Conversion of Heat to Work

Lecture by William T. Furgerson
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54 minutes, 34 seconds

Speaker: William T. Furgerson

Transcribed by: Sherry Yin

Time	Transcription
00:00	Warren Wooster: To start up, I should introduce myself. I am Dr. [Warren S.] Wooster from the Scripps Institution of Oceanography and on behalf of the Scripps Institution and the Theatre Arts Foundation and the General Dynamics, I'd like to welcome you to the fourth lecture in the series Meet the Scientists. Our speaker today, Mr. William Furgerson, graduated in chemical engineering from the University of Tennessee. He has worked with the Manhattan District and at the Oak Ridge National Laboratory and now he is at General Atomics. He will speak on the subject of conversion of heat to work. Mr. Furgerson.
00:48	[Audience Clapping]
01:05	William Furgerson: Our subject today may seem rather unglamorous in this day of sputniks and ICBMs [intercontinental ballistic missiles], but it's important nevertheless. It affects all of us, more than you realize perhaps. Certainly, more of you will be involved in it in your careers than will be involved in the more glamorous projects. I don't know whether we can make power plant engineers out of some of you girls or not but maybe. This is the matter of conversion of energy, heat energy, into work. All of the energy that we use to do work, whether it's mechanical energy or electrical energy, involves either direct conversion of chemical energy or conversion of heat energy. The most important example of direct conversion of chemical energy I believe is in animal muscles. Certainly, the conversion of heat involves the largest amount of energy that we use. This is true whether the heat is from combustion of fuel or from a nuclear reactor, even water power is only nature's way of converting solar heat into work. If the process is man-made, we call it a power cycle. I'm going to draw a box over here and it's going to be our power cycle.
02:48	William Furgerson: We will flow a certain amount of heat into this box and something is going to come out. Now the first law of thermodynamics, which you are probably familiar with as the law of conservation of energy, says that every bit of heat that we put into this box has to come out in some form, or else remain stored in the box. Now, let's forget for the moment about this matter of storing in the box and say we have an equilibrium system here. So that everything that goes in also comes out. Now, this thing works very well in reverse. In other words, if we were putting mechanical or electrical energy into the box, certainly everything that would come out would be heat. All energy is ultimately converted into heat, no matter what form the energy is. But if we try to make it go the other way and convert the heat into mechanical or electrical energy, we run into the second law of thermodynamics, which perhaps you are not so familiar with. And that simply says that heat is not all available for conversion. So coming out of this box we have two streams.
04:40	William Furgerson: I don't know if you can read my writing now, one of these says useful work, and the other one says reject heat. This is lost to us; we can't use it. Examples of this reject heat are the heat of the exhaust for instance of an automobile

or in the condenser of a steam plant, the heat, which is taken up by the condenser water. Unfortunately, the percentage of the heat converted into useful work is rather low. Back in the early 1800s, French Investigator Sadi Carnot proved mathematically that the absolute maximum conversion of heat into work can be represented by an equation like this. The efficiency of conversion is equal to the temperature at which the heat flows into our box, that is here, minus the temperature at which it flows out, divided by the temperature at which it flows in. It's that simple.

06:07 William Furgerson: Now this is thermodynamic efficiency. It has nothing to do with the efficiency of the machinery that's used in making the conversion. Unfortunately, this further reduces the efficiency. No power cycle can be more efficient than this, right here and these are absolute temperatures, you know what that is. After imposing the efficiency or say the lack of efficiency of the machinery on this equation, we finally get around 35 percent of useful work out of the heat energy in the fuel in a gasoline engine, if it's a good one. Perhaps 45 percent for a diesel engine, and somewhere between 30 and 40 percent for a steam cycle. What about these power cycles now? What's inside the box? What makes them work? We'll supposedly start off with the definition of work. On page 209 of your physics book, I believe it is, it says that work is force times distance. Well, the pressure acting on an area exerts a force. And if we can let that area move, either pressure pushing a piston or if the motion is circular pushing a turbine blade. We have a machine capable of doing work.

