Name__________________
Student Number______________

CHEMICAL ENGINEERING 4N4

DAY CLASS
Duration of examination: 3 hours
McMaster University Final Examinations

Dr D.R. Woods
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Special Instructions: Candidates may use any materials, papers, notes and texts. The marks allocated for each question are directly proportional to the time suggested in the left hand margin beside each question. The exception is question 6 where the marks are given in the margin. Work directly on the examination sheet if you wish. Please be sure that your name is on all the material that you hand in.

Answer all six questions.

This examination contains 10 pages and 6 questions. You are responsible for ensuring that your copy of the paper is complete. Bring any discrepancies to the attention of the invigilator.

Time 10 min.

1. Given the following symptoms and circumstances for a centrifugal pump, list at least three possible causes of the problem.

a) The pump has been in operation for several years with no maintenance over the past year. The flowrate from the pump has steadily decreased until it is no longer meeting the needs of the system.

b) The pump was just serviced and when it is restarted the flow does not reach the same level as before, even though the pumps draws the same amount of energy.

c) The pump is used to circulate a cooling fluid for a gas phase reaction and gradually, over the past few weeks, the pump has started to have problems with what appears to be cavitation. The cooling fluid is stored in a large return tank, and the design is such that the head supplied to the pump is sufficient to prevent cavitation of the cooling fluid for the maximum design pressure of the reactor.

*********** end of Question 1 **********

Time 20 min.

2. A petroleum company has decided to go ahead with building a new distillation column for its refinery. This estimated 5-year project has been initially calculated to cost up to $25 million. With a net cash flow of $6.5 million during each year of the project:

a) Calculate the present value of all cash flows for discount rates of both **5% and 10%**.

b) Calculate the Net Present Value for each discount rate above.

c) Identify the project that would be the most profitable (at which the discount rate) and justify your answer.

************** end of Question 2 ************

examination continues on the next page

Time 45 min. 3. The effluent from the reactor in the ethylene plant is 598°C and has the following composition:

hydrogen	32.7 mol %	3.52 wt%
methane	6.3	5.42
acetylene	0.2	
ethylene	33.8	50.88
ethane	24.9	40.18
propylene	1.0	
propane	0.9	
Total	**100**	

Propose two complete, separation systems **different** from that given in Fig 1. List the advantages, disadvantages of all three. For each of your proposals, list two implications, concerns and issues that might affect the technical feasibility of your options.

********************** end of Question 3 ***************

Time 30 min. 4. Capital Cost Estimation.

A current last quarter 1992 estimate is required for the Total Module cost (including contractors fees and contingencies but excluding interest during construction, startup, working capital and land) for modifications to minimize waste for our process. The following equipment is needed:

horizontal, cylindrical, dished end pressure vessel including access hole and support at 200 psig and made of 316 s/s. This vessel has average complexity. The volume is 5000 US gal.

