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Professional Development Training Course for Registered Engineers

Heat Exchanger Applications

Tape 1 – Side 1 (Disk 1)

This is titled Heat Exchanger Applications. My name is Ed Hardin and I'm a registered chemical engineer in the State of North Carolina and have been involved in construction and design of process chemical plants for the last 30 years here in North Carolina. Prior to that, in the operation of several varieties of plastics and chemical plants where I've run into the use of a lot of heat exchangers and quite a variety of heat exchangers in a number of different plant positions and operating locations and performance methods.

When you mention heat exchangers and begin to talk about them in process applications, a lot of different things come to mind. Many people think that only a shell and tube type heat exchanger should properly be called a heat exchanger. However, those of us who have been involved in a variety of operating situations recognize that there are a great many different things that can be referred to as heat exchangers and as methods of heat exchange. Plate type, the shell and tube, there are fixed, welded units that involve closely separated or reduced sized plates. There are extended surface exchangers that were developed for special applications. Then, sometimes there are the non-contact type varieties that are a type of heat exchanger, too, but go under different names. There are heat exchangers used to heat the bottoms of distillation columns, which are often called reboilers. There are condensers, which really are simply just a heat exchanger. There are heat exchangers that are used for a combination of services for cooling gases and then trying to condense them.

There are a lot of other uses where heat exchange and the heat exchange activities are an important part of the operating activity and the heat exchanger may not be entirely enclosed and it may be a significant part of the operating equipment. We might talk about some of those later in the system, but thin film evaporators and specialty equipment related to thin film evaporators would be included in that type of equipment.

We'll discuss uses just a bit. Heating, cooling, condensing, evaporating, recirculating, recovery of heat, all of these things are uses for the heat exchange process and for heat exchange technology. The discussions that we're going to go through on this tape and that I want to interest you in is the concentration on selection of appropriate physical activities or physical components of the heat exchanger that affect their process uses and their uses in various processes.

I don't intend to discuss mechanical details. In order to do that, it would take many drawings and references to the drawings that would not really be convenient to utilization of these tapes and the reference materials that go along with it. Also, those types of comments are generally

more completely covered in some of the TEMA publications and arrangements or some of the ASME publications. I suggest that you take a look at those things for picking out many of the specifics of mechanical details.

The other thing that's important to recognize when discussing heat exchangers and their applications is to understand that many of the comments that will be made here are somewhat personal. They're based on my experience and observations. There are some different opinions that will exist. Hopefully, this will be a cause for you to possibly discuss with other people these components and find out if there are particular reasons why something that I say about a general use in one area may apply or not apply to the particular activity that you'd like to be involved in. So, special applications quite often require special conditions.

A key thing to start with in discussing heat exchangers is to look at the one that is most typically used and this is the shell and tube heat exchanger. Many people through time have found that there are very good reasons for making differences in the design of the heads or the ends of each of the shell arrangements. Also, making specific arrangements of baffling and supports inside the shell. These things are generally discussed in the reference papers that have come with this tape. Those reference papers came from an old reference on heat exchangers, prepared by the Patterson Kelly Company. There's a page in there summarizing some physical arrangements of exchangers that also come from a chemical engineering article.

One of the key reasons for using shell and tube type heat exchangers is the general simplicity of fabrication. This is simply a number of tubes connected to tube sheets on each end and inserted in a shell. It's sometimes fixed in place, sometimes not. We'll discuss that a little later on. The papers that we've indicated above show many of these arrangements.

A significant reason for using shell and tube type heat exchangers over time has been the ease of cleaning and maintenance, which we'll talk about a little. Many applications of heat exchangers allow the periodic removal of these exchangers, opening of the heads, and then the use of various devices for passing through the tubes and cleaning the tubes in that way. So, the tube sides of the exchangers are generally very easy to clean. The shell sides are a little more difficult and we'll have some discussions later on about removal and separation requirements of the shell package from the tube package in relation to cleaning.

In considering the applications of the various shell and tube heat exchangers, the key item is simple heat recovery. Quite often, there are situations where a cool stream is fed into a process, a hot stream is discharging from the process, and what we're looking for is simply the saving of energy. So, a simple passage of one material on one side of the tubes and other material on the other side of the tubes allows that recovery. This is done with a variety of things. It can be done with liquids and gas streams. As a specific example in recent years, the application of the extended plate and extended surface heat exchangers for heat recovery in furnace and gas type operations has been widely reintroduced into industry. Again, that's a different variety, a different type of heat exchanger. It's the same basic operation, but it generally doesn't use the simple shell and tube.

The staged heat recovery is another place. Quite often there are situations where relatively high temperatures are used as part of the processing. Then, you'd like to bring the liquid back down to atmospheric conditions, but in doing it, if you were to flash off all of the vapor that could come off, you'd just be wasting an awful lot of energy. So, quite often, the material is cooled and countercurrent flowed with the material that needs to be heated up. You then end up with the cooled material with relatively little flash and the heated material with a lot less energy for reaching the final operating temperature.

A very significant example of this would be paper treatment and the liquor evaporations that are used in paper systems to apply heat recovery and sometimes water separation. Another example, and one that I worked in quite a bit, is an alumina refinery where they use anywhere from four to eleven stages of heat recovery to take liquor from atmospheric conditions often up to the 630 or 650°F range and back down again. Multi-stage evaporation trains are another example of doing this. Those evaporator trains can be used for a variety of reasons. Something in a sugar refinery might be simply to remove water to make the crystallization easier. Something, again, in the alumina refinery would be to remove the water simply to keep from diluting the recirculated process stream.

From talking about the number and variety of types of heat exchangers, where they're used and how, we can begin to start looking at the two particular components of the shell and tube heat exchanger. The shell and modifications related to it, the tubes themselves, and alternates that are sometimes used there. In looking at the shells, the significant items there should be an inlet and an outlet. Quite often there are preparations made for test connections to be added to them, but generally the shell is a simple, large diameter, determined length pipe-like configuration that's used to cover the outside of the heat exchanger with the appropriate connections to it.

However, when we start looking inside and looking at the tubes, we have to consider two things that are significant: the tubes themselves, their particular arrangement, and also the access to the tubes or the tube heads. Going back for just a moment to the shell side considerations, the tube arrangements have an affect there because they will affect shell side pressure drop and later, as we'll discuss, the potential for cleaning. On the tube side, we now get into the situation of whether the tubes will be straight. Will they go through from one end to the other and allow you the very simple entry and exit conditions or are there some reasons to have the entry and exit on the same end, in which case you might use a heat exchanger that's set up to be a two-pass exchanger on the tube side? One pass going to one end of the exchanger with the liquid turning around, coming back, and coming out the same end of the head. This then requires that the head cover be divided so that the liquor that goes in on one side will indeed be separated and come out of the other side of the head on the exchanger and allow about half of the tubes in each section.

Sometimes that number of tubes is changed and there will be a reason, either from vapor content in the material as it comes in that is reduced during the cooling so that you might end up with a ratio sometimes as high as 3 to 1 of one type of one pass of the tubes to the return pass. Again, you're into the variety of things that can be done with the shell flange connection to the head and the connections to that tube head. This is where we get some very creative activities, particularly in those areas where there are a number of heat exchangers where there are requirements for

specifics on cleaning or access. This, then, is where the tube side inlet head connections become very, very significant.

A typical arrangement that is used is to have a flat flange directly opposite the ends of the tubes. Used either in single or double pass arrangements with the piping supply to that head end, coming in from the sides, so that when the head cover flange is removed and the tube bundle can be removed from the exchanger, none of the other piping needs to be disturbed. Again, if you'll look at the general drawings that are supplied with the tape, you'll see that there are examples of that.

Over the past few years, a very special variety of heat exchanger has been more and more widely used. It's referred to as the plate type exchanger. Of course, the sizes of plates can vary quite a bit and some specifics of construction, but the general condition that exists is that the plates are stacked fairly close together and there are a wide variety of indentations and flutes that are molded into the sheets as they are placed together. These exchangers have the very interesting application phenomenon that the very thin sheets greatly improve overall heat transfer coefficients. The arrangements of the embossings, the flutes, and on the sheets themselves promote turbulent flow and, therefore, increase the side heat exchanger coefficients. Of course, this is all to the benefit of efficiency in heat recovery.

It's generally accepted, though, that a plate type exchanger should only be used in a continuous type operation. One of the most sensitive areas of the exchanger is its gasketing from sheet to sheet. In use, if the temperatures vary over a reasonable range in their application, you quite often find that the gaskets expanding and contracting will be affected by this continual flexing to the point that they'll begin leaking. So, you then have losses and mixtures of fluids as they drain away from the plates that create housekeeping problems and, of course, cause loss of product that no one likes to see. The other situation is that they require constant attention in order to be able to keep them tight. With the pressures that are in these things, it's very difficult to keep the platens that hold the plates together very tight once they've been expanded a little and loosened up.

Anyone who's tried to put a cap back on a flowing pipe or to close off the end of a hose could pretty easily recognize that what seems like a simple 15 or 20 psi pressure in one case ends up becoming multiplied quite a bit because of the hydraulic paradox when you start using larger surface areas and trying to contain a larger flow of fluids. This is particularly true with the plate types. Usually the plates are fairly large and, because of this, a very simple pressure ends up creating a very large force because it's exerted over a very large area. These exchangers usually have rather significant bolting all the way around. Of course, then you're into the question as you begin working with and using them of maintaining a good uniform bolting tightening pattern in order to keep the platens parallel and get good uniform compression around all of the gaskets.

