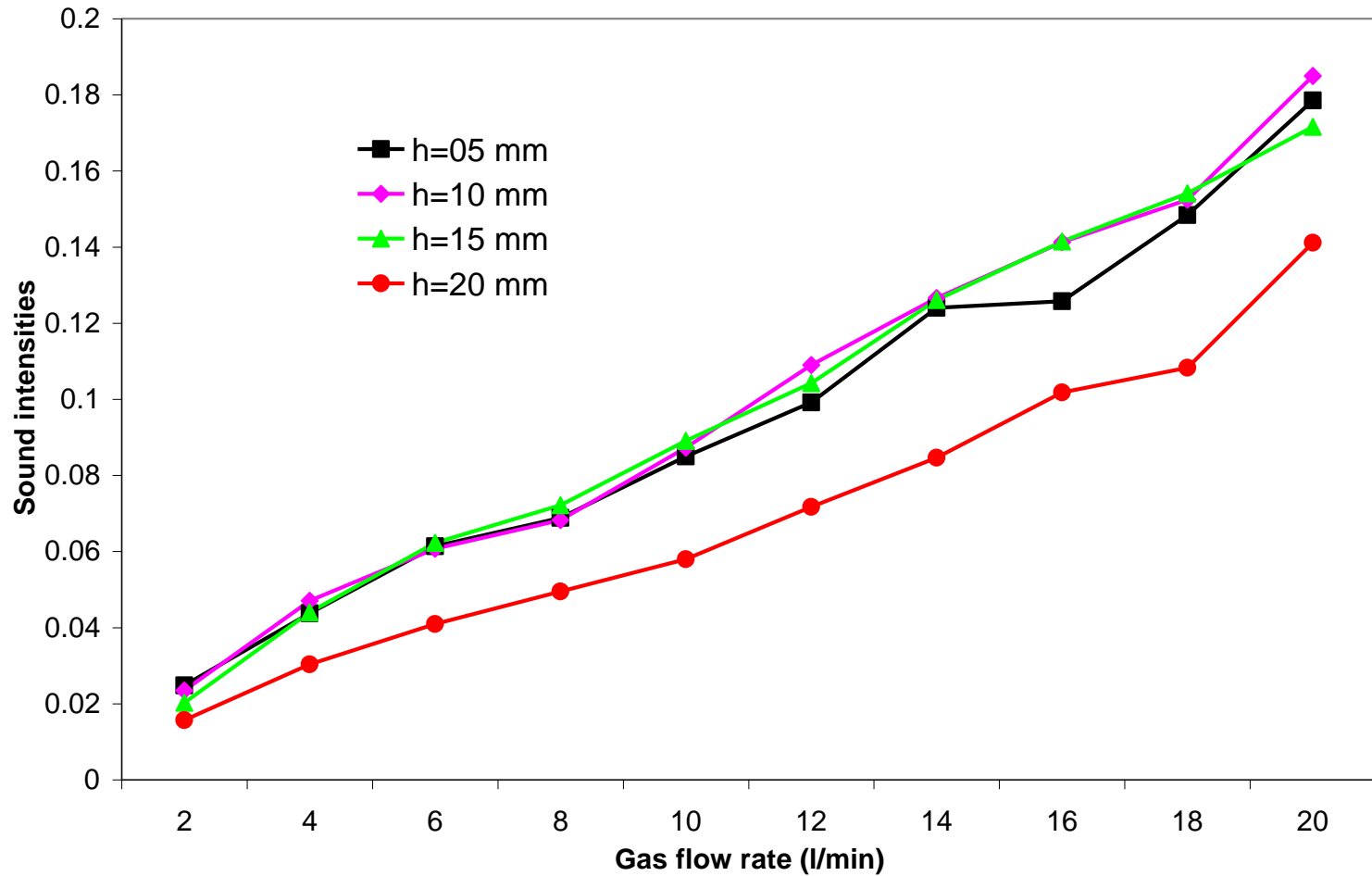
Comparison of the standard deviation for manual and threshold technique (h=10mm)





