

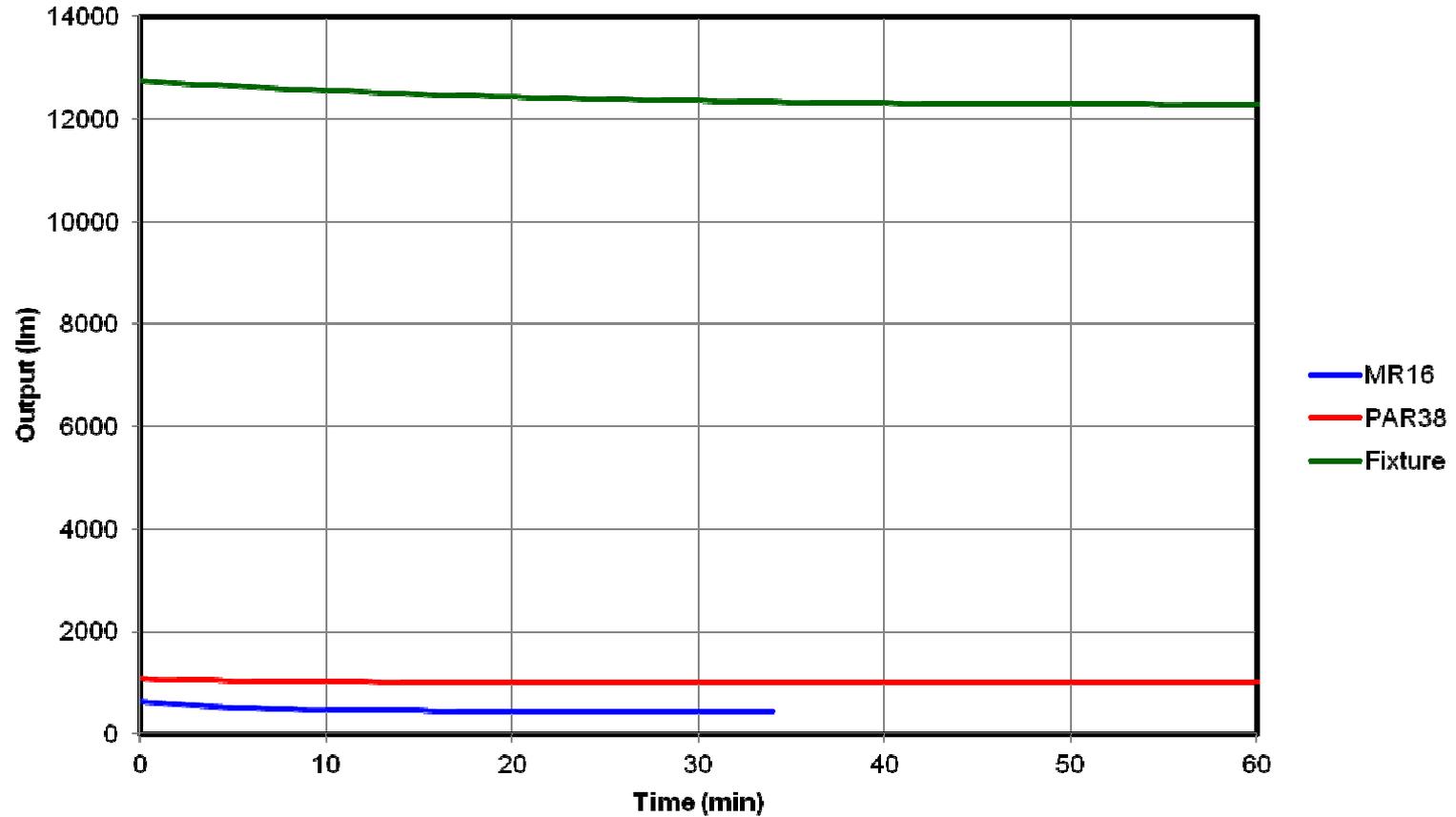
SSL Stabilization: Some Data and Some Math

