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RHEOLOGICAL MODELS USED TO CHARACTERIZE THE RUMINAL FLUID

MODELE REOLOGICE UTILIZATE PENTRU CARACTERIZAREA FLUIDULUI RUMINAL

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From the literature data resulted that the high ratio of cereals from the feeding diets in ruminants led to the marked increase of the ruminal fluid viscosity. The studies from the present research were done on young sheep of the Tsurcana breed divided into two groups each comprising a number of nine heads, as follows: control group (LM) fed with feed diet composed of alfalfa hay 60% and barley 40%; the experimental group (LE) fed with the same basic feed diet but with an addition of yeast (1.5 g Saccharomyces cerevisiae, Yea-Sacc[1026] strain /head/day). Ruminal fluid was sampled from the ventral sack of the slaughtered animals and analyzed with a high-tech rheometer. The obtained data were modeled after the power law, Herschel-Bulkley, Volcado, Casson, Cross, Carreau. Modeling was done with the Table Curve program. A very good correlation was noticed between the experimental data and the rheological models. This suggests that the experimental data can be interpreted by any of the given models, and the simplest model was selected (power law) because it is the most used model. As well, this model is at the basis of the rheological fluid classification.
Keywords: ruminal fluid, sheep, rheological models

Introduction

From the literature data resulted that the high ratio of cereals in the feeding diets in ruminants leads to the marked increase of the ruminal fluid viscosity (McAllister,1990;McAllister,1993).

Materials and Methods

Researches were done at the Ovine department within the DES Timisoara (Didactical and Experimental Station) on young sheep of the Tsurcana breed. Animals were divided into two groups comprising nine heads each, as follows: the control group (LM) fed with feed diet composed of alfalfa hay 60% and barley

40%; the experimental group (LE)fed with the same basic feed diet but with an addition of yeast (1.5 g Saccharomyces cerevisiae, Yea-Sacc[1026] strain /head/day).

Table 1

The experiment organizing scheme

Specification	Control group (LM)	**Experimental group (LE)**
m	9	**9**
Young sheep	**Diet without yeast**	**Diet with added yeast**

Chemical composition of the feeds used in the feeding diets was determined in the nutrition lab after standardized classical models, as shown in Table 2. Feeds source was the Didactical Farm.

Table 2

Chemical composition of the diet feeds (%)

Crt. no.	feed	DM	BP	CB	GB	**Raw celulosis**
1	Barley	87.74	9.85	10.79	1.8	**7.27**
2	**Alfalfa hay**	**92.01**	**17.35**	**8.65**	**2.9**	**27.36**

At the end of the experiment, after two hrs from feeding in the morning, animals were slaughtered and ruminal fluid was sampled from the ventral sack of the slaughtered animals and analyzed with a rheometer in order to perform the rheological studies.

Physica MCR 300 Rheometer is a complex rheometer which satisfies the measuring requirements of the rheological and magnetorheological properties of different types of complex fluids, with practical applications in all the technical domains, in Biology and Medicine, as well as in the Aeronautics and Spatial technique.

Physica MCR 300 Rheometer has a compact structure, comprising a great variety of systems and geometries for measurements, concentric cylinders, con-plate, plate-plate, and a special cell for magnetorheological measurements, easily adaptable to the fluid medium subjected to the rheological and magnetorheological investigations.

Data, obtained using this rheometer, were modeled after the following models: power law, Herschel-Bulkley, Volcado, Casson, Cross, and Carreau. Modeling was done with the Table Curve program.

Table Curve program allows the definition of a maximum of 50 linear functions defined by the user. A non-linear function defined by the user contains all the information needed to fit the function; fitted (constants) parameters; function formula; initial estimation of the parameters; constraints for each parameter.

It is possible to graphically adjust the initial estimations to ensure a good convergence of the fitting. The model allows the introduction and adjustment of maximum 10 parameters, presented either as A. B. C. .... or A0. A1. A2. The goal of the graphical adjustment is to set the parameters so that the non-linear fitting start begins with data closer to the obtained values.

To find the insignificant parameters the partial derivates of the defined functions can be used. If a partial derivate is constant, it has to have the value 1, which means it is a real constant (parameter) in the defined function. If a parameter has no significant contribution, this is a prime hint that this parameter does not belong to the defined model.

Results and Discussion

The dependence of the shearing tension and the apparent viscosity on the shearing rate, for the ruminal fluid obtained when feeding with diets having 40% barley, in the absence (LM) and in the presence (LE) of yeast, is graphically shown in Figure 1. The variation of the apparent viscosity suggests that the fluid is a pseudoplastic one. K and n values (where K ($mPa \cdot s^n$) represents the consistence coefficient and (n) the flowing behavior index), as well as the apparent viscosity for the shearing tension of $\dot{\gamma} = 0.1 s^{-1}$ were calculated using the algorithm previously presented at a scientific symposium (Creţescu, 2005). The values of the rheological characteristics shown in Table 3 confirm that the addition of feeding yeast increases the value of the consistency coefficient.