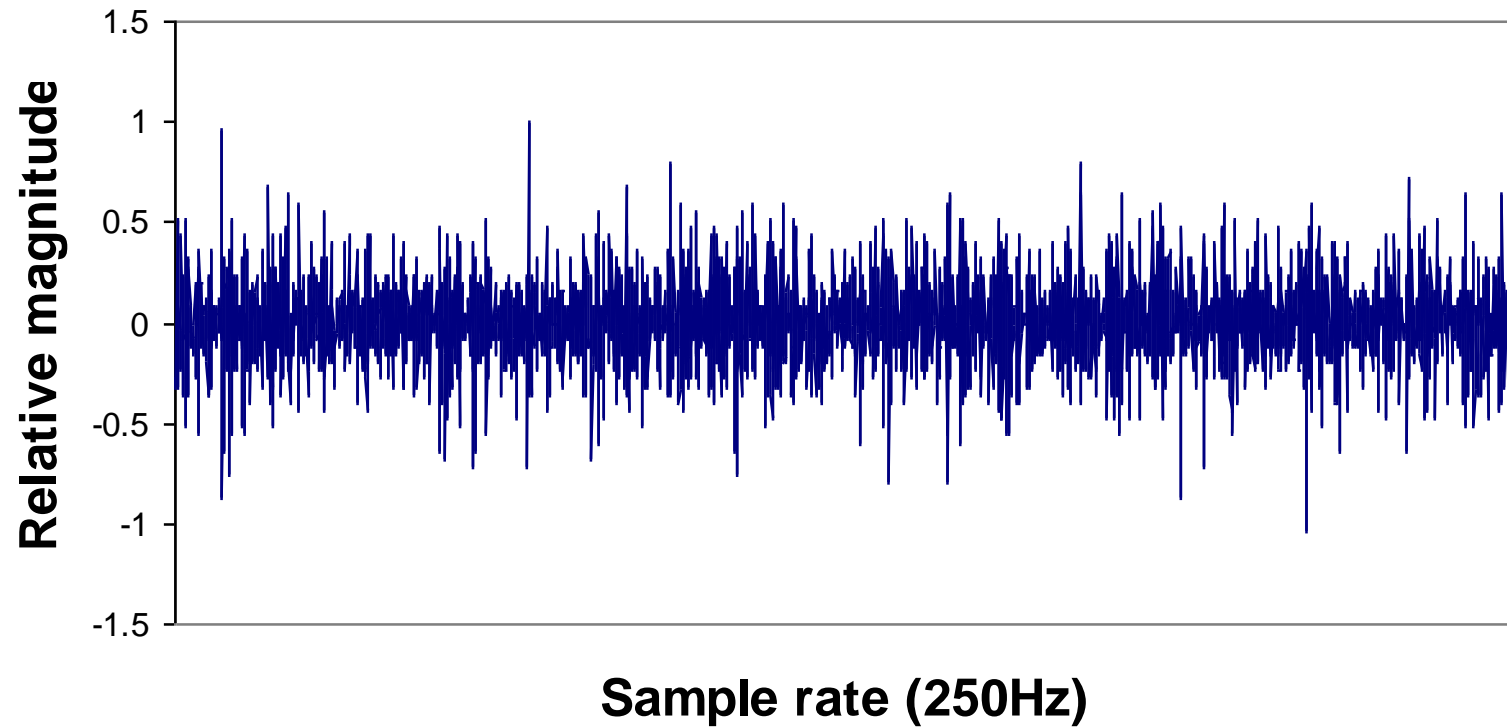


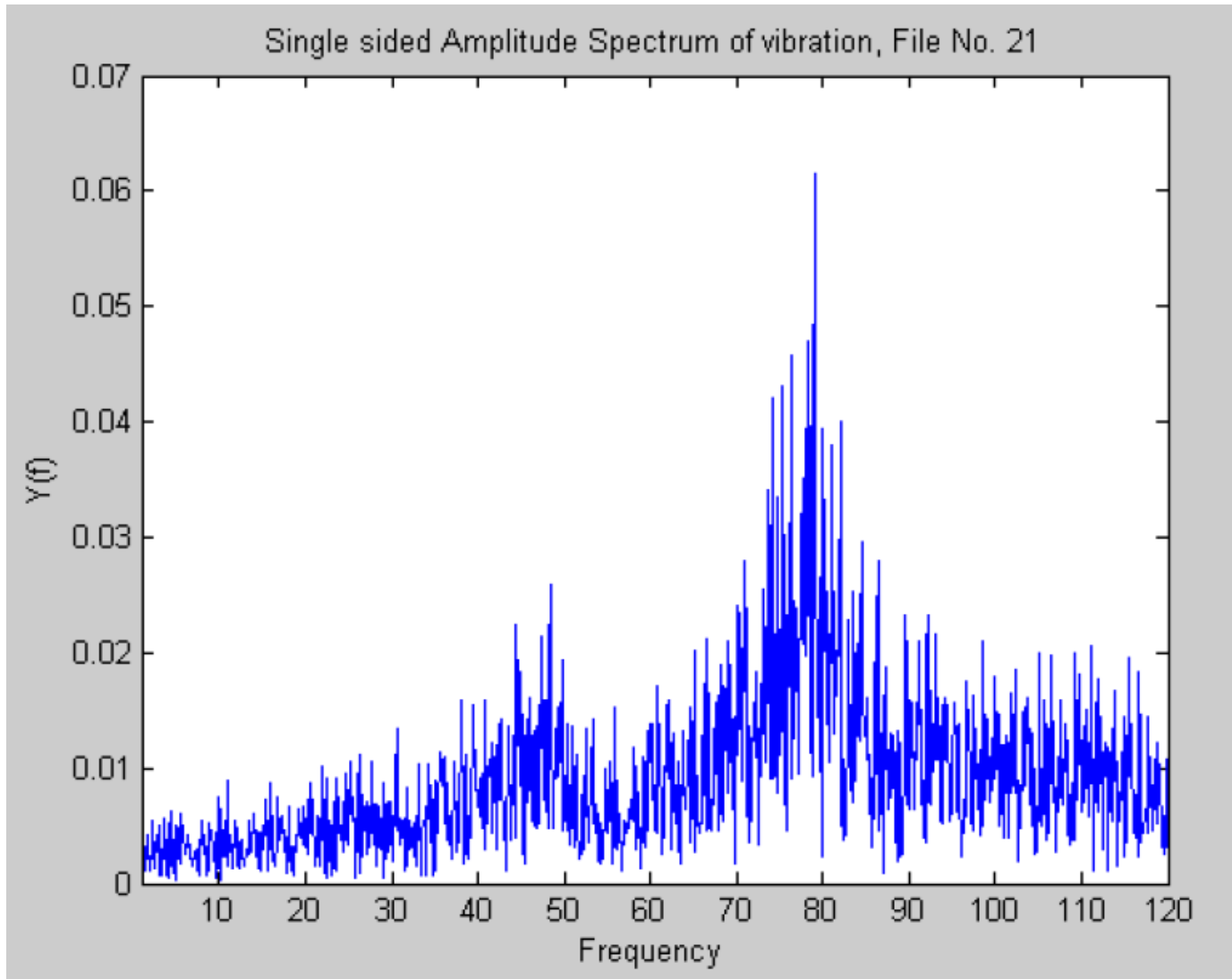




