

# Online Monitoring of Ladle Stirring

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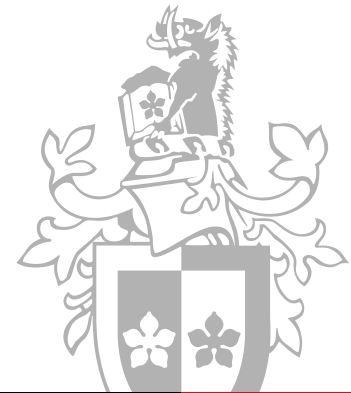
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# Stirring Process



Homogenization of temperature and chemical composition

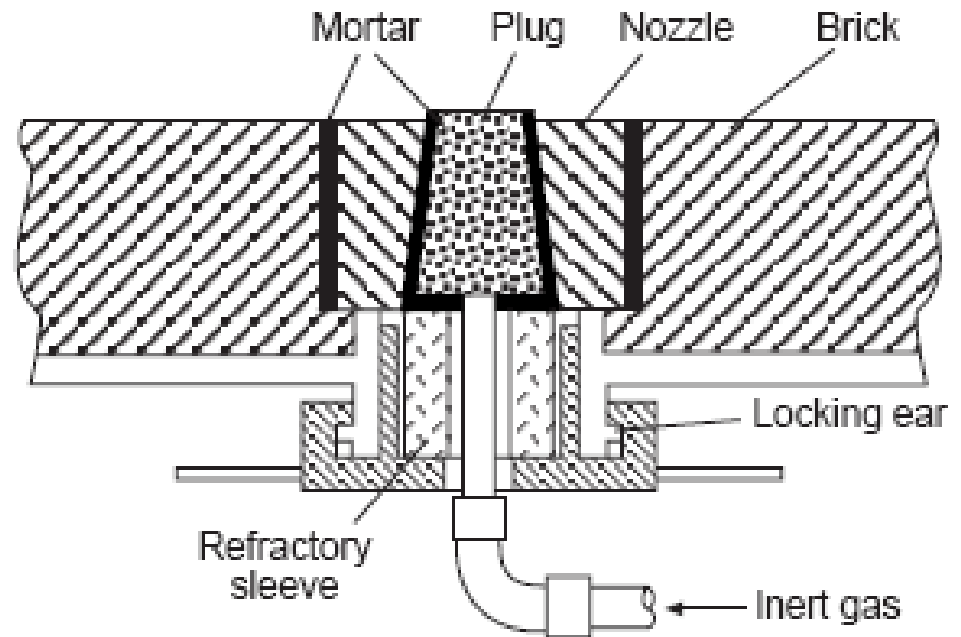
Enhance chemical reactions



# Measurement of stirring process

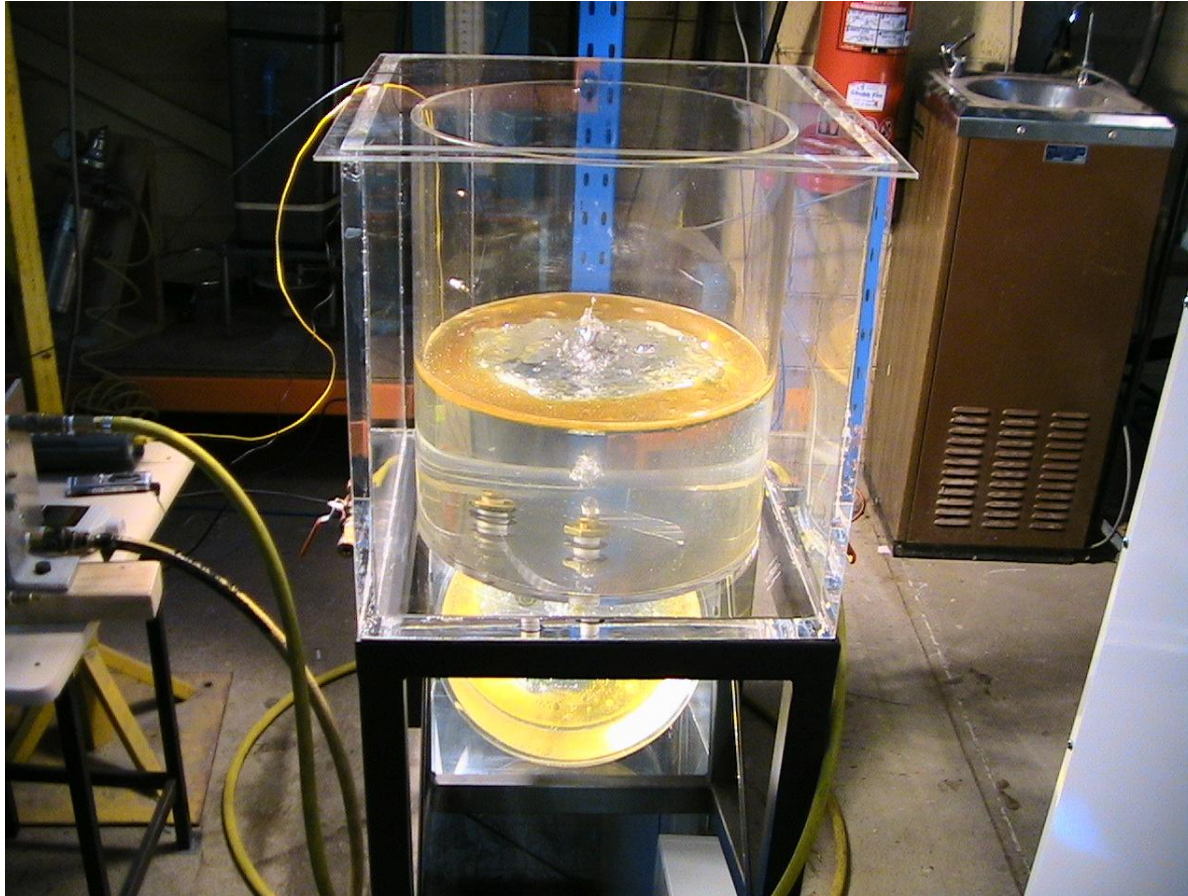
Current method:  $P_{Gas-line} \dot{V}$

- o Erosion
- o Leakage
- o Partially plugged



# Cold model rig

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



# Rapid image analysis

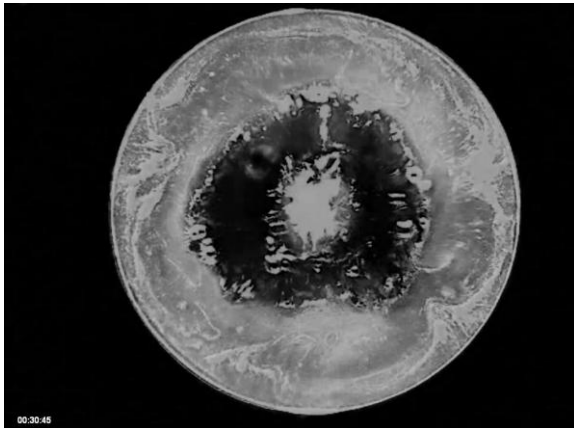
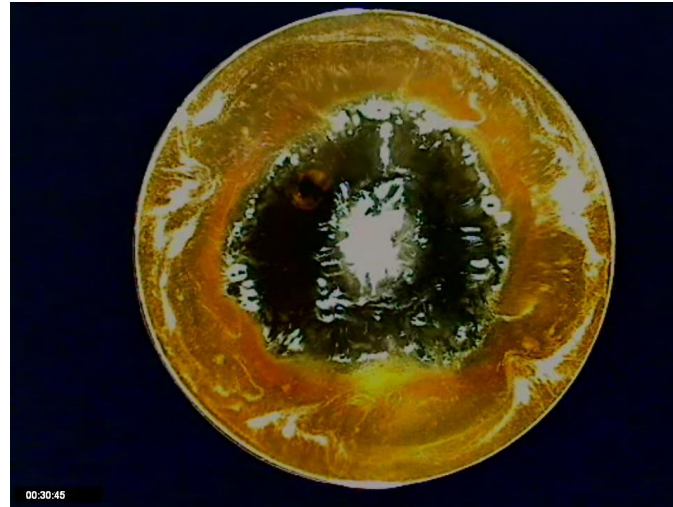