D.C. Gross | 5/13/2015 | CORM 2015
Light is OSRAM



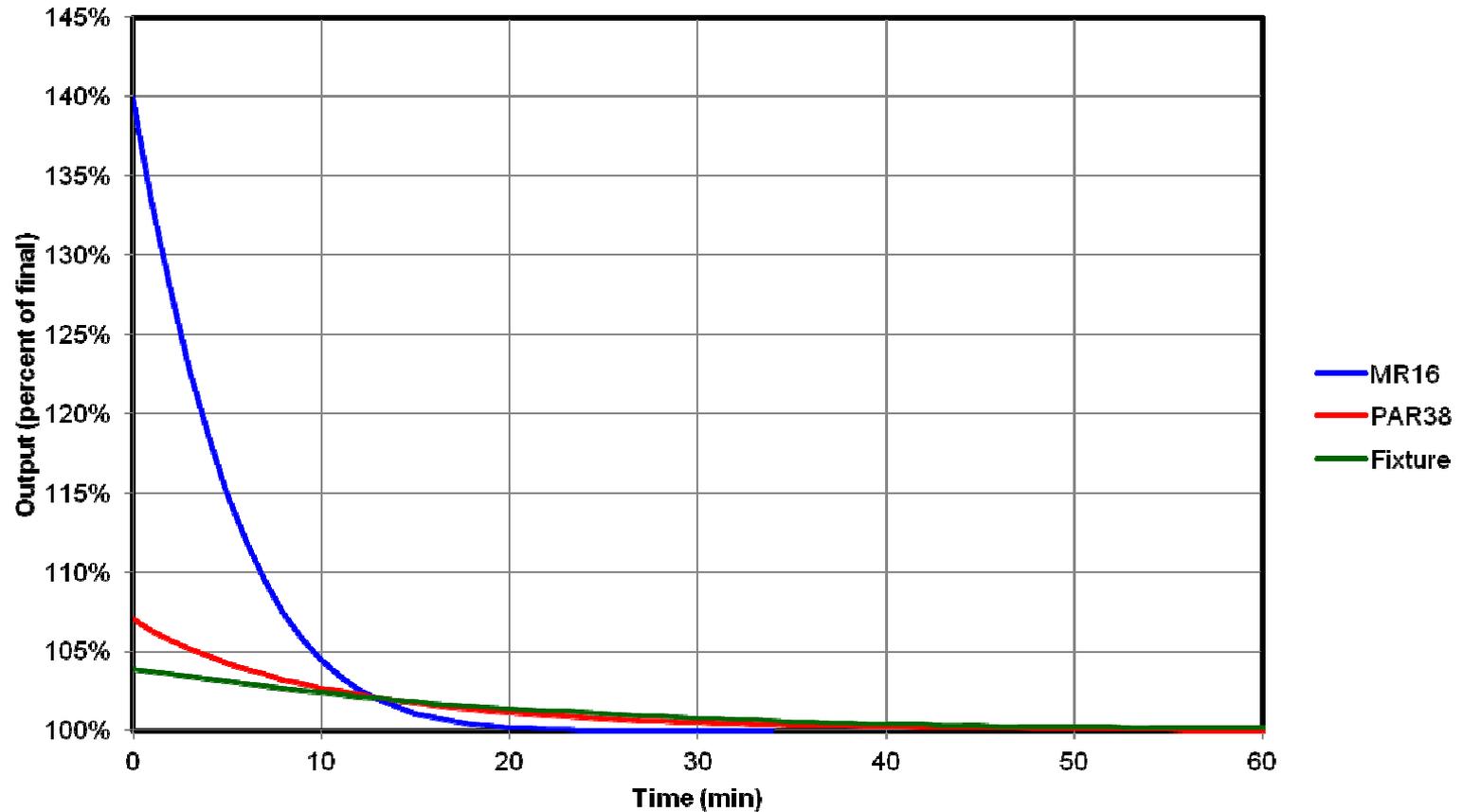
SSL Stabilization

Simple lamps, simple behavior



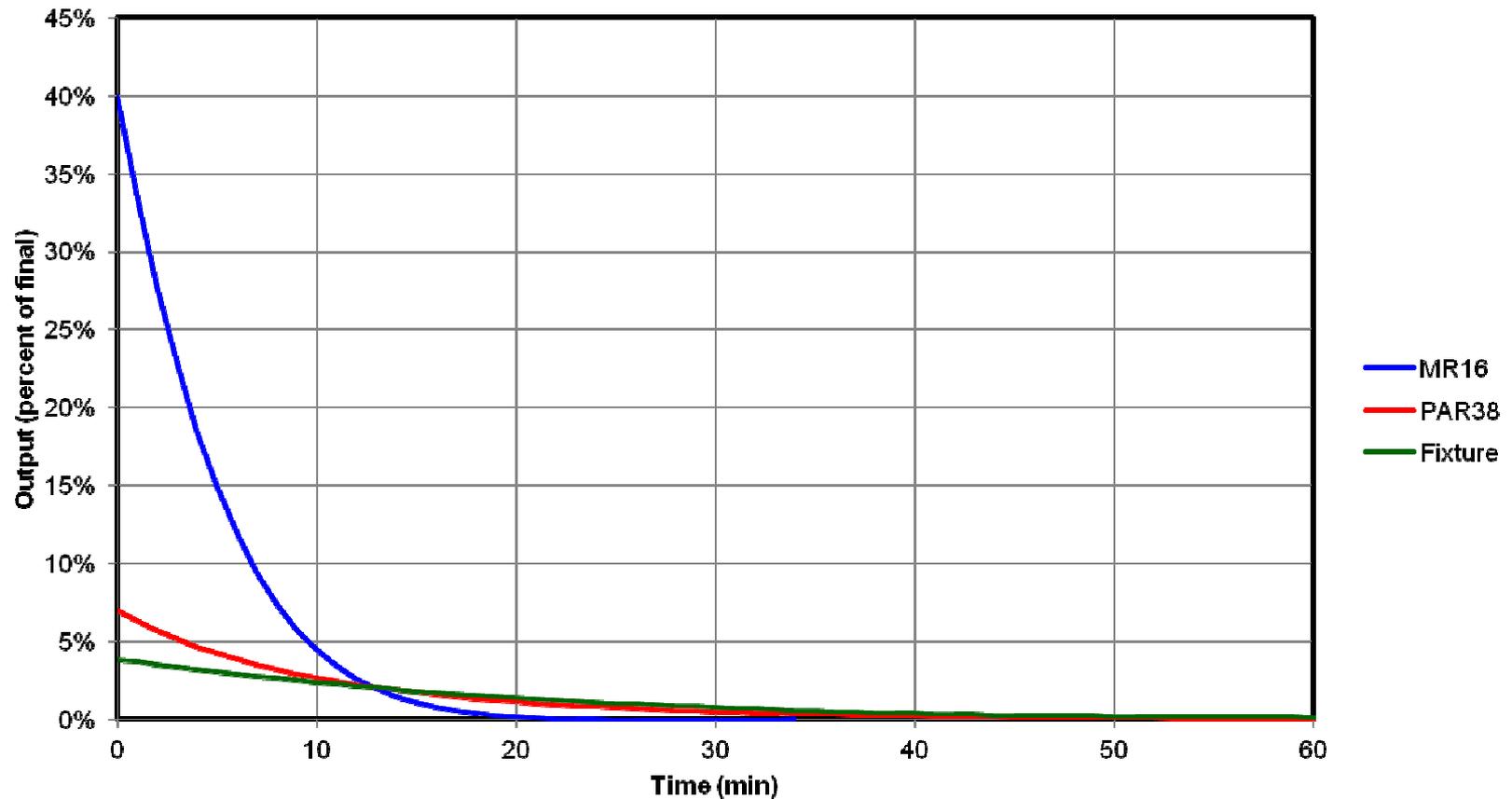
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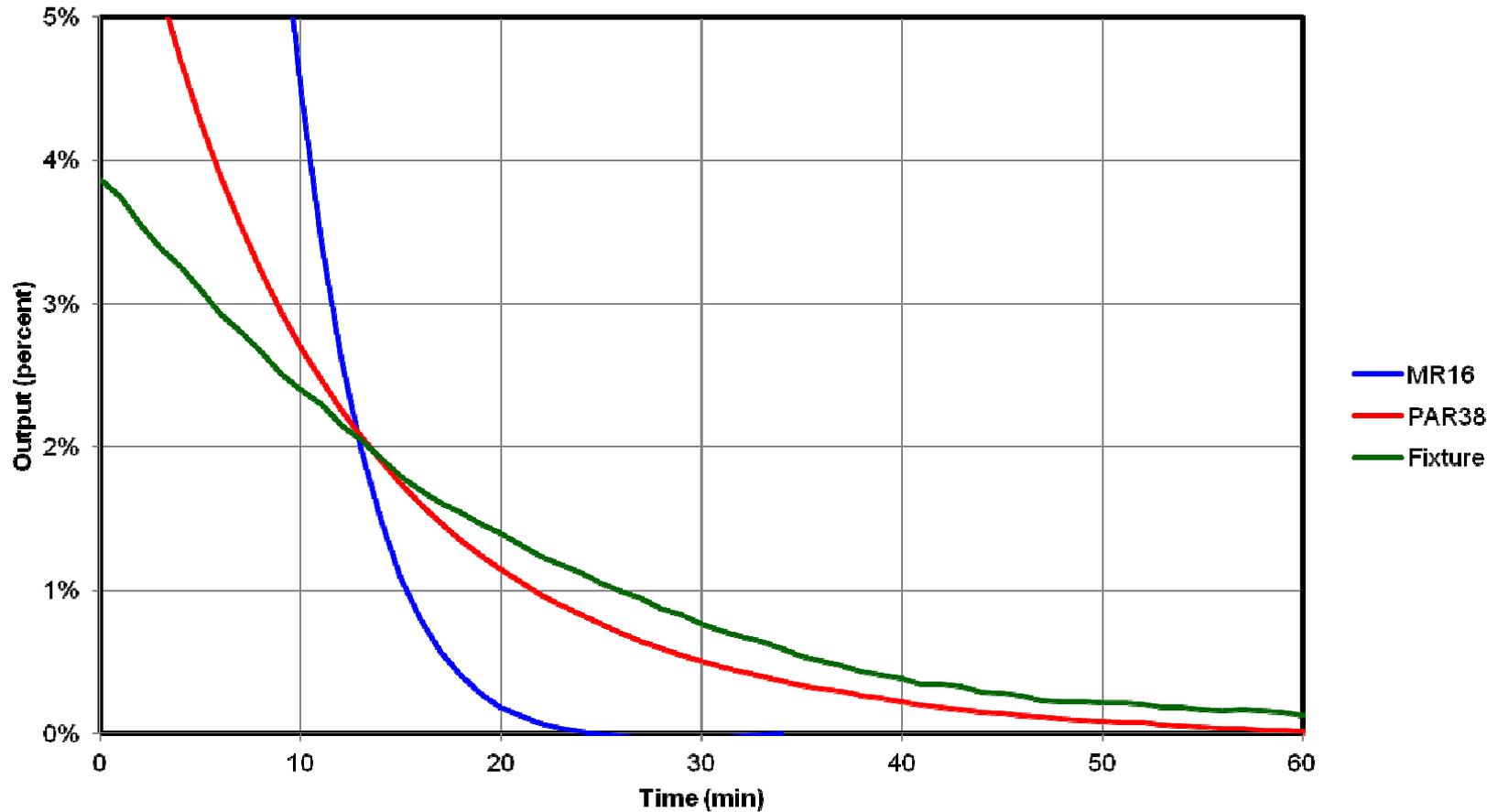
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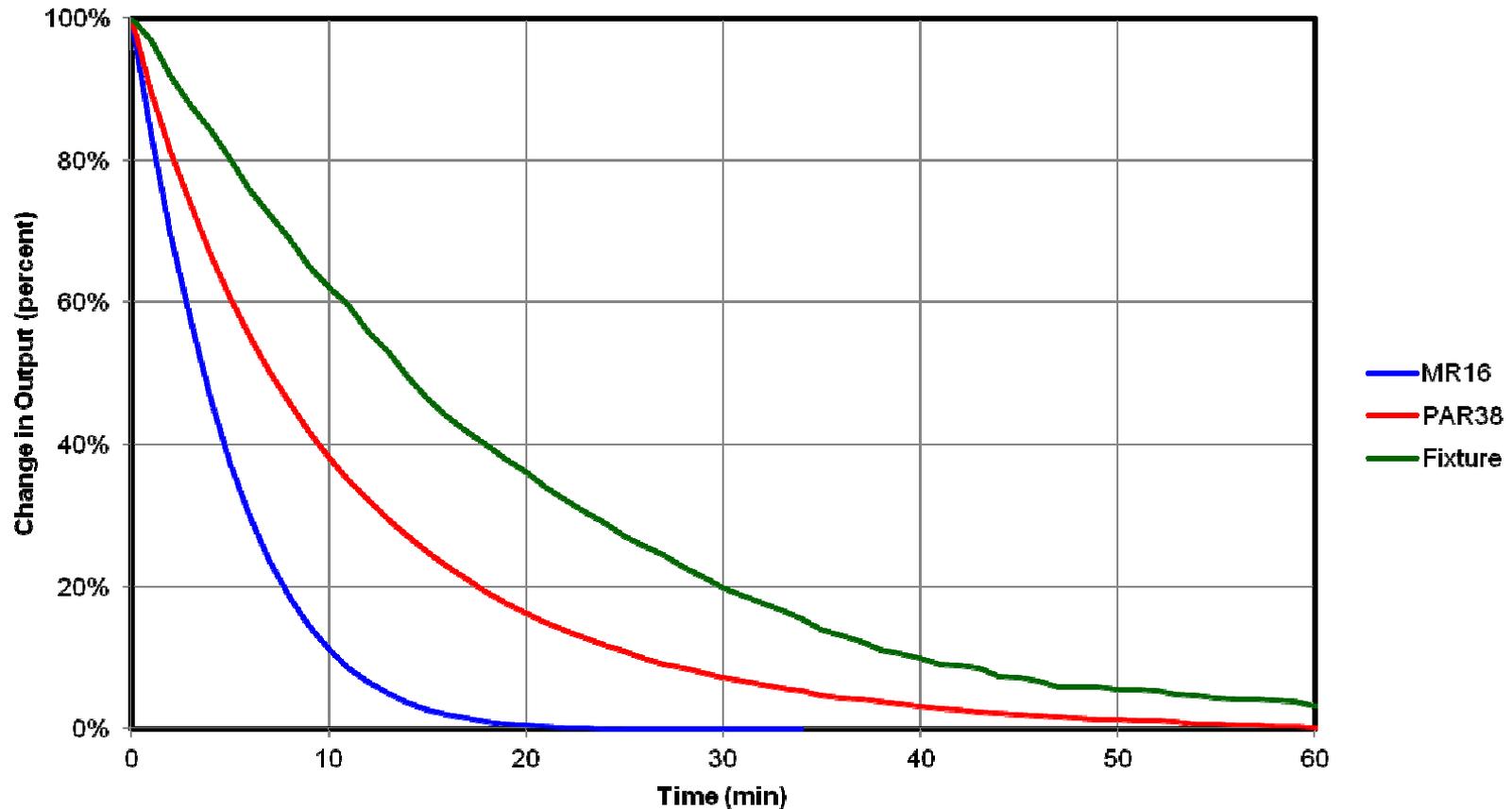
