A. I. Ch. E. STUDENT CONTEST PROBLEM FOR 1948

Prepared by Roland Voorhees, Chairman, M. W. Butenhoff,
C. S. Oldach, R. W. King, and C. C. Neas

To the Contestant:

The problem which we have selected is an entirely practical one such as might be encountered in everyday work in industry. It emphasizes among other things the fact that the technical information which is available is often vague or incomplete, and that under such circumstances judgment is more important than the mere solving of equations in arriving at the proper result. You will have plenty of equations to solve, nevertheless. Please do not form the impression that we have exaggerated the lack of specific information, or the apparently cursory fashion in which important assumptions are often made. The problem is very realistic.

From this point on you are to assume that your name is Irvin M. Greenatit and that you are a new employee of the Engineering Department of a fair-sized industrial company. We will now introduce you to your associates, who are as follows:

Dr. Carl S. Oldach, Chief Engineer - Engineering Department
Mr. Robert W. King, Project Engineer - Engineering Department
Dr. Charles C. Neas, Project Leader - Research Department
Mr. Melvin W. Butenhoff, Area Supervisor - Operating Department

We wish you the best of luck.

THE COMMITTEE

TRANSCRIPT OF CONFERENCE HELD IN MR. OLDACH'S OFFICE

NOVEMBER 3, 1947

(Attended by Mr. C. S. Oldach, Mr. R. W. King, Dr. C. C. Neas, Mr. M. W. Butenhoff, and Mr. I. M. Greenatit)

DR. OLDACH: Irvin, do you know anything about making acetone?

MR. GREENATIT: No, sir, I'm afraid I don't.

DR. OLDACH: Well, that's fine. You are just the man we are looking for. We have been given the job of trying to find out whether we can make acetone in some existing equipment in the Organic Chemicals Area here at our Plant No. 1. I have discussed this previously with Mr. King, and have asked him to turn this job over to you. This is a very important assignment, and although you are very new with the company, I think you will be able to handle it. Unfortunately, Mr. King and I have to leave tomorrow for a visit to our Texas plant, and consequently, we will not be able to give you very much help on the problem. I have therefore arranged this meeting, and arranged to have a stenographic transcript made of it, hoping that we can discuss the matter pretty completely and bring out all the information which you will need. Bob, you are familiar with what we want; suppose you explain the problem in a general way to Mr. Greenatit.

MR. KING: Well, what we have in mind is to look into the possibility of manufacturing acetone at the Iso Unit. This unit - the official name of which is Isomerization Unit - was built during the war for the manufacture of a chemical for which there is no longer any need and the unit is now standing idle, having been shut down for some time. As I understand it from Carl, our New York office has asked that we determine whether or not we could make acetone in it in order to satisfy our estimated requirements. We use acetone in a number of manufacturing operations and have been purchasing it at a delivered price of 8¢ per pound. The idea is that maybe we could make acetone by dehydrogenation of isopropanol in the Iso Unit. Mel Butenhoff thinks that this could probably be done with the addition of only a moderate amount of equipment. Our estimated requirements for next year total about 25,000,000 pounds, and we would like to use this figure as a basis in determining whether it would be worth while to convert the Iso Unit to the manufacture of acetone.

MR. GREENATIT: How much would we have to pay for isopropanol?

MR. KING: 6.2¢ per pound delivered to our plant.

Now, as I was going to say, we once considered building a plant to make acetone from isopropanol before. Our usage was smaller at that time and the catalyst which we proposed to use was not so hot. We got a good deal of data on the process, but the conclusion reached was that it would not be a very profitable undertaking. Charlie Neas has dug up some information on a new catalyst, and although we do not know very much about it yet, it looks promising. This new catalyst together with the availability of the Iso Unit and the larger scale of production should improve the picture considerably. You will have to find out whether the existing equipment is big enough to produce 25,000,000 pounds per year and will also have to determine what new equipment we will have to buy. It will also be necessary to make up an estimate of the new investment required and the manufacturing cost for acetone. You can disregard the investment in the existing facilities.

DR. OLDACH: You ought to emphasize, Bob, that it will be important to utilize as much of the existing equipment as possible since the management's interest in this undertaking is based largely on the assumption that relatively little additional investment will be required. Of course, some new equipment will be needed, but if the acetone process is to be worth while it should at least make use of the major existing items, such as the converter and the Dowtherm system. As Bob says, we have looked into this acetone thing before, and I am almost sure that it would not pay if we had to build an entirely new plant from the ground up.

MR. GREENATIT: Do we have to make the full 25,000,000 pounds per year? Suppose it turns out that we could make 15,000,000 or 20,000,000 pounds in the Iso Unit, but not the full 25,000,000?

DR. OLDACH: Well, of course, that is a possibility. It's also possible that we might be able to make more than 25,000,000 pounds and sell the surplus. Our New York office, however, is primarily interested in satisfying our own requirement of 25,000,000 pounds per year. If it turns out that this production can not be obtained in the existing equipment, that will have to be our answer. Let's confine curselves to investigating the production of 25,000,000 pounds. You will have enough work to do as it is. I would like you to have your report finished and ready to send out by the time Bob and I return from Texas, and that will be only about three weeks from now--twenty-four days to be exact. You will have to digest the available information, make your calculations, and complete your report within that time, so you won't have much time to investigate variations of the main idea. Go ahead, Bob, with your discussion of the problem.

