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Publication date:
2017

Document Version
Publisher's PDF, also known as Version of record

Pelletization of torrefied biomass: a modelling approach

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Abstract – The present study aims to apply and validate a simple model for biomass pelletization to describe the pelletization process of wet and dry torrefied biomass (giant reed and willow, respectively). The goal is to allow for a fast estimation of important pelletization parameters by combining a theoretical background with the use of a single pellet press. For this reason, pelletization tests at different die temperatures and compression ratios were carried out and the model was applied to explain the experimental data obtained. The model proved to be a good tool to better understand and describe the pelletizing behaviour of torrefied biomass material.

1. Introduction

Nowadays, it is necessary to develop renewable feedstock and conversion strategies for making solid fuels that can displace coal for heat and power production. Among the biomass upgrading methods, torrefaction and pelletization are two remarkable routes for solid fuel production. To be an effective alternative to coal, increasing the energy density of pellets is as important as increasing bulk density and durability. Thus, the combination of both pretreatment techniques produces energy dense solid fuels with better chemical, physical and fuel properties than the raw biomass [1] which make them an interesting option as replacement for coal in existing power plants [2].

Presently, there are two torrefaction concepts: wet and dry. Dry torrefaction (DT) is thermal treatment of biomass in an inert environment at atmospheric pressure and temperatures within the range of 200-300°C. Wet torrefaction (WT) can be defined as a treatment of biomass in a hydrothermal media, or hot compressed water, at temperatures within 180-260°C. While dry torrefaction has been intensively studied in the last couple of decades and developed to the stage of market introduction, wet torrefaction has only been studied to a lesser extent. However, the optimal process conditions have not been well determined for the various concepts and different feedstock in any of them [3]. Pelletization of torrefied biomass has, for long time, been an underestimated bottleneck in the production process of torrefied fuels and their commercialization [4]. Optimization of pelletization process is still mainly based on trial and error and personal experience. Thus, finding the optimal processing conditions is time consuming and expensive. For this reason, the present work combines the use of a single pellet press with modelling to describe the pelletizing behaviour of torrefied material in a large-scale pellet mill. The goal is to prove the usefulness of the model also for torrefied biomass and to provide the large-scale pellet mills with an easy and inexpensive procedure for the evaluation of the pelletization behaviour of different torrefied materials.

2. Method

The model used in the present study, developed by Holm et al. [5,6], is a simple theoretical model that describes the building up forces along the dies of the matrix. Thus, according to the model, the pelletizing pressure (P_x) required to press out a pellet can be calculated as follows:

$$\boldsymbol{P_x(x) = \frac{P_{N0}}{\upsilon_{LR}}\left(e^{2\mu\upsilon_{LR}x/r} - 1\right)} \qquad (1)$$

Where υ_{LR} is Poisson's ratio, P_{N0} is the prestressing term, r is the radius, μ the sliding friction coefficient, and x is the length of the pellet. To avoid the problem of experimentally determining the value of P_{N0} and the difficulty of finding υ and μ values depending on the moisture content and temperature for different biomass; Holm et al [6] defined two new parameters: U and J.

$$U = \mu P_{N0} \qquad (2)$$

$$J = \mu\upsilon_{LR} \qquad (3)$$

$$c = \frac{x}{2r} \qquad (4)$$

Introducing Eqs 2-4 in Eq 1 leads to:

$$P_x(c) = \frac{U}{J}\left(e^{4Jc} - 1\right) \qquad (5)$$

As it was shown in Holm et al [5], in the limit of small compression ratios (c<<1), Eq. 5 is given as:

$$P_x(c) \cong 4U_c \qquad (6)$$

The procedure followed in the present study was to analyse the pelletizing process at different die temperatures and compression ratios. Initially, 3 or 4 pelletizing tests were made in the linear region (0.7<c). Then, a linear fit was applied to the data obtained (including 0.0) and U was determined from the linear slope obtained from the fit. Later, more measurements were made at higher compression ratios (1<c<4) and the J value was obtained by performing a nonlinear fit of Eq. 5 to all experimentally measured data points. In this fit, the previously obtained value of U was used. More details of the biomass thermal pre-treatment, procedure and equipment used can be find elsewhere [7].