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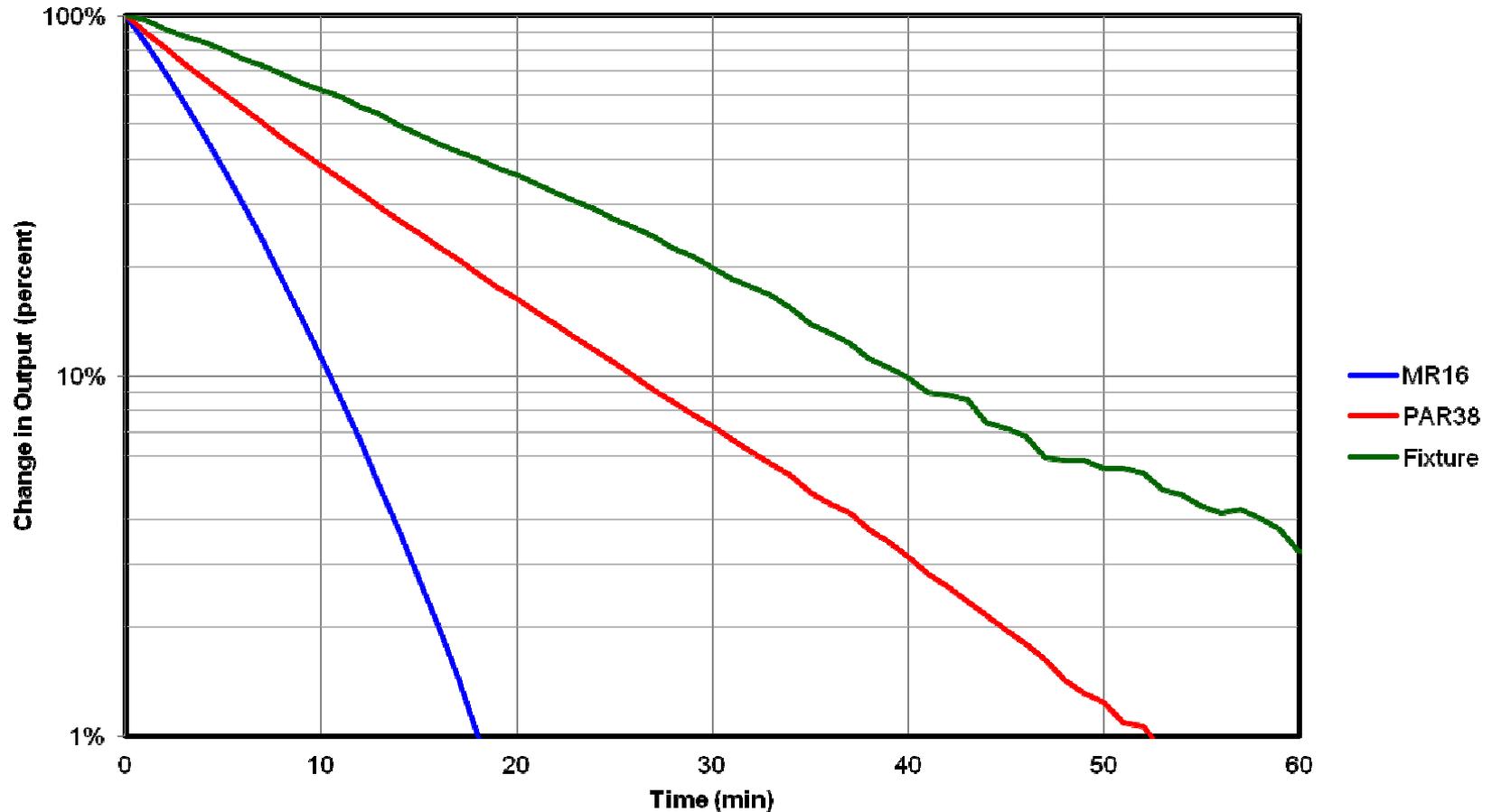
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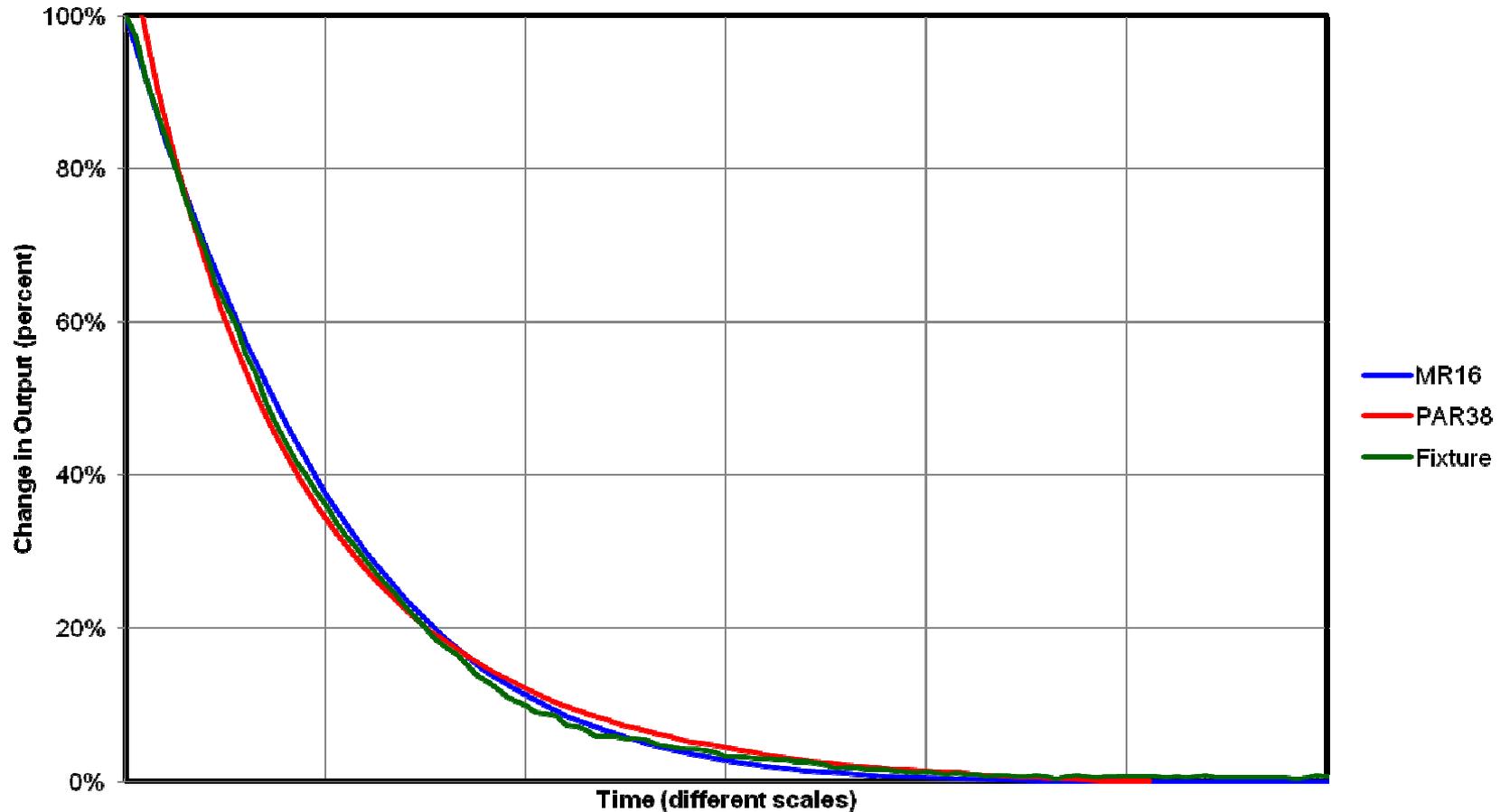
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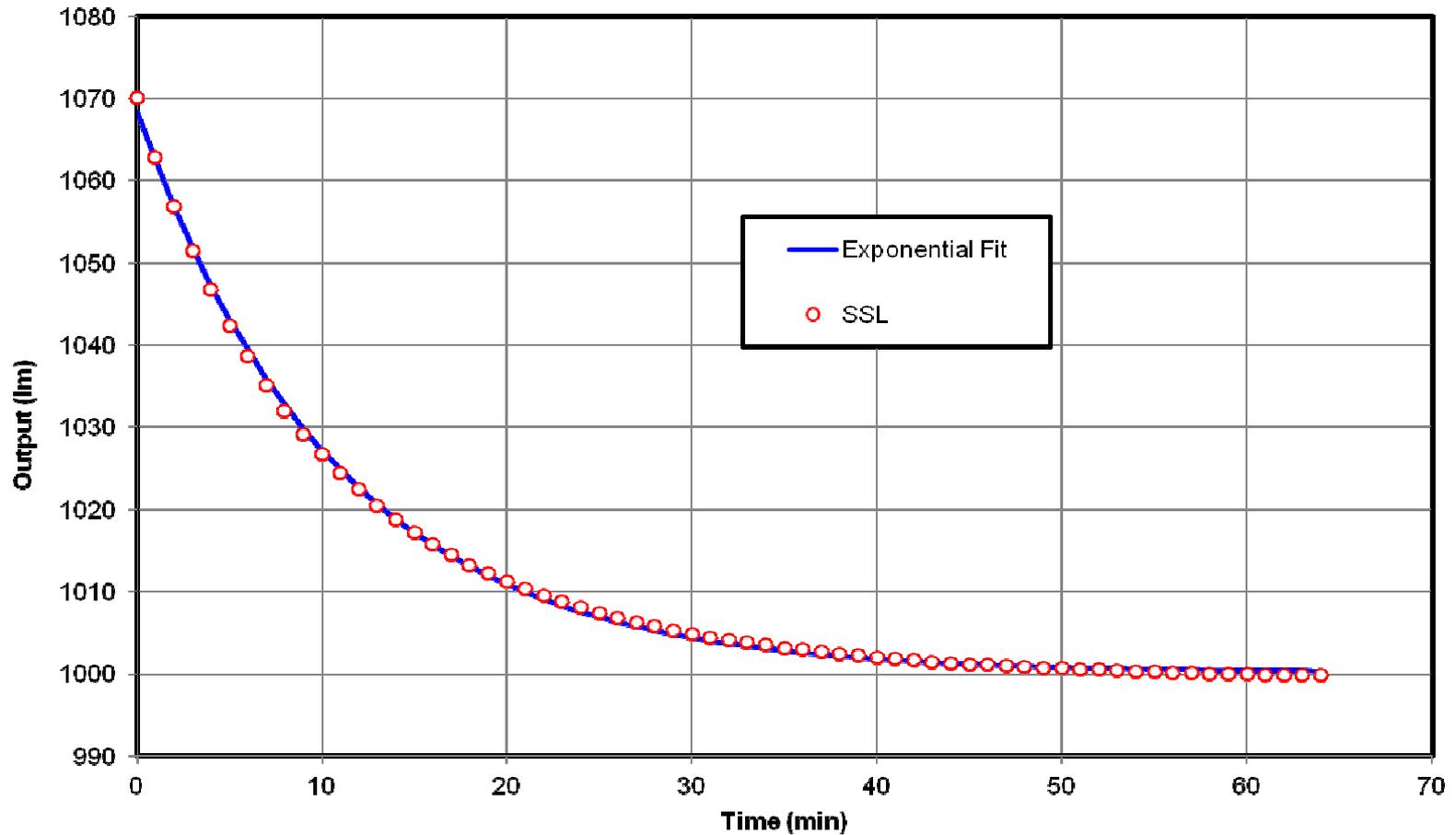
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Constant current or constant power supply