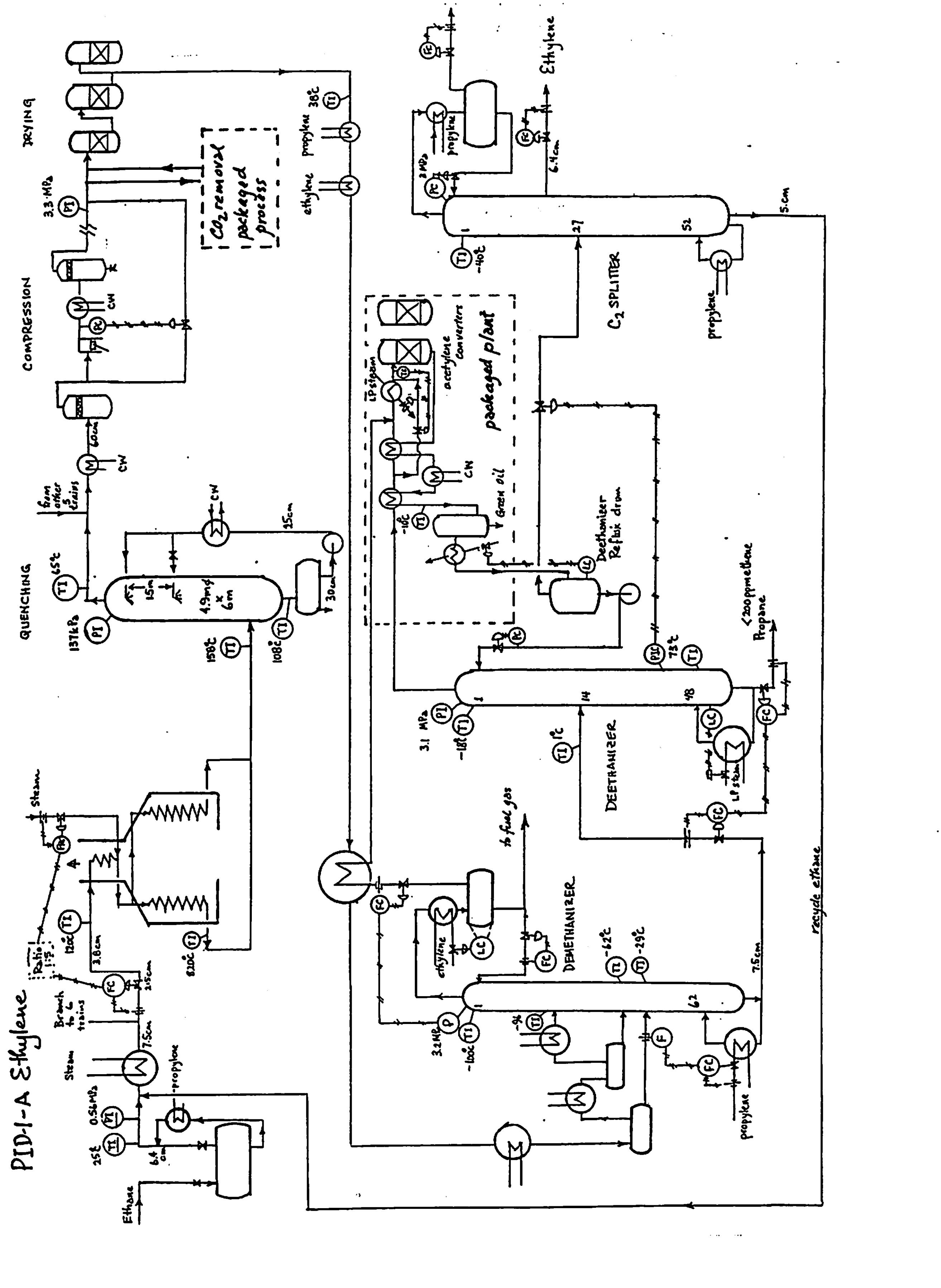
a 316 s/s alloy centrifugal pump, single stage, suction pressure 1135 kPa for heavy duty application. The size is 150 kW. We have the appropriate motor on hand but it has to be installed.

a 60 cm diameter basket centrifugal filter: vertical, underdriven with batch, top discharge. The unit must be 316 s/s.

**************************** end of Question 4 ***************

examination continued on the next page

Figure 1: The Ethylene Process (Diagram for Question 3).



Time: 5. Trouble Shooting Application
40 min.
5 1) summarize briefly your strengths and weaknesses as a trouble shooter.

READ ALL THE INSTRUCTIONS FOR THIS PROBLEM BEFORE YOU PROCEED.

2.) Trouble on the ammonia plant: in the heat exchanger just following the reformer. The overall process is given in PID 4. Read the trouble shooting situation given in Figure 2, case 51.

(Allowed time about 3 min).