MR. GREENATIT: Excuse me, but one other question. If the equipment is bigger than really necessary, can I figure on operation for only part of the year to make 25,000,000 pounds, instead of the full year? This ought to save operating expense.

DR. OLDACH: No, let's not figure on anything like that at this stage. If we ran only part of the year and then shut down, many of the expense items would go on just the same, and the problem of shifting trained operators back and forth would be difficult.

MR. KING: Well, maybe we'd better get Charlie to tell Irvin how this process works.

DR. NEAS: Well, you make acetone by dehydrogenation of isopropanol. Most of the laboratory work has been done with pure anhydrous isopropanol, but I understand that if we were to do it we would use the commercial grade which is the CBM - that is, the constant boiling mixture - of isopropanol and water, containing 88 per cent isopropanol by weight. Bob, is that price for isopropanol on the basis of contained pounds or gross pounds, or what?

MR. KING: The price of 6.2¢ per pound is for the 88 per cent constant boiling mixture, but is 6.2¢ per pound of contained isopropanol.

DR. NEAS: The process consists of passing the isopropanol in the vapor phase over a solid catalyst in the form of granules or pellets. The isopropanol decomposes to acetone and hydrogen. You make a few by-products, but if the temperature is not too high, the efficiency is pretty good. We have recently run across an article describing some results with a catalyst which looks better than the one we previously worked with. We haven't done any work ourselves with this new catalyst but intend to. As I understand it, though, they want us to make this investigation about using the Iso Unit on the basis of using this new catalyst.

DR. OLDACH: Yes, that's right.

DR. NEAS: Well, I don't really see how you can make any very accurate estimates on this because we still don't know anything about the life of the catalyst or very much about the effect of variables, such as temperature and pressure.

DR. OLDACH: Well, I knew that was the case, and when our general manager in New York called me on the phone I told him that we were hardly in a position to make any engineering calculations until the thing had been investigated a little better in the laboratory. He took this up with some of the other people in New York, but, as is usually the case, the white-haired gentlemen were not impressed by this argument and we have been told to go ahead anyhow, with what information we now have. I know that Charlie is too busy now to do any more work on this for at least three weeks. Of course, we will have to verify our assumptions in the laboratory as soon as possible.

DR. NEAS: That's right. Well, to continue, this paper I ran across gives some reaction velocity data which the author obtained with this catalyst of his. The data look pretty good and he gets some nice straight lines when they are plotted. He gives a formula for the reaction velocity constant in terms of the variables involved in the system. His dope is for anhydrous isopropanol, however, and if you use CBM isopropanol, the results will be affected by the presence of water. I am pretty sure that the water will have no effect on the reaction other than to act as a diluent. Based on this assumption, I have recalculated the formula in this paper to apply to the use of CBM isopropanol. I will put it on the blackboard:

(The following is copied from the blackboard)

$$k = \frac{1.71NT}{V} \left[2.46 \ln \left\{\frac{1}{1-\alpha}\right\} - \alpha\right]$$

α = fraction of isopropanol converted

T = absolute temperature, °K.

N = feed rate, gm. moles per min. of contained isopropanol

V = volume occupied by catalyst, cc.

k = reaction rate constant, seconds $^{-1}$

ln = logarithm to the base e

Now you can see from this thing that if you know the temperature and if you know k, you can get α if you know N and V; or if you know N and α, you can get V, and so on. This paper I have been speaking of gives an initial value for k of 0.30 sec. $^{-1}$. This is a good deal higher than for our previous catalyst.

MR. KING: Charlie, let me interrupt a minute. That volume occupied by the catalyst - I assume that that means the volume of the tube in which the catalyst is placed; in other words, it includes the voids as well as the actual solid particles themselves.

DR. NEAS: Yes, that's correct. We always speak of catalyst volumes on that basis.

MR. KING: O.K. Incidentally, Irvin, you better convert this stuff to English units before you start your calculations. Use pounds, hours, and cubic feet. I don't want to have to wade through a lot of grams and ccs. in checking your calculations.

MR. GREENATIT: All right.

DR. NEAS: Now the only trouble with these data is that the catalyst activity decreases as it gets older. This paper makes mention of this fact and gives some curves for catalysts at different levels of activity, but the author does not say how old the catalyst was at each of these activity levels. This means that if we are going to use this information at all, we'll have to guess as to the effect of catalyst age on the catalyst activity. The only thing I know of to go on is the work we did with our previous catalyst. This also showed a decrease in activity with increase in age, and I have looked up some of these figures. It turned out that the catalyst lost about half of its initial activity after 10,000 pounds of isopropanol per cubic foot of catalyst had been passed over it.

MR. BUTENHOFF: Is the loss in activity a function of the amount of isopropanol passed over it, or a function of the amount converted?

DR. NEAS: Our experience indicates that the loss in activity is directly proportional to the amount of alcohol fed. But we still don't know how this new catalyst is going to behave. I am pretty sure that it won't lose activity as fast as the old one.

MR. BUTENHOFF: How do you know that?

DR. NEAS: Well, I don't really. I just have a hunch that it ought to be superior.

MR. KING: How much superior?

DR. NEAS: Oh, maybe twice as good.

MR. KING: Would it be reasonable to assume something like that? For instance, that it would lose half its activity after the passage of 20,000 pounds of isopropanol per cubic foot instead of 10,000?

