Mariz, I., **Pais**, L., Barreiro, F., and Silva, J.

Equilibrium Moisture Content and Heat of Desorption of Garlic

in *ChemPor'2005 9th International Chemical Engineering Conference*, Coimbra, Portugal, 21st -23rd September, 2005.

(poster)

CHEMPOR 2005

Coimbra – 21st – 23rd September 2005

PROGRAMME

Wednesday 21 st September

18:00-19:30 Welcoming participants

Thursday 22nd September

Anfiteatro 1

08:30-09:00 Welcoming participants

09:00-09:30 Opening Session

Session 1 Chairpersons: *F. Ramôa Ribeiro* and *Lélio Quaresma Lobo*

09:30-10:15 Invited Lecture: Dr.Trevor Evans (Chief Executive& Secretary IchemE);
"The role of National Societies and the European Federation of Chemical Engineering in promoting a better appreciation of chemical engineering as an essential contributor to the quality of life and to achieving a suitable future."

10:15-11:00 Invited Lecture: Prof. Jens Nielsen (Technical University of Denmark)
"The role of chemical engineering in modern biotechnology."

11:00-11:15 Coffee Break

Anfiteatro 1

Session 2 Chairpersons: *Moura Bordado* and *Salvador Pinheiro*

11:20-12:05 Invited Lecture Engº C. Pedro Nunes (CUF)
Uma Perspectiva Estratégica da Indústria da Refinação de Petróleos e Petroquímica em Portugal.
Chairpersons: *Moura Bordado* and *Salvador Pinheiro*

12:05-12:25 IP006- **Methylacetylene and Propadiene Reactors Optimization in the Sines Repsol Steam Cracker Plant**
André A.Vilelas, José P. Braga
Interface Team, Olefins Plant, Repsol Steam Cracker,Sines, Portugal.

12:25-12:45 IP034- **Study and optimization of a hydrogen distribution network: refinery case study**
André Fonseca, Vítor Sá, Hugo Bento, Manuel L.C. Tavares, Luísa A.C.N. Gomes
Chemical Engineering Department, Instituto Superior de Engenharia, IPP, Porto;
Technology Area, Galp Energia, 4451-852 Leça da Palmeira, Portugal.

12:45-13:05 IP010- **Separation of branched hexane isomers on zeolite BETA**
Patrick S. Bárcia, José A. C. Silva, Alírio E. Rodrigues
Escola Superior de Tecnologia e Gestão, Instituto Politécnico de Bragança;
Laboratory of Separation and Reaction Engineering, Departamento de Engenharia Química, FEUPorto.

13:05-13:25 IP068- **Recuperação do ciclohexanol e da ciclohexanona do processo de produção de anilina**
Fernando P. Mendes, Marco A. F. Prior, Rui M. F. Andrade, Susana C. G. Caldas, Mário Jorge O. Pinho, Laura M. T. Santos, Luís M. Castro, Nazaré C. Pinheiro, Manuel A. Ramos, Belmiro P. M. Duarte
Quimigal S.A., Química de Portugal, Portugal;
Departamento de Engenharia Química, Instituto Superior de Engenharia de Coimbra.

13:25-13:45 MSC031-**Multivariate analysis of the benzene nitration process for pollution prevention**
Paulo A. Quadros, Marco S. Reis, Cristina M. S. G. Baptista
Gepsi-PSE Group, Chemical Engineering Department, University of Coimbra.

Anfiteatro 2

Session 3 Chairpersons: *Alírio Rodrigues* and *Rosa Quinta Ferreira*

12:05-12:25 ESF005-**Efeito protector da matriz em catalisadores de "cracking" catalítico em relação ao envenenamento por bases azotadas**
G. Caeiro, Patrick Magnoux, J.M. Lopes e F. Ramôa Ribeiro
CEBQ, Instituto Superior Técnico, Lisboa ; Lab. de Catalyse en Chimie Organique, Poitiers, France

12:25-12:45 ESF021- **Degradação fotocatalítica de corantes têxteis**
Edilberto T. Soares, Maria A. Lansarin, Celso C. Moro, Cristina L. Souza e Natália Klafke

16:25-16:45 ESF051- **Effect of hydrodynamic conditions in osmotic evaporation using membrane contactors**
V. D. Alves, I. M. Coelhoso
REQUIMTE / CQFB, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa.

