U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER

DIRECT COAL LIQUEFACTION BASELINE DESIGN AND SYSTEM ANALYSIS

CONTRACT NO. DEAC22 90PC89857

TASK IV: TOPICAL REPORT

SEPTEMBER 1991
PITTSBURGH, PENNSYLVANIA

TASK IV: ALGORITHMS FOR EQUIPMENT SIZING, COSTING, AND TRAIN DUPLICATION

TABLE OF CONTENTS

		PAGE
1.	INTRODUCTION	1-1
2.	EXECUTIVE SUMMARY	2-1
3.	DISCUSSION OF RESULTS	3-1
3.1	Overview	3-1
3.2	Plant 2 Equipment Sizing Algorithms	3-2
3.3	Equations for Capital Cost Estimation	3-3
3.4	Multiple Train Requirements	3-4
3.5	Fortran User Block Model Implementation	3-5
3.6	ASPEN/SP Implementation	3-10

APPENDICES

A.	EQUIPMENT SIZE SCALING EQUATIONS	A-1
B.	FORTRAN SUBROUTINE FOR GENERATING AND REPORTING EQUIPMENT SIZES FOR PLANT 2	B-1
C.	SAMPLE EQUIPMENT SIZING OUTPUT	C-1
D.	ASPEN/SP COST MODEL USERS INSTRUCTIONS	D-1

U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER

DIRECT COAL LIQUEFACTION BASELINE DESIGN AND SYSTEM ANALYSIS

CONTRACT NO. DEAC22 90 PC89857

TASK IV: TOPICAL REPORT

SEPTEMBER 1991

PITTSBURGH, PENNSYLVANIA

Bechtel

3000 Post Oak Boulevard
Houston, Texas 77056-6503
Mailing address: P.O. Box 2166
Houston, Texas 77252-2166

September 20, 1991

U. S. Department of Energy
Pittsburgh Energy Technology Center
Mail Stop 922-H
P. O. Box 10940
Pittsburgh, PA 15236

Attention: Mr. Swenam Lee
Project Manager

Subject: D.O.E. Coal Liquefaction
Base Line Design and System Analysis
Contract No. DE-AC22 90PC89857
Bechtel Job No. 20952
TASK IV FINAL REPORT
Letter No. BLD-066

Dear Mr. Lee:

Attached for your files are three copies of the subject report. As requested, one of these copies is bound in a loose leaf 3-ring binder for your desk use.

Copies to other members of DOE, as required by the contract are separately and directly transmitted.

This final Task IV report incorporates all the DOE comments which appeared on the "draft" issue and brings Task IV to a 100% completion. The report does not contain any confidential information which, as agreed, would have been segregated in the appendix of this report.

On behalf of the Amoco/Bechtel project team we thank DOE/PETC for the opportunity to conduct this important direct coal liquefaction study.

Sincerely yours,

Sam N Habash

Sam N. Habash
Project Manager

Attachment

cc: Martin Byrnes, DOE/PETC
Robert Hamilton, DOE/PETC
A. B. Schachtschneider, AMOCO
File
Gilbert V. McGurl, DOE/PETC
Joanne Wastek, DOE/PETC

The information and data contained in this report are the result of an ecomonic evaluation and a preliminary design effort and because of the nature of this work no guarantees or warranties of performance, workmanship, or otherwise are made, either expressed or by implication.

U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER

DIRECT COAL LIQUEFACTION BASELINE DESIGN AND SYSTEM ANALYSIS

CONTRACT NO. DEAC22 90PC89857

TASK IV: TOPICAL REPORT

SEPTEMBER 1991
PITTSBURGH, PENNSYLVANIA

TASK IV: ALGORITHMS FOR EQUIPMENT SIZING, COSTING, AND TRAIN DUPLICATION

TABLE OF CONTENTS

		PAGE
1.	INTRODUCTION	1-1
2.	EXECUTIVE SUMMARY	2-1
3.	DISCUSSION OF RESULTS	3-1
3.1	Overview	3-1
3.2	Plant 2 Equipment Sizing Algorithms	3-2
3.3	Equations for Capital Cost Estimation	3-3
3.4	Multiple Train Requirements	3-4
3.5	Fortran User Block Model Implementation	3-5
3.6	ASPEN/SP Implementation	3-10

APPENDICES

A.	EQUIPMENT SIZE SCALING EQUATIONS	A-1
B.	FORTRAN SUBROUTINE FOR GENERATING AND REPORTING EQUIPMENT SIZES FOR PLANT 2	B-1
C.	SAMPLE EQUIPMENT SIZING OUTPUT	C-1
D.	ASPEN/SP COST MODEL USERS INSTRUCTIONS	D-1

1. INTRODUCTION

This report presents the Task IV topical report. Task IV concerns the development of mathematical algorithms and equations for equipment sizing and scale-up of the coal liquefaction section (Plant 2) and for costing and train duplication of the entire complex. These equations are being incorporated into the ASPEN/SP computer simulation program of the entire complex which is being developed in Task V.

The U. S. Department of Energy (DOE) has established a program to "foster an adequate supply of energy at a reasonable cost," in accordance with the National Energy Policy Plan IV (NEPP IV). A cost-effective direct coal liquefaction program sponsored by the Pittsburgh Energy Technology Center (PETC) is an integral part of NEPP IV.

The overall goal of the coal liquefaction program is "to develop the scientific and engineering knowledge base with which industry can bring economically competitive and environmentally acceptable advanced technology for the manufacture of synthetic liquid fuels from coal."

The present assignment from PETC is undertaken by Bechtel (in collaboration with Amoco as the main subcontractor) to develop a computer model for a baseline coal liquefaction design based on two-stage direct coupled catalytic reactors. Specifically, the scope of work calls for the development of:

1. A baseline design based on previous DOE/PETC results from the Wilsonville pilot plant and other engineering evaluations.

2. A cost estimate and economic analysis.

3. A computer model incorporating the above two steps over a wide range of capacities and selected process alternatives.

Task IV

2. EXECUTIVE SUMMARY

This report presents the Task IV topical report. Task IV concerns the development of the mathematical algorithms and models for equipment sizing, scale-up, costing, and train duplication for incorporation into the ASPEN/SP process simulation model being developed in Task V. Table 2-1 contains a description of the individual subtasks as detailed in the Task I Management Plan. Task IV was done in parallel with the process model development work of Task V.

Subtasks 4010 and 4020 called for a review of the existing ASPEN/SP equipment sizing equations for the major pieces of process equipment. This presumed that the simulation program would calculate the cost of each plant section by building it up from the costs of the individual pieces of major equipment. However, in line with conventional industrial practice, DOE/PETC agreed to a costing philosophy which involves a combination of individual equipment costing and factored costs based upon either the capacity of an entire plant or the capacity of an individual plant sub-section (see the topical report for Task III). The costing algorithms that are being implemented in the simulation model parallel this philosophy and eliminate the need for using the ASPEN/SP equipment sizing equations for costing purposes. Costing equations based on individual plant capacity or on individual plant subsections (Plant 2) are presented and discussed herein.

Since the coal liquefaction plant is the only plant in the entire complex that is being modeled in detail, equipment sizing equations were developed only for this plant. As discussed, these equipment sizes are not used directly for plant costing purposes.

Subtask 4030 deals with incorporating equipment size limitations in the process simulation model. Algorithms were developed which control the maximum train size of Plant 2 so as to keep the equipment sizes developed in the baseline design for Plant 2 below the maximum size limitation. This is reflected in the equipment sizing/scaling equations developed for Plant 2. Maximum size limits for the Plant 2 reactor diameter are handled in the kinetic model and are described in the topical report for Task V.

Subtask 4040 deals with the equations to handle multiple train requirements within a process unit. These equations were developed, and for flexibility, incorporate a train duplication parameter tailored to the particular plant. The number of trains may be supplied by the user as an input parameter. If the number of trains is not specified, the model will calculate the number of duplicate plants from the specified maximum and minimum plant capacities.

Subtasks 4050 and 4060 deal with the preparation and issuance of this document, the topical report for Task IV.

TABLE 2-1

TASK IV DESCRIPTION

Task IV concerns the development of the mathematical algorithms and models for equipment sizing, scale-up, costing, and train duplication for incorporation into the ASPEN/SP process simulation program that is being developed in Task V. Task IV has been done in parallel with Task V.

Following is a description of the individual subtasks of Task IV.