DR. OLDACH (Smiling): It looks as if the Research Department, as usual, knows practically nothing about the process they are supposed to be working on.

DR. NEAS: But Carl, we haven't worked at all yet with this new catalyst!

DR. OLDACH: Yes, I know. Well, anyhow, unless the catalyst turns out to have a life at least as long as the one we worked with before, I don't think we will wish to go ahead with this project. However, I don't think that just a guess of Charlie's is sufficient grounds for us to assume that the new catalyst will prove to be twice as good. I think that we should assume that it will be no worse than the old one; in other words, that it will have a life equal to the old one. If it turns out to be better when Charlie has had a chance to evaluate it, that will be just fine. But we shouldn't just assume that it will be better.

MR. KING: Yes, I guess that's right, Carl; in fact, I'm sure it's right. O.K. then, we'll use a half-life equivalent to the passage of 10,000 pounds of contained isopropanol per cubic foot of catalyst. Now, if I get this straight, Charlie, that means that k will decrease from 0.30 to 0.15 sec.$^{-1}$ after that much isopropanol has been fed to the converter?

DR. NEAS: That's right.

MR. KING: And don't I remember that these things tend to fall off logarithmically; in other words, if you plot k against the amount of isopropanol fed on semi-log paper, with k on the logarithmic coordinates and the amount of isopropanol fed on the arithmetic coordinates, you ought to get a straight line?

DR. NEAS: Yes, that's right. At least the data we had with our earlier catalyst followed that sort of pattern and I think it is a fair guess that the same will be true here.

MR. KING: There's something I don't quite understand here. You say that k has an initial value of 0.30 sec.$^{-1}$. This must be affected by temperature, isn't it? I mean even though T comes into the equation, k must have a different value for different reaction temperatures.

DR. NEAS: Oh yes, I forgot to mention that. The value of 0.30 is for 300°C. This paper gives values for various temperatures. In fact, it gives a plot of log k versus $\frac{1}{T}$. The reason I picked 300 was that I am sure that this is about where we will want to operate. If you go much higher than this the efficiency begins to suffer and you start making too many by-products. Too low a temperature on the other hand reduces the value of k and thus the productivity of the catalyst. It begins to affect the equilibrium, too.

MR. BUTENHOFF: Well, 300 is all right. In fact, I wouldn't want to go much over this, since we'll have to heat the converter with our Dowtherm system and I don't like to run it much over 350.

MR. KING: Let's settle on 300 then for the purpose of these calculations. This will mean that the initial value of k of 0.30 sec.$^{-1}$ will be correct.

DR. NEAS: O.K. Excuse me, I didn't mean to make a pun.

MR. GREENATIT: When you were speaking of efficiency a few minutes ago, just what did you mean by that?

DR. NEAS: Well, that's the moles of acetone produced divided by the moles of isopropanol consumed. We usually call this efficiency. The moles of acetone produced divided by the total moles of isopropanol feed would be the yield per pass.

MR. GREENATIT: I see. Incidentally, what pressure are we going to operate this process at?

MR. BUTENHOFF: I think we ought to operate at atmospheric pressure. Does everybody agree with this?

DR. NEAS: Well, I'm not so sure that I do. We haven't done any work at higher pressures, it's true, but if you put the isopropanol through under pressure, you ought to get more acetone formed per unit of catalyst. In other words, I would think that k would be higher as the pressure was increased and that we would probably get more out of this converter if we ran under some pressure. The data I have given you were obtained at 1 atmosphere.

MR. KING: Yes, but how about equilibrium? This reaction is accompanied by an increase in volume and if you raise the pressure you will tend to repress the equilibrium.

DR. NEAS: Well, I know that, but at 300° the equilibrium is so far over on the side of making acetone that raising the pressure some shouldn't make too much difference.

MR. BUTENHOFF: Well, I don't know about the effect on the catalyst, but the equipment in the Iso Unit would not be good for much more than 1 atmosphere, anyhow. The shell side of the converter is built for 150 pounds per square inch and is suitable for Dowtherm. but the heads on the tube side are pretty light. This equipment was operated at atmospheric pressure in the Iso process. We would probably have to modify the converter and perhaps some of the heat exchangers if the process was to be operated under pressure. The vaporizer feed pumps wouldn't be suitable either.

DR. OLDACH: It seems to me that we have very little to go on in this process as it is, without bringing in any more variables that we have to. It seems to me that it just stands to reason that a dehydrogenation process of this type ought to be operated at as low a pressure as possible. If the equipment is only good for atmospheric pressure, that's another very good reason. Let's plan on running it at 1 atmosphere. Charlie here can investigate the effect of higher pressure when he gets around to doing his experimental work, but in the meantime let's not consider anything but 1 atmosphere total pressure.

MR. GREENATIT: In connection with this question of equilibrium, what provision is made for the rate of the reverse reaction in the equation which you put on the blackboard, Dr. Neas?

DR. NEAS: The reverse reaction is ignored. In other words, it is assumed to be negligible and the equilibrium is assumed to be 100 per cent on the side of the formation of acetone. At 300°C. this is very nearly true. I think we can ignore the effect of equilibrium and assume the reaction goes to completion at this temperature.

MR. GREENATIT: I don't quite understand this business about the loss in activity of the catalyst. I gather that it falls off in activity in a logarithmic manner and that k is reduced to one-half when 10,000 pounds of isopropanol has been passed over per cubic foot of catalyst. But you must not be able to go on indefinitely like this, because after a while the catalyst activity would fall away to practically nothing. Is there some reactivation procedure to restore the original activity?