Image of Red channel

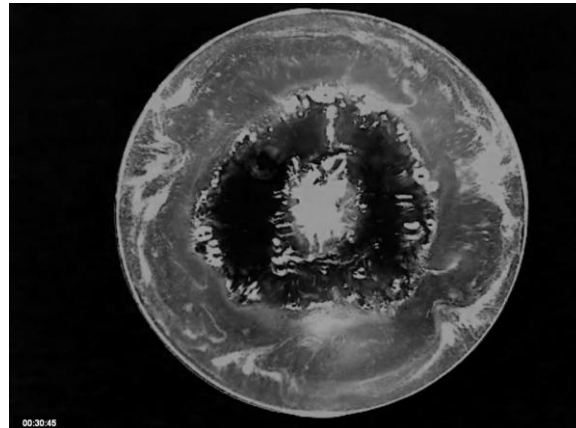


Image of Green channel

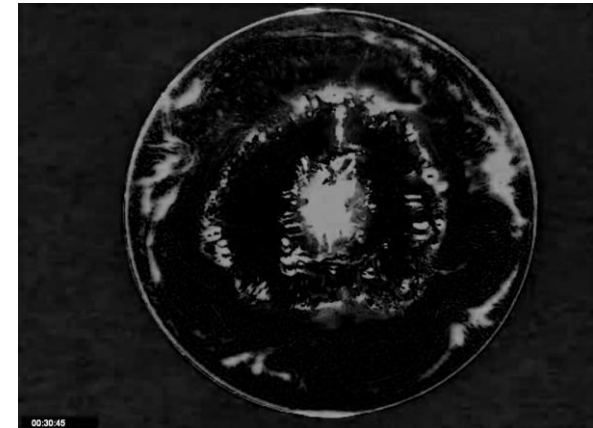
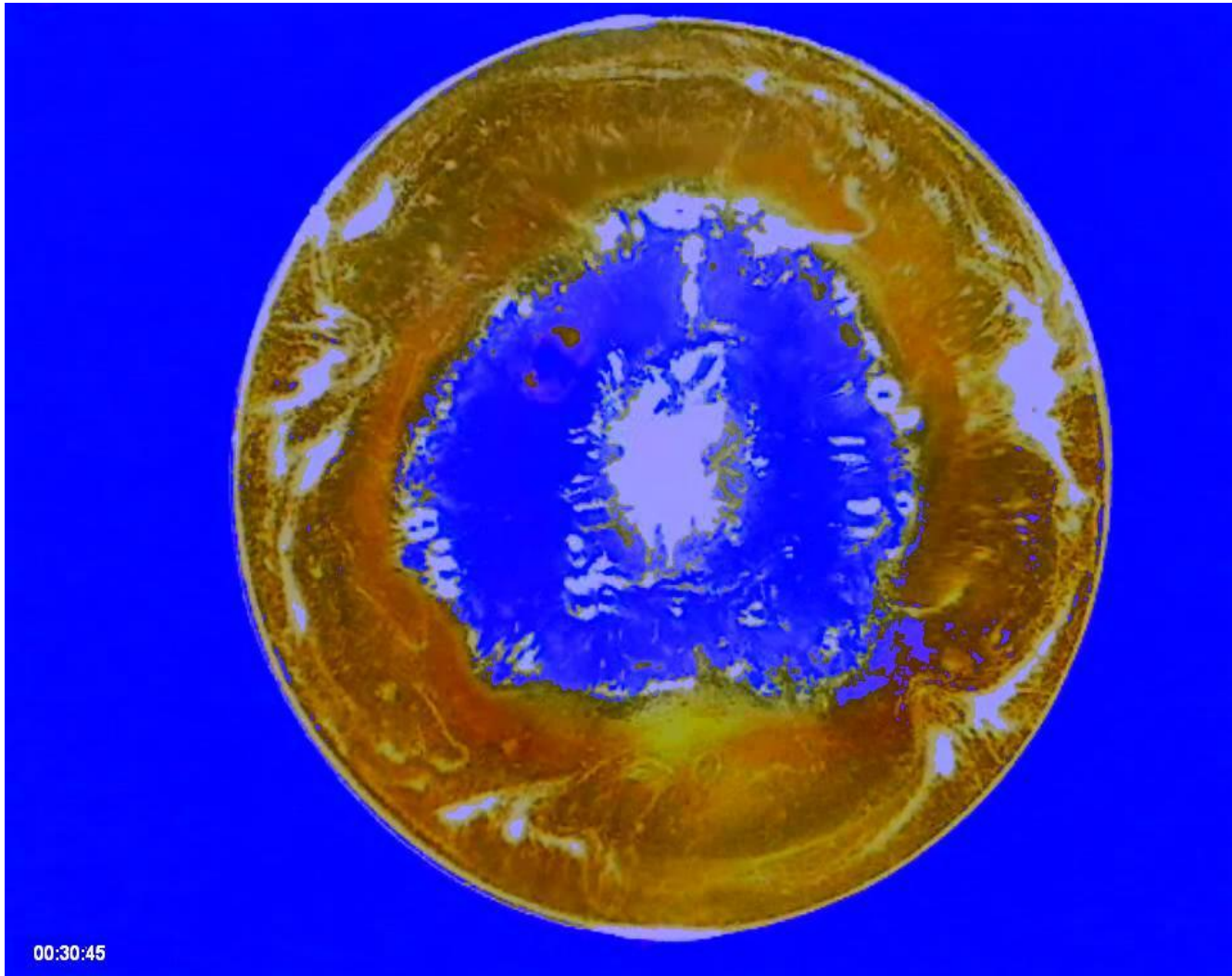
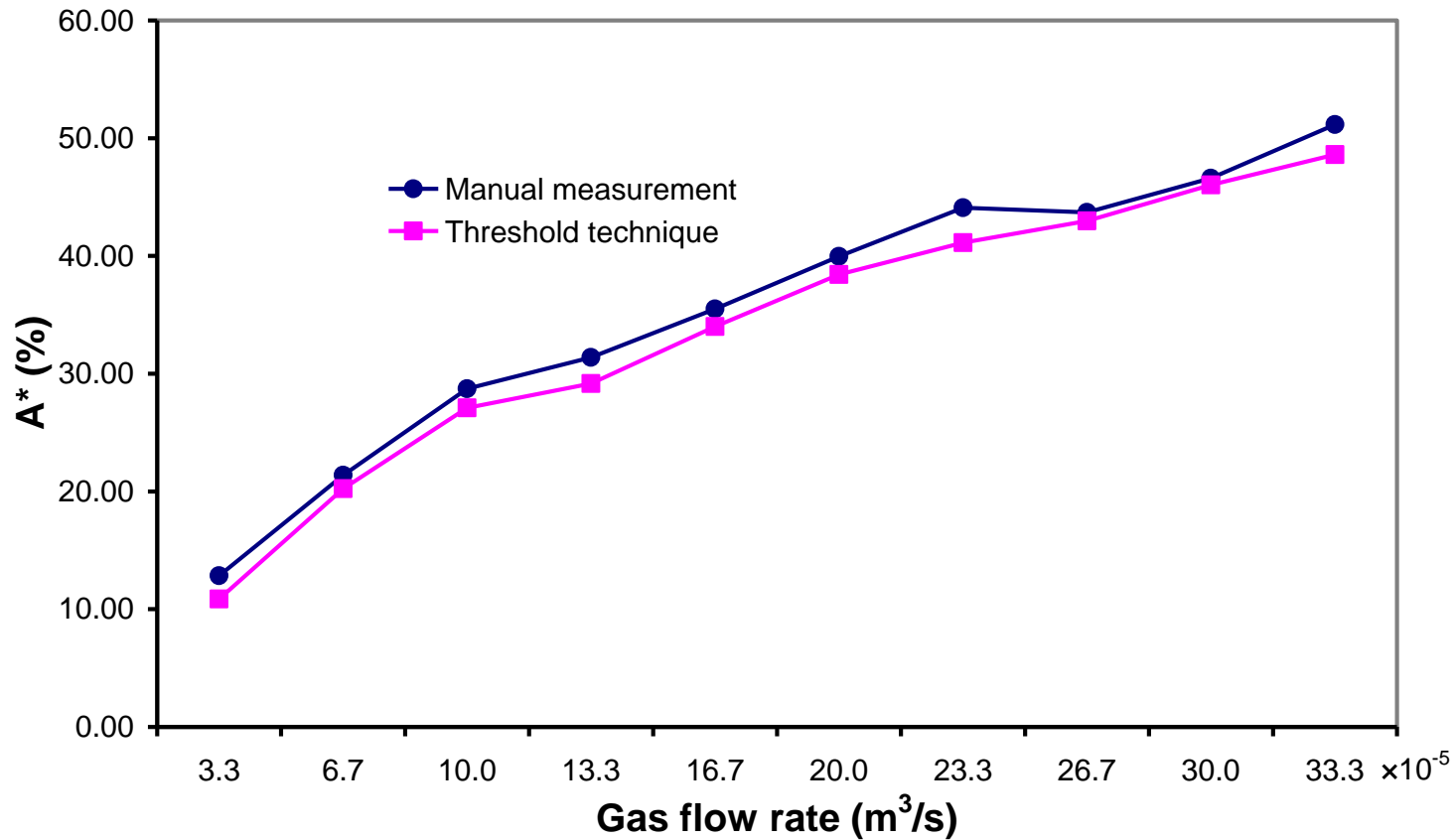


