PEREZ-GUERRERO TRUST FUND
FOR ECONOMIC AND TECHNICAL COOPERATION
AMONG DEVELOPING COUNTRIES MEMBERS OF THE GROUP OF 77

FINAL REPORT ABSTRACT

Project title:

Water and energy optimization in sugar and alcohol integrated production (WESAP)

Partners:

Organization	Country	Organization activity	Role in the project
Consortium partners			
Cuban Research Institute for Sugar Cane By-products (ICIDCA)	Cuba	Research and teaching (Sugar and sugar cane by-products)	Coordinator and Developer (energy balance analysis, modeling, software development)
National University of Tucuman (UNT)	Argentina	Teaching and research (Chemical Engineering)	Developer (Data reconciliation, automatic control, modeling)
Center for Advanced Technology (CIATEQ)	Mexico	Research and technical assistance (Sugar and sugar cane by-products)	Developer (energy balance analysis, industrial validation)

Duration of project : 1.5 years

Starting date : January 2003

Ending date : June 2004

It was conceived for two years, beginning in February 2002; but, because of approval delays, it really began in January 2003 with the First Project Meeting in Queretaro, Mexico. So it was adjusted for one and a half year duration; but maintaining all the objectives proposed for the two years. WESAP had its Final Project Meeting in June 16, 2004 in Havana, Cuba.

Project objectives.

The research work aimed at improving our understanding (referring to all institution involved) of the methods for overall management, control and operation of energy efficient, environmentally respectful and economically sound process plants in sugar from cane and alcohol industry. As an immediate objective, it was expected to establish new criteria and develop the methodology and software tools aiming at improving the energy management in sugar and alcohol integrated production, as an integral part of sustainability, energy conservation, environmentally respectful and economically sound process operations.

This objective will contribute to carry on process analysis in sugar and alcohol production complexes that will permit:

- Identify the critical process steps in energy consumption that allow significant improvement in the overall process efficiency.
- Optimize the material and energy balances, studying main stages of the process.
- Increase productivity and minimize the cost associated to develop and test improved operating conditions and policies for better product quality.
- Increase the reliability and availability of plant data with open access to be used in conjunction with accurate energy modeling.
- Automation of information systems across the enterprise for informed production decisions.
- Enhance intelligent support to the process engineer by application of information technologies in the plant operation decision-to select those options which best match the optimum cost-waste/energy trade-off.

So, this Project (known as WESAP) will provide methodologies and software tools for process analysis allowing, in both sugar and alcohol production, to:

- reduce fresh water consumption by identifying optimal water reusing policies
- reduce waste water, not also by reusing policies but selecting best treatment alternatives
- reach optimal energy balances in the factories, studying main stages of the process
- diagnose process faults and propose corrective actions
- select more profitable integrated production (sugar, alcohol, bagasse, power) policies

The expected results of the proposed research work will be applicable in a wide range of scenarios whose decisions imply a complex trade-off when energy savings, technical and economical benefits and environmental protection are taken into account among other costs.

Steering Committee of the Project.

Institution	Contact person	Contact information
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Three industrial plants, in Argentina, Mexico and Cuba, agreed to provide information (data) and run validation tests of resulting methodologies:

Industry	Contact person	Contact information
"Concepcion" Sugar Factory and Distillery (CACSA)	Luis Valera	Address: Ave. José María Paz 1. Banda del Río Salí 4109 Tucumán. Argentina Telephone: 54-381-4260028 Fax: 54-381-4260346 e-mail: lvarela@ingcon.com.ar
"Paraiso" Distillery	Fernando Romero	Address: Empresa Azucarera Melanio Hernandez Tuinicu. Sancti Spiritus. Cuba Telephone: 53-041-47285 Fax: 53-041- e-mail: destileria@paraiso.minaz.ss.cu
"El Potrero" Sugar Mill	Pedro Valiente Cadena	Address: Ingenio El Potrero. Congregación Miguel Alemán, 94965 Atoyac, Ver. Mexico Telephone: +273-7350420 Fax: +273-7350866 e-mail: pcadena2000@hotmail.com

Project Outputs. Expected and actual results.