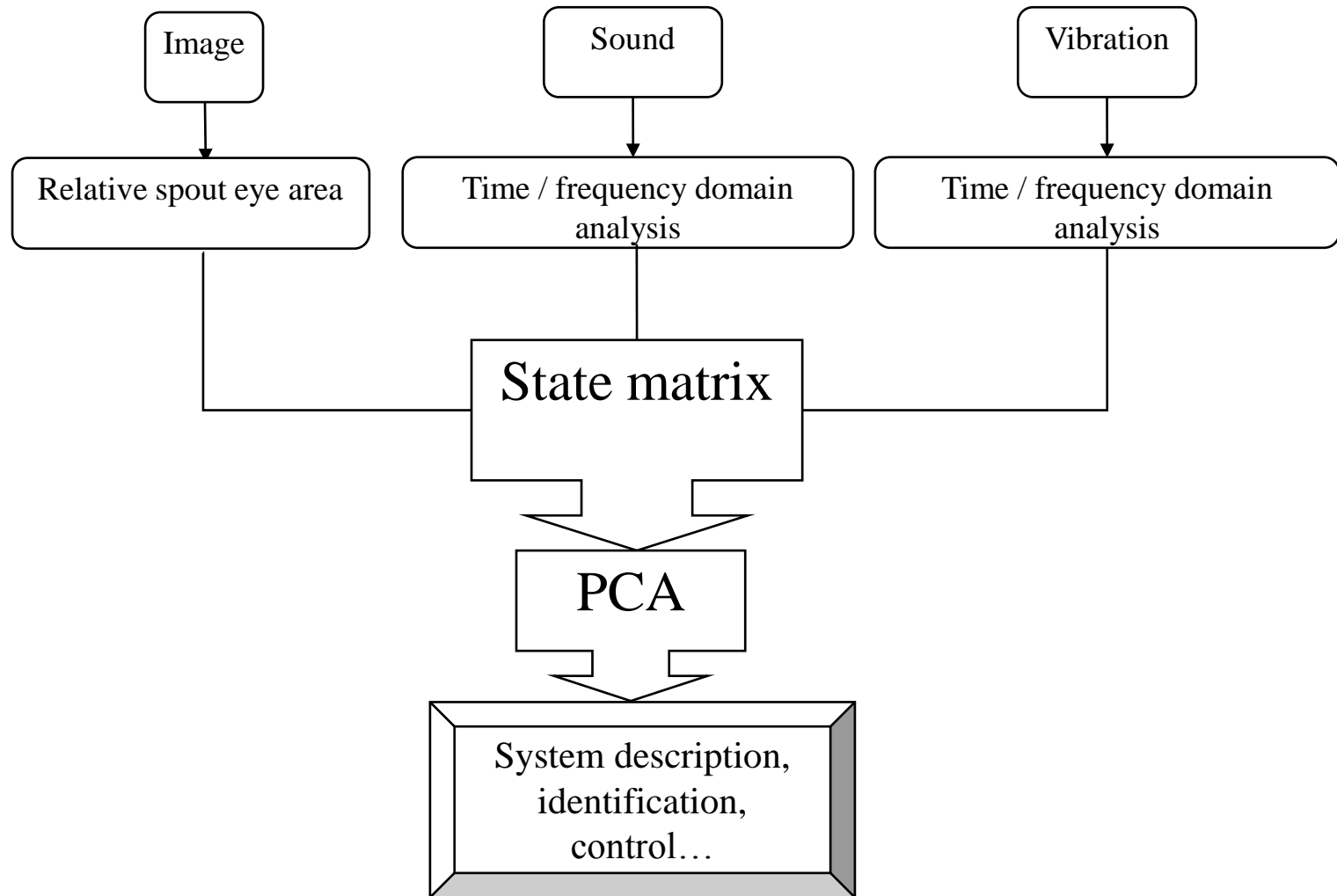
Average sound intensities at different stirring conditions