LED on aluminum heat sink

Convective cooling

$$\text{heating} = P_{ele} - P_{light} - h \cdot A \cdot (T - T_{amb})$$

P_{ele} = Electric input power

P_{light} = Optical output power

$h \cdot A$ = convective/conductive loss (coefficient x area)

T = Device surface temperature

T_{amb} = Ambient temperature

$$\partial T / \partial t = [P_{ele} - P_{light} - h \cdot A \cdot (T - T_{amb})] / (m \cdot c)$$

m = mass

c = specific heat

$\partial T / \partial t$ = rate of temperature change

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$$\partial T / \partial t = [P_{ele} - P_{light} - h \cdot A \cdot (T - T_{amb})] / (m \cdot c)$$

$$T = T_{\infty} - T_H \cdot e^{-R \cdot t}$$

If the LED output varies linearly with temperature

$$\partial \phi \approx -\partial T$$

$$\partial \phi / \partial t = -[P_{ele} - P_{light} - h \cdot A \cdot (T - T_{amb})] / (m \cdot c)$$

$$\phi = \phi_{SS} + H \cdot e^{-R \cdot t}$$

At what time (t) will we measure steady state output, Φ_{SS} ?

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$$\phi = \phi_{SS} + H \cdot e^{-R \cdot t}$$

At what time (t) will we measure steady state output, Φ_{SS} ?

$$\phi = \phi_{SS} \quad t \rightarrow \infty$$

At what time (t) will we will we be close enough ?

$$\phi = \phi_{SS} \cdot (1 + \varepsilon) \text{ when } t = \frac{\ln(\varepsilon \cdot \phi_{SS} / H)}{-R}$$

Example

$$\Phi_{SS} = 1000, H = 100, R = 0.1, \text{ and } \varepsilon = 1/4 \%$$

$$\varepsilon \cdot \Phi_{SS} = 2.5$$

$$\ln(2.5/100) = -3.69$$

$$t = 37$$

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A better question is am I now at or near steady state (stability).

$$(\Phi - \Phi_{SS}) / \Phi_{SS}$$

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Extracting the values from an exponential fit.

Iterate (EXCEL solver, etc.)

Assume that you have reached steady state and use a logarithmic transformation.

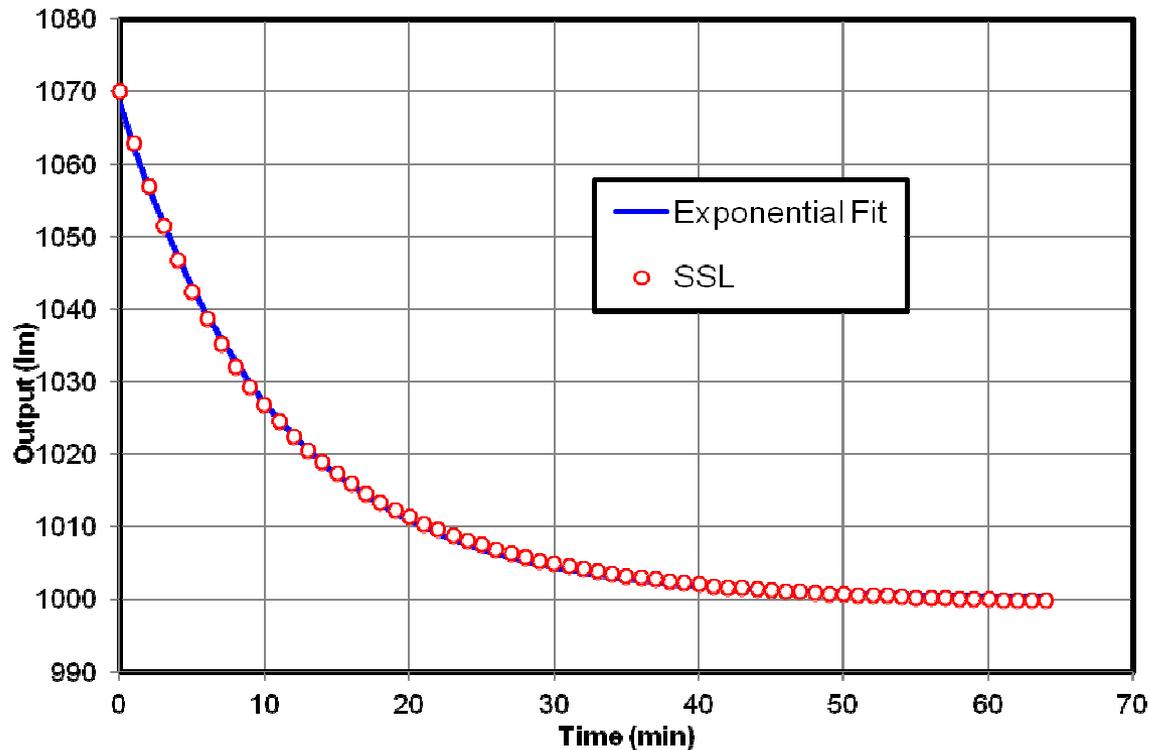
Take the derivative then transform and fit.

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Brute force iteration of the three fitting parameters.

Advantage that the least squares weighting is not distorted



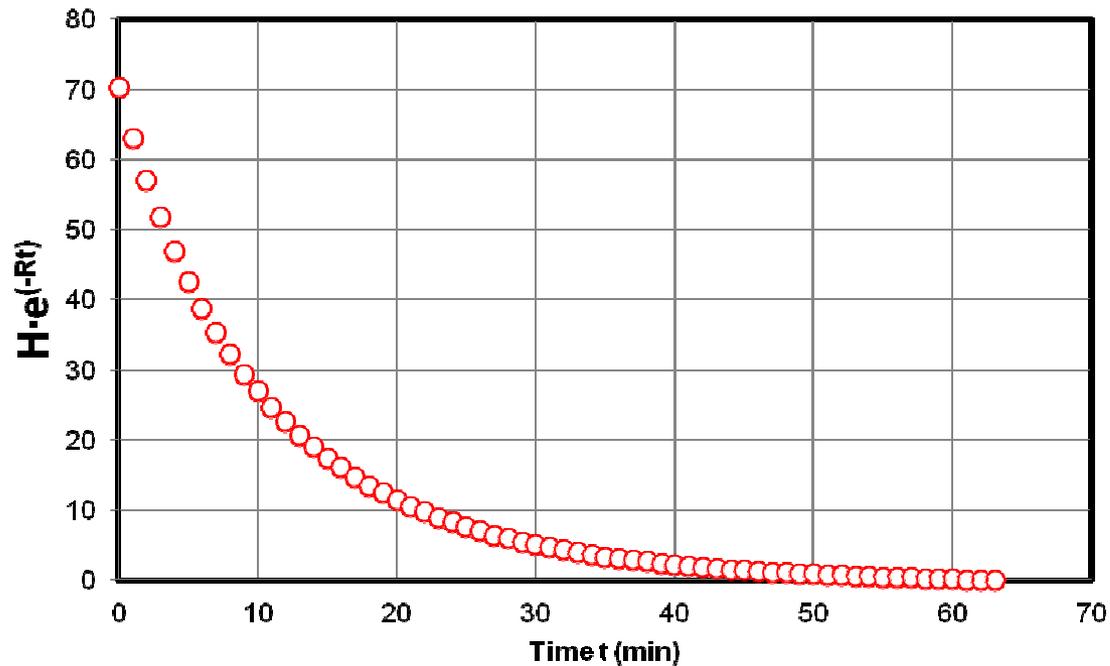
$$\Phi_{SS} = 1000$$
$$H = 68.2$$
$$R = -0.0926$$

$$\Phi_{65} = 999.8$$

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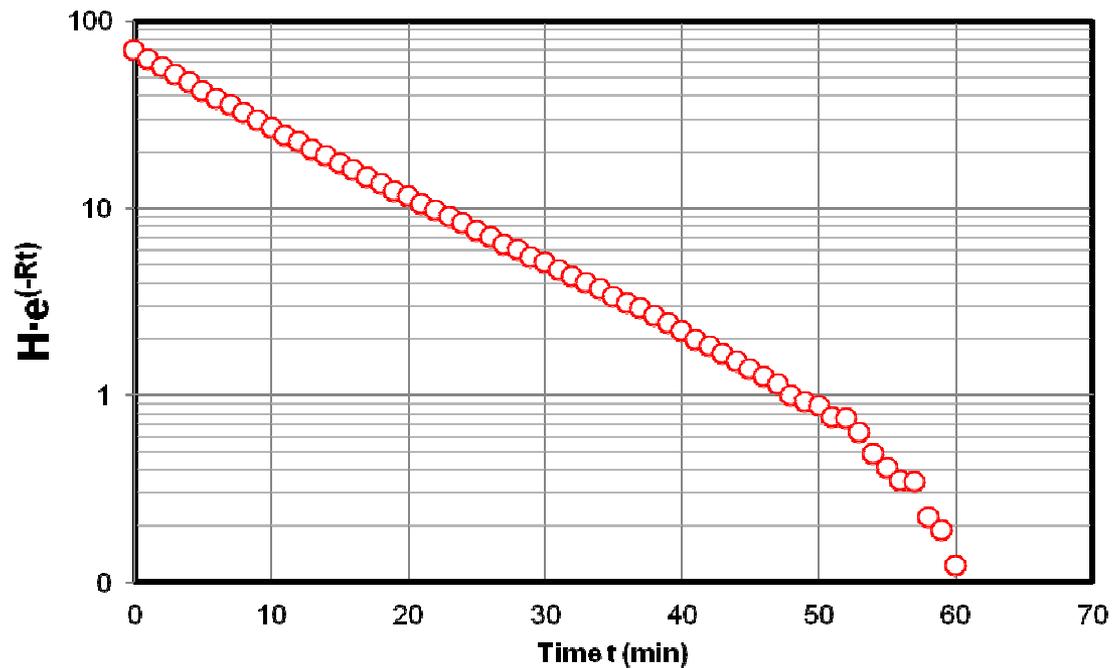
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Subtract the current value assuming you are at steady state



