REFERENCES

1. Perry's Chemical Engineers' Handbook, Sixth Edition
McGraw-Hill, 1984.

2. Smith & Van Ness, "Introduction to Chemical Engineering Thermodynamics",
Third Edition, McGraw-Hill, 1975.

3. Peters & Timmerhaus, "Plant Design and Economics for Chemical Engineers",
Third Edition, McGraw-Hill, 1980.

American
Institute of Chemical Engineers

STUDENT CONTEST PROBLEM

1989

345 East 47 Street • New York, New York 10017

1989 AIChE STUDENT CONTEST PROBLEM

DEADLINE FOR MAILING

Solution must be postmarked not later than midnight, June 1, 1989

RULES OF THE CONTEST
(Revised July 31, 1988)

The Student Contest Problem is designed to be solved by individual chemical engineering students working entirely alone, and it is judged on that basis. There are, however, other academically sound approaches to using the problem. The following confidentiality rules therefore apply:

1. For students whose solutions may be considered for the contest:

The problem may not be discussed with anyone (students, faculty, or others, in or out of class) before or during the period allowed for solution. Discussion with faculty and students at that school is permitted only after complete final reports have been submitted to the chapter counselor.

2. For students whose solutions are not intended for the contest:

Discussion with faculty and with other students at that school who are not participating in the contest is permitted.

3. For all students:

The problem may not be discussed with students or faculty from other schools, or with individuals in the same school who are still working on the problem for the contest, until after June 1, 1989. This is particularly important in cases where neighboring institutions may be using different schedules.

Submission of a solution for the competition implies strict adherence to these conditions.

A period of not more than thirty days is allowed for completion of the solution. This period may be selected at the discretion of the individual counselor, but in order to be eligible for an award a solution must be postmarked not later than midnight, June 1, 1989. Only solutions submitted by national Student Members of AIChE will be considered for awards.
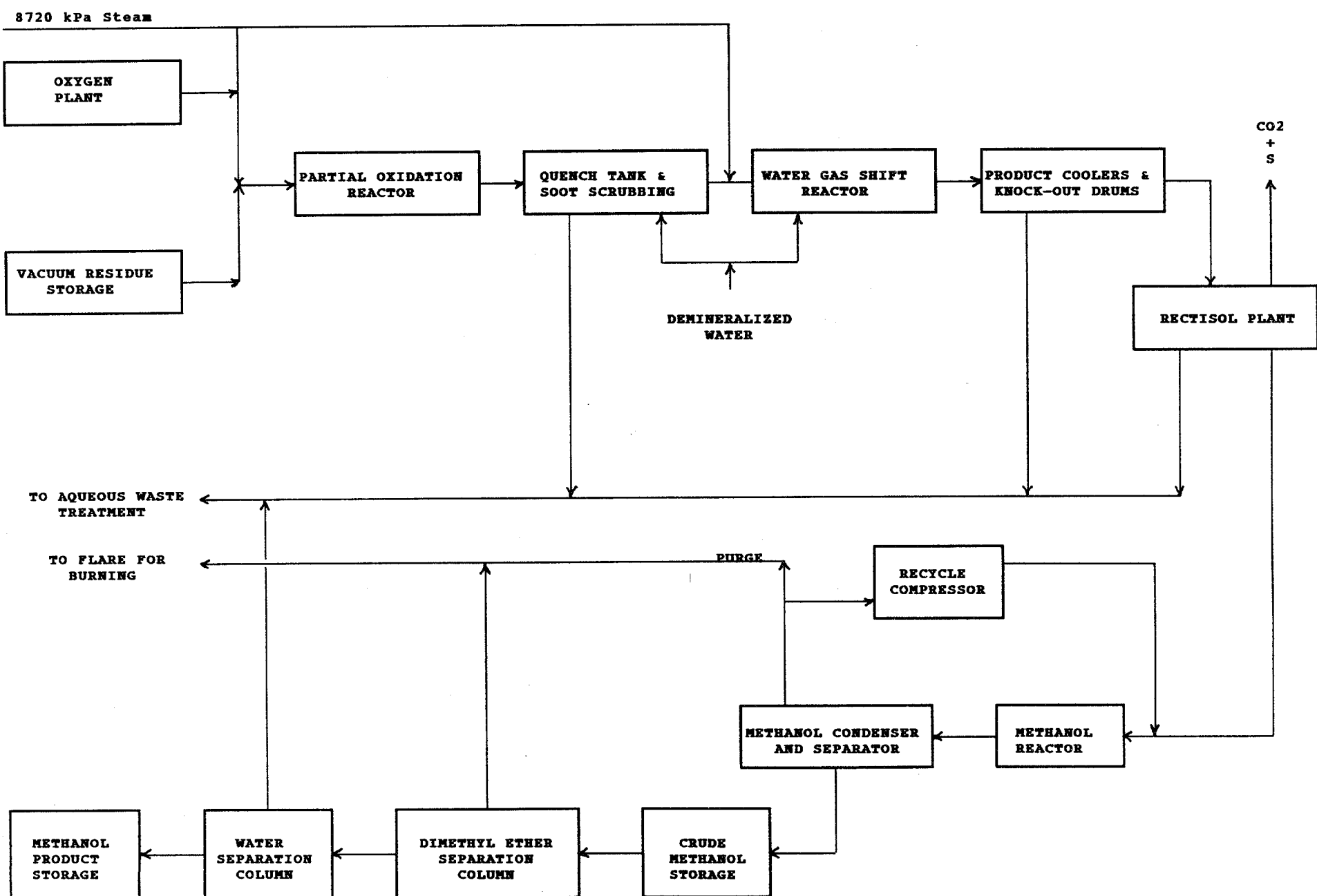
The finished report should be submitted to the chapter counselor within the thirty-day period. There should not be any variation in form or content between the solution submitted to the chapter counselor and that sent to the AIChE office. The body of the report must be suitable for reproduction, that is, typewritten or computer-generated. Tables may be written in ink. Supporting calculations and other appendix material may be in pencil. Each counselor should select the best solution or solutions, not to exceed two, from his or her chapter and send these by registered mail to the Institute.