Anfiteatro 3

Session 16 Chairpersons: *Ana Paula Póvoa and Adélio Mendes*

16:05-16:25 QL082-**Protein recovery from tannery wastewater containing chromium by nitrogen removal**
Francisco N.S. Basilio, Helder F.C. Marques, Marta I.G. Sousa, Raquel A.P. Silva, Nídia S. Caetano
Chemical Engineering Department, Instituto Superior de Engenharia do Porto;
LEPAE, Chemical Engineering Department, Instituto Superior de Engenharia do Porto.

16:25-16:45 QL111-**Preparation of Therapeutic Contact Lenses Using Supercritical and Compressed Fluids**
Hermínio C. de Sousa, Ana Rita C. Duarte, Joana P. Guerra, Viviana P. Costa, Eugénio O.B. Leite, Catarina M.M. Duarte, Maria H. Gil
Departamento de Engenharia Química, Faculdade de Ciências e Tecnologia, Universidade de Coimbra;
Instituto de Biologia Experimental e Tecnológica, Oeiras;
Faculdade de Ciências da Saúde, Universidade da Beira Interior, Covilhã.

Anfiteatro 4

Session 17 Chairpersons: *António Portugal*

16:05-16:25 QL115-**Life Cycle Assessment of bioethanol from sugar beet and wheat – comparison with gasoline**
João Malça, Fausto Freire
Mechanical Engineering Department, ISEC, Coimbra Polytechnic Institute;
Mechanical Engineering Department, Faculty of Sciences and Technology, University of Coimbra.

16:25-16:45 QL090-**The emergence of a new field of application of chemical and systems engineering principles: pharmaceutical engineering**
José Cardoso de Menezes
Centre for Chemical & Biological Engineering, IST, Technical University of Lisbon.

16:45-17:00 Coffee Break

Anfiteatro 1

Session 18 Chairpersons: *Sebastião Feyo de Azevedo* and *Pedro Saraiva*

17:00-17:40 Chemical Engineering Education – Prof. Robert Armstrong, MIT, USA
"Frontiers in Chemical Engineering Education."

17:40-18:40 Forum Chemical Engineering Education

18:40-19:00 Closing Session

POSTER SESSIONS

Thursday 22nd September

17:20-19:00 Chemical Engineering Department

ESF-Engineering Sciences and Fundamentals

ESF001 - **Mass transfer to clean bubbles at low turbulent energy dissipation**
Sebastião S. Alves, Jorge M. T. Vasconcelos, Sandra P. Orvalho,
Centro de Eng. Biológica e Química, Dept. of Chemical Engineering, Instituto Superior Técnico, Lisboa, Portugal.

ESF003 - **Plug Formation and Flow Regimes in Dense-Phase Pneumatic Conveying**
Fernando A. V. Silvano, Severino S. Pandiella
Departamento de Engenharia Mecânica, Escola Superior de Tecnologia e Gestão, Instituto Politécnico de Leiria, Leiria, Portugal.
School of Chemical Engineering and Analytical Science, The University of Manchester, Manchester, U. K.

ESF004 -**Dynamic model of a supercritical carbon dioxide heat exchanger**
João B. Fernandes, Pedro C. Simões, José Paulo Mota
REQUIMTE, Chemistry Department, University Nova of Lisbon, Quinta da Torre, Caparica, Portugal.

ESF006 -**Safety study for scaleup of dehydroabietic acid**
Carlos Lopes, Carla Raminhos, João A.A. Lourenço
Instituto Nacional de Engenharia e Tecnologia Industrial, Lisboa, Portugal.

José P.B. Mota
Requimte/CQFB, Departamento de Química, Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal.

ESF068 -**Phase Equilibria Of Sulphur**

A. G. M. Ferreira1, L. Q. Lobo
Chemical Engineering Department, University of Coimbra, Coimbra, Portugal.

ESF069 -**Solubility of a Spironaphthoxazine Photochromic Dye in Supercritical Carbon Dioxide: Experimental Determination and Correlation**

Patrícia M. Coimbra, B. Mark Heron, Maria H. Gil, Catarina M.M. Duarte, Hermínio C. de Sousa
Departamento de Engenharia Química, Faculdade de Ciências e Tecnologia, Universidade de Coimbra, Coimbra, Portugal;
Instituto de Biologia Experimental e Tecnológica, Oeiras, Portugal;
Department of Colour and Polymer Chemistry, University of Leeds, Leeds, UK.