20 marks 3) Then, in the next 17 min, write out your thought processes as you think about the evidence, the hypotheses and the possible tests you could do to validate some of your hypotheses. Create tables and charts and/or whatever you find useful. **Show your thought processes, include your brainstorming lists, your classifications, your prioritizations.**

5 marks 4) select one test that you feel is crucial. Indicate what it is you wish to find out from the test. Write out the instructions requesting that test so that someone else can carry out the test safely and so that the test provides an unambiguous answer to your question(s).

10 marks 5) In the last 10 min, critique the approach you took. Use your summary from part (a) as a guide.

******* end of question 5 ******

The trouble shooting description is given on the next page called Fig 2.
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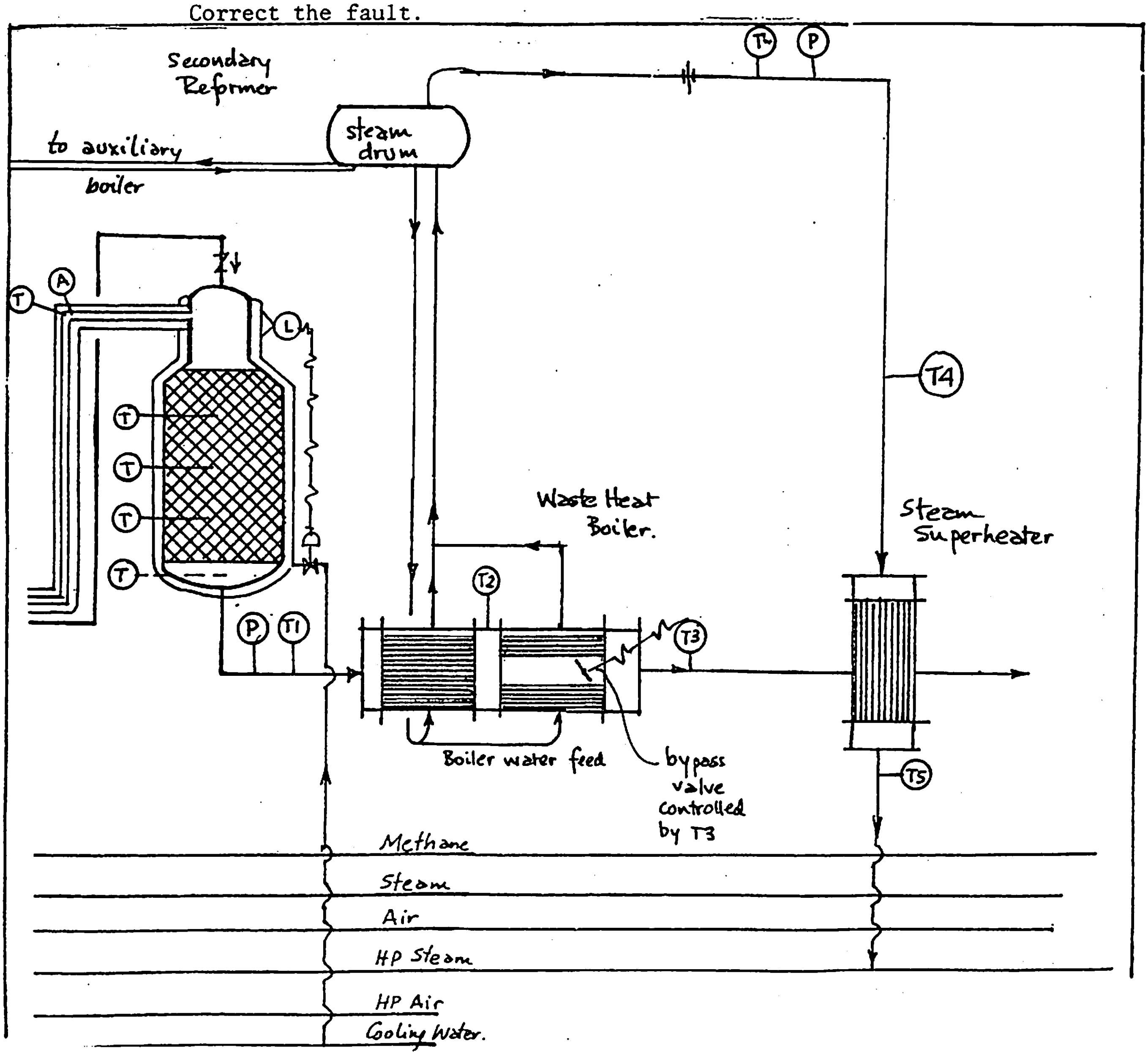
examination continues on the next page