Applications for plate heat exchangers are as varied as they are for almost any other exchanger. Of course, anyone needs to look very closely in making a decision about where to use these. The very large ones, as I suggested a little earlier, are typically best used where you have heat recovery requirements and continuous flows. The sizes of the heat exchangers can vary from something sometimes smaller than a shoebox to something quite often that's maybe two by six

or eight feet and sometimes so many plates that the unit itself might be 10 or 12 feet long between the platens. Again, efficiency, continuous flows, and relatively constant temperature conditions are the best conditions for applying this type of exchanger.

There are special applications, particularly for some pieces of these that are typically welded together and solid, where their use in a vent condition makes them very appropriate and reliable for recovering of materials that otherwise might go up a stack. So, vent condensers for relatively light flows are another very good application for this type of heat exchanger.

We can continue the discussion of application of plate heat exchangers by looking at some specific criteria that are important to considering when to use these units. One of the particular items that becomes very significant is solids content of the flows passing through the exchangers. Generally, these types of exchangers cannot handle solids. Very well distributed solids, very possibly. Materials where they are very intimately mixed, say a plastisol, where there is a temperature that you wish to use or a glue type of material where a temperature control needs to be applied. It certainly is an application that could be considered for plate heat exchangers, but for variable solids content or solids that vary in size, this usually is not a good application.

Flow distribution in plate heat exchangers is also a matter of some considerable concern. In the plates and along with the plates, there are some very particular methods for distributing flow from plate to plate. While these methods are very reliable for liquid conditions, if there are other things in the liquids, solids, variable types of materials, they can affect the distribution to the different plates.

A significant advantage of the plate type heat exchanger is the surface of the separating mediums themselves. As we mentioned before, these things are usually embossed. They can be embossed with a variety of patterns. One of the things that's very important in selecting and looking at these patterns is the distribution of flow through the units and the pattern of embossing because these patterns will promote turbulence and increase the heat transfer effects.

Quite often with tube and shell heat exchangers, people will be talking about heat transfer coefficients around 20 and on the very low end. When you're talking gases, up to maybe 200 to 250 for some very clean liquid applications. Of course, that's a pretty good variety, but when you get into plate heat exchangers, because of the very thin sheets and them being organized for high flow velocities and a lot of turbulence, it's very easy for the manufacturers to begin talking of heat exchange coefficients in the 300 to 500 range. Quite often, for some very specialized applications, they might talk of even higher heat transfer coefficients. These are overall used, not individual coefficients on one side or the other of the plate. Again, this is made possible by the very thin sheets. So, there's relatively little metal control of conduction in the heat transfer and it's all based on the high turbulence in the liquid medium, which will lead to the high heat transfer coefficients in the individual mediums.

Materials of construction are another item that make plate heat exchangers very interesting for some applications. It's very easy to use, very thin, very strong plates, and, thereby, reduce metal content. Also, the processing, the embossing program, and embossing methods that are used make it very easy to use simple sheets in making the plates for the heat exchanger. So, often, a

rather exotic material in a plate heat exchanger can be relatively inexpensive for an application. Whereas, if the same thing were incorporated into a shell and tube type heat exchanger, the cost of making the tubes, the problems of metallurgic control in making the tubes, and the techniques that would be necessary for welding the tubes into the various heat exchanger tube sheets, or other methods of maintaining the tubes in the tube sheet, could make the exchanger very expensive. Of course, head linings, head types, and so on, would also bring up costs. So, quite often, if you have a clean material, if it's relatively exotic in its material content, and you need some very specialized metals, a plate heat exchanger might be worth considering.

One of the things that also adds to the interest of applying plate heat exchangers is piping configurations. Since the supply and return connections for a plate heat exchanger are arranged in a rather substantial plate that is on one end of the unit only, the plates then take care within themselves of distribution from plate to plate of the liquids on both sides of the plates. The piping can be fixed very early and this allows minimum involvement with changing, removing, or adding piping during maintenance times, which can often be quite substantial with other types of heat exchangers. However, there is some reasonable space that is required behind the piping plate in order to provide access to the plates for removing and replacing them and, of course, some working space to be able to get into the bolting to tighten the exchanger up well after it has been cleaned and reassembled. So, there are, as with everything, advantages and disadvantages on both sides. Possibly, later on, we'll talk about some additional details of the application of these types of heat exchangers.

Some other heat exchangers that we can consider for a variety of applications go into the scrape surface, non-contact type heat exchangers, and another function often referred to in European type processing as drowning. The scrape surface heat exchangers had very special applications in their original development. They're still quite available. They are used in a variety of situations, all the way from a liquid application where the inside surface of the tubes is regularly scraped, as it's defined, or rubbed with a flat plate in order to prevent solids build up or solids stopping on the surface of the tube. This paddle like unit that is inside the tube also helps maintain some mixing of the solids as they pass through. This is a typical application for the removal of moisture from solids or in a material that has a high solids content for heat exchange and not wanting the solids to accumulate in the unit.

However, these type units do have the problem that, on at least one end, there will be a seal that will have to be maintained. Of course, in order to be able to provide the scraping of the internal surfaces, there must be a mechanical drive of some kind driving the units. These drives can be quite a maintenance problem and quite extensive. They generally consist of sprocket type gears on each end of the driven shaft and a chain that moves among all the shafts. Of course, you're now into the question of a rather significant knowledge of the material that you're handling so that you don't end up with one or two of the tubes becoming very dry and difficult to have the mixer shaft move inside the tube. This puts some rather extensive stresses on the driving chain, or whatever mechanism might be used, and can have a big affect on the performance of the unit.

The other surface and the connections to the other side of the heating or cooling function in a scraped exchanger also becomes a rather significant piping involvement. There are a lot of small connections into each end of the tube. Of course, distribution of the heat transfer material used

on the non-mixed side now becomes very important, too. A combination of hot oils with a heating arrangement is quite typical and very often water is used to cool down a rather thick slurry.

Non-contact heat exchange is an item worth considering in many applications. Quite often, we look to the idea of removing a vaporizable material from a mixture and consider doing it strictly through an evaporating heat exchanger. Something that can make that just as functional, quite often a little simpler and more reliable, is to use just the evaporation itself. In other words, maintain the material in a relatively warm vessel and then apply a vacuum to the overall system and draw the vapors off to somewhere else where they can be condensed. Now, whether that condensing is done in a heat exchanger or in a surface absorber of some kind, like a scrubber, it gives a very efficient way of removing the heat because, usually, if you're doing a cooling with cooling water, your actual heat pick up is 1 BTU/lb°F, the heat capacity of the water. Whereas with evaporation for each pound of water that's removed by evaporation, you can remove 1,000 BTUs.

There are additional advantages to evaporative type cooling. In removing the volatile or vaporizable fluid to provide the cooling, you will also increase the concentration of a desired product in the remaining reaction mixture. This is quite often a real benefit for future processing and recovery of the material, but these same kinds of arguments apply also to organic liquids. Again, with organic liquids on a strict heat transfer basis, you're down into the point of a 0.6 to 0.8 BTU/lb for a conductive and convective heat transfer condition. Whereas in evaporation, heat removal rates are in the neighborhood of 400 to 600 BTU/lb°F as it is removed from the system. Quite often, you also remove a recoverable material that can be recycled and reduce a problem of separation for processes later on.

The condensers that go along with this, as briefly indicated before, can be a variety of things. Certainly, the direct spray type scrubbers for recovery of things like water or steam where it's not necessary to keep that liquid separated. For organic fluids, obviously, the application of other heat exchangers, as we discuss them here, is something to consider.

Finally, from the non-surface type heat exchangers that we're discussing here, the idea of the typical European methods referred to as drowning become an item of some interest. The old chemists of long, long ago, in order to get rapid cooling, just took the reaction mixture they had and mixed it into a very large volume of water. This became known as the drowning process. This goes back to where we're now diluting a product and then creating a problem of separating that product from a much-diluted stream for future recovery. Whereas, with an evaporative or direct surface type cooling, you at least maintain a constant concentration and just change temperature. So, when you're considering drowning, the idea of future separation of the drowning liquid is a matter of some consideration and importance.

Often, this is done with ice. Here again, we're into the discussion of the relative heat transfer efficiency of the materials. For each pound of water that you use, you have an absorption based on heat capacity. For each pound of ice that you have available, you get about 540 BTU of fusion heat from melting the ice. That is a very important consideration in reducing temperature and recovering materials, but from an evaporative standpoint, if you can evaporate a pound of

water out of that same system that you're going to add ice to, you can remove 1,000 BTU and remove some of the water that may improve some of your recovery processing later on.

We can now move into a discussion of some of the specifics of selecting and sizing heat exchangers. This is an area where some very significant effects can be observed in the overall process. Today, there are quite readily available a number of computer based programs for discussing heat exchanger sizing and applications. The TEMA/BJAC, the various process programs, all have their methods of developing sizing. There are some excellent applications and uses of these programs.

I would suggest that if you're going into a frequent development of heat exchanger sizing, you should go back to the basics a little bit and begin to understand the program and the selections that are made within the program that end up going outside of the control of the sizer or selector as he's putting things together. The equations that are used can sometimes become very significant. If you're going to use a program on a regular basis, become familiar with what the basis is of the equations that will be used for sizing, whether they be internal heat transfer coefficient development, pressure drop development through the shells, nozzle selection methods, or how the distribution will be done from inlet nozzles into the operating areas of the exchangers. Each one of these things will have an affect on how the heat exchanger mechanical design is completed.

All of these items will have an affect on the cost of the heat exchanger that you request. So, it becomes important to understand these little details to recognize when you need to apply certain details for the advantage of the process, for maintenance, or the simplicity of construction. When details that are made part of the program are doing nothing but adding to the cost of the unit that you intend to buy without providing you with a process, maintenance, or operation advantage that you'd like to have, this kind of selection criteria is something that comes a lot more with experience than it does with immediate initial understand.