Subtask Number	Subtask Title	Description
4010	Review ASPEN equations	Review of existing ASPEN equipment sizing equations for major equipment
4020	Develop supplementary scale-up equations	Develop equations and algorithms, as required, to scale major equipment items
4030	Incorporate equipment size limitations	Incorporate major equipment size limits (reactor diameter, etc.) into scale-up equations
4040	Incorporate multiple train requirements	Incorporate into equipment scaling equations a means to handle multiple trains within a process unit. Philosophy may vary with process unit
4050	Draft topical report for Task 4	Report covering development of equations for equipment sizing, scaling, size limitations, and train requirements will be prepared
4060	Review of draft topical report for Task 4	The draft topical report for Task 4 will be reviewed with PETC prior to issue

3. DISCUSSION OF RESULTS

3.1 Overview

Task IV concerns the development of the mathematical algorithms and models for costing and train duplication for all plants, and for sizing of the major equipment in the coal liquefaction section (Plant 2). These equations are to be incorporated into the ASPEN/SP computer simulation model that is being developed in Task V.

For Plant 2, common equipment scaling algorithms were used to scale the sizes of the major pieces of process equipment. The scaling of the coal liquefaction reactors were not done using this basis, but are being sized by the kinetic model. This is described in the Task V report.

For all plants, the capital costs are being scaled from the baseline design case cost by a commonly used cost scaling equation that has been extended to allow for multiple trains.

All plants, other than the coal liquefaction plant, are being modeled by black box Fortran user block models. These models incorporate the capital cost scaling equation to predict the cost of each plant as a function of plant capacity and the number of duplicate plants.

The ASPEN/SP model also has been modified to utilize these cost scaling equations to predict the cost of individual pieces or groups of processing equipment as a function of capacity, where required.

3.2 Plant 2 Equipment Sizing Algorithms

Various pieces of process equipment are sized as a function of flow rate in order to maintain a constant key parameter for that piece of equipment. For example, tanks and separator drums are sized to maintain a constant residence time. This requires that the vessel volume vary linearly with the volumetric flow rate through it.

Heat exchanger areas and duties vary linearly with capacity. Pump and compressor power requirements also vary linearly with capacity. However, for distillation columns, the cross-sectional area varies linearly with capacity which means that the diameter varies with the square root of the flow rate.

The specific equations used to size the various individual pieces of process equipment for Plant 2 are given in Appendix A. These equations were programmed in a Fortran subroutine to calculate the sizes of the various major pieces of equipment in Plant 2. These equations are keyed to the material and/or energy flows calculated by the process model for each section of interest in Plant 2. Sizes are calculated for each major piece of equipment, including tanks, overhead receivers, separators, knockout drums, heat exchangers, towers, fired heaters, compressors, and pumps. A listing of the Fortran source code for this subroutine, which calculates and reports the sizes of the major equipment for Plant 2, is given in Appendix B.

For the coal liquefaction reactors, the process model calculates the required sizes based on reaction kinetics which may vary according to the process conditions specified for a particular run. The equipment sizing subroutine will obtain the reactor size results from the process model.

Appendix C shows the Equipment Summary Report for Plant 2. Equipment sizes are reported under the following categories: Reactors and Vessels, Heat Exchangers, Towers, Fired Heaters, Compressors, and Pumps. Individual items in each category are listed by plant section number, according to the major unit operations performed: Coal Slurry Preparation, Section 2.1; Coal Slurry Heating, Section 2.2; First- and Second-Stage Coal Liquefaction, Sections 2.3 and 2.4; Primary Separation, Section 2.5; Crude Product Atmospheric and Vacuum Fractionation Systems, Section 2.6; and Hydrogen Recycle System, Section 2.7.

3.3 Equations for Capital Cost Estimation

The capital cost for each plant is calculated as a function of the key flow rate by Equations 1 through 3. The key flow rate may be either the total flow rate of a specific feed or product stream or the flow rate of the major component in a specific feed or product stream. For example, the key flow rate for the coal cleaning plant is the clean coal product stream rate in Mlb/hr, and the key flow rate for the hydrogen plants is the useable hydrogen production rate (flow rate of hydrogen in the hydrogen-rich product gas stream) in MM SCF/hr of hydrogen.

$$COST = FCOST + (N - 1) * SCOST \quad \text{(Eq. 1)}$$

$$FCOST = A + B * (F_O / (N * RF_O))^E \quad \text{(Eq. 2)}$$

$$SCOST = F * FCOST \quad \text{(Eq. 3)}$$

Where:

COST = Total capital cost of all duplicate plants

FCOST = Capital cost of the first plant

SCOST = Capital cost of each subsequent duplicate plant after the first one

N = Total number of duplicate plants, including duplicates and spares

F_O = Total key flow rate of all duplicate plants in appropriate units, such as MM SCF/hour or Mlb/hour

RF_O = Reference key flow rate of a single plant in appropriate units, such as MM SCF/hour or Mlb/hour. This flow rate is used to scale the capital cost of a single plant as a function of plant capacity

A, B, E and F = Constants for the calculation of the capital cost of a single plant as a function of plant capacity

In the above capital cost equation, constant A is the fixed capital cost associated with a single plant. The sum of constants A and B is the capital cost of a single plant of capacity RF_O. Thus, constant B is the variable capital cost of a single plant of capacity RF_O. Constant E is the plant cost scaling exponent. Constant F is the cost reduction factor for the construction of duplicate plants after the first one.

3.4 Multiple Train Requirem nts

The calculation of the number of multiple trains for any specific plant is being handled in a very simplistic way in the Fortran user block models.

First the user has the option of specifying the number of operating duplicate plants. When the number of duplicate plants is specified, that value is used, and no calculations are performed.

Otherwise, the number of operating duplicate plants is calculated based on the supplied maximum and minimum capacity for that plant. The minimum number of operating duplicate plants is selected such that they all have the largest capacity that will not exceed the specified maximum capacity to provide the desired total plant capacity.

This can be expressed mathematically by

$$P = INT (F_O / RF_O) \qquad \text{(Eq. 4)}$$

If $RF_O - P * F_O$ is greater than zero, then increase the value of P by one.

Where:

P = Total number of operating duplicate plants

F_O = Total key flow rate of all duplicate plants in appropriate units, such as MM SCF/hour or Mlb/hour.

RF_O = Maximum key flow rate of a single plant in appropriate units, such as MM SCF/hour or Mlb/hour.

INT( ) = Integer function; generates the largest integer value that is less than the value of the argument. This is the standard Fortran integer function.

Thus, the capacity of each operating duplicate plant is F_O / P.

Each Fortran user block model has been programmed with the above logic for calculating the number of operating duplicate plants. In addition, for cost calculation purposes, provisions have been provided to allow the user to specify the number of spare plants that may be required only for operating reliability.

However, when the maximum capacity of a single plant is not specified, a single plant will be used. In addition, warning messages will be printed in the plant summary report if either the calculated capacity of a single plant is below the specified minimum capacity of a single plant, or if the capacity of a single plant is above the specified maximum capacity of a single plant.

3.5 Fortran Model Implem ntation

The previously described algorithms and equations have been programmed in the Fortran user block models for each of the process plants. Unit specific values are passed to and from the Fortran user block models via input parameters.

There are two types of input parameters to the Fortran user block models, integer parameters and real (floating point) parameters. The NINT= phrase of the PARAM sentence specifies the number of integer parameters, and the NREAL= phrase specifies the number real parameters. The values of the integer parameters are specified in the INT sentence, and the values of the real parameters are specified in the REAL sentence.

A common Fortran user block model input format was developed for Task V for passing these input values to each block model. In addition, parameters are passed to each Fortran user block model for calculating utility consumptions.

Described below are the common input parameters for all Fortran user block models. This general Fortran user block model has at least four integer input parameters (INT) and 70 real input parameters (REAL).

Parameter	Description
INT(1)	User block summary report control switch. 0 => Write the complete user block summary report. 1 => Skip the capital cost portion of the summary report. 2 => Skip the capital cost and utilities portions of the summary report. 3 => Skip writing the entire user block summary report.
INT(2)	User block summary report destination control switch. 0 => Write the user block summary report to the normal ASPEN/SP output report file. 1 => Write the user block summary report to a separate user block output report file.
INT(3)	Number of operating duplicate plants, excluding spares. If INT(3) = 0, the minimum number of operating duplicate plants, excluding spares, will be determined so that the capacity of each plant does not exceed the maximum plant capacity specified by parameter REAL(52). If INT(3) > 0, the number of operating duplicate plants, excluding spares.
INT(4)	History file additional output control switch. 0 => Write no additional output to the history file. 1 => Write only the subroutine entry and exit messages to the history file. 2 => Write some additional output to the history file. 3-5 => Write some more additional output to the history file. Larger values will generate more additional output.