Two copies of the solution(s) must be accompanied by a letter of transmittal giving only the contestant's name, school address, home address, home telephone number, and student chapter, lightly attached to the report. This letter will be retained for identification by the executive director of the Institute. The solution itself must bear no reference to the student's name or institution by which it might be identified. In this connection, graph paper bearing the name of the institution should be avoided. Original manuscript(s) must remain in the possession of the student chapter counselor, or faculty member, sponsoring the student(s).

As soon as the winners have been notified, original manuscripts for first, second, third and honorable mention categories must be forwarded to the office of the Executive Director as soon as possible.

Richard E. Emmert
Executive Director
American Institute of Chemical Engineers
345 East Forty-seventh Street
New York, New York 10017

Solutions will be graded on (a) substantial correctness of results and soundness of conclusions, (b) ingenuity and logic employed, (c) accuracy of computations, and (d) form of presentation. Accuracy of computations is intended to mean primarily freedom from mistakes; extreme precision is not necessary.

It is to be assumed that the statement of the problem contains all the pertinent data except for those readily available in handbooks and similar reference works. The use of textbooks, handbooks, journal articles, and lecture notes is permitted. In cases where there is disagreement in the data reported in the literature, the values given in the problem have been chosen as being most nearly applicable.

Students may use any available commercial or library computer programs in preparing their solutions. Students are warned, however, that physical property data built into such programs may differ from data given in the problem statement. In such cases, as with data from other literature sources, values given in the problem statement are most applicable. Students using commercial or library computer programs or other solution aids should so state in their reports and include proper references and documentation. Students are further advised that the problem can be solved without the use of sophisticated computer programs. Judging is based on the overall suitability of the solution, not on skills in manipulating computer programs.

