Appendix Minitab output from the regression analysis

Appendix 1 Minitab output from regression analysis of the heat transfer data for serrated fins

Here the different steps of the regression analysis of the heat transfer data for serrated fins will be presented. The output from Minitab (both the best subsets regression and the regression itself) will be presented:

1) In the first step all the heat transfer data for F_t/F_d<1,0 were included in the analysis:

Best subsets regression using the following dimensionless groups:

$$Re, \frac{P_t}{d_e}, \frac{P_t}{P_l}, \frac{h_e}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}$$

This gave the following results:

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; ...

Response is logNuPr

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/Pl	logPt/de	logheff/sf	logdf/de	logt/sf
1	92,1	92,1	161,1	0,069958	X					
1	12,4	12,2	5442,1	0,23303						X
2	93,3	93,3	84,6	0,064582	X	X				
2	93,2	93,1	93,6	0,065233	X			X		
3	94,1	94,0	36,0	0,060879	X	X		X		
3	93,9	93,9	46,1	0,061658	X			X	X	
4	94,4	94,4	12,5	0,058962	X	X		X	X	
4	94,4	94,3	17,8	0,059387	X		X	X	X	
5	94,6	94,5	5,8	0,058341	X	X	X	X	X	
5	94,5	94,4	13,7	0,058980	X	X		X	X	X
6	94,6	94,5	7,0	0,058358	X	X	X	X	X	X

The R^2 reached its maximum for five variables, and Mallows Cp was here at its minimum. But, here both P_t/d_e and P_t/P_l were included at the same time. Therefore it was decided to use four variables instead so that only one of the dimensionless groups for tube bundle layout was included. It was observed that using P_t/P_l(marked in red) was slightly better than using P_t/d_e (marked in green).

Regression Analysis: logNuPr versus logRe; logPt/Pl; ...

```
The regression equation is
logNuPr = - 0,906 + 0,703 logRe + 0,214 logPt/Pl - 0,195 logheff/sf
          + 0,468 logdf/de


Predictor       Coef   SE Coef       T      P    VIF
Constant    -0,90617   0,05112  -17,73  0,000
logRe       0,703339  0,009512   73,94  0,000  1,066
logPt/Pl     0,21369   0,03619    5,90  0,000  1,131
logheff/sf  -0,19451   0,02281   -8,53  0,000  1,298
logdf/de     0,46791   0,09371    4,99  0,000  1,345


S = 0,0589616   R-Sq = 94,4%   R-Sq(adj) = 94,4%


Analysis of Variance

Source           DF       SS      MS        F      P
Regression        4  21,3205  5,3301  1533,20  0,000
Residual Error  361   1,2550  0,0035
Total           365  22,5755


Source      DF   Seq SS
logRe        1  20,7940
logPt/Pl     1   0,2674
logheff/sf   1   0,1724
logdf/de     1   0,0867
```

The regression equation was:

$$Nu \cdot Pr^{-1/3} = 0{,}124 \cdot Re^{0{,}7033} \cdot \left(\frac{P_t}{P_l}\right)^{0{,}2137} \cdot \left(\frac{h_e}{s_f}\right)^{-0{,}19451} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}4679} \qquad \text{(A-1)}$$

The data from Schryber (1945) were calculated 25-45 % higher than the experimental values. On the other hand, the data from Cox (1973) were calculated 15-25 % lower than the experimental values. In addition, some of the data from Kawaguchi et al. (2006b) were calculated lower than the real values.

2) For the same data as in 1), Ar was used instead of all the dimensionless groups for fin geometry:

Best subsets regression with the dimensionless groups:

$\frac{P_t}{P_l}, \frac{P_t}{d_e}, Ar, Re$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; logPt/de; logAr

```
Response is logNuPr

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                                                     o o
                                                     g g
                                                   l P P l
                                                   o t t o
                                                   g / / g
                                                   R P d A
Vars  R-Sq  R-Sq(adj)  Mallows Cp           S      e l e r
   1  94,1       94,1       146,4  0,065256        X
   1  10,1        9,8      6171,6   0,25494              X
   2  96,1       96,1         7,0  0,053318        X X
   2  94,8       94,7       101,7  0,061656        X     X
   3  96,1       96,1         4,3  0,052966        X X   X
   3  96,1       96,0         8,8  0,053399        X X X
   4  96,2       96,1         5,0  0,052938        X X X X
```

The R^2 stopped to increase for three variables. The Mallows Cp was at its minimum for three variables as well. The regression should be performed using the three dimensionless groups $\frac{P_t}{P_l}$, Ar, Re. It should be noted that the data from Kawaguchi et al. (2005)/Kawaguchi et al. (2006b) were not included here, as the segment width was not published in the paper so that the Ar-value could not be calculated for those geometries.

Regression Analysis: logNuPr versus logRe; logPt/Pl; logAr

```
The regression equation is
logNuPr = - 0,752 + 0,681 logRe + 0,352 logPt/Pl - 0,0512 logAr


Predictor       Coef    SE Coef       T      P    VIF
Constant    -0,75213    0,04886  -15,39  0,000
logRe       0,680713   0,008829   77,10  0,000  1,069
logPt/Pl     0,35175    0,03529    9,97  0,000  1,232
logAr       -0,05124    0,02364   -2,17  0,031  1,278


S = 0,0529660   R-Sq = 96,1%   R-Sq(adj) = 96,1%


Analysis of Variance

Source           DF       SS      MS        F      P
Regression        3  19,3275  6,4425  2296,46  0,000
Residual Error  276   0,7743  0,0028
Total           279  20,1018


Source     DF   Seq SS
logRe       1  18,9180
logPt/Pl    1   0,3964
logAr       1   0,0132
```

Regression equation:

$$Nu \cdot Pr^{-1/3} = 0{,}177 \cdot Re^{0{,}68} \cdot \left(\frac{P_t}{P_l}\right)^{0{,}351} \cdot Ar^{-0{,}0512} \qquad \text{(A-2)}$$

Also for this correlation the data from Schryber (1945) were calculated to high (ca. 25-35 % higher than the experimental value). The data from Cox (1973) were underestimated (ca. 15-25 % lower than the experimental values).

In order to include the data from Kawaguchi et al. (2005)/Kawaguchi et al. (2006b), Ar was calculated as for solid fins. Best subsets regression was performed using the dimensionless groups below:

$$\frac{P_t}{P_l}, \frac{P_t}{d_e}, Ar_{sol}, Re$$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; ...

Response is logNuPr

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/Pl	logPt/de	logArsol.
1	92,1	92,1	117,4	0,069958	X			
1	5,4	5,1	5386,4	0,24224		X		
2	93,3	93,3	47,5	0,064582	X	X		
2	92,9	92,9	68,4	0,066222	X			X
3	94,0	93,9	9,2	0,061397	X	X		X
3	93,5	93,5	34,2	0,063453	X		X	X
4	94,1	94,0	5,0	0,060957	X	X	X	X

Regression Analysis: logNuPr versus logRe; logPt/Pl; logArsol.

```
The regression equation is
logNuPr = - 0,693 + 0,694 logRe + 0,279 logPt/Pl - 0,139 logArsol.
```

Predictor	Coef	SE Coef	T	P
Constant	-0,69304	0,05010	-13,83	0,000
logRe	0,694190	0,009759	71,14	0,000
logPt/Pl	0,27881	0,03591	7,76	0,000
logArsol.	-0,13891	0,02206	-6,30	0,000

```
S = 0,0613972   R-Sq = 94,0%   R-Sq(adj) = 93,9%
```

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	21,2109	7,0703	1875,60	0,000
Residual Error	362	1,3646	0,0038		
Total	365	22,5755			

Source	DF	Seq SS
logRe	1	20,7940
logPt/Pl	1	0,2674
logArsol.	1	0,1494

$$Nu \cdot Pr^{-1/3} = 0{,}203 \cdot Re^{0{,}694} \cdot \left(\frac{P_t}{P_l}\right)^{0{,}27881} \cdot Ar_{sol}{}^{-0{,}13891} \qquad \text{(A-3)}$$

3) In order to get a more accurate correlation for the rest of the data for F_t/F_d<1,0, the data from Cox (1973) and Schryber (1945) were removed before performing the regression analysis. Best subsets regression using the dimensionless groups below:

$$Re, \frac{P_t}{d_e}, \frac{P_t}{P_l}, \frac{h_e}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}$$

Best Subsets Regression: logNuPr versus logRe; logPtPl; ...

Response is logNuPr

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPtPl	logPtde	logheff/sf	logdf/de	t/sf
1	94,5	94,5	130,4	0,057590	X					
1	9,6	9,4	7310,2	0,23389		X				
2	95,1	95,1	81,0	0,054386	X			X		
2	94,9	94,8	103,2	0,055827	X					X
3	95,8	95,7	28,9	0,050767	X			X	X	
3	95,5	95,5	47,9	0,052096	X		X	X		
4	96,0	96,0	8,3	0,049207	X		X	X	X	
4	95,8	95,8	26,5	0,050524	X	X		X	X	
5	96,1	96,0	6,1	0,048974	X		X	X	X	X
5	96,0	96,0	10,3	0,049281	X	X	X	X	X	
6	96,1	96,0	7,0	0,048966	X	X	X	X	X	X

For five variables the R^2 reached its maximum and the value for Mallows Cp was the smallest one. S was also the lowest here. When the regression was performed with five variables, the dimensionless group t/s_f was found to be insignificant so therefore the regression was performed with four variables instead.