However, the program, the pattern of developing this information, and beginning to understand it is important to begin early in a career. If you're going to a single or relatively infrequent selection of heat exchangers, you might tend to rely a little more on the vendor and his suggestions, but do not be concerned with asking questions. Should this be used? Why should it be used? Is there a possible reason not to use it? Is it going to cause me an extra expense if I use this selection versus another one? Of course, this does take time. It takes the development of a good series of questions, but all of these things will ultimately become important to the use and application of the exchanger.

This is an area that we as engineers must always consider because, from a design standpoint, it's very easy to make several selections that make the design easy to develop. Ultimately, the system must be operated and the man in the field who's going to have to use and operate this exchanger and the maintenance people who are going to have to take care of it and keep it operational will be very appreciative of a little care in consideration in early selections. Good sealing methods, good selection of connection arrangements, all of these things become very important for field applications.

Of course, everybody has their own biases on how to do these things. My own bias is to look to the regular use of flange type connections for all the shell and head positions. If future changes of piping or other connections to the system suggest that some other method be used, whether it's a clamp type fitting or screwed fittings, these can always be adapted through another flange. However, a flange connection on a heat exchanger makes it very easy to install, remove, and provide a good, strong connection for all attachments to the exchanger in later applications.

To carry the idea of investigation of details of the exchanger a little further, for those of you who would do heat exchanger design on a regular basis, I would suggest that you go back into history a little bit. Go to a book such as Process Heat Transfer by Kern or to the *Chemical Engineering Magazine* series that was done by Mr. Gilmore of Union Carbide a number of years ago. In both of these, there were calculation methods laid out for investigating many of the little details of both process and mechanical applications of heat exchangers. You should go through the sizing of one or two heat exchangers, following one of these programs, one of these mapped out strategies in the textbook or magazine, and follow it very rigorously to understand the relative effect of any individual consideration in the program or sizing calculations that are made.

So, as you get into a broader application of exchangers and the selection of many exchangers for particular applications, you can have a better understanding of what an individual item of information will do to your exchanger calculation methods and techniques and to the effect inside the program. Little changes in thermal conductivity of the liquid sometimes can be significant in a heat transfer coefficient. Changes in viscosity can quite regularly have a big effect on pressure drop. The calculation methods that are used and the understanding of the process liquid and how it's handled will provide an excellent background for making the appropriate selections. Again, to come up with a heat exchanger that's easy to build, easy to install, and reliable to operate over the long term.

Another important aspect of heat exchanger selection and design is related more to the overall position within the plant than to the heat exchanger or its process applications. An important part of making some of the design selections is to recognize what physical limitations may exist for the exchanger. Some exchangers have some very specific requirements for where they must be placed. If a condenser must be placed above a reactor, you're relatively limited in what you can do. However, it can be placed immediately over the reactor, which may or may not help or hinder involvement to mixers or other piping configurations. It may even be placed above and to the side of the reactor where the exchanger will be more easily mounted and the other connections to the top of the vessel are unaffected. Yet, the piping can be rather simple to get to the exchanger and to be sure that it's removed.

Well, we're coming very close to the end of the first tape. So, I'll discontinue this discussion at this point and go to the second side, please.

Tape 1 – Side 2 (Disk 2)

It's now appropriate to look at some basics on heat exchanger selection. If your normal plant solutions are fairly simple solutions of water with low concentrations of acids, caustics, or organics, where you would typically use a stainless steel or some of the other basic metals for the heat exchangers, and the size of the equipment that you're looking for is something less than 100 sq ft in transfer surface area, one of the things you should very seriously consider is the standardized heat exchangers that are available from several manufacturers. The reason for looking at this first for the basic solutions, which might be things like circulated vacuum pump water cooling, hydraulic cooling in certain areas, or certain basic oil cooling situations with minimum contamination of the oil, is that the actual cost per square foot of heat transfer area will probably be the least of any available. The standardized exchangers are made repeatedly on a regular basis. The patterns, techniques, and methods for doing it are highly standardized. Of course, the manufacturing personnel are very used to preparing this kind of equipment. So, you can get a very reliable unit for a very reasonable cost, particularly in the smaller sizes.

Where other special connections are necessary and even if the size is small, very simple transfer connections from the basic units that could be supplied to a specialty connection can be affected right at the exchanger. For instance, the exchangers that you're looking at suggest screwed connections and your plant operation uses a clamp type pipe connection. As you talk with the vendors, you might find that they are very reluctant to change from the screw connections because of their standardized manufacturing. They put a relatively high charge on making the change from the standard screwed connections to a flange connection. In this case, for your simplicity, something that could be done very easily would be to buy it in the screw condition and then use some very effective screw thread sealant materials as you buy or install a component in your plant. Then, go immediately to the typical plant connections that you might normally use. Therefore, you would effect a savings and also get a very reliable unit that will be easy to change out later on.

Selection and movement to a specialized design of heat exchangers is a relatively expensive step and decision to make. Therefore, whenever possible, it's worthwhile to consider using something other than a specific design. This is also true for conditions like vents or temperature maintenance on test equipment, particularly that it might be near a laboratory or in a semi-commercial or development condition. Of course, from a standardized heat exchanger standpoint, don't neglect the units that we mentioned earlier of the all welded plate type. These are also available in stainless steels and certain other basic corrosion resistant metals, readily available, and relatively inexpensive. Again, some of the same suggestions and criteria about connections and adaptations to plant standard connections might be considered.

Another important consideration when looking for heat exchangers is to review the heat exchangers that are normally used in your plant. There are certain criteria that are quite likely to be standardized or made typical for any unit selected for your plant. It will save time and effort and end up developing a unit much more acceptable for all concerned if the criteria and selection factors that you put on the exchanger agree with these plant standards. If it's appropriate for them to deviate from those plant standards, you should have an explanation or consideration of why you think a deviation would be appropriate in a given application.

An important criterion in the selection of all heat exchangers is the property of the fluids that will be handled—all of the properties, of course. Again, there are some typical conditions that are often defined for plants that should be considered and evaluated for any exchanger that you're looking for. Specific conditions that should be considered here are the temperatures, viscosities, thermal conductivities, and latent heats or phase change thermodynamic considerations for the fluid.

In all of the applications, in addition to these fluid properties, the temperature conditions under which the heat exchangers are expected to operate should be a matter of some importance. Of course, with water there are some wide latitudes that are available and we can generally recognize that we don't want to try and cool water to something less than 32°F. Also, we wouldn't want to try heating water to anything over 212°F because then we'll have a phase change problem, unless there's a specific need for doing that. With some organics, to be more aware of the specific temperatures of phase change, particularly solidification or solidification of materials that might be carried in the organics, are matters to be noted as developing a design.

Generally, the temperatures that are looked at for heat exchangers and the design is a temperature developed for both the shell side and the tube side that's considered the mixing cup temperature, or essentially the average temperature from the inlet to the outlet of the fluid, whether it be shell side or tube side. Of course, under these conditions, you can recognize that if there is a broad temperature change to be addressed, particularly with organics, the low end temperature on discharge may be approaching a temperature at which some materials could create blockages on the surfaces by condensing or solidifying a wax, solid, or another crystal that is inside the solution. This kind of thing should obviously be avoided and should be considered as part of the design.

In continuing to consider those special items that might be appropriate to an individual plant, there are a number of other areas where we should question and look around at normal plant operation. One of those special areas would be tube size. If the maintenance equipment for the tubes in the plant is relatively limited, it's inappropriate to select a heat exchanger with a 5/8-inch diameter tubes when all of the existing tools are 1/2-inch and all other heat exchangers are 1/2-inch tubes, or for any other given size. Don't select a 7/8 when 3/4 is typical; use the 3/4 tubes. Consider a different number of tubes and a different tube arrangement. The same thing is somewhat true on the shell side. Although, a little more limited in creating problems because outside surfaces are generally not something that are limiting in their placement, location, or support.

Of course, another thing that might be considered in any given plant is if a heat exchanger is to be a condenser with limited slope and you'd like to be able to keep it out of the way and keep it from blocking further pipe transfer through a given area, you might tend to look for a somewhat longer 12- or 14-inch diameter shell rather than going to an 18- or 20-inch diameter shell if you're going to hang it in a ceiling area that has 12- or 14-inch beams. So, many little aspects of differences in the plant are worth consideration as you begin selecting, looking at, and working out the different geometric criteria to be used in arranging your heat exchanger.

Certainly, the quality of whatever will be used as a heating or cooling fluid should also be a significant consideration in plant activities as you begin selecting the internal details for your heat exchangers. If you are generally making a very good quality steam, the kind of distributor used under the steam inlet nozzle in a heating type application would not have to be as significant or as resistant as that in a plant that would make steam in a secondary operation that might be somewhat contaminated with a fluid from a flashing condition or that might for some reason be solids contaminated because it's coming out of a bed that might have some sand or other materials in it. So, the selection of a slightly thicker wear plate at the entrance to a steam heater where the steam quality is somewhat less can be a real maintenance and operation saver in the future when you have that opportunity for additional wear and you can prevent direct impingement on tubes that become very easily cut or damaged by solids passing over them.

Pressure drop inside tubes is also a matter of significance in relationship to our prior comments. If you do indeed expect to have some kind of build up on either side of the tubes, then the selection of the size, placement, and distance between them is a matter of some considerable importance. By properly selecting or providing yourself with a bit of extra room in those areas during the design phase, you can improve the operating life of the heat exchanger, as well as the overall productivity and efficiency for the plant. Although it's a significant item in the development of a particular plant modification or development, capital costs are relatively unimportant once the plant gets into operation. A few more dollars and a capital design function can be a difference between a unit operating for a few months and one that would operate a year without having to have maintenance. Of course, the clean up time will probably be the same, whether it's filled up and taken out of service for repair and modification at the end of one month or a year. So, your overall efficiency of utilization is going to be another factor that is significantly affected by many of the little decisions that are made as the heat exchanger criteria are defined.