The tangible and actual "products" of WESAP Project are:

1. A software tool for both mass and energy balances in sugar and alcohol integrated production.

   A module for studying process integration in sugar factories was included in the software package SIMFAD, being called CALIFA. It has been designed and implemented for analyzing raw and refined sugar production flowsheets. Based on the user description of the flowsheet (nodes, flows in each one, brix and purities, technological constraints and objective function to optimize, if any) the system will generate automatically the mathematical model which is formed by solids, purities and total balances in each node. The model generated is solved using a sequential quadratic programming (SQP) method giving as results the description of the flows involved in the flowsheet (solids tons, brix and purity). The steam and power generation areas of the sugar factory can be included in the analysis considering the consumption rates in each node.

   Case studies in Cuba, Mexico and Argentina, in sugar factories El Potrero, Camilo Cienfuegos and Concepción (CACSA) have been done for validation purposes. In a case study did for the comparison of two flow sheets for refined sugar production in a sugar factory and with the purpose of reaching a maximum of refined sugar with a minimum steam consumption, the results of the simulation for both flow sheets demonstrated the best values for double seed raw sugar production with no affination in refinery. In order to precise the results it is necessary to extend the material balances to equipment level. It will give us a better way of analysis and a case study with this purpose is being prepared.

   Also another software tool based on Excel worksheets called SIDEL was developed. These tools permit to calculate mass and energy balances in any given configuration (flowchart) of the sugar and

alcohol factories. Case studies in Paraiso Distillery were done. Another case study is being done with data from CACSA Distillery.

2. Methodologies for selecting best water reuse and treatment alternatives in sugar and alcohol integrated production.

   A mathematical model that allows determining and calculating the values of the water flows that should be reused to reduce fresh water demand and waste waters was developed. This model is supported on GAMS optimization tool. It takes into account the contaminant characteristics of each flow and treatment alternatives could be recommended. The mathematical programming model that was implemented allows identifying strategies to minimize the fresh water consumption and wastewater discharge. The combined effect of lowering fresh water consumption and wastewater discharge reducing simultaneously contaminant leads to get a maximum reuse/recycled water.

   Case studies in a sugar factory have been carried out and its results published and reported in several technical meetings and congresses. In a sugar industry, the flow diagrams were elaborated, the COD and temperature were measured in each streams and a total of fourteen process units and four water sources were selected. The results of the case study show a significant reduction from the consumption index of fresh water to 0.55 and the wastewater discharge decrease in 67%. This is translated in a decreasing of the fresh water costs and the taxes that are paid to discharge the wastewater to the river. The cooling pond contribute to decrease the condensers rejection water temperature and allow re-using this water, This modification shows an important effect in the decreasing of the fresh water consumption and the discharge of wastewater.

   An alternative methodology was also developed to avoid detailed mass balances when available data is not enough, by means of the calculation of an index that allows diagnosing the efficiency of the use of water, to analyze the improvements for inclusion of reuse systems and to compare how the water is used in different geniuses. For the calculation of the index it is necessary to study possible circuits of water reuse. Acceptable yields of the water reuse cycles are assumed. The index was calculated for the operative and structural situation of the Concepción Mill (Tucumán, Argentina) and the relative improvements are analyzed for the different strategies of water reuse.

3. A software tool for selecting more profitable alternatives in sugar and alcohol integrated production.

   A software tool prototype called SANPAD 4.0 has been developed. This tool is designed for analyzing alternatives of integrated sugar and alcohol production. It takes into account the economic information to select the best (more profitable) products survey in the complex. It was programmed in Borland C++ language.