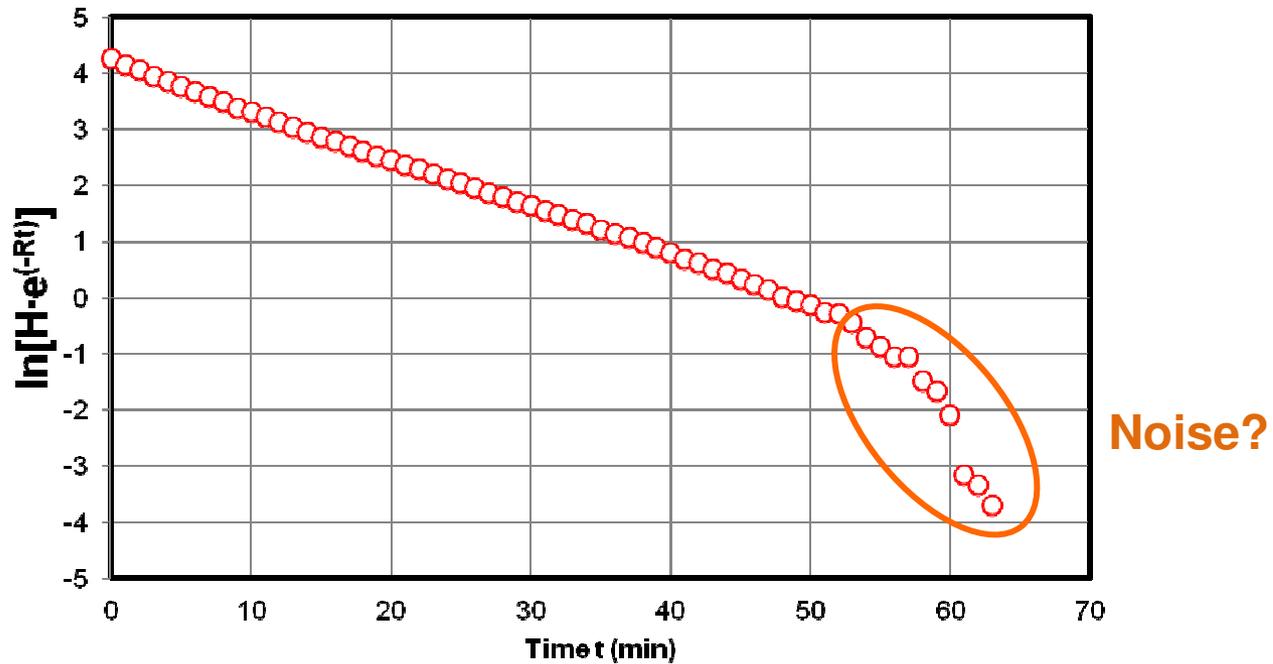
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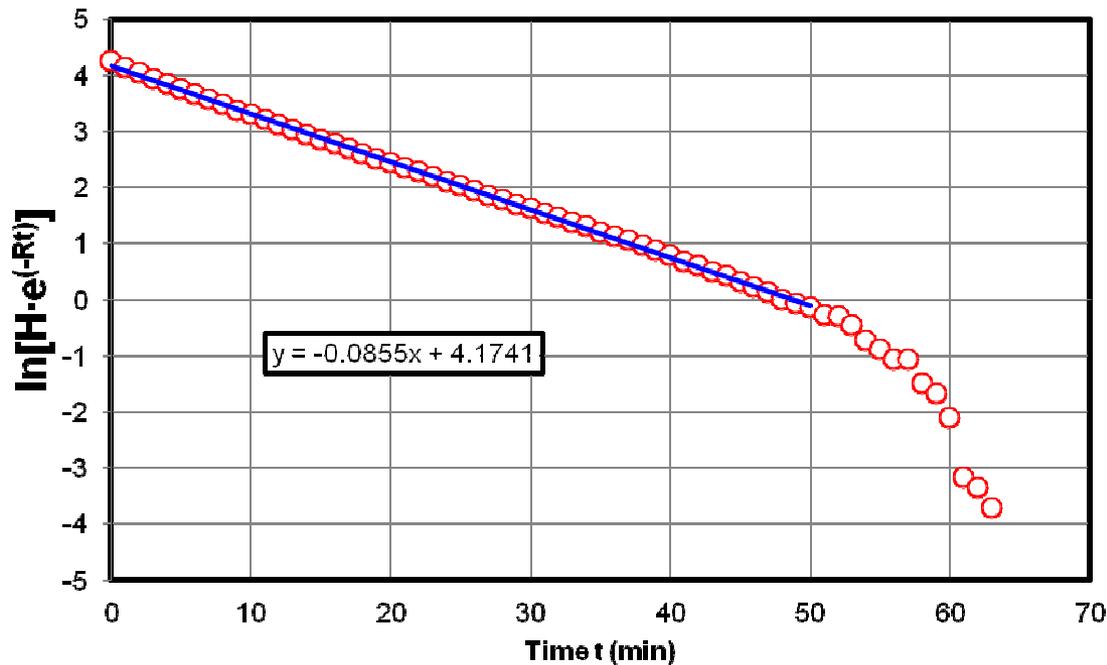
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$$R = -0.0855$$

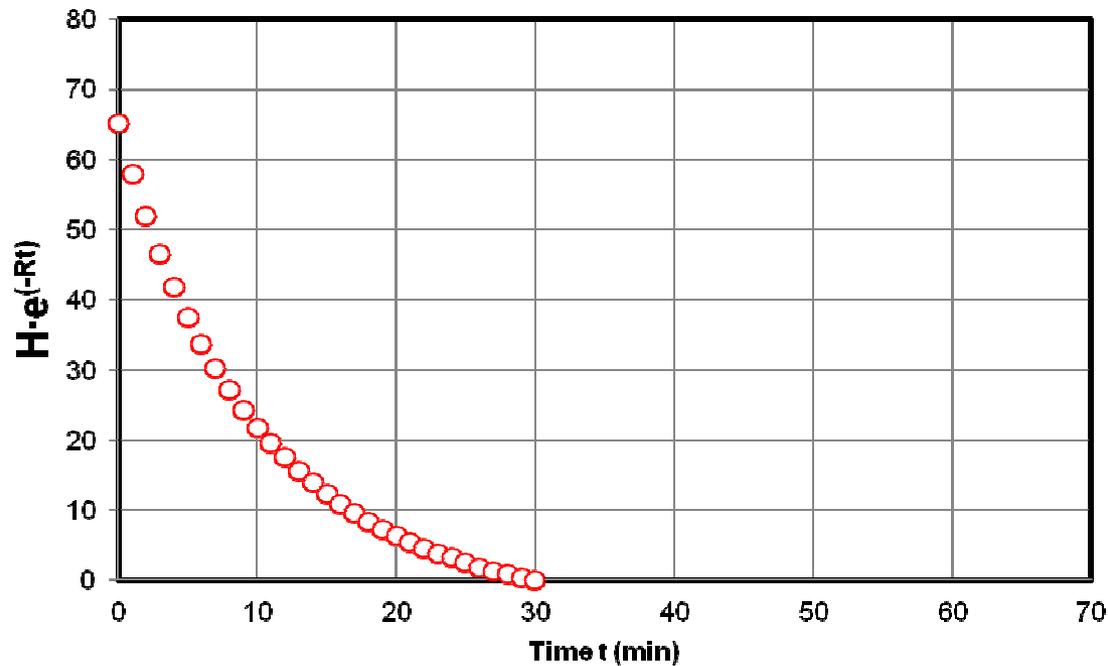
$$H = e^{4.1741}$$
$$= 65$$

$$\Phi_{SS} = 1070 - 65$$
$$= 1005$$

$\Phi_{65} = 1000 !$
Beyond
stable ?

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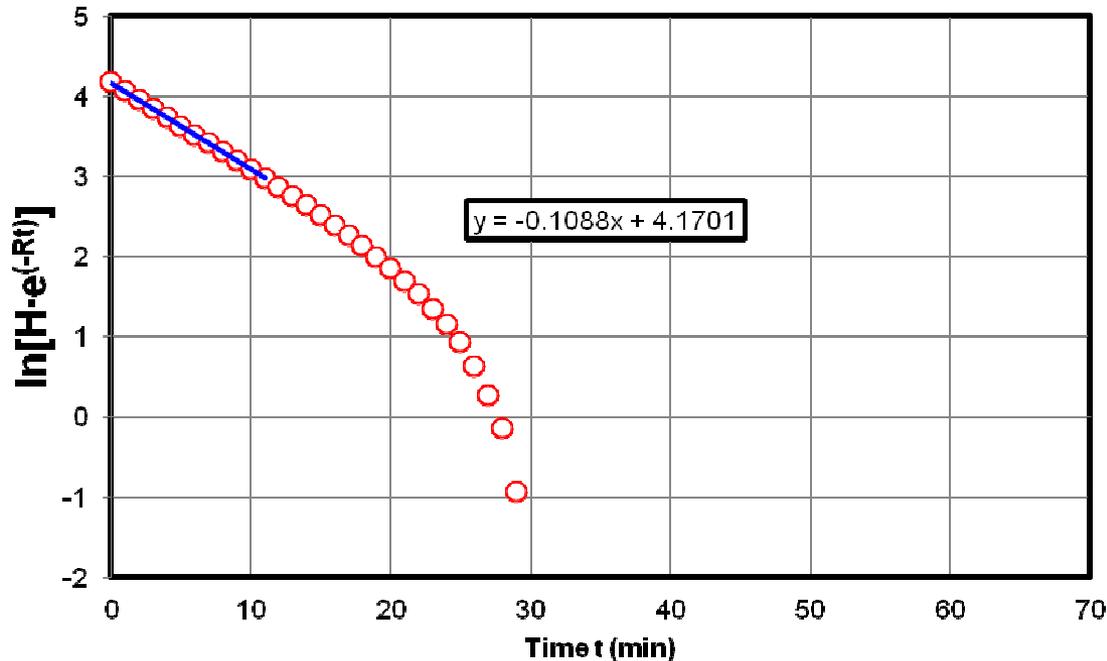
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Stable ?