The regression was performed with the dimensionless groups:

$Re, \frac{P_t}{d_e}, \frac{h_e}{s_f}, \frac{d_f}{d_e}$

Regression Analysis: logNuPr versus logRe; logPtde; logheff/sf; logdf/de

```
The regression equation is
logNuPr = - 1,15 + 0,740 logRe + 0,236 logPtde - 0,206 logheff/sf
          + 0,507 logdf/de


Predictor       Coef   SE Coef       T      P    VIF
Constant    -1,15304   0,04873  -23,66  0,000
logRe       0,740438  0,008687   85,24  0,000  1,090
logPtde      0,23588   0,04979    4,74  0,000  1,229
logheff/sf  -0,20572   0,01970  -10,44  0,000  1,356
logdf/de     0,50728   0,07899    6,42  0,000  1,301


S = 0,0492073   R-Sq = 96,0%   R-Sq(adj) = 96,0%


Analysis of Variance

Source           DF       SS      MS        F      P
Regression        4  19,4764  4,8691  2010,90  0,000
Residual Error  332   0,8039  0,0024
Total           336  20,2803


Source      DF   Seq SS
logRe        1  19,1692
logPtde      1   0,0274
logheff/sf   1   0,1799
logdf/de     1   0,0999
```

The regression equation is (presented and recommended in chapter 3.4.2.2):

$$Nu \cdot Pr^{-1/3} = 0{,}0703 \cdot Re^{0{,}7404} \cdot \left(\frac{P_t}{d_e}\right)^{0{,}2359} \cdot \left(\frac{h_e}{s_f}\right)^{-0{,}20572} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}5073} \quad (25)$$

4) Further the regression analysis was performed using Ar for the same data as in 3):

Best subsets regression:

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; logPt/de; logAr

```
Response is logNuPr

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                                                   g / / g
                                                   R P d A
Vars  R-Sq  R-Sq(adj)  Mallows Cp          S       e l e r
   1  97,9       97,9       100,2  0,038961        X
   1  16,6       16,3     13534,8   0,24548              X
   2  98,4       98,4        15,7  0,033832        X X
   2  98,3       98,2        44,0  0,035619        X   X
   3  98,5       98,5         3,9  0,032990        X X X
   3  98,4       98,4        16,1  0,033796        X X   X
   4  98,5       98,5         5,0  0,032996        X X X X
```

The best subsets regression gave the impression that the two dimensionless groups for tube bundle layout should be used, but this was not wished as the aim was to find the effect of Ar. A trial and error procedure was carried out; when Ar and P_t/P_l was used the effect of Ar was not significant. However when P_t/d_e and Ar was tried, the effect of Ar was significant (see results below):

Regression Analysis: logNuPr versus logRe; logPt/de; logAr

```
The regression equation is
logNuPr = - 1,09 + 0,740 logRe + 0,290 logPt/de - 0,0697 logAr


Predictor      Coef    SE Coef        T      P    VIF
Constant   -1,08533    0,03987   -27,22  0,000
logRe      0,739639   0,006669   110,91  0,000  1,219
logPt/de    0,29021    0,03515     8,26  0,000  1,207
logAr      -0,06969    0,01649    -4,23  0,000  1,318


S = 0,0344661   R-Sq = 98,4%   R-Sq(adj) = 98,4%


Analysis of Variance

Source           DF       SS      MS        F      P
Regression        3  17,7081  5,9027  4968,96  0,000
Residual Error  247   0,2934  0,0012
Total           250  18,0015


Source    DF   Seq SS
logRe      1  17,6235
logPt/de   1   0,0633
logAr      1   0,0212
```

The regression equation was (also presented in chapter 3.4.2.2):

$$Nu \cdot Pr^{-1/3} = 0{,}0821 \cdot Re^{0{,}7396} \cdot \left(\frac{P_t}{d_e}\right)^{0{,}2902} \cdot Ar^{-0{,}0697} \quad (35)$$

At last the Ar calculated as for solid fins was used instead of the Ar above, so that the data from Kawaguchi et al. (2005)/Kawaguchi et al. (2006b) were included:

Best subsets regression:

$\frac{P_t}{P_l}, \frac{P_t}{d_e}, Ar_{sol}, Re$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; ...

Response is logNuPr

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/Pl	logPt/de	logArsol.
1	94,5	94,5	64,7	0,057590	X			
1	9,6	9,4	6227,2	0,23389		X		
2	95,0	95,0	32,9	0,055171	X			X
2	94,8	94,7	48,7	0,056353	X	X		
3	95,4	95,3	6,1	0,053021	X		X	X
3	95,2	95,2	18,5	0,053992	X	X		X
4	95,4	95,4	5,0	0,052853	X	X	X	X

Regression Analysis: logNuPr versus logRe; logPt/de; logArsol.

The regression equation is
logNuPr = - 0,983 + 0,741 logRe + 0,285 logPt/de - 0,148 logArsol.

Predictor	Coef	SE Coef	T	P	VIF
Constant	-0,98309	0,05243	-18,75	0,000	
logRe	0,741209	0,009354	79,24	0,000	1,089
logPt/de	0,28496	0,05325	5,35	0,000	1,211
logArsol.	-0,14814	0,02045	-7,24	0,000	1,166

S = 0,0530212   R-Sq = 95,4%   R-Sq(adj) = 95,3%

Analysis of Variance

Source	DF	SS	MS	F	P

Regression	3	19,3441	6,4480	2293,66	0,000
Residual Error	333	0,9361	0,0028		
Total	336	20,2803			

Source	DF	Seq SS
logRe	1	19,1692
logPt/de	1	0,0274
logArsol.	1	0,1475

Regression equation:

$$Nu \cdot Pr^{-1/3} = 0{,}104 \cdot Re^{0{,}7412} \cdot \left(\frac{P_t}{d_e}\right)^{0{,}28496} \cdot {Ar_{sol}}^{-0{,}14814} \qquad \text{(A-4)}$$

5) The regression analysis was also performed for the data where $F_t/F_d>1{,}0$, i.e. geometry 3,5,7,8,9,10 and 11 from Næss (2007):

The aim was to find the change in tube bundle layout effect, so the $NuPr^{-1/3}$-values were divided by the fin geometry and Reynolds number effect found for $F_t/F_d>1{,}0$:

$$C_3 = \frac{Nu \cdot Pr^{-1/3}}{f(fin\ geometry) \cdot Re^m}$$
$$C_3 = \frac{Nu \cdot Pr^{-1/3}}{0{,}0703 \cdot Re^{0{,}7404} \cdot \left(\frac{h_e}{s_f}\right)^{-0{,}20750} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}5073}} \tag{36}$$

Best subsets regression with C_3 as the response (y-variable):

Best Subsets Regression: logC3 versus logPt/Pl; logPt/de

```
Response is logC3

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                                                 t t
                                                 / /
                          Mallows                P d
Vars  R-Sq  R-Sq(adj)          Cp            S   l e
   1  80,8       80,5         5,2     0,026534   X
   1  63,4       62,9        79,6     0,036618     X
   2  81,8       81,3         3,0     0,026012   X X
```

Regression Analysis: logC3 versus logPt/Pl

```
The regression equation is
logC3 = 0,340 - 0,773 logPt/Pl


Predictor      Coef   SE Coef       T      P    VIF
Constant    0,34033   0,01757   19,36  0,000
logPt/Pl   -0,77264   0,04242  -18,21  0,000  1,000


S = 0,0265338   R-Sq = 80,8%   R-Sq(adj) = 80,5%


Analysis of Variance

Source           DF       SS       MS       F      P
Regression        1  0,23358  0,23358  331,77  0,000
Residual Error   79  0,05562  0,00070
Total            80  0,28920
```

The regression equation for F_t/F_d>1,0 was as follows (presented in chapter 3.4.2.2 as well):

$$Nu \cdot Pr^{-1/3} = 0{,}1539 \cdot Re^{0{,}7404} \cdot \left(\frac{h_e}{s_f}\right)^{-0{,}20572} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}5073} \cdot \left(\frac{P_t}{P_l}\right)^{-0{,}7726} \tag{37}$$

6) The same as in 5) was done using Ar for F_t/F_d>1,0:

$$C_4 = \frac{Nu \cdot Pr^{-1/3}}{f(fin\ geometry) \cdot Re^m} = \frac{Nu \cdot Pr^{-1/3}}{0{,}0821 \cdot Re^{0{,}7396} \cdot Ar^{-0{,}0697}} \tag{38}$$

Best subsets regression with C_4 as response (y-variable):

Best Subsets Regression: logC4 versus logPt/Pl; logPt/de

```
Response is logC4

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                                                 P P
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                                                 / /
                               Mallows           P d
Vars  R-Sq  R-Sq(adj)       Cp         S  l e
   1  70,9       70,6      3,1  0,027441  X
   1  41,4       40,7     84,6  0,038968    X
   2  71,7       71,0      3,0  0,027248  X X
```

Regression Analysis: logC4 versus logPt/Pl

```
The regression equation is
logC4 = 0,315 - 0,609 logPt/Pl


Predictor       Coef   SE Coef       T      P    VIF
Constant     0,31522   0,01818   17,34  0,000
logPt/Pl    -0,60923   0,04387  -13,89  0,000  1,000


S = 0,0274411   R-Sq = 70,9%   R-Sq(adj) = 70,6%


Analysis of Variance

Source          DF       SS       MS       F      P
Regression       1  0,14523  0,14523  192,86  0,000
Residual Error  79  0,05949  0,00075
Total           80  0,20471
```

The regression equation (also presented in chapter 3.4.2.2):

$$Nu \cdot Pr^{-1/3} = 0{,}1698 \cdot Re^{0{,}7396} \cdot \left(\frac{P_t}{P_l}\right)^{-0{,}60923} \cdot Ar^{-0{,}0697} \tag{39}$$

Appendix 2 Minitab output from regression analysis of the heat transfer data for solid fins