07:50 William Furgerson: Power is simply the rate of doing work. The machine of high power can do work at a greater rate than a machine of low power. Since force is pressure times an area, we can say categorically that any power cycle involves pressure. What we have to do then is find some way of using heat to generate a pressure in some medium. We'll call this medium a working fluid. Let's take the simplest example, suppose we take a cylinder filled with a gas, this gas is now our working fluid. We put a piston in the cylinder, and up here we have a fly-wheel connected to the piston. And suppose this thing is leak tight, now we heat the gas that's in the cylinder, put a fire underneath. That's supposed to be a flame. We heat the gas, if the gas were turned loose, it would expand according to Charles's Law. We are going to restrain the gas and not let it expand as much as it would like to. The pressure rises, if the pressure rises, it forces the piston up and does work. Then, suppose we take the flame away and put an insulator underneath the cylinder here. There's still some excess heat in this gas, so we allow it to expand some more. But now since we are not putting heat in, the temperature and the pressure both drop, and finally the expansion goes as far as it can. It turns around, the machine, the energy of the fly-wheel starts to push the piston back down again.

10:05 William Furgerson: Well suppose then we put a block of ice under our piston, under our cylinder, that cools the gas - makes it contract, pulls the piston down. We let it come down a certain distance, then we take the ice away and put the insulator back. Let the stored energy of the fly-wheel push it down still further. Then we take the insulator away and go back to the heat, we have a power cycle. That's why it's called a cycle, it repeats. Now, this may seem sort of elementary to you, and it is. But it's a good place to start because it is the simplest power cycle and incidentally it's the one Carnot showed was the most efficient. It's not a gasoline engine cycle, that's the otto cycle. Not auto but otto. You notice there's no intake or exhaust in this power cycle, it shows the relationship between temperature and pressure. If our fire is hotter, it makes the pressure rise more, it makes the piston expand further and it makes the machine capable of doing more work. And it shows basically why a high-compression engine, for instance, is more efficient than a low-compression engine. I'm not aware of any Carnot cycle engines in use today. The early investigators despaired of ever trying to make one. We could build one now if we wanted to, the thing that limits it is the ability to transfer heat from our fire into the gas through the piston or through the cylinder wall and then back again to the heat sink to the ice here. I used ice figuratively, incidentally. Actually, of course, you wouldn't use ice. You'd use cold water or maybe even air as your heat sink.

12:19 William Furgerson: Because of this limitation on heat transfer through the cylinder walls, an engine using this power cycle would have to be quite large in order to develop a certain amount of power. We can get the same amount of power out of a smaller engine by using some other cycle which is less efficient, however. Rudolf Diesel was trying to approach the Carnot cycle when he invented the diesel engine. All power cycles have these four basic processes. First, the compression process, then the heating process, then the expansion, then the cooling, and then the process repeats. This is true whether the working fluid pushes against a moving piston, as I showed here, or whether it pushes against the moving turbine blade. The ultimate simplicity of a power plant of course is a rocket engine where the working fluid pushes against the entire engine and makes it move. There's not much point in our talking about automotive engines or diesel engines here. I'm sure you're quite familiar with these already. We will talk about some of the steam cycles and gas turbine cycles though. As I mentioned before, all power cycles involve some means of creating pressure with heat. One good way to create a pressure with heat is to boil water in a confined space. The steam will come off under pressure and we allow the steam to expand through the turbine, doing work. And the steam is condensed, and that's where we reject the waste heat. The condensed water is pumped back to the boiler and boiled all over again.

14:10 William Furgerson: I will draw a schematic of the steam plant. We have our boiler here, we put heat into the boiler and we get steam out of the boiler. The steam goes and expands through the turbine, the turbine shaft does work. Low pressure, steam comes out of the turbine. Low-pressure steam goes into the condenser. We run cold water into the condenser, the water picks up the heat from the steam, is warmed in the process, and that heat is lost to us. Then the condensate from the steam comes back through a pump which pumps it into the boiler. And here we go again. Now, this is the basic steam cycle, this is the simplest steam cycle.