3. Results

An example of how the fitting of the model to the experimental data was carried out for WT giant reed at a die temperature of 80ºC and DT willow, also at 80ºC, is shown in Fig. 1. The circular points in the figure correspond to the linear region, at small compression ratios. These values were used to determine the U parameter of the model by adjusting a linear regression fit (red solid line). Then, the J parameter was calculated by adjusting a nonlinear fit of Eq. 5 to all the measured data points (dotted black line). Thus, a value of U and J parameters were obtained for each temperature. For all temperatures and low compression ratios, the P_x values showed good linearity so it was acceptable to use a linear least-square fit to determine the U parameter. It was not possible to achieve lower compression ratios because of the lowest detection limit of the load cell. However, the fittings for the different temperatures provided good results.

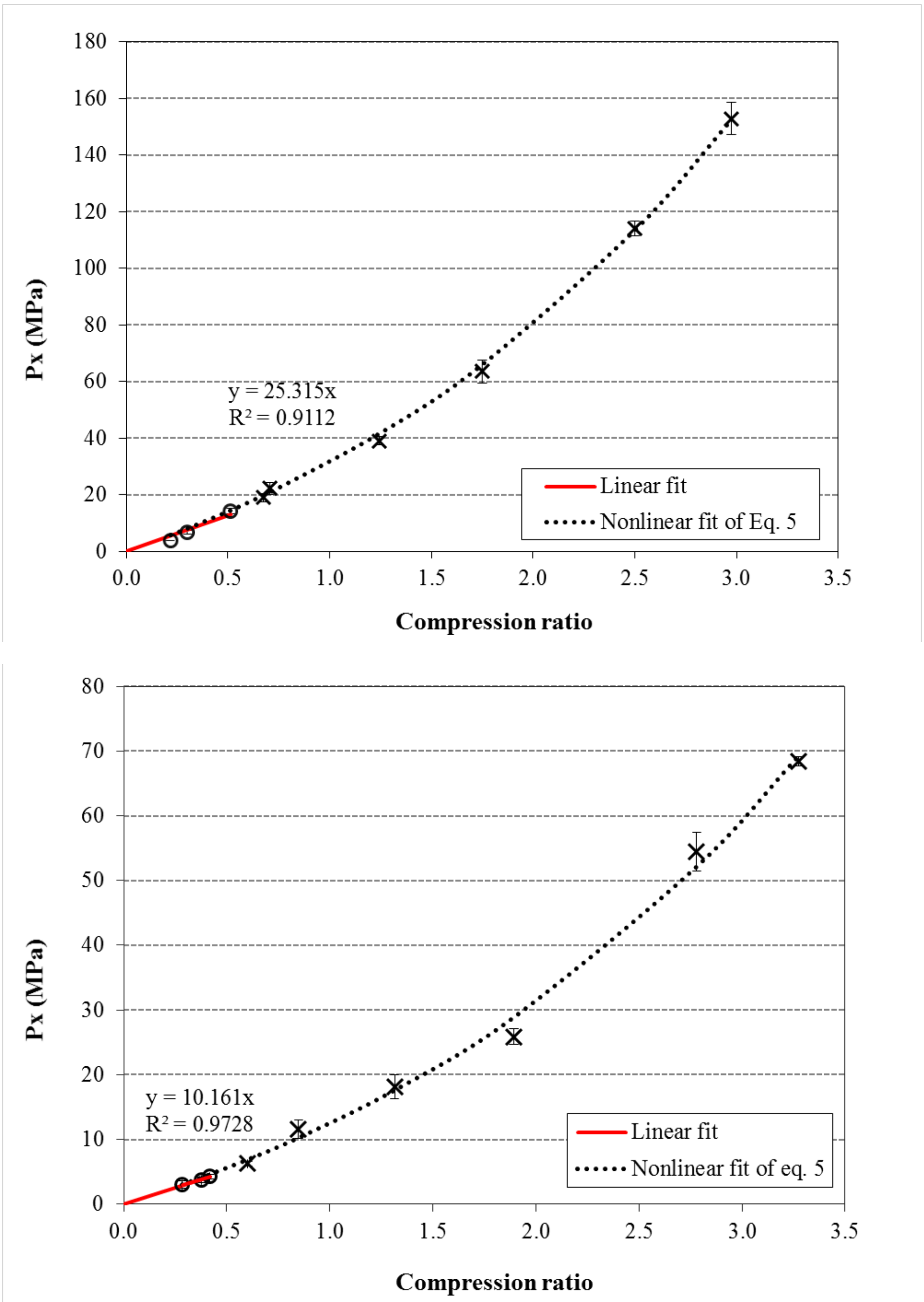

Figure 1. Experimental data and data fittings to determine the U and J parameters of the model for WT giant reed at 80ºC (top) and DT willow at 80ºC (bottom). Error bars indicate standard deviations of the measurements.