Figure 2: Case 51: The Really Hot Case (for Question 5)

The exit gas from the secondary reformer is used to generate steam according to the scheme shown below. The conditions are as follows:

	Temp, °C		Pressure, MPa	
Exit Gas	design	reads	design	reads
T1	1000	1000	4.5	4.55
T2	750	820	?	?
T3	600	730	?	?
Steam				
T4	sat	sat	12.0	12.0
T5	30 super heat	120		

We cannot seem to control the exit gas temperature at all; the control response is very sluggish if at all. The steam is much too superheated. Correct the fault.



Time 6. Process for the production of **Maleic Anhydride: C4H2O3**
35 Maleic anhydride is produced by the air oxidation of butane according to the following reaction:
min.

$$C_4H_{10} + 3.5\,O_2 \rightarrow C_4H_2O_3 + 4\,H_2O \qquad 1$$

The reaction conditions is to contact a gas stream containing about 1.6 mol% butane with a catalyst. This "low" concentration of butane in air is used to ensure that the butane concentration is below the explosive limits (45 g/m^3 STP air). Typical reaction conditions are in the range:

temperature: 340 to 430°C;
pressure: slightly above atmospheric, 240 kPa.

These are selected to minimize the side reactions which include the production of CO and CO_2.

$$C_4H_{10} + 6.5\,O_2 \rightarrow 4\,CO_2 + 5\,H_2O \qquad 2$$

$$C_4H_{10} + 4.5\,O_2 \rightarrow 4\,CO + 5\,H_2O \qquad 3$$

Both reactions #1 and #2 are exothermic (-1.26 MJ/mol butane converted and -2.70 MJ/mol butane converted, respectively). In general, for the typical reaction conditions and reactor configuration,

about 17% of the butane passes through the reactor unconverted,
about 53% of the butane is converted to maleic anhydride, Reaction #1,
about 30% of the butane is converted to the oxides of carbon, Reactions #2 and 3.

For this process, the reactor configuration is:

Plug Flow Tubular Reactor "Fixed catalyst bed" packed inside the tubes of a shell and tube exchanger. On the shell side is often a molten salt which, in turn, boils water to generate steam.

The high temperature gaseous product from the reactor is cooled to partially condense about 50% of the maleic anhydride. The liquid is separated in a cyclone and goes to crude product storage. The off-gas is water scrubbed (to remove the remaining maleic anhydride) with the remaining gas being incinerated to produce an environmentally acceptable stack gas.

Quality maleic anhydride product is recovered from the two liquid streams by distillation. Throughout the whole process, energy is recovered by raising steam. The process is given in **P&ID 3**, with the emphasis on the front end of the process: feed preparation, reaction, steam raising, partial condensation and gaseous scrubbing. Here are some details.