15:51 William Furgerson: From Carnot's cycle efficiency, which I have to write back up here, I suppose. From this, you can see that the higher the temperature, the steam leaving our boiler. And the lower the temperature of our condenser, the colder the water we have to go into the condenser, the more efficient this cycle will be. The pressure in the boiler is tied to the temperature. As long as we have water boiling at a certain pressure, the temperature is fixed by the pressure and conversely, if the temperature is fixed the pressure will be fixed. The two go hand in hand. As the temperature is increased to about 705 degrees, we reach a condition which is called critical, that is above this temperature, water can't exist as water. We can't boil water above 705 degrees because we can't have water above 705 degrees. It's all steam no matter how much pressure we put on it. Above 705 is called supercritical, the pressure here would be about 3,500 pounds per square inch. It's difficult to design machinery, the boilers and the pipes, and even the turbine, to hold pressures this high. We'd still like to use high temperature though so we can get a high efficiency in our steam cycle.

17:36 William Furgerson: So we resort to a trick that's known as superheating. We boil here at some temperature well below the critical temperature, say 500 degrees. The critical temperature, remember, is 705. We take the steam coming off the boiler at 500 degrees and we run it through a superheater, where we put in more heat. We heat the steam just as if it were any other gas now, the water - all the boiling was done here. Once we get out of the boiler and are not trying to, not being limited by this fact of having water present, we can do anything we want to to the steam. So we heat it up some more and we can get it up to 1,000 degrees or so or 1,200 perhaps and handle it very nicely at whatever pressure we please. The basic steam cycle at, say, 1,000 PSI, pounds per square inch, and 1000 degrees F [Fahrenheit], which you can get with a superheater arrangement like this would give cycle efficiency of 30 to 35 percent. The amount, the cost of fuel that goes into a kilowatt hour of electricity is something less than half a cent, so you might think it's not very important to try to save fuel or try to make a more efficient process if we could increase the efficiency of the process from 30 percent to 40 percent, we could save something less than a tenth of a cent on each kilowatt hour of electricity.

19:41 William Furgerson: This sounds small but the amounts of power we consume are so large that this small amount spread out over a large amount of power makes a lot of money. For instance, the largest steam power plant in this country is the one at Kingston, Tennessee, which generates about 1,500 megawatts. That's one and a half million kilowatts. If we can save a tenth of a cent per kilowatt hour on that, we are saving about $1,500 an hour on fuel. So it's well worthwhile to resort to these tricks. There's another trick that can be used, this is called reheating. As the steam goes through our turbine, the temperature decreases as well as the pressure. And somewhere along the line, the water will start or the steam will start to condense. Then we have little droplets of water flying through the turbine along with the steam. Well, this is bad for the turbine because the velocities are high and these little droplets of water can actually wear the turbine blades away. It's also bad thermodynamically. The water droplets create pressure losses that lower the efficiency of the process. So, somewhere along here, at a convenient spot, we take the steam out of the turbine. We take it to another furnace, something like our superheater, call this a reheater. We put in some more heat and we take this steam from the reheater, which is still at about the same pressure but at a higher temperature now, put it back in the turbine, and expand it some more. By doing this we can gain a few more points of efficiency.

21:41 William Furgerson: Still another thing we can do is what's known as regenerative feed water heating. Every bit of steam that comes out the discharge end of the turbine and goes to the condenser, the heat of condensation of that steam is lost to the process. It's gone and we can't use it. So what we'd like to do is minimize the amount of heat that's rejected here. This water is coming out at maybe 100 degrees F [Fahrenheit], we are boiling over here maybe at 500. So we can use some heat to preheat this water, get it up to boiling temperature before it ever gets in the boiler. And we do that by bleeding some steam off at intermediate points in the turbine. And just simply mixing it with the water. That way the heat of condensation of that steam is not lost but just recycled, sent round and round through the process. This gives us some more efficiency. Finally, our very best modern steam plants, using the highest temperatures and pressures that modern metallurgy will let us use, using all these tricks, the most efficient machinery we have, will give us about 40 percent useful work for the heat energy that's put in. And you are all familiar with simple gas turbine cycles such as an aircraft jet engine.

