SIGNIFICANT PARAMETERS ON THE DEVIATION OF HAIR CONDITIONER VISCOSITY: PART I. REGRESSION ANALYSIS BY THE MINITAB PROGRAM

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ABSTRACT

According to highly competitive business, the production of high quality products at the lowest cost becomes the most important business strategy. In this case study of a hair conditioner process, the deviation of hair conditioner viscosity leads to product loss of about US$ 100,000 in 2004. The highest standard deviation of the product viscosity was 4,217 cP corresponding to the defect per million opportunities (DPMO) of the process of 532,230. A Cause and Effect diagram was used to detect the potential causes; subsequently the Minitab program was applied to pinpoint the significant parameters. The analytical results indicate that six parameters, which are quantities of chlorinated water and chilled water, melting time of fatty alcohols, cooling period after adding chilled water, times used for adjusting the temperature of chilled water and for adding the additives, play significant effect on the deviation of hair conditioner viscosity.

KEYWORDS: Viscosity, Regression analysis, Minitab program, Cause and Effect diagram

1. INTRODUCTION

The production of high quality products at the lowest cost has become the most important business strategy. One of the common problem solving techniques to reach a business goal is using QC tools, for example, the Cause and Effect diagram or Fishbone diagram to indicate potential causes, and the Pareto diagram to prioritize causes. It was found that the main loss of liquid personal care products from a case study about US$ 100,000 came from the deviation of viscosity of hair conditioner. Due to product quality and customer satisfaction, the lower and upper specification limits (LSL and USL) were set up at 15,000 and 35,000 cP, respectively as shown in Figure 1. The hair conditioner viscosity substantially deviated from the target value of 25,000 cP, mostly in the upper range. In this paper the Cause and Effect diagram was used to identify the potential causes of the problem. The Minitab program was used for regression analysis of all potential causes to pinpoint the significant parameters. Based on a literature review, the viscosity of the mixture depends on shear rate, temperature and time of shearing [1]. P. Rezayati-Charani et al. [2] applied multiple linear regression analysis using the Minitab program to obtain a correlation between three pulping variables and chemical properties for the optimum operating conditions in the pulping industry. Temsawangleart [3] used multiple linear regression with the Minitab program to find the specific factors that affect the deviation of bulk density of the non-soap detergent.

2. EXPERIMENTAL METHODS

The hair conditioner process in this case study is illustrated in Figure 2. The study focused on seven formulae of hair conditioner. The experiments were divided into two parts. Firstly, the apparent viscosities at various shear rates were measured by a Brookfield viscometer. The data were analyzed

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by the power-law model. Consequently, significant parameters were determined by the Cause and Effect diagram and the Minitab program, respectively.
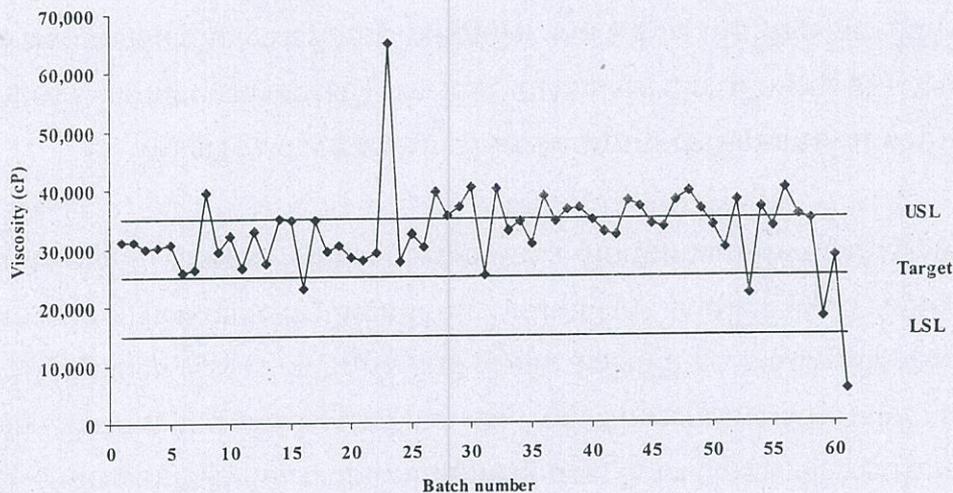

Figure 1. An example of the deviation of hair conditioner viscosity

2.1 The power-law model [4-5]

$$\eta_{app} = m \; \gamma^{n-1} \tag{1}$$

where η_{app} is the apparent viscosity (cP), m is the consistency (cP·s^n), γ is shear rate (s^{-1}), and n (dimensionless) is the degree of deviation from Newtonian behavior (for newtonian fluid n = 1; pseudoplastic fluid n < 1; and dilatant n > 1).