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$$R = -0.0855$$

$$H = e^{4.1701} \\ = 65$$

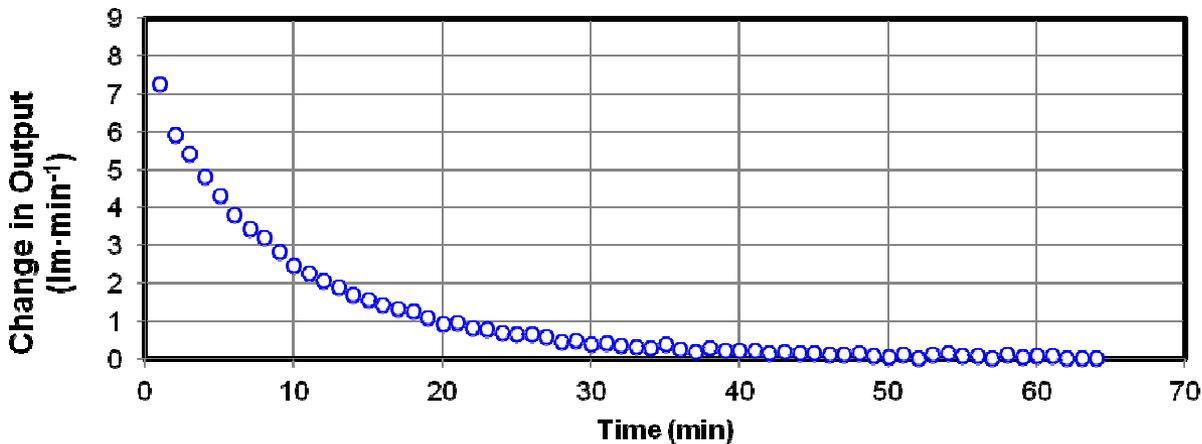
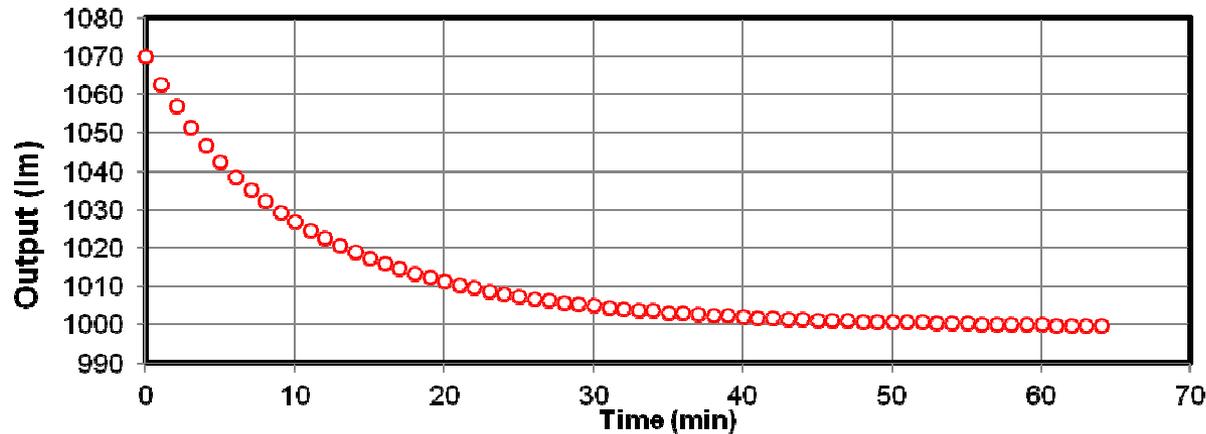
$$\Phi_{SS} = 1070 - 65 \\ = 1005$$

$$\Phi_{30} = 1005$$

Stable ?

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$$\frac{\partial H \cdot e^{(R \cdot t)}}{\partial t} =$$

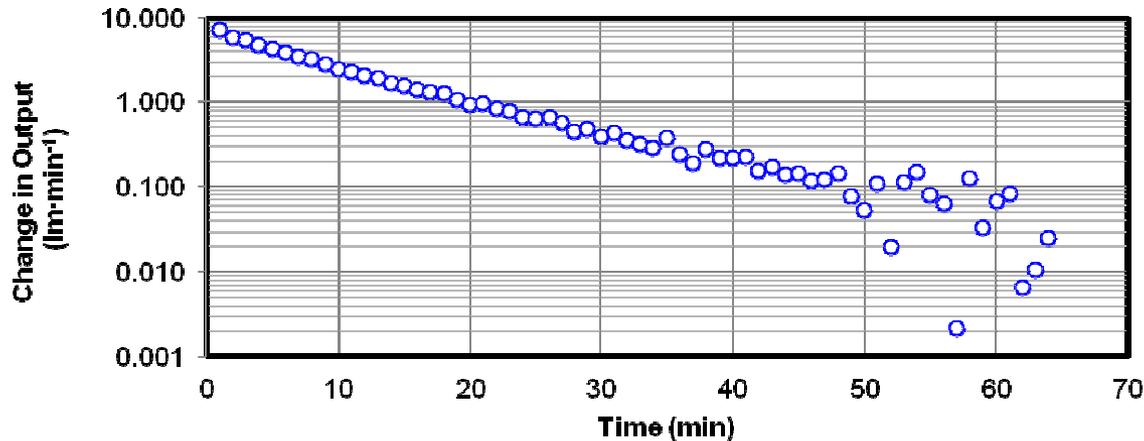
$$H \cdot R \cdot e^{(R \cdot t)}$$

$$\Phi' = \Phi_n - \Phi_{n-1}$$

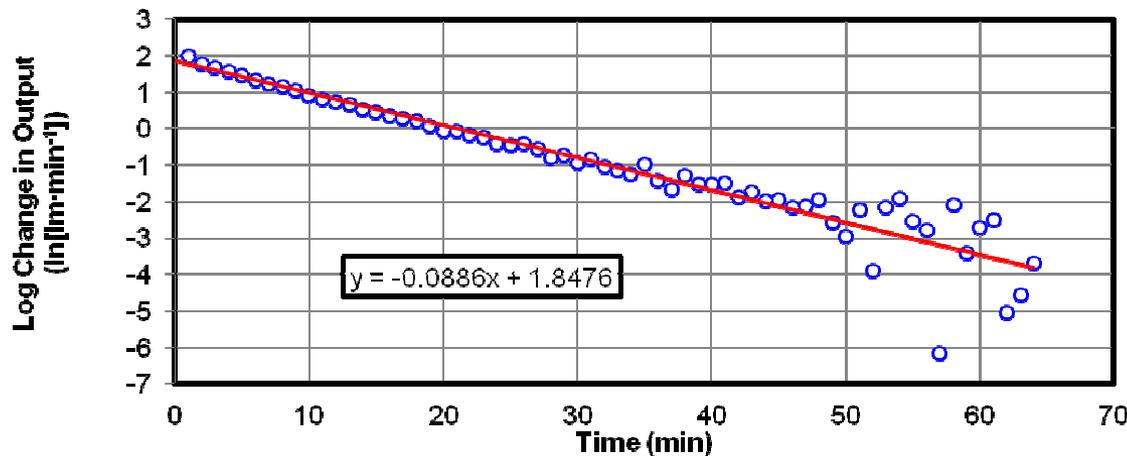
$$\Phi' = \Phi_n / \Phi_{n-1} - 1$$

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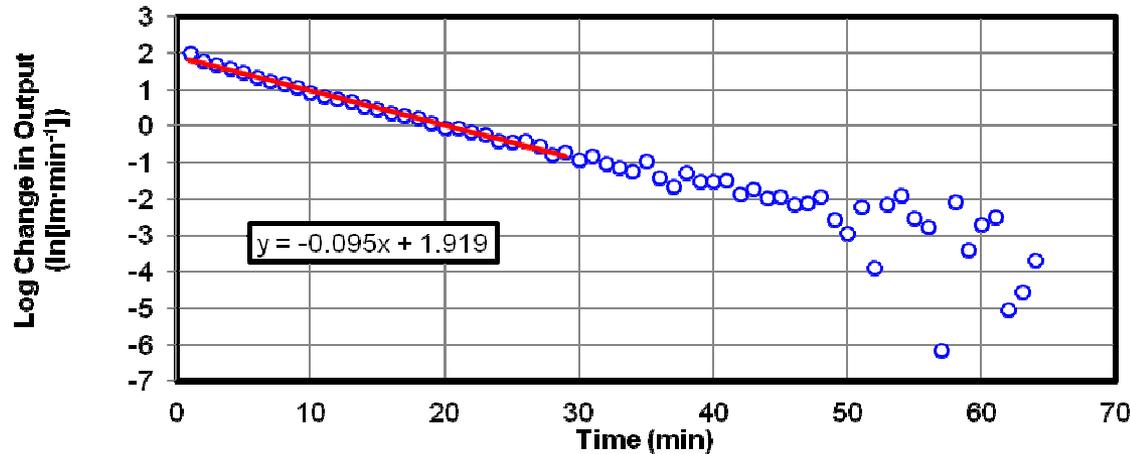
$$\ln[H \cdot R \cdot e^{(R \cdot t)}] = \ln(H) + \ln(R) + R \cdot t$$