**Vibration signals from cold model bubbling
(h=5mm, Q=2lpm)**

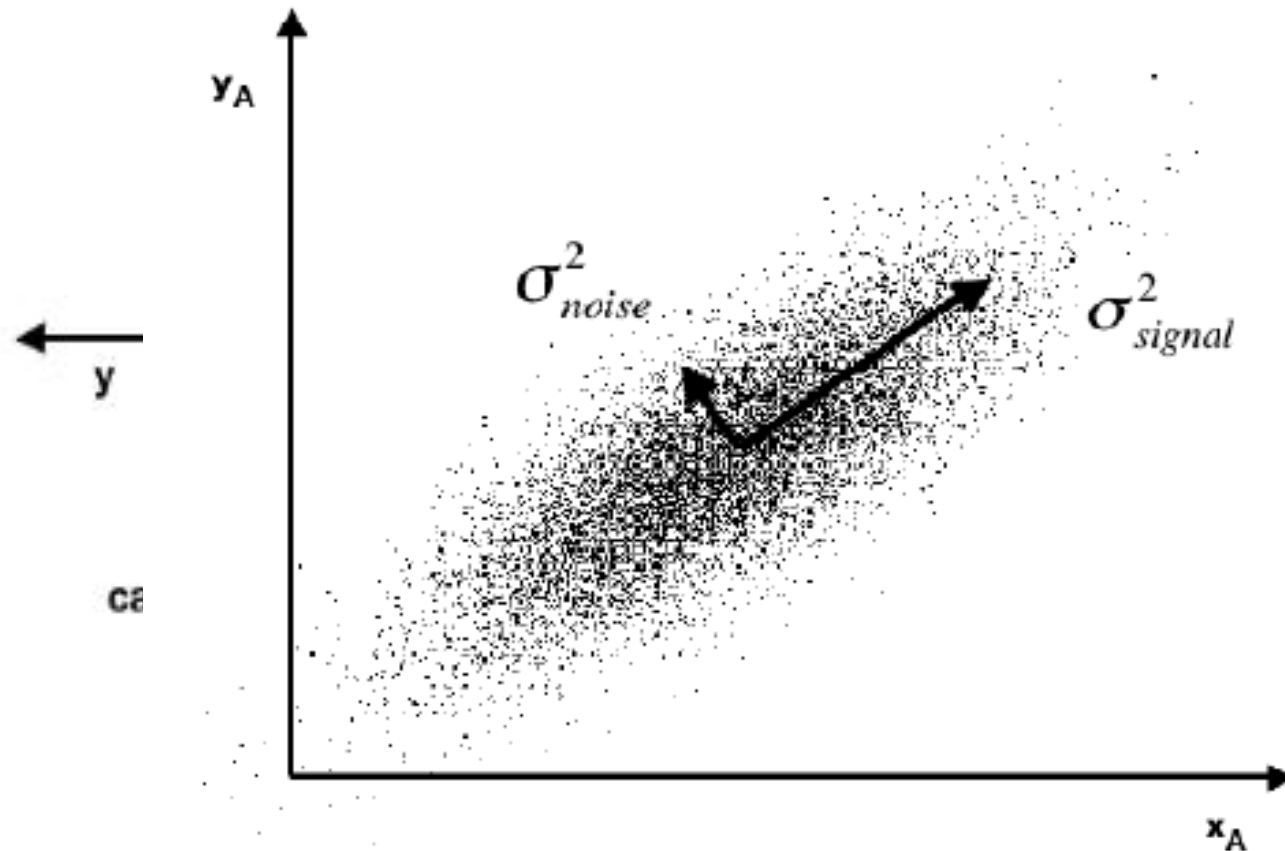




Analysis strategy



What is PCA?



