Concepts of Thermodynamics
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Lecture – 66
Review of Learning Concepts

So, today we are going to have a Review session, where we will essentially try to revise certain concepts on entropy by asking some short questions.

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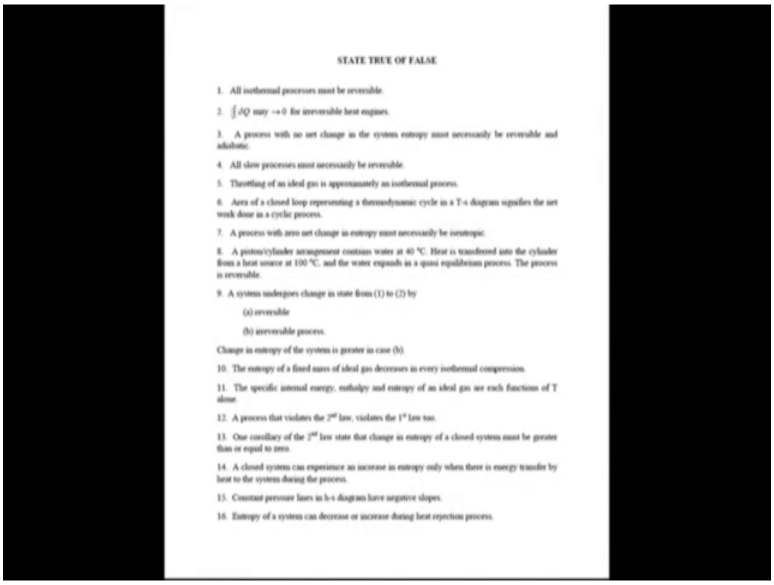

STATE TRUE OF FALSE

1. All isothermal processes must be reversible.

2. $\oint \delta Q$ may $\to 0$ for irreversible heat engines.

3. A process with no net change in the system entropy must necessarily be reversible and adiabatic.

4. All slow processes must necessarily be reversible.

5. Throttling of an ideal gas is approximately an isothermal process.

6. Area of a closed loop representing a thermodynamic cycle in a T-s diagram signifies the net work done in a cyclic process.

7. A process with zero net change in entropy must necessarily be isentropic.

8. A piston/cylinder arrangement contains water at 40 °C. Heat is transferred into the cylinder from a heat source at 100 °C, and the water expands in a quasi equilibrium process. The process is reversible.

9. A system undergoes change in state from (1) to (2) by

   (a) reversible

   (b) irreversible process.

Change in entropy of the system is greater in case (b).

10. The entropy of a fixed mass of ideal gas decreases in every isothermal compression.

11. The specific internal energy, enthalpy and entropy of an ideal gas are each functions of T alone.

12. A process that violates the 2nd law, violates the 1st law too.

13. One corollary of the 2nd law state that change in entropy of a closed system must be greater than or equal to zero.

14. A closed system can experience an increase in entropy only when there is energy transfer by heat to the system during the process.

15. Constant pressure lines in h-s diagram have negative slopes.

16. Entropy of a system can decrease or increase during heat rejection process.

So, I have projected the questions on the screen, but I will read this questions out and we will discuss this questions one by one. So, these questions are relating to state whether the following statements are true or false.

So, certain statements are given you have to say whether these are true or false and in case you are able to give the correct answer you also have to justify it. So, the first question is all isothermal processes must be reversible this is the first statement, so true or false.