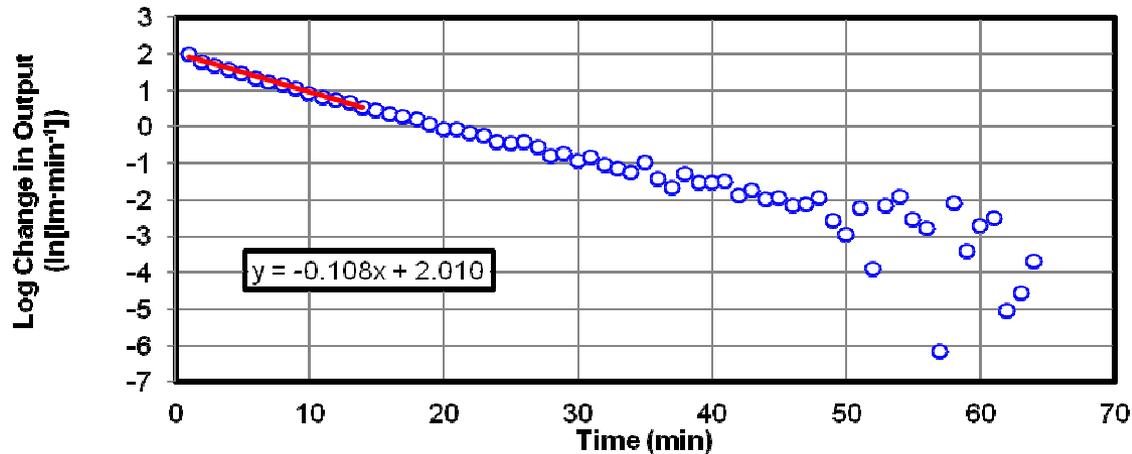
$$R = -0.0886$$
$$\ln(H) = 1.8476 - \ln(R)$$
$$H = 71.6$$
$$\Phi_{SS} = 998.4$$

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$\Phi_{SS} = 998.5$

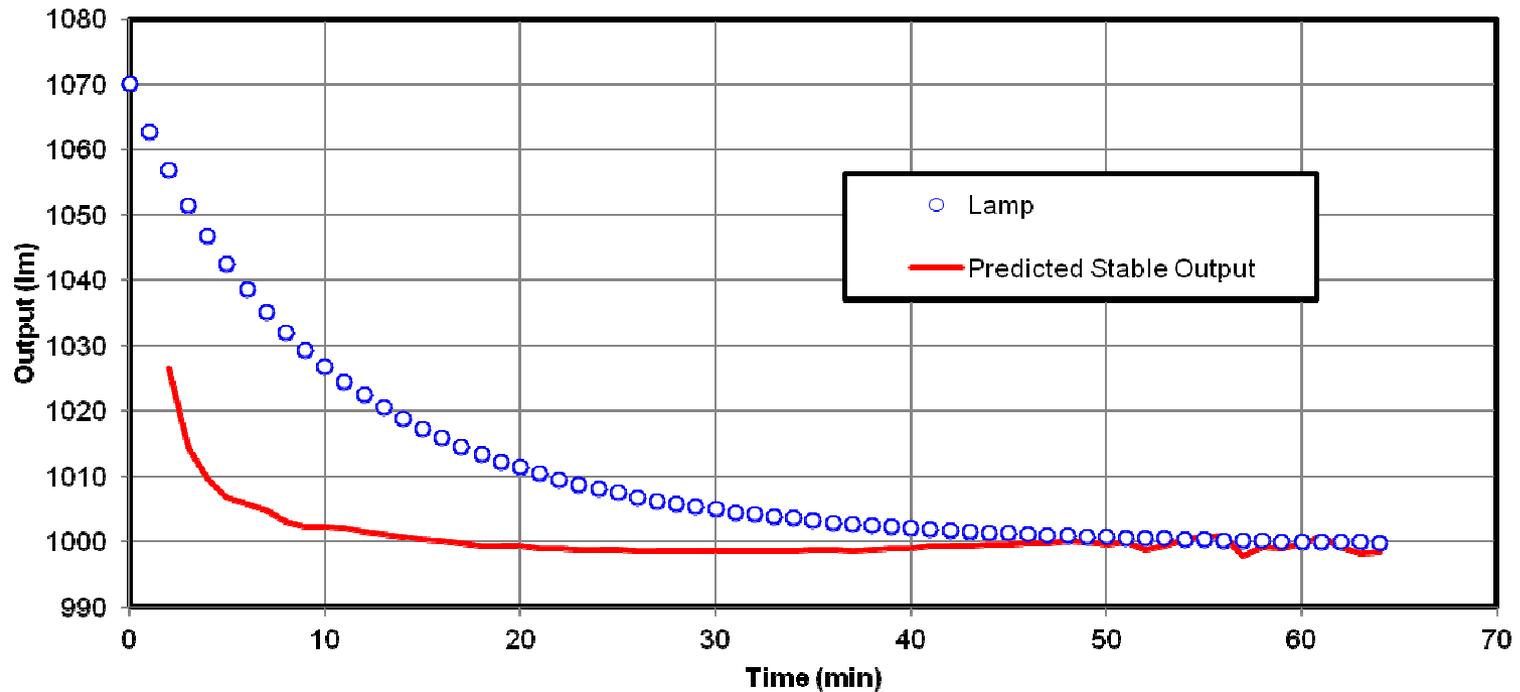


$\Phi_{SS} = 1000.7$

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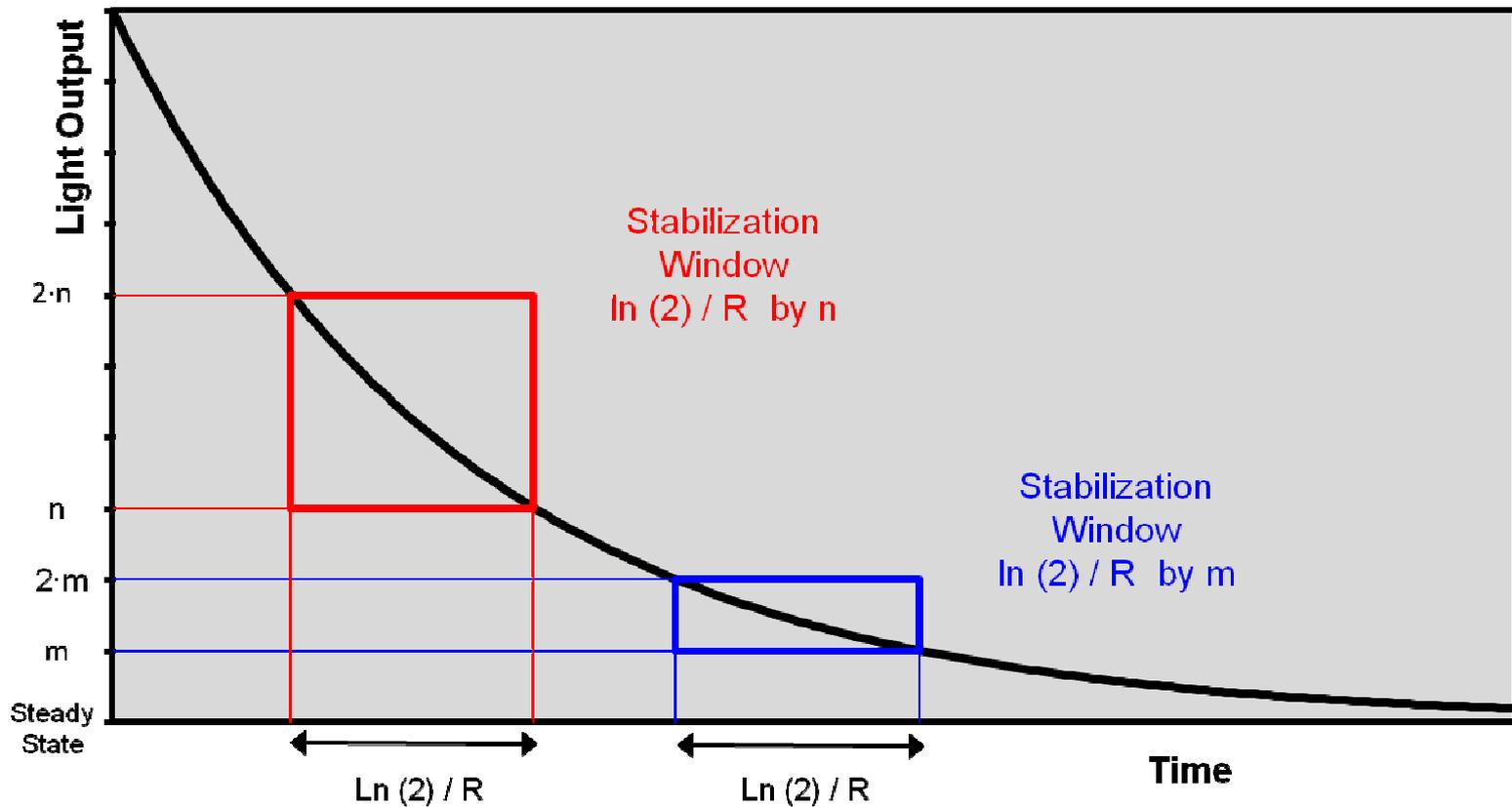
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Using logarithm of derivative



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using a window for defining stability



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A stability window of n % over a time that is equal to $\ln(2)/R$ will result in a reading, at the end of the window, that is n % greater than the steady state value.

This particular mathematical solution shows the impact of R on the difference of the reading from the stable condition.