2.2 Regression analysis [6-7]

Regression analysis is used to investigate and model the relationship between a dependent or response variable, which is the hair conditioner viscosity in this work, and one or more independent or explanatory variables, for example, pH and quantity of chlorinated water. In the linear regression model, the dependent variable is assumed to be a linear function of one or more independent variables plus an error introduced to account for all other factors as follows:

$$y = \beta_0 + \beta_1 \; x_1 + \beta_2 \; x_2 + \; \cdots \cdots \; + \beta_k \; x_k + u \tag{2}$$

where y is the dependent variable, $x_1, x_2, ..., x_k$ are the independent variables, and u is the disturbance or error term. The objective of regression analysis is to estimate the unknown parameters $\beta_1, \beta_2 ..., \beta_k$ which indicate how a change in one of the independent variables affects the value of the dependent variable. The reliability of the data to conclude the effect of the independent variables on the dependent variable is observed by the residual model diagnostics. The significant independent variables are considered by use of scatter plots, and confirmed by using the best subset regression analysis of the Minitab program.

3. RESULTS AND DISCUSSION

From the data collected in the hair conditioner process, the highest standard deviation of the product viscosity was 4,217 cP, corresponding to the defect per million opportunities (DPMO) of the process of 532,230. This means that the number of possible defects produced in the process based on 1,000,000 total opportunities is 532,230 which is equivalent to the process capability index (C_p) of -0.02 [8]. The DPMO and the process capability index are used as the indicators of the capability level of process. If the process is in control, the DPMO and process capability index are less than 6,200 and above 1.33, respectively [8]. The process is recommended for immediate corrective action(s) if the DPMO is higher than 6,200 and the process capability is less than 1.33.

Main mixer:

Add chlorinated water

↓

Add cationic surfactant-1

↓

Turn on high shear pump for 5 minutes

↓

Add cationic surfactant-2

↓

Add cationic surfactant-3

↓

Add fatty alcohols ←----- **Side mixer-1:** fatty alcohols

↓

Turn on high shear pump for 10 minutes, cool down to 62 °C

↓

Add chilled water

↓

Add thickener agent ←----- **Side mixer 2:** thickener agent

↓

Add perfume

↓

Add silicone-1

↓

Add silicone-2

↓

Add additives

↓

Add preservatives

↓

Turn on high shear pump for 5 minutes

↓

Quality control (pH, % cationic surfactant and viscosity)

↓

Hair conditioner ----→ **Storage tank**

Figure 2. Simple steps in hair conditioner production

The apparent viscosities of 7 formulae of hair conditioner were plotted with different shear rates. From the results, the average consistency (m) is 34,343 $cP \cdot s^n$, and the average degree of deviation from Newtonian behavior (n) is 0.348. Therefore, the hair conditioners are time-sensitive to shearing action and behave as the pseudoplastic fluid because their viscosities decrease with an increase in shear