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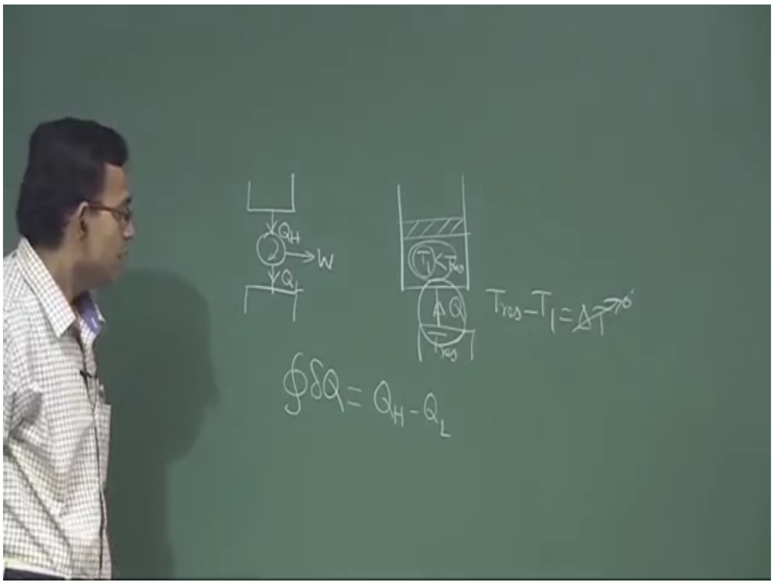

So, let us try to analyse this. Let us say there is a piston cylinder arrangement and there is a heat transfer from a thermal reservoir. Let us say the temperature within the system is T 1, which is less than T reservoir.

So, that there is a heat transfer. So, if this temperature T 1 of the system remains the same there it is an isothermal process for the system. And if it is isothermal it is supposed to be a very slow process. So, that it is a reversible Isothermal process. However, the reversible isothermal process by reversible we mean internally reversible, but if you look at this temperature difference between the thermal reservoir and the system boundary there may be a finite temperature difference.

So, isothermal may assure internal reversibility, but it will never assure total reversibility. It will be totally a reversible process if this T reservoir minus T 1 is some delta T very small tending to 0, then it is reversible externally reversible. Otherwise it is not externally reversible and we can say that, it is just an internally reversible process. So, all isothermal processes must be reversible this statement is not correct.

Let us, consider the second statement cyclic integral of del Q may tend to 0 for irreversible heat engines. So, cyclic integral of del Q. So, let us say that there is a heat engine, which takes heat Q H rejects heat Q L and does some work W in a cyclic process.

So, cyclic integral of del Q is Q H minus Q L, can it tend to 0 for an irreversible heat engine surely because the difference of this is work done. And if the engine is highly reversible the work done will be less and less and therefore, in the limiting condition for a highly reversible situation this may tend to 0. The third question is a process with no net change in the system entropy must necessarily be reversible and adiabatic. So, process with no net change in entropy must necessarily be reversible and adiabatic.

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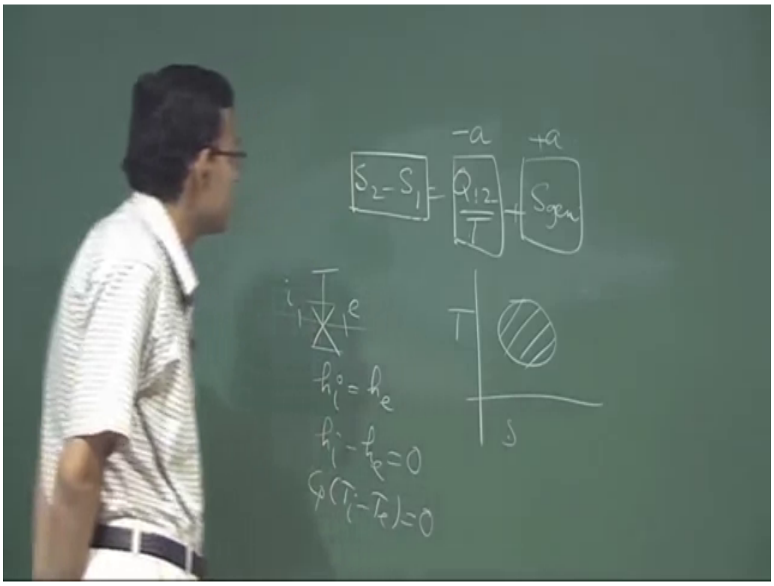

See, let us write the expression for change in entropy of the system S 2 minus S 1 is equal to Q 1 2 by T plus S gen. So, what is saying is that this is 0. How can this be 0? There are some possibilities, one is it is a reversible adiabatic process if it is reversible entropy generation is 0 if it is adiabatic Q 1 2 is 0. However, there could be some other case also when this is 0, when this is 0.