4. A HAZOP analysis based system for fault detection and analysis in sugar and alcohol integrated production.

   The HAZOP study will permit to identify faults in the process and to recommend corrective actions. It will be built over factory operators and managers experience and a fuzzy inference system will permit abnormal operation management. Recommendations for installation of instruments for data logging and automatic control were released for Paraiso and CACSA Distilleries. Paraiso factory has bought almost all recommended instruments and its installation will be done during WESAP II Project.

5.- Other methodologies for process analysis in integrated sugar and alcohol production

   a) Use of functional diagrams and MILP for the exergoechonomical optimization of sugar plants
   Cogeneration systems contribute to meet these targets because they make efficient use of a common fuel for the generation of useful heat and power. The approach used to evaluate alternatives of cogeneration combines Second Law of Thermodynamics, through the exergy concept, with the

economic evaluation of the thermal system. The economic optimization of these systems has been object of numerous analysis and the main approaches are the following:
1) Those that make use of functional diagrams that allow to analyze and to distribute exergetic costs in a systematic way
2) Those that use mathematical programming using binary variables for the structural optimization of systems
It is proposed an hybrid strategy that combines the best of both focuses, getting a powerful tool for their versatility and robustness to implement a superstructure of optimization that contemplates all the possible cases outlined according to the exergetic cost functions defined by the functional diagram. The thermodynamic functions of interest have been modeled in such way that the outlined problem of optimization is a mixed integer linear programming (MILP), where use of binary variables is made to make structural decisions and for linearization purposes, getting a global optimum for the system under consideration.

b) Optimization of water and energy consumption in the ethanol production
In the production of azeotropic ethanol via fermentation of molasses from a sugar plant, the separation system to obtain ethanol free from harmful impurities most frequently used is distillation. The accepted impurity level in the ethylic alcohol depends on alcohol usage. For chemical and food uses it is required that the ethanol to be almost free of these impurities. Due to the strong interaction among the polar molecules that conform the mixture, the phase equilibrium properties strongly depend on water concentration. The addition of water in the separation train is an usual policy in the ethanol industry to increase the relative volatilities of the impurities-ethanol, therefore a large percentage of the energy consumed in the distillation process is used to remove these impurities. In this work, the distillation process is simulated using Aspen Plus and the influence of the key process variables is analyzed simulating a conventional ethanol distillation scheme that consists of a sequence of three columns. In order to meet the target, an objective function of economic nature that takes into account the different weights of products and by-products and the cost of utilities was chosen. Among the many possibilities of choosing design variables for the process optimization, we select the dilution water fed and the reflux ratio of the different columns of the separation train. The problem under consideration does not present conflicting objectives, since the formulation of the problem to maximize benefits does not compromise the environment. The environmental impact is related to the consumption of condensation water of both columns and the amount of residual liquid of the proposed modifications.

The complementary nature and the integrated utilization of these results should lead to the achievement of the proposed long-term objectives, that is, a sustainable and profitable production of sugar and alcohol. The proposed continuation of the Project (WESAP II) is conceived following these aims.

Evaluation of the objectives of the WESAP Project.

All the objectives conceived for this Project have been achieved. Tasks have gone through the expected plan, although new ideas complementing the final aims have been arise and will be include in a new proposal for continuation (WESAP II Project, already submitted to Group of 77 for evaluation).

The team work climate was very good among all participants. The contacts were stable and new ideas for bilateral and multilateral new projects are being under study. Some dissemination activities have been done; they are described in this report.

National Projects in each country were also supporting the project tasks. These are projects financed by national organizations that permitted the inclusion of many other people in the tasks of the project.

The collaboration of some institutions which were not part of the project consortium is well valued. These institutions are:

- University of Yucatan (UADY), Mexico

- Experimental Station (EEAOC), Argentina
- INTEC, University of Litoral, Argentina
- INGAR, Argentina
- University of Waterloo, Canada
- University of Valladolid, Spain

Project Activities.

