Energy differences in a grass mixture drying

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Abstract: To understand the energy differences in the drying process of a mixture of grasses, in which the tissue dries at different rates, an analysis of the Isotherm Curves, Drying Curves, Vaporizing enthalpy and Latent Heat of Ryegrass and White Clover was made. Data of Equilibrium Moisture Content was obtained from literature and drying curves were developed in the drying lab. In general, White Clover Leaves dries first and the White Clover Stems slowest. The Isotherm Curves of the parts of the ryegrass was similar, but not the White Clover parts. Drying curves are different for every part in each temperature, but for all the plants and plant parts the drying is similar at 75 and 60℃. Vaporization Enthalpy is very similar for the two plants and plant parts, for almost all the Moisture Contents. The heat of vaporization during the drying was calculated; Ryegrass needs more heat for evaporating water than the White Clover parts.

Keywords: grass drying energy, isotherms, vapour enthalpy, grass mixture drying

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1 Introduction

Grazed mixed pastures are important for milk and meat production. In a prairie with grass and legumes the grass takes advantages of the Nitrogen fixed in the soil by the legumes. On the other hand, with several species a prairie is more persistence and has more productivity than with single species, also with the combination of plants of different life cycle it can hold dry or wet seasons, the production is longer and less seasonal. Species with several root depth take more advantage of the water resources.

Drying of a mixture of grass is an extended practice that subjects the species to the effect of hot air, which reduces the moisture content of each plant and of the plant parts to the desired final moisture in different time. Under the same condition of air, the time of drying of several species varies between each other according to the initial moisture content, plant morphology, the species and the age of the forage. Also many researchers have shown that leaves dry faster than stems in several plants and not only grass specie: Devendra (1969), Phani et al. (2004) and Zheng et al. (2005) in alfalfa; Jones et al. (1981) in tall fescue and perennial ryegrass, Shepherd (1964) in White Clover, Fatouh et al. (2006) in Jew's mallow, spearmint and parsley herbs, Silva et al. (2008) in Coriander.

In many dryer plants in Europe and North America, direct contact type rotary drum dryers are often used for forages, which produce uniform product quality because of their long residence time and relative good mixing of the product. In these driers the energy consumption is between 3 and 8 MJ kg^{-1} dry product. If the dryer is badly designed or operated it could lead to failures in the quality and to more energy consumption (Sudhagar et al., 2005).

Depending of the initial moisture content (χ_0) of the product the energy requirements could vary from 1.5 – 1.7 MJ kg^{-1} dry product with an initial χ of 35 kg water kg^{-1} dry mater, and 10 MJ kg^{-1} dry product if the initial χ is near 65 kg water kg^{-1} dry matter, and the average fuel

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consumption depends on the drying technology (Andi et al., 2007).

This way, when there are differences in the evaporation rate of the parts of the mixture, some energy could be saved if the already dried parts where pulled out of the dryer. On the other hand, with the over drying of one part there is a reduction in the quality of the final product, because the material can crumble during or after the process, which could lead to losses.

The objective of this research was making a comparison of the theoretical energy required to dry the parts of a mixture of grass composed by White Clover and Ryegrass. To do this, the analysis of the isotherms, drying curves and energy of drying of their stems, leaves and the complete plant were made. This way literature was employed while missing data were developed by own.

2 Materials and method

In order to characterize and understand the differences of the drying behavior and heat energy required of one Ryegrass and White Clover mixture, some parameters of their performance were analyzed and compared between each other. In this way Isotherms, Drying Curves, Evaporation Enthalpy and Latent Heat were used for the comparison.

Isotherm and drying data was the base for all the comparisons, however, while the isotherm data were obtained from the literature, drying data where developed directly in the lab. With this data, Evaporation Enthalpy and Latent Heat during the drying were calculated and compared. Every of these parameters were obtained for the entire plant and the plant parts.

Shepherd (1958) reports data of Isotherms of White Clover Leaves and Stems, but not of the whole plant, then data of the whole plant Red Clover Extra Green and Brown were used from ASAE (2007). In the same way, Isotherm data of Leaves and Stems of Ryegrass are available in Shepherd (1958).

2.1 Isotherms

Normally Isotherms are expressed in the form of models; the most used are GAB, Henderson, Chung and Pfost, Halsey and Oswin. For this analysis, the Isotherm models reported by ASAE (2007) and Shepherd (1956) were used to make the comparisons, taking in account to choose the reported model which has the minimum Standard Error.