For example, this is some minus positive number a when this is negative when heat is transferred from the system to the surroundings. And let us say this is plus a. So, then the total is 0, but it is not a reversible an adiabatic process. So, net change in entropy is 0 does not mean it is an isentropic process, isentropic means the entropy remain same throughout the process not just the final entropy minus initial entropy is 0. So, this is a case when the change in entropy at the end of the process is 0, but it is not reversible and adiabatic.

So, a process with no net change in system entropy need not necessarily be reversible and adiabatic. Let us consider the fourth question. All slow processes must necessarily be reversible. So, this is also not true, because all slow processes must necessarily be internally reversible, but they may be externally reversible. So, if they are externally reversible; that means, the net process becomes irreversible.

The next question is throttling of an ideal gas is approximately an isothermal process. So, throttling the process of throttling is something like this. So, you have a throttle valve and across the valve the fluid is flowing in such a way, that there is no scope of any heat transfer or work done. And if you neglect changes in kinetic energy and potential energy, the 1st law for a steady flow process will tell that h i equal to h e.

Remember that this does not mean that it is an isenthalpic process. The enthalpy does not remain same, it is just the enthalpy before immediately before throttling is same as enthalpy immediately after throttling, but we are talking about an ideal gas. So, now, this means that d h so, h i minus h e equal to 0. So, if it is a constant specific heat even if it is a constant specific heat, it means C p into T i minus T e equal to 0 not for all ideal gas only for ideal gas with constant specific heat, but even then you cannot say that it is an isothermal process.

Why, because it is for a ideal gas with constant C p C v this means that the temperature before throttling is same as temperature after throttling, but this does not mean that temperature remains same throughout the process. So, it is not an isothermal process.

Next question area under the close loop representing a thermodynamic cycle in a T s diagram signify signifies the net work done in a cyclic process. So, if you have a T s diagram and you have an area enclosed in the T s diagram. So, the area enclosed in the T d s in a T s diagram in a cyclic process. So, that is integral of T d s that will be del Q provided it is a reversible process. So, if it is a reversible process then of course, this area also represents the work done, because cyclic integral of heat is equal to cyclic integral of work from the 1st law of thermodynamics.

But, if the process is such that it is not a totally reversible process then you cannot write del Q equal to T d S and then this equivalence will not be there. Next question a process with 0 net change in entropy, but must necessarily be isentropic. So, this is the same question that we had here 0 net change in entropy means S 2 minus S 1 is equal to 0. So, S 2 minus S 1 is equal to 0 does not mean it is an isentropic process, because it just indicates that the final entropy is same as initial entropy, but it does not assure that entropy remains constant throughout the process.

Next question a piston cylinder arrangement contains water at 40 degree centigrade. Heat is transferred into the cylinder from a heat sources at 100 degree centigrade and water expands in a quasi-equilibrium process. The process is reversible, clearly the pros the cylinder the water expands in a quasi-equilibrium process; that means, it is internally reversible.

However, there is a temperature difference between the system and the heat source; heat source is 100 degree centigrade and system boundary is at 40 degree centigrade. So, because of this finite temperature difference across which heat transfer is taking place it is an externally irreversible process. Therefore, the process is not reversible it is only internally irreversible, but not externally reversible.

Next question a system undergoes change in state from state 1 to state 2 by a reversible and irreversible process. The change in entropy of the system is greater in the irreversible process. This is not true, because when the system goes from state 1 to state 2 the change in entropy S 2 minus S 1 does not depend on the path. It depends only on the n states 1 and 2, because it is a point function the entropy is a point function.

The next question, the entropy of a fixed mass of ideal gas decreases in every isothermal compression. So, entropy of a fixed mass of an ideal gas decreases in every isothermal compression. So, let us try to address this question.