Ref. Jon Shlens, "A tutorial on principal component analysis"

Variable defined

$$a = \frac{1}{60} \sum_{i=1}^{60} A_i^*$$

$$v = \frac{1}{4 \times 250} \sum_{i=1}^{4 \times 250} v_i$$

$$vf = \sum_{i=1}^{120} l_i$$

$$s = \frac{1}{4 \times 16000} \sum_{i=1}^{4 \times 16000} s_i$$

$$sf = \sum_{i=100}^{1500} l_i$$

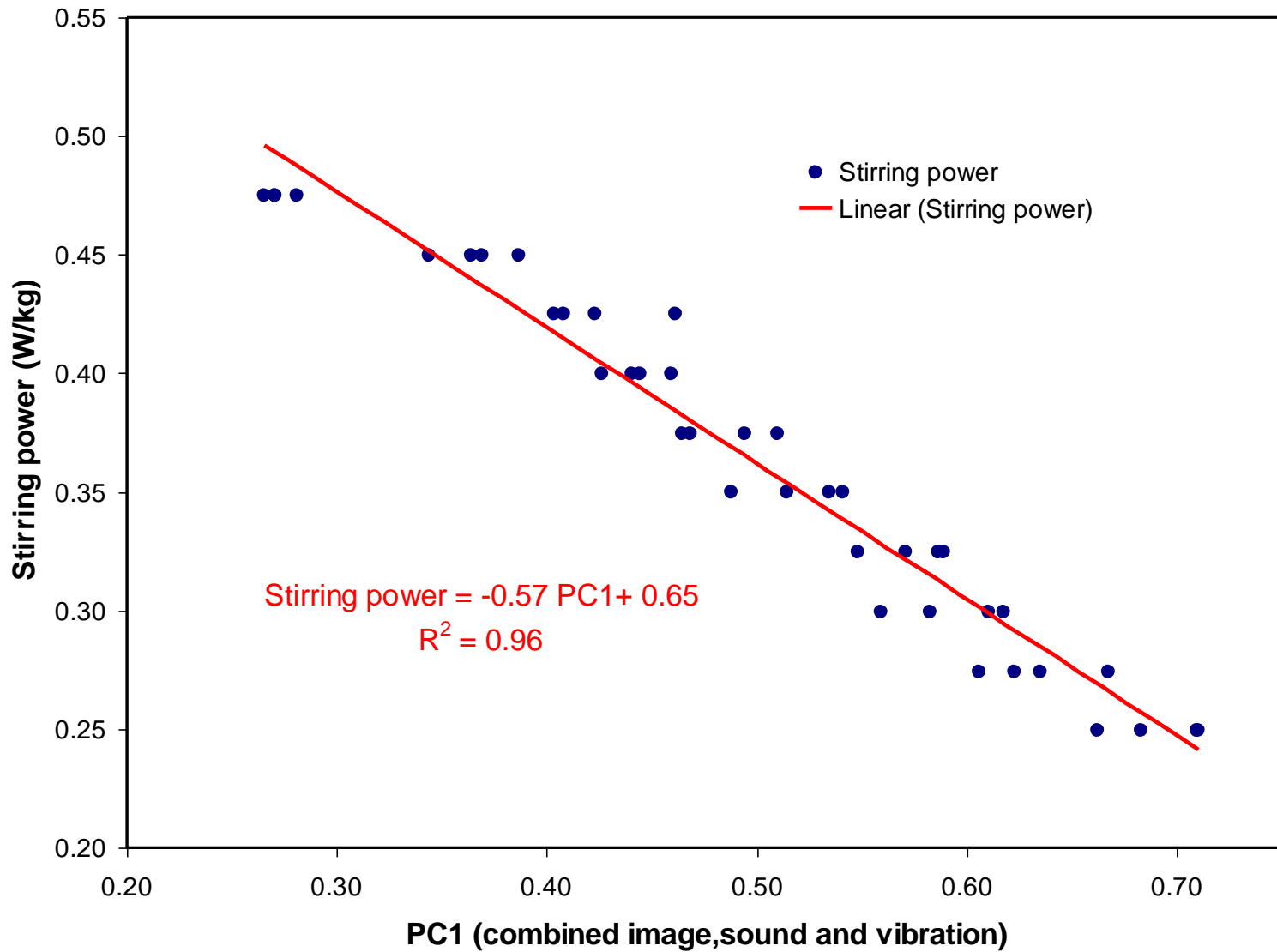
Loading vectors and eigenvalues of cold modeling experiments

