Combining High-level Programming Languages and Spreadsheets An Alternative Route for Teaching Process Synthesis and Design

Mauricio A. Colombo*, María Rosa Hernández* and Jorge E. Gatica Chemical Engineering Department, Cleveland State University, Cleveland, OH * Instituto de Ingeniería Química, Universidad Nacional de Tucumán, ARGENTINA

Abstract

The present paper focuses on the combination of programming languages as an effective approach towards teaching process design concepts. The cornerstone for the success of this approach is the combination of widespread techniques, such as spreadsheets, with high-level languages as C or FORTRAN and object-oriented languages such as JAVA or Visual BASIC. This paper specifically demonstrates the combination of Microsoft Excel with FORTRAN programs, through a Visual BASIC interface. The popularity of spreadsheets makes them the ideal tools to illustrate nonlinear interrelations among different design variables in complex processes. These variables, however, are typically connected through a complex set of algebraic and differential equations, whose solution demands a robust numerical approach. Students are frequently distracted or frustrated in trying to deal with these difficulties. When these calculations are not essential to the process design principles being demonstrated, instructor-developed "black boxes" can be used to carry out cumbersome calculations in the background. This synergetic effect enables to highlight the most relevant process synthesis principles, while the student is kept away from the mathematical and numerical complexities involved in the solution of the problem. The case study presented serves to illustrate the effectiveness of a proper combination of programming techniques with conceptual design ideas.

I. Introduction

The use of calculation packages in Chemical Engineering (FLOWTRAN, PROCESS, and TK Solver) has become increasingly popular with technical advances in hardware. The use of these packages, however, is not an integral part of Chemical Engineering curriculum. Furthermore, there is not a consensus on which program or programs are preferable (Harb et al., 1997). This decision seems to depend in general of two factors: the instructor, and the course main topic.

Despite the technical advances in operating systems, and the development of graphical user interfaces that simplify the use of complex simulation packages, the controversy is still unresolved. The technological advances in new or alternative processes to deal with new financial, technical, environmental, and/or social issues impose new demands on instructors and course curricula. Indeed, while the total credits to obtain a Chemical Engineering degree has remained practically constant, a steadily increasing demand for supplementary material has been observed in courses covering fundamental Chemical Engineering principles (cf. Hernández and Gatica, 1997). Thus, much of the support material, such as computer programming and numerical analysis, has been relegated to support courses.

Senior-level courses, such as Process Synthesis and Design, are meant to demonstrate the combination of the fundamentals learnt in Sophomore and Junior years in the analysis of complex processes (cf. Douglas, 1988). Attention, however, has been primarily paid on the development of new analysis and simulation methods, while the process synthesis has remained as heavily dependent upon the expertise and experience of the engineer.

Experience in the classroom has shown that requiring students to develop their own solvers, when learning fundamental engineering principles, is typically an overwhelming and frustrating practice. Indeed, besides a solid understanding of the principles being demonstrated, developing a solver requires mastering programming and numerical analysis skills. The most common route to overcome these roadblocks, is to train students to use pre-packaged commercial, instructor-developed solvers, or some combination of both. The shortcoming to this approach is that students use these programs as "black boxes" that implement some "esoteric" algorithm or numerical method. Moreover, the lack of motivation to understand the software, typically results in students losing interest in understanding what happens "behinds the curtains" or how the interrelation between engineering principles influences the calculations.

This paradox is very apparent in sophomore and junior-level courses. Seniors, on the other hand, concentrate their attention on process synthesis and design. Most teaching philosophies dictate to steer senior students to integrate principles learnt during their junior and sophomore years to well defined process synthesis and design problems. The goal of the instructor is to now instill in the students an engineering approach towards the problem. In other words, students should develop the skills to clearly pinpoint the critical units in the process and identify the design variables which have a major impact on the quality of the final design and/or problem solution.

This paper proposes an alternative based on a combination among different programming languages to streamline tutorial-like exercises for users with minimal programming skills. Particular attention is given to new programming techniques and the potential of combining novel object-oriented languages such as JAVA or Visual BASIC (cf. Bruzas and Gatica, 1999) with interfaces which are common to most engineering students. On this end, spreadsheets such as Microsoft Excel, Lotus 1-2-3, and Corel Quattro Pro are the natural choice (Mitchell, 1997). The objective of this work is to show through a case of study, the usefulness of efficiently merge a systematic procedure of processes synthesis with suitable software.

The case study selected to illustrate this approach consists on an optimization problem that requires the solution of a set of coupled non-linear ordinary differential equations. This paper specifically demonstrates the combination of Microsoft Excel with FORTRAN programs, through a Visual BASIC interface. The spreadsheets illustrate the effect of nonlinear interrelations among the different design variables, while instructor-developed "black boxes" are used to carry out cumbersome calculations in the background. This synergetic effect enables to highlight the most relevant process synthesis principles, while the student is kept away from the mathematical and numerical complexities involved in the solution of the problem. The case study presented serves to illustrate the effectiveness of a proper combination of programming techniques with conceptual design ideas.

II. Statement of the Problem

Process Design problems typically present a challenge for Chemical Engineering students. The assignment can rapidly become a frustrating experience unless a systematic analysis approach is followed. The underlying philosophy is to formulate several alternate designs and evaluate their appropriateness to reach a given (usually economic) goal.

Although one can resort to heuristics to combine creativity and theoretical background to simplify the problem, a large number of design variables to define is typically present in these problems. Thus, a computational tool that would enable the student to rapidly explore different design alternatives and the impact of design variables on the objective function, becomes of primary importance. A number of user-friendly of process simulation packages (e.g. Aspen Plus) are readily available to students. To take advantage of these tools, nevertheless, the student needs to have a solid understanding of the flowsheeting process and the design variables.

Due to the open-ended nature characteristic of processes synthesis problems, their solution typically reduces to breaking down the overall problem into smaller subsystems. A precedence order for their resolution, with hierarchical levels of growing complexity is established next (cf. Douglas 1988). This strategy possesses the following advantages:

- It yields a larger number of alternative flow sheets.
- It highlights key design variables
- It enables to identify the variables that cause process units interaction.