process description and examination continue on next page

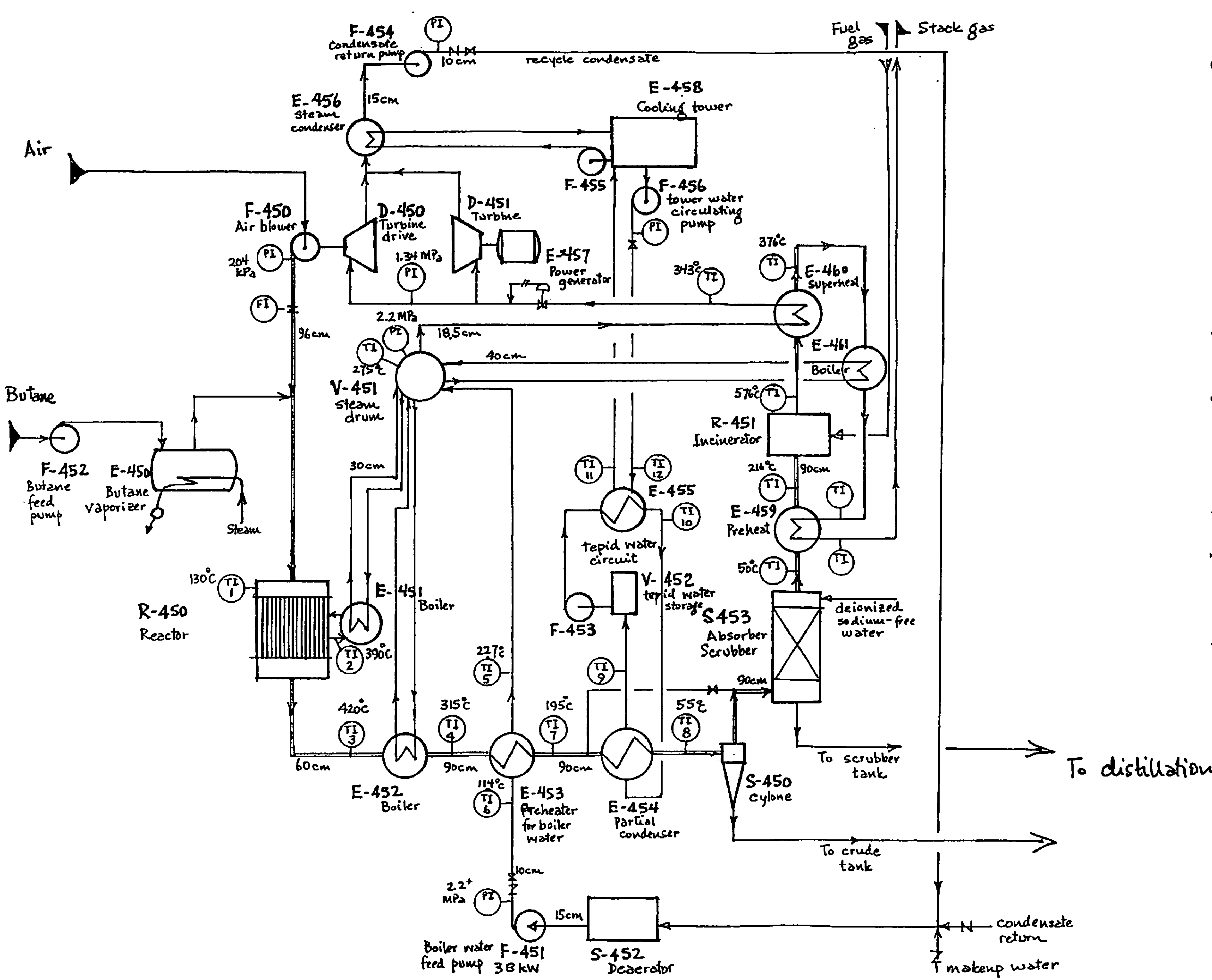


Figure 3: **P&ID 3:** Maleic anhydride production. (for question 6)

Ambient air is filtered, compressed (via 3730 kW steam turbine driven, **D-450**, blowers, **F-450**) and mixed with vaporized butane feed. The gaseous reactor feed enters the reactor, **R-450**, at about 130°C. The reactor temperature is controlled by removing the heat of reaction via a circulating molten salt. The molten salt, in turn, circulates through a boiler, **E-451**.

The gases leave the reactor at about 420°C and are cooled via a steam boiler, **E-452**, a boiler water preheater, **E-453**, and a "tepid water cooled" partial condenser, **E-454**. The resulting gas is about 55°C. About 50% of the maleic anhydride has condensed and the liquid droplets are separated from the off-gas in a cyclone, **S-450**.