Parameter	Description
REAL(1)-REAL(20)	Model specific parameters. These parameter locations are reserved for items which are specific to each user Fortran block process model, such as conversion, component distribution factors, etc.
REAL(21)	Constant factor for the power consumption, kw.
REAL(22)	Power consumption per CAP unit, kw/(CAP units).
REAL(23)	Constant factor for the 900 psig / 750 F steam consumption, Mlb/hr.
REAL(24)	900 psig / 750 F steam consumption per CAP unit, (Mlb/hr)/(CAP units).
REAL(25)	Constant factor for the 900 psig saturated steam consumption, Mlb/hr.
REAL(26)	900 psig saturated steam consumption per CAP unit, (Mlb/hr)/(CAP units).
REAL(27)	Constant factor for the 600 psig / 720 F steam consumption, Mlb/hr.
REAL(28)	600 psig / 720 F steam consumption per CAP unit, (Mlb/hr)/(CAP units).
REAL(29)	Constant factor for the 600 psig saturated steam consumption, Mlb/hr.
REAL(30)	600 psig saturated steam consumption CAP unit, (Mlb/hr)/(CAP units).
REAL(31)	Constant factor for the 150 psig saturated steam consumption, Mlb/hr.
REAL(32)	150 psig saturated steam consumption per CAP unit, of hydrogen (Mlb/hr)/(CAP units).
REAL(33)	Constant factor for the 50 psig saturated steam consumption, Mlb/hr.
REAL(34)	50 psig saturated steam consumption per CAP unit, (Mlb/hr)/(CAP units).
REAL(35)	Constant factor for the plant fuel consumption, MM BTU/hr.
REAL(36)	Plant fuel consumption per CAP unit, (MM BTU/hr)/(CAP units).

Parameter	Description
REAL(37)	Constant factor for the cooling water consumption, Mgal/hr.
REAL(38)	Cooling water consumption per CAP unit, (Mgal/hr)/(CAP units).
REAL(39)	Constant factor for the process water consumption, Mgal/hr.
REAL(40)	Process water consumption per CAP unit, (Mgal/hr)/(CAP units).
REAL(41)	Constant factor for the nitrogen consumption, MM SCF/hr.
REAL(40)	Nitrogen consumption per CAP unit, (MM SCF/hr)/(CAP units).
REAL (42) - REAL (50)	Future Use.
REAL(51)	Reference capacity of a single plant as defined by the key flow rate in CAP units for the calculation of the capital cost of a single plant as a function of plant capacity.
REAL(52)	Maximum size of a single plant as defined by the key flow rate in CAP units.
REAL(53)	Minimum size of a single plant as defined by the key flow rate in CAP units.
REAL(54)	Constant A in the plant costing equation, the fixed capital cost of a single plant in MM $.
REAL(55)	Constant B in the plant costing equation, the variable capital cost of a single plant having the key flow rate specified in variable REAL(51) in MM $.
REAL(56)	Constant E in the plant costing equation, the plant cost scaling exponent.
REAL(57)	Constant F in the plant costing equation, the cost reduction factor for the construction of duplicate plants after the first one.
REAL(58)	Number of spare plants.
REAL(59) - REAL (70)	Future Use.

The plant capacity as used in the various calculations is defined as a key flow rate. This key flow rate may be either the total flow rate of a specific stream or the flow

rate of the main component in a specific stream. This flow rate is expressed in an appropriate set of units such as MM SCF/hr, Mlb/hr, or MM SCF/hr of hydrogen. In this table, this set of units is called CAP units since the key flow rate item and appropriate units are not known.

All Fortran user block models have four common integer input parameters, INT(1) through INT(4). The first integer parameter, INT(1), is the user block summary report control switch which controls the printing of the three sections of the user block summary report. When INT(1) has a value of 0, all three sections of the summary report are printed. When it has a value of 1, only the stream report and utilities report sections are printed. When it has a value of 2, only the stream report section is printed. When it has a value of 3 or more, the entire user block model summary report is not printed.

The second integer parameter, INT(2), is the user Fortran block summary report destination control switch. When INT(2) has a value of 0 (zero), the summary report will be written to the normal ASPEN/SP report file. When it has a value of 1, the user block summary report will be written to a separate summary report file for each plant. This file name will begin with the letters DCL followed by some numbers and possibly some letters to identify the specific plant or option, and have a filespec of REP. Thus, the separate summary report file for Plant 1 is DCL01.REP; the separate report file for Plant 4 is DCL04.REP, and that for Plant 10 is DCL10.REP. Consequently, files DCL01B.REP, DCL01A1.REP, and DCL01A2.REP are the separate plant summary report files for the three Plant 1 coal cleaning options with the DCL01B.REP file being used for the baseline design case and the A1 and A2 files being used for the two alternate cases.

The third integer parameter, INT(3), is the number of operating duplicate plants, excluding spares. When INT(3) has a positive value, it is the number of operating duplicate plants that will is used in the calculation of the total capital cost of the plant. When INT(3) is zero, the number of operating duplicate plants will be calculated based on the specified maximum plant capacity given in parameter REAL(52).

The fourth integer parameter, INT(4), controls how much additional information is written to the history file for debugging purposes. When INT(4) has a value of 0 (zero), no information except any warning or error messages are written to the history file. When INT(4) has a value of 1 or greater, some additional information will be written to the history file. In general, the amount of information written to the history file increases as the value of INT(4) increases. Normally, INT(4) should be set either to 0 (zero) so that no additional information is written to the history file, or to 1 so that only the master subroutine entry and exit messages are written to the history file.

The initial group of REAL (floating point) parameters, normally 20, are used to specify model specific parameters which are used for the calculation of the output stream flow rates and compositions.

The next 30 REAL parameters, normally REAL(21) through REAL(50), are used to calculate the utilities consumptions or productions for this plant as a linear function of the plant capacity expressed as the flow rate of a key stream.

The next 10 REAL parameters, normally REAL(51) through REAL(60), are used to calculate the number of duplicate plants, the capacity of each duplicate plant, and the total capital cost of all the duplicate plants.

The final 10 REAL parameters, normally REAL(61) through REAL(70), are reserved for future use or additional unit specific model parameters.

3.6 ASPEN/SP IMPLEMENTATION

At our request, Simulation Sciences, Inc. has programmed the above described duplication and costing equations in Version 8.0 of ASPEN/SP for use with the standard ASPEN/SP unit operations, such as drums, pumps, compressors, fractionators, etc. This addition now gives ASPEN/SP the capability of estimating the cost of a specific piece or group of processing equipment from the known cost of a similar piece or group of processing equipment having a different capacity by the standard capacity cost scaling equation.

This model for costing of plant processes based only on plant capacity is called CAC01 (COST-CAPACITY). In addition, it calculates the chemical and catalyst costs also as a function of plant capacity. It may be used in either in a complete process simulation or in the stand-alone mode when the process capacity is provided.

Appendix D contains the users instructions prepared by Simulation Sciences, Inc. for this cost-capacity model.

APPENDIX A

EQUIPMENT SIZE SCALING EQUATIONS

APPENDIX A

EQUIPMENT SIZE SCALING EQUATIONS

The following equations are used to size the various pieces of process equipment.

I. Tanks, Overhead Receivers, Separators, and Compressor Knockout Drums

1. Maintain constant H/D.

2. Use correlation $\left(\frac{F_2}{F_1}\right)^{1/3} \times H_1$ or D_1 for calculating the new diameter D_2 and new height H_2.

   F_1 and F_2 are the baseline design case and current case feed rates, respectively.

II. Exchangers

Heat duty: linear with capacity.

Area: linear with capacity.