Image of Blue channel

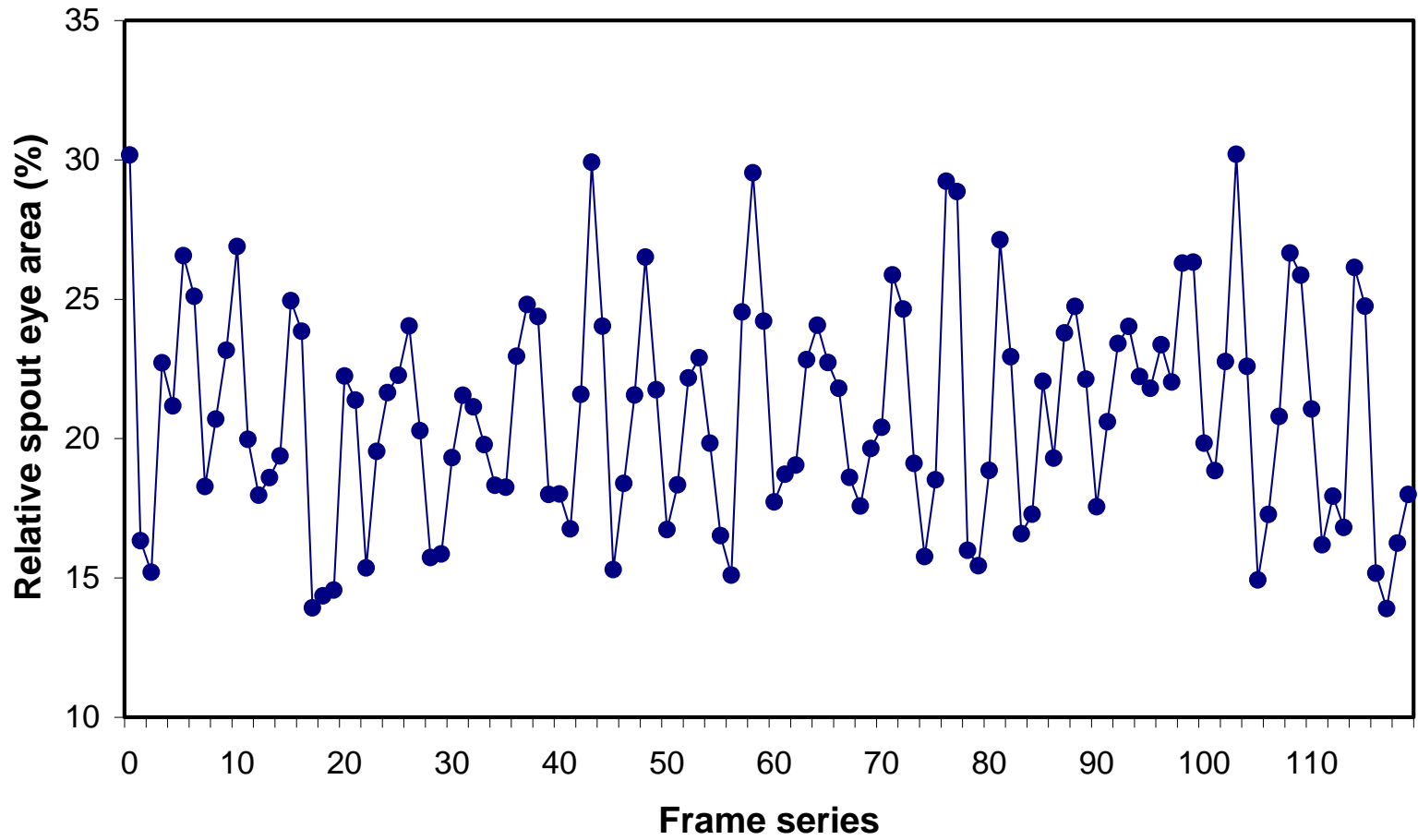


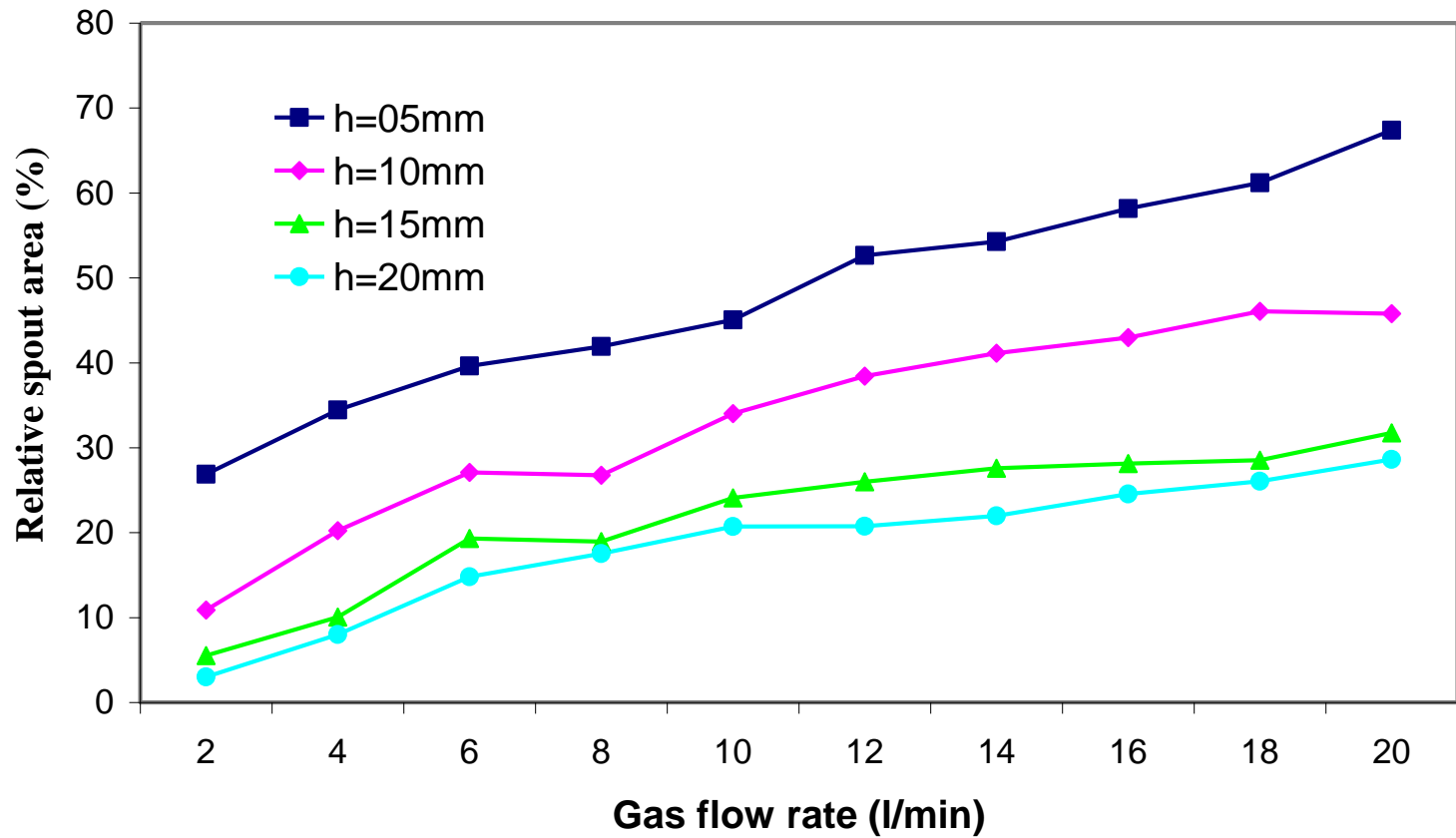
Xu, X., Brooks, G. A., Yang, W., and Stefanie, C., *Rapid image analysis of ladle eye area using a threshold technique*.  