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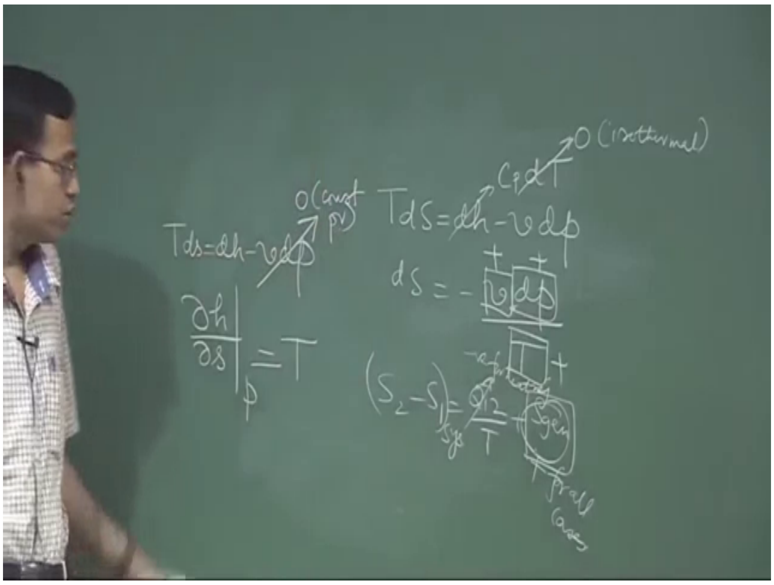

So, let us try to use this T d s relationship, T d s is equal to d h minus v d p. For an ideal gas d h is C p d T isothermal means d p d T is 0. So, d s is minus v d p by T. Compression means pressure increases right. So, d p is positive specific volume is positive and this is absolute temperature it is always positive. So, d s is negative; that means entropy of a fixed mass of an ideal gas decreases in every isothermal compression.

Next question, the specific internal energy enthalpy and entropy of an ideal gas are each functions of temperature alone. So, internal energy and enthalpy of an ideal gas are functions of temperature alone, but entropy is not. Recall the formula for change in entropy of an ideal gas with constant C p C v. So, S 2 minus S 1 is C p l n T 2 by T 2 minus r l n p 2 by p 1. So, you can see that entropy of an ideal gas will depend on temperature.

So, entropy of an ideal gas is not is a function of temperature as well as pressure whereas, internal energy an enthalpy of functions of temperature only, but entropy is a function of temperature and pressure or temperature and specific volume right. So, this statement is not correct. Again I am repeating the specific internal energy and enthalpy are functions of temperature only for an ideal gas, but entropy is a function of the temperature as well as pressure.

Next question, a process that violates 2nd law violates, the 1st law too, this is not correct, because, 2nd law talks about the directionality of a viable process. So, according to 1st law if energy balance is satisfied you can still have heat transfer from a lower temperature body to a higher temperature body without any work input. However, according to 2nd law such a process will not be feasible until and unless you give a work input.

So, even though you satisfy energy balance which is the essence of first law, the 2nd law may not be satisfied. So, a process that violates 2nd law violates the 1st law too is not correct. In a sense that a process that violates 2nd law may not violate first law, energy balance is satisfied, but 2nd law is not satisfied.

Next question, one corollary of the 2nd law states that the change in entropy of a close system must be greater than or equal to 0. So, the change in entropy of a close system, if you see this is the change in entropy of a close system can we guarantee whether this is positive negative or 0 we do not give a guarantee. See when it many times we loosely say, that entropy always increases, but we do not mention that it is the entropy of the universe system plus surrounding together that increases.

Entropy of a system or surrounding separately those might either increase or decrease or remain the same, some total of entropy of the system and surrounding if you consider that will always increase. So, for example, entropy of a system can decrease; how it can decrease? Like if you have heat rejection then this is negative for heat rejection. This is always positive for all cases. So, some total may be positive negative or 0. So, entropy of a close system change in entropy of a close system must be greater than or equal to 0 this is not a correct statement.