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$$\partial T / \partial t = [P_{ele} - P_{light} - h \cdot A \cdot (T - T_{amb})] / (m \cdot c)$$

$$T = T_{\infty} - T_H \cdot e^{-R \cdot t}$$

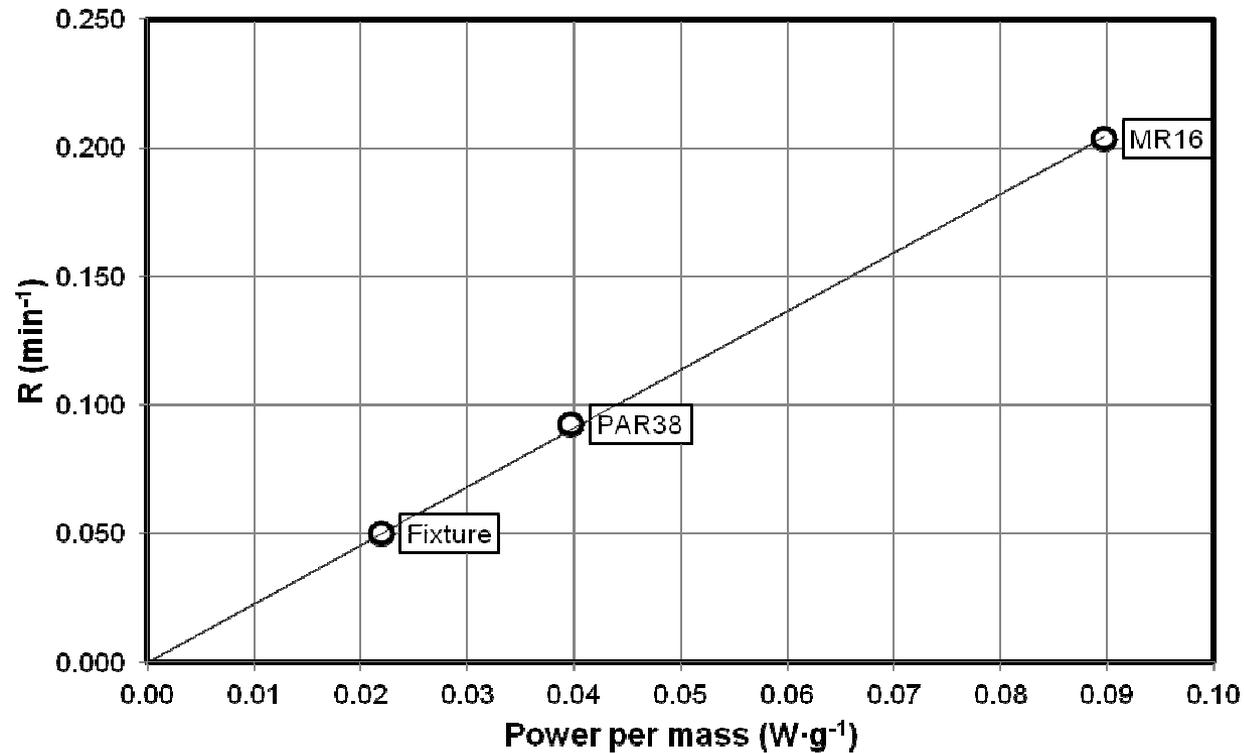
$$\partial T / \partial t = C_1 + C_2 \cdot T \quad C_2 = h \cdot A / (m \cdot c)$$

so rate should be proportional to mass $R \approx 1/m$

but I found $R \approx P / m$!

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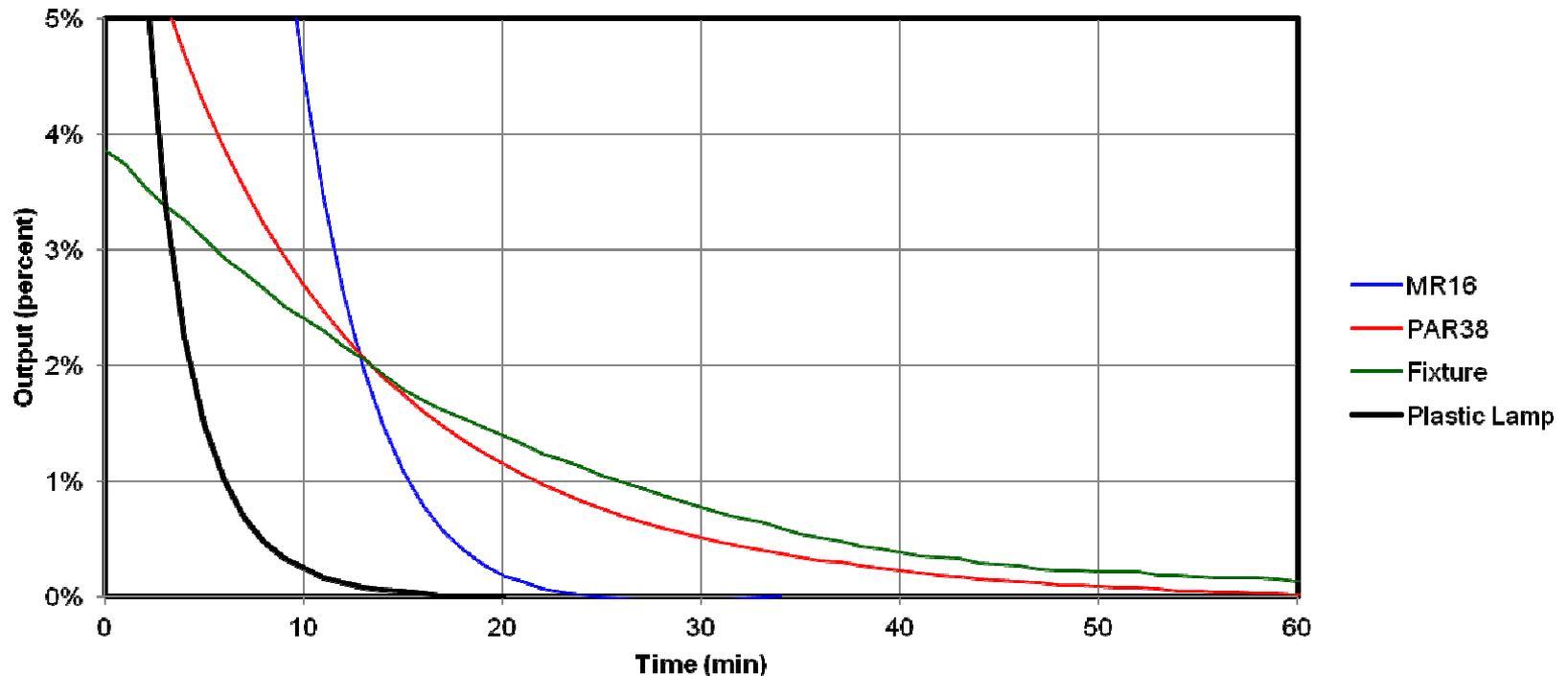
	Mass	Input Power	Rate	Factor
	(g)	(W)	(min ⁻¹)	R / (W·g ⁻¹)
MR16	78	7	0.203	2.27
PAR38	501	20	0.093	2.33
Fixture	6370	140	0.05	2.28

$$R = 2.3 * W \cdot g^{-1} \quad (\text{For lamps of aluminum with LPW} \sim 75)$$

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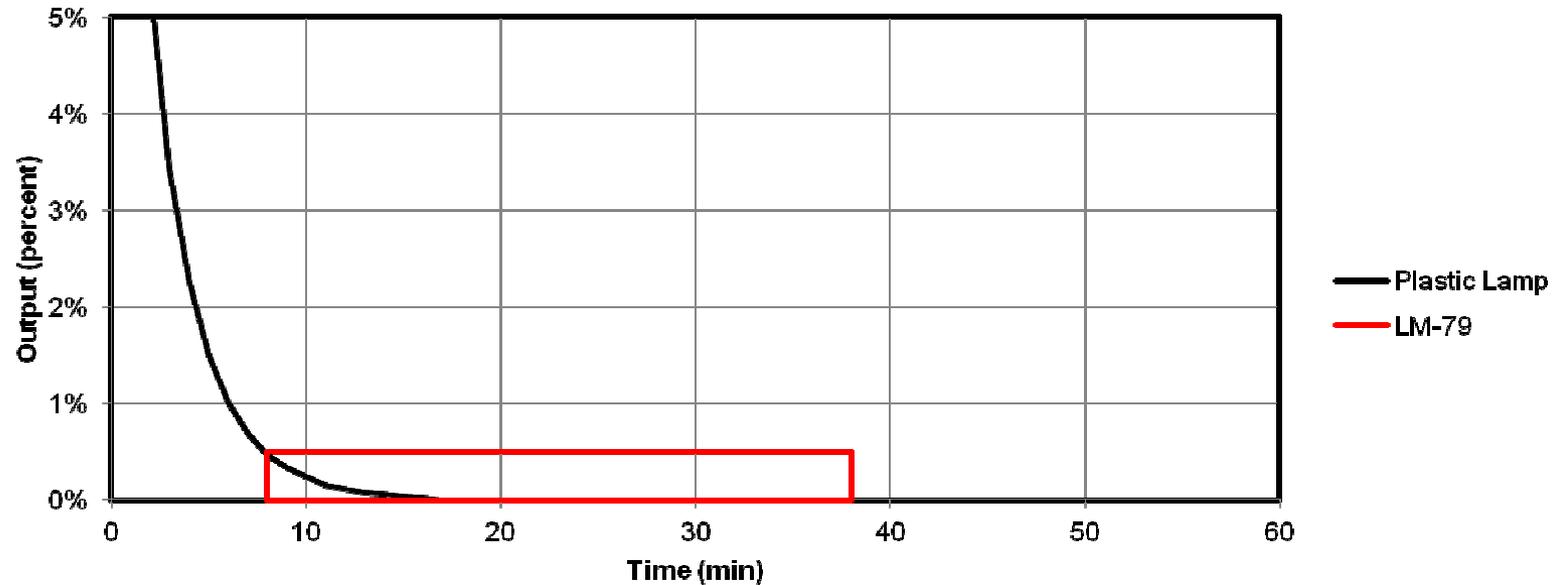
For the sake of “accuracy” and productivity we should consider new methods for judging stability.



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The current standard is 30 minutes and 1/2 %.



Legal reading at 38 minutes, stable at 15 minutes.

Thank you for your attention.