Ironmaking and Steelmaking: Processes, Products and Applications, 2010(Accepted on 03/11/2009).

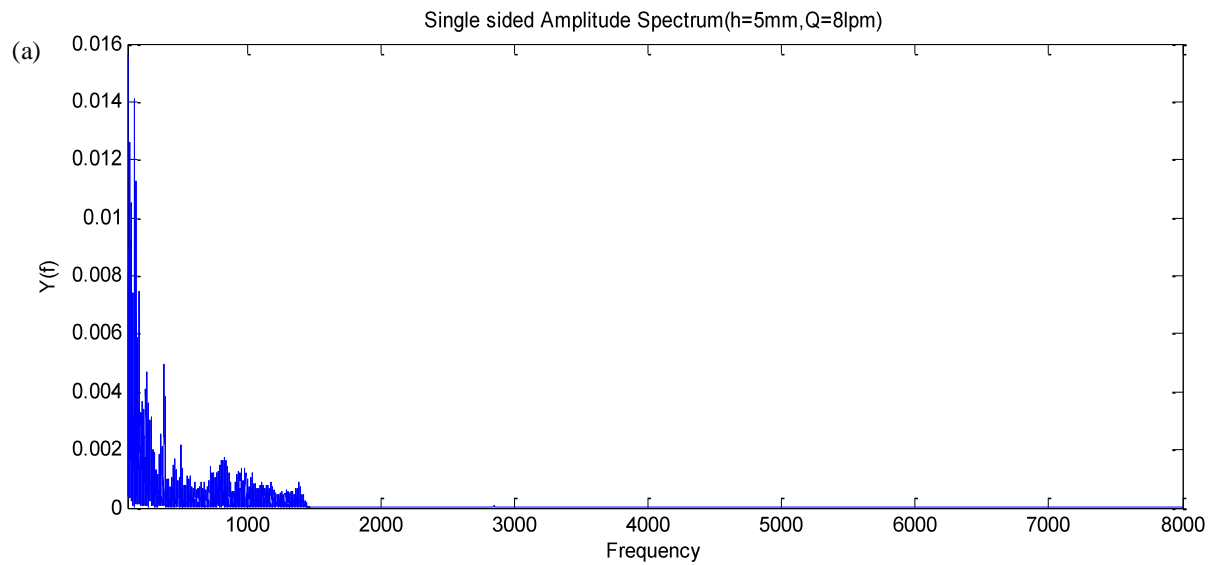
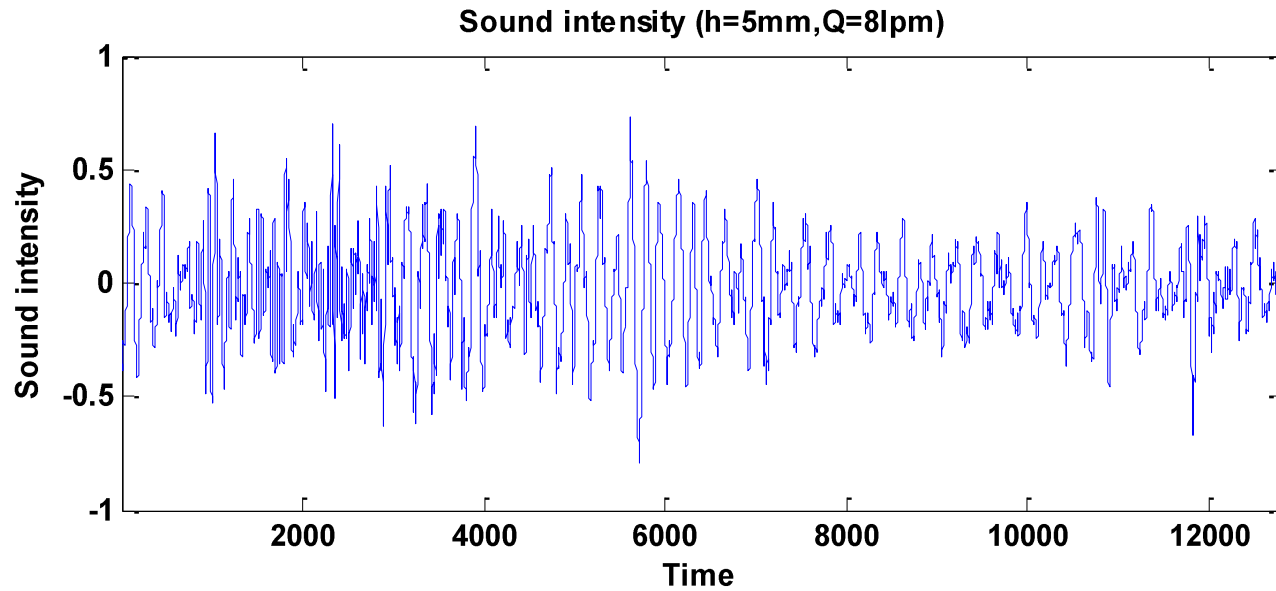
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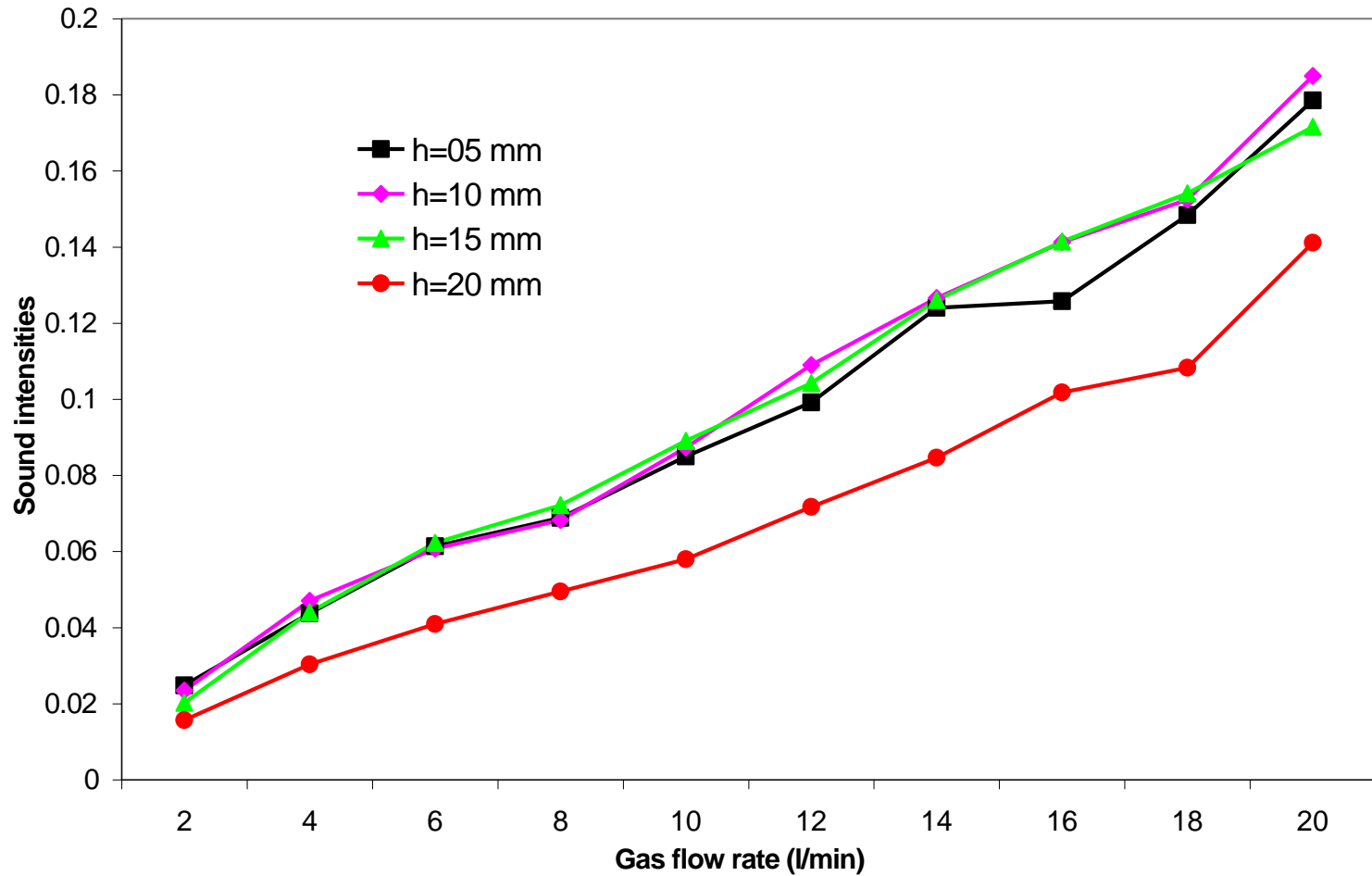