DR. NEAS: Oh yes, I forgot to mention that. The catalyst can be reactivated and restored in its original activity. I believe that Mr. Butenhoff can tell you something about this.

MR. BUTENHOFF: We had a somewhat similar problem in the Iso Process. From what I know about this new catalyst of Charlie's my guess is that the same sort of reactivation treatment can be used here as was used in that process. This reactivation procedure is a nuisance. It means taking the equipment out of production for about two days while the reactivation is going on. Aside from the loss of production involved, it will cost us about $1,000.00 per reactivation for materials and miscellaneous labor.

MR. KING: $1,000.00? That sounds pretty high.

MR. BUTENHOFF: Well, I may be allowing a little leeway. You can't tell what sort of reactivation treatment Charlie may come up with. I remember one process about ten years ago where they wanted to reactivate the catalyst with ozone. I think you ought to make an allowance of $1,000.00 per reactivation in your calculations and assume that two days will be required for each reactivation.

MR. GREENATIT: You mean two full days of twenty-four hours each and that no acetone will be made during this period?

MR. BUTENHOFF: Yes, that's right.

DR. OLDACH: I think that's as good a basis as any, Irvin. It is obvious that we don't know all the answers and it will be necessary to make a number of arbitrary assumptions such as this. Let's assume, too, that the reactivation technique used in the Iso process will also do the job here, and make no allowance in your cost estimates for any new equipment for reactivation. This is a somewhat questionable assumption, but we really haven't got much basis for assuming something else.

MR. GREENATIT: All right, I'll use this as the basis. One other question, is this reaction endothermic?

DR. NEAS: Yes, it is.

MR. GREENATIT: What is the heat of reaction?

DR. NEAS: We calculated that once before. I think I have it in my files. Yes, here it is. I'll put the formula on the blackboard.

(The following is copied from the blackboard)

$$\Delta H_{T^\circ} = 12{,}620 + 3.0T \text{ gram calories per gram mole,}$$

where T is temperature in °K.

MR. GREENATIT: Then the function of the Dowtherm system will be to supply the heat of reaction?

MR. KING: Yes, that's right. The Dowtherm system will also supply the heat necessary to raise the isopropanol vapor to the reaction temperature of 300°C. I have been meaning to show you this flow sheet that shows the equipment available in the Iso Unit and the general manner in which it is hooked up. This is the flow sheet here. (See flow sheet page 33.) The flow sheet also shows the size of each piece of equipment and gives a brief description. The unit includes a vaporizer equipped with a steam coil where the isopropanol will be vaporized. The vapor then passes through a heat exchanger, and then upward through the tubes of the converter. From the converter the reaction products pass through the heat exchanger and then to a water-cooled condenser.

MR. GREENATIT: How is this converter built?

MR. KING: It is built like a heat exchanger. It contains 253 3-1/4 inch O.D. 11-BWG steel tubes each 20 feet long. These are secured in tube sheets at either end. The catalyst is placed in the tubes. You can assume that the entire length will be filled with catalyst. Screens are provided at the top and bottom for holding it in place. Liquid Dowtherm flows around the outside of the tubes.

MR. GREENATIT: What is the pressure drop going to be across the catalyst?

DR. NEAS: It will be very small. Maybe a pound or two.

MR. KING: I think we ought to assume that pressure drop throughout the system, including both the catalyst bed and heat exchangers, is negligible. In other words, Irv, assume that the entire process operates at a pressure of 1 atmosphere.

The Dowtherm flows up through the converter, through a small surge tank and then back to the Dowtherm heater. I think you ought to assume that the entire catalyst bed will be at a temperature of 300°C.; or, in other words, that the process is isothermal. Of course this won't be strictly true, but it'll be close enough for practical purposes. The Dowtherm temperature in the shell won't be constant, and the entering isopropanol vapor - from the heat exchanger - won't be at 300, but you can ignore this. The converter has such a large area from the standpoint of heat transfer that the entering vapor will be heated up to 300° in the first few inches of catalyst.

The Dowtherm heater has a capacity of 3,000,000 BTU per hour. This refers to the difference in heat content between the liquid streams entering and leaving the heater. You ought to allow 20% of this for heat losses from the piping and equipment, so a maximum of 2,400,000 BTU per hour will be available for the process. You can assume that the thermal efficiency of the heater is 60 per cent; in other words, 60 per cent of the heat in the fuel gas is transferred to the Dowtherm. This heater burns natural gas having a heating value of 1,000 BTU per cubic foot. Incidentally, the Dowtherm heater will have to run during reactivations, at about the same rate as when the unit is on steam.

MR. GREENATIT (Referring to flow sheet): I assume that this partial condenser will condense most of what comes out of the converter but not all of it. The hydrogen must leave here at the top of the condensate tank.

MR. KING: Yes, that's where it will leave.

MR. GREENATIT: And it will be saturated with a mixture of isopropanol, acetone, and water at the temperature and pressure existing in the condensate tank?

MR. KING: Yes, and that's something I hadn't thought very much about. With our cooling water temperature of 30°C., about the best we can hope to do is cool the condensate and uncondensed hydrogen and vapor to about 35. At 35° there will be quite an appreciable amount of acetone and isopropanol remaining uncondensed.