rate. Accordingly, the parameters related to time and shear rate should be considered in particular when the deviation of viscosity is observed.
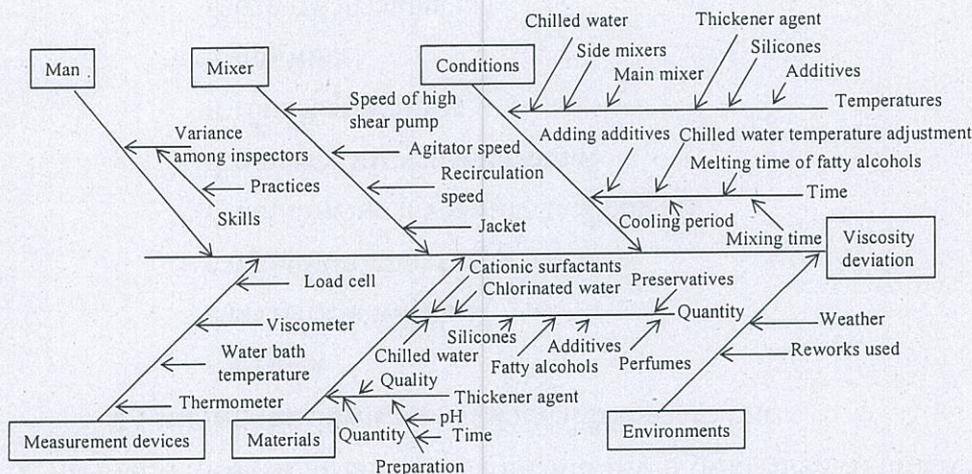
Figure 3. Cause and Effect diagram of potential causes of the deviation