Figures 2-3 show the *U* and *J* values found at different temperatures for WT giant reed and DT willow. As observed by Holm et al [6] for untreated spruce and beech, the *U* parameter shows a temperature dependence. Thus, increasing the temperature results in a linear decrease of *U* values. WT giant reed shows a stronger temperature dependence as evidenced by a more pronounced decrease of *U* values when increasing the temperature than DT willow. On the other side, *J* values do not seem to have any systematic correlation. Following these observations, the correlation between the *J* and *U* parameter variation was further studied. This was done by assuming the linear fit given in Fig. 2 for each biomass and using it to calculate a new *U* value for each temperature. Then, the *J* parameter was also recalculated for each temperature. The new *J* values obtained still vary with the temperature, but the variations are smaller (10 versus 15% obtained before). The results for the recalculated model with the new *U* and *J* values are presented in Fig. 4 for DT willow and in Fig. 5 for WT giant reed. In both figures, the experimental data points are plotted together with the model predictions for linear *U* values and constant *J* values. The *J* values used are 0.1097 for WT giant reed and 0.0893 for DT willow.

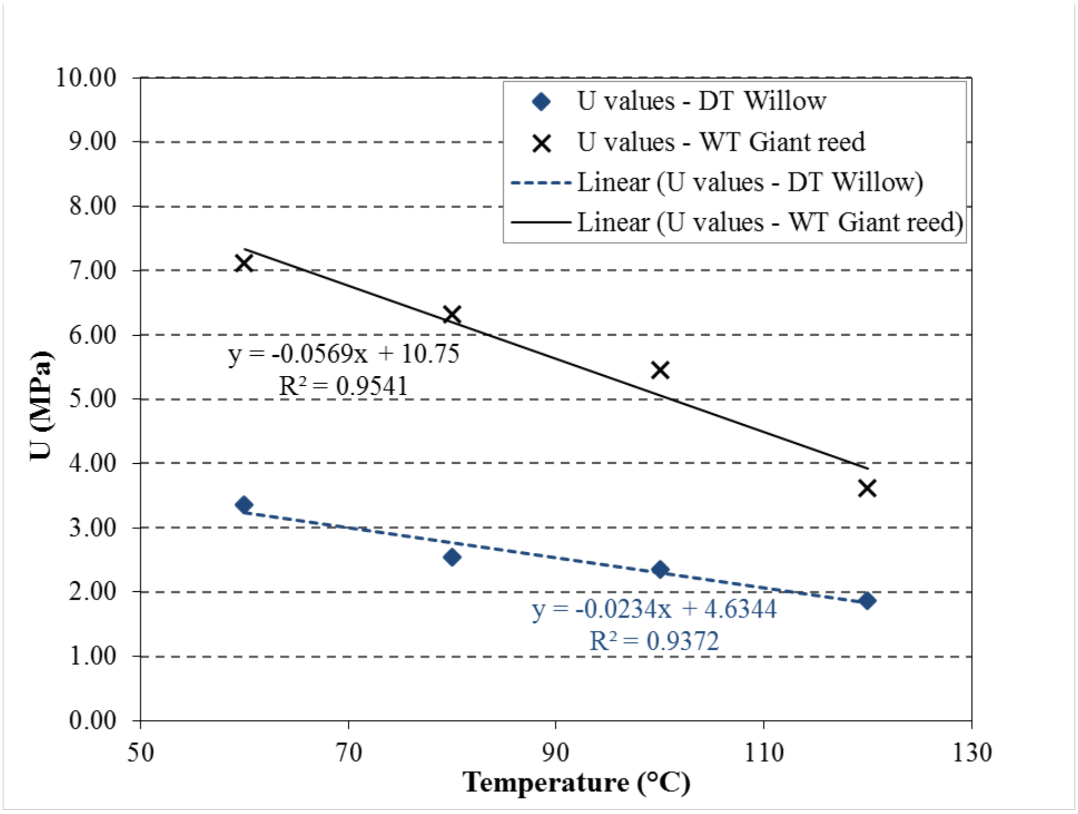

Figure 2. U values for WT Giant reed and DT Willow at different pelletization temperatures