A general procedure for the synthesis of chemical processes ("onion diagram") is outlined in Fig. 1. This procedure clearly highlights the hierarchical levels in the definition of design variables



Figure 1: Process design hierarchical "Onion diagram" (adapted from Douglas, 1988)

Thus, it is apparent that the reactor performance is at the core of the process, the reactor performance will dictate the necessary conditions for the separator, which in turn will define the heat exchanger network, with the latter determining the utilities consumption.

Even with use of heuristics, the reactor presents numerous variables to specify whose determination

is not a simple task! How to select the value of important design variables as temperature, pressure, molar ratio of reactants, etc? Unfortunately, in agreement with Murphy's laws, the heart of the proposed system, of which the value of other proposed subsystems depends, is the most difficult to solve,, even if we had *all* the needful information.

The solutions of the equations that model reactor behavior are, for their nature, complicated and time consuming . As a consequence of that, the solutions are always limited, based on simplified assumptions and they depend on a limited set of selected variables in order to their numerical computation. With the use of tools like the proposed in this work, the students can extend their calculations to more rigorous models, obtaining a deeper knowledge of the requirements of the synthesis problem.

Even more, the combination of powerful computational tools with graphic interfaces allows to explore trade offs among different variables to find an optimal solution. It is highly advisable to encourage students to evaluate and to recommend alternatives according to the desired targets, using the deeper knowledge acquired of the synthesis process, being able to identify the most important variables and their influence. This and many other opportunities can be achieved through the use of the proposed tool.

III. Case Study

The case study selected consists of catalytic dehydrogenation process for the production of butadiene (cf. Fig. 2). The objective is to optimize the operating conditions to yield annual production of 25,000 ton of butadiene. A thermodynamic analysis (which is also integrated in the working file) indicates that a catalytic process may be the only feasible route to inhibit complete combustion reactions.



Figure 2: Schematic of the catalytic butene dehydrogenation process

The catalytic butene dehydrogenation occurs through a complex mechanism of combined reactions as shown in Figure 3.



Figure 3: Catalytic dehydrogenation of butene to butadiene mechanism

IV. Formulation of the Design Problem

The design problem can be formulated in two stages:

- Define the reactor operating conditions, and
- □ Optimize the process financial profit for these operating conditions.

The solution to the first design question reduces to a parametric analysis of the operating conditions space. In other words, a set of non-linear ordinary differential equations must be solved repeatedly for different operating conditions. The complexity of the governing equations is compounded by the intricacy of the reaction mechanism for this process (cf. Fig. 3).

The first question posed requires optimizing conversion and selectivity. The pressure, temperature, and composition of the inlet stream of the reactor will define the operating conditions. Although the volumetric flow rate and the reactor volume are also design variables, the problem can be easily optimized by its optimum residence time by resorting to dimensionless variables. Once the optimum values for the conversion per pass and selectivity are found, the flow rate (to treat) will define the reactor volume needed.

V. Model Formulation

For the sake of simplicity, this reactive process has been assumed isothermal. Thus, only five ordinary differential equations are needed. For a packed bed reactor, these equations take on the form:

$$\frac{dF_i}{dV} = r_i$$

where, "F" is species "i" molar flux, "V" is the reactor volume, and "r" stands for the rate of reaction expression. For instance, for butene ("B"), the governing equation would be:

$$\frac{dF_B}{dV} = -2r_1 - 2r_3$$

or, in dimensionless form:

$$\frac{dx_B}{d\theta} = \text{Da}_1 f_1(x_B, x_O, Y_{BD}) + \text{Da}_2 f_2(x_B, x_O, Y_{BD})$$

where "x" represents the conversion, " θ " is the dimensionless residence time, "Y" is the yield, "f" is a concentration non-linear function, while "Da" is the Damk The Damk The Damk hler number is defined as:

$$Da_i = \frac{k_i \tau}{C_B^o}$$

where " k_i " is the reaction rate constant (with a Arrhenius exponential dependence on temperature, " τ " is the characteristic time, and C_B° is the inlet butene concentration. All kinetic parameters and rate of reaction expressions have been adapted from the literature (Sterret and McIlvried , 1974).

VI. Solution Approach

The set of equations can be easily solved using an explicit method. Fixed-step routines might prove inefficient, and an adaptive integration step algorithm is recommended. The method selected for the case study has been a fourth-order Runge-Kutta method with adaptive integration step. To minimize round-off errors, the algorithm uses the formulas developed by Gill (method frequently referred to as Runge-Kutta-Gill). This is a well-known method, described in most numerical analysis textbooks (cf. Chapra and Canale, 1998). For this example the authors have written their own version, but robust FORTRAN and ANSI C codes can be readily found in several public domain libraries.

The solution to the set of non-linear ordinary differential equations is attained via a FORTRAN program ("reactor.for"). This program can be run as an interactive program or on a batch mode via an input file. The approach chosen here is the use of an input file, "reactor.ini," which defines the reactor operating conditions (cf. Fig. 4), i.e.,

- □ Inlet temperature
- □ Inlet volumetric flow rate
- □ Total Pressure
- □ Inlet butene molar fraction
- Dilution ratio (oxygen/butene molar ratio in the feed).

```
open (1, file='reactor.ini')
          : inlet temperature, K
С
     То
          : inlet volumetric flowrate, m^3/hr
С
     QO
     PT
          : total pressure, atm
С
          : inlet molar butene molar fraction
     уВо
С
С
     beta : dilution ratio, beta = FO2o/FBo
read (1, *, end = 10) To, Qo, PT, yBo, beta
         Figure 4: Input to FORTRAN program
```

The student defines these conditions in the worksheet "Reactor" of the spreadsheet. A macro can be recorded to write this data into the input file and execute the FORTRAN program. The program will integrate the reactor governing equations (e.g., $0 \le \theta \le 4$) and will write (cf. Fig. 5) the solution (butene, x_B , and oxygen x_{O2} , conversion and the yield for butadiene, Y_{BD} , carbon dioxide, Y_{CO2} , and water, Y_{H2O}).

```
open (2, file='reactor.out')
c 1: butene conversion
c 2: oxygen conversion
c 3: butadiene yield
c 4: carbon dioxide yield
c 5: water (steam) yield
volume = time * Tau * Qo
```

write
$$(2, *)$$
 time, $(x(k), k = 1, neq, 1)$

Figure 5: Output from FORTRAN program

The reactant conversion is defined as:

$$x_i = \frac{F_i}{F_i^o}$$

while yield is defined as:

$$Y_i = \frac{F_i}{F_B^o}$$

The results are written to an output file, "reactor.out," and integrated into the spreadsheet for graphical and economical analysis.