of hair conditioner viscosity

Figure 3 shows the Cause and Effect diagram of potential causes affecting the deviation of hair conditioner viscosity, which are summarized in Table 1. The residual model diagnostics evaluated by the Minitab program of the hair conditioner viscosity data from 15 measurement values are shown in Figure 4. The normal probability plot of the residuals shows a linear pattern and the histogram of the residuals shows normal distribution, which indicate the normal data. The plot of residuals versus the fitted values shows that the residuals get larger and are away from the reference line as the fitted values increase indicating that the residuals have non-constant variance and no repeating pattern. In addition, from the plot of residuals versus the order of data, all of the data were random without any trend. According to these results compared with the statistical concepts, it is concluded that the data in this work are sufficient and reliable.
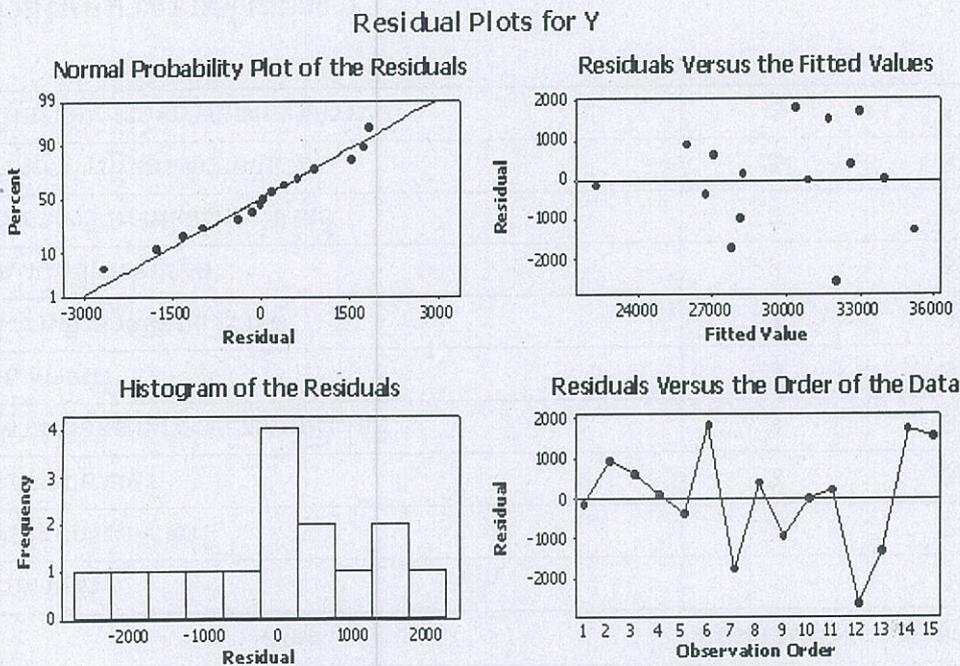
Figure 4. Residual model diagnostics of the hair conditioner viscosity
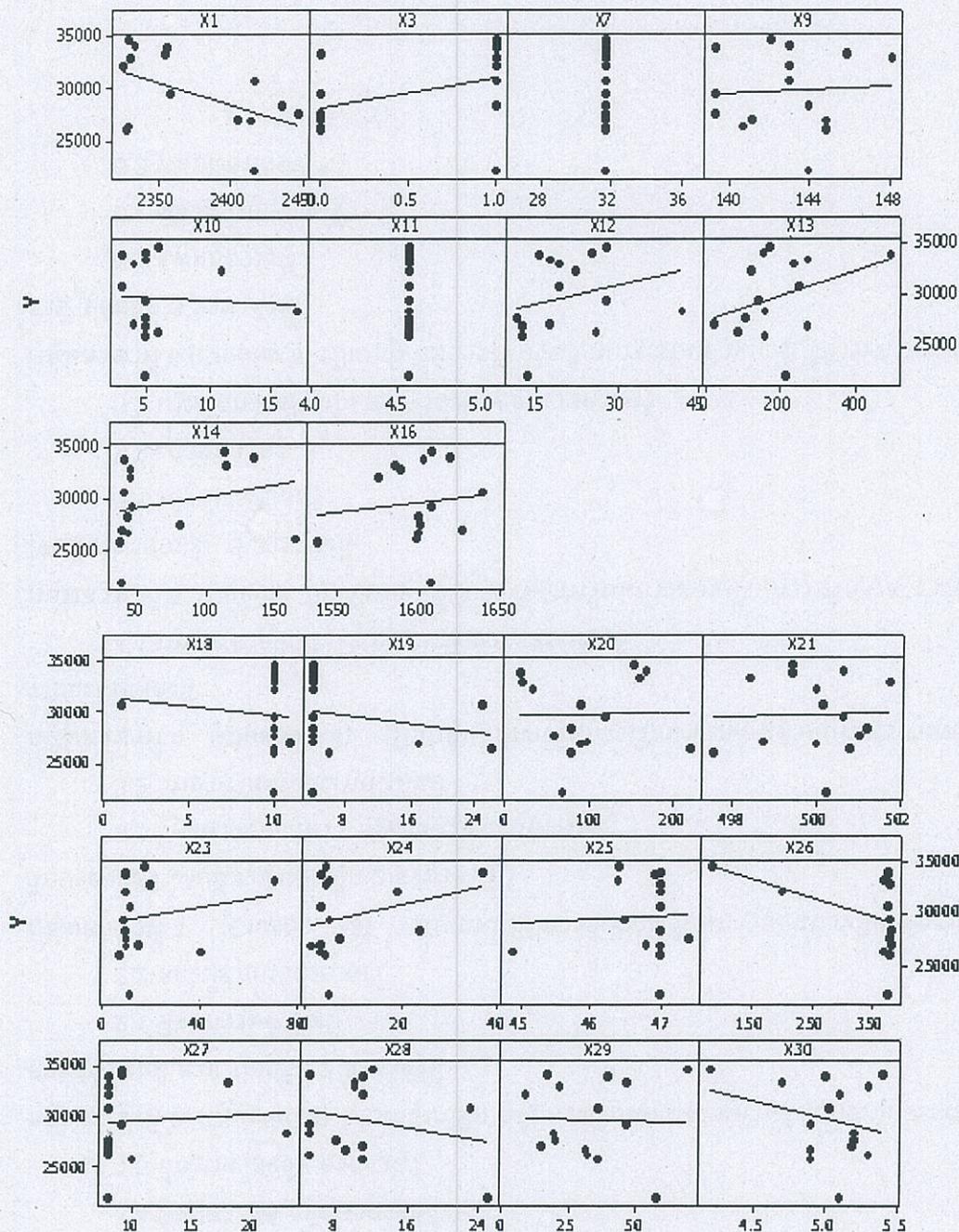
Figure 5. Examples of scatter plots between viscosities (Y) and potential parameters (X_i)