DR. NEAS: Can't you add a brine-cooled condenser? This is what we did in the laboratory.

MR. KING: No, I'm sure this would be too expensive. Furthermore, we haven't got any brine in the area. Probably the thing to do is to scrub the hydrogen with water to remove the acetone and isopropanol. We haven't got any scrubber either.

MR. BUTENHOFF: Well, Bob, we'll probably want to use this hydrogen in the Organic Chemicals Hydrogenation Unit, so why can't we just take it as it comes from the condensate tank and compress it up to 200 pounds in our regular hydrogen feed compressors? The acetone and isopropanol will be condensed out in the intercoolers and aftercoolers and this condensate can be returned to be added to the main condensate stream from the partial condenser. Furthermore, we have activated carbon traps on the high-pressure hydrogen, and they will take out whatever the coolers don't catch.

MR. KING: That's a good idea. Are you sure your compressors and intercoolers and aftercoolers will handle this load?

MR. BUTENHOFF: Oh, I think so. The compressors have more capacity than we really need and the coolers are also pretty big. We will check on this for you later, but I think you can assume that we can handle it.

DR. OLDACH: How about compressor oil getting into the condensate?

DR. NEAS: I don't think this would be too serious. The process makes some oily by-products which will come out at the base of the isopropanol recovery still, anyhow. Most of the oil will just go out here.

MR. BUTENHOFF: Incidentally, we never did settle on what we are going to take for the efficiency.

DR. NEAS: Oh yes. We talked about that but never set a figure. I think we ought to get about 98 per cent efficiency if we operate at 300°. A small amount of gas other than hydrogen will be formed and there will be some high-boiling by-products. The gas will go on out with the hydrogen, but it won't be enough that you will notice it. The other by-products, as I have said, will leave with the water from the base of the isopropanol recovery still.

MR. KING: 98 per cent sounds like a good number for efficiency to me. Let's assume that this will allow for all losses, including by-product formation.

MR. GREENATIT: About this partial condenser again, this mixture of hydrogen, acetone, isopropanol, water, and perhaps a few other things sounds rather complicated. Is there any liquid-vapor equilibrium data for this mixture?

DR. NEAS: You mean are there any data? No, I'm afraid not. That is something we intend to get but we haven't anything on it yet.

MR. KING: Well, about all you can do, Irv, is assume Raoult's Law is right. It won't be right, but it won't be too far off for this sort of thing. You understand what I mean, don't you? You can ignore the solubility of the hydrogen. This is going to involve a lot of calculations, and if you can figure out some short cut you better use it.

MR. GREENATIT: I think I can figure how to calculate it.

MR. KING: We haven't said anything much about the still system yet. You see, you are only going to get a partial conversion here of isopropanol to acetone. The converter product, after removal of hydrogen, will have to be put through two continuous stills in series. The first still will recover the acetone. The liquid from the base of this will flow to the second, where the unreacted isopropanol will be recovered. This isopropanol will be taken off the top of this still at a concentration very closely approximating that of the CBM. This recovered isopropanol will be returned to the vaporizer along with make-up. The water and by-products will leave from the bottom of the isopropanol still. Now one of the principal things you will have to find out, Irv, is how big the new still should be. As the flow sheet shows, the Iso Unit only has one still and we will have to add another. Of course, I don't know for sure that it can be used at all; it may be too small. In connection with the work that was done on the manufacture of acetone some time ago, we calculated the number of plates and reflux ratios it would take for each of these two distillation jobs. I have looked these calculations up, and it takes fifty plates - actual plates, that is - for both the acetone still and the isopropanol recovery still. This is based on a plate efficiency of 40% which is what we usually assume. It so happens that the present still has just 50 plates, so from that standpoint it could be used, either as the acetone still or as the isopropanol still. The acetone still requires a reflux ratio of three to one, that is, three reflux to one of product, and the isopropanol still requires a reflux ratio of one to one. You can use these figures in your calculations, and they will save you the trouble of having to draw McCabe-Thiele diagrams and that sort of thing.

MR. GREENATIT: Were these calculations based on the usual simplifying assumptions, such as the feed and reflux being at their boiling points?

MR. KING: Yes, I'm sure they were. However, you needn't worry about that. If the feed and reflux are not at their boiling points, you can ignore that fact insofar as the number of plates and reflux ratios are concerned. Also, you can assume in your calculations, that the distillate from the acetone still is pure acetone, and that the residue from the isopropanol still is pure water.

Now the thing I was going to say was that you will have to figure out what the diameter of each still should be, and then see whether this existing one will work out best for the acetone recovery job or for isopropanol recovery. The existing still at the Iso Unit has 12-inch plate spacing, and the new one should be the same. Incidentally, we have standardized on distillation column diameters which are even multiples of six inches, and the new still should be specified on this basis.

Now when we made these still calculations, we also determined the column areas required and some other things. You can use these factors, and they'll save you a lot of work. I'll put this stuff on the blackboard:

(The following is copied from the blackboard)

	Per 1,000 Lb./Hr. Acetone Distilled	Per 1,000 Lb./Hr. Isopropanol Distilled
Column cross-sectional area, sq. ft.	6.4	4.2
Condenser area, sq. ft.	220	150
Steam, lb./hr.	1100	915

These figures are per 1,000 lb. of actual product at the reflux ratios I just gave you. They are not per 1,000 lb. of reflux plus product - make sure you get that straight. Also, the isopropanol is contained isopropanol.