Comparison of results between manual measurement and threshold technique (h=10mm)



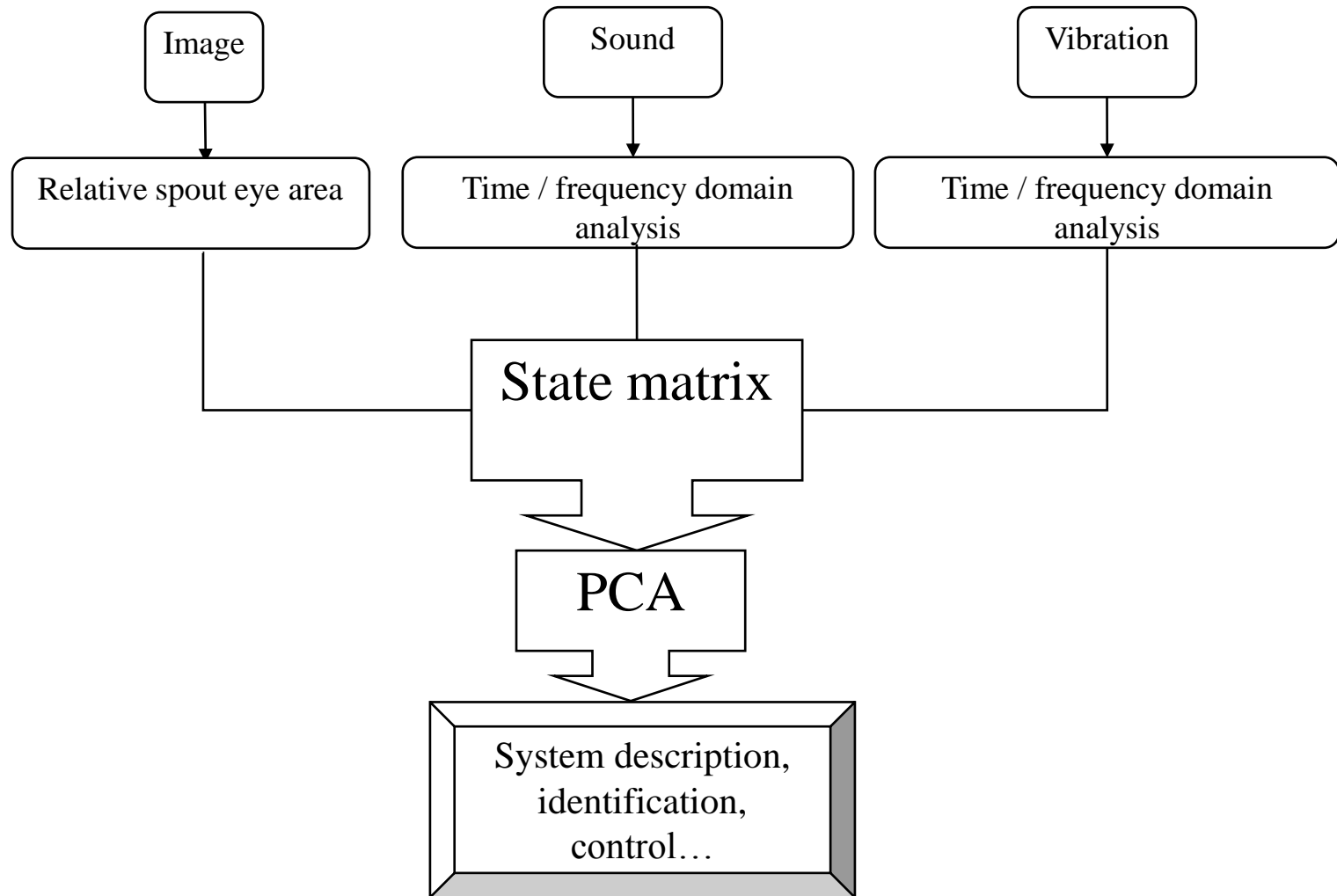




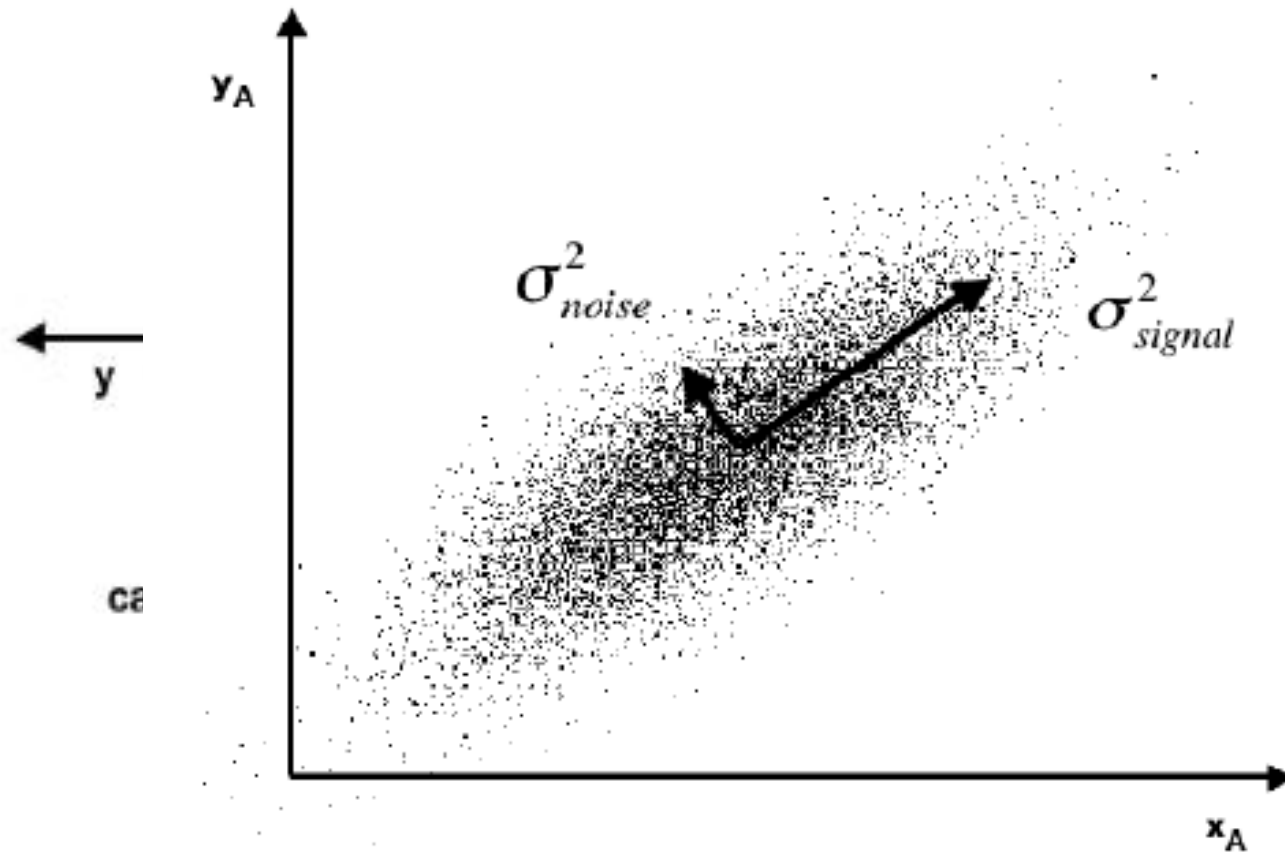


Average sound intensities at different stirring conditions

# Analysis strategy



# What is PCA?



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

## 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. p670.

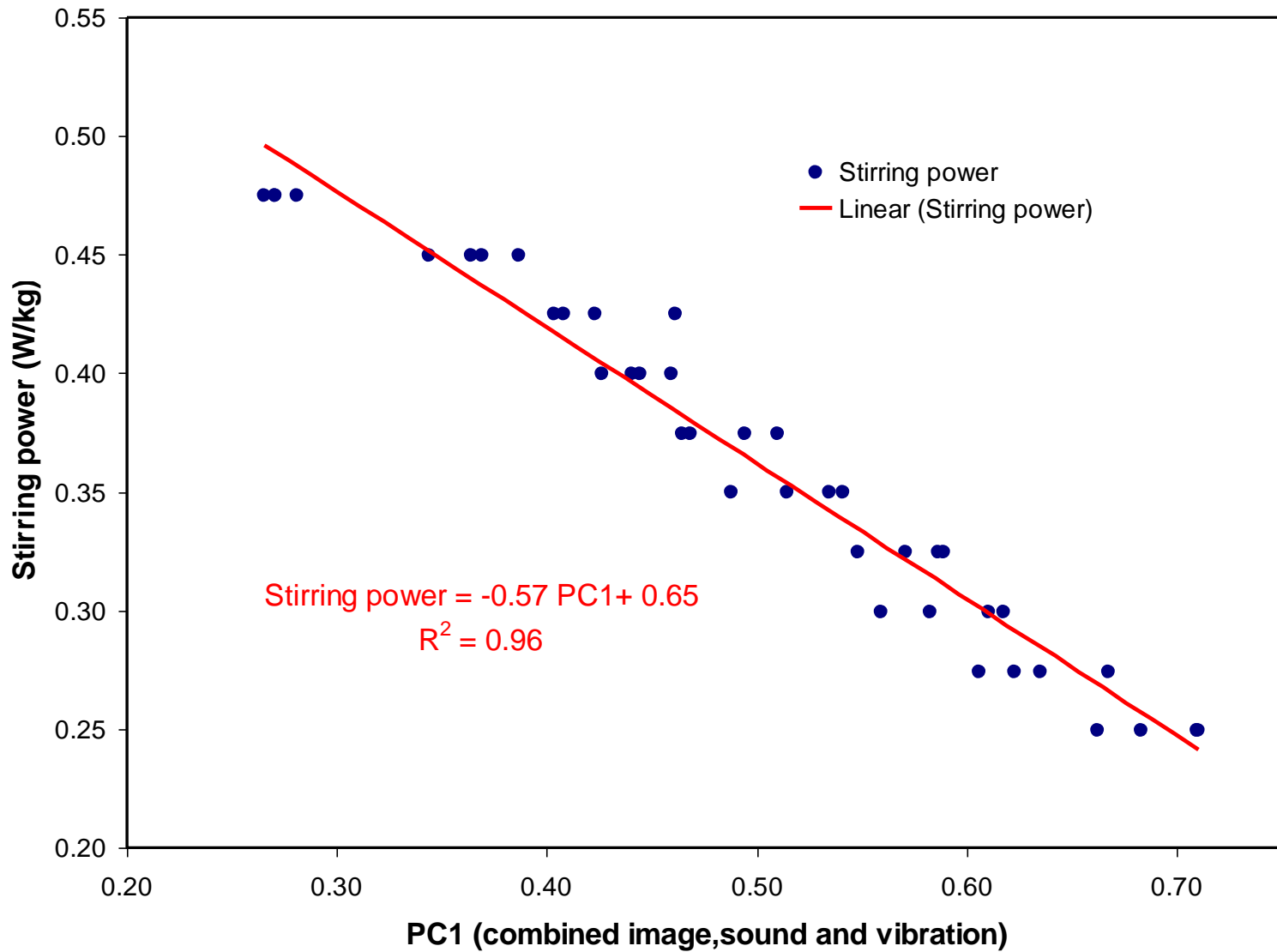
Desulfurization:  $k_s = m_s \left( \frac{A}{V} \right) \quad k_s \propto \dot{\varepsilon}^n$