Figure 6: Flow of information between FORTRAN program and Spreadsheet

The flow of information (cf. Fig. 6) between the spreadsheet (in the foreground) and the computer program (in the background) is controlled by a key component: a Visual BASIC macro integrated in the spreadsheet, "SolveReactor" (cf. Fig. 7).

```
Sub SolveReactor()
Reset
'define input file
FileIn = "a:\reactor.ini"
' read operating conditions from the spreadsheet
Call WriteDataToInputFile(FileIn)
```

```
' run program
RetVal = Shell("a:\reactor.exe", 1)
' define output file
FileOut = "a:\reactor.out"
' process results and transport them to
spreadsheet
Call ReadBackFromOutputFile(FileOut)
End Sub
```

Figure 7: "SolveReactor" Visual BASIC Macro

The two major subroutines in this macro are (cf. Figs. 8 and 9):

WriteDataToInputFile

Reads the values for the operating variables and creates the input for the FORTRAN program

ReadBackFromOutputFile

Reads the output file created by the FORTRAN program and transcribes them to the spreadsheet.

```
Sub WriteDataToInputFile(FileIn)
' subroutine to coordinate input
' file with a given worksheet
' indexes
Dim I As Integer
Dim J As Integer
' operating variables
Dim Flow As Single 'Flow rate, m<sup>3</sup>/hr
Dim Temp As Single 'Temperature, K
Dim Pres As Single
'Total Pressure, atm
Dim yBo As Single
'butene molar fraction
Dim beta As Single
'dilution ratio FO20/FB0
' I/O cells
I = 5
J = 5 + 2 * Cells(11, 3)
' read data from spreadsheet
Flow = Cells(I, J)
beta = Cells(I + 1, J)
yBo = Cells(I + 2, J)
Temp = Cells(I + 3, J)
Pres = Cells(I + 4, J)
' write information to input fie
Open FileIn For Output As #1
Write #1, Temp, Flow, Pres, yBo, beta
Close #1
                                         Loop
Figure 8: Suroutine in "SolveReactor" macro
```

Coordinates Spreadsheet to Program flow

Sub ReadBackFromOutputFile(FileOut) ' subroutine to coordinate output file ' with a given set of cells in a ' spreadsheet ' indexes Dim I As Integer Dim J As Integer Dim K As Integer ' output variables Dim time As Single 'time Dim xB As Single 'butene conversion Dim xO2 As Single 'oxygen conversion Dim yB As Single 'yield of butadiene Dim yCO2 As Single ' yield of carbon dioxide Dim yH2O As Single ' yield of water Dim Conversion As Single Dim Selectivity As Single ' figure out cells in spreadsheet J = 5 + 2 * Cells(11, 3)I = 10' read output file Open FileOut For Input As #1 RowIndex = IDo Until EOF(1) Input #1 time,xB,xO2,yBD,yCO2,yH2O RowIndex = RowIndex + 1Conversion = xBSelectivity = 1If xB > 0 Then Selectivity = yBD / xB Cells(RowIndex,J) = Conversion Cells(RowIndex, J+1)=Selectivity End If If J < 6 Then ' optimum conditions ... then ' store complete solution K = 17Cells(RowIndex, K) = time Cells(RowIndex, K + 1) = xB Cells(RowIndex, K + 2) = xO2 Cells(RowIndex, K + 3) = yBDCells(RowIndex, K + 4) = yCO2Cells(RowIndex, K + 5) = yH20End If Close #1

End Sub

Figure 9: Suroutine in "SolveReactor" macro Coordinates Program to Spreadsheet flow

VII. Results and Discussion

The "tutorial" begins in the worksheet "Reactor," where the student can test the performance, based for instance on the selectivity, of different sets of operating conditions. The trial-and-error process will continue until an optimum set is identified. The results can be easily analyzed in graphical format, the navigation between specific sections of the worksheets can be easily implemented through hyperlinks. (cf. Fig. 10).

Once the optimum reactor operating conditions, the values of the design variables are inserted in the corresponding block ("set #0"), and a macro is used to generate the reactor solution. The "SolveReactor" output generates automatically the columns required for the economical analysis. The student can then proceed to the Economical Analysis (cf. Fig. 11).

VIII. Conclusions

- Students can readily develop their own calculation sheets, leaving the most complicated calculations for the instructor-supplied package.
- Students need to understand the problem that they are trying to solve, basic knowledge of some spreadsheet (in contrast to deep knowledge of programming), and a basic knowledge of numerical methods. The emphasis can then be put on understanding the foundations of the outlined problem, instead of having to pay attention to the solution procedure.
- The pedagogic importance of the use of new available tools has been demonstrated through a concrete example of process synthesis.

IX. Acknowledgements

The authors gratefully acknowledge support from the National University of Tucumán (UNT). One of the authors (JEG) gratefully acknowledges support from the Established Full-time Faculty Research Development (EFFRD) program and the Graduate Council at Cleveland State University (CSU). Financial support from the University Center for Teaching and Learning (UCTL) at CSU and the National University of Tucumán Research Council (CIUNT) are also gratefully acknowledged.

Bibliography

1. Bruzas, A. E. and J. E. Gatica "JAVA-based Interactive Computer Modules for Computer-aided Instruction," *Ohio Space Grant Consortium*, April 1999 (Ohio Aerospace Institute, Cleveland, OH).