Figure 5 shows examples of the scatter plots between viscosity (a dependent variable: Y) and potential parameters (independent variables: X_i) in Table 1. Each plot is obtained from 15 measurement values. The slope of the scatter plot shows how much that relevant parameter, X_i, affects the viscosity. The positive relation is indicated by a positive slope, conversely the negative relation is indicated by a negative slope. In case of no notable relation, the scatter plot does not indicate any trend. Of 22 parameters, 11 parameters (X_1, X_3, X_{12}, X_{13}, X_{14}, X_{16}, X_{18}, X_{19}, X_{26}, X_{28} and X_{30}) have significant slopes as shown in Figure 5. However, in case plots of X_{28} or X_{30} with the dependent variable, if they are considered the polynomial thirld order equation or cubic regression model as X_{28}^3 and X_{30}^3, their plots fit much better, and the correlations appear higher consistency. Therefore, X_{28}^3 and X_{30}^3 were considered as the independent variables and included with the former 11 independent variables. The 13 variables were used for the best subset regression analysis of the Minitab program to select the

significant parameters to the response, which is viscosity deviation of hair conditioner in this work. A group of the independent variables, about 4-6 from 13 parameters and their coefficient of determination (r^2) greater than 80%, is defined as the significant parameters in the experiment. From Table 2, the six significant parameters, of which $r^2 = 88.3\%$, are quantities of chlorinated water and chilled water, melting time of fatty alcohols, cooling period after adding chilled water, times used for adjusting the temperature of chilled water and for adding the additives.

The results in this work analyzed by the Minitab program is confirmed at the significance level (α) of 0.05 (or the confidence level of 95%) and the p-value (probability value) of every significant parameter less than 0.05, which is acceptable and agreed with that stated in the theory [9]. Therefore, the correlation in this work from the program is:

$$Y = 36{,}913 - 443\,X_1 + 11.5\,X_{13} + 68.0\,X_{16} - 1{,}037\,X_{18} - 243\,X_{19} - 0.516\,(X_{28})^3 \qquad (3)$$

The effects of these 6 significant parameters to conclude the parameters which strongly affect the deviation of the viscosity will be studied. Their optimum values and the process performance capability index (C_{pk}) before and after the improvement will be reported in our future work.

4. CONCLUSIONS

The hair conditioners are time-sensitive to shearing action and behave as pseudoplastic fluids. From the DPMO the deviation of the hair conditioner in this case study must be prioritized. The significant parameters on the deviation of viscosity are quantities of chlorinated water and chilled water, melting time of fatty alcohols, cooling period after adding chilled water, times used for adjusting the temperature of chilled water and for adding the additives

Table 1. Summary of potential causes affecting the deviation of hair conditioner viscosity

Parameters (X_i)	Definitions
X_1	Quantity of chlorinated water (kg)
X_2	Conductivity of chlorinated water (W/m-K)
X_3	Chlorine contents in chlorinated water (% wt)
X_4	pH of chlorinated water
X_5	Main mixer temperature before adding fatty alcohols ($^{\circ}$C)
X_6	Side mixer-1 temperature before discharge fatty alcohols ($^{\circ}$C)
X_7	Quantity of cationic surfactant-1 (kg)
X_8	Cationic surfactant-1 dissolving time in main mixer (min)
X_9	Quantity of cationic surfactant-2 (kg)
X_{10}	Cationic surfactant-2 dissolving time in main mixer (min)
X_{11}	Quantity of cationic surfactant-3 (kg)
X_{12}	Time used for adding fatty alcohols from side mixer-1 to main mixer (min)
X_{13}	Fatty alcohols melting time at side mixer-1 (min)
X_{14}	Cooling period to 62 $^{\circ}$C before adding chilled water (min)
X_{15}	Main mixer temperature before adding chilled water ($^{\circ}$C)
X_{16}	Quantity of chilled water (kg)
X_{17}	Chilled water temperature ($^{\circ}$C)
X_{18}	Cooling period to 50 $^{\circ}$C before adding chilled water (min)
X_{19}	Time used for adjusting the temperature of chilled water (min)
X_{20}	Thickener agent dissolving time (min)
X_{21}	Quantity of chlorinated water in side mixer-2 (kg)
X_{22}	pH of chlorinated water in side mixer-2
X_{23}	Time used for adding thickener agent from side mixer-2 to main mixer (min)
X_{24}	Waiting time to cool down main mixer before adding perfumes (min)
X_{25}	Main mixer temperature before adding perfumes ($^{\circ}$C)
X_{26}	Quantity of silicones (kg)
X_{27}	Time used for adding silicones (min)
X_{28}	Time used for adding additives (min)
X_{29}	Final homogenization time (min)
X_{30}	pH of product