The parameters of Isotherm Models of Ryegrass, the whole plant of Red Clover Green and Brown and the stems and leaves of White Clover are summarized in Table 1, which also includes the temperature at which the data were obtained, and the path i.e. if the isotherm corresponds to adsorption, desorption, or both.

In the report of Shepherd (1956), the isotherms of the material are shown as the curves, but there are not any models, then a regression was made and the parameters of the best one are shown in Table 1.

Table 1 Parameters of the Isotherm models used

Source	Tissue	Path	Isotherm Model	Constants			S.E.	T °C	Model in comparison
				a	b	c			
ASAE (2007)	Red Clover Extra Green	Mix	Halsey modified	3,8949	0,0200	2,0146	0,02	27	Halsey Modified
	Red Clover Brown	Mix	Halsey Modified	4,0939	0,0100	2,0029	0,03	29	
Shepherd (1956)	White Clover. Leaves.	Ads	Halsey Modified	3,867	-0,018	1,441	0,014	20	Oswin Modified
	White Clover Stems	Ads	Oswin Modified	18,637	-0,133	1,718	0,021		
	Ryegrass Leaves	Ads	Oswin Modified	16,4090	-0,2330	2,0490	0,002		
	Ryegrass Stems	Ads	Oswin Modified	17,0370	-0,2180	1,7680	0,005		
	Ryegrass Plant	Ads	Oswin Modified	16,2960	0,2240	1,7160	0,001	30	
	Ryegrass Plant	Des	Oswin Modified	18,6750	-0,2870	1,7310	0,026	30	

The Isotherms of the parts or of the plants were compared in the form of parallel lines, in which the slope is adjusted to be the same for all and the intercept of the line is allowed to vary. To do this, the data where transformed in order to fit the linear form of Oswin Modified and Halsey Modified as is shown in Equation (1) and Equation (2).

Linear Oswin Modified:

$$\ln(\chi_{eq}) = -\frac{1}{c}\cdot\ln(a+b\cdot\theta) - \frac{1}{c}\cdot\ln\left(\frac{1-U}{U}\right) \quad (1)$$

Linear Halsey Modified:

$$\ln(\chi_{eq}) = \frac{a+b\cdot\theta}{c} - \frac{\ln(-\ln(U))}{c} \quad (2)$$

2.2 Drying curves

The drying curves of each part or plant were developed in the lab in order to find one model of drying which allows making the comparison with the other parts or plants, and use the parameters of each model for the vaporization enthalpy analysis.

The samples were cut by hand from a field in Eichenberg- Hessen- Germany, with a mixture of Ryegrass and White Clover. In the lab the Ryegrass was separated from the White Clover; leaves and stems of the Clover were carefully detached. Three trays of each material were organized in a drier of axial flow, for every temperature of the air, after the determination of the initial Moisture Content of the samples.

The drying curves were obtained with air at 40, 60 and 75℃ and 25 m min^{-1}, in the laboratory of drying of the Kassel University in Witzenhausen, in October of 2010.

The curves of MR – t, were adjusted to some of the models suggested by Gunhan et al. (2005), shown in Table 2.

Table 2 Model Drying used. From Gunham et al, 2005

Model Name	Expression
Lewis	$MR = \exp(-k.t)$
Page	$MR = \exp(-k.t^n)$
Modified Page	$MR = \exp[(-k.t)^n]$
Henderson and Pabis	$MR = a.\exp(-k.t)$
Yagcioglu et al or logarithmic	$MR = a.\exp(-k.t) + c$

2.3 Evaporation enthalpy

The Evaporation Enthalpy h_v of each specie or tissue and the drying curves help to understand the differences in energy during the drying. To find the Evaporation Enthalpy the procedure of Othmer (1940) reported by Marques et al. (1991) and the Equation (3), proposed by Clausius Clapeyron, were used.

$$\frac{dP_d}{d\theta} = \frac{h_v}{(V_v - V_1)}\cdot\theta \quad (3)$$

Neglecting the value of V_1 in comparison with V_v, using the gas perfect relation for the water vapor and resolving the differential equation, the previous Equation (4) gives:

$$\ln P_v = \frac{h_v}{h_s}\cdot\ln P_s + f \quad (4)$$

This relation is a line in a log-log plane, with slope h_v/h_s.