Here the different steps of the regression analysis of the heat transfer data for solid fins will be presented. The output from Minitab (both the best subsets regression and the regression itself) will be presented:

1) The regression analysis was first performed for all the data (except from some Brauer (1964) geometries, see chapter 3.4.3.2) for Re<50 000:

Best subsets regression with the following dimensionless groups:

$$Re, \frac{P_t}{P_l}, \frac{P_t}{d_e}, \frac{h_f}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}$$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; ...

```
Response is logNuPr

                                                      l l l l
                                                      o o o o l
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                                                    l P P h d g
                                                    o t t f f t
                                                    g / / / / /
                                                    R P d s d s
Vars  R-Sq  R-Sq(adj)  Mallows Cp         S         e l e f e f
   1  90,8       90,8       419,9  0,086486         X
   1   5,8        5,6      7868,1   0,27740               X
   2  93,9       93,9       153,6  0,070642         X     X
   2  91,2       91,2       386,8  0,084679         X X
   3  95,3       95,2        37,8  0,062436         X     X X
   3  94,2       94,2       129,1  0,068953         X X   X
   4  95,6       95,6         9,3  0,060183         X X   X X
   4  95,3       95,3        35,1  0,062164         X   X X X
   5  95,7       95,6         5,5  0,059809         X X   X X X
   5  95,6       95,5        10,9  0,060229         X X X X X
   6  95,7       95,6         7,0  0,059848         X X X X X X
```

Regression Analysis: logNuPr versus logRe; logPt/Pl; ...

```
The regression equation is
logNuPr = - 1,14 + 0,750 logRe - 0,224 logPt/Pl - 0,342 loghf/sf
          + 0,693 logdf/de + 0,0732 logt/sf


Predictor       Coef    SE Coef        T       P    VIF
Constant    -1,14234    0,03981   -28,70   0,000
logRe       0,750385   0,009789    76,66   0,000  1,249
logPt/Pl    -0,22417    0,03724    -6,02   0,000  1,257
loghf/sf    -0,34171    0,01819   -18,78   0,000  2,134
logdf/de     0,69323    0,06151    11,27   0,000  2,401
logt/sf      0,07318    0,03043     2,41   0,017  1,432


S = 0,0598088   R-Sq = 95,7%   R-Sq(adj) = 95,6%
```

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	5	30,0224	6,0045	1678,59	0,000
Residual Error	380	1,3593	0,0036		
Total	385	31,3817			

Source	DF	Seq SS
logRe	1	28,5094
logPt/Pl	1	0,1259
loghf/sf	1	0,9301
logdf/de	1	0,4362
logt/sf	1	0,0207

Regression equation (presented in chapter 3.4.3.2, but not recommended):

$$Nu \cdot Pr^{-1/3} = 0{,}072 \cdot Re^{0{,}7504} \cdot \left(\frac{P_t}{P_l}\right)^{-0{,}22417} \cdot \left(\frac{h_f}{s_f}\right)^{-0{,}34171} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}69323} \cdot \left(\frac{t}{s_f}\right)^{0{,}0732} \qquad (44)$$

2) The same data as in 1) but using Ar instead of all the dimensionless groups for fin geometry:

Best subsets regression:

$$Re, \frac{P_t}{P_l}, \frac{P_t}{d_e}, Ar$$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; logPt/de; logAr

Response is logNuPr

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/Pl	logPt/de	logAr
1	90,8	90,8	207,0	0,086486	X			
1	4,4	4,1	5772,3	0,27956		X		
2	93,3	93,2	53,9	0,074327	X			X
2	91,2	91,2	183,2	0,084679	X	X		
3	93,6	93,6	33,4	0,072469	X	X		X
3	93,4	93,3	48,5	0,073786	X		X	X
4	94,1	94,0	5,0	0,069832	X	X	X	X

Regression Analysis: logNuPr versus logRe; logPt/Pl; logAr

```
The regression equation is
logNuPr = - 1,12 + 0,792 logRe - 0,192 logPt/Pl - 0,199 logAr


Predictor      Coef  SE Coef       T      P    VIF
Constant   -1,12155  0,04701  -23,86  0,000
logRe       0,79244  0,01107   71,58  0,000  1,088
logPt/Pl   -0,19185  0,04197   -4,57  0,000  1,088
logAr      -0,19918  0,01678  -11,87  0,000  1,002


S = 0,0724690   R-Sq = 93,6%   R-Sq(adj) = 93,6%


Analysis of Variance

Source           DF       SS      MS        F      P
Regression        3  29,3755  9,7918  1864,49  0,000
Residual Error  382   2,0062  0,0053
Total           385  31,3817


Source    DF   Seq SS
logRe      1  28,5094
logPt/Pl   1   0,1259
logAr      1   0,7402
```

Regression equation:

$$Nu \cdot Pr^{-1/3} = 0{,}0756 \cdot Re^{0{,}7924} \cdot \left(\frac{P_t}{P_l}\right)^{-0{,}19185} \cdot Ar^{-0{,}19918} \tag{A-5}$$

3) The sign of the exponent for P_t/P_l was not as expected (expected to be positive as discussed in chapter 3.4.3.2) in equation 44 and equation A-4. When the data from Stasiulevicius et al. (1988) and geometry 4v from Brauer (1964) were removed the sign changed, see the results below:

$$Re, \frac{P_t}{P_l}. \frac{P_t}{d_e}, \frac{h_f}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}$$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; ...

```
Response is logNuPr

                                                    l l l l
                                                    o o o o l
                                                    g g g g o
                                                  l P P h d g
                                                  o t t f f t
                                                  g / / / / /
                                                  R P d s d s
Vars  R-Sq  R-Sq(adj)  Mallows Cp          S      e l e f e f
   1  92,9       92,9       358,5  0,077969       X
   1  13,8       13,5      7697,6   0,27249               X
   2  94,6       94,6       204,0  0,068128       X     X
   2  93,5       93,4       310,6  0,075069       X   X
   3  96,5       96,5        28,7  0,054766       X     X X
   3  95,4       95,4       132,4  0,063001       X   X X
   4  96,7       96,7        12,7  0,053292       X X   X X
   4  96,7       96,6        20,3  0,053958       X     X X X
   5  96,8       96,8         8,0  0,052789       X X X X X
   5  96,8       96,7        11,3  0,053083       X X   X X X
   6  96,8       96,8         7,0  0,052612       X X X X X X
```

It was decided to use four variables, as the increase in R^2 was only 0,1 when including one more variable.

Regression Analysis: logNuPr versus logRe; logPt/Pl; loghf/sf; logdf/de

```
The regression equation is
logNuPr = - 1,32 + 0,769 logRe + 0,371 logPt/Pl - 0,330 loghf/sf
          + 0,755 logdf/de


Predictor       Coef   SE Coef       T      P    VIF
Constant    -1,32354   0,03706  -35,71  0,000
logRe       0,768958  0,009743   78,92  0,000  1,199
logPt/Pl     0,37087   0,08839    4,20  0,000  1,080
loghf/sf    -0,33038   0,01816  -18,20  0,000  1,602
logdf/de     0,75496   0,05728   13,18  0,000  1,733


S = 0,0532917   R-Sq = 96,7%   R-Sq(adj) = 96,7%
```

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	4	24,8210	6,2052	2184,94	0,000
Residual Error	295	0,8378	0,0028		
Total	299	25,6588			

Source	DF	Seq SS
logRe	1	23,8472
logPt/Pl	1	0,0012
loghf/sf	1	0,4792
logdf/de	1	0,4934

Regression equation:

$$Nu \cdot Pr^{-1/3} = 0{,}0475 \cdot Re^{0{,}76896} \cdot \left(\frac{P_t}{P_l}\right)^{0{,}37087} \cdot \left(\frac{h_f}{s_f}\right)^{-0{,}33038} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}75496} \qquad \text{(A-6)}$$

4) The same data as in 3) but with Ar instead of all the dimensionless groups for fin geometry:

Best subsets regression with the dimensionless groups below:

$$Re, \frac{P_t}{P_l}, \frac{P_t}{d_e}, Ar$$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; logPt/de; logAr

Response is logNuPr

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/Pl	logPt/de	logAr
1	92,9	92,9	146,9	0,077969	X			
1	1,6	1,2	5878,7	0,29113			X	
2	94,2	94,2	68,4	0,070648	X			X
2	93,5	93,4	115,2	0,075069	X		X	
3	95,1	95,1	15,2	0,065158	X		X	X
3	94,4	94,3	61,4	0,069880	X	X		X
4	95,3	95,2	5,0	0,063956	X	X	X	X

Regression Analysis: logNuPr versus logRe; logPt/de; logAr

The regression equation is
logNuPr = - 1,34 + 0,819 logRe + 0,259 logPt/de - 0,185 logAr

Predictor	Coef	SE Coef	T	P	VIF
Constant	-1,34457	0,04638	-28,99	0,000	
logRe	0,81939	0,01092	75,04	0,000	1,008
logPt/de	0,25938	0,03558	7,29	0,000	1,032
logAr	-0,18483	0,01865	-9,91	0,000	1,036

S = 0,0651585   R-Sq = 95,1%   R-Sq(adj) = 95,1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	3	24,4021	8,1340	1915,86	0,000
Residual Error	296	1,2567	0,0042		
Total	299	25,6588			

Source	DF	Seq SS
logRe	1	23,8472
logPt/de	1	0,1379
logAr	1	0,4170

Regression equation:

$$Nu \cdot Pr^{-1/3} = 0{,}0452 \cdot Re^{0{,}81939} \cdot \left(\frac{P_t}{d_e}\right)^{0{,}25938} \cdot Ar^{-0{,}18483} \tag{A-7}$$

5) Instead of removing the data from Stasiulevicius et al. (1988), the data from Kawaguchi et al. (2005)/Kawaguchi et al. (2006b) were removed. Also in this case the data for geometry 4v from Brauer (1964) were removed. Best subsets regression with the dimensionless groups:

$$Re, \frac{P_t}{P_l}, \frac{P_t}{d_e}, \frac{h_f}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}$$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; ...