23:34 William Furgerson: Here we take air from the atmosphere which is our working fluid, we go through a compressor where the air is compressed. We go through a combustor where the air is heated and we go through a turbine. In this simple diagram, the turbine simply has enough power to grab a compressor. There's still some energy left in the working fluid as it leaves the turbine so we expand that through a nozzle and that propels an airplane. Now if we want to do something besides driving airplanes, say we want to run an electrical generator, we put some more stages on this turbine. And instead of letting the remaining energy in the working fluid be dissipated in this nozzle, we let it be dissipated in this section of our turbine. And we take a power shaft out and take out our power as useful work in that shaft. The waste heat here, the unavailable energy, is in the hot gas that goes out the exhaust. These are called open cycles for obvious reasons, it's open to the atmosphere. Air goes in, exhaust goes out and we don't pump the fluid around as we do in the steam cycle. It's possible to have a closed cycle in which this fluid is pumped around. We simply take a pipe and connect our exhaust, we go back through a cooler and back to the inlet again. That's a closed cycle. Now if we try to burn fuel in our working fluid. pretty soon we'd use up all the oxygen so instead of using a combustor now we use a heat exchanger. We have a combustor outside someplace.

26:09 William Furgerson: Now here we have our combustor, we burn our fuel here, circulate hot gas through one side of the heat exchanger, and circulate our gas from our compressor through the other side of the heat exchanger. And then back around through this cooler, which is cooled probably with water and into the compressor again. Well, this is a lot more complicated than the simple open cycle. It's complicated by the fact that we have to have this heat exchanger instead of just a fire. And we have to have this cooler here which we didn't have at all in the first place. And these pieces of equipment are quite large and expensive. But why worry with a closed cycle if it's so much more complicated? The answer is that by having a cycle closed, we have a much wider choice of working fluid. If it's an open cycle, we can only use air. By using a closed cycle, we can use some other gas which may be more favorable to the power cycle. We can use, for instance, helium which is inert and the hot helium will not tend to oxidize our turbine blades for instance.

27:31 William Furgerson: We can also get more work out of a small or out of a given size piece of machinery by having this closed cycle and applying a pressure raising the pressure of this cycle so that the density of our working fluid is increased, and more of it flows through the machinery so it can do more work. This is sort of like supercharging in an ordinary combustion engine, except that here we don't have to drive a supercharger. The closed cycle maintains the pressure for us. I mentioned this regenerative feed water heating a minute ago on the steam cycle. We can do the same thing, or an analogous thing, with a gas turbine cycle. We can take some of this heat which we would throw away in the exhaust and take the gas from our compressor and use a regenerator, another heat exchanger, which takes some of the heat from this exhaust gas and transfers it to the outlet gas from the compressor. Then we take that and run it through our heat exchanger.

29:02 William Furgerson: Well since this gas now is already pretty hot, we don't have to burn as much fuel to raise it up to our turbine inlet temperature. Then we put in a cooler, we still have to have one but much smaller now, with the water. That's the regenerative gas turbine cycle. That would work with an open cycle too, except here we would just remove this much. We would have air coming in through the machinery, through the regenerator and then finally would be exhausted here. In a steam cycle, the amount of power required to run the boiler feed pump, to pump the water from the condenser back into the boiler, is maybe 1 percent of the total power output. In a gas turbine, this compressor requires about three times as much power to run as the net power output. This power is not lost, it's merely circulated through the cycle. But since it's such a large amount, inefficiency in the machinery will give losses that are large. The idea of a gas turbine is quite old, it's as old as the steam turbine at least. But only in the last twenty years or so have gas turbines been built and this is mainly because people didn't know how to build compressors.