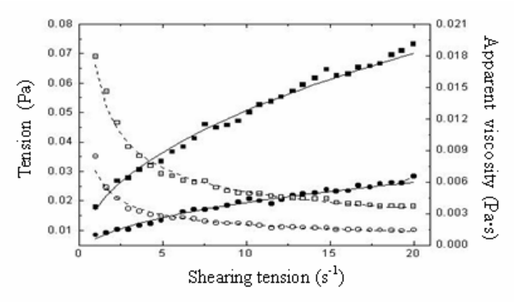

Figure 1. The influence of the shearing rate on the experimental values of the shearing tension and the apparent viscosity for the ruminal fluid obtained from feeding 40% barley + yeast (■ - shearing tension; □ - apparent viscosity), and for the ruminal fluid obtained from feeding 40% barley (●- shearing tension; ○ - apparent viscosity), at 39°C. Continuous line – calculated dependence $\tau = f(\dot{\gamma})$; dotted line – calculated dependence $\eta = f(\dot{\gamma})$.

Table 3

Values of the rheological characteristics of the ruminal fluid obtained from feeding with diets with 40% barley in the absence and presence of yeast (LM and LE)

Feeding type	Consistency coefficient - K($mPa \cdot s^n$)	Flowing behavior index (n)	$\eta_a(\dot{\gamma} = 0{,}1 s^{-1})$ **(Pa·s)**
40% (LM) barley	7.12 ± 0.20	0.436 ± 0.013	**0.026**
40% barley + yeast (LE)	**17.16 ± 0.50**	**0.470 ± 0.010**	**0.058**

Because the PHYSICA MCR 300 rheometer allows the accurate control of the temperature, for the ruminal fluid obtained from feeding with 40% barley in the presence of yeast (LE), rheograms were recorded for three different temperatures: 39, 40 and 41°C. No other temperatures were used so that the temperatures are ranked within the normal physiological temperatures for sheep.

Figure 2 shows the influence of temperature on the apparent viscosity of the ruminal fluid. The graphic suggests obvious differences between the apparent viscosities.

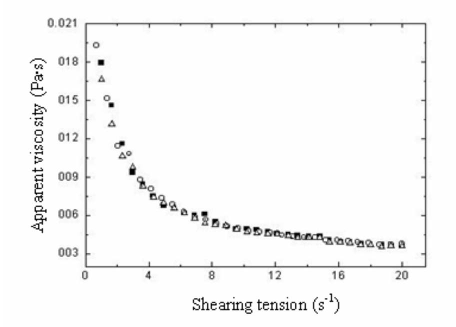

Figure 2. The influence of the temperature on the apparent viscosity at different shearing rates for the ruminal fluid obtained when feeding with 40% barley + yeast (LE) (■ - 39°C; O - 40°C; □ - 41°C)

Rheograms calculated with the K and n values superpose very well on the experimental data. The experimental dependence $\tau = f(\dot{\gamma})$ for the ruminal fluids obtained when feeding with 40% barley (LM) and 40% barley + yeast (LE), respectively, was mathematically modeled by six rheological models: power law, Herschel-Bulkley, Vocaldo, Casson, Cross and Carreau. Modeling was done using the Table Curve program. A very good correlation between the experimental data and the rheological models was noticed. This suggests that the experimental data can be interpreted with any of these models, thus selecting the simplest (power law) being the most widely used. As well, this model was at the basis of the rheological fluid classification.

Table 4

Rheological equations obtained through modeling the experimental dependence $\tau = f(\dot{\gamma})$ for the ruminal fluids obtained when feeding with 40% barley

Model	Feeding with 40% barley (LM)	Feeding with 40% barley + yeast (LE)
Power law	$\tau = 0.00712 \cdot \dot{\gamma}^{0.436}$	$\tau = 0.01716 \cdot \dot{\gamma}^{0.470}$
Herschel-Bulkley	$\tau = 0.0039 + 0.0038 \cdot \dot{\gamma}^{0.605}$	$\tau = 0.0085 + 0.0095 \cdot \dot{\gamma}^{0.637}$
Vocaldo	$\tau = \left(0.0063^{\frac{1}{0.587}} + 0.0001 \cdot \dot{\gamma}\right)^{0.587}$	$\tau = \left(0.0106^{\frac{1}{0.571}} + 0.0048 \cdot \dot{\gamma}\right)^{0.571}$
Casson	$\tau = \left(0.0686 + 0.0218 \cdot \dot{\gamma}^{0.5}\right)^2$	$\tau = \left(0.09905 + 0.0387 \cdot \dot{\gamma}^{0.5}\right)^2$
Cross	$\tau = \left(0.00043 + \frac{0.688}{1 + 97.17 \cdot \dot{\gamma}^{0.677}}\right) \cdot \dot{\gamma}$	$\tau = \left(0.0025 + \frac{0.0258}{1 + 0.775 \cdot \dot{\gamma}^{1.106}}\right) \cdot \dot{\gamma}$
Carreau	$\tau = \frac{0.00817 \cdot \dot{\gamma}}{\left[1 + \left(4.307 \cdot \dot{\gamma}\right)^2\right]^{\frac{0.395}{2}}}$	$\tau = \frac{0.034 \cdot \dot{\gamma}}{\left[1 + \left(4.85 \cdot \dot{\gamma}\right)^2\right]^{\frac{0.495}{2}}}$

In the case of the pseudoplastic fluids, the temperature influences the consistency coefficient; for the flowing behavior index there is not noticed a temperature influence (Whorlow, R.H., 1992). The consistency coefficient decreases exponentially with the temperature increase:

$$K = K_T \exp^{\left(\frac{E_a}{R \cdot T}\right)}$$

(1.)