2. Chapra, S.C. and R.P. Canale "Numerical Methods for Engineers," 3rd. Ed., McGraw-Hill, New York, NY (1997).

3. Douglas, J.M. "Conceptual Design of Chemical Processes," McGraw-Hill, New York, NY (1988).

^{4.} Harb, J.N., A. Jobes, R.L. Rowley and W.V. Wilding "Use of Computational Tools in Engineering Education," *Chemical Engineering Education*, pp. 180-187 (Summer 1997).

^{5.} Hernández de Colombo, M.R. and J. E. Gatica "Nuevas metas de la Computación Aplicada a la Ingeniería," *Revista de la Facultad de Ciencias Exactas y Tecnología (UNT)*, <u>6</u>(11), pp. 48-52 (1997).

^{6.} Mitchell, B.S. "Use of Spreadsheets in Introductory Statistics and Probability, "*Chemical Engineering Education*, pp. 194-200 (Summer 1997).

^{7.} Sterret, J.S. and H.G. McIlvried "Kinetics of Oxidative Dehydrogenation of Butene to Butadiene over a Ferrite Catalyst," *Ind. Chem. Process Des. & Develop.*, 13(1), pp. 54-58 (1974)

FLOWTRAN. Monsanto Company, Engineering Teac. - F4EE, 800 N. Lindbergh Blvd., St. Louis, Missouri 63166.
 PROCESS . Simulation Sciences, Inc., 1440 North Harbour Blvd., Fullerton, California 92635.

10. TK SOLVER . Universal Technical Systems Inc. 1220 Rock Street , Rockford, Illinois 61101. MAURICIO A. COLOMBO

Mauricio Colombo is currently a doctoral student at the National University of Tucumán (UNT, Argentina). He received his B.Sc. in Chemical Engineering from the UNT where he serves as a Lecturer for Process Design and Optimization and for Chemical Thermodynamics in the Chemical Engineering department. Mauricio's interests include new applications of educational software tools to Process Design problems, area in which he has been active for several years. He has numerous presentations and publications on the subject.

MARÍA ROSA HERNÁNDEZ

María Rosa Hernández is currently Associate Professor at the National University of Tucumán (UNT, Argentina). Professor Hernández teaches undergraduate core Chemical Engineering courses in Process Design and Optimization and Chemical Thermodynamics. She received her B.Sc. degree from the UNT and her M.Sc. degree from the Southern National University (UNS, Bahía Blanca, Argentina), both in Chemical Engineering. She is the Director of the "Industrial Process Engineering" research program funded by the National University of Tucumán Research Council (CIUNT). Professor Hernández is actively involved in joint research with industry.

JORGE E. GATICA

Jorge Gatica is currently an Associate Professor and Graduate Program coordinator in the Chemical Engineering Department at Cleveland State University (CSU). He has degrees in Chemistry, Applied Statistics, and Chemical Engineering. His current interests include the application of Reaction Engineering principles to materials manufacturing and processing, computers and programming in engineering curricula, and the use of computers in education. A long-term active member of the AIChE Catalysis and Reaction Engineering Division, Dr. Gatica is actively involved in basic and applied research. He has over 70 technical presentations at national and international meetings, and more than 50 publications in refereed journals. Dr. Gatica has taken the lead in several WWW-based developments at CSU, where he has received several Teaching Enhancement Awards in support of computer-aided instruction developments in Engineering. Dr. Gatica serves as a mentor for undergraduate minority and high-school students, as well as a summer advisor for Project SEED students.