30:32 William Furgerson: Now, they are learning. Since this power in the compressor is so large and since it's so sensitive to the efficiency of the machinery if we designed a gas turbine power plant and assumed in the course of the design that we can get a compressor that was say 85 percent efficient. We go ahead and build our plant, we build our compressor, and when we finally start to run the thing we find that instead of being 85 it was 80 percent. This could mean the difference between a gas turbine plant that ran and one which didn't run. It's that sensitive. Whereas in the steam cycle, if we were off by a factor of two on our boiler feed pump power requirement, it wouldn't make much difference. Well, why then if this gas turbine is such a sensitive beast, are we interested in it at all? There are two, perhaps three reasons. First, for comparable machine efficiencies, the gas turbine cycle is more efficient than a steam cycle. The reason for this is that the, in spite of all the tricks we can pull, the amount of heat that has to be rejected to condense steam from the turbine in the steam cycle is large. We can't get around this, it's part of the property of water. With the gas turbine cycle, we don't have this.

32:06 William Furgerson: A gas turbine will let us go to higher temperatures in the steam cycle, first because high-temperature steam is rather corrosive. And we can use inert gases in the gas turbine, this will let us go to higher temperatures and higher efficiency. In the closed-cycle gas turbine, will operate efficiently over a wider range of power levels than any other power cycle by simply controlling the pressure in all of this piping. If we design the machine for say 100,000 horsepower, we can run it at 50,000 horsepower simply by reducing our pressure in the system to half. The machinery won't know the difference. It will run just as efficiently at half-power. In a steam cycle, however, the only way we can run at reduced power would be to throttle the steam. This involves thermodynamic losses and it makes the turbine less efficient too. So, this flexibility of a gas turbine is an important thing. Right now, since steam power plants have been built for so many years, we can get them at a wider range of sizes. It's not uncommon at all to get a single steam turbine of 100,000 horsepower. Our gas turbine power plants are about 20,000 horsepower maximum.

33:37 William Furgerson: We have the technology to build larger ones if there's a demand for them. Right now the demand doesn't exist but it's developing. You may wonder why we at General Atomic are interested in power cycles and power plants. Well, that's easy. We are building reactors and the best reactor in the world is not much use unless we can couple it to an efficient power cycle. So we want to know enough about power cycles that we can design our reactor so that it will match up with a new modern and efficient power plant. The Nautilus power plant, in the submarine for instance, was a great success mainly because it ran. But it used liquid water to cool the reactor, to remove the heat from the reactor. We have here a reactor, we pump water through it. Cool water going in, hot water coming out. And this goes through a heat exchanger. This is under very high pressure about 2,000 PSI [pounds per square inch]. Here we have a steam boiler, we put water in with a pump, we have steam coming out, then we go through our turbine which drives the propeller. We come out of the turbine through a condenser and back to the boiler feed pump.

35:45 William Furgerson: This is liquid water all the way around. Now, remember what I said a minute ago about this super criticality condition above 705 degrees is approximately, water can't exist as water. This means that nowhere in this circuit can we get as high as critical pressure, critical temperature. This limits us to something less than 705 degrees in here. And considerably less than 705 degrees over here because of the temperature drop and going through this. Well, 700-degree steam or 600-degree steam is about what they were using fifty years ago. It's a pretty low-grade steam. The efficiency of the power plant is quite low. It's on the order of 20 percent, instead of the 30 or 40 percent of a modern steam plant. Since this was a pioneering effort and since it's a naval power plant, the efficiency is not too important. But if we want our new generation of reactors to be competitive with other forms of heat such as combustion of fuels, we must design these reactors that will couple up with power plants of high efficiency. Pressurized water reactors of this type have been installed in other nuclear submarines, also in the nuclear surface ship Savannah. And the reactor that has been running for a year or so now in Shippingport, Pennsylvania, is also a pressurized water reactor. These are all pioneering efforts and as such they deserve credit but the thermal efficiency is low.