The obtained results were fitted to the model suggested by Brooker (1984), reported by Marques et al. (1991) in Equation (5) and also to inverse, polynomial and quadratic models.

$$\frac{h_v}{h_s} - 1 = d\cdot e^{-j\cdot\chi} \quad (5)$$

This way, with the value of the ratio h_v/h_s, it was possible to get the curves for h_v as function of χ.

Finally with both the curve of Vaporization Enthalpy in Equation (9) as function of the Moisture Content and the curve of Moisture Content as function of the time, for each part of the mixture, the amount of heat that it is required for the evaporation of free water in the tissues during the drying was calculated (Equations (6), (7) and (8)).

For water:

$$L = m_w\, \hbar_v \quad (6)$$

by definition:

$$m_w = \chi_{bd} * m_s \quad (7)$$

χ varies with time in the drying process:

$$\chi_{db} = f(t) \quad (8)$$

Vaporizing Enthalpy, for each tissue is:

$$h_v = h_{vs} * g(\chi), \text{(Equation 5)} \quad (9)$$

Then q_{vap} will be calculated as Equation (10) using Equations (6), (7) and (8):

$$L(t) = f(t)*g(f(t))\, m_s\, \hbar_{vs} \quad (10)$$

The expresion for $f(t)$ and $g(\chi)$ depends on each tissue and each specie. The vaporization heat can be calculated by unit of mass.

3 Results and discussion

3.1 Isotherms comparison

As the Figure 1 shows, the stems of ryegrass have the higher isotherms of the group, while the lowest correspond to the plants of the Red Clover Green and Brown, whose isotherm lines are almost the same. In the same way the leaves and the stems of the White Clover show similar isotherm lines in the scale of this figure and the same happens with the whole plant of Ryegrass in dessorption and sthe stems of Ryegrass in adsorption.

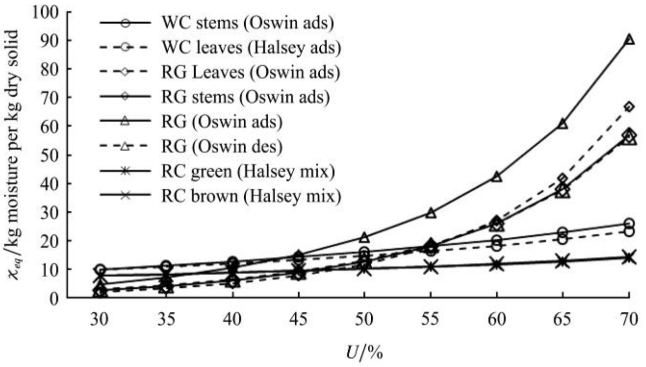
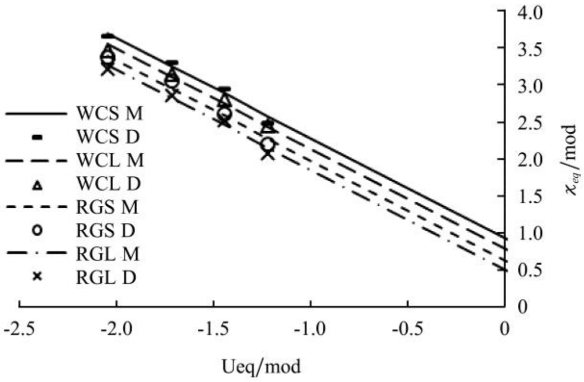


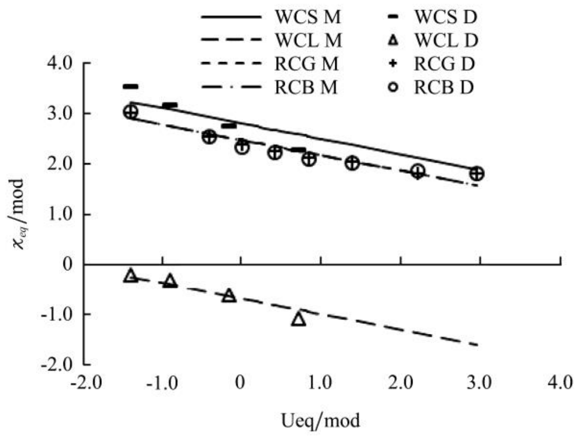
Figure 1 Isotherms of part and plant parts

The test with the isotherms transformed into straight lines shows how big this similiarityes are. Statistic F, with a certainty of 95.0% showed that in every case there was a good fitting between the lineal model and the data transformed into a linear form. Statistic T with a 97.5% certainty showed that the model parameters represent the data of the authors.