Score	1	2	3	4	5
Loading vector	0.312	-0.147	-0.935	0.080	-0.030
	0.568	0.418	0.124	-0.239	-0.656
	0.333	-0.320	0.239	0.836	-0.175
	0.514	0.455	0.239	0.095	0.716
	0.454	-0.703	0.086	-0.478	0.159
Eigenvalue	0.01552	0.00178	0.000502	0.00021	0.00002
Total variance (%)	85.92	9.86	2.95	1.15	0.11

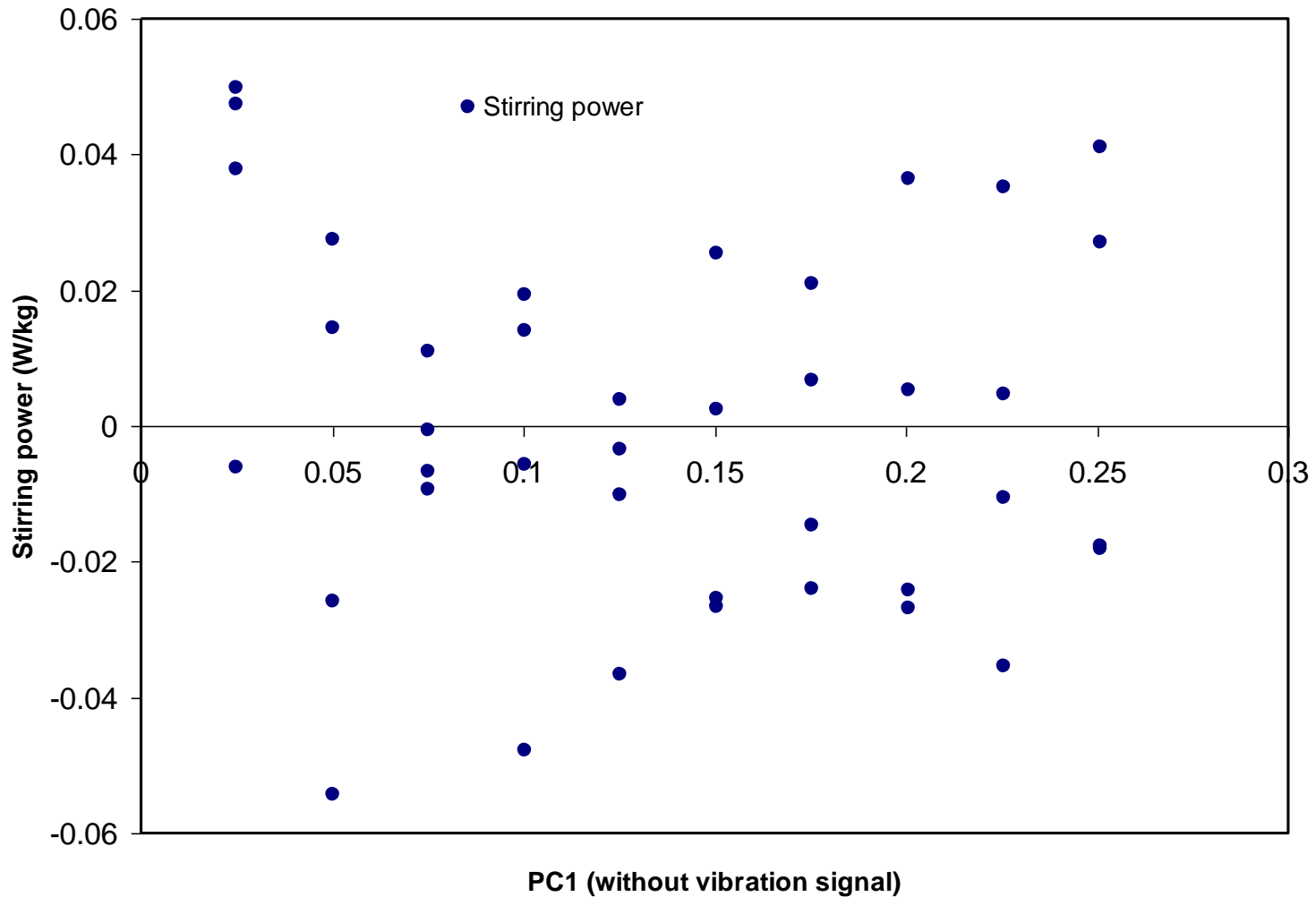
Stirring power

$$\dot{\varepsilon} = 14.23 \left(\frac{\dot{V} T}{M} \right) \log \left(\frac{1 + H}{1.48 P_0} \right)$$

From: Turkdogan, E. and Fruehan, R. J., *The Making, Shaping and Treating of Steel - Steelmaking and Refining Volume*. 11th ed. Fundamentals of Iron and Steelmaking, ed. Fruehan, R.J. 1998: The AISE Steel Foundation. 759.