37:35 William Furgerson: The British took a step forward in thermal efficiency of reactor power plants with their Calder Hall series of plants. In these, the reactor coolant was not water but was instead carbon dioxide gas. By using a gas to cool the reactor, they are not limited by this criticality condition, so they can get above 700 degrees. They have here a blower now instead of a pump and they still have their boiler but they just circulate carbon dioxide gas through the loop. By doing this, they can increase the thermal efficiency to maybe 25 percent. Now the reason they are limited to 25 percent is that they use magnesium-coated fuel elements in the reactor. Magnesium melts at a low temperature so they are limited by their fuel element rather than by the fluid that circulates through the reactors. At General Atomic, we have two projects underway for power reactors that will be coupled to power plants.

38:50 William Furgerson: One, a modern steam plant, and the other a gas turbine plant. Our HTGR, which stands for High-Temperature Graphite Reactor, is an attempt to get a nuclear reactor that will provide steam conditions that are equivalent to the best modern steam plants. As its name implies, it's made of graphite, even its fuel elements are encased in bars of graphite. Graphite is an excellent high-temperature structural material, it retains its strength at high temperature better than almost anything else. But it has one obvious disadvantage. If it's exposed to oxygen or to air while it's at high temperature, it will burn just like carbon in any other form. Even carbon dioxide which the British use dissociates at high temperatures into carbon monoxide and oxygen. And this oxygen would burn the graphite. So we can't use carbon dioxide, we certainly can't use air. The coolers are to remove the heat from this HTGR [High-Temperature Graphite Reactor], so we use helium, which is inert at all temperatures. The helium is blown through the reactors just as it's in this diagram. It goes through the boiler, boils water, and the steam goes to the power plant. I noticed the gas that circulates through here, the helium for HTGR [High-Temperature Graphite Reactor], is not a working fluid. It's simply a heat transfer medium. The working fluid is the steam and the steam power cycle.

40:21 William Furgerson: Our initial thermal efficiency for HTGR [High-Temperature Graphite Reactor] power plants would be 30 to 35 percent and as we learn more about materials we can reach perhaps 40 percent by going to higher temperatures. Our MGCR, or Maritime Gas-Cooled Reactor, is coupled to a closed-cycle gas turbine. Here, the working fluid goes directly through the power machinery. We have a compressor driven by a turbine and then the turbine has the additional power stages on it. We have regeneration like I told you a little while ago but I'm not going to draw it on here. Gas leaves the compressor, goes through the reactor, is heated, comes back out of the reactor, expands through the turbine, leaves the turbine, goes through the regenerator-cooler, and then goes back to the compressor again. And we have a power shaft which comes off and drives the propeller of a ship. And here the helium is a working fluid since it goes through the turbomachinery.

42:11 William Furgerson: The choice of helium here was not nearly so easy as it was in the MGCR [Maritime Gas-Cooled Reactor] or as it was in the HTGR [High-Temperature Graphite Reactor], where it was simply a heat transfer medium. Helium is an excellent heat transfer medium. If we flow helium over a hot surface, it will readily pick up the heat from the hot surface. Or if we flow hot helium over a cool surface, as in the boiler, again it will give up its heat very readily. But helium is not the best material to use in the design of turbomachinery. The velocity of sound in helium is about 4,000 feet per second, the velocity of sound in air is about 1,100 and in carbon dioxide, it's about 1.000. This means that the pressure ratio we can get in the stage of a turbo compressor is much less with helium than it is with carbon dioxide or air. And if our cycle calls for a certain pressure ratio, we have to have many more stages. In fact, about 3 times as many stages if we use helium than if we use carbon dioxide or air. So in the design of the MGCR [Maritime Gas-Cooled Reactor], we were torn between the desire to use a good heat transfer medium, which was also inert, and the desire to have a heat transfer or working fluid which would make the design of the turbomachinery easier. We finally decided on helium since we felt that it would benefit the reactor more than carbon dioxide would benefit the turbomachinery.