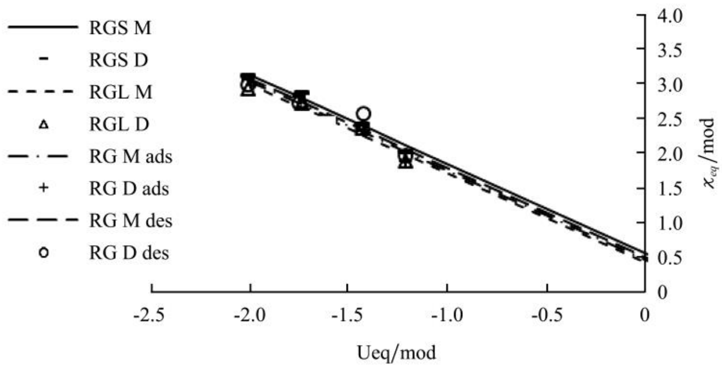
Figure 2a shows the lineal comparison of the isotherms for White Clover and Ryegrass with data of Shepherd (1958). Figure 2b, corresponds to the comparison of the White Clover tissues and the whole plant in accordance with the data of ASAE (2007). In Figure 2c, there is the comparison of the isotherms for the tissues of the Ryegrass.



a. White Clover and Ryegrass (θ=22°C) Shepherd (1958)



b. White Clover Leaves and Stems Shepherd (1958), and White Clover Green and Brown ASAE 2007. (θ=30°C)



c. Rye Grass Leaves and Stems and Ryegrass Whole plant. Shepherd 1957 (θ=30°C)

M: Model, D: Data

Figure 2 Transformed data and linear regression for Isotherms

With the obtained result, in accordance with Figures 2a, 2b and 2c, a pair comparison with a 95.0% of confidence, between the most similar lines was made, as shown in the Table 3.

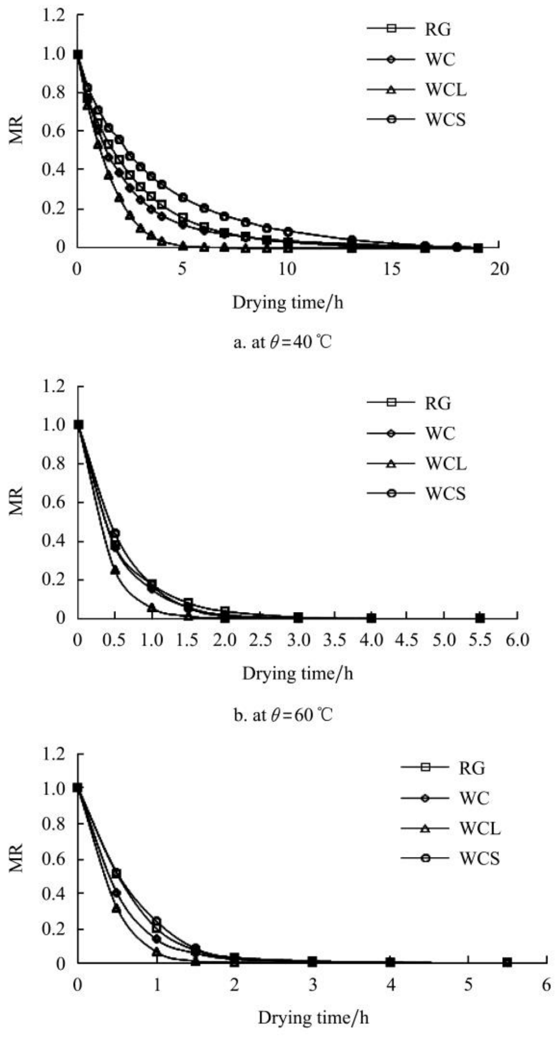
For this relation it could be concluded that there is almost complete similarity between all the tisues of the Ryegrass, but not between those of White Clover. This tendency is not an index of the performance of the drying curves, the vaporization entalpy or vaporization heat.