III. Pumps and Compressors

1. Pumps: BHP: linear with capacity.
   GPM: linear with capacity.

2. Compressors: BHP: linear with capacity.
   CFM: linear with capacity.

IV. Distillation Towers, Fractionators, and Strippers

1. Maintain constant tray spacing, number of trays and overall height.

2. New diameter $D_2 = D_1 \left(\frac{F_2}{F_1}\right)^{1/2}$

APPENDIX B

FORTRAN SUBROUTINE FOR GENERATING AND REPORTING EQUIPMENT SIZES FOR PLANT 2

(PRELIMINARY VERSION)

APPENDIX B

FORTRAN SUBROUTINE FOR GENERATING AND REPORTING EQUIPMENT SIZES FOR PLANT 2
(PRELIMINARY VERSION)

Following is a listing of a preliminary version of the Fortran subroutine that will be used in the process simulation model that is being developed in Task V to calculate and report the equipment sizes for Plant 2, the coal liquefaction plant.

```
C    Dummy main routine to test Subroutine USRXXT which calculates and
C    and prints the Equipment Summary Report for Plant 2.
C
C     Required user Fortran unit operation block declarations.
      IMPLICIT DOUBLE PRECISION (A-H, O-Z)
      DIMENSION F(7)
C
      NHISTRY = 6
      NOUT    = 6
      IPASS   = 4
      INT1    = 0
      INT2    = 1
      INT3    = 0
      KTEST   = 2
C
C     Load the key flow rates in the seven plant section for sizing the
C     reactors and vessels, heat exchangers, towers, fired heaters,
C     compressors and pumps in that section.
C     The seven plant sections are:
C       1.  Coal Slurry Preparation Section
C       2.  Coal Slurry Heating Section
C       3.  First Stage Reaction Section
C       4.  Second Stage Reaction Section
C       5.  Primary Separation Section
C       6.  Crude Product Fractionation Section
C       7.  Recycle Gas Compression Section
      F(1) = 10000.0D0
      F(2) = 10000.0D0
      F(3) = 10000.0D0
      F(4) = 10000.0D0
      F(5) = 10000.0D0
      F(6) = 10000.0D0
      F(7) = 10000.0D0
C
      CALL USRXXT (NHSTRY, NOUT, IPASS, INIT1, INIT2, INIT3, KTEST,
     1  F)
C
      STOP
      END
C
```

```
C$ USRXXT
      SUBROUTINE USRXXT (NHSTRY, NOUT, IPASS, INT1, INT2, INIT3, KTEST,
     1  F)
C
C     This subroutine calculates and prints the sizes of the major
C     equipment for Plant 2 (coal liquefaction plant) by scaling them
C     from the baseline design case.
C
C     Prepared under DOE contract no. DE-AC22 90PC89857.
C
C     FUNCTION (MODEL, REPORT, OR BOTH): Report
C     PROGRAMMED:  Sam Hayes (June 25, 1991)
C     REVISED:     Sheldon J. Kramer (August 19, 1991)
C
C     Calling arguments:
C      NHSTRY = Logical unit number of the history file.
C      NOUT   = Logical unit number of the plant output report file.
C      IPASS  = The results pass flag.
C      INT1   = User block output report control switch.
C               0 => Write the complete user block summary report.
C               1 => Skip the capital cost section of the report.
C               2 => Skip the capital cost and utilities sections of
C                    the report.
C               3 => Skip writing the entire user block summary report.
C      INT2   = User block summary report destination control switch.
C               0 => Write the complete user block summary report
C                    to the normal ASPEN/SP output report file.
C               1 => Write the complete user block summary report
C                    to a separte user block output report file on
C                    logical unit 62.
C      KTEST  = Switch for controlling the printing to the history file.
C      F(J)   = Actual flow rates in plant section J for scaling the
C               sizes of the reactors and vessels, heat exchangers,
C               towers, fired heaters, compressors and pumps in that
C               section.  The seven plant sections are:
C               1.  Coal Slurry Preparation Section
C               2.  Coal Slurry Heating Section
C               3.  First Stage Reaction Section
C               4.  Second Stage Reaction Section
C               5.  Primary Separation Section
C               6.  Crude Product Fractionation Section
C               7.  Recycle Gas Compression Section
C
C     Variable declarations.
      IMPLICIT DOUBLE PRECISION (A-H, O-Z)
C     The following variables contain the reference flow rates and
C     equipment dimensions for the baseline design case.
      DIMENSION XRF(7), RANDV(2,23), PUMPS(2,21), HEATEX(22),
     1  TOWERS(2,6), FHEAT(2,4), COMP(2,3)
C     The following variables contain the actual flow rates and
C     equipment dimensions for the current case.
```

```
      DIMENSION F(7), RV(2,23), PMP(2,21), HX(22), TWR(2,6), FHT(2,4),
     1  CMP(2,3)
C
C     Set the reference flow rates for the baseline design case.
      DATA XRF / 7 * 10000.0D0 /
C
C     Set the length and diameter (in feet) of the reactors and vessels
C     for the baseline design case.
      DATA RANDV / 11.0,11.0, 16.0,13.0, 43.0,18.0, 32.0,4.0, 9.0,3.0,
     1  85.5,15.0, 85.5,15.0, 22.5,10.5, 26.0,9.5, 24.0,9.5, 19.0,9.5,
     2  22.5,6.5, 12.0,3.0, 27.0,9.5, 26.0,6.5, 24.5,7.0, 26.5,7.5,
     3  13.0,6.5, 29.5,10.5, 26.0,6.5, 8.0,4.0, 16.0,4.0, 8.0,4.0 /
C
C     Set the duties of the heat exchangers (MM Btu/hr) for the base-
C     line design case.
      DATA HEATEX /34.5, 4.3, 6.5, 6.5, 24.8, 9.1, 13.9, 3.5, 30.8,
     1  28.6, 36.3, 5.9, 7.0, 0.5, 34.6, 6.2, 1.7, 3.9, 30.3, 15.6,
     2  0.08, 0.003 /
C
C     Set the height and diameter (in feet) of the towers for the base-
C     line design case.
      DATA TOWERS / 150.0,5.6, 150.0,8.5, 30.0,2.5, 60.0,6.5, 60.0,16,
     1  30.0,3.5 /
C
C     Set the absorbed duty (MM Btu/hr) and fired duty (MM Btu/hr) of
C     the fired heaters for the baseline design case.
      DATA FHEAT / 88.0,115.0, 44.0,57.0, 19.9,25.6, 15.7,19.9 /
C
C     Set the flow rate (MMSCFD) and brake horsepower (hp) of the
C     compressors for the baseline design case.
      DATA COMP / 176.0, 1086.0, 0.4, 25.0, 0.03, 2.0 /
C
C     Set the flow rate (gpm) and brake horsepower (hp) of the pumps
C     for the baseline design case.
      DATA PUMPS / 1.0,1.0, 15.0,1.0, 1100.0,70.0, 535.0,3450.0,
     1  1625.0,120.0, 15.0,1.0, 1.0,1.0, 630.0,20.0, 455.0,30.0,
     2  215.0,545.0, 1145.0,150.0, 370.0,50.0, 120.0,45.0,
     3  1110.0,150.0, 15.0,50.0, 1500.0,50.0, 120.0,50.0, 85.0,100.0,
     4  455.0,100.0, 90.0,50.0, 5.0,50.0 /
C
C
C     In equations below, XRF() is the reference flow rate for the
C     baseline design case, and Fx is the actual flow rate for this
C     case.
C
C     Size the reactors and vessels.
      DO 29 J = 1, 2
        DO 21 K = 1, 5
          RV(J,K) = (F(1) / XRF(1)) ** 0.33333 * RANDV(J,K)
   21   CONTINUE
        RV(J,6) = (F(3) / XRF(3)) ** 0.33333 * RANDV(J,K)