ESF070 -**Applicability of Taylor-Aris Analysis to Non-Newtonian Fluids**

Cláudio A. Filho, Carlos M. Silva, Eugénia A. Macedo, Marintho B. Quadri
Departamento de Engenharia Química e Engenharia de Alimentos - Universidade Federal de Santa Catarina – Brasil;
CICECO, Departamento de Química, Universidade de Aveiro, Campus de Santiago, Aveiro, Portugal;
LSRE - Departamento de Engenharia Química Faculdade de Engenharia da Universidade do Porto, Porto, Portugal.

ESF071 -**Kinetic Modelling of the Catalytic Cracking N-Heptane over a ZSM-5 zeolite**

R. Ramos Pinto, P. Borges, M.A.N.D.A. Lemos, F. Lemos, J.C. Védrine, E.G. Derouane, F. Ramôa Ribeiro
Centro de Engenharia Biológica e Química, Departamento de Engenharia Química, Instituto Superior Técnico, Lisboa, Portugal.
ISCSP, Polo Universitário do Alto da Ajuda, Lisboa, Portugal;
Laboratoire de Physico-Chimie des Surfaces, ENSCP, Paris, France.
Faculdade de Ciências e Tecnologia, Centro de Investigação em Química e Catálise, Universidade do Algarve, Faro, Portugal.

ESF072 -**Baker's yeast filtration through mixed beds of filtration aids and large glass beads**

Manuel Mota, José A. Teixeira, Alexander Yelshin
Centro de Eng. Biológica, University of Minho, Braga, Portugal.

ESF073 -**Equilibrium Moisture Content and Heat of Desorption of Garlic**

Inês F.A. Mariz, Luís S. Pais, Filomena F. Barreiro, José A.C. Silva
LSRE Laboratory of Separation and Reaction Engineering, Instituto Politécnico de Bragança, Bragança, Portugal.

ESF074 -**Modificação pós-síntese de zeólito BEA por desaluminação ácida: caracterização catalítica das amostras**

João P. Marques, Isabelle Gener, João C. Bordado, José M. Lopes, Fernando Ramôa Ribeiro, Michel Guisnet
Centro de Engenharia Biológica e Química, Instituto Superior Técnico, Lisboa, Portugal;
Laboratoire de Catalyse en Chimie Organique, Poitiers, France.

IP- Industrial Processes

IP003 -**Soda Pulp From Abaca. Influence Of The Operational Variables**

José Luis Ferrer, Victoria Angulo, Antonio Pérez, Enrique Ramos, Alejando Rodríguez, Luis Jiménez
Departamento de Ingeniería Química, Universidad de Córdoba, Córdoba, Spain;
Servicio de Investigación del Instituto de la Vid y el Vino de Castilla-La Mancha, Tomelloso, Ciudad Real, Spain;
Departamento de Ciencias Ambientales, Universidad Pablo de Olavide, Carretera de Utrera, Sevilla, Spain.

IP009 -**Influence of Mobile Phase Composition on the Preparative Separation of Profens by Chiral Liquid Chromatography**

António E. Ribeiro, Luís S. Pais, Alírio E. Rodrigues
Laboratory of Separation and Reaction Engineering,
School of Technology and Management, Bragança Polytechnic Institute, Bragança, Portugal
Faculty of Engineering, University of Porto, Portugal

IP011 -**Multivariate and Multiscale Analysis of Paper Surface**

Marco S. Reis , Pedro M. Saraiva, Dina Angélico and José Ataíde
GEPSI – PSE Group, Department of Chemical Engineering, University of Coimbra, Coimbra, Portugal;
Portucel SA, Setúbal, Portugal.

IP013 -**Use of peracetic acid and hydrogen peroxide mixture to bleach soda abaca pulp**

I. Pérez, E. Ramos, M.J. de la Torre, L. Martínez, S.F. Calatrava, L. Jiménez, J.C., Gutiérrez, A. Rodríguez
Chemical Engineering Group, Environmental Science Department, University Pablo Olavide, Sevilla, Spain;
Chemical Engineering Department, University of Córdoba, Córdoba, Spain.