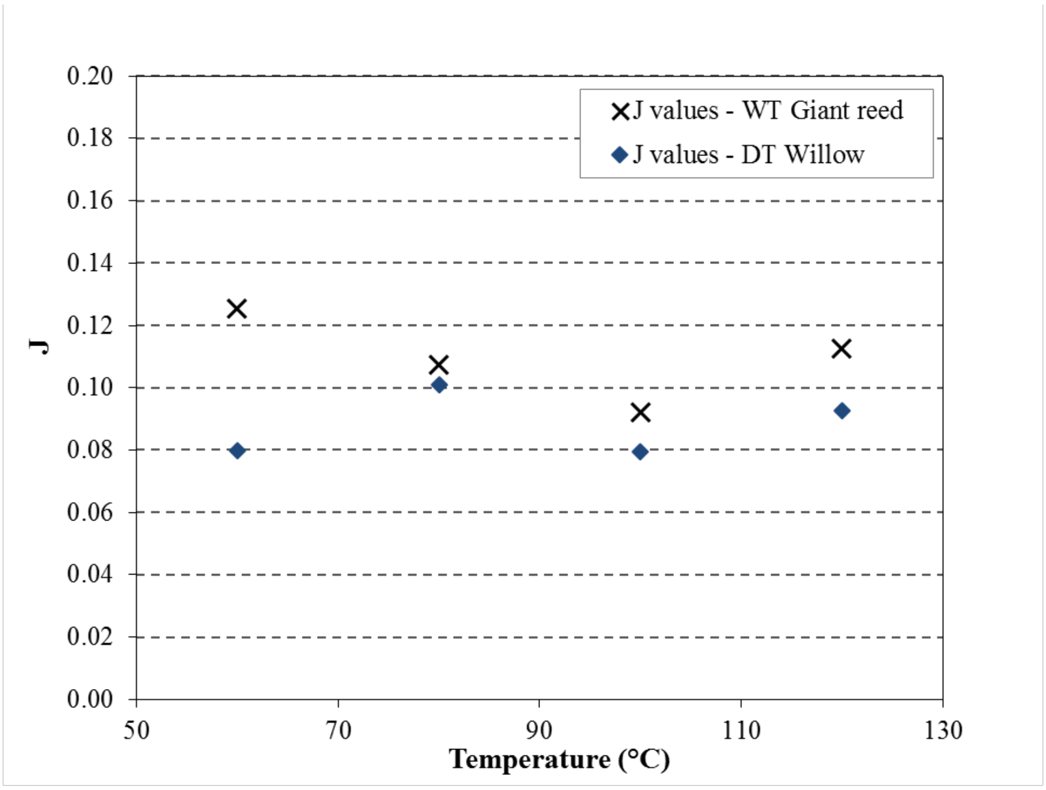

Figure 3. J values for WT Giant reed and DT Willow at different pelletization temperatures

Figures 4-5 show that the model can describe the experimentally obtained data for both WT giant reed and DT willow by considering the *U* value as a linear function of the temperature, and *J* approximated by a constant. Only at 60ºC for WT giant reed it deviates from the last data point where there is a significant increase of the pelletizing pressure that was not observed for the other temperatures. Probably, the difficulty of pressing out the pellets with the manual hydraulic press at that point may have affected the value measured by the load cell, giving rise to higher logged values than the real ones.

In both cases, as expected, increasing the compression ratio resulted in higher pelletizing pressures. It is known that the length of the press channel and the compression ratio are the most relevant factors affecting the pressure built up in the die of a pellet press [8,9]. On the other hand, decreasing the die temperature also increased the pelletizing pressure. This could be explained because the friction in the press channel is lowered due to polymer softening and extractive migration to the pellet surface caused by high temperatures [10]. The glass transition temperature of lignin is likely increased during the torrefaction process due to the decrease of moisture in the biomass. Thus, increasing the pelletizing temperature compensates for the increase of the softening temperature of the lignin and favours the extractive migration.

Direct comparison of both samples is not possible due to different thermal pretreatments and different biomass origin. However, for the same pelletizing conditions, DT willow requires less pelletization pressure than WT giant reed. This could be related to greater extractives content on DT willow.