43:53 William Furgerson: Now, since we have graphite in this reactor too, and since carbon dioxide dissociates at higher temperatures, it would've been necessary to clad the graphite, in the event we use carbon dioxide. This was one of the reasons that we felt helium was a better choice. And in the HTGR [High-Temperature Graphite Reactor] power plant, once we get the reactor and the helium-heated boiler, we can go to any manufacturer and get a turbogenerator set, practically an off-the-shelf item. But in the MGCR [Maritime Gas-Cooled Reactor], the power machinery is a very special thing. We can't go to a manufacturer and say give me a helium compressor or give me a helium turbine. They just don't exist. So here we have two problems, we have to get the reactor and we have to have the special equipment to go with it. And as I indicated a little while ago, these plants are very sensitive to the efficiency of the machinery. So we have a very extensive program underway to develop efficient turbomachinery which works with helium. Nobody has ever done this before.

44:57 William Furgerson: When completed, this power plant will be rated at 20,000 horsepower and it will be put in a tanker, 40,000-ton tanker. It will be able to run about three years at full speed without refueling. The thermal efficiency of this power plant will be about 30 percent, this is equal to the best steam turbine power plant for maritime use. We could probably design a better steam plant right now but we anticipate future developments in reactor technology that let us go to higher temperatures and the gas turbine will be able to use these higher temperatures to better advantage than the steam plant. In other words, our steam plants are right now just about as good as they can be but gas turbines still have room for improvement. The latest thing in conversion of heat into mechanical or electrical energy are the so-called direct conversion processes. Now, these are not power cycles at all, they involve taking heat and going directly to electric power. We're interested in these at General Atomic too. We are just now trying to learn what makes them work, we know that they do work but we don't know exactly why.

46:14 William Furgerson: Things are not now developed to a point where we could build a power plant using direct conversion but we are working on it. There are two avenues of investigation here. One is the thermoelectric effect, there are certain materials which if heated, will generate electricity. The other is the thermionic effect, certain materials have the property of generating a flow of electrons when heated. The filament of a vacuum tube is the best illustration of this. If we allow the electrons to flow to a plate which collects them and then allow them to flow through a circuit, we have flow of electric current. We don't know enough about these yet, to know whether we can ultimately improve on the Carnot cycle or not. We do know that the process is not 100 percent efficient. Our current attempts are about ten percent. Direct conversion has a very decided advantage of having no moving machinery, everything is standing still. Perhaps fifty years from now, we will have large power plants which work on direct conversion processes. But in the meantime, we are going to have a lot of power cycle equipment with us. Now I've been told that you people have all sorts of questions, I wonder.

47:42 Speaker 1: On a television program several weeks ago I saw pictures of [unclear] powered by direct conversion by thermal electricity.

47:55 William Furgerson: That's quite right. I understand the Russians have been building these things for the Chinese, they use a kerosene lamp for the heat. When I said we didn't know much about the process, I meant we didn't know enough to build a large power plant. Certainly, there are examples of small units all over the place. Do you know what a thermocouple is?

48:24 Speaker 1: Vaguely.

48:26 William Furgerson: It's the best illustration for direct conversion I know of. Of course, it generates a small flow of electric current which you measure and then this tells you how much heat or how much temperature you have.

48:41 Speaker 1: Well this - I'll lean towards this thing - this apparatus, as I recall, it showed these - they were just very, very poor, almost destitute Chinese, just sitting there with a small kerosene lamp and they were heating up this little - you couldn't say exactly - looks like some sort of a plate and you hear the radio coming in loud and clear. I thought this was rather amazing.

49:00 William Furgerson: Yes. Did I see a hand over here someplace? No? Everybody knows all about power cycles?

49:18 Speaker 2: I have a question here. How about the use of sodium and potassium metals in heat transference?