Table 3 Comparison of linearized isotherm data of several plants and tissues

Tissue 1	Tissue 2	Coincidence
White Clover Stems	Red Clover Extra green (ASAE)	No
White Clover Stems	Red Clover Brown (ASAE)	No
Ryegrass Whole Plant Adsorption	Ryegrass Whole plant Desorption	Yes
Ryegrass Whole Plant Adsorption	Ryegrass Stems	Yes
Ryegrass Whole Plant Adsorption	Ryegrass Leaves	No
Ryegrass Whole plant Desorption	Ryegrass Stems	No
Ryegrass Whole Plant Desorption	Ryegrass Leaves	Yes

3.2 Drying curves

Figure 3 shows the drying curves of Ryegrass, White Clover, White Clover Leaves and White Clover Stems at different temperatures. All the curves are in the form of MR-t.



a. at θ=40 ℃

b. at θ=60 ℃

c. at θ=75 ℃

Figure 3 Drying Curves of Ryegrass, White Clover, White Clover leaves and White Clover stems

With air at 40℃, the Leaves of White Clover dryed faster, and the Stems of White Clover slower, the curve of the White Clover Plant is in the middle of its individual tissues and is similar to Ryegrass. This behavoir seems to be independent of the initial χ as showed in Table 4.

Table 4 χ_0 / kg moisture per kg solid of the material

θ/℃	Ryegrass	WhiteClover	WhiteClover Leaves	WhiteClover Stems
40	3,86	4,25	3,64	3,79
60	2,29	2,88	3,76	8,11
75	3,68	3,72	3,96	4,62

With air at 60 and 75℃, the drying curves were closer, althought the Leaves of the White Clover were always the first dryed.

From Figure 3 it can be concluded that the behaviour of drying at 60 and 75℃ is similar for these tissues, in this way in a drying process, it is enough the use air at 60℃.

Althought the data were adjusted to all the models reported by Gunhat et al. (2005), it was found that the best fitting was with the simplest models as: Lewis, Page, Henderson and Pabis and Logaritmic, like those reported by Menzies et al. (1971) and Harris et al. (1982), for leaves and stems.

Figure 4 is an example of the performance of the models for drying of Ryegrass at 40℃. This figure shows that Lewis model fix better than the others, although all were good predictor.

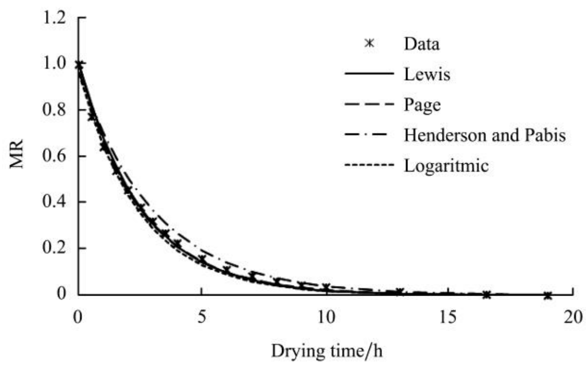


Figure 4 Fixing of models to drying of Ryegrass at 40℃

Table 5 summarizes the fitted models for the two plants and their tissues, and Tables 6 and 7 are the sumary of the fitting statistics for the Lewis moddel. In order to find the k value as function of θ for every tissue, a nonlinear regession was made between the k costant obtained for every repetition and the temperature of the air; using SPSS 19.0.0.1 licenced to Kassel University.