        RV(J,7) = (F(4) / XRF(4)) ** 0.33333 * RANDV(J,K)
```

```
C       The sizes of the coal liquefaction reactors calculated by the
C       above equation are incorrect.  The kinetic model will size
C       these reactors by accounting for hydrodynamic effects.
        DO 25 K = 8, 18
          RV(J,K) = (F(5) / XRF(5)) ** 0.33333 * RANDV(J,K)
   25   CONTINUE
        DO 26 K = 19, 21
          RV(J,K) = (F(6) / XRF(6)) ** 0.33333 * RANDV(J,K)
   26   CONTINUE
        DO 27 K = 22, 23
          RV(J,K) = (F(7) / XRF(7)) ** 0.33333 * RANDV(J,K)
   27   CONTINUE
   29 CONTINUE
C
C     Size the heat exchangers.
      DO 31 K = 1, 3
        HX(K) = (F(1) / XRF(1)) * HEATEX(K)
   31 CONTINUE
      DO 35 K = 4, 10
        HX(K) = (F(5) / XRF(5)) * HEATEX(K)
   35 CONTINUE
      DO 36 K = 11, 22
        HX(K) = (F(6) / XRF(6)) * HEATEX(K)
   36 CONTINUE
C
C     Size the towers.
      DO 46 J = 1, 6
        TWR (1,J) = TOWERS(1,J)
        TWR (2,J) = SQRT(F(6) / XRF(6)) * TOWERS(2,J)
   46 CONTINUE
C
C     Size the fired heaters.
      DO 59 J = 1, 2
        FHT(J,1) = (F(2) / XRF(2)) * FHEAT(J,1)
        FHT(J,2) = (F(3) / XRF(3)) * FHEAT(J,2)
        DO 56 K = 3, 4
          FHT(J,K) = (F(6) / XRF(6)) * FHEAT(J,K)
   56   CONTINUE
   59 CONTINUE
C
C     Size the compressors.
      DO 69 J = 1, 2
        DO 66 K = 2, 3
          CMP(J,K) = (F(6) / XRF(6)) * COMP(J,K)
   66   CONTINUE
C       The recycle gas compressor.
        CMP(J,1) = (F(7) / XRF(7)) * COMP(J,1)
   69 CONTINUE
C
```

```
C     Size the pumps.
      DO 79 J = 1, 2
        DO 71 K = 1, 3
          PMP(J,K) = (F(1) / XRF(1)) * PUMPS(J,K)
   71   CONTINUE
        PMP(J,4) = (F(3) / XRF(3)) * PUMPS(J,4)
        DO 75 K = 5, 10
          PMP(J,K) = (F(5) / XRF(5)) * PUMPS(J,K)
   75   CONTINUE
        DO 76 K = 11, 21
          PMP(J,K) = (F(6) / XRF(6)) * PUMPS(J,K)
   76   CONTINUE
   79 CONTINUE
C
C     Print the calculated results in tables.
      WRITE (NOUT, 600)
  600 FORMAT (1H1, 29X, 'EQUIPMENT SUMMARY' /
     1  25X, 'Plant 2 - Coal Liquefaction' //
     2  28x, 'Reactors and Vessels' /
     3  28X, 20('_') // )
      WRITE (NOUT, 601)
  601 FORMAT (2X, 'Equipment', 38X, 'Length', 8X, 'Diameter' /
     1  5X, 'No.', 6X, 'Equipment Description',
     2  12X, '(T-T in ft)', 4X, '(ID in ft)' /
     3  2X, 9('_'), 3X, 30('_'), 3X, 2(11('_'), 4X) / )
C
      WRITE (NOUT, 602) ((RV(J,K), J = 1, 2), K = 1, 5)
  602 FORMAT (2X, 'COAL SLURRY PREPARATION' /
     1  2X,'2.1- C101   Slurry Vortex Mx Tnk Innr Shll',6X,2(F5.1,9X) /
     2  2X,'            Slurry Vortex Mx Tnk Outr Shll',6X,2(F5.1,9X) /
     3  2X,'2.1- C102   Slurry Surge Tank             ',6X,2(F5.1,9X) /
     4  2X,'2.1- C103   Slurry Surge Tank Vent Scrubbr',6X,2(F5.1,9X) /
     5  2X,'2.1- C104   Scrubber Overhead Receiver    ',6X,2(F5.1,9X)/)
C
      WRITE (NOUT, 603) ((RV(J,K), J = 1, 2), K = 6, 7)
  603 FORMAT (2X, 'REACTOR SYSTEM' /
     1  2X,'2.3- C105   Coal Liquefaction - Stage 1   ',6X,2(F5.1,9X) /
     2  2X,'2.4- C106   Coal Liquefaction - Stage 2   ',6X,2(F5.1,9X)/)
C
      WRITE (NOUT, 604) ((RV(J,K), J = 1, 2), K = 8, 18)
  604 FORMAT (2X, 'PRIMARY SEPARATION' /
     1  2X,'2.5- C107   Hot High Pressure Separator   ',6X,2(F5.1,9X) /
     2  2X,'2.5- C108   Hot Low Pressure Separator    ',6X,2(F5.1,9X) /
     3  2X,'2.5- C109   Recycle Slurry Hold Drum      ',6X,2(F5.1,9X) /
     4  2X,'2.5- C110   Warm High Pressure Separator  ',6X,2(F5.1,9X) /
     5  2X,'2.5- C111   Warm Low Pressure Separator   ',6X,2(F5.1,9X) /
     6  2X,'2.5- C112   Recy Slry Hold Drm Cond Accum ',6X,2(F5.1,9X) /
     7  2X,'2.5- C113   Cold High Pressure Separator  ',6X,2(F5.1,9X) /
     8  2X,'2.5- C114   Cold Low Pressure Separator   ',6X,2(F5.1,9X) /
     9  2X,'2.5- C115   Wash Water Drum               ',6X,2(F5.1,9X) /
     A  2X,'2.5- C116   Sour Water Drum               ',6X,2(F5.1,9X) /
     B  2X,'2.5- C117   Compressor Knockout Drum      ',6X,2(F5.1,9X)/)
```

```
C
      WRITE (NOUT, 605) ((RV(J,K), J = 1, 2), K = 19, 21)
  605 FORMAT (2X, 'CRUDE PRODUCT FRACTIONATION' /
     1  2X, 'ATMOSPHERIC TOWER' /
     2  2X,'2.6- C117    Feed Flash Drum              ',6X,2(F5.1,9X) /
     3  2X,'2.6- C120    Overhead Accumulator         ',6X,2(F5.1,9X) /
     4  2X,'2.6- C121    Vent Gas Compress Knockout   ',6X,2(F5.1,9X)/)
C
      WRITE (NOUT, 606) ((RV(J,K), J = 1, 2), K = 22, 23)
  606 FORMAT (2X, 'CRUDE PRODUCT FRACTIONATION'/
     1  2X, 'VACUUM TOWER' /
     2  2X,'2.6- C124   Vacuum Jet Condenser Accum    ',6X,2(F5.1,9X) /
     3  2X,'2.6- C125   Vent Gas Compress Knockout    ',6X,2(F5.1,9X)//)
C
      WRITE (NOUT, 607)
  607 FORMAT (1H1, 28X, 'Heat Exchangers' /
     1  29X, 15('_') // )
      WRITE (NOUT,608)
  608 FORMAT (2X, 'Equipment', 40X, 'Duty', 10X, 'Type of' /
     1  5X, 'No.', 6X, 'Equipment Description',
     2  13X, '(MM Btu/hr)', 5X, 'Exchanger' /
     3  2X, 9('_'), 3X, 30('_'), 4X, 2(11('_'), 4X) / )
C
      WRITE (NOUT, 609) (HX(J), J = 1, 3)
  609 FORMAT (2X, 'COAL SLURRY PREPARATION' /
     1  2X,'2.1- E101   Recycle Slurry Steam Generator',6X,F5.1,7X,
     1                                                 'Shell & Tube' /
     2  2X,'2.1- E102   Recycle Solvent Cooler        ',6X,F5.1,7X,
     2                                                 'Air-Fin'      /
     3  2X,'2.1- E103   Slurry Surge Tank Ovhd Cond   ',6X,F5.1,7X,
     3                                                 'Air-Fin'     /)
C
      WRITE (NOUT, 610) (HX(J), J = 4, 10)
  610 FORMAT (2X, 'PRIMARY SEPARATION' /
     1  2X,'2.5- E104   Hot LP Sep Vapor Cooler       ',6X,F5.1,7X,
     1                                                 'Shell & Tube' /
     2  2X,'2.5- E105   Hot LP Sep Vapor Steam Gen    ',6X,F5.1,7X,
     2                                                 'Shell & Tube' /
     3  2X,'2.5- E106   1st Hydrogen Preheater        ',6X,F5.1,7X,
     3                                                 'Shell & Tube' /
     4  2X,'2.5- E107   2nd Hydrogen Preheater        ',6X,F5.1,7X,
     4                                                 'Shell & Tube' /
     5  2X,'2.5- E108   Slurry Hold Drum Vapor Cond   ',6X,F5.1,7X,
     5                                                 'Air-Fin'      /
     6  2X,'2.5- E109   Warm HP Sep Vapor Cooler      ',6X,F5.1,7X,
     6                                                 'Air-Fin'      /
     7  2X,'2.5- E110   Warm LP Sep Vapor Cooler      ',6X,F5.1,7X,
     7                                                 'Air-Fin'     /)
C
```

```
      WRITE (NOUT, 611) (HX(J), J = 11, 14)
  611 FORMAT (2X, 'CRUDE PRODUCT FRACTIONATION' /
     1  2X, 'ATMOSPHERIC TOWER' /