Response is logNuPr

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/Pl	logPt/de	loghf/sf	logdf/de	logt/sf
1	94,6	94,6	307,5	0,064165	X					
1	50,6	50,4	4551,1	0,19479		X				
2	96,5	96,5	129,3	0,051903	X	X				
2	96,4	96,3	142,7	0,052926	X			X		
3	97,3	97,3	53,0	0,045567	X			X	X	
3	97,2	97,1	66,6	0,046752	X		X	X		
4	97,6	97,5	29,8	0,043389	X	X		X	X	
4	97,5	97,5	37,0	0,044054	X	X		X		X
5	97,8	97,7	11,8	0,041579	X	X		X	X	X
5	97,7	97,7	18,5	0,042229	X	X	X	X		X
6	97,9	97,8	7,0	0,041012	X	X	X	X	X	X

Regression Analysis: logNuPr versus logRe; logPt/Pl; ...

```
The regression equation is
logNuPr = - 0,932 + 0,659 logRe + 0,245 logPt/Pl - 0,218 loghf/sf
          + 0,297 logdf/de - 0,118 logt/sf


Predictor       Coef  SE Coef       T      P    VIF
Constant    -0,93175  0,03973  -23,45  0,000
logRe        0,65937  0,01012   65,17  0,000  1,787
logPt/Pl     0,24502  0,04437    5,52  0,000  2,539
loghf/sf    -0,21808  0,02031  -10,74  0,000  2,987
logdf/de     0,29684  0,05767    5,15  0,000  2,422
logt/sf     -0,11758  0,02663   -4,42  0,000  1,663


S = 0,0415795   R-Sq = 97,8%   R-Sq(adj) = 97,7%


Analysis of Variance

Source           DF       SS      MS        F      P
Regression        5  15,8518  3,1704  1833,79  0,000
Residual Error  207   0,3579  0,0017
Total           212  16,2097


Source    DF   Seq SS
logRe      1  15,3409
logPt/Pl   1   0,3030
loghf/sf   1   0,1085
logdf/de   1   0,0656
logt/sf    1   0,0337
```

The regression equation was (recommended in chapter 3.4.3.2):

$$Nu \cdot Pr^{-1/3} = 0{,}117 \cdot Re^{0{,}659} \cdot \left(\frac{P_t}{P_l}\right)^{0{,}24502} \cdot \left(\frac{h_f}{s_f}\right)^{-0{,}21808} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}29684} \cdot \left(\frac{s_f}{t}\right)^{0{,}11758} \tag{45}$$

6) For the same data set as in 5), Ar was used instead of all the dimensionless groups for fin geometry:

Best subsets regression with the dimensionless groups below:

$$Re, \frac{P_t}{P_l}, \frac{P_t}{d_e}, Ar$$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; logPt/de; logAr

Response is logNuPr

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/Pl	logPt/de	logAr
1	94,6	94,6	209,1	0,064165	X			
1	50,6	50,4	3644,1	0,19479		X		
2	96,5	96,5	65,3	0,051903	X	X		
2	96,1	96,1	96,6	0,054809	X			X
3	97,1	97,0	22,0	0,047504	X	X		X
3	97,1	97,0	24,8	0,047797	X		X	X
4	97,3	97,3	5,0	0,045584	X	X	X	X

P_t/P_l was slightly better than P_t/d_e as the value for S was lower. Therefore P_t/P_l was chosen as dimensionless group for tube bundle layout:

Regression Analysis: logNuPr versus logRe; logPt/Pl; logAr

```
The regression equation is
logNuPr = - 0,754 + 0,652 logRe + 0,367 logPt/Pl - 0,0969 logAr


Predictor       Coef   SE Coef       T      P    VIF
Constant    -0,75438   0,04121  -18,31  0,000
logRe        0,65224   0,01141   57,19  0,000  1,739
logPt/Pl     0,36664   0,04365    8,40  0,000  1,883
logAr       -0,09694   0,01501   -6,46  0,000  1,157


S = 0,0475043   R-Sq = 97,1%   R-Sq(adj) = 97,0%


Analysis of Variance

Source           DF       SS      MS        F      P
Regression        3  15,7380  5,2460  2324,67  0,000
Residual Error  209   0,4716  0,0023
Total           212  16,2097
```

```
Source     DF   Seq SS
logRe       1  15,3409
logPt/Pl    1   0,3030
logAr       1   0,0941
```

The regression equation was as follows (recommended in chapter 3.4.3.2):

$$Nu \cdot Pr^{-1/3} = 0{,}176 \cdot Re^{0{,}652} \cdot \left(\frac{P_t}{P_l}\right)^{0{,}3667} \cdot Ar^{-0{,}0969} \tag{46}$$

Appendix 3 Minitab output from regression analysis of the pressure drop data for serrated fins

Here the Minitab output from the different steps in the regression analysis of the pressure drop data for serrated fins will be presented:

1) Best subsets regression for all the data for $F_t/F_d<1{,}0$ with the dimensionless groups below ($Re<50\ 000$):

$$Re, \frac{P_t}{d_e}, \frac{P_l}{d_e}, \frac{h_e}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}$$

Best Subsets Regression: logEu versus logRe; logPt/de; ...

```
Response is logEu

                                                l
                                                o
                                            l l g l
                                            o o h o l
                                            g g e g o
                                          l P P f d g
                                          o t l f f t
                                          g / / / / /
                       Mallows            R d d s d s
Vars  R-Sq  R-Sq(adj)       Cp         S  e e e f e f
   1  21,3       21,1    126,9   0,10765  X
   1   4,1        3,9    238,1   0,11878        X
   2  28,5       28,1     82,2   0,10274  X X
   2  23,7       23,3    113,0   0,10610  X     X
   3  33,7       33,2     49,9  0,099006  X X   X
   3  29,4       28,9     77,8   0,10216  X X     X
   4  37,8       37,1     25,7  0,096067  X X X X
   4  35,7       35,0     39,3  0,097666  X   X X   X
   5  40,5       39,8      9,8  0,094027  X X X X   X
   5  38,0       37,2     26,3  0,096017  X X X X X
   6  41,3       40,4      7,0  0,093568  X X X X X X
```

R^2 was to low and as mentioned in chapter 3.4.2.3 it was decided to remove the data from authors with a small amount of data points.

2) The data from authors with few data points (less than six data points) were removed before doing the analysis again. This gave the following results:

Best subsets regression:

$Re, \frac{P_t}{d_e}, \frac{P_l}{d_e}, \frac{h_e}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}$

Best Subsets Regression: logEu versus logRe; logPt/de; ...

Response is logEu

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/de	logPl/de	logheff/sf	logdf/de	logt/sf
1	22,2	21,9	932,1	0,081045	X					
1	17,8	17,5	1000,7	0,083326			X			
2	52,8	52,4	460,9	0,063243			X	X		
2	44,8	44,4	584,6	0,068391	X	X				
3	65,1	64,7	272,3	0,054463	X		X	X		
3	56,4	55,9	406,9	0,060878	X	X			X	
4	79,5	79,2	52,4	0,041858	X	X	X	X		
4	69,0	68,6	214,2	0,051432	X	X	X			X
5	82,0	81,6	15,7	0,039295	X	X	X	X	X	
5	80,6	80,2	37,0	0,040772	X	X	X	X		X
6	82,7	82,3	7,0	0,038607	X	X	X	X	X	X

All the six variables could have been used, but when the regression was performed with all the variables it was observed that there was a collinearity problem between t/s_f and h_e/s_f (VIF ca. 7 for the two parameters). Therefore the regression was performed with five variables:

Regression Analysis: logEu versus logRe; logPt/de; ...

```
The regression equation is
logEu = 0,853 - 0,178 logRe - 0,693 logPt/de - 0,623 logPl/de + 0,283 logheff/sf
        + 0,495 logdf/de
```

Predictor	Coef	SE Coef	T	P	VIF
Constant	0,85324	0,04786	17,83	0,000	
logRe	-0,177506	0,009240	-19,21	0,000	1,311
logPt/de	-0,69280	0,04375	-15,83	0,000	1,499
logPl/de	-0,62306	0,03303	-18,86	0,000	1,767
logheff/sf	0,28269	0,01808	15,63	0,000	1,953
logdf/de	0,49537	0,08103	6,11	0,000	1,359

```
S = 0,0392952   R-Sq = 82,0%   R-Sq(adj) = 81,6%


Analysis of Variance

Source           DF        SS       MS       F      P
Regression        5   1,88934  0,37787  244,72  0,000
Residual Error  269   0,41537  0,00154
Total           274   2,30471


Source       DF   Seq SS
logRe         1  0,51155
logPt/de      1  0,52093
logPl/de      1  0,19420
logheff/sf    1  0,60495
logdf/de      1  0,05771
```

Regression equation (the one recommended in chapter 3.4.2.3):

$$Eu = 7{,}132 \cdot Re^{-0{,}1775} \cdot \left(\frac{P_t}{d_e}\right)^{-0{,}6928} \cdot \left(\frac{P_l}{d_e}\right)^{-0{,}6230} \cdot \left(\frac{h_e}{s_f}\right)^{0{,}2827} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}4954} \quad (40)$$

3) For the same data as in 2), Ar was tried instead of the dimensionless groups for fin geometry. The data from Kawaguchi et al. (2004)/Kawaguchi et al. (2006a) were not included (the segment width was not given). Best subsets regression:

$Re, \frac{P_t}{d_e}, \frac{P_l}{d_e}, Ar$

Best Subsets Regression: logEu versus logRe; logPt/de; logPl/de; logAr

Response is logEu

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/de	logPl/de	logAr
1	22,9	22,5	768,9	0,087726			X	
1	17,9	17,4	831,6	0,090545	X			
2	57,5	57,0	340,3	0,065315			X	X
2	45,2	44,6	493,0	0,074139	X	X		
3	69,4	68,9	194,1	0,055566	X		X	X
3	61,2	60,6	296,4	0,062581		X	X	X
4	84,7	84,4	5,0	0,039337	X	X	X	X

All variables had a very significant effect. The regression was performed using all the variables:

Regression Analysis: logEu versus logRe; logPt/de; logPl/de; logAr

```
The regression equation is
logEu = 0,768 - 0,180 logRe - 0,584 logPt/de - 0,880 logPl/de + 0,415 logAr

Predictor      Coef  SE Coef       T      P    VIF
Constant    0,76840  0,05394   14,25  0,000
logRe      -0,18042  0,01053  -17,13  0,000  1,276
logPt/de   -0,58387  0,04223  -13,82  0,000  1,348
logPl/de   -0,88026  0,04051  -21,73  0,000  2,432
logAr       0,41529  0,02176   19,08  0,000  2,319


S = 0,0393366   R-Sq = 84,7%   R-Sq(adj) = 84,4%


Analysis of Variance

Source           DF       SS       MS       F      P
Regression        4  1,63221  0,40805  263,71  0,000
Residual Error  190  0,29400  0,00155
Total           194  1,92621


Source    DF   Seq SS
logRe      1  0,34394
logPt/de   1  0,52694
logPl/de   1  0,19778
logAr      1  0,56356
```

Regression equation (the Ar correlation recommended in chapter 3.4.2.3):

$$Eu = 5{,}867 \cdot Re^{-0{,}1804} \cdot \left(\frac{P_t}{d_e}\right)^{-0{,}58387} \cdot \left(\frac{P_l}{d_e}\right)^{-0{,}88026} \cdot Ar^{0{,}4153} \qquad (41)$$

4) The analysis was also carried out with Ar as calculated for solid fins so that the data from Kawaguchi et al. (2004)/Kawaguchi et al. (2006a) could be included. This led to the results below:

Best subsets regression:

$Re, \frac{P_t}{d_e}, \frac{P_l}{d_e}, Ar_{sol}$

Best Subsets Regression: logEu versus logRe; logPt/de; ...

```
Response is logEu

                                                     l
                                                   l l o
                                                   o o g
                                                   g g A
                                                 l P P r
                                                 o t l s
                                                 g / / o
                           Mallows               R d d l
Vars  R-Sq  R-Sq(adj)           Cp            S  e e e .
   1  22,2       21,9        867,4  0,081045  X
   1  17,8       17,5        932,4  0,083326      X
   2  53,5       53,1        411,7  0,062784      X X
   2  44,8       44,4        538,7  0,068391  X X
   3  65,7       65,3        234,6  0,053993  X   X X
   3  57,8       57,3        350,5  0,059907    X X X
   4  81,5       81,3          5,0  0,039688  X X X X
```

Regression Analysis: logEu versus logRe; logPt/de; logPl/de; logArsol.

```
The regression equation is
logEu = 0,729 - 0,172 logRe - 0,635 logPt/de - 0,654 logPl/de + 0,360 logArsol.


Predictor       Coef   SE Coef       T      P    VIF
Constant     0,72945   0,04941   14,76  0,000
logRe      -0,172135  0,009235  -18,64  0,000  1,283
logPt/de    -0,63537   0,04175  -15,22  0,000  1,338
logPl/de    -0,65401   0,03170  -20,63  0,000  1,595
logArsol.    0,36050   0,01771   20,36  0,000  1,569


S = 0,0396881   R-Sq = 81,5%   R-Sq(adj) = 81,3%


Analysis of Variance

Source           DF        SS       MS       F      P
Regression        4   1,87942  0,46985  298,29  0,000
Residual Error  270   0,42529  0,00158
Total           274   2,30471


Source     DF   Seq SS
logRe       1  0,51155
```

```
logPt/de     1   0,52093
logPl/de     1   0,19420
logArsol.    1   0,65274
```

The regression equation:

$$Eu = 5{,}364 \cdot Re^{-0{,}1721} \cdot \left(\frac{P_t}{d_e}\right)^{-0{,}63537} \cdot \left(\frac{P_l}{d_e}\right)^{-0{,}65401} \cdot Ar_{sol}{}^{0{,}3605} \qquad \text{(A-8)}$$

5) The regression analysis was performed for $F_t/F_d>1{,}0$ as well. Here the fin geometry and Reynolds number effect was kept from the equation 40 for $F_t/F_d<1{,}0$:

$$C_1 = \frac{Eu}{f(fin\ geometry) \cdot Re^m}$$
$$C_1 = \frac{Eu}{7{,}132 \cdot Re^{-0{,}1775} \cdot \left(\frac{h_e}{s_f}\right)^{0{,}2827} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}4954}} \qquad (42)$$

The regression analysis was performed with the C_1-values as the response and the dimensionless groups for tube bundle layout as predictors. This gave the following output in Minitab:

Best subsets regression:

$\frac{P_t}{d_e}, \frac{P_l}{d_e}$

Best Subsets Regression: logC1 versus logPt/de; logPl/de

```
Response is logC1

                                                   l l
                                                   o o
                                                   g g
                                                   P P
                                                   t l
                                                   / /
                                                   d d
Vars  R-Sq  R-Sq(adj)  Mallows Cp          S       e e
   1  80,4       80,3       957,1   0,061380       X
   1  35,0       34,8      3706,8    0,11168         X
   2  96,1       96,1         3,0   0,027276       X X
```

Regression Analysis: logC1 versus logPt/de; logPl/de

```
The regression equation is
logC1 = 1,02 - 3,08 logPt/de + 0,968 logPl/de


Predictor       Coef  SE Coef       T      P    VIF
Constant     1,02153  0,02623   38,94  0,000
logPt/de    -3,07789  0,05056  -60,88  0,000  1,055
logPl/de     0,96755  0,03129   30,92  0,000  1,055


S = 0,0272755   R-Sq = 96,1%   R-Sq(adj) = 96,1%


Analysis of Variance

Source           DF      SS      MS        F      P
Regression        2  4,3386  2,1693  2915,90  0,000
Residual Error  234  0,1741  0,0007
Total           236  4,5127


Source    DF  Seq SS
logPt/de   1  3,6273
logPl/de   1  0,7113
```

Regression equation (also presented in chapter 3.4.2.3):

$$Eu = 74{,}945 \cdot Re^{-0{,}1775} \cdot \left(\frac{P_t}{d_e}\right)^{-3{,}0779} \cdot \left(\frac{P_l}{d_e}\right)^{0{,}9676} \cdot \left(\frac{h_e}{s_f}\right)^{0{,}2827} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}4954} \qquad (43)$$

However, as discussed in chapter 3.4.2.3, the exponents for the tube bundle layout parameters were not realistic, so the correlation is not recommended to use.

6) For the same data as in 5), the Ar correlation (eq. 41) found in 3) was used:

$$C_2 = \frac{Eu}{f(fin\ geometry) \cdot Re^m} = \frac{Eu}{5{,}867 \cdot Re^{-0{,}1804} \cdot Ar^{0{,}4153}} \qquad \text{(A-9)}$$

Best subsets regression with C_2 as the y-variable:

$$\frac{P_t}{d_e}, \frac{P_l}{d_e}$$

Best Subsets Regression: logC2 versus logPt/de; logPl/de

```
Response is logC2

                                                    l l
                                                    o o
                                                    g g
                                                    P P
                                                    t l
                                                    / /
                                                    d d
Vars  R-Sq  R-Sq(adj)  Mallows Cp         S         e e
   1  75,6       75,5       999,0  0,064817         X
   1  39,9       39,7      2806,8   0,10182           X
   2  95,4       95,3         3,0  0,028309         X X
```

Regression Analysis: logC2 versus logPt/de; logPl/de

```
The regression equation is
logC2 = 0,848 - 2,78 logPt/de + 1,03 logPl/de


Predictor       Coef  SE Coef       T      P    VIF
Constant     0,84804  0,02722   31,15  0,000
logPt/de    -2,77964  0,05248  -52,97  0,000  1,055
logPl/de     1,02598  0,03248   31,59  0,000  1,055


S = 0,0283091   R-Sq = 95,4%   R-Sq(adj) = 95,3%


Analysis of Variance

Source          DF      SS      MS        F      P
Regression       2  3,8666  1,9333  2412,41  0,000
Residual Error 234  0,1875  0,0008
Total          236  4,0542


Source    DF  Seq SS
logPt/de   1  3,0669
logPl/de   1  0,7998
```

Regression equation:

$$Eu = 41{,}34 \cdot Re^{-0{,}1804} \cdot \left(\frac{P_t}{d_e}\right)^{-2{,}77964} \cdot \left(\frac{P_l}{d_e}\right)^{1{,}02598} \cdot Ar^{0{,}4153} \qquad \text{(A-10)}$$

Also in this correlation the exponents for the tube bundle layout variables were unrealistic.