FIGURE I
...DL BY PARTIAL OXIDATION OF VACUUM DISTILLATION RESIDUE

INTRODUCTION

The DJ&D Chemical Company is a petrochemical manufacturing subsidiary of DJ&D Energy Corporation, which produces and refines petroleum products. It is located in a heavy industrial zone of a Gulf coast metropolitan area adjacent to a DJ&D petroleum refinery. The refinery generates a considerable tonnage of vacuum distillation column bottom residue with high sulfur, vanadium, and nickel content. The vacuum residue has traditionally been burned as a supplemental fuel within the refinery, with any balance being landfilled. New environmental regulations have been announced which would not only require much lower sulfur and metal furnace stack emissions, but also forbid landfilling the vacuum residue. Management is apparently faced with choosing from among at least three alternatives:

1. Equip one furnace with appropriate pollution control systems; get it permitted as a hazardous waste incinerator; and go into the business of disposing of low-heating-value hazardous wastes using the vacuum residue as the main source of auxiliary heat. Disposal of metals and sulfur would be as inorganic solids to a hazardous waste landfill.

2. Build additional capacity to manufacture hydrogen and to hydrogenate the vacuum residue to lighter fractions suitable for use as diesel fuel or chemical feedstocks. Sulfur would be recovered as the element. Metals are troublesome but would ultimately be disposed of as inorganic solids to a hazardous waste landfill.

3. Build a plant to make methanol by partial oxidation of the vacuum residue and react the methanol with isobutylene to make methyl-t-butyl ether (MTBE) for use as a gasoline octane booster. Sulfur would be recovered as the element; metals would be disposed of as inorganic solids to a hazardous waste landfill.

Your group within the Engineering Department of DJ&D Chemical Company has been designated to prepare a process analysis for the methanol synthesis portion of the MTBE alternative based on a plant design capacity of 100,000 metric ton per year of MTBE.

STATEMENT OF THE PROBLEM

Your assignment is to:

1. Synthesize an optimum flowsheet for the methanol production process.
2. Complete material and energy balances around each major equipment piece.
3. Determine the size and cost of the major equipment pieces and their auxiliaries.
4. Estimate the installed capital equipment cost for methanol manufacture.
5. Estimate the manufacturing cost.
6. Calculate the discounted cash flow rate of return for the project based on selling the methanol.
7. Recommend any major design changes you feel would positively impact the overall economics of the process. Estimate what that impact would be.
8. Based on incremental rate of return, recommend whether or not it is in the corporation's best interest to manufacture and sell MTBE or simply sell the methanol.

FINAL REPORT FORMAT

Your final report should include the following sections:

1. Cover letter to your management.
2. Title page including your name, organization and the date
3. Table of Contents
4. Summary Page - Present your results and conclusions in a clear and concise manner.
5. Introduction - Give a concise statement of the problem, covering background and objectives.
6. Discussion - Give a general discussion of results and the proposed design. Include technical matters of importance including any assumptions you made and their impact on the final conclusions. Tables and graphs need not be included in this section but should be referred to as attachments if they are essential for understanding the discussion.
7. Conclusions - List the major conclusions in decreasing order of importance. More detail should be given here than on the summary page.
8. Recommendations - Present your final recommended design. Include reference to process flow diagrams, tables listing equipment and specifications, and tables giving material and energy balances. Summarize process economics and recommend whether or not building the proposed facility is a cost-effective move for the corporation to make.
9. Attachments, Figures, Tables (including one for nomenclature), and Appendices (including sample calculations). Include any appropriate data, any special theories, calculations, assumptions, diagrams, and references.