Table 5 Constants for drying models

		Ryegrass	White Clover	White Clover leaves	White Clover stems
Lewis	*k*	$-0.0005.\theta^2+0.0901.\theta-2.4133$	$-0022.\theta^2+0.2952.\theta-7.806$	$-0.0037.\theta^2+0.4742.\theta-12.389$	$-0.0021.\theta^2+0.2773.\theta-7.5253$
Page	*k*	$-0.0022.\theta^2+0.2841.\theta-7.4313$	$-0002.\theta^2+0.2668.\theta-7.008$	$-0.0034.\theta^2+0.4522.\theta-12.008$	$-0.0021.\theta^2+0.2781.\theta-7.498$
	n	$0.0008.\theta^2-0.0774.\theta+2.7774$	$0.0001.\theta^2-0.0065.\theta+0.9746$	$0.0005.\theta^2-0.0555.\theta+2.5443$	$-0.0004.\theta^2+0.048.\theta-0.4757$
Henderson and Pabis	*a*	$-1E\text{-}5.\theta^2+0.0027.\theta+0.8724$	$-3E\text{-}5.\theta^2+0.0039.\theta+0.862$	$4E\text{-}05.\theta^2-0.0048.\theta+1.1551$	$-7E\text{-}05.\theta^2+0.0093.\theta+0.6964$
	k	$-0.0026.\theta^2+0.3286.\theta-8.6631$	$-0.024.\theta^2+0.3153.\theta-8.3523$	$-0.0037.\theta^2+0.4711.\theta-12.29$	$-0.0021.\theta^2+0.2814.\theta-7.6543$
Logariτmic	*a*	$2E\text{-}05.\theta^2-0.0005.\theta+0.9459$	$-4E\text{-}5.\theta^2+0.0058.\theta+0.7949$	$5E\text{-}05.\theta^2-\ 0.0067.\theta+1.2093$	$-9E\text{-}05.\theta^2+0.0123.\theta+0.6026$
	k	$-0.0028.\theta^2+0.3552.\theta-9.3279$	$-0.022.\theta^2+0.2926.\theta-7.7174$	$-0.0038.\theta^2+0.4808.\theta-12.545$	$-0.002.\theta^2+0.2704.\theta-7.3349$
	c	$-4E\text{-}05.\theta^2+0.0036.\theta-0.0787$	$3E\text{-}05.\theta^2-0.0039.\theta+0.1314$	$-2E\text{-}5.\theta^2+0.0025.\theta-0.0734$	$3E\text{-}05.\theta^2-0.0044.\theta+0.1379$

Table 6 Fitting of the regressions for the Lewis model.

	75℃			60℃			40℃		
	Estimated /k	S.E.	R^2	Estimated /k	S.E.	R^2	Estimated /k	S.E.	R^2
Ryegrass	1.526	0.062	0.987	1.189	0.081	0.986	0.389	0.013	0.961
Clover	1.8990	0.043	0.997	1.947	0.096	0.985	0.464	0.011	0.979
Clover Leaves	2.4420	0.115	0.99	2.793	0.069	0.998	0.681	0.011	0.993
Clover Stems	1.719	0.055	0.993	1.719	0.055	0.993	0.281	0.004	0.992

Table 7 Fitting of the k coefficient for the Lewis model.

	R^2	Std. Error of the Estimate	RSM	F	Sig
Clover	0.843	0.375	2.255	16.065	0.004
Ryegrass	0.861	0.311	1.803	18.598	0.003
Clover Leaves	0.905	0.372	3.977	28.680	0.001
Clover Stems	.963	.151	17.789	78.429	.000

3.2 Vaporization Entalpy, *h*

Table 8 summarizes the constants of the relation h/hs – MC of the Equation 5, although cuadratic and inverse models were tested, and in most of the cases these last showed better fitt, just for Red Clover Brown the expression 5, given by Ottomer (1984), and reported by several researchs is the best fitting. In order to maintain the standard for the hv/hvs relationship, the expressión 5 was used.

Table 8 Constans for the Equation (5)

Tissue	Isotherm Model	*d*	*j*	R^2
White Clover Leaves	Modified Halseydesorption	0.031	0.106	0.939
White Clover Stems	Modified Oswindesorption	0.011	0.052	0.993
Ryegrass Leaves	Modified Oswindesorption	0.036	0.102	0.981
Ryegrass Stems	Modified Oswindesorption	0.024	0.076	0.981
Ryegrass Whole plant	Modified Oswin Adsorption	0.024	0.078	0.977
Ryegrass Whole plant	Modified Oswindesorption	0.031	0.080	0.977
Red CloverBrown	Modified Halsey Mix	-0.051	0.238	0.989

Having in account that the enthalpy for saturated water vapor is given by Equation (11):

$$h_s = 3.11\times10^6 - 2.38.10^3.\theta(\theta \text{ in } K) \tag{11}$$

It is possible calculate the vaporizing enthalpy for each χ. Figure 5 shows the vaporizing enthalpy of leaves and stems of White Clover and of Ryegrassas function of χ (kg moisture/kg solids). The curves are drawn in the rank of χ reported by the ASAE (2007) and Shepher (1956) and at 30℃ of Temperature in desorption.

In accordance with Figure 5, it exists a very little differences between the Water Vaporization Enthalpy of all the plant and plant parts.