In looking at some of these details, let's go back to some selection criteria for the smaller heat exchangers. Again, standardized heat exchangers exist and, as we suggested before, for anything under 100 sq ft, they should be seriously considered because their cost, availability, and ease of replacement are fairly attractive. One thing that does get important in making decisions like this, though, is that if it is important and it becomes significant to buy a heat exchanger that is specifically designed as you begin selecting a size, do not do what I consider cheating yourself by only putting 150 tubes in a shell that for the configuration that you'd like to use for tube arrangement could handle 165 or 170 tubes. The relative cost of adding a few additional tubes in a shell that must be a little larger than a minimum is so small and the potential improvement in operation is so great that a filled shell should very seriously be considered.

There are many maintenance or operating criteria that could also be used to argue for that. If you have a few extra tubes, plugging a few tubes will not normally affect later operation and this will extend the overall service life of the exchanger. With a few extra tubes, you're given the opportunity of a little better temperature control and performance. So, these kinds of selection criteria become important aspects in the details of heat exchanger component selection.

Additional considerations relate to the specifics of operation. First, let's look at the idea of whether an exchanger will be batch or continuous. If you're looking at an exchanger that will be

used for relatively short durations, a day or less for given performance and then it will have some rest time, your decisions about accessibility and removability of the tubes, tube sheets, tube bundles, may be a little different than something that will be put in service and continued in service for several months without a significant change in operating conditions. Certainly, with a batch system, you also want to look very carefully at the velocities that you expect in that side of the exchanger that will see the variations of the batch operation.

Take, for instance, a condenser on a process vessel. Normally, the cooling fluid in that condenser would have a relatively consistent flow through the condenser, sometimes temperature controlled and limited, but you're quite often looking for maximum condensation. The flow rate of a bit more cooling fluid in the shell is not a significant factor in making a decision about how the system will operate. So, in cases like that, you want to make sure, depending on the quality of the material that will be used for the cooling, that the velocities are kept sufficient for good long term operation on that side of the exchanger that will be used more continuously. Of course, if the cleanup criteria are going to be affected by how these flow rates are modified, that is an item that must be considered.

Many little details of operation will have similar affects. Another affect that should be considered, as we've mentioned before, is the time period of operation. If something is a relatively continuous operation and will be serving for several weeks or months, you would certainly like to have very good efficiency. However, if you're in an operation where long-term operation is considered in terms of years or 10 to 20 months, then your operating efficiency considerations are a much more significant factor. From this standpoint, in many cases, it has been recommended that an additional pump be placed on the utility circulating fluid to be sure that velocities are kept up and that the cleaning cycle is preserved for as long as the operation is desired to continue. In a condition like this where temperature control may or may not be critical, sometimes a bypass line is used to assist the temperature control and the pump circulating additional fluid to keep velocities up.

This type of operation has been discussed in several publications, particularly by D. Q. Kern in several articles and in his textbook. The velocity efficiency comparison for fluids in heat exchangers is very easily demonstrated by looking at a combination of both pressure drop and heat transfer coefficients. It is a matter that can lead to significant savings and improvements in operation where long-term operation is an important item.

Gas separation operations are also very critical to consider. In multiple effect evaporators, this is an item that certainly will not be unfamiliar to anyone working in those areas. Quite often, the liquids that are circulated and effected in multiple effect operations, such as in paper processing, liquid recycle, alumina manufacturing, and quite possibly also in some areas of hydrocarbon processing, the collected or separated gases that can accumulate inside an exchanger are matters of significant consideration. Certainly, anything that will contain a little bit of air, or other relatively difficult to condense materials, should have a connection and an arrangement made in the exchanger so that these gases can be taken out. The accumulation of a gas inside a heat exchanger can effectively block its performance in a very short period of time and create some considerable analysis problems in trying to determine where the difficulty lies.

In one application that I'm familiar with, the gases that could collect inside the shell of the heat exchangers that we were processing had the potential for collecting both at the bottom and top of the exchanger. So, small pipes were inserted to be sure that there was a continuous draw of a small amount of the process vapors into a non-condensable collection system that passed directly on to a vacuum assisted gaseous removal process within the operating train. There were several occasions where normal maintenance and operation changes of these materials would result in the small connecting valves being inappropriately set. Under those conditions, it was often an operating difficulty and there was a significant reduction in performance of the units that showed immediately in recovery of liquids or in concentration of the process fluid. Then, with a quick review and a rearrangement of valving and flow streams, it would very quickly return to operation. However, determining where the open valve and where the closed valves existed can be a very tedious process if people are unfamiliar with the items that can be collected and the procedures necessary to keep this system aligned and in proper service.

Details of physical configuration and arrangement of the heat exchangers are additional items that become very significant. If a heat exchanger is used in a vertical condition, the tube should be appropriate to the amount of phase change that might occur if the fluid is condensing or evaporating in the vertical tube. Flow rates are of extreme importance. Nothing is more annoying than to find that a tube has been made too long or too short and, as a result, there are ineffective length areas of the tubes that were paid for, but are not performing. So, the amount of flow and the circulation rates are a matter of significant concern. It would be wonderful if there were ways to provide general criteria to answer this for all operations. Unfortunately, there are not and each operation will have its own limiting criteria.

One thing that should be very seriously considered in vertical flows, either within the heat exchanger tubes or for external situations where liquids need to be drained away, is to consider the Reynolds number and the typical bubble velocities to make sure that there is not a blocking bubble trapped within a down comer. Whether it is a tube or a draining fluid, that will continually form, collapse, and create quite a bit of physical vibration and disturbance to the system. This can have a big affect on all of the other piping and structure, as well as on the operating performance of the system.

There are many types of individual heat exchanger applications that will have significant criteria that must be considered in making these kinds of selections. Of course, simple liquid exchange for hydraulic cooling is something that might be considered relatively typical of a straightforward application of exchangers. Whereas, the condensers used in relationship to turbines in utility and power plants are an area where the additional surface that can be put into a system and its long-term performance will have significant benefits in energy recovery efficiency for the system.

This was another small example that was brought to my attention early in my career when I had the opportunity to go through a new and very nicely designed and operated power generation facility where they had the good fortune of a very cool river water that was used as the cooling medium in a condenser. They loved to have the wintertime temperatures of 30 to 31°F in the water, when it had a little ice in it, because they would increase their efficiency of steam utilization by 10 to 15% versus a summertime temperature that might run into the 55 to 60°F. Of

course, that obviously was a situation that was a little more toward the northern latitudes, but similar activities can occur in the south. A very simple change of a few degrees in dew point or a few percent in humidity, however you normally like to look at it, can have a big affect on the cooling water temperature available and the performance of the unit and overall efficiencies.

Another item of consideration, again related to the geometry of application of a heat exchanger, as well as to the materials that are involved, is the problem of multiple phase flow that can occur. We spoke of it a while ago from the standpoint of evaporation or condensation in vertical tubes. Of course, it also becomes significant in horizontal tubes where there happens to be an addition or collapse of gases along the length of the tube. Two-phase flow pressure drop is something that can jump dramatically from the straight liquid pressure drop because of the significant change in velocity of the gas and the combination velocity of the gas-liquid mixture that moves down the tube. Many very significant design calculation developments have been performed over time, relating specifically to steam, but with applications to other flow materials also.

Another area of consideration, particularly for the shell and tube heat exchanger, is clearances for the baffles, the tubes, and the shell on the shell side. Often, it's easy to ignore the fact that at every opening in the shell, there is some fluid transfer and some fluid movement. The larger the hole that the tube passes through, the more bypass flow can occur in the shell of an exchanger where there are baffles that are to direct fluid transverse to the tubes. Of course, this can be a big affecting factor in overall efficiency. The same thing is true about the clearance between the baffles and the outside wall of the tubes.

One experiment that was done quite a while ago demonstrated that a 15 to 20% improvement in efficiency could be used by sealing all of these areas. The sealing was done in rather unique ways, but it's a very difficult and expensive thing to do in any given exchanger. Certainly, as with anything else in design considerations, there are trade offs. If the velocities within the tubes are relatively high, there will be a tendency to induce vibration. A vibrating tube in a very closely fit baffle will end up cutting the tube on the outside and cutting its life. So, a consideration would have to be made if you're going to try and improve efficiency in that manner to prevent vibration of the tube at the baffle plate. Again, mechanisms can be applied to limit this, but their installation and performance are cost items in the manufacture of the exchanger and significant quality items of where their application comes in. This is because the items that would prevent that vibration are usually fairly small and requires a lot of detail installation. Of course, they would also require some significant work to make sure that they are all in and properly applied so that the vibration is, in fact, eliminated.

Of course, I would be remiss if I did not include in this consideration the idea of some specific modifications that are available for tubes. There are many inserts and many manufacturing techniques for tubes that will provide a somewhat extended surface and improve some of the mixing that occurs within the tube. This will have an effect on heat transfer coefficients and improve efficiency. Applying techniques such as this come back to our earlier decisions of the quality of the fluids passing through. In commercial air conditioning equipment, such extended surfaces are quite readily used because the materials that are handled are generally kept very clean. The refrigerant fluid inside the circulating system must be kept clean in order to maintain the operation of the compressor. Therefore, there's not much concern about solids pick up in

extended or modified surface tubes. The same thing is somewhat true of those units that use coil fins on the outside of the tubes where you're looking at air-cooling. Those extended surface conditions greatly improve the efficiency and are items of some interest and concern for some industrial applications.

For many years, our friends, the Europeans, have used air heat exchangers and used them particularly at the tops of large columns for cooling. They save themselves piping up and down the columns. They reduce the overall load on the columns because of the extra components that are involved and get very good performance. However, they do have to be sure that their air will be clean and not create a problem on their extended surface tubes. Another thing that is very often used with systems like that is a frothing or light water spray to help. A little bit of water sprayed on extended surface tubes, particularly on the outside applications where air is drawn over them, gives a significant improvement in operating efficiency because of the evaporation of the water as it passes over the tubes.