Next question, a close system can experience and increase in entropy only when there is energy transferred by heat to the system during the process. So, a close system can experience and increase in entropy only when there is energy transfer by heat to the system during the process. That is not correct, even this heat transfer is not there or there is heat transfer from the system a close system can experience at increase in entropy because of entropy generation right. This statement is not correct.

Next question number 15, constant pressure lines in h s diagrams have negative slope, h s diagrams are very important and for steam this particular diagram is also known as

Moliere diagram or Moliere chart, which is used commonly in industry. So, why this diagram is important is because for working out various for changes in thermodynamics properties for analysing devices in power plants you may often required the enthalpy and entropy data.

So, if you have enthalpy versus entropy diagram by looking into the diagram you can immediately read out the data. So, the question is constant pressure lines in the h s diagram have negative slopes. So, let us write this T d s is equal to d h minus v d p, constant pressure line means d p is 0. So, you can write in the h s diagram. The slope of the constant pressure line is the absolute temperature and absolute temperature is always positive. So, constant pressure lines in the h s diagram will have positive slope, because this is absolute temperature this is always positive.

The next question entropy of a system can decrease or increase during heat rejection process. So, during heat rejection process this is negative, entropy generation is always positive sum total may be positive negative or 0. So, during heat rejection entropy of a system may decrease, it may increase or it may not change all these three possibilities are there during a heat rejection process. So, entropy of a system can decrease or increase during heat rejection process this is possible even it may remain same ok.

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LEARNING CONCEPTS

1. Isolated system
2. Closed system
3. Simple compressible substance
4. Pure substance
5. Phase
6. Thermodynamic equilibrium
7. Law of corresponding states
8. State postulate
9. Flow work
10. Uniform state

STATE ASSUMPTIONS

$$\left.\begin{array}{l} \delta W = pdV \\ \delta Q = dU + pdV \\ \delta Q = dU + \delta W \\ Tds = dU + pdV \\ Tds = dU + \delta W \\ w_{12} = -\int vdp \end{array}\right\}$$

SHORT QUESTIONS

1. Name the different processes for an ideal gas shown in the figure below

Now, I will come to a different set of short questions. So, this set of short questions. So, because this is a review session I want you to review this following concepts and I do not want to give you the answers to these learning concepts because we have already discussed in grate details, but just consider this isolated system. So, a system that does not interact with the surrounding close system, simple compressible substance, pure substance, phase, thermodynamic equilibrium, law of corresponding states, state postulate, flow work, uniform state.

So, please try to revise this learning concepts so, these concepts are important, because I mean based on these concepts you can basically develop a foundation on the basic laws of thermodynamics, these are not exactly the laws of thermodynamics, but these are concepts which act as preloves to the practical application and realisation of the various intricacies of the laws of thermodynamics.

Next, the next questions we will discuss state the assumptions behind the equations that are given first equation del W is equal to p d v. So, what are the assumptions for del W is equal to p d v? The assumptions are very straightforward simple compressible substance and quasi equilibrium process. These are just the two important assumptions; there is no other assumption that goes behind this. Next del Q is equal to d u plus p d v.

So, basically it is a 1st law where you have neglected 1st law for a closed system where we have neglected the changes in kinetic energy and potential energy, that is why d U and not d e. And in place of delta W you have written p d v; that means, you have assume it is a quasi-equilibrium process.

So, it is a 1st law for a close system with negligible changes in kinetic energy and potential energy and quasi equilibrium process, del Q equal to d u plus del W. So, del Q equal to d U plus del W is a 1st law for any process for a close system. Then, next T d s is equal to so, this s will be capital S T d s equal to d U plus p d v. So, T t d s equal to d U plus p d v this is a T d s relationship that is valid for any process. Now, I want to discuss a little bit on this because there are confusions. On this in almost all students, that why the T d s relationship is valid for all process.