TABLE IV

RECOMMENDED MATERIALS OF CONSTRUCTION

EQUIPMENT	MATERIAL	Cost Information
Partial Oxidation Reactor	Steel, 5% Cr & 0.5% Mo	3.5 x Carbon Steel
Partial Oxidation Reactor Liner	9" Dense Al_2O_3 + 9" Insul Al_2O_3	$140/ft^3 $ 70/ft^3
Equipment Handling Wet CO & H_2	304 L Stainless Steel	4.7 x Carbon Steel
Equipment Handling Dry CO & H_2	304 L Stainless or Aluminum	4.7 x Carbon Steel 1.6 x Carbon Steel
Equipment Handling Crude Methanol	Carbon Steel	(base)
Methanol Storage	Carbon Steel	(base)

TABLE V

CATALYST PROPERTIES

| ITEM	WATER GAS SHIFT	METHANOL SYN.
Composition	Co/Mo	Cu/ZnO
Form	Tablet	Extruded Cylinder
Size	6mm diam x 6mm	6mm diam x 6mm
Operating Temperature Range	200-500 °C	200-265 °C
Life, Yr	3	2
Bulk Density, kg/m^3	960	1120
Cost, $1000/m^3	14.8	6.2

DESCRIPTION OF THE PROCESS

PARTIAL OXIDATION & SOOT SCRUBBING

The first step in converting the vacuum residue to methanol is to "gasify" it by partial oxidation to form carbon monoxide and hydrogen according to the equation:

$$C_nH_m(l) + n/2\ O_2(g) <=======> n\ CO(g) + m/2\ H_2(g) \qquad (1)$$
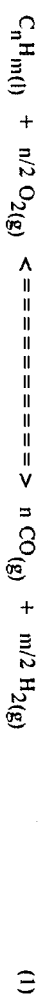
A schematic process flow diagram for the overall methanol synthesis system is shown in Figure 1. The vacuum residue is burned with oxygen enriched air in the partial oxidation reactor. High pressure steam is added to the reactor to moderate the combustion and maintain the desired reactor temperature. In the presence of water, the carbon monoxide reacts to form carbon dioxide and hydrogen gas according to the water gas shift reaction:

$$H_2O(g) + CO(g) <=======> H_2(g) + CO_2(g) \qquad (2)$$
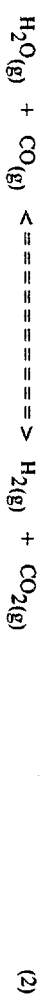
The sulfur in the vacuum residue undergoes several reactions to form hydrogen sulfide (H_2S), and carbonyl sulfide (COS) which must be removed before methanol synthesis to avoid poisoning of the Cu/ZnO catalyst used. The gas leaving the partial oxidation reactor contains soot formed in the reactor and ash from the feedstock (ash includes the inorganic vanadium and nickel). These solids are removed from the product gases by water scrubbing to avoid plugging of the shift reactor catalyst beds. A quench tank between the partial oxidation reactor and scrubber reduces the temperature of the gas mixture to to the steam saturation point by evaporation of plant cooling water. The solids-laden water from the scrubber is sent to the plant's aqueous waste treatment facility.

WATER GAS SHIFT REACTION

The ratio of CO to H_2 in the partial oxidizer effluent is not stoichiometrically correct for the methanol synthesis reaction:

$$CO + 2H_2 <=======> CH_3OH \qquad (3)$$

This ratio is adjusted by passing a portion of the gas through a shift converter in which excess CO is converted to CO_2 and H_2 by the water gas shift reaction from equation (2) above. A cobalt/molybdenum catalyst is used which allows the reaction to proceed at relatively low temperatures (350° C TO 450°C) but which is not affected by the sulfur compounds in the partial oxidizer effluent. Using this catalyst, the reaction can be assumed to go essentially to thermodynamic equilibrium. Owing to the high heat of reaction, there is a potential for a large temperature rise in the converter. The temperature rise is controlled by separating the catalyst into two beds and injecting demineralized water in between for cooling. The shift converter effluent gas is cooled and de-humidified in a series of condensers and knock-out drums before removal of sulfur and CO_2.

## REMOVAL OF SULFUR COMPOUNDS AND CARBON DIOXIDE

As mentioned earlier, sulfur compounds must be removed from the CO and H_2 before they reach the methanol reactor to avoid catalyst poisoning. Most of the carbon dioxide must be removed also to avoid build up in the methanol reactor recycle stream which would require an unacceptable purge rate. The removal of sulfur compounds and carbon dioxide is accomplished via a Rectisol* absorption system. The efficiency of the Rectisol* process is based on the high solubility of CO_2, H_2S, and COS in cold methanol. Current absorption technology allows removal of these gases from synthesis gas to the low ppm level. For the purpose of this study, you should assume that a turn-key absorption system can be purchased which meets the needs of this process. You need only calculate the material and energy balances around the system and estimate its operating costs as a turn-key system. Information for this can be found in the "Design Data" section.