     2  2X,'2.6- E111   Atmos Frac Ovhd Condenser     ',6X,F5.1,7X,
     2                                                 'Air-Fin'      /
     3  2X,'2.6- E112   AGO Product Cross Exchange    ',6X,F5.1,7X,
     3                                                 'Shell & Tube' /
     4  2X,'2.6- E113   AGO Product Cooler            ',6X,F5.1,7X,
     4                                                 'Shell & Tube' /
     5  2X,'2.6- E121   Atm VG Comp Aftercooler       ',6X,F5.1,7X,
     5                                                 'Air-Fin'      /)
C
      WRITE (NOUT, 612) (HX(J), J = 15, 22)
  612 FORMAT (2X, 'CRUDE PRODUCT FRACTIONATION' /
     1  2X, 'VACUUM TOWER ' /
     2  2X,'2.6- E114   LVGO Pumparound Cooler        ',6X,F5.1,7X,
     2                                                 'Air-Fin'      /
     3  2X,'2.6- E115   HVGO Pumparound Steam Gen     ',6X,F5.1,7X,
     3                                                 'Shell & Tube'/
     4  2X,'2.6- E116   HVGO Pumparound Cooler        ',6X,F5.1,7X,
     4                                                 'Air-Fin'      /
     5  2X,'2.6- E117   HVGO Product Steam Gen        ',6X,F5.1,7X,
     5                                                 'Shell & Tube'/
     6  2X,'2.6- E118   Bottoms Product Steam Gen     ',6X,F5.1,7X,
     6                                                 'Shell & Tube'/
     7  2X,'2.6- E119   1st Steam Jet Condenser       ',6X,F5.1,7X,
     7                                                 'Shell & Tube'/
     8  2X,'2.6- E120   2nd Steam Jet Condenser       ',6X,F5.2,7X,
     8                                                 'Shell & Tube'/
     9  2X,'2.6- E122   Vac VG Aftercooler            ',6X,F5.3,7X,
     9                                                 'Shell & Tube'/)
C
      WRITE (NOUT, 613)
  613 FORMAT (1H1, 32X, 'Towers' /
     1  33X, 6('_') // )
      WRITE (NOUT, 614)
  614 FORMAT (2X, 'Equipment', 39X, 'Length', 8X, 'Diameter' /
     1  5X, 'No.', 6X, 'Equipment Description',
     2  13X, '(T-T in ft)', 4X, '(ID in ft)' /
     3  2X, 9('_'), 3X, 30('_'), 4X, 2(11('_'), 4X) / )
C
      WRITE (NOUT, 615) ((TWR(J,K), J = 1, 2), K = 1, 6)
  615 FORMAT (2X, 'CRUDE PRODUCT FRACTIONATION' /
     1  2X,'2.6- C118   Atmospheric Fractionator      ',6X,2(F5.1,9X) /
     1  2X,'                                          ',6X,2(F5.1,9X) /
     2  2X,'2.6- C119   AGO Stripper                  ',6X,2(F5.1,9X) /
     3  2X,'2.6- C122   Vacuum Fractionator           ',6X,2(F5.1,9X) /
     3  2X,'                                          ',6X,2(F5.1,9X) /
     4  2X,'2.6- C123   Vac Recy Solvent Stripper     ',6X,2(F5.1,9X)//)
C
```

```
      WRITE (NOUT, 616)
  616 FORMAT (//31X, 'Fired Heaters' /
     1  31X, 13('_') // )
      WRITE (NOUT, 617)
  617 FORMAT (49X,'Absorbed        Fired' /
     1  2X, 'Equipment', 40X, 'Duty', 11X, 'Duty' /
     2  5X, 'No.', 6X,' Equipment Description              '
     3  '(MM Btu/hr)', 4X, '(MM Btu/hr)' /
     4  2X, 9('_'), 3X, 30('_'), 3X, 2(12('_'), 3X) / )
C
      WRITE (NOUT, 618) ((FHT(J,K), J = 1, 2), K = 1, 4)
  618 FORMAT (2X,'REACTION SYSTEM' /
     1  2X,'2.2- F101   Coal Slurry Heater_          ',6X,2(F5.1,9X)/
     2  2X,'2.3- F102   Gas Heater                   ',6X,2(F5.1,9X)//
     3  2X, 'CRUDE PRODUCT FRACTIONATION' /
     4  2X,'2.6- F103   Atmospheric Fractionator Htr  ',6X,2(F5.1,9X)/
     5  2X,'2.6- F104   Vacuum Fractionator Preheater ',6X,2(F5.1,9X)//)
C
      WRITE (NOUT, 619)
  619 FORMAT (//31X, 'Compressors' /
     1  31X, 11('_') // )
      WRITE (NOUT, 620)
  620 FORMAT (2X, 'Equipment', 37X, 'Flow Rate', 8X, 'Brake'/
     1  5X, 'No.', 6X, 'Equipment Description      ',
     2  7X, '(MMSCFD)', 7X, 'Horsepower' /
     3  2X, 9('_'), 3X, 30('_'), 3X, 2(12('_'), 3X) / )
C
      WRITE (NOUT,621) ((CMP(J,K), J = 1, 2), K = 1, 3)
  621 FORMAT (2X, 'PRIMARY SEPARATION' /
     1  2X,'2.7- K101   Recycle Hydrogen             ',6X,2(F5.0,9X)//
     2  2X,'CRUDE PRODUCT FRACTIONATION' /
     3  2X,'2.6- K102   Atmospheric Vent Gas         ',6X,2(F5.1,9X)/
     4  2X,'2.6- K103   Vacuum Vent Gas              ',6X,2(F5.2,9X)//)
C
      WRITE (NOUT, 622)
  622 FORMAT (1H1, 33X, 'Pumps' /
     1  34X, 5('_') //)
      WRITE (NOUT, 623)
  623 FORMAT (2X, 'Equipment', 37X, 'Flow Rate', 9X, 'Brake' /
     1  5X, 'No.', 6X, 'Equipment Description            ',
     2  3X, '(gpm)', 9X, 'Horsepower' /
     3  2X, 9('_'), 3X, 30('_'), 3X, 2(12('_'), 4X) / )
C
```

```
      WRITE (NOUT, 624) ((PMP(J,K), J = 1, 2), K = 1, 10)
  624 FORMAT (2X, 'COAL SLURRY PREPARATION'/
     1  2X,'2.1- G101   Scrubber Condenser Product    ',6X,2(F6.1,9X)/
     2  2X,'2.1- G102   Scrubber Sour Water           ',6X,2(F6.1,9X)/
     3  2X,'2.1- G103   Coal Slurry Booster Pump      ',6X,2(F6.1,9X)//
     4  2X, 'REACTION SYSTEM' /
     5  2X,'2.3- G105   Slurry Charge                 ',6X,2(F6.1,9X)/
     6  2X,'2.3- G108   Stage 1 Ebullating            ',5X,
     7     '------ Proprietary ------ '                                /
     8  2X,'2.4- G109   Stage 2 Ebullating            ',5X,
     9     '------ Proprietary ------ '                                //
     A  2X, 'PRIMARY SEPARATION' /
     B  2X,'2.5- G110   Slurry Recycle Pump           ',6X,2(F6.1,9X)/
     C  2X,'2.5- G111   Recy Slr Hld Drm Cnd Acumm Liq',6X,2(F6.1,9X)/
     D  2X,'2.5- G112   Recy Slr Dr Cnd ac Sour Water ',6X,2(F6.1,9X)/
     E  2X,'2.5- G113   Sour Water Drum Pump          ',6X,2(F6.1,9X)/
     F  2X,'2.5- G114   Wash Water LP Pump            ',6X,2(F6.1,9X)/
     G  2X,'2.5- G115   Wash Water HP Pump            ',6X,2(F6.1,9X)/)
C
      WRITE (NOUT, 625) ((PMP(J,K), J = 1, 2), K = 11, 21)
  625 FORMAT (2X, 'CRUDE PRODUCT FRACTIONATION' /
     1  2X, 'ATMOSPHERIC TOWER'/
     2  2X,'2.6- G116   Atmos Heater Charge           ',6X,2(F6.1,9X)/
     3  2X,'2.6- G117   Reflux Naphtha Product        ',6X,2(F6.1,9X)/
     4  2X,'2.6- G118   AGO Product                   ',6X,2(F6.1,9X)/
     5  2X,'2.6- G119   Bottoms Product               ',6X,2(F6.1,9X)/
     6  2X,'2.6- G120   Atmos Ovhd Accum Sour Water   ',6X,2(F6.1,9X)//
     7  2X, 'CRUDE PRODUCT FRACTIONATION' /
     8  2X, 'VACUUM TOWER' /
     9  2X,'2.6- G121   LVGO Pumparound               ',6X,2(F6.1,9X)/
     A  2X,'2.6- G122   HVGO Pumparound               ',6X,2(F6.1,9X)/
     B  2X,'2.6- G123   HVGO Product                  ',6X,2(F6.1,9X)/
     C  2X,'2.6- G124   Bottoms Product               ',6X,2(F6.1,9X)/
     D  2X,'2.6- G125   Vacuum Jet Accum Sour Water   ',6X,2(F6.1,9X)/
     E  2X,'2.6- G126   Vacuum Jet Accum Product      ',6X,2(F6.1,9X)/)
C
      STOP
      END
```