MR. GREENATIT: How about the reboiler areas?

MR. KING: You mean calandrias? We call them calandrias. That's funny, I don't seem to have those figures. I guess you'll have to calculate them from the steam requirements.

MR. GREENATIT: I notice from the flow sheet that all this equipment is steel. Is that going to be all right for this process?

MR. KING: Yes, I think so. How about it, Charlie?

DR. NEAS: As far as we know steel ought to be O.K.

MR. BUTENHOFF: What are you going to do about tanks for these various streams?

MR. KING: Well, the Iso Unit already has three 10,000-gallon feed tanks. My thought was that these could be used for make-up isopropanol, which will be delivered by tank car, and for the recycle. There is a 1,000 gallon converter product tank which will serve for this prupose, and also as a still feed tank. No tank will be needed between the two stills. Since you already use acetone in one of the buildings of the Organic Chemicals Area, which is close by, I see no reason why the acetone we make should not flow directly to the storage tanks you already have there. I thought, too, that we would run the water and by-products from the base of the isopropanol still to one of the existing feed tanks of your Miscellaneous Chemicals Department. This material could be worked up in one of the batch stills there, if the by-products contained in this stream make this worth while.

MR. BUTENHOFF: I guess that's all right. We are pretty badly loaded up as far as tanks go in the Miscellaneous Chemicals Department, but it may turn out that the water from the base of the isopropanol still can simply be thrown away.

MR. GREENATIT: Should I put in a cooler or heat exchanger to cool this water?

MR. BUTENHOFF: No, I wouldn't bother. If we throw it away, we won't need to cool it and I doubt if the heat is worth saving. If we work it up, we can use it hot.

DR. OLDACH: Sounds all right to me. Let's not put in any new tanks unless we have to; that area is already crowded.

MR. BUTENHOFF: Can we assume, Bob, that we will run with a constant isopropanol feed to the converter?

MR. KING: Yes, I think so, Mel. We have had that problem come up before and there are several ways you can run it. You could run with constant per cent conversion, with constant acetone production, or with constant isopropanol feed. It usually turns out, as far as the calculations are concerned, that it doesn't make much difference which method you pick, but constant isopropanol feed is the simplest.

MR. BUTENHOFF: I was hoping that you would say that. It would be an awful nuisance to have to try to vary the isopropanol feed all the time in order to maintain constant acetone production or constant conversion. As far as our tanks are concerned, I am pretty sure we have plenty of storage to take care of any variation in acetone production rate.

DR. NEAS: I should think it would be better to run at a constant percentage conversion. There must be some conversion level at which the catalyst is utilized to best advantage, and this point should be maintained at all times.

MR. KING: Well, I wouldn't say you were wrong from a theoretical point of view, but I don't think it makes much difference. It is simpler to maintain constant isopropanol feed. Let's figure on it that way, anyhow.

DR. OLDACH: One thing you're going to have to do, Irvin, is investigate the capacity of the Dowtherm system for this job. Of course, it is going to be necessary first to find out whether the converter and the one still are somewhere near the right size, but assuming that they can be made to do the job, it is also going to be important to make sure that the Dowtherm system is big enough. This is a relatively expensive part of the unit and it would be the dickens of a job to add another Dowtherm heater. I don't know just how you are going to go about this problem; it is going to take some thinking before you start. You ought to make sure, though, that the converter, the one still we have, and the Dowtherm system can be made to do the job provided the proper conditions are chosen.

MR. KING: Yes, I'm sure that's right; these are the most important items. It will also be necessary, though, to figure out whether the existing still should be used as the acetone still or as the isopropanol still, and to calculate how big the new still should be. You will also have to find out how often the catalyst should be reactivated. All this will probably involve some sort of economic balance between the operating variables you have to play with and the cost of the new still. Amortize new investment on a 5-year basis in making any such balance; in other words, charge 20% of the new investment per year to the process. It will also be necessary to check the size of the miscellaneous items of equipment, such as the heat exchangers, to see what else will have to be bought.

DR. OLDACH: Another thing that's going to be important is to keep the steam usage to a minimum. The increasing price of coal is making our steam costs go up and up and up, and anything you can do within reason to save steam will be very much to the good. Our steam plant is pretty well loaded up, too, and if we keep putting in new steam users the Utilities Department is going to start hollering for another boiler. Boilers don't come cheap these days, either.

MR. BUTENHOFF: Amen!

MR. KING: I agree 100% too. But don't put in any heat-saving schemes that are too fancy to be practical.

MR. BUTENHOFF: Amen again!

DR. OLDACH: Well, gentlemen, I think it's about time for lunch. It is unfortunate that Bob King and I will be away while Irv is working on this problem, and he will just have to do the best he can. (Turning to Mr. Greenatit):

Where all the information is not available, you will just have to make your own assumptions, bearing in mind the things we have talked about this morning. Don't worry too much about the details of the problem and try to keep on the main track. You ought to realize, too, that this whole thing is in a very preliminary stage and we don't expect a very finished job at this time. What New York wants is an indication of whether we can use this unit and how much it will cost for new equipment and what the operating cost will be.

MR. GREENATIT: Bob, I wonder if you could give me some help on things like heat exchange coefficients and cost data before you leave?