METHANOL SYNTHESIS & PURIFICATION

The carbon monoxide and hydrogen which are essentially free of CO_2, H_2S, COS, and particulate contaminants (but which still contain inert gasses) are now reacted to form methanol according to equation (3) above. As was the case with the water gas shift reactors, the relatively high heat of reaction will cause a large temperature rise in the methanol reactors if not removed by some means. Direct water injection is not used here in order to minimize undesireable side reactions. Instead, the heat is removed by carrying out the reaction in several packed cylindrical tubes which are surrounded by water (similar to a shell-and-tube heat exchanger). Heat is transferred through the tube walls and is dissipated by boiling the water and removing the steam from the system. The reactor tubes are packed with ZnO supported Cu catalyst. The reactor product is cooled just enough to condense the methanol and is then recompressed, reheated, and recycled to the reactor feed. A small purge must be taken from this stream to prevent the build-up of inert gasses, reaction by-products, and unreacted hydrogen in the system. By-products of the reaction are dimethyl ether and water which must be removed in a two-column distillation train to produce high purity methanol. The recycle purge and the low boilers are disposed of by burning in a flare. The recovered water is sent to the plant's aqueous waste treatment facility. The purified methanol is stored pending sale or conversion to MTBE.

MTBE SYNTHESIS

MTBE is formed through the reaction of methanol with isobutylene (2-methyl-1-propene) as follows:

$$CH_3OH(l) + (CH_2)=C-(CH_3)_2(l) <=======> CH_3-O-C(CH_3)_3(l) \qquad (4)$$
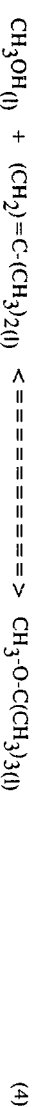
For the purpose of this problem, only the economics of the MTBE manufacturing process need be considered. These are summarized in the "Profitability" section.

TABLE I
VACUUM RESIDUE SPECIFICATIONS

ITEM	UNITS	VALUE
SpGr (15°C/4°C)	(none)	1.02
Viscosity @50°C	(m²·s⁻¹)	1.3 x 10⁻⁴
Viscosity @200 °C	(m²·s⁻¹)	2.4 x 10⁻⁵
C Content	Weight %	83.25
H Content	Weight %	9.55
S Content	Weight %	5.60
O Content	Weight %	1.05
N Content	Weight %	0.50
Ash Content	Weight %	0.05

TABLE II
UTILITIES SPECIFICATIONS

TYPE	CONDITION	COST
Electricity	60 Hz, 13.2 KV	$0.09/KWh
Steam: High Pressure	8720 kPa	$3.63/1000 kg
Medium Pressure	1135 kPa	$2.72/1000 kg
Low Pressure	450 kPa	$2.27/1000 kg
Cooling Water	30 °C, 690 kPa	$15/gpm/yr
Demineralized Water	20 °C, 690 kPa	$1.65/1000 kg
Ambient Air	31 °C, 690 kPa	(none)
Boiler Feedwater	240 °C, 3250 kPa	$2.20/1000 kg
No. 6 Fuel Oil	80 °C, 345 kPa	$0.13/liter
Refrigeration	-60 °C	$1.50/ton/day

TABLE III
EFFECTIVE METHANOL REACTION RATE
(all values in table expressed as kmol/hr methanol produced per kg catalyst contacted)

TEMPERATURE (°C)	Mole Percent of Methanol in Mixture			
	0	2	4	6
235	0.014	0.013	0.011	0.010
245	0.025	0.023	0.020	0.017
255	0.038	0.034	0.030	0.026
265	0.050	0.043	0.037	0.030