| WORKS CONTRACTOR | S 19 🗸 | <u></u> | | | J + 10 | | | 23 | ≈ Z∙ | A. | | | 47 | | | |
|---|--|---|-----------------------------------|---|---|---|----------------------|---|---|--|--|--|---|--|--|-----------------------|
| <u>) F</u> ile <u>E</u> dit | <u>V</u> iew <u>I</u> nser | rt F <u>o</u> rma | t <u>T</u> ool | s <u>C</u> ha | art <u>W</u> i | indow | <u>H</u> elp | | | | | | | | | E |
| Chart Area | <u> </u> | = | | | | | | | | | | | | _ | | _ |
| A Tariaklar da dis | B C Minimum | 0 Cundici | E anos Opt (| F Sat 20 | G Sot\$1 | н | l Sot#2 | 3 | K Sot#3 | L | S | M 24#4 | N | | 0 | P |
| Q bota | 126324 | Q= bota | 7003 1 10,29 F | 02s/FBs | 75 10.29 | m*3/hr F02a/FBa | 75 3.99 | m*3/Ar FOZa/FBa | 75 1.89 | #*3# F02## | hr FBa | 75 0.84 | FO2a/F | Ba | - | - |
| yBa Ta | 2 300 | 78a Ta | 0.02 575 I | c | 0.02 575 | ĸ | 0.05 575 | ĸ | 0.10 575 | ĸ | | 0.20 575 | ĸ | - | | - |
| PT Ejecute MACRO (+ | Ctrls+cShifts | PT R) Formula | 1 4 Canversia S | ieloctivid (| 1 Canversia | atm Selectivid | 1 Conversio | atm Selectivid | Conversio | otm Select | ivid- Cr | 1 Inversio | atm Selecti | vidad | | - |
| para calcular Camparician da | Sat 8 0 | #VALUE! | 0.193606 | 0.910216 | 0 0.193606 | 0.910216 | 0 0.084742 | 0.916622 | 0.045239 | 0.922 | 503 298 0. | 0 .024109 | 0.928 | 411 | | |
| y₿ y02 | | 0 <u>Graficar</u> | 0.326947 | 0.819593 | 0.326947 | 0.819593 | 0.142216 | 0.847127 | 0.075478 | 0.860 | 429 0. 936 0. | .039981 .053091 | 0.870 | 548 819 | - | _ |
| yN2 yBD | 0.77 0.75 0.00 0.00 | i2 🔰 | 0.536453 | 0.759583 | 0.536453 0.62618 | 0.759583 | 0.232451 0.271267 | 0.805071 | 0.122742 | 0.824 | 1439 0. 1919 0. | .064667 .075231 | 0.837 | 986 052 | - | _ |
| yCO2 yH2O | 0.00 0.07 0.00 0.07 | 9 | 0.709375 | 0.707259 | 0.709375 | 0.707259 | 0.307476 | 0.771692 | 0.161928 | 0.796 | 825 0. 1824 0. | .085063 .094333 | 0.813 0.802 | 486 964 | | - |
| Produccion portubo | uBe \$\$\$ \$ tubar Tate | ss . L taly | 0.860273 0.928453 | 0.657379 | 0.860273 0.928453 | 0.657378 | 0.374287 | 0.742956 | 0.196768 | 0.773 | 691 0. 271 0. | .103156 .111609 | 0.793 | 271 257 | | |
| 655.25 rendimients | 38 250 uBD/uBs 47.2 | 8% | 0.989864 0.999883 | 0.605304 | 0.989864 0.999883 | 0.605304 | 0.435744 | 0.717183 | 0.228785 | 0.753 | :448 0. 1134 0 | .119752 0.12763 | 0.77 | 581 848 | | |
| Datur edicional | a | | 0.999861 | 0.574261 | 0.999861 0.999892 | 0.57426 | 0.493346 0.520996 | 0.693475 | 0.25878 | 0.73 | 526 0. 772 0. | 135276 | 0.760 | 305 129 | | |
| CBo FBo | 4.242E-04 mal/lit 2970.52 mal/hr | OF . | 0.999961 0.999938 | 0.546734 | 0.999961 0.999938 | 0.546734 | 0.547989 | 0.671277 | 0.287233 | 0.718 | 625 0. | 149981 | 0.746 | 276 | | |
| MB MBD | 56 54 | and Reeson of | 0.999962 0.999992 | 0.521119 | 0.999962 0.999992 | 0.52111 | 1.0 | 1000000 | | | | | | - | | |
| R rha,B | 0.082 atm m 1.188 kg/m^ | *3/kmalK 3 | 0.999753 0.999876 | 0.497317 | 0.999753 0.999876 | 0.49731 | 0.8 - | A STATE | a abaa | | -0- | - A | | | | |
| rha,BD rha,aire | 1.145 kg/m^ 0.615 kg/m^ | 3 | 0.999866 | 0.472851 | 0.999866 | 0.47285 | 0.6 | | -tunta | 900 | 10000 | kn | -8-0- | 1 | FI | luja |
| | Bearerar a la Haia | de Direnia | | | | | 0.5 | | | | 4 | - (Set | #0) #1 | | | |
| | | | | | | | v 0.3 - | | | | -0- | - Set f | #2 | | | |
| | | | | | | 100 P | 0.2 - | | | | * | - Set i | #4 | | | |
| | | | | | | | 0.0 - | 0 0 | 2 4 | 4 | 0.6 | • • • | * xB | | | |
| a lash - Barris | - Dummer - 2 | Theres | lue to a | a a lucitor |) n. | | Charact | deal - | | 6 | 11 | 1 | 1.00.00 | 10 | 1 | |
| re ren V Desig | n ourninary X | mennoo | ignamic A | naigsis | Anea | actor A | oneer | | | _ | 4 | | | | | 1 |
| Aicrosoft E | xcel - ASI | E - 200 | O, Cola | mbo | et al. | | | | | | | | | | | 1 2 |
| Aicrosoft E) <u>Eile E</u> dit | xcel - ASI View Inser ☞ 🗟 🥵 | E - 200 t Forma | 0, Colo t <u>T</u> ools | mbo Data | et al. ⊨ <u>W</u> inc | dow H | elp | ΣΓε | A1 | 21 | 474 | 0 | | 50% | | 시 인 인 문 |
| Aicrosoft E) Eile Edit 1 😂 🔛 (E30 | xcel - ASE View Inser | E - 200 t F <u>o</u> rma & B | 0, Cola t <u>T</u> ools 🔁 🚿 | mbo Data | et al. ⊨ <u>W</u> inc → C≃ | dow <u>H</u> | elp | Σf× | Ê↓ | Z I | 10. | 9 | | 50% | | 시 키 키 { |
| ficrosoft E Eile Edit Eile F39 | xcel - ASE | EE - 200 t Format & Po = | 0, Colo t Tools C S | embo Data | etal. ⊧ <u>W</u> ind ∼ C× | dow <u>H</u> | elp | Σfx | ê↓ | Z↓ A↓ | н. | 9 | ₽ | 50% | | 시 원 원 { |
| Aicrosoft E Eile Edit E Edit F39 | xcel - ASE | EE - 200 t Forma & Po = | 0, Colo t Iools | embo Data Constanti Consta | etal. Wind Cu H Booseo | dow <u>H</u> | elp • 😴 | Σ Γ × κ | Â↓ 2↓ | Z ↓ А↓ | н к к к к к к к к к к к к к к к к к к к | 0 33 | P Tatal, 2590 | \$0% | | 지 된 된 { |