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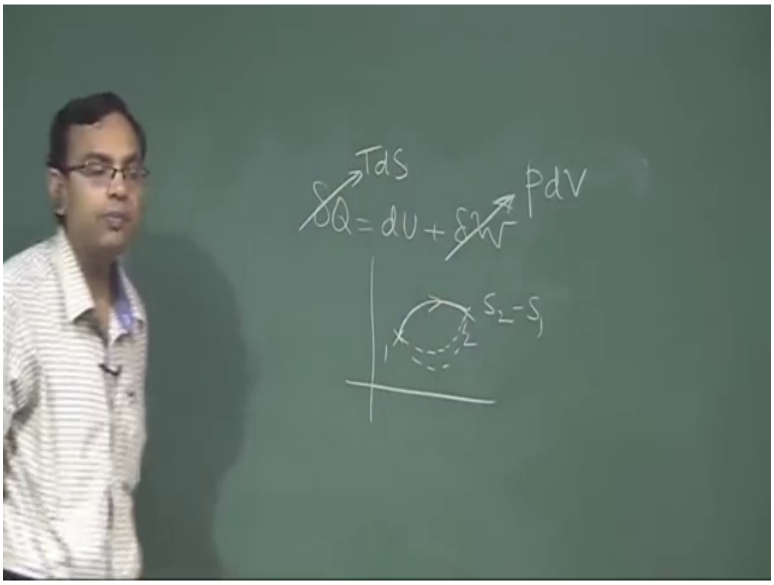

So, if you write del Q equal to d U plus del W for a reversible process for a simple compressible substance you write p d v. Reversible process for simple compressible substance and you write T d s. So; that means, this e you are considering a reversible process of a simple compressible substance, but then how do you claim that it is true for any process.

It is true for any process in the sense that if you use this to calculate the change in entropy, between 2 states 1 and 2 you just construct a reversible hypothetically reversible process and calculate S 2 minus S 1 using this formula by integrating this. Once you have evaluated this that S 2 minus S 1 will remain valid, even if you have any other arbitrary process which is not reversible, because it is a point function.

And all the parameters here in this formula are point functions therefore, it is valid for any process. So, the integration of this formula has to be carried over a reversible path, but once the integration has been carried out that result can be applied for any process, that is the spirit of calling that or mentioning that this is valid for any process provided it is a simple compressible substance.

Next one, T d s is equal to d U plus delta W again here d s will be d capital S T d s is equal to d U plus delta W. So, what are the assumptions see this is 1st law where you have substituted delta Q is equal to T d s; that means, this must be a reversible process. You may argue that if it must be a reversible process why you have not written delta W as p d v, the reason is that it might not be a simple compressible substance; it could be another case where other forms of work are also there. So, you are actually not committing what is delta W, but as you have committed the delta Q equal to T d s; that means you have committed it is a reversible process.

The last one state the assumptions W is equal to minus integral of v d p. So, this is any reversible steady state steady flow process with single inlet and single outlet with negligible changes in kinetic energy and potential energy the derivation of this formula, we have done in one of the lecture. So, you already know, but the assumptions we can summarise, that steady state steady flow process with single inlet and single outlet and negligible changes in kinetic energy and potential energy ok.

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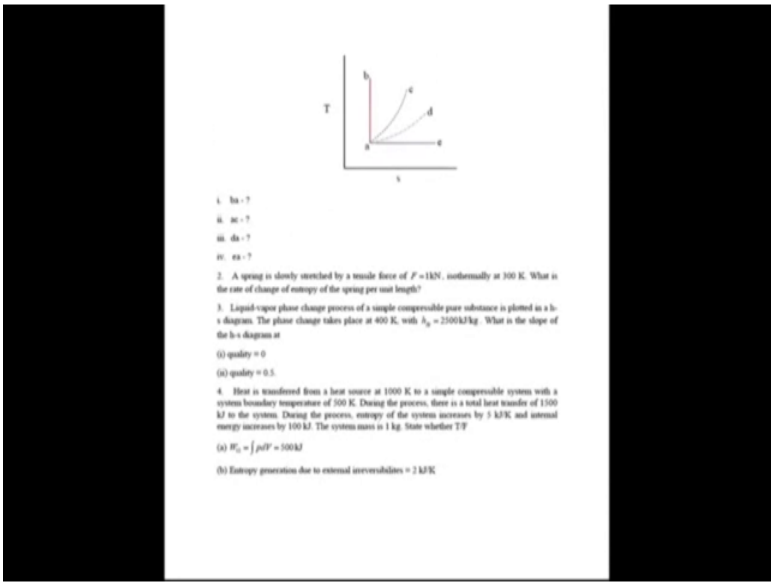

i. ba - ?