Appendix 4 Minitab output from regression analysis of the pressure drop data for solid fins

Here the Minitab output from the regression analysis of the pressure drop data for solid fins will be presented:

1) The regression analysis was first performed for all the data for Re<50 000:

Best subsets regression:

$$Re, \frac{P_t}{d_e}, \frac{P_l}{d_e}, \frac{h_f}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}$$

Best Subsets Regression: logEu versus logRe; logPt/de; ...

```
Response is logEu

                                                          l
                                                          o
                                                      l l g l
                                                      o o h o l
                                                      g g e g o
                                                    l P P f d g
                                                    o t l f f t
                                                    g / / / / /
                                                    R d d s d s
Vars  R-Sq  R-Sq(adj)  Mallows Cp         S         e e e f e f
   1  34,5       34,4      1387,1   0,11919           X
   1  22,6       22,4      1735,7   0,12959         X
   2  64,1       64,0       522,6  0,088284           X   X
   2  57,9       57,8       704,5  0,095633         X X
   3  78,4       78,3       107,8  0,068594         X X   X
   3  70,3       70,1       345,3  0,080459         X X     X
   4  81,4       81,3        20,8  0,063639         X X X X
   4  79,0       78,9        91,6  0,067661         X X   X X
   5  81,9       81,7         9,1  0,062891         X X X X X
   5  81,5       81,4        19,9  0,063525         X X X X   X
   6  82,0       81,8         7,0  0,062704         X X X X X X
```

It was decided to perform the regression with all the variables though the dimensionless group t/s_f did not seem very significant:

Regression Analysis: logEu versus logRe; logPt/de; ...

```
The regression equation is
logEu = 0,929 - 0,207 logRe - 0,664 logPt/de - 0,293 logPl/de + 0,257 logheff/sf
        + 0,0627 logt/sf + 0,252 logdf/de


Predictor        Coef   SE Coef       T      P    VIF
Constant      0,92868   0,04454   20,85  0,000
logRe       -0,206903  0,009778  -21,16  0,000  1,138
logPt/de     -0,66356   0,03478  -19,08  0,000  2,323
logPl/de     -0,29340   0,03461   -8,48  0,000  2,264
logheff/sf    0,25717   0,01475   17,44  0,000  1,931
logt/sf       0,06273   0,03086    2,03  0,043  1,147
logdf/de      0,25159   0,06527    3,85  0,000  1,965
```

```
S = 0,0627043   R-Sq = 82,0%   R-Sq(adj) = 81,8%


Analysis of Variance

Source           DF       SS      MS       F      P
Regression        6   9,4308  1,5718  399,76  0,000
Residual Error  525   2,0642  0,0039
Total           531  11,4950
```

Regression equation:

$$Eu = 8{,}49 \cdot Re^{-0{,}2069} \cdot \left(\frac{P_t}{d_e}\right)^{-0{,}66356} \cdot \left(\frac{P_l}{d_e}\right)^{-0{,}2934} \cdot \left(\frac{h_f}{s_f}\right)^{0{,}2572} \cdot \left(\frac{t}{s_f}\right)^{0{,}0627} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}2516} \quad \text{(A-11)}$$

The correlation failed for Eu>1,2 (as discussed in chapter 3.4.3.3). The data from Briggs and Young (1963) and geometry 5v from Brauer (1964) were overestimated.

2) Using the same data as in 1), but now using Ar instead of the dimensionless groups for fin geometry. Best subsets regression:

$$Re, \frac{P_t}{d_e}, \frac{P_l}{d_e}, Ar$$

Best Subsets Regression: logEu versus logRe; logPt/de; logPl/de; logAr

```
Response is logEu

                                                  l l
                                                  o o
                                                  g g
                                                l P P l
                                                o t l o
                                                g / / g
                                                R d d A
Vars  R-Sq  R-Sq(adj)  Mallows Cp          S    e e e r
   1  34,5       34,4      1323,6    0,11919      X
   1  22,6       22,4      1660,6    0,12959    X
   2  63,4       63,3       507,7   0,089144      X   X
   2  57,9       57,8       663,7   0,095633    X X
   3  78,2       78,1        92,3   0,068894    X X   X
   3  68,9       68,7       354,4   0,082251    X   X X
   4  81,4       81,2         5,0   0,063771    X X X X
```

Regression Analysis: logEu versus logRe; logPt/de; logPl/de; logAr

```
The regression equation is
logEu = 0,726 - 0,202 logRe - 0,624 logPt/de - 0,323 logPl/de + 0,324 logAr


Predictor        Coef   SE Coef       T      P    VIF
Constant      0,72642   0,04386   16,56  0,000
logRe       -0,202041  0,009548  -21,16  0,000  1,049
logPt/de     -0,62361   0,03327  -18,74  0,000  2,055
logPl/de     -0,32347   0,03424   -9,45  0,000  2,142
logAr         0,32398   0,01283   25,25  0,000  1,118


S = 0,0637706   R-Sq = 81,4%   R-Sq(adj) = 81,2%


Analysis of Variance

Source           DF       SS      MS       F      P
Regression        4   9,3518  2,3380  574,90  0,000
Residual Error  527   2,1431  0,0041
Total           531  11,4950


Source    DF  Seq SS
logRe      1  2,5945
logPt/de   1  4,0625
logPl/de   1  0,1019
logAr      1  2,5929
```

Regression equation:

$$Eu = 5{,}33 \cdot Re^{-0{,}202} \cdot \left(\frac{P_t}{d_e}\right)^{-0{,}62361} \cdot \left(\frac{P_l}{d_e}\right)^{-0{,}32347} \cdot Ar^{0{,}32398} \qquad \text{(A-12)}$$

The same trends were observed for this correlation as for the correlation developed in 1). Therefore some of the data needed to be removed before performing the analysis.

3) In order to get a more accurate equation for the rest of the data, all the data from Briggs and Young (1963) and geometry 5v from Brauer (1964) were removed. It was also decided to perform the analysis for Eu≤1,2. The analysis for the remaining data gave the following results:

$$Re, \frac{P_t}{d_e}, \frac{P_l}{d_e}, \frac{h_f}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}$$

Best Subsets Regression: logEu versus logRe; logPt/de; ...

Response is logEu

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/de	logPl/de	logheff/sf	logt/sf	logdf/de
1	27,4	27,2	2314,4	0,098971				X		
1	26,5	26,4	2347,1	0,099563	X					
2	64,2	64,0	940,5	0,069636		X		X		
2	48,4	48,2	1528,7	0,083509	X	X				
3	82,1	82,0	269,4	0,049232	X	X		X		
3	68,5	68,3	779,7	0,065359	X	X				X
4	85,7	85,5	139,3	0,044165	X	X	X	X		
4	85,5	85,4	143,9	0,044353	X	X		X	X	
5	87,6	87,5	67,3	0,041059	X	X		X	X	X
5	87,5	87,3	73,4	0,041329	X	X	X	X		X
6	89,3	89,1	7,0	0,038248	X	X	X	X	X	X

Regression Analysis: logEu versus logRe; logPt/de; ...

The regression equation is
logEu = 0,992 - 0,210 logRe - 0,724 logPt/de - 0,196 logPl/de + 0,263 logheff/sf
+ 0,397 logdf/de + 0,193 logt/sf

Predictor	Coef	SE Coef	T	P	VIF
Constant	0,99216	0,03652	27,17	0,000	
logRe	-0,209786	0,007652	-27,42	0,000	1,044
logPt/de	-0,72394	0,02424	-29,87	0,000	1,573
logPl/de	-0,19613	0,02486	-7,89	0,000	1,600
logheff/sf	0,263399	0,009873	26,68	0,000	1,780
logdf/de	0,39710	0,04467	8,89	0,000	1,957
logt/sf	0,19259	0,02329	8,27	0,000	1,324

S = 0,0382481   R-Sq = 89,3%   R-Sq(adj) = 89,1%

Analysis of Variance

Source	DF	SS	MS	F	P
Regression	6	4,89164	0,81527	557,29	0,000
Residual Error	401	0,58663	0,00146		
Total	407	5,47827			

```
Source        DF   Seq SS
logRe          1  1,45367
logPt/de       1  1,20020
logPl/de       1  0,00959
logheff/sf     1  2,02875
logdf/de       1  0,09942
logt/sf        1  0,10001
```

Regression equation (recommended in chapter 3.4.3.3):

$$Eu = 9{,}82 \cdot Re^{-0{,}20979} \cdot \left(\frac{P_t}{d_e}\right)^{-0{,}72394} \cdot \left(\frac{P_l}{d_e}\right)^{-0{,}19613} \cdot \left(\frac{h_f}{s_f}\right)^{0{,}2634} \cdot \left(\frac{t}{s_f}\right)^{0{,}19259} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}3971} \quad (47)$$

4) For the same data as in 3), Ar was used instead of all the dimensionless groups for fin geometry. Best subsets regression:

$$Re, \frac{P_t}{d_e}, \frac{P_l}{d_e}, Ar$$

Best Subsets Regression: logEu versus logRe; logPt/de; logPl/de; logAr

```
Response is logEu

                                                        l l
                                                        o o
                                                        g g
                                                      l P P l
                                                      o t l o
                                                      g / / g
                                                      R d d A
Vars  R-Sq  R-Sq(adj)  Mallows Cp         S           e e e r
   1  26,5       26,4      1757,4  0,099563           X
   1  26,4       26,2      1761,3  0,099653                 X
   2  65,2       65,0       622,8  0,068641             X   X
   2  48,4       48,2      1114,8  0,083509           X X
   3  82,3       82,2       120,7  0,048988           X X   X
   3  68,3       68,0       533,7  0,065600             X X X
   4  86,3       86,2         5,0  0,043152           X X X X
```