IP014 -**High Solids Alkyd Resins**

M. Boaventura, I. Fernandes, J. L. Nogueira, A.Mendes
CIN, Corporação Industrial do Norte, S.A., Maia, Portugal;
Resiquímica - Resinas Químicas, S.A., Mem Martins, Portugal;
LEPAE – Departamento de Engenharia Química, Faculdade de Engenharia, Universidade do Porto, Porto, Portugal.

IP015 -**Determinação da Permeabilidade de Revestimentos por Pintura ao Dióxido de Carbono e aos Iões Cloreto**

C. Carneiro, F.Oliveira, J. Nogueira, A.Mendes
CIN, Corporação Industrial do Norte, S.A., Maia, Portugal;

FCT Fundação para a Ciência e a Tecnologia
MINISTÉRIO DA CIÊNCIA, TECNOLOGIA E ENSINO SUPERIOR
POCTI/AGG/45674/2002

Equilibrium Moisture Content and Heat of Desorption of Garlic

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5301-857 Bragança, Portugal.

Introduction

Garlic (*Allium sativum* L.) has been cultivated for centuries all over the world on account of its culinary and medicinal properties. Clinical trials have shown that garlic has important health benefits. The most encouraging results have occurred in the area of cholesterol reduction (Reuter et al., 1996). The compound responsible for these benefits is allicin, which gives garlic's characteristic flavour and odour. More recently, it has found uses as a raw material in the pharmaceutical industry and, in its dried form, as an ingredient of precooked and instant convenience foods, which has led to a sharp increase in the demand for dried garlic.

Objectives:

- Determine the effect of temperature on the moisture desorption isotherms of garlic in the temperature range 5-45°C;
- Analyze two sorption isotherm equations available in the literature;
- Find the suitable model corresponding to the isotherms of garlic;
- Evaluate and compare monolayer moisture content (X_m);
- Determine the net isosteric heat of desorption of garlic.

Experimental Section

Substrate

Fresh heads of garlic were purchased from Badajoz (Spain) and were stored in a cold chamber maintained at a temperature of 4°C and 70% relative humidity. The initial moisture content of the garlic was determined at 103°C in the Sartorius moisture balance (Figure 1, A) and varied from 1.55-1.85 kg of water/kg dry mass.

Table 1. Average percentage of composition of garlic.

Component	%
Water	63
Minerals	17
Vitamin	14
Proteins	3
Carbohydrates	2
Calories	1

Procedure for Desorption Isotherms Determination

Novasina AW SPRINT (Figure 1, C) with saturated salts solutions was used for the determination of desorption isotherms for 1 mm thick garlic slices at temperatures between 5 and 45°C, in the relative humidity range from 11 to 86%. To inhibit microbial growth a small quantity of thymol was also placed in the recipient for water activity higher than 0.7. The garlic samples were weighed at smaller periods (initial phase) and then at every 24 hours (latter phase) in the Denver Instrument balance (Figure 1, B), until their mass varied ≤ 0.03% between weightings. At the end of the experiment the garlic slice and the saturated salt solution are in equilibrium, and the final mass was used to determine the moisture content at the corresponding water activity. This moisture content was subsequently adjusted by dividing it by the dry mass, which was determined using the Sartorius MA45 moisture balance (Figure 1, A) (at 103°C) after the final equilibrium had been reached.

Real view of the experimental system

Figure 1. Schematic diagram of apparatus used in the determination of desorption isotherms: (A) Sartorius MA45 (moisture balance); (B) Denver Instrument (analytical balance); (C) Novasina AW SPRINT (water activity measuring) and (D) Computer for data recorded.

Modelling of Desorption Isotherms

BET model (Brunauer, Emmett and Teller)

$$X_e = \frac{X_m C a_w}{(1-a_w)(1-a_w+Ca_w)}$$

GAB model (Guggenheim, Anderson and De Boer)

$$X_e = \frac{X_m C k a_w}{(1-ka_w)(1-ka_w+Cka_w)}$$

where X is the moisture content (kg of water/kg dry mass), a_w is the water activity, X_m is the monolayer moisture (kg of water/kg dry mass) content and C and k are the fitting constants of the BET and GAB model.