Data from tests performed by your R&D group suggest the following guidelines to use as a basis for design calculations:

PARTIAL OXIDATION & SOOT SCRUBBING

o The optimum temperature leaving the partial oxidation reactor is 1125 °C.
o For reaction temperatures this high, a refractory lined steel reactor must be used.
o The standard enthalpy of reaction for reaction (1) at 298 K is -148.1 kJ/gmol of CO produced.
o The standard enthalpy of reaction for reaction (2) at 298 k is -41.2 kJ/gmol of CO reacted.
o At 1125 °C you can expect the molar ratio of H_2S to COS to be approximately 15:1 regardless of the concentration of the other species.
o Approximately 3% by weight of the carbon in the feed will be converted to soot.
o The reactor should have a length to diameter ratio of 4:1 and provide a residence time of 4 seconds.
o Determine the reactor effluent concentrations based on thermodynamic equilibrium of the water gas shift reaction.
o The water gas shift reaction equilibrium constant at 1125 °C and 8720 kPa is 0.42.
o Other pertinent thermodynamic data can be obtained from references 1 and 2.

WATER GAS SHIFT REACTION

o The two stages should be designed such that neither catalyst bed exceeds 510 °C
o Calculate equilibrium concentrations based on the outlet temperature of each catalyst bed.
o Equilibrium constants for the water gas shift reaction in this temperature range and 8375 kPa are:

T (°C)	K
350	19.6
400	11.5
450	7.3
500	4.9
550	3.5

o The upper catalyst bed should have a space velocity (volumetric throughput of reaction gases if they were at 25 °C and 1 atm divided by the volume of the catalyst bed) of 2100 hr^{-1}.
o The lower catalyst bed should have a space velocity of 1100 hr^{-1}.
o Other pertinent thermodynamic data can be found in references 1 and 2.

METHANOL SYNTHESIS AND PURIFICATION

o The optimum molar ratio of hydrogen to carbon monoxide in the product from Rectisol* has been determined to be 2.5:1. The maximum ratio in the total feed to the methanol synthesis reactor should be 7.5:1.
o Assume that approximately 0.4% by weight of the CO in the feed will react to form dimethyl ether and water according to the reaction:

$$2 CO_{(g)} + 4 H_{2(g)} \Longleftrightarrow CH_3\text{-}O\text{-}CH_{3(g)} + H_2O_{(g)}$$
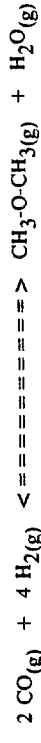
o Assume that all dimethyl ether formed dissolves in the condensed methanol and water.
o The methanol synthesis reaction (equation (3)) is kinetically limited and will not go to thermodynamic equilibrium without an unacceptably long reaction time.
o Rate data for the reaction using this particular catalyst are given in Table V.
o The reactor can be effectively sized by choosing successive differential elements of length and performing a stepwise integration for mass and energy balance, pressure drop, and heat transfer to the boiling water.
o Assume that data from computer models can be used to determine the size of both distillation columns. These data are given in the "Design Data" section.

GENERAL INFORMATION

o Assume that construction of the plant will begin in July of 1990 and will be completed in July of 1991.
o Calculate discounted cash flow rate of return based on the 1 year construction time and a service life of 15 years.
o Determine the total capital investment as the sum of fixed capital investment and working capital as outlined below.
o Assume that working capital will be 10% of the total capital investment.
o Determine the total operating costs as the sum of variable costs and fixed costs as outlined below.
o Assume that state and federal income taxes will be 40% of gross revenues.
o Assume that operating costs and selling prices will all escalate at 2.5% per year.
o Calculate depreciation using the straight line method over the 15 year service life.
o Assume that the cost of vacuum residue is equivalent to the cost of No. 6 fuel oil which be required to replace it as a fuel in the refinery. Assume the heat of combustion for both is 41,870 kJ/kg.
o The net cost of operating the oxygen plant is $7.42 per thousand standard cubic meters of O2 not including depreciation.
o The cost of operating the rectisol plant is the sum of the utility costs plus depreciation.
o The current selling price of methanol is $153 per m^3.