The off-gases from the cyclone separator contain about 50% of the maleic anhydride as uncondensed gas. This is scrubbed with deionized, alkali-free water in the packed tower **S-451**. The unabsorbed gas contains the residual unreacted butane, the oxides of carbon. The gas is preheated in **E-459** and then combusted in incinerator **R-451**. Hot exit gases from the incinerator are used to superheat steam, **E-460**, produce steam in boiler **E-461** and preheat the off-gas to the incinerator, in **E-459**. From here the gas goes to the stack.

For the steam production, deionized water is dearated, in **S-452**, and pumped through the boiler feedwater preheater, **E-453**, to the steam drum, **V-451**. Steam is generated from the heat of reaction (via boiler **E-451**); from the reactor effluent gas, (via boiler **E-452**); and from the hot gases from the incinerator (via boiler **E-461**). Steam from the steam drum, **V-451**, is superheated by the exhaust gas from the incinerator (in exchanger **E-460**). The superheated steam drives the turbines to run the blowers and to generate electricity (in drives **D-450** and **D-451** respectively, and the generator **E-457**). All of the turbines are "condensing turbines" so as to get the maximum power from the steam. The condenser, **E-456** is cooled by water circulating to the cooling tower **E-458**. The steam condensate is recycled to the dearator. Cooling tower water also removes the heat from the "tepid water circuit" via exchanger **E-455**.

end of description of the process

Based on this description of the process, together with the numerical data as to the sizes, temperatures and pressures....
ANSWER YOUR CHOICE OF **THREE** OF THE FOLLOWING EIGHT QUESTIONS.

6.1. <u>Check flowrates:</u> For the blower, **F-450**, estimate and cross check the air flowrate.

or

6.2. <u>Specify controllers/safety:</u> For the reactor, **R-450**, add several control systems. Bear in mind the explosive limits, operability. Suggestion: focus primarily on the butane vaporizer system.

or

6.3. <u>Quick size a heat exchanger:</u> For boiler water preheater **E-453**, estimate the required area in m^2.

OPTIONS and examination continue on the next page.

Question 6, continued: DO THREE OF EIGHT OPTIONS

or

6.4. Estimate steam and area for turbine: For the steam driven turbine, **D-450**, estimate the kg/h of steam required. Estimate the condenser surface area required, m^2.

or

6.5. Vacuum and vacuum hookup: For the exhaust steam conditions of the steam driven turbines, at present, the "pressure" is whatever occurs because of the condensation. Assume we want to hook up a three stage steam ejector system with two or three interstage direct contact condensers so that the exhaust pressure is very low.

a) Estimate what that "very low" exhaust pressure would be.

b) Draw a sketch of how the vacuum system would be arranged. Show clearly the type of condenser, the location of the steam ejectors and where the lines "hook in" to the exhaust line from the turbine.

or

6.6. Track steam conditions: Steam is generated and used on this plant. On the H-S diagram given in Fig 4, show clearly the temperature and pressure conditions for each of the three boilers (**E-451, -452, -461**), leaving the superheater, **E-460**, expanded across the pressure reducing valve, passing through the condensing turbine **D-450**.

or

6.7 Startup: For the startup of this plant (excluding the separation and purification section of the plant), what additional equipment would be needed. Draw it in on the P&ID 3.

or

6.8 Safety and power and instrument air failure: For the reactor **R-450**, including exchanger **E-452**, and for all of the butane and air feed preparation facilities, list five things that should happen, draw on appropriate valves on lines, as needed, and indicate whether these should be Fail Open, FO, or Fail Close, FC.

MAKE SURE YOU ANSWER THREE OF THE OPTIONS: 6.1, 6.2, 6.3, 6.4, 6.5, 6.6, 6.7 or 6.8

************* end of question 6 *******************

180 min END OF EXAM

the next page has Figure 4, to be used for option 6.6 in question 6

Figure 4: H-S diagram for steam (for Question 6, option 6.6)

TABLE C-1 C-33