APPENDIX C

SAMPLE EQUIPMENT SIZING OUTPUT

APPENDIX C

SAMPLE EQUIPMENT SIZING OUTPUT

EQUIPMENT SUMMARY
Plant 2 - Coal Liquefaction

Reactors and Vessels

Equipment No.	Equipment Description	Length (T-T in ft)	Diameter (ID in ft)
COAL SLURRY PREPARATION			
2.1- C101	Slurry Vortex Mx Tnk Innr Shll	11.0	11.0
	Slurry Vortex Mx Tnk Outr Shll	16.0	13.0
2.1- C102	Slurry Surge Tank	43.0	18.0
2.1- C103	Slurry Surge Tank Vent Scrubbr	32.0	4.0
2.1- C104	Scrubber Overhead Receiver	9.0	3.0
REACTOR SYSTEM			
2.3- C105	Coal Liquefaction - Stage 1	85.5	15.0
2.4- C106	Coal Liquefaction - Stage 2	85.5	15.0
PRIMARY SEPARATION			
2.5- C107	Hot High Pressure Separator	22.5	10.5
2.5- C108	Hot Low Pressure Separator	26.0	9.5
2.5- C109	Recycle Slurry Hold Drum	24.0	9.5
2.5- C110	Warm High Pressure Separator	19.0	9.5
2.5- C111	Warm Low Pressure Separator	22.5	6.5
2.5- C112	Recy Slry Hold Drm Cond Accum	12.0	3.0
2.5- C113	Cold High Pressure Separator	27.0	9.5
2.5- C114	Cold Low Pressure Separator	26.0	6.5
2.5- C115	Wash Water Drum	24.5	7.0
2.5- C116	Sour Water Drum	26.5	7.5
2.5- C117	Compressor Knockout Drum	13.0	6.5
CRUDE PRODUCT FRACTIONATION ATMOSPHERIC TOWER			
2.6- C117	Feed Flash Drum	29.5	10.5
2.6- C120	Overhead Accumulator	26.0	6.5
2.6- C121	Vent Gas Compress Knockout	8.0	4.0
CRUDE PRODUCT FRACTIONATION VACUUM TOWER			
2.6- C124	Vacuum Jet Condenser Accum	16.0	4.0
2.6- C125	Vent Gas Compress Knockout	8.0	4.0

APPENDIX C (Continued)

Heat Exchangers

Equipment No.	Equipment Description	Duty (MM Btu/hr)	Type of Exchanger
COAL SLURRY PREPARATION			
2.1- E101	Recycle Slurry Steam Generator	34.5	Shell & Tube
2.1- E102	Recycle Solvent Cooler	4.3	Air-Fin
2.1- E103	Slurry Surge Tank Ovhd Cond	6.5	Air-Fin
PRIMARY SEPARATION			
2.5- E104	Hot LP Sep Vapor Cooler	6.5	Shell & Tube
2.5- E105	Hot LP Sep Vapor Steam Gen	24.8	Shell & Tube
2.5- E106	1st Hydrogen Preheater	9.1	Shell & Tube
2.5- E107	2nd Hydrogen Preheater	13.9	Shell & Tube
2.5- E108	Slurry Hold Drum Vapor Cond	3.5	Air-Fin
2.5- E109	Warm HP Sep Vapor Cooler	30.8	Air-Fin
2.5- E110	Warm LP Sep Vapor Cooler	28.6	Air-Fin
CRUDE PRODUCT FRACTIONATION ATMOSPHERIC TOWER			
2.6- E111	Atmos Frac Ovhd Condenser	36.3	Air-Fin
2.6- E112	AGO Product Cross Exchange	5.9	Shell & Tube
2.6- E113	AGO Product Cooler	7.0	Shell & Tube
2.6- E121	Atm VG Comp Aftercooler	.5	Air-Fin
CRUDE PRODUCT FRACTIONATION VACUUM TOWER			
2.6- E114	LVGO Pumparound Cooler	34.6	Air-Fin
2.6- E115	HVGO Pumparound Steam Gen	6.2	Shell & Tube
2.6- E116	HVGO Pumparound Cooler	1.7	Air-Fin
2.6- E117	HVGO Product Steam Gen	3.9	Shell & Tube
2.6- E118	Bottoms Product Steam Gen	30.3	Shell & Tube
2.6- E119	1st Steam Jet Condenser	15.6	Shell & Tube
2.6- E120	2nd Steam Jet Condenser	.08	Shell & Tube
2.6- E122	Vac VG Aftercooler	.003	Shell & Tube

APPENDIX C (Continued)

Towers

Equipment No.	Equipment Description	Length (T-T in ft)	Diameter (ID in ft)
CRUDE PRODUCT FRACTIONATION			
2.6- C118	Atmospheric Fractionator	150.0	5.6
		150.0	8.5
2.6- C119	AGO Stripper	30.0	2.5
2.6- C122	Vacuum Fractionator	60.0	6.5
		60.0	16.0
2.6- C123	Vac Recy Solvent Stripper	30.0	3.5

Fired Heaters

Equipment No.	Equipment Description	Absorbed Duty (MM Btu/hr)	Fired Duty (MM Btu/hr)
REACTION SYSTEM			
2.2- F101	Coal Slurry Heater	88.0	115.0
2.3- F102	Gas Heater	44.0	57.0
CRUDE PRODUCT FRACTIONATION			
2.6- F103	Atmospheric Fractionator Htr	19.9	25.6
2.6- F104	Vacuum Fractionator Preheater	15.7	19.9

Compressors

Equipment No.	Equipment Description	Flow Rate (MMSCFD)	Brake Horsepower
PRIMARY SEPARATION			
2.7- K101	Recycle Hydrogen	176.	1086.
CRUDE PRODUCT FRACTIONATION			
2.6- K102	Atmospheric Vent Gas	.4	25.0
2.6- K103	Vacuum Vent Gas	.03	2.00

APPENDIX C (Continued)

Pumps

Equipment No.	Equipment Description	Flow Rate (gpm)	Brake Horsepower
COAL SLURRY PREPARATION			
2.1- G101	Scrubber Condenser Product	1.0	1.0
2.1- G102	Scrubber Sour Water	15.0	1.0
2.1- G103	Coal Slurry Booster Pump	1100.0	70.0
REACTION SYSTEM			
2.3- G105	Slurry Charge	535.0	3450.0
2.3- G108	Stage 1 Ebullating	------ Proprietary ------	
2.4- G109	Stage 2 Ebullating	------ Proprietary ------	
PRIMARY SEPARATION			
2.5- G110	Slurry Recycle Pump	1625.0	120.0
2.5- G111	Recy Slr Hld Drm Cnd Acumm Liq	15.0	1.0
2.5- G112	Recy Slr Dr Cnd ac Sour Water	1.0	1.0
2.5- G113	Sour Water Drum Pump	630.0	20.0
2.5- G114	Wash Water LP Pump	455.0	30.0
2.5- G115	Wash Water HP Pump	215.0	545.0
CRUDE PRODUCT FRACTIONATION ATMOSPHERIC TOWER			
2.6- G116	Atmos Heater Charge	1145.0	150.0
2.6- G117	Reflux Naphtha Product	370.0	50.0
2.6- G118	AGO Product	120.0	45.0
2.6- G119	Bottoms Product	1110.0	150.0
2.6- G120	Atmos Ovhd Accum Sour Water	15.0	50.0
CRUDE PRODUCT FRACTIONATION VACUUM TOWER			
2.6- G121	LVGO Pumparound	1500.0	50.0
2.6- G122	HVGO Pumparound	120.0	50.0
2.6- G123	HVGO Product	85.0	100.0
2.6- G124	Bottoms Product	455.0	100.0
2.6- G125	Vacuum Jet Accum Sour Water	90.0	50.0
2.6- G126	Vacuum Jet Accum Product	5.0	50.0

APPENDIX D

ASPEN/SP COST MODEL USERS INSTRUCTIONS

COSTING OF PLANT PROCESSES

BASED ONLY ON PLANT CAPACITY

Model Name: CAC01 (COST-CAPACITY)

Function:

COST-CAPACITY calculates the installed cost of a plant using the capacity associated with a particular plant section. In addition, this model can calculate the chemical and catalyst costs also as a function of capacity.