MR. KING: Yes, I had intended to do that. Since time is getting short this morning, I will try to get some of this information and send it to you before I leave. Charlie, I wonder if you will send Irv the data he will need on the physical properties of these materials? Things like latent heats, boiling points, and so on.

DR. NEAS: Yes, I'll be glad to do that. I'll try to dig this stuff up and send it to you right away.

MR. BUTENHOFF: Well, let's have lunch.

INTEROFFICE MEMORANDUM

November 3, 1947

TO: Mr. I. M. Greenatit
FROM: Mr. R. W. King

As was mentioned at our conference this morning, I am sending you herewith certain additional data and information you will need in connection with your investigation of the proposed acetone process. A number of things have occurred to me that we did not discuss at the meeting and I will try to set them down since Mr. Oldach and I are leaving town tomorrow.

1. Use the following heat transfer coefficients (BTU per hr. per sq. ft. per °F.) for all types of heat exchangers:

(a)	Condensing vapor to boiling liquid	250
(b)	Condensing vapor to flowing liquid	150
(c)	Condensing vapor to gas	20
(d)	Liquid to liquid	50
(e)	Liquid to gas	20
(f)	Gas to gas	10

In the special case of the partial condenser in the reaction system, add the latent and sensible heat loads together and use an overall coefficient of 30 BTU per hr. per sq. ft. per °F. for the entire load.

In the case of condensers such as those on the stills, assume that condensation and condensate cooling take place in sequence, and calculate each zone separately. Then add the required areas together.

Where water-cooled coolers or condensers are employed, assume that cooling water is available at 30°C., and that the process fluid (liquid or gas) is to be cooled to 35°C. The cooling water outlet temperature should be based on the following tabulation:

Temperature of Hot Process Fluid Entering Exchanger, °C.	Cooling Water Outlet Temperature °C.
Less than 75	40
75 to 100	45
Over 100	50

In the case of equipment heated by condensing vapors, assume that the condensate leaves at the condensing temperature. Incidentally where heat is being transferred to a boiling liquid, as in the isopropanol vaporizer, do not use a ΔT of more than 50°C. in your calculations even though more may be available. If you do not understand the reason for this, I'll explain it to you some time.

You should realize that it will not be practical at this stage to investigate the performance of heat exchange equipment in detail. Areas should be calculated from for foregoing information, without regard for other factors.

2. I forgot to mention this morning that I think you can assume that the tray design and downpipe arrangement in the existing column at the Iso Unit is such that this column will be satisfactory for use as either the acetone still or the isopropanol still. The column was designed for a liquid overflow considerably larger than you will have here.

3. Our standard gas conditions in the plant are 14.7 lb. per sq. in. abs. and 70°F. All gas volumes should be referred to this basis. This is equivalent to 387 cu. ft. per lb. mole.

4. Use the following information in calculating investment costs:

Heat Exchangers (Steel)

Surface, Sq. Ft.	Cost, $ per Sq. Ft.
50	20.00
100	14.00
200	10.50
300	8.50
500	6.50
1000	5.00
3000	4.00

Use these costs for all types of heat exchange equipment, including converters.

Distillation Columns (Steel)

Estimate on the basis of $25.00 per sq. ft. of tray area.

Pumps

Take the cost of pumps at $800.00 each regardless of size or material. Note that we always provide a spare pump for each pump in continuous service, or at least a common spare for two pumps in continuous service, where this is practical.

Storage Tanks (Steel)

We have standardized on a limited number of tank sizes. These standard sizes and the cost of each are as follows:

Capacity, Gal.	Cost, $
100	200.00
500	400.00
1,000	600.00
5,000	1,400.00
10,000	2,000.00
50,000	4,500.00
200,000	7,500.00

Dowtherm Heaters

Estimate Dowtherm heaters on the basis of $5,000.00 per million BTU output capacity.

Catalyst

Do not forget the new catalyst charge which will be required. We do not have much information on this. Assume that the catalyst will cost $1.00 per lb. and that it will weigh 40 lb. per cu. ft. of converter volume.

5. Estimate the cost of any major new equipment that will be needed from the foregoing data. Get the total of this new equipment. Then multiply by 3 to get the total new investment required. In other words, the installation cost including such things as labor, minor equipment items, piping, wiring, instruments, foundations, engineering, and the like will be about two times the cost of the major equipment itself, thus making the entire cost three times the cost of the equipment. Use this same basis in making economic balances. I believe you can ignore the cost of any minor piping changes which may be required in connection with the reuse of existing equipment. If, however, it is necessary to revise drastically the service of a given piece of equipment, you should charge the amount equal to two times its estimated cost to cover the expense of reinstalling it. As an example, if the heat exchanger now in use in the conversion system were to be reinstalled as a condenser or heat exchanger for the

new still, it would be necessary to figure in this reinstallation cost. Unless you plan on doing something of this sort, I do not believe it will be necessary to include anything for rearrangement.

Incidentally, do not multiply the catalyst cost by 3 along with the equipment. Figure the total cost without the catalyst, and then add the catalyst in at the end.

In case it turns out that some piece of equipment is too small, you will have the option of replacing it with a larger unit, or of retaining it and adding another unit to operate in parallel. You will have to use your own judgment in deciding which is preferable. We will probably be able sooner or later to find some use for any equipment you do not require. Do not take credit in your cost estimate, however, for any equipment you do not utilize.

6. The present building and equipment structure at the Iso Unit should be adequate for the acetone process, so you will not have to allow anything for a new building or for alterations.