| Aicrosoft E Eile Edit Eile Edit F39 A Tariablaz da Eau (Candicianao 70 Candici 70 | xcel - ASE View Inser → C | E - 200 t Format S P = D E an detalledate intel | 0, Colo t Iools C S | embo Data S S G | et al. <u>W</u> ind ~ Cu H BVIERO | dow H | elp | Σ f× κ απο απο | L Bu | Z ↓ A ↓ | N ess As alic trau | 0 8 tub 3 tub ir do F xB | P Tatal, 2500 yBD | 2 50% tały tały | NUN | /1 P 2 2 |
| ficrosoft E Eile Edit F39 A Condicioner O Condicioner O Condel 10 Condel 11 Condel 11 | XCEI - ASE | E – 200 t Format B E D E andetalleda- tatal) sutenaj aire) | 0, Cola t Iools | embo Data Contention C | et al. Wind Ca Buseno Accos | dow <u>H</u> | elp | Σ fx κ το certo το certo | L Bu BTEC 34 | Z A + M | N 655 641 647 647 647 647 647 647 647 647 647 647 | 0 * tub 3* ×B 0.00 0.19 | P Tatal, 2500 stard 0.00 0.17 | 2 50% taly (al.m^3 0 1401 | R R R R Val, Ft3 0 49441 | л Р 2 2 2 |
| Aicrosoft E Eile Edit Eile Edit F39 A A Candiciner O Candiciner O Cand | xcel - ASE | EE - 200 t Format B E D E andetallades tatal) sire) | 0, Cola t Tools | embo Data G | et al. Wind Co BUERO ACION E VIAIRE | dow H | elp | ET FICEEA | L Bu 8100 30 211 211 | M tong a 0 9.145 6.074 7.708 | N 655 64 64 0.00 0.20 0.20 0.20 0.20 0.20 0.20 0.2 | 0 33 xB 0.00 0.19 0.33 0.33 0.44 | P Tatal, 2500 yBD 9 0.00 0.17 0.27 0.35 | 2 50% 50% 1401 2801 4202 | NUN | /1 P 2 2 |
| Aicrosoft E Eile Edit F39 A Variabler de Eau (Candei ma 24 Candei ma 24 Candei ma 25 Candei ma 2 | xcel - ASE | EE - 200 t Format B E D E andetalledeb tatal) butena) sire) | 0, Colo t Tools | embo Data G | et al. Winc Cu BURGAO ACTOR ACTOR BURGAO ACTOR | dow <u>H</u> | | Σ fx K K K K K K K K K K K K K | Eu 8736 221 16 16 16 | M tonu a 0 9.145 6.074 7.703 26.17 | N 555 A a dia 1.00 | 0 33 33 33 33 33 33 33 33 33 33 33 33 33 | P Tatal. 2500 yBD 1 0.07 0.27 0.31 0.46 | 0 50% 50% 50% 50% 1401 2801 2801 2801 2801 2802 7003 | R R Val,ft3 0 93832 149324 149765 247206 | |
| Aicrosoft E File Edit F39 A Tarieblar de Ent (Candel ma 24 Candel ma 25 Provins Temperatus Temperatus Provins Temperatus Provins Temperatus Provins Temperatus Provins Temperatus Provins Temperatus Provins Temperatus Provins Temperatus Provins Temperatus Provins Temperatus Provins | xcel - ASE View Inser C A AC C AC C A AC C AC | EE - 200 t Format S Po = D E andetalleteter attal) buttona) aire) | 0, Colo t Iools | embo Data S | et al. Wind C B B B C B C B C C C C C C C C C C C | | | Σ fx K (GELHO SEO GELHO HT RIGHEAL HEHO MIDO & C | Eu Bu Bu 21 16 11 11 10 | M tong 4 0 9.145 2.093 26.17 7.709 26.17 7.805 | N 555 640 640 0.40 0.40 0.40 0.40 0.40 1.40 | 0 38 xB 0.00 0.19 0.33 0.54 0.54 0.54 0.79 | P Tata 2500 0.00 0.17 0.27 0.37 0.37 0.37 0.37 0.37 0.35 0.41 0.45 0.50 0.54 | Q tafy 1401 2801 1401 2801 5602 5602 9804 | NUN B Val,63 0 49441 98832 148324 197765 247664 247664 247664 346088 | |
| Aicrosoft E File Edit File Edit F39 A Fariablar de Ent Condel ma 249 Condel ma 249 Conde | xcel - ASE | EE - 200 t Format B E D E and obtailed attai) sutena) sire) | 0, Colo t Iools T r | embo Data Costa Costa Costa | et al. <u>Winc</u> Cu Burgeno Actor Burgeno Purving WA Curva | | | Σ fx κ ceepso so ceepso freeso rateso so ceepso so ceepso so ceepso rateso so ceepso rates | E E Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu | Z H tons a 1 0 145 6.074 7.708 2.093 2.093 2.093 2.093 2.093 2.093 2.093 2.093 2.093 2.093 2.093 2.093 2.095 1.45 5.45 1 | N 855 655 657 600 0.20 0.40 0.60 1.20 1.40 1.60 1.80 1 | 0 33 38 0.00 0.19 0.33 0.44 0.54 0.71 0.74 0.74 0.54 0.73 0.74 | P P Tatal, 2500 Tatal, 2500 1000 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.00 0.05 0.04 0.05 0.55 0. | 2 c tafy iel Ecse 0 1401 2801 1401 2801 5602 5602 5603 5404 9804 12805 1 | R R Val,fx3 0 499441 2140324 14034 1 | |
| Aicrosoft E File Edit F39 A Tariablar da En (Candel 78 Candel 78 Cande | xcel - ASE | E - 200 t Format S E D E andetalledat sutona) sire) | O, Colo t Tools | embo Data | et al. <u>Winc</u> Cu Burneso Actos BUTAIRE VA 200 R (| dow H B TIMENO B TIMENO TALLERO TALLERO ACTA B OR C2 | | Σ fx K K CELEO BO GELO SO GELO SO GELO SO GELO SO GELO SO GELO | E E Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu | Z↓ teng a 0 9,145 2,093 2,095 2,005 | N 555 555 555 555 555 555 555 5 | 0 38 38 38 38 38 38 38 38 0.00 0.19 0.33 0.44 0.554 0.633 0.719 0.643 0.719 0.643 0.719 0.643 0.719 0.654 0.635 0.719 0.654 0.655 0. | P Tatal yED (0.00 0.17 0.27 0.46 0.50 0.54 0 | 0 14017 0 1401 2602 5602 5602 7003 8404 11205 12605 12605 12605 12605 12605 15007 | R R R Val,e3 Val | |