All of these things have their economic trade offs and must be considered. Certainly, in areas where water availability is high and temperatures are reliable and consistent, things like this would not normally be considered. However, where there are limitations to the availability or where there are wide swings in temperature, some of these modifications are worth very serious consideration.

For those applications of shell and tube heat exchangers to materials that have very viscous or tacky materials as a component of the liquid mixture that needs to be either heated or cooled, recent developments of lined or process coated tubes for use in applications like this may be worth some consideration. Some Teflon coating of the tubes preventing the internal roughness that would allow the accumulation or development of solids coating inside the tubes will have some effect on the heat transfer coefficient. However, it may be worthwhile in order to improve overall long-term operation at a more reliable heat transfer condition rather than wide swings in performance due to relatively quick dirt pick up and significant blockages of heat transfer.

Again, everything that connects to the tube or that touches the tube will have an affect on heat transfer in one way or another. In all of these things, experience is a much better guide to the potential performance of an exchanger and the design criteria that should be used for the exchanger than making guesses or assumptions based on interpretations of other people's opinions from textbooks or guidebooks. Of course, this is a fundamental fact in almost everything that is done in professional application of design, but it must be recognized and considered as we move forward through the heat exchangers also.

It's appropriate now to throw in one additional type of heat exchanger that has yet to be mentioned because it's somewhat specialized. There are a variety of designs of what could be referred to as spiral heat exchangers. Several of them can be spiral tubes with a very simple covering jacket. In some cases, they are spiral wound plates with rather sophisticated connections that keep one fluid between the arrangement of the plates and the other fluid in the other arrangement. These tend to be very useful in areas where there's a significant space limitation and where there are some relatively reliable conditions of operation that can be addressed. They are a very efficient means of achieving heat transfer.

They're very economically efficient, but do require the understanding that solids and solids content is very severely limited. The small gaps and paths that are usually involved in this type of exchanger can easily become plugged or blocked when this is arranged. With some of the situations, particularly those using wound parallel plates, the gasketing is something that becomes a significant concern. Packing the plates and doing any maintenance on the exchangers once they have been in service becomes a matter of some considerable technique in requiring good performance of these exchangers.

I would also include in the consideration of these exchangers some of the carbon block exchangers that are used. The efficiency of graphite as a heat transfer means is quite often not seriously considered when it's very good. However, as with any specialty unit, the arrangement and physical configuration of the exchanger, its development during manufacture and installation, and during transfer from the manufacturer to the application become items of significant concern. A manufacturer that provides these exchangers will quite regularly deliver the units themselves so they are assured that they will not run into problems created in transit. They can be assured that the unit they delivered to the site is the unit that they promised to deliver. Of course, once they deliver it to the site, they must then rely on the owner and installer to appropriately treat it from there. Any movement, vibration, drops, or hits to a unit like that can have an affect on the sealing surfaces and gasketing that is used within them. They do have some very good applications, particularly in the recovery of relatively hazardous vapor materials.

I'll take this opportunity as I come close to the end of this tape to go back with a reminder of something that we discussed earlier. There is relatively little that can be better in selecting a heat exchanger and the specifics of the components that will become part of that heat exchanger than to go through a particular calculation sequence. As I suggested before, the ones detailed in Kern's, or the ones that were developed in the 50s and 60s by Gilmore as a method of calculation for the details of heat exchangers, are particularly good ones to bring out the many little details that will have a significant affect on how the exchanger that you select for a given application will perform long-term and will approach the criteria that you wish them to meet in operation.

Understanding that slight velocity changes can have a significant affect on heat transfer coefficients. Understanding that the method of connection and piping as it goes into the shell can also affect distribution and flow conditions inside the shell. Recognizing that a simple thing like providing a bar or a dummy tube on the lower quadrant of a tube bundle and letting it slide on a shell support going in and out. All of these can be something that makes the difference between a good long-term, reliable operating unit that is easy to maintain and one that becomes a millstone hung on your career for the balance of your exposure to the industry.

This is the end of tape one, side two.

Tape 2 – Side 1 (Disk 3)

I now recommend that you take a little time to look at the paperwork that came along with the tape, particularly the package of pages showing the different heads, shells, and tubing arrangements for heat exchangers, particularly shell and tube heat exchangers. These were provided to me a long time ago through the Patterson Kelly Company. This is one of the better assemblages of different types of connections that I've seen over the years and that's why I have included it for your reference.

At this point, I'd like to begin discussing some of the particulars of why the various components of the heat exchangers are designed and selected in certain ways. The principle components of a shell and tube heat exchanger consist of what is defined as a head on each end, the shell itself, and the tube bundle. The tube bundle is made up of the tubes and, usually, the baffles that direct the cross flow of the liquid flowing over the tubes. Of course, the heads sometimes have dividers in them in order to allow multiple passes through the exchanger.

One of the key components to consider in the front head is the specifics of the direction of connection or entry of the fluids into the head. A very significant item is the idea of whether the fluid connection is directly in line with the heat exchanger or whether it comes in as side connections to the head component of the exchanger. It really doesn't make any particular difference in the assembly or fabrication of the heat exchanger which type of connection is used. The side connections will possibly require a bit more metal and welding. The key factor to consider here is the idea of the convenience of installing, removing, and making the piping connections to the components, if the heads have to be removed periodically or if the exchanger needs to be moved periodically.

In the case where it would need to be moved more regularly, the connections into and out of the sides of the head will make it much more convenient to work with the exchanger. Piping on each end usually forces you into a condition of having to drop the exchanger in a direct vertical condition in order to get it out of place, if it's mounted horizontally. If for some reason it should be mounted vertically, it means then that the piping would either have to be dropped away from the top or bottom in order to allow the exchanger shell to move out of the way. When the connections are made to the sides of the head, that makes it very simple to remove an elbow or to spread the piping just a bit in order to allow easy removal of the head end. This allows for a fairly clear path for the removal of the shell with minimum disturbance to the piping and less overall operating maintenance and difficulties for the system.

Of course, the direct connections to the heads can be made either with screwed connections, which is very simply done by welding in couplings into the head components, allowing a standard screwed piping fitting to be connected to it. As I suggested a little earlier, my general preference is to use flanged connections for all of the head items. This makes them a little more simply removed, gives you a little more reliable gasketing when taking out or replacing the unit, and it also minimizes the difficulties with the piping and threaded connection itself. Quite often, after a period of time, threads will become either galled or rusted in place and be very difficult to remove, clean up, and reinstall.

As you begin looking through the various components that are shown on the drawings, you see that the heads can be baffled to allow both an entry and exit on one end. It can also be connected so that there is only one direct entry, either in line or from the sides. Of course, this allows some significant advantages in selecting how to utilize the exchanger and how to get the most cost efficiency in putting an exchanger or piping system together. One thing to seriously consider in this light, though, is the more small gasketed separating surfaces within the head, the more you will lose in tubes in order to provide enough space for a flat surface that can be reliably sealed with a small gasket inside the head section and directly on the tube sheet.

I would point specifically to the head design that is identified as FH-12. You'll notice in that particular situation that the head really consists of a single flange and is connected to a shell that has within it a completely internally welded tube sheet. Of course, this is something that can often be used and allows for a somewhat simplified overall design, but still with good access for tube cleaning if that becomes appropriate. However, it does tend to argue for the use of a much cleaner fluid in the shell because any cleaning, repairs, or adjustments to the shell side activities of the unit would be somewhat complicated by the fact that the whole of the piping connections and tube sheets are welded together into a single unit. Most of the other head connections as shown there become a matter of convenience and decision of a variety of piping connections to the unit and various levels of simplicity for removal and mounting of the units themselves.

We'll move now to a discussion of the shells used in a tube and shell heat exchanger and reserve the second end since it can be quite extensive after we discuss the shells. Of course, one of the basic arrangements that can be used in a tube and shell heat exchanger is just a straight through arrangement. That is shown in the SS-4 configuration included in the package of information provided. This provides for the tube sheets welded to each end of the pipe and the tubes connected to each tube sheet and passing directly through the shell. We go to this one first, even though it's the fourth one in the list, because it is the simplest of designs and it presumes several things. Basically, there's not much in the way of temperature change between the fluids, there are no particular stress differences that will result in using a fixed welded unit in this way, and that there are no particular requirements for cleaning and other such removal of the tube bundle itself.

Going back to the beginning of the shells, though, they start in the demonstration package shown. The SS-1 configuration shows what looks like only one end to the shell. This typically is used for a U-tube bundle where the tubes are installed and removed from the same end and are mounted to their own tube sheet. This is particularly done to allow quick repairs and more convenient cleaning of the shell itself and the area around the tube bundle. It minimizes the number of connections, but it also exaggerates the requirement for significant concern about the head connections so that the head is easily removed and that there's plenty of room to draw the tube bundle from the shell.

The second unit shown is even more specialized because it implies that the U-tube bundle would be inserted into a vessel where the end of the shell would be left open. This was fairly regularly done in the past in oil tanks in order to allow a heating of the oil that was then fed to a pump for transfer into or out of the tank. You'll notice that material can be pumped through the heater and go into open discharge. This arrangement required some very specialized care and handling if

you ever needed to make some modifications to the tubes. The tank that it was inserted into had to be drained to below the level of the shell in order to be able to safely remove the tube bundle.

The SS-3 designation represents another rather specialized U-tube type exchanger where they imply that there are also baffles in there to promote cross flow and they show a double tube sheet arrangement. This arrangement allows for an observation of the tubes in use to notice whether any of the conditions within the tube has a serious affect on the tube material and will tend to cause leakages. There are some specialized requirements in considering applying these that are somewhat beyond our discussion, but the double tube sheet arrangement is quite unique, particularly for that U-tube construction.