The activities of the Project were distributed in 7 work packages, one of them being the coordination tasks. Every one of these packages was lead by an institution in the Project; but every partner participated in all work packages. In the first meeting of the project every work package was discussed and individual tasks assigned to each institution.The partners have worked in the work packages since the First Project Meeting. The starting and finishing date for each task have been changed in order to achieve the expected results in one and a half year instead of two.

Meetings.

There were changes in the meetings schedule because of the delay of project approval. The project technical work meetings were scheduled in the following dates and places:

Date	Objectives	Meeting place
January 2003	Kick-off meeting. Definition of individual tasks and final arrangements in work packages.	Querétaro, Mexico
July 2003	Progress evaluation.	Tucumán, Argentina
June 2004	Final meeting. Discussion of results and final reports.	Havana, Cuba

The Final Meeting was done jointly with a Technical Workshop of the project, among the activities of the VIII International Congress on Sugar and Sugarcane by-products (Diversification 2004). The representatives of each institution presented their final report on activities done during this project. All they considered that the project was a success for their groups not only because of the reached results, but because of the provided training possibilities for young specialists and the team work achieved among all participants. During the conclusions of this meeting, Mr. Pablo Mandeville, resident representative from UNDP, expressed his satisfaction about the way in which this project have been done and the results that have been reached with a low funding. Dr. Luis Galvez, ICIDCA General Director, spoke about the importance of this project and expressed his support for next tasks in WESAP II Project if it is approved.

International Technical Workshops

Five international technical workshops were done during the project, two in Argentina and three in Cuba. In Argentina the hosts were UNT and Concepcion Distillery and in Cuba, Paraiso Distillery and ICIDCA. Representatives of all partners participated as well as from other collaborating institutions. These workshops represented a great opportunity to discuss partial and final results of the project among all participants and industry collaborators.

National Teams Meetings.

In every institution, technical work meetings have been carried out for fulfilling the tasks of the project. The relevant information on these meetings has been distributed among the partners. All tasks were done as conceived in the work packages agreed in Queretaro. Internal reports on these national teams meetings have been distributed among all partners.

Training.

Three postgraduate courses have been given during the project using the facilities of the Iberia American Reference Center for Process Analysis in Sugar Industry (CRIAPIA) in Havana, Cuba. The courses were:
a) Course on "Process Optimization with GAMS".
b) Course on "Process Optimization with XPRESS".
c) Course on "Process Integration with Pinch Methodology".

Dissemination activities

a) Web site.

The web page of the WESAP Project have been designed and hosted by the web site www.icidca.cu . Links from web sites of CIATEQ and UNT have been also established. This web site have been a way for distributing all relevant information and reports of the project among participants.

b) Participation in the 6th Conference on Process Integration, Modeling and Optimization for Energy Saving and Pollution Reduction (PRES 2003)

WESAP Project was in charge of the organization of the session "Sustainable Sugar and Alcohol Production" in the 6th Conference on Process Integration, Modeling and Optimization for Energy Saving and Pollution Reduction (PRES 2003), held in Hamilton, Canada, jointly with the 53rd edition of the Canadian Chemical Engineering Congress. In this session there were presented 8 oral contributions and 6 posters. All the papers were presented by their main authors and the Organizing Committee recognized the celebration of this session in the congress.

c) Participation in the VIII International Congress on Sugar and Sugar Cane By-products (Diversification 2004)

WESAP Project was present in this international congress that was hold in Havana in June 2004. A Technical Workshop was organized for the presentation of final reports on activities done during the project, 10 papers for oral presentations were submitted to organizers.

d) Publications

Three papers on the tasks of the project have been submitted to international journals for publication. These journals are "Revista Industrial y Agricola de Tucuman" (RIAT), Argentina, "Integrated Processes and Energy Saving" (ITE), Ukraine and "Journal of Cleaner Production", Elsevier.

Nine full text papers were published in the Proceedings of the VIII International Congress on Sugar and Sugar Cane By-products (Diversification 2004), ISBN 959-7165-17-1.

Acknowledgments

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Havana, June 2004