Table 2. The best subset regression analysis result by the Minitab p

Vars	R-Sq	R-Sq(adj)	Mallows C-p	S	X1	X3	X12	X13	X14	X16	X18	X19	X26	X28	X30	X28^3	X30^3
1	25.3	19.5	18.6	3358.0	X												
1	18.5	12.2	21.3	3507.9										X			
2	51.9	43.9	10.1	2804.4	X											X	
2	39.3	29.2	15.1	3150.0	X	X											
3	63.9	54.1	7.3	2537.0	X				X							X	
3	61.9	51.5	8.1	2608.1	X											X	X
4	73.6	63.0	5.5	2276.0	X				X						X	X	
4	73.5	62.9	5.5	2281.5	X				X							X	X
5	79.0	67.4	5.3	2137.1	X	X			X						X	X	
5	78.7	66.9	5.4	2154.5	X	X			X							X	X
6	88.3	79.6	3.6	1690.8	X		X		X	X	X					X	
6	86.4	76.3	4.4	1824.1				X	X	X	X	X				X	
7	93.0	86.0	3.8	1400.6	X		X		X	X	X	X				X	
7	90.3	80.6	4.8	1649.6	X			X	X	X	X	X				X	
8	94.5	87.1	5.2	1342.7	X		X	X	X	X	X	X				X	
8	93.8	85.6	5.5	1422.3	X				X	X	X	X	X			X	X
9	96.0	88.9	6.6	1246.9	X	X			X	X	X	X	X	X		X	
9	95.4	87.2	6.8	1337.0	X				X	X	X	X	X	X		X	X
10	96.7	88.5	8.3	1270.1	X	X	X			X	X	X	X		X	X	X
10	96.4	87.2	8.4	1337.8	X	X		X	X	X	X	X	X	X		X	
11	97.1	86.5	10.1	1375.9	X	X	X			X	X	X	X	X	X	X	X
11	97.0	86.1	10.2	1395.7	X	X			X	X	X	X	X	X	X	X	X
12	97.4	81.9	12.0	1591.2	X	X	X		X	X	X	X	X	X	X	X	X
12	97.3	81.0	12.1	1632.2	X	X	X	X	X	X	X		X	X	X	X	X
13	97.5	64.7	14.0	2224.7	X	X	X	X	X	X	X	X	X	X	X	X	X

(Arrow indicates the 6-variable row: 6 | 88.3 | 79.6 | 3.6 | 1690.8)

5. ACKNOWLEDGEMENTS

REFERENCES

[1]   Barnes, H. A., Hutton, J. F. and S. K. W. **1989** *An Introduction to Rheology*. New York, Elsevier Science.

[2]   Rezayati-Charati, P., Mohammadi-Rovshandeh, J., Hashemi,S. and Kazemi-Najafi, S. **2005** Influence of Dimethyl Formamide Pulping of Bagasse on Pulp Properties, *Bioresource Technology,* [Online]. Available: http://www.sciencedirect.com.

[3]   Temsawangleart, P. **2001** *A Reduction of Bulk Density Variation in A Non-Soap Detergent Making Process*. Master Thesis, Department of Chemical Engineering, Faculty of Engineering, King Monkut's Institute of Technology Ladkrabang. (in Thai)

[4]   Bird, R. B., Stewart, W. E. and Lightfoot, E. N. **2002** *Transport Phenomena*. 2nd Edition. United States of America, John Wiley & Sons.

[5]   Barnes, H. A., Hutton, J. F. and Walters, K. **1989** *An Introduction to Rheology*. New York, Elsevier Science.

[6]   MINITAB Inc. **2003** *MINITAB Statistical Software Release 14*.

[7]   Economics Department, University of California, Berkeley. "**Regression Analysis**." [Online]. Available: http://www.elsa.berkeley.edu/sst/regression.html.

[8]   Breyfogle, F. W., Cupello, J. M. and Meadows, B. **2001** *Managing Six Sigma*. John Wiley & Sons.

[9]   Currel, G. and Dowman, A. **2005** *Essential Mathematics and Statistics for Science*. John Wiley & Sons.