The SS-5 configuration presents something that I would think most people would expect to be normal in a shell and tube heat exchanger and that is an expansion joint in the shell itself. The need or requirement for an expansion joint in a fixed tube sheet exchanger comes from a dramatic difference in temperatures that might be possible in the two fluids used in the exchanger. Say, for instance, that a very hot oil is to be cooled with cooling water. In the case that one or the other of those flows happen to be stopped or restricted for a period of time and then initiated again, a rather dramatic change in temperature could occur in the tubes and in the shell itself. That could tend to pull the tubes loose from the tube sheet or to create fatigue problems in the shell. The purpose, then, of the expansion joint is to prevent those difficulties from affecting long-term operations.

The next arrangement of the shell SS-6 shows is a totally fixed arrangement, fixed ends, fixed connections in and out, a baffle can certainly be put into it, but this situation requires something that is generally a very simple process application. It would require very infrequent cleaning, particularly of the shell, and would be very reliable for long-term use in isolated arrangements. Something like this might be used in a hydraulic cooling system where the hydraulic oil is used for drives, normally kept clean and very well filtered, with the heating being provided with steam, or cooling provided with a very clean cooling water.

The next exchanger, again, shows an expansion joint in the shell itself. It shows fixed tube sheets and a completely welded arrangement. Again, this would be for the more dramatic temperature differences in operation. As shown, it indicates a two-pass exchanger. Normally, you would only expect a flange on the right-hand end as shown in the photograph. This then gives the opportunity for both inlet and outlet on one end, but as with SS-6, implies some very clean fluids and relatively little requirement for any cleaning expected in order to use it in long-term operation.

The final situation of SS-8 goes into the use of double tube sheets. Again, arrangements like this are used for some specialty isolations, for awareness of conditions of the tubes as they are in use, and for a relatively specialized application.

The next several shells shown are relatively minor variations of earlier discussions until we move into the SS-12 shell. It's not immediately evident there. We'll discuss it a little more with the opposite end, the not normally fed end of the exchanger, with some unique criteria. The item

that is shown there in SS-12 is showing a follower ring that would hold a packing in place. That will be more thoroughly discussed later on.

SS-13 is the kind of arrangement that would be used for a heating or possibly a reboiler arrangement, using a little bit of flow limitation in order to encourage vapor flows in given directions from the internals of the shell.

SS-14 would be the type of arrangement that would be used with a reboiler in order to be able to give a disengaging volume. The same thing with SS-15, the tubes would be put in usually a U-tube configuration. Some disengaging is allowed in order to allow a relatively clean vapor to leave from the top of the unit.

The SS-16 shell allows a through tube bundle. There are some specialty requirements also in using those. Shell designs, while varied, have unique requirements that should be investigated with vendors or people very well schooled in the application of the exchanger in order to make good selections.

One recent review that I observed of heat exchanger applications pointed out the use of a shell similar to the SS-14 or 15 as a reboiler on a distillation column. In the study that was discussed, they pointed out that a problem with the down comers on the bottom plate in the column redirected some of the flows. This created quite a difficulty because level control was generally used by connections to the shell rather than to the column itself. The confusion of the level and some variations that occurred in the column created quite a few difficulties in maintaining continuous operation. After a thorough review, they were able to determine a method that would allow them continuing operations for a sufficient period of time to complete the normal operating run at somewhat reduced throughput, but still efficiently and effectively, until they could come to a good time for a total draining of the system, repair of the column, and cleanup of other related equipment in reinstallation and operation. In that case, they did add some additional level control functions into the system to prevent running into these difficulties in the future.

The SS-16, again, provides many of the similar advantages of the SS-14 or 15. Some vapor disengaging space, but it also allows for a complete pass through tube arrangement that can be sealed on both sides and gives a little better opportunity for cleaning of the tubes only, if that were an arrangement that were advantageous for operation and plant performance.

We now begin moving into what are identified as the rear-head designs. Many of them shown are very similar to the simple head designs used for the lead-in. When you begin to move into the R-3, R-4, and R-5 designations, as shown in the information package, you see that they are for simple single pass or double pass arrangements, using flanges or thickened plates in order to affect the control on the non-functional end. On R-8 and R-9, they give you a little more volume, tend to make the heads out of pieces of piping rather than thickened plates, and give a little more room for some other things like temperature measurements and so on that might be placed in that portion of the heat exchanger.

When we start moving into the R-13 and R-14 arrangements, we start approaching some very unusual arrangements. We spoke before about shells having expansion joints in them to take

care of temperature differences. R-13 is an example of an alternative method where the expansion joint is provided by the flexibility of the packed control of the discharge piping on the rear head. The opportunities that are presented with this are very interesting, but it comes at a relatively significant price and inconvenience.

As you'll notice on the drawing, the connection flange for the tube outlet is shown with a threaded flange on it. The potential for difficulties in the long term with this threaded connection are somewhat mitigated by making that piece of pipe somewhat longer as it's made initially, but that pipe will have to be machined and welded together to the head in order to allow for good packing on it. You'll be in the situation of needing to do a very good job with the packing and select some very unique packings depending on the materials being handled. This is something that may have had some significant reasons for use in times past, but I think many of the requirements can be met in more attractive ways with other designs.

R-14 shows an entirely enclosed inside head. That combination of the double heads avoids the problem of the expansion joint on the shell. Those additional welds on the shell expansion joint are quite often points of difficulty and are often the kind of thing people like to avoid. The use of these shell head dual units as shown on R-14 are somewhat dictated by some significant differences in material. However, this arrangement does leave you with the convenience of being able to remove the whole tube bundle for repair and maintenance and also makes it very easy to do clean out of the shell with the full diameter flange available.

The R-15 arrangement is now beginning to discuss a further refinement of the U-tube exchanger. A typical application of this type of construction could also be used as a head end where the head were baffled and allowed for both an inlet and outlet with the tube sheet having both ends of the tube connected into it. In this particular application, they tend to show that the front head of the exchanger is quite possibly fixed, whereas the rear head has a very limited potential movement. So, they use a combined packing on the outside of the tube sheet. Of course, this requires some significant machining and preparation of that tube sheet. It requires a significant thickness for that tube sheet and brings in all the questions of sealing and proper holding methods. R-16 has some of the same situations, but goes into a two-pass exchanger where it's a simple turnaround.

R-17 is quite a specialized unit. It has some of the peculiarities that we discussed earlier with the expansion requirements. The multiple flanging arrangements that are shown here might be suggested because of some dangerous materials being held and some very specialized care in connection that would be involved. However, the cost of a unit such as this would be very high and have some very stringent requirements to suggest considering anything quite this dramatic.

The R-21, R-24, and R-25 show many different specialties that are sometimes used with rear heads. It's difficult to pick out or point out any conditions where something like that might be advantageous. The additional problems of packing, packing following, the construction arrangement, the alignment that is required, are all expense adding items that, in general, seem to have little to recommend them. In those cases where you might find an application like this, I would strongly suggest you seriously consider revising the exchanger and finding a better way to handle it. Replacement costs in kind of this type of equipment gets beyond what is reasonable for normal capital installations.

The rear heads shown on the final page begin to get more and more exotic, again, emphasizing some of the same previous comments. The one that does fascinate me in particular is designated RH-26. They talk about it as a means of providing separation. I would also suggest that it's a pretty good means of being assured that you're using all of the tubes of the exchanger by making sure you have the little overflow dam toward the end. Quite often, flows are not quite as significant as we expect them to be and vapor flows or partially used exchanger tubes then allow a reduction in performance. Using a baffle such as this would help force the condition of some very good fluid filling in all of the tubes and improve the probability that the efficiency of the exchanger would continue. 27 and 28 are very simple outlet conditions showing what can be done for certain specific connections.

In looking through particularly the shells, you'll notice that there's generally no specific length that is indicated there. One of the advantages that has come to heat exchanger development over the last 10 or 15 years is the idea that tube lengths are no longer particularly difficult to acquire in any given arrangement. Formerly, tubes of 8, 10, 12, even numbers of feet would be the typical things that would be stocked and the most readily available. Generally, with tube manufacturing methods today, if there were a particular reason to use a 15-foot tube, you would be able to get it, get the number you need, get the criteria that you need for the tubes, and get them fairly conveniently and with relatively little difference in cost. So, restricting yourself in one or another tube length is generally not a productive change to make in the exchanger. However, in looking through the details of the many configurations that are used on these, you can now understand why the ASME and the Tubular Exchanger Manufacturers Association (TEMA) have many pages of standards for developing the mechanical requirements in sizing, rating the pressures of the various components of the exchangers, and specifying their manner of manufacture in order to provide for long-term reliability and reasonable cost.

Of course, this brings us back to an idea mentioned initially, but I will emphasize again, that in preparing a shell, you will not do yourself a favor by skimping on shell size or reducing the number of tubes below that which can be put into a shell. A filled shell will almost always be more economical long-term and just as easy to put together and take care of as one with a few tubes less. The biggest problem with changing a shell diameter is not the particular size of the shell, but the size of the flanges, the amount of welding necessary to put the flanges and connections on each end, and the cost of acquiring those units.

Moving on into the idea of providing specifications and arranging for the bidding of a heat exchanger, we need to look at the idea of both good tricks and possibly a few that are somewhat bad. You should definitely look at the idea of bidding the need that you have. Too often, and there are many examples in a variety of purchasing and acquisition procedures, where everyone who looks at a unit, whether it be a pump, heat exchanger, or sometimes even the range on instrumentation, will add just a little to the size or the range just to be sure that it's covered. In doing any of those things, you're adding to the cost and not particularly helping the performance of the unit. Often, if a unit is made a little too large, it will end up being of greater difficulty in operation than one that is appropriately sized.