| Aicrosoft E File Edit F39 A Tariabler de Ent Candel ma 28 Candel ma 145 Candel ma 145 Ca | xcel - ASE View Inser → C ASC → C ASC → C ASC → C ASC → C ASC → C ASC → C ASC → C ASC → C ASC → → → → → → → → → → → → → | EE - 200 t Format | 0, Colo t Tools | mbo Data | et al. Wind Col B VIEBO ACION B VIAIDE VIA | dow H | | K K K K K K K K K K K K K K K K K K K | E E Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu | M tong a 0 0 145 6,074 7,708 2,043 2,043 2,043 2,045 2,343 6,557 6,557 6,557 6,557 2,348 6,557 2,348 2,529 2,249 2,459 2 | N N N N N N N N N N N N N N | 0 33 38 0.00 0.19 0.33 0.44 0.53 0.79 0.554 0.554 0.79 0.454 0.454 0.54 0.54 0.54 0.454 0 | P Tatel, yBD 1 0.00 0.17 0.55 0.46 0.57 0.59 0 | 0 tafy iel Ecce Vel.m*3 0 1401 2801 2801 2801 2801 2801 2801 1401 1205 14006 15407 15602 15405 15405 | R R Val,fe3 0 49441 197765 296642 296642 296529 4449712 542852 292544 449412 | |
| Aicrosoft E Eile Edit F39 A F39 A Tarieblar de Ent (Candicianer O Candel ma 24 Candel ma 24 Candel ma 25 Candel ma 25 | xcel - ASE View Inser | EE - 200 t Format = D E andotalledes andotalledes andotalledes | | | et al. Wind Call BUILED ACTON ACTON BUTAILE VA 200 B VA | | | Σ fx K COLLEO SEO CALLEO FATELEO CALEO CALLEO CALLEO CALLEO CALLEO CALLEO CALLEO CALLEO | E E E E E E E E E E E E E E E E E E E | M tonua 0 9.145 6.0744 7.805 2.083 26.17 7.805 2.383 6.5547 6.5547 6.3390 6.3290 6.3292 | N SS5 SS6 N N N SS5 SS6 SS6 N N N N N SS5 SS6 N N N N N SS5 SS6 N N N N N N N N N N N N N | 0 * tub 34 0.00 0.19 0.33 0.44 0.53 0.99 1.00 1.00 1.00 1.00 | P Tatkal, 2500 yBD 4 0.00 0.37 0.27 0.27 0.27 0.25 0.54 0.57 0.55 0.55 0.55 0.55 0.55 0.55 0.55 | 0 tafy 30 41,m*3 0 1401 2801 4201 2801 4201 2801 1401 1205 14006 15407 11205 14006 15407 11205 14006 21009 | R R Vulcfr3 0 49441 197755 247206 296607 395522 247206 494412 542853 295244 494412 542853 295244 494412 542853 295244 494412 542853 295244 494412 542853 295244 49521 49522 49521 49521 49521 49521 49521 49521 49522 49521 495521 4955521 49555555555555555555555555555555555555 | |
| Aicrosoft E File Edit File Edit | xcel - ASE View Inser View Inser C ASE C | EE - 200 t Format = D E an detalladas an detalladas | | | et al. Wind Cuint BUTALES ACTOR BUTALES TALES CUINA | | | Σ fx K CEERO SO CEERO FEISO CEERO SO CEERO SO CEERO SO CEERO SO CEERO SO CEERO SO CEERO SO CEERO | E E E E E E E E E E E E E E | X + + + + + + + + + + + + + + + + + + + | B B B B C C C C C C C C C C C C C | 0 5 tub 33 ×B 0.00 0.33 0.63 0.64 0.55 0.55 | P Tatal 2500 0.00 0.017 0.27 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.55 0 | 2 50% el testy o 1401 2801 0 1401 2807 1203 3404 9804 12405 12405 12405 12405 12405 12405 12405 22410 23810 | R R Val,fr3 247206 24720000000000 | |
| Aicrosoft E Aicrosoft E File Edit F39 A Variables de En (Candicianes O Candel 78 Candel 78 | xcel - ASE View Inser View Inser A for the service of the servi | EE - 200 t Format D E andetalledes andetalledes andetalledes | | | et al. <u>Wind</u> Cu Burneno Actos BUTAIRE TAR | | | Σ fx K K COEDEO SO COEDEO SO COEDEO SO COEDEO SO COEDEO SO COEDEO SO COEDEO SO COEDEO SO COEDEO SO COEDEO | E E E E E E E E E E E E E E | M tonna 0 0 9.145 6.074 7.035 2.093 2.693 4572 0.839 4572 0.839 4572 392 1111 2.705 392 1111 2.705 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 4572 392 457 | N S55 S55 S55 S55 S55 S55 S55 S5 | 0 5 tub 38 58 58 58 58 58 58 58 58 58 5 | P Tata yED 0.00 0.17 0.25 0.44 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.59 0.55 | 0 tafy 0 1401 2801 1402 5602 15403 12405 12405 12405 12405 12405 12405 22410 22410 22410 22410 22410 22511 25511 2 | R R Val,43 9 49441 197055 592244 295627 592244 249526 449471 543552 592244 249527 592244 249527 592244 249547 251257 2512 | |
| Aicrosoft E File Edit F39 A F39 A Tariablar do Ent (Candicianar O Candal ma 20 Candal ma 145 Candal m | xcel - ASE View Inser | EE - 200 t Format | | | et al. | | | Σ fx K K CELETO SO CELETO SO CELETO S | E Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu | M tenna a 0 9.145 2.093 6.074 7.708 2.393 6.5547 2.393 6.5547 2.393 4.572 2.393 4.572 4.392 4.392 4.392 4.545 | N 855 855 855 855 855 855 855 85 | 0 5 tob 38 58 58 50 50 50 50 50 50 50 50 50 50 | P Textel, y500 4 0.000 0.17 0.25 0.44 0.57 0.59 0.55 0.5 | 0 tafy intervention 1401 1400 1400 1200 1400 1200 15007 18208 19508 19508 19508 19508 22010 2001 200 | R R Val,fe3 0 49441 197765 29564 29564 29564 295529 444971 54285529 444971 54285529 444971 54285529 444971 5428529 542857 545857 54575757 54575757 54575757 5457575757 | |