7. The following should be used in calculating operating costs:

Steam (available at 50 psig. sat.)	$0.55 per M lb.
Fuel gas	$0.20 per MM BTU (net)
Hydrogen	Credit at its fuel value only, based on a net heating value of 270 BTU per cu. ft.
Catalyst replacement	Even with reactivation the catalyst will not last forever. Assume that it will have to be replaced entirely once a year.
Labor and supervision	Take as $36,000.00 per yr.
Maintenance, supplies, etc.	Take as $30,000.00 per yr.
Plant overhead	Take as $50,000.00 per yr.
Other miscellaneous charges	Take as $20,000.00 per yr.

This last item will include water and electric power, which will not amount to much and need not be otherwise considered.

8. You should report the manufacturing cost for acetone calculated from the above data and from the cost of isopropanol mentioned at our conference this morning. This will be the direct manufacturing cost, without amortization. The manufacturing cost plus amortization is not required.

Your manufacturing cost figures should be presented on an annual (rather than daily or monthly) basis, to conform with our standard practice.

9. Your calculations should be based on operation of the unit 24 hours per day 350 days per year. (This 15 day allowance is to take care of shut-downs for repairs and the like; it is over and above time down for catalyst reactivation).

10. We neglected to discuss this morning the manner in which your report should be written and presented. After you complete your calculations the results should be assembled in the form of a report. I will check this after I get back, and Mr. Oldach will then transmit it to our management in New York. You should bear in mind that this report will be primarily for their benefit, and that they will be most interested in the overall picture and will not care too much about the details. The report should be prepared in accordance with our standard form and should include the following divisions:

A. Foreword

This should explain what the report is about. It should include the basis and reasons for making the report, but should not include any of the results obtained from the studies you have made. Remember that the readers in New York were not at the conference this morning and that some may not even have heard of this project, so include enough background to acquaint them with the scope of the problem. This section of the report should preferably cover no more than one-half of a standard single-spaced typewritten page.

B. Summary

This section should give the answers to the following questions:

1. Will it be practical to make 25,000,000 lb. per yr. of acetone in the Iso Unit?
2. Briefly, what changes and additions will be required?
3. How much will it cost to make these changes and additions?
4. How much will it cost to make acetone in this equipment? How much will be saved over the present cost of purchased acetone?
5. Include any other matters in the summary which you feel should be brought to the attention of the management. Cost data should be presented in tabular form in the Summary, wherever this is feasible. The Summary should be on a separate page. It should be as concise

as you can make it. If possible, it should not occupy more than one single-spaced typewritten page.

C. Discussion

The Discussion should outline the method you used in attacking the problem, and should explain and elucidate the results reported in the Summary. It should not include any detailed calculations. This section of the report may be as long or as short as you think necessary. It should give the reader an understanding of what you have done and satisfy him as to your major assumptions and methods. It should bring out any technical matters not important enough to include in the Summary.

D. Appendix

This section of the report should contain your calculations. Include only enough of these calculations so that someone like myself can follow them and check them. If several successive calculations are made using the same formula, give the formula and a sample calculation, perhaps accompanied by a tabulation of the other resultant figures. It will not be necessary to include a flow diagram.

INTEROFFICE MEMORANDUM

November 3, 1947

TO: Mr. I. M. Greenatit
FROM: Dr. C. C. Neas

As requested by Mr. King this morning I am transmitting to you herewith the physical properties of the materials which will have to be handled in manufacturing acetone from isopropanol.

You will find the vapor pressures of acetone and isopropanol on pages 377 and 380, respectively, of the 2nd edition of Perry's Handbook. I am giving you certain physical properties from our files, including the vapor pressures of the isopropanol-water CBM, and the properties of Dowtherm.

Table I - Physical Properties of Isopropanol, Isopropanol-Water CBM, and Acetone

	Specific Gravity At 20/20°C.	Change in Sp.Gr. Per °C.	Specific Heat (Liquid) BTU/Lb./°F	Specific Heat (Vapor) BTU/Lb./°F.	Latent Heat of Vaporization BTU/Lb.
Isopropanol	0.7862	0.00084	0.606	0.48	287
Isopropanol-Water CBM	0.8179	0.000871	---	---	---
Acetone	0.7910	0.001136	0.511	0.42	220

Table II - Vapor Pressure of Isopropanol-Water CBM Versus Temperature

Vapor pressure, mm Hg.	760	700	600	500	400	300	200	100
Temperature, °C.	80.4	78.5	74.5	70.3	65.1	58.8	50.5	37.3

Table III - Properties of Dowtherm

Temperature		Pressure	Heat Content, BTU/Lb.			Sp. Ht. of Liquid	Density, Lb./Cu.Ft.	
°F.	°C.	PSI Abs.	Liquid	Latent	Sat.Vapor	BTU/Lb.°F.	Liquid	Sat. Vapor
53.6	12.0	---	0.0	164	164	0.37	---	---
300.0	149.0	0.74	108.0	142	250	0.50	59.6	0.012
400.0	204.0	4.10	162.0	134	296	0.57	56.7	0.068
500.0	258.0	14.7	222.0	123	345	0.63	54.1	0.28
600.0	315.0	44.3	288.0	110	398	0.66	50.4	0.88
700.0	371.0	104.0	358.0	97	455	0.68	46.9	1.7

ISOMERIZATION UNIT FLOW DIAGRAM