ii. ac - ?

iii. da - ?

iv. ea - ?

2. A spring is slowly stretched by a tensile force of $F = 1\text{kN}$, isothermally at 300 K. What is the rate of change of entropy of the spring per unit length?

3. Liquid-vapor phase change process of a simple compressible pure substance is plotted in a h-s diagram. The phase change takes place at 400 K, with $h_{fg} = 2500\text{kJ/kg}$. What is the slope of the h-s diagram at

(i) quality = 0

(ii) quality = 0.5

4. Heat is transferred from a heat source at 1000 K to a simple compressible system with a system boundary temperature of 500 K. During the process, there is a total heat transfer of 1500 kJ to the system. During the process, entropy of the system increases by 5 kJ/K and internal energy increases by 100 kJ. The system mass is 1 kg. State whether T/F

(a) $W_{12} = \int p dV = 500\text{kJ}$

(b) Entropy generation due to external irreversibilities = 2 kJ/K

Next question, there is a T s diagram given here, you can see where there are certain lines which are drawn for an ideal gas and may be ideal gas you as a special case you may consider ideal gas with constant C p C v. So, what do these lines represent? So, v a; v a is what? So, this you can tell very clearly. So, it is an isentropic process no doubt about it, but expansion or compression. So, let us see. Let us use the T d s relationship here. So, T d s is equal to d h minus v d p.

So, reversible adiabatic process means d s is equal to 0. So, d h is equal to v d p d h is for an ideal gas is C p d T. So, for as you go from b to a if you look in to the diagram, here if you go from b to a the temperature is decreasing; that means, d T is negative; that means, d p is negative; that means, it is an expansion. So, it is an isentropic expansion. Next a c and d a so, we are trying to consider whether out of these two, I give a choice one is a constant volume and another is a constant pressure.

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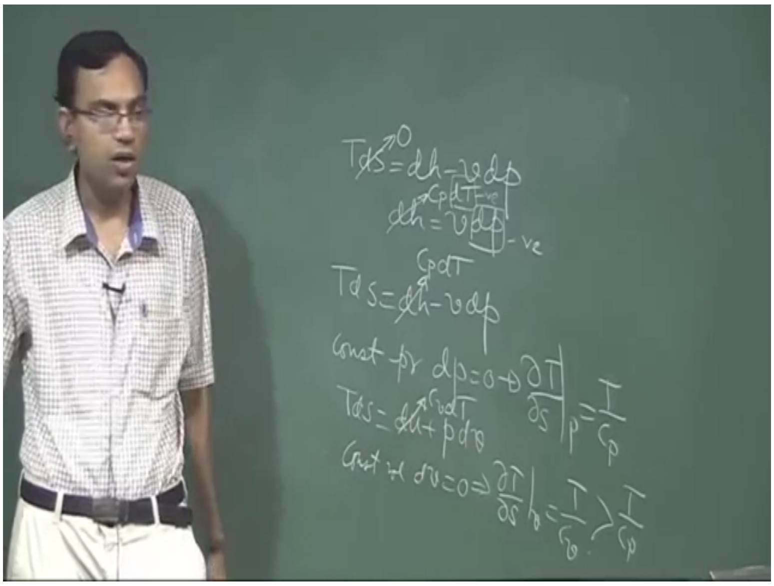

So, out of these two which one is a constant volume line and which one is a constant pressure line. So, you have T d s is equal to d h minus v d p. So, for constant pressure now d h is C p d T. So, constant pressure means d p is equal to 0. So, del T del S at constant pressure is equal to T by C p. Similarly, if you use T d s is equal to d h my sorry d u plus p d v and for an ideal gas d u is C v d T for constant volume d v is 0; that means, del T del s at constant volume is T by C v.