ESTIMATING CAPITAL EXPENDITURE

o Assume that 60% of the fixed capital expenditure will be made in 1990 and 40% in 1991.
o Use the following data to estimate the fixed capital expenditure.

ITEM	PCT. OF TOTAL
Purchased Equipment Cost	35
Purchased Equipment Installation	10
Electrical & Instrumentation	11
Piping	12
Engineering	10
Construction	15
Environmental Permits	2
Contingency	5
	100

ESTIMATING VARIABLE OPERATING COSTS

o Estimate the following variable costs based on the percentages of the cost of Raw Materials & Utilities costs provided:

ITEM	PCT. OF RAW MATLS. + UTILITIES COSTS
Operating Labor	50
Clerical & Supervisory Labor	5
Laboratory Charges	7
Technology Licensing	2
Waste Disposal	2

o Assume the cost of Maintenance & Repair will be 4% of the fixed capital investment.
o Assume that operating supplies will be 1% of the fixed capital investment.

ESTIMATING FIXED OPERATING COSTS

o Estimate the following fixed costs based on the percentages of the cost of Raw Materials & Utilities costs provided:

ITEM	PCT. OF RAW MATLS. + UTILITIES COSTS
Plant Overhead Costs	30
Administrative Costs	10
Marketing & Distribution Costs	14
Research & Development Costs	6

o Assume that insurance costs will be 1.5% of the fixed capital investment.

MTBE ANALYSIS

o Assume 96% overall molar conversion of methanol to MTBE.
o Assume that the total capital investment of the MTBE plant will be $9 million.
o Assume the cost of isobutylene is $0.71 per kg.
o Assume the operating costs excluding raw materials are $35 per metric ton of MTBE.
o Assume the selling price of MTBE is $0.26 per kg.

GENERAL

o Assume the process will operate 24 hours per day, 329 days per year.

o Maximum cylindrical vessel diameter is 4.88 m because of transportation limitations.

o Vessel design pressure (kPa) = (1.1 x operating pressure in kPa) or 450 kPa + operating pressure in kPa, whichever is greater.

o Vessel design temperature = 50°C + operating temperature.

o All reactors should be axial downflow vertical vessels.

o Catalyst bed pressure drop for the shift reactors and the methanol synthesis reactor should be calculated using the correlation given in reference 1, equation 5-202. Both the catalyst shape factor and the modified friction factor are 1.0. Use the gas density at the reactor outlet temperature for the average density. Assume the pressure drop for nozzles, distributor, and supports is equivalent to 0.91 m of bed height.

o The maximum temperature of cooling water (except for the methanol synthesis reactor) is 50 °C.

o The maximum allowable diameter and length of heat exchangers are 3.05 m and 6.10 m, respectively.

PARTIAL OXIDATION & SOOT SCRUBBING

o Oxygen for the process will be made by a turn-key package plant. Specific design data for this plant are:

- The plant is sized to produce 16,990 standard m³/hr of oxygen

- The oxygen composition is 95% O_2, 2.5% Ar, and 2.5% N_2 by volume

- The plant requires 9000 kW of electricity, 1632 kg/hr of medium pressure steam, and 0.75 m³/hr of cooling water.

- The plant will deliver the oxygen at the inlet pressure of the partial oxidation reactor.

- The estimated installed cost of the plant is $9.6 million

o Vacuum residue storage should be sufficient for 30 days of operation.

o Bayonet heaters using medium pressure steam should be used to maintain vacuum residue storage temperature at 150°C.

o Vacuum residue should be pre-heated to 260°C prior to feeding to the partial oxidation reactor.

o Vacuum residue pumps should be of the reciprocating piston type.

o All reactor feeds should be at the same pressure as the plant's high pressure steam (8720 kPa).

o The 0.457 m thickness of the reactor lining should be taken into consideration when designing vessel diameter (see Table IV).

o Reactor pressure drop is 0.6 kPa per m of length. Assume the pressure drop for nozzles and burners is equivalent to 0.61 m of reactor height.

o The quench tank should be a vertical, cylindrical vessel with a residence time of 3 seconds. Water is injected through a standard nozzle. Pressure drop for this vessel is 4 kPa per m of length.

o The scrubber should be a venturi type and should be designed to remove all particles greater than 0.8 x 10⁻⁶ m in effective diameter (see reference 1, p. 18-81). The soot may be assumed to be hydrophobic.