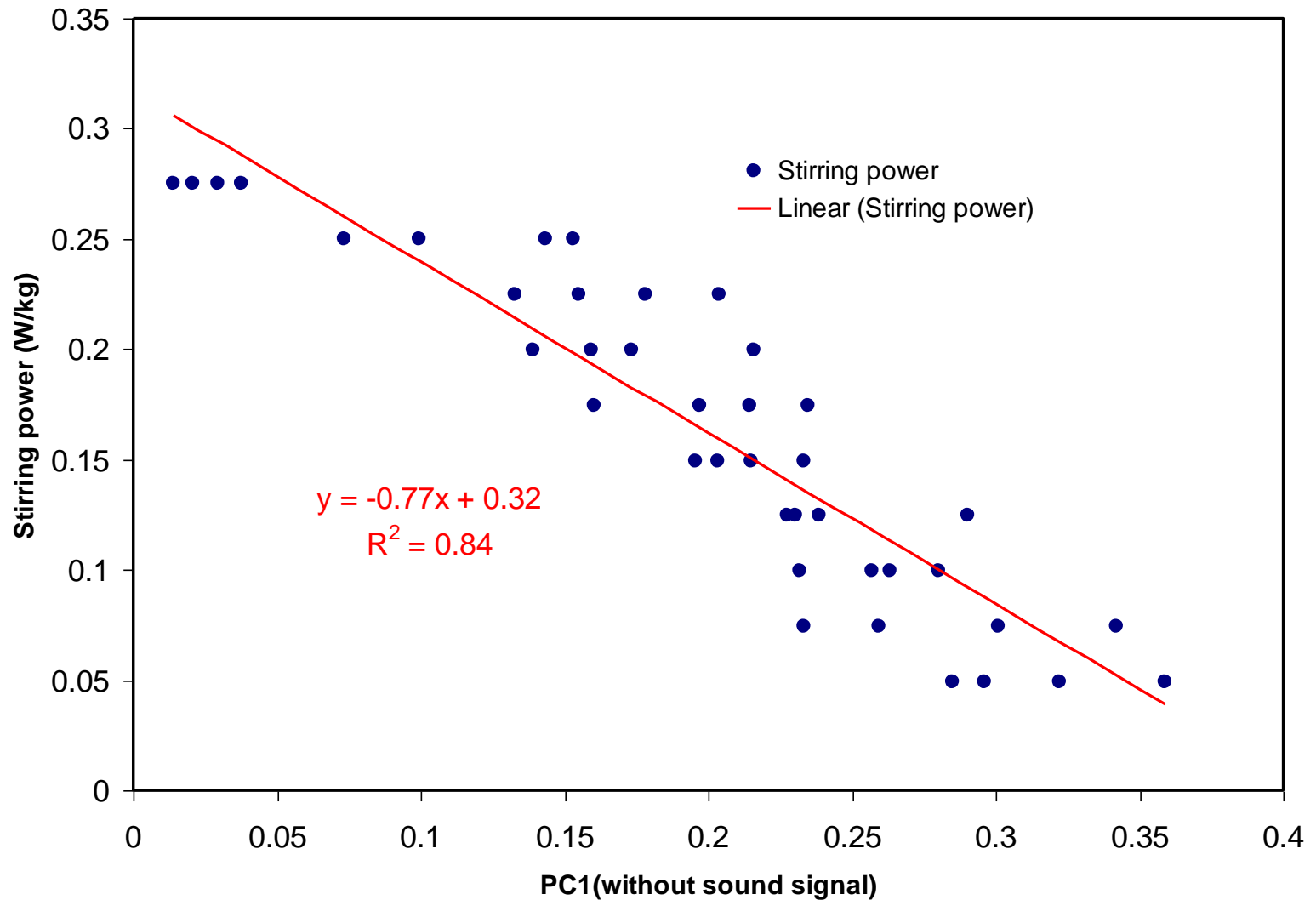


Removal of one channel of signal

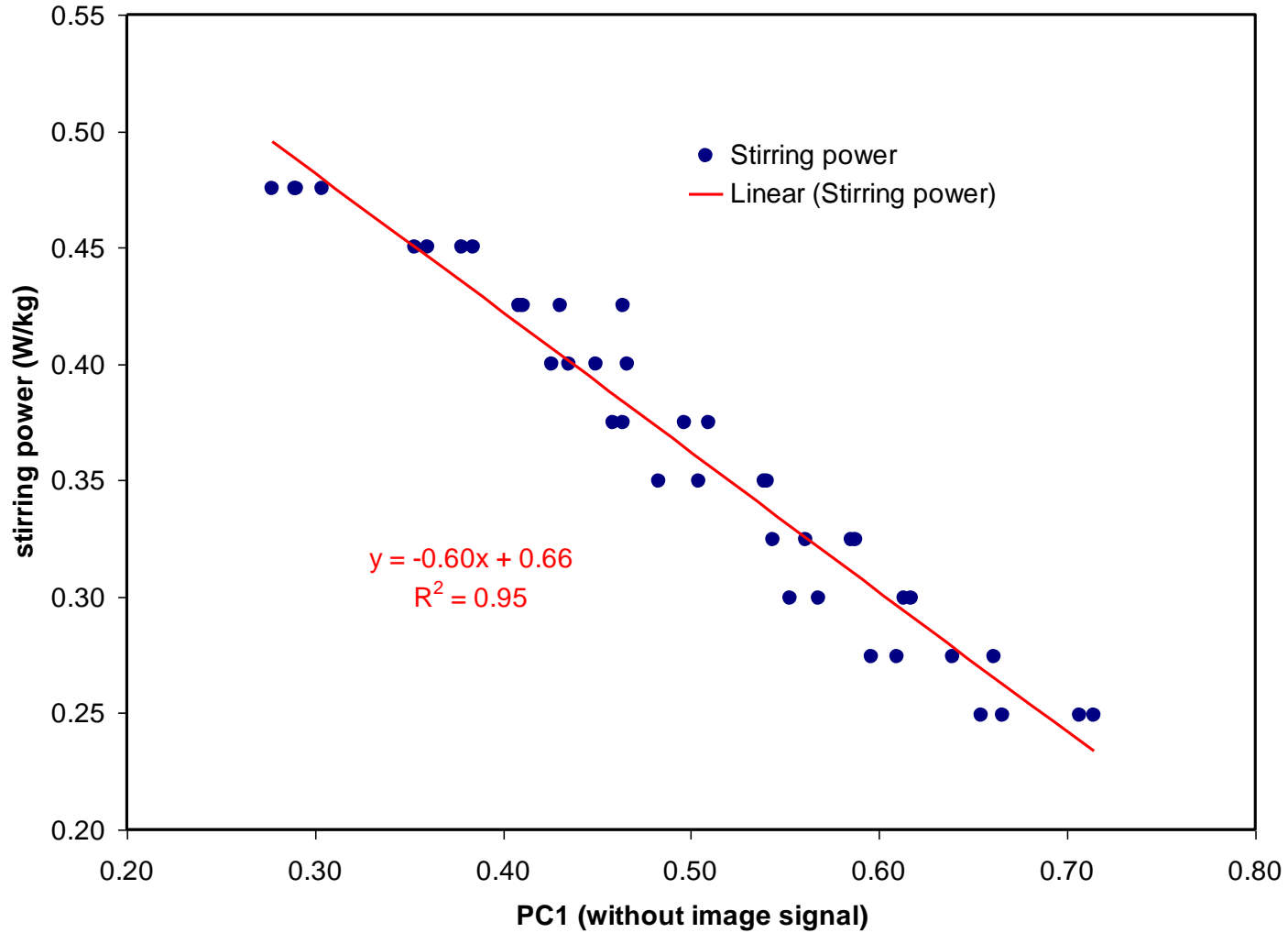


The relationship between the stirring power and PC1 (without vibration signal)

The relationship between the stirring power and the PC1 (without sound signal)



The relationship between stirring power and PC1 (without image signals)



Comparison of the results by removal of one channel of signal

Removal of Signal	Dominant Principal	Relationship between PC1 and stirring power
Vibration	93.9%	No clear relationship
Sound	89.3%	Linear ($R^2=0.84$)
Image	87.6%	Linear ($R^2=0.95$)

Results

- Stirring process can be monitored by signals from image sound and vibration and they are highly correlated.
- PC1 of the combined signal can describe most of the variation of the cold model data (86%). There is a strong linear relationship ($R^2=0.96$) between this “latent” variable and stirring power.
- Stirring process can also be monitored without image signals. The combined signals from sound and vibration can pick up most of the variation of stirring process (88%), and there is also a clear linear relationship ($R^2=0.95$) between PC1 (without image signal) and stirring power.