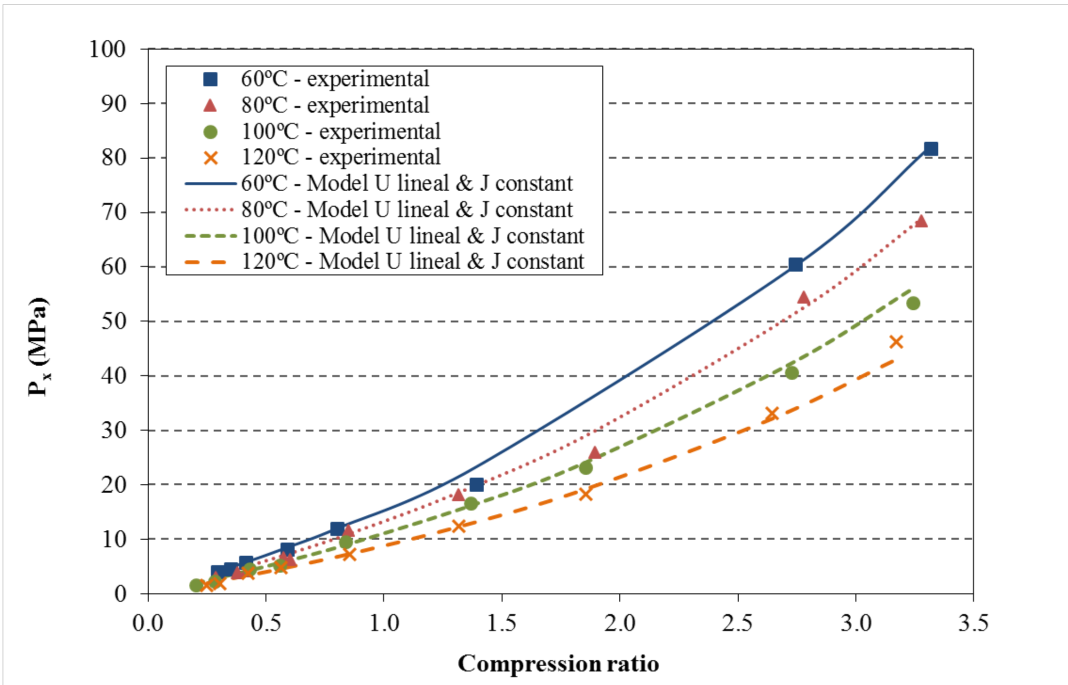

Figure 4. Pelletizing pressure of DT willow as function of compression ratio for different die temperatures.