Dephosphorization:  $k_p \propto c \dot{\varepsilon}^n$

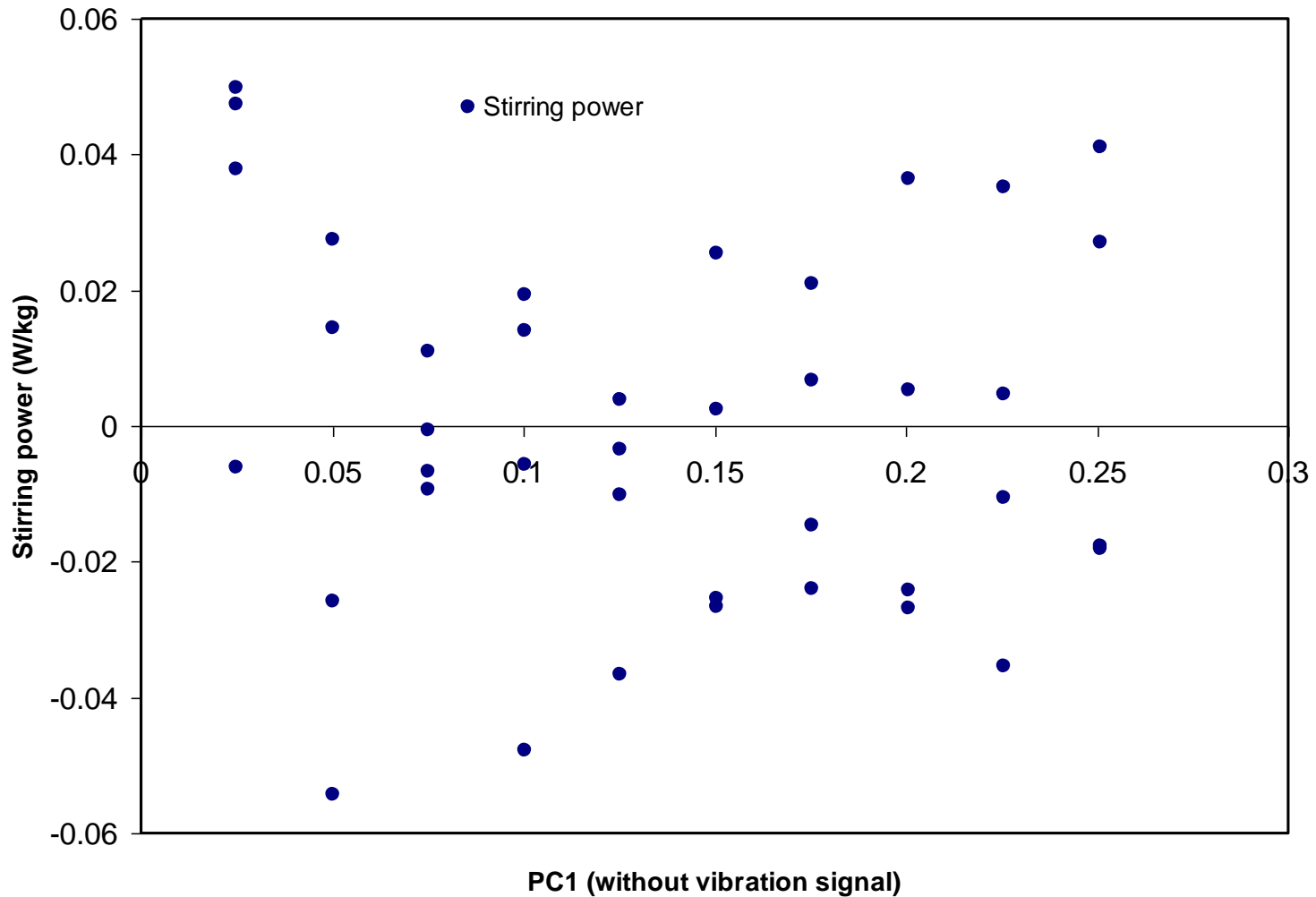
Inclusion removal:  $\frac{C_t}{C_i} \propto e^{-\dot{\varepsilon} \tau / 27}$

Mixing time:  $\tau (s) = 116 (\dot{\varepsilon})^{-1/3} (D^{5/3} H^{-1})$

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. P670-673.