Where: K_T= constant related to the temperature effect ($Pa \cdot s^n$)

E_a= energy for activation of the flowing process ($kJ \cdot mol^{-1}$)

R= universal gas constant ($8.31\ J \cdot mol^{-1} \cdot K^{-1}$)

T= absolute temperature of the ruminal fluid (K)

Logarithming relation (1.) is obtained:

$$\ln K = \ln K_T + \frac{E_a}{R} \cdot \frac{1}{T}$$

(2.)

Logarithming we obtain a linear dependence between lnK and 1/T. From the $\ln K = f\left(\frac{1}{T}\right)$ graphic the $\ln K_T$ values are obtained (intersection of the graphic with the value axis for lnK), and the line inclination is the ratio between $\frac{E_a}{R}$. Knowing the value of the ratio, the activation energy can be calculated:

$$E_a = R \cdot \text{inclination} \quad (3.)$$

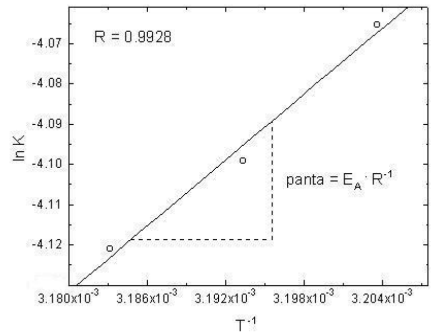

Figure 3. Graphic determination of the energy of activation of the flow process for the ruminal fluid obtained from feeding with 40% barley + yeast

Interpreting the data obtained for the three temperatures for experimental dependence $\tau = f\left(\dot{\gamma}\right)$ allowed the estimation of the K and n values, for the ruminal fluid obtained after feeding with 40% barley and feeding yeast (LE) (Table 5.)

Table no. 5

The values of the rheological characteristics of the ruminal fluid (LE) at the three temperatures

Temperature(°C)	K(mPa·s^n)	n
39	17.16 ± 0.050	0.470 ± 0.010
40	16.59 ± 0.40	0.483 ± 0.008
41	16.23 ± 0.30	0.0483 ± 0.007

From the graphic representation of $\ln K = f\left(\frac{1}{T}\right)$ the following values were obtained through linear regression:

$K_T = (2.72 \pm 0.15) \cdot 10^{-6}\, Pa \cdot s^n$
$E_a = 22.70 \pm 2.74\, kJ \cdot mol^{-1}$

From Table 5 can be noticed that the temperature does not influence the value of the consistency index. For the subsequent calculations, the mean value of this index is considered $\overline{n} = 0.479 \pm 0.004$. Under such conditions, the rheological equation for the ruminal fluid obtained when feeding with 40% barley in the presence of yeast, is:

$$\tau = f\left(\dot{\gamma}, \tau\right) = 2.72 \cdot 10^{-6} \exp\left(\frac{2731.1}{T}\right) \cdot \dot{\gamma}^{0.479}$$

(4.)

And the influence of the temperature on the apparent viscosity is given by the expression:

$$\eta_a = f\left(\dot{\gamma}, \tau\right) = 2.72 \cdot 10^{-6} \exp\left(\frac{2731.1}{T}\right) \cdot \dot{\gamma}^{-0.521}$$

(5.)

In the expressions (4.) and (5.) is taken under consideration the fact that $\frac{E_a}{R} = \frac{22{,}700 J \cdot mol^{-1}}{8.31 J \cdot mol^{-1} \cdot K^{-1}} = 2{,}731.1 K$

The values for the activation energy are similar to the values obtained by Rao (1986) for the apple and orange juices (Rao, 1986).

Conclusions

The dependence of the shearing tension on the shearing rate for the ruminal fluid obtained when feeding with diets having 40% barley, both in the absence of yeast (LM) and in the presence of yeast (LE) is non-linear. The variation of the apparent viscosity suggests that the fluid is a pseudoplastic fluid.

The experimental dependence $\tau = f(\dot{\gamma})$ for the ruminal fluids obtained when feeding with 40% barley (LM) and 40% barley + yeast (LE), was modeled mathematically by six rheological models: power law, Herschel-Bulkley, Vocaldo, Casson, Cross and Carreau, obtaining a very good correlation between the experimental data and the rheological models. This suggests that our data can be interpreted by any of these models.

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