Regression Analysis: logEu versus logRe; logPt/de; logPl/de; logAr

```
The regression equation is
logEu = 0,683 - 0,198 logRe - 0,626 logPt/de - 0,284 logPl/de + 0,346 logAr


Predictor       Coef   SE Coef       T      P    VIF
Constant     0,68275   0,03909   17,47  0,000
logRe      -0,197609  0,008578  -23,04  0,000  1,030
logPt/de    -0,62601   0,02494  -25,11  0,000  1,308
logPl/de    -0,28395   0,02617  -10,85  0,000  1,393
logAr        0,34595   0,01039   33,30  0,000  1,180


S = 0,0431516   R-Sq = 86,3%   R-Sq(adj) = 86,2%


Analysis of Variance

Source           DF      SS      MS       F      P
Regression        4  4,7279  1,1820  634,76  0,000
Residual Error  403  0,7504  0,0019
Total           407  5,4783


Source    DF  Seq SS
logRe      1  1,4537
logPt/de   1  1,2002
logPl/de   1  0,0096
logAr      1  2,0644
```

Regression equation (recommended in chapter 3.4.3.3):

$$Eu = 4{,}817 \cdot Re^{-0{,}1976} \cdot \left(\frac{P_t}{d_e}\right)^{-0{,}626} \cdot \left(\frac{P_l}{d_e}\right)^{-0{,}28395} \cdot Ar^{0{,}34595} \tag{48}$$

Appendix 5 Minitab output from the regression analysis investigating the effect of the segment height on the heat transfer

Here the Minitab output from the analysis of the effect of the segment height on the heat transfer will be presented:

1) Using the data from the three geometries compared in Kawaguchi et al. (2006b) (named SR210K, SR211HK and SR211LK) gave the output below (The geometries differed only in segment height and fin height):

Regression Analysis: logNuPr versus logRe; loghs/hf

```
The regression equation is
logNuPr = - 0,912 + 0,756 logRe + 0,306 loghs/hf


Predictor      Coef  SE Coef      T      P    VIF
Constant    -0,9121   0,1181  -7,72  0,000
logRe       0,75644  0,02647  28,57  0,000  1,009
loghs/hf    0,30554  0,03734   8,18  0,000  1,009


S = 0,0238025   R-Sq = 97,5%   R-Sq(adj) = 97,3%


Analysis of Variance

Source          DF       SS       MS       F      P
Regression       2  0,52944  0,26472  467,24  0,000
Residual Error  24  0,01360  0,00057
Total           26  0,54304


Source    DF   Seq SS
logRe      1  0,49150
loghs/hf   1  0,03794
```

The equation (presented in chapter 3.7):

$$Nu \cdot Pr^{-1/3} = 0{,}1224 \cdot Re^{0{,}7564} \cdot \left(\frac{h_s}{h_f}\right)^{0{,}30554} \qquad (53)$$

2) Further only the two geometries SR211HK and SR211LK that only differed in segment height were included in the regression analysis. This led to the output below:

Regression Analysis: logNuPr versus logRe; loghs/hf

```
The regression equation is
logNuPr = - 0,867 + 0,735 logRe + 0,220 loghs/hf


Predictor       Coef   SE Coef       T      P    VIF
Constant    -0,86698   0,06508  -13,32  0,000
logRe        0,73470   0,01454   50,52  0,000  1,012
loghs/hf     0,22007   0,01950   11,28  0,000  1,012


S = 0,0108249   R-Sq = 99,5%   R-Sq(adj) = 99,4%


Analysis of Variance

Source          DF       SS       MS        F      P
Regression       2  0,33275  0,16637  1419,83  0,000
Residual Error  15  0,00176  0,00012
Total           17  0,33451


Source    DF   Seq SS
logRe      1  0,31783
loghs/hf   1  0,01492
```

The equation (also presented in chapter 3.7):

$$Nu \cdot Pr^{-1/3} = 0{,}1358 \cdot Re^{0{,}7347} \cdot \left(\frac{h_s}{h_f}\right)^{0{,}22} \tag{54}$$

3) All the data for serrated (I-foot fins) and solid fins (except from the data from Brauer (1964)) gave the results below:

Best subsets regression:

$$Re, \frac{P_t}{P_l}. \frac{P_t}{d_e}, \frac{h_e}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}, \frac{h_f - h_s}{h_f}$$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; ...

Response is logNuPr

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/Pl	logPt/de	log(hf-hs)/hf	logheff/sf	logdf/de	logt/sf
1	92,0	92,0	473,5	0,078810	X						
1	8,9	8,7	10786,3	0,26610						X	
2	93,0	92,9	358,1	0,074067	X			X			
2	92,5	92,4	418,5	0,076584	X	X					
3	94,1	94,1	219,4	0,067910	X			X	X		
3	93,1	93,1	339,8	0,073274	X			X		X	
4	95,6	95,6	31,4	0,058511	X			X	X	X	
4	94,3	94,3	192,7	0,066633	X			X	X		X
5	95,9	95,8	4,4	0,056984	X	X		X	X	X	
5	95,7	95,6	28,3	0,058293	X		X	X	X	X	
6	95,9	95,8	6,0	0,057018	X	X		X	X	X	X
6	95,9	95,8	6,4	0,057038	X	X	X	X	X	X	
7	95,9	95,8	8,0	0,057073	X	X	X	X	X	X	X

Regression Analysis: logNuPr versus logRe; logPt/Pl; ...

```
The regression equation is
logNuPr = - 1,30 + 0,771 logRe - 0,167 logPt/Pl - 0,286 log(hf-hs)/hf
          - 0,318 logheff/sf + 0,764 logdf/de
```

Predictor	Coef	SE Coef	T	P	VIF
Constant	-1,30377	0,03280	-39,75	0,000	
logRe	0,770933	0,008407	91,70	0,000	1,204
logPt/Pl	-0,16731	0,03103	-5,39	0,000	1,278
log(hf-hs)/hf	-0,28598	0,01769	-16,17	0,000	1,737
logheff/sf	-0,31774	0,01749	-18,17	0,000	2,247
logdf/de	0,76399	0,05408	14,13	0,000	1,637

S = 0,0569837   R-Sq = 95,9%   R-Sq(adj) = 95,8%

```
Analysis of Variance

Source           DF        SS       MS        F      P
Regression        5   38,7503  7,7501  2386,73  0,000
Residual Error  516    1,6755  0,0032
Total           521   40,4258


Source         DF   Seq SS
logRe           1  37,1961
logPt/Pl        1   0,1857
log(hf-hs)/hf   1   0,2309
logheff/sf      1   0,4895
logdf/de        1   0,6481
```

Equation (presented in chapter 3.7.1):

$$Nu \cdot Pr^{-1/3} = 0{,}0497 \cdot Re^{0{,}7709} \cdot \left(\frac{P_t}{P_l}\right)^{-0{,}1673} \cdot \left(\frac{h_f - h_s}{h_f}\right)^{-0{,}286} \cdot \left(\frac{h_e}{s_f}\right)^{-0{,}3177} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}764} \quad (58)$$

4) The tube bundle layout effect was not as expected (as discussed in chapter 3.7.1) and the removal of the data from Stasiulevicius et al. (1988) led to a change of sign for the P_t/P_l-exponent. In addition the data from Hashizume (1981) and geometry 6 from Ward and Young (1959) were removed (calculated ca. 30-50 % higher than the experimental values using equation 58). The analysis for the remaining data gave the following output:

Best subsets regression:

$$Re, \frac{P_t}{P_l}. \frac{P_t}{d_e}, \frac{h_e}{s_f}, \frac{t}{s_f}, \frac{d_f}{d_e}, \frac{h_f - h_s}{h_f}$$

Best Subsets Regression: logNuPr versus logRe; logPt/Pl; ...

Response is logNuPr

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/Pl	logPt/de	loghe/sf	log(hf-hs)/hf	logt/sf	logdf/de
1	93,7	93,6	648,5	0,073164	X						
1	12,8	12,6	14492,9	0,27111							X
2	94,1	94,1	570,6	0,070507	X			X			
2	94,1	94,1	572,5	0,070574	X				X		
3	95,6	95,6	311,2	0,060745	X			X	X		
3	94,8	94,7	460,2	0,066533	X			X			X
4	97,2	97,2	43,9	0,048619	X			X	X		X
4	96,0	96,0	244,3	0,057936	X		X	X	X		
5	97,4	97,3	19,9	0,047327	X	X		X	X		X
5	97,3	97,2	39,2	0,048327	X			X	X	X	X
6	97,5	97,4	7,8	0,046632	X	X		X	X	X	X
6	97,4	97,3	20,2	0,047293	X	X	X	X	X		X
7	97,5	97,4	8,0	0,046592	X	X	X	X	X	X	X

Six variables could have been used, but used five variables as the increase in R^2 was very small adding more variables.