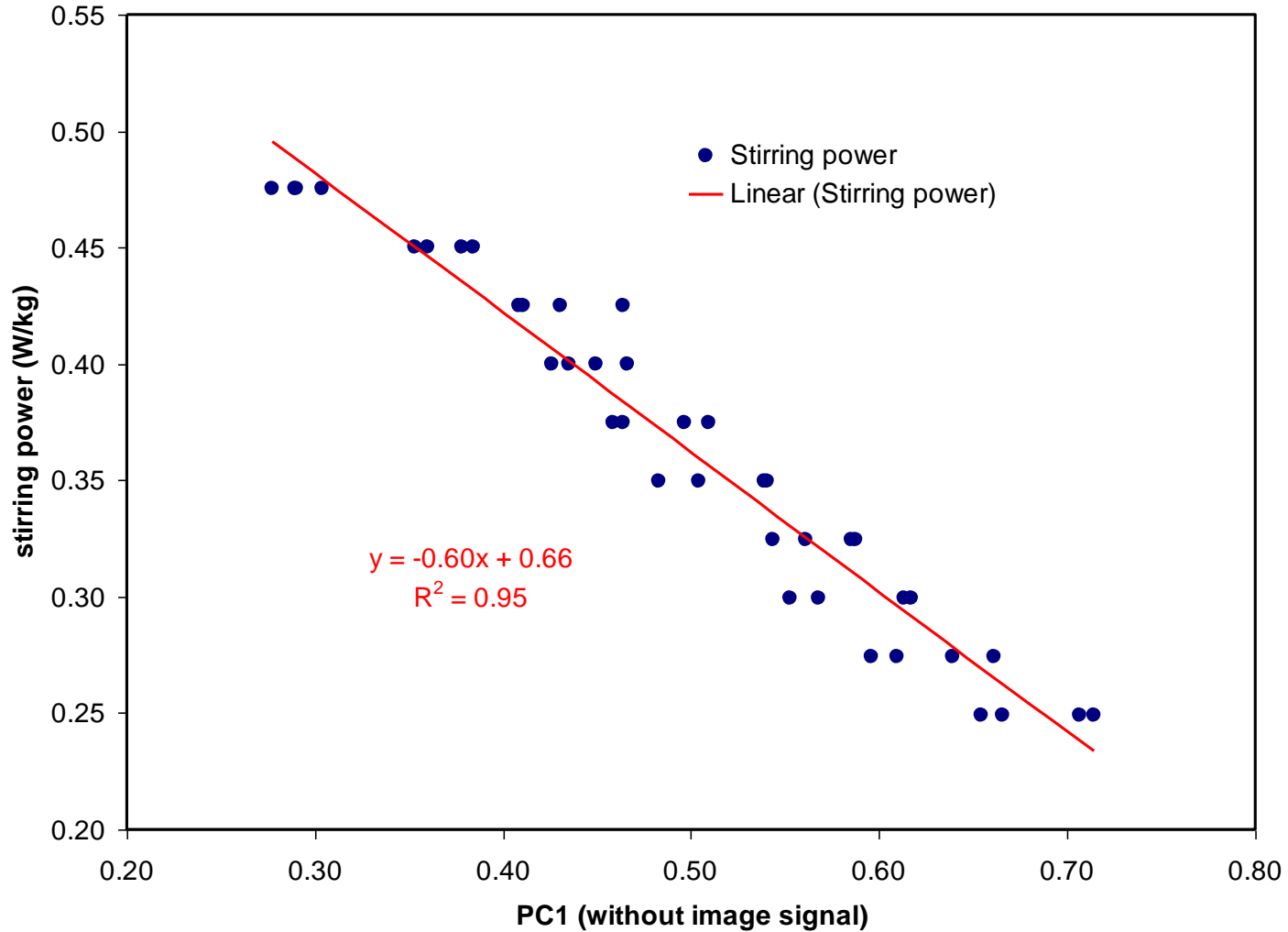


# Removal of one channel of signal



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

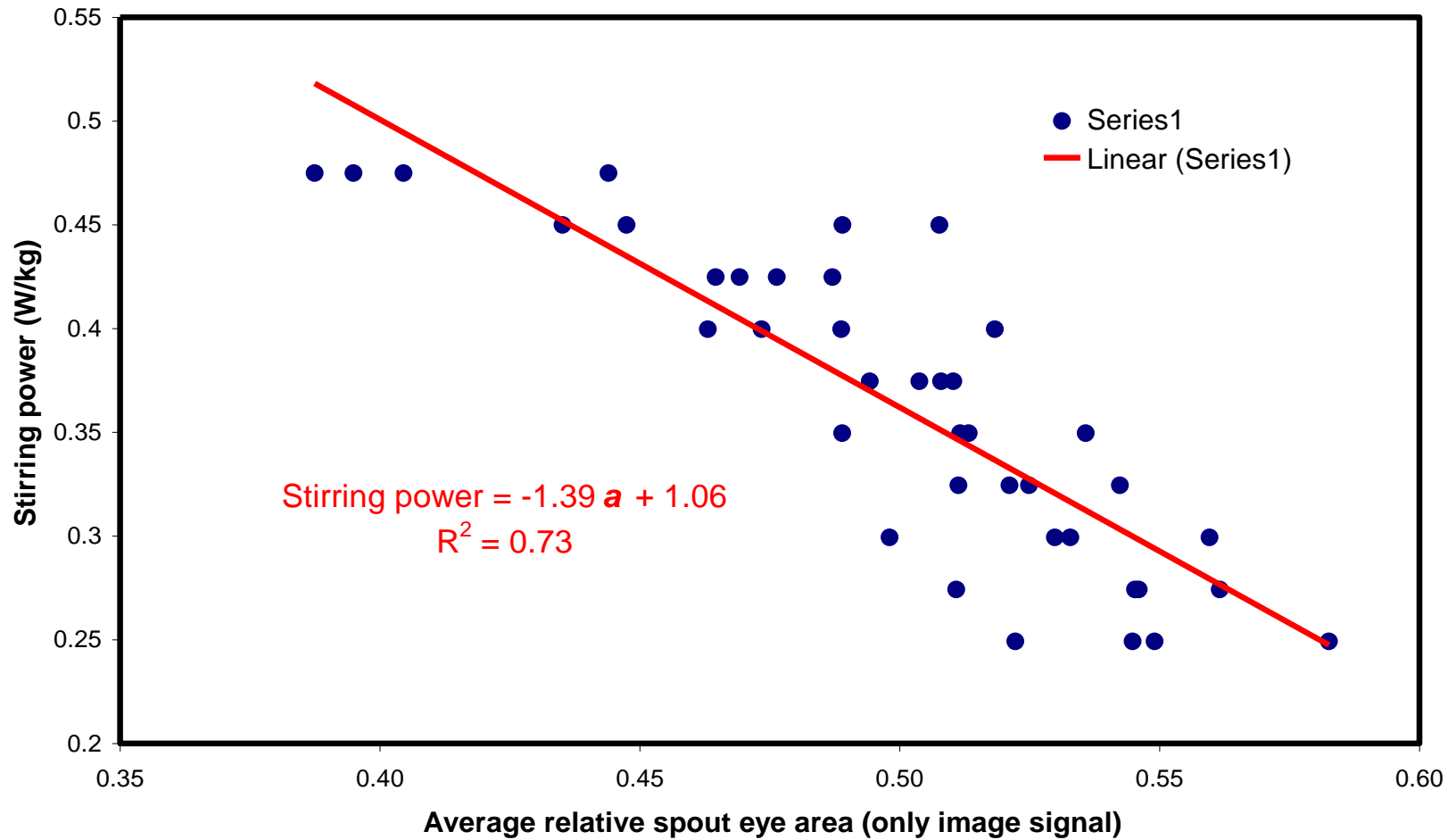
# The relationship between stirring power and PC1 (without image signals)



## 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 ( $R^2=0.95$ )

# Representing the stirring process by just one signal

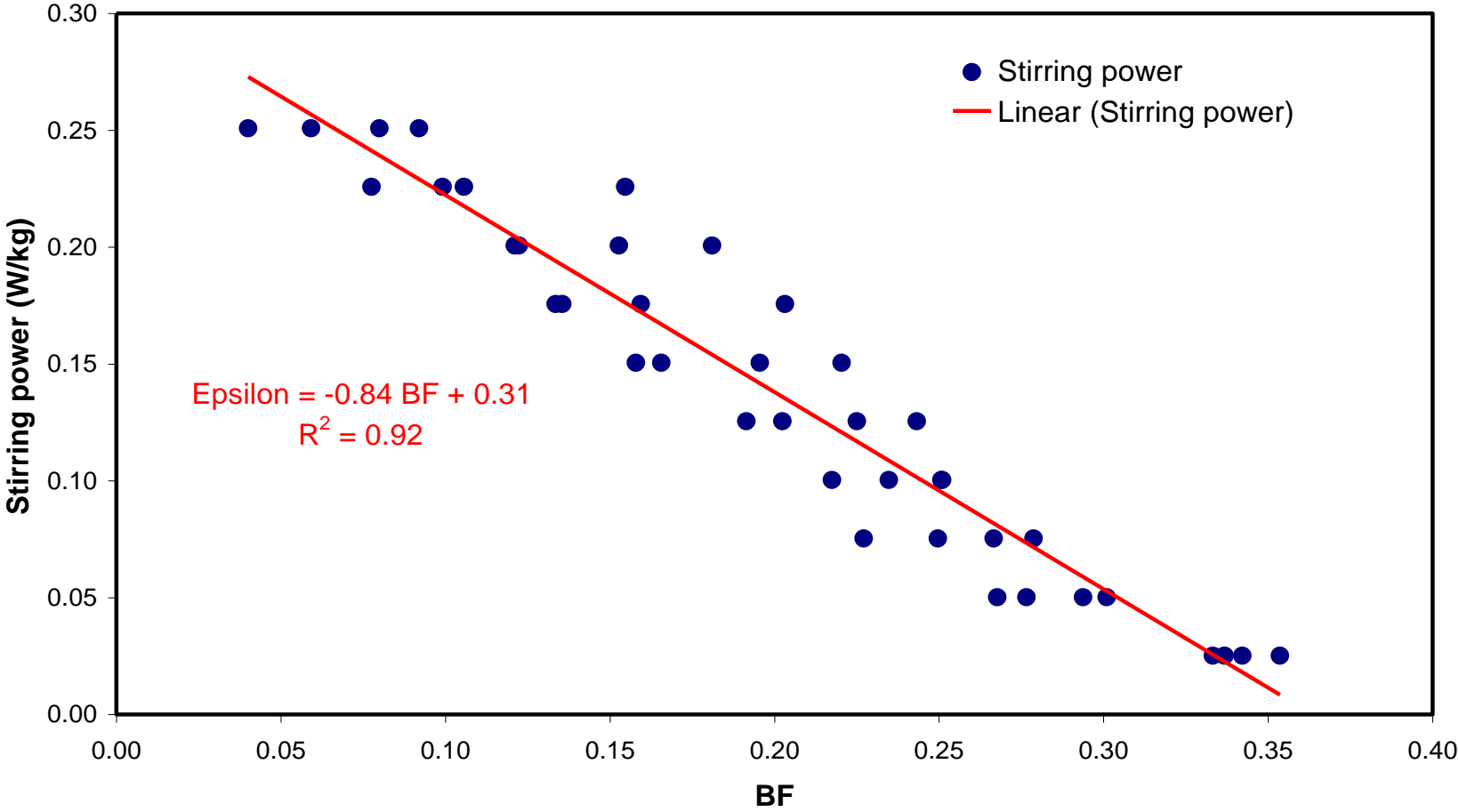


## Loading vectors and eigenvalues (2.0 seconds period)

Score	1	2
Loading vector	-0.8770	0.4805
	-0.4805	-0.8770
Eigenvalue	0.0069	0.0007
Total variance (%)	91.33	8.67

$$BF = -0.877s - 0.481v$$

# Relationship between *BF* and stirring power



# 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%).
- Stirring process can be monitored without image signals.
- It is possible to monitor the stirring process by “stirring factor ( $BF$ )”, and it can provide a quick feedback signal to the control system.

# Development Concept

This concept should be applicable to a wide range of bubbling processes, such as chemical, mineral and metallurgical operations, particularly for high temperature processing, eg. secondary steelmaking.

Established techniques exist for filtering out the noise for the practical industrial environment.

Seeking industrial partner to commercialize this idea.