So, the selection or the definition of real need is probably going to be a best condition not only for the initial cost of the unit, but also for operation. Of course, if your ambiguity about potential need is great, that should be addressed, too. Sometimes there are methods of handling that can be discussed with vendors in order to find a way to get the most efficient change from one condition to another rather than making guesses without consultation and forcing a decision that ends up being costly for everyone.

One of the other items that is certainly significant in part of bidding the need that you have is an understanding of the process need. An overall heat transfer coefficient that is suitable for your operation, something that is known, should be provided and included in your request for conditions. To specify heat loading and then require a vendor to guarantee an operation based on heat loading and his guess of the heat transfer coefficient, you will generally end up with a unit inappropriately sized. Generally, it's larger and a little more expensive because the vendor will always want to assure the protection of his guarantee. If you feel comfortable with an overall heat transfer coefficient that has served reliably for you, making that known to the vendor will end up helping you get a more appropriately sized unit, avoid the problem of discussions and confusions on why one particular heat exchanger is bigger or smaller than another one, and prevent many discussions and questions back and forth on the overall system.

The other thing is don't be obscure in the specifications that you prepare. Do ask the questions of the vendor and try to get more of his comments and experience in order to make the specifications and need requirements that you put together more functional for your plant. Fouling factors is certainly a good way to include comments on overall performance, but simple definitions and expecting a vendor to guess in a fouling factor are inappropriate. If you know that over time you'd like to have a certain range of operating capability, provide that information to the vendor and he will help you select tube and tube bundle requirements to meet those conditions.

Also, recognize that there is time required to develop a unique unit. Nobody likes the idea of missed deliveries. Of course, we've all been in the situation of not getting required information until it's too late and, yet, needing an exchanger in a certain period of time. Then, of course, costs and delivery problems begin running in and creating many difficulties related to this. If the exchanger is fairly simple and can be done in a fairly standardized way, certainly look to an appropriate period of time and purchase accordingly. However, if the requirements are somewhat unique, are difficult to define, and there are some specialties, begin the purchasing process early. You may get a surprise and find out that it's not quite as specialized as you expected and vendors will help you realize that. You will also have a much better scheduled installation arrangement and probably a better arrangement for the long term maintenance and operation. To try and force a short time fabrication and a quick time delivery when it's unnecessary, just in order to change a cash flow condition, it usually ends up providing very significant difficulties for everyone.

With heat exchangers today, we're very concerned with the materials of construction. In more and more industries today, we're faced with dealing with exotic materials. For those areas where materials are very simple, the additional information that is normally provided with a design made according to ASME or TEMA specifications and certifications will be helpful and useful.

However, when you're into a first time application or an unusual application, some of those pieces of information become absolutely mandatory. So, if things occur in the future, you can understand what the reasoning was initially for selecting a particular set of specifications for the materials and to know why or why not to move to those things in the future. Again, certified designs under the various manufacturing methods that are available, even including the European standards of several varieties, give some good bases for making these investigations thorough and effective if a difficulty comes up.

One thing I would suggest in looking at the specifications or selections of materials, particularly for tubes, is to recognize that periodically there are reasons for the selection of a tube being made by a specific manufacturing process. Tubes can be drawn very accurately and this is a typical way of doing it. Sometimes tubes are rolled and then later surface processed, such as a typical seamless pipe. This provides a somewhat different metallurgy for the tube and, in some cases, would be influenced by the kind of materials handled and have an affect on the life of the tube.

In some relatively unusual instances, tubes are made by welding. A piece of metal is rolled and then either longitudinally or spirally welded to get the tube, with the final sizing being done after the basic manufacturing. These would often be relatively exotic materials or specialized conditions, but periodically you might run into this where foreign manufacturers would be supplying materials. This would be a matter of some interest and concern in selecting your unit and reviewing it.

I had an experience with a system where we had a considerable number of exchangers; something approaching 80. We had what seemed relatively straightforward applications and applications that we had considerable experience with in other plants. Unfortunately, when the initial exchangers were installed, we began experiencing very poor service life. This led to an investigation of exactly this, the type of manufacturing on the tubes, and it was discerned that the particular method of manufacture for these tubes was inappropriate. It created a grain boundary and grain distribution pattern that was not suitable for the application that we had. Changing from those initial tubes to tubes made in the appropriate mechanical and metallurgical method simplified our life greatly.

Unfortunately, for a period of six to eight months, we began a pattern of investigating a variety of materials and some of those were very expensive. One attempt that we had to try for a while was an entire nickel tube. When you have 1,000 tubes in an exchanger that are over 20-feet long and made of solid nickel, they can become very expensive when they have to be changed out. Coming back to appropriate metallurgy allowed us to go back to a basic steel tube with good reliability, but with the appropriate metallurgical conditions for long-term operation.

Certainly, another area that must be considered and thought about in the tubes, although this is generally a specific requirement of the manufacturer or fabricator, is the uniformity of the tubes. From a process standpoint, this is of significant interest in knowing what the overall heat transfer coefficient will be in a reliable way. From a physical standpoint, it's particularly appropriate in those areas where differences in pressures are significant. We do have that very favorable anomaly in pipes and tubing that are normally used that hoop stresses are very forgiving. We usually use enough material that we don't have to be particularly concerned.

When we start looking at actual burst strengths on tubes, they're usually significantly beyond the operating pressures that we request of the systems. However, if there were to be some difficulties, certainly a thin spot in a tube is going to be the place where that difficulty will be manifested and is a thing to be avoided. Specific testing, specific guarantees, and some reports of tube performance are certainly not out of the ordinary to request of fabricators and can generally be provided without difficulty. If it's appropriate and necessary, don't hesitate to ask for them.

Although, if they are unnecessary, it is recommended that you don't ask for them because that is another item of expense to be assured that all of this is provided and accumulated and documented that will add to the cost of an exchanger. If you have long-term service reliability with a particular vendor, type of unit, or materials, the additional paperwork may or may not be justified. That is a particular decision that each of us must make as we move into any given selection, sizing, and purchasing decision.

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Tape 2 – Side 2 (Disk 4)

Some new techniques have been developed that allow methods of achieving the use of the exotic metals in containing certain fluids, but reducing the cost of the exchangers themselves. This method is to use very thin wall tubing liners on the tubes and putting the exotic metal on the tube side of the material. These thin liners are certainly thick enough for whatever flow conditions and velocities are being affected, but they can be used in very thin situations, .015 to .020 or less, and put inside steel tubes that will then be their pressure containment.

These thin liner tubes are then welded to each end of the steel tubes after they're installed. Then an overlay cover sheet on the tube sheet of the same exotic metal is also welded to the tubes. It allows the fabrication of the head ends of the exchangers to be done with either clad materials, sometimes also with linings, so that the quantity of exotic metals used in these lining arrangements are reduced considerably. Also, the problems of drawing very heavy tubes or preparing very heavy tubes of the exotic metals are bypassed.

Welding techniques and some of the protections on the required welding of these exotic metals requires some very interesting modifications of the tube sheets and, quite often, the heads themselves. Therefore, it requires people with some considerable experience in order to provide these things. If you should get into a position where you need to have this kind of exchanger or you'd like to consider this kind of exchanger, be sure and do your homework. Look around and find people who have done this work in the past and who can be more assured of providing you with the construction and a reliability that you'd like to have in the exchanger.

You can run into many situations where people would like to get into the business. These are always limitations and a limitation that I often fight myself in the business world. You don't really want to be the guinea pig for somebody just starting into a new business, but evaluations and consideration of the people, their personnel, past performance, and other items that you go with can be a mitigating factor. Again, this is always a decision that has to be developed of using somebody who knows what they're doing.

In addition to exotic metals, we talked about carbon graphite units a little earlier. This is another area where you run into the same kind of situation. People who know how to handle carbon graphite and people who make these units on a regular basis are certainly very reliable. Again, do your homework. Carbon graphite can often be the solution to some of the exotic metal preferences that might come up on a first shot. Carbon graphite exchangers, whether they be the block cross flow type or the tube type with tube and shell design specially configured for graphite, can often be the answer to some of the exotic fluid handling conditions. Of course, the significant advantage is that, in addition to graphite being an excellent electrical conductor, it is also an excellent heat conductor. This is what suggests its use in heat exchange applications.

It's appropriate to return for a minute to the plate type heat exchange discussion we had earlier in order to add a little to it. Certainly, one of the things that is argued quite consistently on the plate heat exchangers are the variations that can be used to improve operation. Embossing techniques, the way they are used, and by using a variety of embossing techniques, depending on the

material and the flow methods and velocities, are things that can be added to the exchanger in order to improve its application.

A further consideration of the embossed plate type heat exchanger would be the welded together embossed plate exchangers. Several different manufacturers put these together, sometimes with one flat side, sometimes with both sides embossed, significant additional heat exchange. They're often used as formed units to wrap on the outside of a vessel. In many cases, they're used as the basis for manufacturing the vessel itself. Of course, this is something that is akin to the dimple jacket design, which was developed a number of years ago for reactor vessels. It can be a very attractive thing to consider.

I would suggest that when looking at wrapping a vessel with the formed embossed plate type heaters, that an overall consideration of heat transfer coefficient be seriously reviewed. Quite often, heat transfer cements are placed between the formed plates and a vessel. In looking at overall heat transfer coefficients, certainly the combination of the plate, its performance, the heat transfer paste that is put on it, and the condition of the existing vessel wall, must be seriously looked at. Often, the overall heat exchange coefficients in conditions like that drop down into the 5 to 15 U-values, which is considerably different than a 30 to 60 U-value that can be achieved with a bare plate and heating directly applied to the plate.