49:24 William Furgerson: Yes, that - we could do that. In fact, there are two reactors I know of which make use of liquid metals. Let's go back to our steam cycle again. Where the submarine power plant uses high-pressure water and the gas-cooled power plants use a gas, you could just as easily pump a liquid metal around through here and then use the heat which it picks up to boil water.

50:07 Speaker 2: Is there an advantage to that?

50:09 William Furgerson: It has the advantage that you can go to higher temperatures, yes. You can go to temperatures about as high as you can with the gases but you do have a corrosion problem. A liquid metal wants to dissolve some of the materials in your reactor.

50:28 Speaker 3: How do you get the liquid metal to flow in the first place?

50:32 William Furgerson: How do you get it what?

50:33 Speaker 3: How do you get the liquid metal flowing?

50:35 William Furgerson: With a pump.

50:36 Speaker 3: Well, how can you get the whole system hot enough so the metal is flowing?

50:39 William Furgerson: You use a - probably the commonest one is what they call a NAK, N-A-K - simply the chemical symbols of sodium and potassium - it's liquid at room temperature.

51:01 Speaker 4: Is there not also an intermediate type of reactor, a power plant system, a boiling water reactor where they boil the water right in the reactor?

51:11 William Furgerson: That is the boiling water reactor. Yes.

51:14 Speaker 4: Is that intermediate in efficiency too?

51:17 William Furgerson: It is. It's - you can get some violent arguments, pro and con, on the boiling water reactor. People who like it say it's the very thing, people who don't like it are afraid of the controllability of the thing. Since the water is boiling, you don't know exactly how much reactivity you have all the time. It is an intermediate. It's more efficient than the pressurized water reactor, less efficient than the gas-cooled or liquid metal-cooled reactors.

51:55 Speaker 5: I have a question that intrigues me. Why is not a solid material used to transmit the heat on the nuclear reactor to the water to the boiler, in other words -

52:09 William Furgerson: Use a solid conductor.

52:12 Speaker 5: Yes, what is the big objection to this? You would think it would have some real advantages.

52:18 William Furgerson: It would have some advantages. I think the main advantage is the pressure drop or the temperature drop that would be involved in going through any length of solid material. I remember one reactor that we worked on where we were trying to get a large amount of power out of a small reactor, where the temperature dropped through a little, the wall of a little tube which was 20,000th of an inch thick. And the temperature drop through there was about 50 degrees. You can see what would happen if the thing were even a foot long, how much temperature drop you would get. This is the biggest disadvantage I can think of for such a thing.

53:03 Speaker 5: You couldn't insulate it adequately.

53:06 William Furgerson: No, it was just the resistance, insulating would have nothing to do with it. It was just the resistance of the material to the flow of heat. It took that much temperature to drop to force of heat through the material. You can go to such things as silver which have a higher conductivity than this, material-wise. Perhaps, decrease the temperature drop by a factor of 10 but it still would be high.

53:42 Speaker 6: I have a comment which I hope is related. Are you familiar with the wind tunnel that Dr. [uclear] is using at the University of Southern California?

53:53 William Furgerson: Tell me more about it. I don't know it by that name.

53:57 Speaker 6: Well, this is a hypersonic test tunnel utilizing a temperature near absolute zero at one end in order to create the wind velocities or the gaseous velocities that he needs for demonstration and as utilization of a differential, temperature differential, for creating these velocities. I thought perhaps this was a, would be of interest in terms of power.

54:31 William Furgerson: Well, I think he does it the other way around, he uses pressure to get velocity and the temperature is just sort of a byproduct of this. He takes a gas at high pressure and expands it through a nozzle and as it expands, its velocity increases and its temperature decreases. This is what happens in a turbine blade, really. He's just got it going straight in a wind tunnel and the power machinery man would have it going through a turbine blade. But it's the same process.

55:17 Warren Wooster: Well I think, if there aren't any more questions, we should thank Mr. Furgerson very much for this interesting talk.

55:24 William Furgerson: It's been a pleasure.