All the differences tend to zero at high Moisture Content, but they are higher for the lows. This behavoir could mean that, in the starting of the drying process, the energy required for the different parts of a mixture of grass is very similar, but for the end of the process, after around χ of 18 kg water per kg dry mater, this differences grow a little.

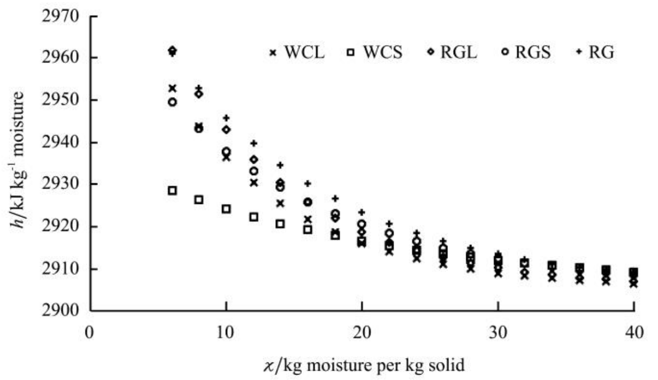


Figure 5 Vaporizing Enthalpy at 30℃ for the grass species

The maximum differences are near 35 kJ per kg-water, but if a ratio is made between the two tissues, the max difference is only close to the 1% of the maximum. This could mean that the differences in drying of each plant and parts, not depend on the enthalpy of the inside water, but on other factors.

3.3 Latent Heat for each specie and tissue

Latent heat (L) of Ryegrass and White Clover was calculated, using the Lewis model whose constant χ_0 is explained in Table 4, the expresion for entalpy of Eqaution (5), and the constants of Table 5. Then, the general expressions is Equation (12):

$$L=[e^{-k\cdot t}\cdot(\chi-\chi_{eq})+\chi_{eq}][d\cdot e^{-j\cdot[e^{-k\cdot t}\cdot(\chi_0-\chi_{eq})+\chi_{eq}]}+1]\cdot h_{vs}\cdot m_s \qquad (12)$$

In general in Figure 6, appears that stems of White Clover need more heat than the leaves, the entire plant of the clover and the Ryegrass. It is also remarkable that the leaves of White Clover need very less heat than the rest of the parts.

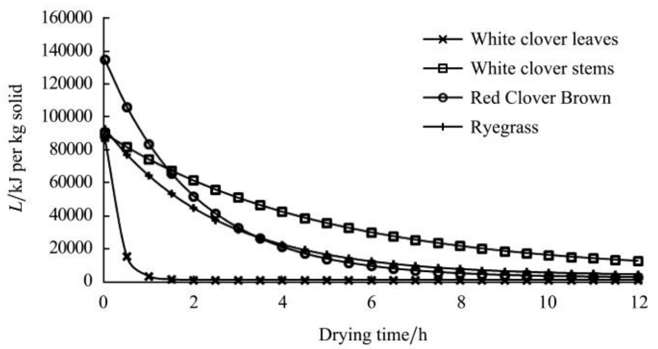


Figure 6 Evolution of Latent Heat in the drying process for each plant

At the begining of the drying, the Red Clover Brown, had the higher L, but it decreased quickly and after 2 and 4 h had the same L as the leaves of the white clover.

In order to calculate the total heat of the drying process, the next differencial equation must be writen Equation (13):

$$\mathrm{d}h/\mathrm{d}\chi = f'(\chi),\ \mathrm{d}\chi/\mathrm{d}t = g'(t)$$

Then

$$\mathrm{d}hv = f'(\chi)*g'(t)*\mathrm{d}t \qquad (13)$$

Integration of Equation (13) along the time invested to reach the desired χ, should give the teorethical heat required to evaporate the free water present in the tissues (Equation (14)).

$$\frac{dh}{d\chi}=-h_{vs}\cdot d\cdot j\cdot e^{-j\cdot\chi}$$

$$\frac{d\chi}{dt}=-k\cdot\chi_{eq}\cdot(\chi_0-\chi_{eq})e^{-k\cdot t}$$

$$dh=[-j\cdot d\cdot h_s\cdot e^{-j\cdot[(\chi_0-\chi_{eq})\cdot e^{-k\cdot t}+\chi eq]}]\cdot[-k\cdot\chi_{eq}\cdot(\chi_0-\chi_{eq})\cdot e^{-k\cdot t}]\cdot dt \qquad (14)$$

Integration of Equation (14), between t_0 and t_1, gives the heat required to evaporate the free water in the drying process. The solution of 14 is Equation (15):

(15)

Then, the Table 9 shows the time and the heat required to reach an χ of 0,2 and 0,1 kg water per kg dry matter.