Again, the formed embossed plates can be provided with a variety of embossing methods to allow single pass or multiple pass operations, to enhance heat transfer in certain areas, to provide better ways for condensate pick up and control where steam might be used or condensing vapor of some kind for the heat transfer. Usually, the manufacturers will be able to provide you with a number of suggestions and alternatives in embossing methods and piping and collection techniques to the exchangers so that a good, efficient system can be developed. Again, as I said, do be concerned about overall heat transfer values, how and where paste would be used, and the methods of maintaining good solid contact between the wall and the formed plate unit applied to it.

Another specialty item in heat transfer that could be considered similar is the idea of electrical tracing. Certainly, one of the things that comes to mind there is a very convenient way of applying that. Obviously, there are concerns of the materials being handled and the proper connections and isolations of any electrical materials to prevent any flammability concerns, if that's part of the safety background of the materials being handled. One of the things that also comes to mind is the electrical heat is very limited in its application. It has to be wrapped closely. It usually has to be very carefully spaced and organized in order to get uniform heating and prevent hot spots. Of course, it also needs to be well insulated in order to prevent losses because any energy applied to the electrical heat methods is a kilowatt to BTU direct transfer and an equally easily applied consideration of cost and potential cost loss where insulation is somewhat limited in its use.

Now, having dealt at some length with some of the peculiarities, both the process application requirements and some mechanical requirements of shell and tube heat exchangers and, to an extent, other types of heat exchangers, it's appropriate to throw in a few comments on the overall use of heat exchangers in process activities. A significant portion of the understanding of the use

of heat exchangers has to be related to the efficiency of use and the efficiency of energy recovery. To this extent, there are two methods of analyzing and using exchangers and doing them efficiently.

Certainly, there are many process programs that are available for computers today that provide some insight into the application of heat exchangers. Looking at the overall analysis of the plant, one of the things that can be very important and very useful is to look at all of the streams, the energy, the enthalpies involved, and the temperatures that are related, and begin putting together a kind of domino or wall stack of appropriate exchangers with appropriate temperature differences at different steps along that grouping of energies and temperatures that are related to the plant. Certainly, this is very simple in looking at something like an evaporation train or a single series heat recovery operation train. Quite possibly even on a hydrocarbon processing system where there are a number of distillation columns or process steps that require the exchange of heat and where it's easy to see that the energy coming out of one stream can be used to counterbalance the energy needs of another stream.

This can be done on an overall plant operation, too, and should be considered and seriously developed for a plant. This is because the potential for energy recovery, the appropriate use of heat exchangers for this energy recovery, and efficiency and smoothness in operation of the plant, is not a small item. In pursuing this activity, there have been several developments over the last 10 years or so that relate to what is identified as pinch technology. This is somewhat newer terminology applied to the same basic function of looking at all of the energy needs of the plant, the temperatures, and appropriate heat interchange.

Certainly, in looking through systems like this, it's not difficult to find places where energy use can be overlapped and essentially all of it could be used. One of the difficulties then comes in when deciding the relative value because sometimes a given heat exchanger is somewhat separated from one of the streams that it would be appropriate to use in that. Now, we're back into real engineering and the analysis of whether it is justified in terms of plant operations to go through the additional piping in order to recover a moderate amount of heat and the additional control that would be required in order to be able to utilize. Also, it should be considered whether there are safety considerations that should be evaluated more closely to determine whether it's appropriate to use this kind of arrangement. The analysis and looking at the system is a worthwhile study and a valuable effort in coming up with a designed development on any given plant.

Another item that should be addressed and considered very seriously in terms of heat exchanger application is that, in almost all cases, the information that is the basis for heat exchanger application and analysis is information that has been developed empirically. Of course, there are a number of studies done in many different colleges as well as industrial applications that deal with the specifics of heat transfer coefficients on certain materials under certain conditions. These then have been developed over time into the empirical, dimensionless number curves and graphs that become the frequent basis for college study and final reference where questions come up in actual plant operations.

Recognizing that these are all empirical studies and that they are all based on current developments of information, they all must be reviewed with considerable interest. It sometimes seems appropriate to use some particular information. We then find later on that there are little differences in how it was applied that may or may not have been the generation of significant problem, but certainly was the reason for a difference from what we initially understood or expected a particular performance to be. Again, these background analyses should be looked at fairly seriously and certainly where there is specific plant data and application. Experience that can be used to verify or to justify a particular decision or selection of a process or mechanical application of a type of heat exchanger should be a primary consideration in everything that is done.

Again, I would emphasize that several key research or reference materials that I use in my observations of these applications are the textbook Process Heat Transfer by Kern and, generally, trade magazines having to do with current applications of heat exchangers and their design. *Chemical Engineering Information* and *Chemical Engineering Progress* both provide valuable information and references in doing much of this. Of course, the discussion of pinch technology is something that has been discussed in both magazines over the last decade or so.

As we conclude our review, I take the opportunity to add to this the comments that originally came from Fourier in reference to his analysis and development of much of the basic technology of heat transfer quite some time ago. He starts his discussion of his technology with these statements:

Primary causes are unknown to us, but are subject to simple and constant laws, which may be discovered by observation, the study of them being the object of natural philosophy.

Heat, like gravity, penetrates every substance of the universe. Its rays occupy all parts of space. The object of our work is to set forth the mathematical laws which this element obeys. The theory of heat will hereafter form one of the most important branches of general physics.

The knowledge of rational mechanics, which the most ancient nations had been able to acquire, has not come down to us, and the history of this science, if we accept the first theorems in harmony, is not traced up beyond the discoveries of Archimedes. The great geometer explained the mathematical principles of the equilibrium of solids and fluids. About 18 centuries elapse before Galileo, the originator of dynamical theories, discovered the laws of motion of heavy bodies. With this new science, Newton comprised the whole system of the universe. The successors of these philosophers have extended these theories and given them an admirable perfection. They have taught us that the most diverse phenomena are subject to a small number of fundamental laws, which are reproduced in all the acts of nature. It is recognized that the same principles regulate all the movements of their stars, their form, the inequalities of their courses, the equilibrium and oscillations of the seas, the harmonic variations of air and bodies, the transmission of light, capillary actions, the undulations of fluids. But whatever may be the range of these mathematical theories, they do not apply to the affects of heat. These make up a

special order of phenomena which cannot be explained by the principles of motion and equilibrium. We have, for a long time, been in possession of ingenious instruments adapted to measure many of these affect. Valuable observations have been collected, but in this manner, partial results only have become known and not the mathematical demonstration of the laws which include them all.

I have deduced these laws from prolonged study and attentive comparison of the facts known up to this time. All these facts I have observed afresh in the course of several years with the most exact instruments that have hitherto been used. To found the theory, it was in the first place necessary to distinguish and define with precision the elemental properties which determine the action of heat. I then perceive that all of the phenomena which depend on this action resolve themselves into a very small number of general and simple facts, whereby every physical problem of this kind is brought back to an investigation of mathematical analysis. From these general facts, I have concluded that to determine numerically the most varied movements of heat, it is sufficient to submit each substance to three fundamental observations. Different bodies, in fact, do not possess in the same degree the power to contain heat, to receive or transmit it across their surfaces, nor to conduct it through the interior of their masses. These are the three scientific qualities which our theory clearly distinguishes and shows how to measure.

It would seem that Fourier has provided us with the stepping-stones for us to move forward. We have been very efficient in using these stones throughout the last 150 years from his original observations. We've also been very fortunate to have many people provide a lot of additional information that has been helpful in those movements along that trajectory.

I would now recommend that the printed information that has been provided be reviewed. Possibly a consideration be made to acquiring more detailed copies of some of the information where it might be available. Of course, going back and looking up Kern and any other good heat transfer text that might be of assistance.

As is typical with this course, it is now appropriate to review the set of review questions that are used as a basis for judging your participation and listening through the course. Of course, those questions are included in the paperwork that also came with the course.

A few auxiliary items are worth mentioning in relationship to heat exchangers. These deal primarily with the cooling of solids. Large solids processing operations, particularly kilns, quite often end up with a solid that is very, very hot from having been exposed to open flames in its later processing in the kiln as it comes close to the firing end of the kiln. Certainly, there are heat regeneration coolers that are sometimes placed on the kilns to do a preheat of the incoming air, which is an energy saver.

However, even beyond that, the solids themselves are very difficult to cool; the air preheating very seldom reduces the temperature below several hundred degrees Fahrenheit. This temperature is still a very difficult material to handle, particularly if you're looking to convey it or transport it in any kind of hopper situation. The residual heat that would be given off would be significant and could easily damage belts and create thermal stresses on a number of the other

things that might be used for the conveying. In this case, a fluid bed type cooler of plates or pipes inside a box is quite often used to reduce the temperature on the solids. The solids themselves are usually then fluidized or are passing at relatively slow velocities with good surface transfer to try and effect this cooling. This is a very inefficient way of doing it, in general, but a very practical way for the protection of the later processing equipment.

In looking at this and another potential application for heat exchangers that are often referred to as compact heat exchangers, these are situations where extended surfaces might be used on both sides of the exchangers for particular reasons. One of the predominant uses of this type of exchange technology is in submarines and military applications. You run into a number of questions about how to handle geometric details of the exchanger and some of the related components.

I feel it appropriate to suggest to you that at this time a reference book by the name of Kays & London Compact Heat Exchangers would be an appropriate thing to look at. In addition to discussions of the technology of heat transfer and some expansions on standard heat transfer calculations and methods, there are several good discussions in there of the effects of geometry, particles, and particle arrangements on what can be done with heating and cooling, particularly in relationship to extended surfaces, unusual tube configurations, and things having to do with solids cooling or mixed solid heat transfer. An excellent reference, it's not something that can be covered very deeply in a discussion like this, but something that is appropriate to be aware of if you should run into a need for that kind of heat transfer.