| Aicrosoft E File Edit File Edit F39 A Tariablar da Ent (Candicianer O Candal ma 23 Candal ma 24 Candal ma 24 Candal ma 24 Candal ma 24 Candal ma 25 Candal ma | xcel - ASE View Inser View Inser View Inser Contrade view Informasi contrade view Informasi view Informasi | EE - 200 t Format | | | et al. | | | Σ fx K CELEO SO CELEO FI DI CELEO FI DI CELEO SO CELEO SO CELEO CALEGO FI DI CELEO SO CELEO CALEGO FI DI CELEO CELEO FI DI CELEO FI | E E E E E E E E E E E E E E E E E E E | Z + tenna 4 9.145 6.0744 7.805 2.093 26.17 7.805 2.305 2 | N SS5 SS5 SS5 SS5 SS5 SS5 SS5 SS | 0 5 5 5 5 5 5 5 5 5 5 5 5 5 | P Testal yBD 0 0.00 0.17 0.55 0.41 0.55 | 2 50% 1 1 1 1 1 1 1 1 1 1 1 1 1 | R Val, Fr3 0 49441 197755 247206 494412 296647 197755 247206 494412 296647 741618 395520 494973 395932 993932 993932 993932 | |
| Aicrosoft E File Edit File Edit | xcel - ASE View Inser View Inser Control Contro | E - 200 t Format | 0, Colo t Iools | | et al. | | | Σ fx K CEEPO EN CEEPO EN CEEPO | E E E E E E E E E E E E E E | Z + M 19.145 6.0744 7.805 26.17 5.405 2.093 26.17 5.405 1.208 2.657 6.3392 4.522 1.906 6.3292 4.522 1.906 6.3292 4.522 1.906 6.3292 4.522 1.906 6.3292 4.522 1.906 6.3292 4.522 1.906 6.328 1.906 6.328 1.906 6.328 1.906 6.328 1.906 6.328 1.906 | N N N N N N N N N N N N N N | 0 3 3 3 3 5 4 5 4 5 4 5 4 5 4 5 4 5 4 5 4 5 4 5 4 5 4 5 4 5 5 5 5 5 5 5 5 5 5 5 5 5 | P Tatal 2500 0.00 0.17 0.27 0.46 0.50 0.51 0.59 0.48 0.48 0.47 0.59 | 0 1401 2801 0 1401 2801 2802 14006 12605 14006 15407 15602 12605 12605 2300 23310 23310 23310 23310 | R R 49441 918524 197755 247206 2472006 247206 24706 247206 24706 247000000000000000000000000000000000000 | |
| Aicrosoft E File Edit File Edit File Edit File Edit File Edit Gadel and File File Edit File | xcel - ASE View Inser (inser Contrade (inser) (inser) | E - 200 t Format | | | et al. <u>Winc</u> Cu BURGOS ACTOS EUTAIRE TA CU CU CU CU CU CU CU CU CU CU | | | Σ fx K CEEDO SO CEEDO SO CEEDO SO CEEDO SO CEEDO SO CEEDO SO CEEDO TO | E E E E E E E E E E E E E E | M 19.145 6.074 9.145 6.074 5.405 5.405 5.405 5.405 6.339 4.552 9.06 3.922 4.522 9.4572 9.4572 9.4572 1.328 2.329 2.4517 2.329 2.4517 2.329 2.4517 2.329 2.4517 2.329 2.4517 2.329 2.4517 2.4512 2.4517 2.4512 2.451 2.4512 | N 1.00 1.00 1.00 1.00 1.00 1.20 2.20 2.40 2.20 2.40 2.20 3.00 3.20 3.40 3.20 3.40 3.20 3.40 | 0 8 tub 38 18 tub 19 0.33 0.71 0.73 0.74 0.74 0.73 0.74 1.00 1.00 1.00 1.00 1.00 1.00 | P Tatta yED 0.00 0.17 0.27 0.46 0.59 0.46 0.59 0.5 | 0 tafy 0 1401 2801 2801 2801 2803 8404 9804 9804 15407 15407 15407 15407 15407 15407 15407 22410 22511 22611 22611 22611 22611 | R R Val,43 98882 197755 294647 3495529 4494712 543852 593284 449471 294512 593284 99412 593283 999824 | |
| Aicrosoft E Eile Edit File Edit F39 A Pariabler de Ent (Candei ann 145 Candel ann 145 | xcel - ASE View Inser | EE - 200 t Format | | Data Data | et al. Wind PUESO ACTOR PUESO ACTOR PUESO 0.30 | | | Σ fx K CELINO ENO GELINO ENO GELINO ENO GELINO ENO GELINO ENO GELINO ENO GELINO TO TO TO | E E E E E E E E E E E E E E E E E E E | Z + tonna 0 9,145 6,074 7,708 2,093 6,074 7,708 2,203 6,554 7,805 2,233 6,554 7,805 2,233 4,572 4,906 4,572 4,945 4,94 | N 555 555 555 555 555 555 555 5 | 0 stability xB xB xB xB xB xB xB xB xB xB | P Tatel yBD (0.00 0.77 0.25 0.44 0.50 0.57 0.59 0.59 0 | 0 tafy in Ecca 0 1401 2801 1401 2801 1402 5602 12605 1507 15807 15807 15807 15807 15807 22410 22410 22811 22611 22611 22611 22611 | R R R 49441 197755 294647 395529 444971 542855 293264 444971 7910590 8409442 99328 99328 444971 7910590 8409442 99383 898824 | |
| Aicrosoft E Eile Edit File Edit | xcel - ASE View Inser Control of the second secon | E - 200 t Format | | Desta Desta Contraction Contra | et al. Wind Cu BUILED ACTON BUILED CU CU CU CU CU CU CU CU CU CU | | | | E Eu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu Bu | M tenga 0 9.145 2.093 2.093 2.293 2.293 2.293 2.293 2.293 2.293 2.293 2.293 2.293 2.293 2.293 2.293 2.293 2.455 455 455 455 455 455 455 455 | N SS5 SS5 SS5 SS5 SS5 SS5 SS5 SS | 0 34 55 58 58 58 58 58 58 58 58 58 | P Tatel 2560 2560 2560 2560 2560 2560 0.00 0.07 0.57 0.59 0.59 0.59 0.59 0.59 0.55 0.55 0.55 0.55 0.55 0.55 0.41 0.55 0.55 0.55 0.55 0.55 0.41 0.55 0.55 0.55 0.55 0.41 0.55 0.44 0.55 | Q tafr al, m°3 0 1401, m°3 2801 4202 5602 7003 8404 11205 12605 12605 12605 12605 22810 22810 22811 22812 | R R Val.fx3 0 49441 197765 296647 197765 592244 444971 44497 | |