Table 9 Heat required to reach χ = 0,20 and 0,10 kg moisture/kg solid

Plant	Time/h to χ=0.20	h_{vap} /kJ per kg solid	Time/h to χ=0.10	h_{vap} /kJ per kg solid
RedClover Brown	3.34	591	4.78	720
White CloverLeaves	2.44	177	3.49	203
Ryegrass	4.12	143	5.89	164
WhiteCloverStems	7.79	34	11.14	39

With the data and parameters for this model, in this case, the energy required for evaporate the water and reach a χ = 0, 20 was 591 kJ kg^{-1} moisture for the whole plant of Red Clover. It was less than a half for its leaves and for the Ryegrass. The stems of White Clover require very less heat than for the other plants or tissues.

It is remarkable that the heat required for the leaves of the White Clover and for the plant of ryegrass is almost the same for all the process, and that is required much more for the Whole plant of Clover, and less for the stems of the White Clover.

Although this is a theoretical amount of heat required to evaporate the free water in the plants, it could serve as a guide to design dryers for a mix of material.

4 Conclusions

A general characterization of the main parameters of the drying of a grass mixture has been made. Intent of comparison between these parameters for every tissue and plant in the mixture was made in order to understand how homogenous the performance during the drying is.

Isotherm curves seem to be similar for the tissues of Ryegrass, but not for those of White Clover, and it was found no similarities between Ryegrass and White Clover. This could predict a different performance and energy requirements in the drying.

The time to dry these plants and tissues is almost the same for temperatures between 60 and 75℃, but there were differences for 40℃, which influence the energy requirements for the water evaporation.

The tissues or plants in the mix have few differences between their Vaporization Enthalpy as function of Moisture Content. This can be interpreted to be that the energy required to remove water of this tissues is almost the same for every moisture content during the drying process.

When the latent heat is calculated as function of time in the drying process, using the drying curves, it was found that the entire plant of White Clover requires more heat than the Ryegrass.

The white clover leaves, having the lowest values of Isotherms, are faster in drying; nevertheless the L required to evaporate the water during the drying process is higher than other parts of the mixture.

On the other hand, the stems of White Clover, having the highest values of Isotherms, are the slowest in drying, and have the lowest vaporization enthalpy, then requires the lowest vaporization heat of the materials in the mixture.

The whole plants of Clover and the Ryegrass have a middle position in the mixture, related to isotherms, time in drying, and vaporization enthalpy. However, related to the vaporization heat the White clover requires the maximum heat and the ryegrass is in the middle of the mixture.

It can be conclude that among a mixture of species, the performance of every single part or plant is different, and the global overview of the Moisture Content or the Energy required for the drying masks the individual behaviour, which not only attempts against the quality of the dried product, but also the time and costs of the drying.

This way it is a desirable mechanism to handle the drying of each part, and to separate during the process the parts that have already reach the desired moisture content.

Symbols

a, *b*, *c*: Constants in the Isotherm Models.

k: Constant in the Drying Models

d, *j*: Constants in the Water Vapor Enthalpy – Moisture Content model

h: Water Vapor Enthalpy

h_s: Saturated Water Vapor Enthalpy

t: Time

v_1: Water liquid face volume

v_v: Water vapor face volume

D: Data

M: Model

WC: White Clover

RG: Ryegrass

WCL: White Clover Leaves

WCS: White Clover Stems

RGL: Ryegrass Leaves

RGS: Ryegrass Stems

RCL: Red Clover Leaves

RCS: Red Clover Stems

MR: Moisture Ratio

: Moisture Content

χ_{db}: Moisture Content in dry basis

χ_{eq}: Equilibrium Moisture Content

χ_0: Initial Moisture Content

m_w: Mass of water

m_s: Mass of solids

Ads: Adsorption path in the isotherms determination.

Des: Desorption path in the isotherms determination.

Mix: Adsorption or Desorption path in the isotherms determination.

U: Relative Moisture (dec.)

p_d: Water Vapor Pressure

P_s: Saturated Water Vapor Pressure.

$S.E.$: Standard Error.

θ: Temperature

L: Latent Heat of Vaporization

Δhv: Difference in entalpy

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