Calculation Method

The installed cost is calculated as a function of plant capacity. The plant capacity can be a key flowrate which is either the total flowrate of a specific feed or product stream or the flowrate of a major component in a specific feed or product stream. A reference capacity is used to scale the installed cost of a single plant as a function of the specific plant capacity.

The installed cost of the first plant is calculated from the equation

$$FCOST = A + B * (F0 / (N * RF0))^{E}$$

where,

FCOST = installed cost of the first plant

A = fixed installed cost associated with a single plant

B = variable installed cost of a single plant of capacity RF0

RF0 = reference capacity, flowrate of a single plant

F0 = total key flowrate (capacity) used to calculate the cost

N = Total numb r of duplicate plants including spares

E = plant cost scaling exponent

Once this is known the cost of the duplicate plants is calculated with a cost reduction factor, or

SCOST = REDF * FCOST

where,

SCOST = cost of one duplicate plant

REDF = cost reduction factor

The total installed cost for a process is then calculated by adding the first plant cost to the cost of the duplicate plants resulting in the equation

COST = FCOST + (NOPE - 1 + NSBY) * SCOST

where,

COST = total installed cost of the process

NOPE = number of operating plants

NSBY = number of duplicate spare plants

NOTE: N = NOPE + NSBY

The number of operating plants can be input by the user or the model can calculate the number by using the maximum and minimum capacity values.

Chemical and Catalyst Cost Calculation (based on capacity)

Both the chemical and catalyst cost is calculated by the equation

CCOST = CCFF + LCFF * F0 + QCFF * F0 ** 2

where,

CCOST = chemical and catalyst cost of the process

CCFF = constant coefficient

LCFF = linear coefficient

QCFF = quadratic co fficient

F0 = total key flowrate (capacity) used to calculate the cost

User-Supplied Information

The user has the option of referencing a stream in a simulation as the capacity or in stand-alone mode by providing the capacity value.

When referencing a stream, the user must specify a substream Id and component Id if a component flowrate is desired as a capacity value. In reference mode, the user must specify the reference capacity, the maximum and minimum single plant capacities. In addition, the user must specify the cost duplicating factor, correlation exponent, fixed installed cost of a single plant, and the variable installed cost of a single plant of the reference capacity. The reference capacity must be specified in mass or standard volume units. The maximum and minimum capacity values must be specified in the same units as the reference capacity.

In stand-alone mode the user must specify the plant capacity, reference capacity, and the maximum and minimum capacities in the same units, ie, mass or standard volume. In addition to the capacities, the user must specify the cost duplicating factor, correlation exponent, fixed installed cost of a single plant, and the variable installed cost of the reference capacity.

Input Language

The recommended form of input for stand-alone costing is as follows:

```
CBLOCK cblkid  COST-CAPACITY

     PARAMETERS   nope  nsby fcst rcst redf exp

     If simulation is on a mass basis:

     SIZE-INPUT   uf0m  mrcp  cmxm  cmnm

     If simulation is on a volumetric basis:

     SIZE-INPUT   uf0v  vrcp  cmxv  cmnv
```

The recommended form of input for stream reference costing is as follows:

```
CBLOCK cblkid  COST-CAPACITY

     HMB-REFERENC  STRM=sid

     PARAMETERS  nope nsby fcst rcst redf exp ssid cid

     If simulation is on a mass basis:

     SIZE-INPUT    mrcp  cmxm  cmnm

     If simulation is on a volumetric basis:

     SIZE-INPUT    vrcp  cmxv  cmnv
```

wh re:

HMB-REFERENC used to specify the following:

STRM=sid , where sid is a stream id. Only one stream is allowed.

PARAMETERS used to specify the following:

ssid	substream ID (1)
cid	component ID (1)
nope	number of operating plants
nsby	number of duplicate spare plants
fcst	fixed installed cost of a single operating plant to be costed
rcst	variable installed cost of a single operating plant at the reference capacity
exp	correlation exponent
redf	cost duplicating factor. This factor determines the cost of the duplicate plants

SIZE-INPUT	used to specify the following:
uf0m	user specified capacity (mass) (2)
uf0v	user specified capacity (volumetric) (2)
cmxm	maximum value of the capacity for which the correlation is valid (mass)
cmnm	minimum value of the capacity for which the correlation is valid (mass)
cmxv	maximum value of the capacity for which the correlation is valid (volumetric)
cmnv	minimum value of the capacity for which the correlation is valid (volumetric)
mrcp	reference capacity in mass units
vrcp	reference capacity in volumetric units

Usage Notes:

1. Required if the flowrate of a specific component is deemed the plant capacity.

2. Used only for the stand alone costing option.

COST-CAPACITY COSTING Keyword Summary

Model Name: CAC01 (COST-CAPACITY)

Secondary Keyword	Tertiary Keyword	Alternative Keywords	Description	Default Value
PARAMETERS		PARAM PARM	Commonly used scalar parameters (Mode 0, Left-justified)	
	NOPE	NUM-OPER-PL NUMOPERDUPS	Number of operating plants	1
	NSBY	NUMBER-STAND NUMBERSTANDB	Number of spare duplicate plants	0
	INDX	COST-INDEX INDEX	Cost index value	---
	TYPE	INDEX-TYPE INDEXTYPE	Cost index Type	---
	FCST	FIXED-COST FIXEDCOST	Fixed installed cost for a single plant	---
	EXPO	EXPONENT EXPONENT	Plant cost scaling exponent	0.5
	REDF	COST-REDFAC CREDFACT	Cost reduction factor	1.0
	RCST	REF-CAP-COST REFCAPCOST	Variable installed cost of a plant with reference capacity	---
	SFCT	SCALE-FACTOR SCALEFACTOR	Capacity scale factor	1.0
	AFCT	ADJUST-FACTO ADJUSTFACTOR	Cost adjustment factor	1.0
	CCFF	CONSTANTCOEF CNSTCOEFFICI	Constant coefficient	1.0
	LCFF	LINEARCOEFF LINEAR-COEFF	Linear coefficient	1.0

COST-CAPACITY COSTING Keyword Summary (continued)

Model Name: CAC01 (COST-CAPACITY)

Secondary Keyword	Tertiary Keyword	Alternative Keywords	Description	Default Value
	QCFF	QUADCOEFF QUAD-COEFF	Quadratic coefficient	0.0
	SSID	SUBSTREAMID SUBSSTRMID	Substream Id (1)	---
	CID	COMPONENTID COMP-ID	Component Id (1)	---
SIZE-INPUT		SIZE-INPUT SINP	Size related parameters (Mode 0, Left-justified)	
	VRCP	VRCAPACITY VOL-REF-CAP	Volumetric reference capacity	---
	MRCP	MRCAPACITY MAS-REF-CAP	Mass reference capacity	---
	MUCP	USER-CAPM USERCAPMAS	User specified mass capacity (2)	---
	VUCP	USER-CAPV USERCAPVOL	User specified volumetric capacity (2)	---
	MAXC	MAXIMUMCAP MAXCAP	Maximum capacity	---
	MINC	MINIMUMCAP MINCAP	Minimum capacity	---
	MXMC	MAXMASSCAP MAX-MASS-CP	Maximum mass capacity	---
	MNMC	MINMASSCAP MIN-MASS-CP	Mimumum mass capacity	---
	MXVC	MAXVOLCAP MAX-VOL-CAP	Maximum volume capacity	---
	MNVC	MINVOLCAP MIN-VOL-CAP	Minimum volume capacity	---