WATER GAS SHIFT

o For the purposes of this study, the shift converters should be considered to be adiabatic, fixed-bed reactors containing two beds of cobalt/molybdenum sulfide catalyst.

- The crude synthesis gas should enter the Rectisol* plant at 50 °C.

- Minimum catalyst bed depth is 0.5 x bed diameter.

- If hemispherical heads are used, the catalyst bed may not extend into the heads. If ellipsoidal heads are used, the catalyst bed and supports may extend into the vessel heads up to 15 percent of the vessel diameter.

o The condensate knock-out drums should be sized to settle out water droplets greater than 300 x 10⁻⁶ m (See reference 1, p. 5-63). Allow 5 minutes of liquid residence time above the bottom tangent line. Provide 0.91 m above the inlet nozzle to the top tangent line for disengagement space.

REMOVAL OF SULFUR COMPOUNDS AND CARBON DIOXIDE

o Specific design data for the Rectisol* plant is:

- The plant is sized to treat 707,900 standard m³/day of synthesis gas.

- The plant requires 2250 kW of electricity, 232,200 kg/hr of cooling water, 1800 kg/hr of deminceralized water, and 1200 tons of refrigeration.

- The plant is designed to remove 99.96% by weight of CO_2, and 99.99% by weight of H_2S and COS.

- For the purposes of this study it can be assumed that none of the refinery at no net cost.

- The synthesis gas leaving the Rectisol* plant is at 36 °C.

- The pressure drop through the Rectisol* plant will be 310 kPa.

- The installed cost of the Rectisol* plant is $5.2 million.

METHANOL SYNTHESIS AND PURIFICATION

o The reactor feed should be preheated to 200 °C.

o The reactor is a single-pass shell-and-tube vertical vessel with the following specifications:

- Standard tube bundle lengths available are 3.05, 3.66, 4.88, and 6.10 m.

- The tube inside diameter is 0.05 m.

- The film heat transfer coefficient for the flow of heat from the reaction gas to the boiling water is 125 J/s·m²·°C.

- The number of tubes vs. vessel diameter is given below:

SHELL INSIDE DIAMETER (m)	NUMBER OF TUBES
3.040	1150
3.650	1670
4.870	2960

- The saturated water on the shell side is maintained at 240 °C.

- The steam generated on the shell side is vented through a steam drum and returned to the plant's powerhouse for a credit of $4.00/1000 lb. A level of boiler feed water (BFW) is maintained in the drum to assure a constant water source for the shell.

o Compressors should be of the conventional axial type. The maximum compression ratio is 3.0.

o Compressors can be driven by either electric motors or steam turbines. Motor efficiency is 90%. The maximum efficiency is 80% and the maximum discharge temperature is 230 °C. The isentropic efficiency is 80% and the maximum discharge temperature is 230 °C. The isentropic compression ratio is 3.0.

o The moisture content for the steam turbines at isentropic exhaust conditions is 16%.

o Crude methanol storage should be sufficient for 1 day of production.

o Both distillation columns should be constructed of carbon steel.

o Both distillation columns will use sieve trays spaced 0.61 m apart.

o Pressure drop through the columns will be 0.7 kPa per plate.

o The dimethyl ether column will have 42 trays and require 55 kg/hr cooling water and 550 kg/hr medium pressure steam.

o The water removal column will have 60 trays and require 250 kg/hr cooling water and 1480 kg/hr medium pressure steam.

o The methanol product storage tanks should be designed to hold 30 day's production.