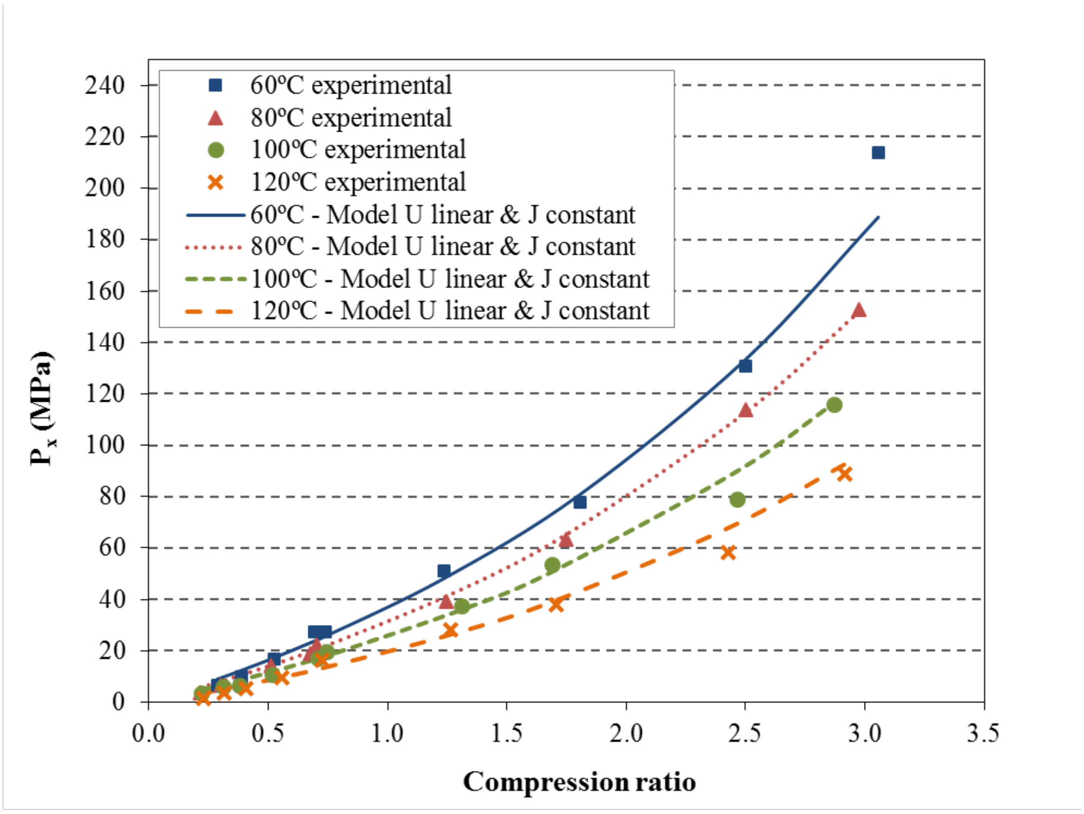

Figure 5. Pelletizing pressure of WT giant reed as function of compression ratio for different die temperatures.

Conclusions

The model developed by Holm et al. [5,6] is able to explain the pelletizing behaviour of two torrefied material at different die temperatures and compression ratios.

The two model parameters (*J* and *U*) which result from the combination of μ, υ_{LR} and P_{N0} were determined. *U* was determined by adjusting a linear fit to the pelletization pressure versus the compression ratio (*c*) for small values of *c*. *J* was determined by fitting an equation of the model to all experimental data points, including higher *c* values. For both materials, *U* parameter decreases linearly when the temperature increases but the *J* parameter remains more or less constant without a clear temperature dependence. The model shows good agreement with the experimental data when *J* is regarded as a fixed constant value and *U* parameter follows the linear temperature dependence.

References

[1] Q.-V. Bach, Ø. Skreiberg, Upgrading biomass fuels via wet torrefaction: A review and comparison with dry torrefaction, Renew. Sustain. Energy Rev. 54 (2016) 665–677. doi:10.1016/j.rser.2015.10.014.

[2] M.J.C. van der Stelt, H. Gerhauser, J.H.A. Kiel, K.J. Ptasinski, Biomass upgrading by torrefaction for the production of biofuels: A review, Biomass and Bioenergy. 35 (2011) 3748–3762. doi:10.1016/j.biombioe.2011.06.023.

[3] Q.-V. Bach, K.-Q. Tran, R.A. Khalil, Ø. Skreiberg, G. Seisenbaeva, Comparative Assessment of Wet Torrefaction, Energy & Fuels. 27 (2013) 6743–6753. doi:10.1021/ef401295w.

[4] W. Stelte, Optimization of product specific processing parameters for the production of fuel pellets from torrefied biomass, Danish Technol. Inst. Cent. Biomass Biorefinery. (2014).

[5] J.K. Holm, U.B. Henriksen, J.E. Hustad, L.H. Sørensen, Toward an Understanding of Controlling Parameters in Softwood and Hardwood Pellets Production, Energy & Fuels. 20 (2006) 2686–2694. doi:10.1021/ef0503360.

[6] J.K. Holm, W. Stelte, D. Posselt, J. Ahrenfeldt, U.B. Henriksen, Optimization of a Multiparameter Model for Biomass Pelletization to Investigate Temperature Dependence and to Facilitate Fast Testing of Pelletization Behavior, Energy & Fuels. 25 (2011) 3706–3711. doi:10.1021/ef2005628.

[7] M. Puig-Arnavat, J. Ahrenfeldt, U.B. Henriksen, Validation of a Multiparameter Model To Investigate Torrefied Biomass Pelletization Behavior, Energy & Fuels. (2017). doi:10.1021/acs.energyfuels.6b02895.

[8] W. Stelte, Guideline: Densification of torrefied biomass, 2012. http://www.teknologisk.dk/_root/media/52683_RK report torrefaction and densifictaion.pdf.

[9] W. Stelte, A.R. Sanadi, L. Shang, J.K. Holm, J. Ahrenfeldt, U.B. Henriksen, Recent developments in biomass pelletization - A review, Bioresources. August (2012). http://ojs.cnr.ncsu.edu/index.php/BioRes/article/view/BioRes_07_3_4451_Stelte_Developments_Biomass_Pelletization_Review.

[10] W. Stelte, J.K. Holm, A.R. Sanadi, S. Barsberg, J. Ahrenfeldt, U.B. Henriksen, Fuel pellets from biomass: The importance of the pelletizing pressure and its dependency on the processing conditions, Fuel. 90 (2011) 3285–3290. doi:10.1016/j.fuel.2011.05.011.