Regression Analysis: logNuPr versus logRe; logPt/Pl; ...

```
The regression equation is
logNuPr = - 1,40 + 0,792 logRe + 0,260 logPt/Pl - 0,352 log(hf-hs)hf
          + 0,766 logdf/de - 0,346 logheff/sf


Predictor         Coef   SE Coef       T      P    VIF
Constant      -1,39818   0,02925  -47,79  0,000
logRe         0,791700  0,007685  103,01  0,000  1,252
logPt/Pl       0,26027   0,05181    5,02  0,000  1,323
log(hf-hs)hf  -0,35153   0,01729  -20,33  0,000  1,984
logdf/de       0,76627   0,04885   15,69  0,000  1,710
logheff/sf    -0,34587   0,01521  -22,73  0,000  2,140


S = 0,0473270   R-Sq = 97,4%   R-Sq(adj) = 97,3%


Analysis of Variance

Source           DF        SS       MS        F      P
Regression        5   36,2039   7,2408  3232,71  0,000
Residual Error  437    0,9788   0,0022
Total           442   37,1827


Source        DF   Seq SS
logRe          1  34,8220
logPt/Pl       1   0,0013
log(hf-hs)hf   1   0,1968
logdf/de       1   0,0261
logheff/sf     1   1,1576
```

The equation (presented and recommended in chapter 3.7.1):

$$Nu \cdot Pr^{-1/3} = 0{,}04 \cdot Re^{0{,}7917} \cdot \left(\frac{P_t}{P_l}\right)^{0{,}2603} \cdot \left(\frac{h_f - h_s}{h_f}\right)^{-0{,}35153} \cdot \left(\frac{h_e}{s_f}\right)^{-0{,}3459} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}76627} \qquad (59)$$

Appendix 6 Minitab output from the regression analysis investigating the effect of the segment height on the pressure drop

Here the Minitab output from the analysis of the effect of the segment height on the pressure drop will be presented:

1) Using the data from the three geometries compared in Kawaguchi et al. (2006a) (named SR210K, SR211HK and SR211LK) gave the output below:

Regression Analysis: logEu versus logRe; loghs/hf

```
The regression equation is
logEu = 0,825 - 0,206 logRe + 0,131 loghs/hf


Predictor       Coef   SE Coef       T      P    VIF
Constant      0,8245    0,1928    4,28  0,000
logRe       -0,20596   0,04160   -4,95  0,000  1,013
loghs/hf     0,13140   0,07718    1,70  0,102  1,013


S = 0,0490987   R-Sq = 51,8%   R-Sq(adj) = 47,8%


Analysis of Variance

Source          DF        SS        MS      F      P
Regression       2  0,062288  0,031144  12,92  0,000
Residual Error  24  0,057856  0,002411
Total           26  0,120144


Source    DF    Seq SS
logRe      1  0,055301
loghs/hf   1  0,006987
```

The equation (presented in chapter 3.7):

$$Eu = 6{,}6757 \cdot Re^{-0{,}20596} \cdot \left(\frac{h_s}{h_f}\right)^{0{,}1314} \quad (55)$$

2) Further only the two geometries SR211HK and SR211LK that only differed in segment height were included in the regression analysis. This led to the output below:

Regression Analysis: logEu versus logRe; loghs/hf

```
The regression equation is
logEu = 0,809 - 0,229 logRe - 0,0738 loghs/hf


Predictor        Coef    SE Coef        T      P    VIF
Constant      0,80918    0,03673    22,03  0,000
logRe       -0,229161   0,008017   -28,58  0,000  1,003
loghs/hf     -0,07377    0,01469    -5,02  0,000  1,003


S = 0,00819482   R-Sq = 98,3%   R-Sq(adj) = 98,1%


Analysis of Variance

Source          DF        SS        MS       F      P
Regression       2  0,057668  0,028834  429,37  0,000
Residual Error  15  0,001007  0,000067
Total           17  0,058676


Source    DF    Seq SS
logRe      1  0,055976
loghs/hf   1  0,001693
```

The equation (also presented in chapter 3.7)

$$Eu = 6{,}444 \cdot Re^{-0{,}229} \cdot \left(\frac{h_s}{h_f}\right)^{-0{,}07377} \tag{56}$$

3) Using all the data for serrated (I-foot) and solid fins (Eu≤1,2 for solid fins) for Re<50 000 gave the results below:

Best subsets regression:

$$Re, \frac{P_t}{d_e}, \frac{P_t}{d_e}, \frac{h_f - h_s}{h_f}, \frac{h_e}{s_f}, \frac{d_f}{d_e}, \frac{t}{s_f}$$

Best Subsets Regression: logEu versus logRe; logPt/de; ...

Response is logEu

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/de	logPl/de	log((hf-hs)/hf)	log(heff/sf)	logdf/de	logt/sf
1	31,9	31,8	1652,5	0,098485		X					
1	21,7	21,6	1996,1	0,10560					X		
2	65,4	65,3	525,1	0,070233		X			X		
2	49,7	49,5	1055,5	0,084724	X	X					
3	75,8	75,6	178,6	0,058844	X	X			X		
3	67,2	67,0	468,0	0,068481		X	X		X		
4	78,6	78,5	85,0	0,055336	X	X	X		X		
4	76,8	76,7	144,0	0,057554	X	X			X	X	
5	79,9	79,7	44,0	0,053702	X	X	X	X	X		
5	79,2	79,0	66,7	0,054592	X	X	X		X	X	
6	80,9	80,8	9,8	0,052291	X	X	X	X	X	X	
6	79,9	79,7	45,0	0,053706	X	X	X	X	X		X
7	81,1	80,9	8,0	0,052176	X	X	X	X	X	X	X

Regression Analysis: logEu versus logRe; logPt/de; ...

The regression equation is
logEu = 0,671 - 0,163 logRe - 0,628 logPt/de - 0,272 logPl/de
- 0,0967 log((hf-hs)/hf) + 0,211 log(heff/sf) + 0,320 logdf/de

Predictor	Coef	SE Coef	T	P	VIF
Constant	0,67065	0,03525	19,03	0,000	
logRe	-0,163127	0,007901	-20,65	0,000	1,110
logPt/de	-0,62769	0,02730	-22,99	0,000	1,998
logPl/de	-0,27162	0,02688	-10,11	0,000	2,076
log((hf-hs)/hf)	-0,09673	0,01264	-7,65	0,000	1,306
log(heff/sf)	0,21052	0,01228	17,15	0,000	2,191
logdf/de	0,31973	0,05329	6,00	0,000	1,835

S = 0,0522912   R-Sq = 80,9%   R-Sq(adj) = 80,8%

```
Analysis of Variance

Source           DF      SS      MS       F      P
Regression        6  7,4240  1,2373  452,51  0,000
Residual Error  639  1,7473  0,0027
Total           645  9,1713


Source           DF  Seq SS
logRe             1  1,0780
logPt/de          1  3,4778
logPl/de          1  0,0031
log((hf-hs)/hf)   1  0,7700
log(heff/sf)      1  1,9967
logdf/de          1  0,0984
```

The equation:

$$Eu = 4{,}68 \cdot Re^{-0{,}1631} \cdot \left(\frac{P_t}{d_e}\right)^{-0{,}62769} \cdot \left(\frac{P_l}{d_e}\right)^{-0{,}2716} \cdot \left(\frac{h_f - h_s}{h_f}\right)^{-0{,}09673} \cdot \left(\frac{h_e}{s_f}\right)^{0{,}21052} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}31973} \qquad \text{(A-13)}$$

4) Using the equation from 3), the data from Hashizume (1981), Briggs and Young (1963) and geometry 5v from Brauer (1964) were overestimated. The mentioned data were removed, and the analysis was performed for the remaining data. Best subsets regression:

$$Re, \frac{P_t}{d_e}, \frac{P_t}{d_e}, \frac{h_f - h_s}{h_f}, \frac{h_e}{s_f}, \frac{d_f}{d_e}, \frac{t}{s_f}$$

Best Subsets Regression: logEu versus logRe; logPt/de; ...

Response is logEu

Vars	R-Sq	R-Sq(adj)	Mallows Cp	S	logRe	logPt/de	logPl/de	log((hf-hs)/hf)	log(heff/sf)	logdf/de	logt/sf
1	30,8	30,7	2186,5	0,095682					X		
1	22,7	22,5	2508,9	0,10115	X						
2	64,2	64,1	865,9	0,068908		X			X		
2	46,1	45,9	1583,4	0,084546			X		X		
3	78,5	78,4	301,2	0,053463	X	X			X		
3	67,2	67,0	748,7	0,066012		X	X		X		
4	82,7	82,5	137,1	0,048022	X	X	X		X		
4	80,8	80,6	212,3	0,050583	X	X			X	X	
5	84,5	84,4	66,4	0,045451	X	X	X		X	X	
5	83,2	83,0	118,3	0,047331	X	X	X	X	X		
6	85,8	85,6	18,5	0,043604	X	X	X	X	X	X	
6	85,6	85,5	23,9	0,043813	X	X	X		X	X	X
7	86,1	85,9	8,0	0,043160	X	X	X	X	X	X	X

Regression Analysis: logEu versus logRe; logPt/de; ...

The regression equation is
logEu = 0,804 - 0,193 logRe - 0,712 logPt/de - 0,322 logPl/de
- 0,0838 log((hf-hs)/hf) + 0,233 log(heff/sf) + 0,483 logdf/de

Predictor	Coef	SE Coef	T	P	VIF
Constant	0,80413	0,03351	24,00	0,000	
logRe	-0,192610	0,007494	-25,70	0,000	1,069
logPt/de	-0,71166	0,02536	-28,06	0,000	1,460
logPl/de	-0,32242	0,02426	-13,29	0,000	1,520
log((hf-hs)/hf)	-0,08384	0,01199	-6,99	0,000	1,456
log(heff/sf)	0,23255	0,01084	21,45	0,000	2,171
logdf/de	0,48310	0,04838	9,99	0,000	1,860

S = 0,0436044   R-Sq = 85,8%   R-Sq(adj) = 85,6%

```
Analysis of Variance

Source           DF       SS       MS       F       P
Regression        6   6,3325   1,0554  555,09   0,000
Residual Error  553   1,0514   0,0019
Total           559   7,3839


Source           DF   Seq SS
logRe             1   1,6748
logPt/de          1   1,6526
logPl/de          1   0,0004
log((hf-hs)/hf)   1   0,6670
log(heff/sf)      1   2,1482
logdf/de          1   0,1896
```

Equation (presented and recommended in chapter 3.7.2):

$$Eu = 6{,}37 \cdot Re^{-0{,}1926} \cdot \left(\frac{P_t}{d_e}\right)^{-0{,}7117} \cdot \left(\frac{P_l}{d_e}\right)^{-0{,}3224} \cdot \left(\frac{h_f - h_s}{h_f}\right)^{-0{,}08384} \cdot \left(\frac{h_e}{s_f}\right)^{0{,}23255} \cdot \left(\frac{d_f}{d_e}\right)^{0{,}4831} \tag{60}$$

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