For computation of monolayer values from moisture desorption data, the BET (k=1) and GAB (k≠1) equations were transformed into the following linear relation:

$$\frac{ka_w}{(1-ka_w)X_e} = a + bka_w \quad \text{with} \quad a = \frac{1}{X_m C} \quad \text{and} \quad b = \frac{C-1}{X_m C}$$

The goodness of fit was applied to experimental data was evaluated through a mean relative percentage deviation (P) between the predicted (X_e) and experimental (X) moisture contents defined as:

$$P(\%) = \frac{100}{n}\sum_{i=1}^{n}\frac{|m_i - m_{e,i}|}{m_i}$$

where values below 10% are indicative of a good fit (Lomauro et al., 1985)

Conclusions

The equilibrium moisture content of garlic has been determined by the static gravimetric method at five temperatures. Among the two sorption models chosen to fit the desorption curves, the GAB model gave the best results for the desorption isotherms of garlic.
The net isosteric heat of desorption of garlic decreases with an increasing in moisture content and can be representably by a potency function. The values obtained were not very high and only must be considered at low moisture content (below 0.3 kg of water/kg dry mass).

Future Works

- Development of a drying apparatus, find the optimal operating conditions for the drying of garlic such as: drying time, temperature, relative humidity and flow rate of air;
- Study of drying kinetics, development of a mathematical model to interpret the drying kinetic results and determinate the effective diffusion coefficient;
- Study the effect of drying conditions in the allicin's level of garlic.

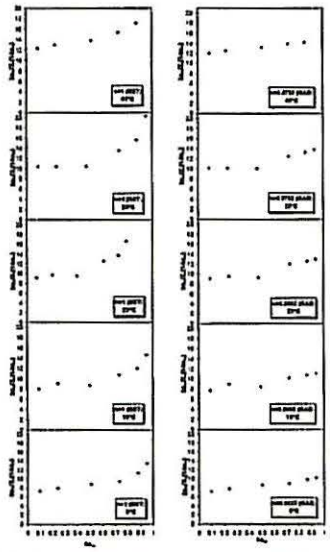
Results and Discussion

Moisture desorption isotherms of garlic at 5, 15, 25, 35 and 45°C

According to Brunauer's (Brunauer, 1945) classification, all of the isotherms determined in this work were of type III. A type III isotherm appears when the binding energy of the first layer is lower than the binding energy between water molecules.

The equilibrium moisture content increased at the same a_w as temperature decreased.

Plots of $ka_w/X_e(1-ka_w)$ *vs* ka_w for desorption of garlic at 5, 15, 25, 35 and 45°C: k=1 (BET isotherm); k≠1 (GAB isotherm)



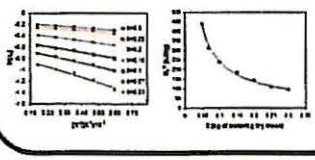
Fitting parameters of BET and GAB models to the desorption isotherms of garlic at 5, 15, 25, 35 and 45°C

	T (°C)	X_m	C	k	P (%)
BET	5	0.0806	1.9815	1	6.77
	15	0.0753	1.8903	1	8.76
	25	0.0669	1.9368	1	8.13
	35	0.0562	2.2376	1	11.61
	45	0.0579	1.4909	1	2.52
GAB	5	0.0988	1.4613	0.9833	1.37
	15	0.0888	1.5034	0.9865	3.51
	25	0.0763	1.5994	0.9892	4.08
	35	0.0723	1.5261	0.9792	3.96
	45	0.0682	1.2385	0.9758	0.65

Net Isosteric Heat of Desorption of Garlic

The net isosteric heat of desorption of garlic (Q_s^n) was calculated from the Clausius-Clapeyron equation:

$$\left[\frac{d\ln a_w}{d(1/T)}\right]_{X_e=\text{const.}} = -\frac{Q_s^n}{RT^2}$$



The Q_s^n values range from 4.40×10^3 kJ/kg at 0.05 kg of water/kg dry mass to 99.2 kJ/kg at 0.3 kg of water/kg dry mass.

The net isosteric heat of desorption of water in garlic can be expressed mathematically as a potency function of moisture content:

$$Q_s^n = 37.567 X^{-0.1134}$$

Acknowledgements

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