So, out of these two which one is more, because C v is less than C p so, T by C v this is greater than T by C p. So, constant volume line in a T s diagram must be steeper than the constant pressure line. So, if you look the look in to the diagram here a c must be constant volume and a d must be constant pressure. So, out of these two, one is heat addition another is heat rejection. So, if you have entropy increase then that will be necessarily heat addition, but if you have entropy decrease that also must be heat rejection.

So, a c is constant volume heat addition and d a is constant pressure heat rejection, if you have an option between constant volume and constant pressure e a. What is e a? e a the temperature is constant. So, it is an isothermal process from e 2 a if you are going it is heat rejection. So, it is an isothermal heat rejection process ok.

Now, we will work out a couple of short questions and these questions short problems this questions are typically very short problems. So, the question is this is question number 2 given in the screenshot, but I am repeating this question a spring is slowly stressed by a tensile force of 1 kilo Newton isothermally at 300 Kelvin. What is the rate of change of entropy of the spring per unit length?

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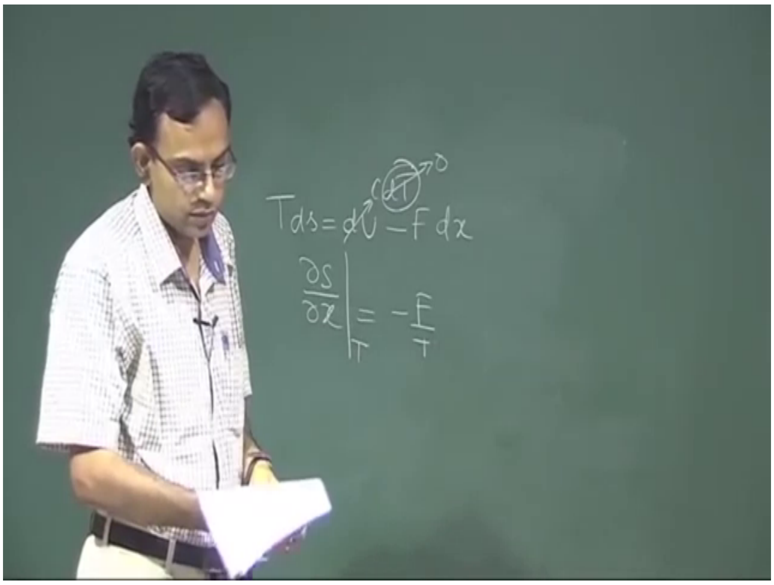

So, this is a case where you have to use T d s is equal to d U instead of p d v, now it is a spring stretching what that is minus F d x. Why this is this is minus; why this is minus? This is minus, because when the p d v work is done work leaves the system and when the spring is stretched. So, or when there is a displacement of the spring with a force this is the work done by the force and when you come to the p d v that is the work done against the resistance. So, it is just a different way of looking into it. So, you can write so, d U is C d T under isothermal condition this is 0.

So, del S del X at constant temperature is minus F by T. So, the spring force is given as 1 kilo Newton and the absolute temperature is 300 Kelvin. So, you can calculate this one. So, the entropy decreases because this is negative. So, on stretching of the spring the entropy decreases why, because if the spring is coiled there are large number of possible microstates for a given macroscopic state, but if the spring is stretched then the number of possible microstates for a given macro state that decreases if it is stretched so, less number of probable microstates for a given macro state.

Next question; question number 3, liquid vapour phase change process of a simple compressible pure substance is plotted in a h s diagram. The phase change takes place at 400 Kelvin with h f g value given. What is the slope of the h s diagram for quality equal to 0 and quality equal to 0.5. So, basically again we are talking about an h s diagram for a phase change process.

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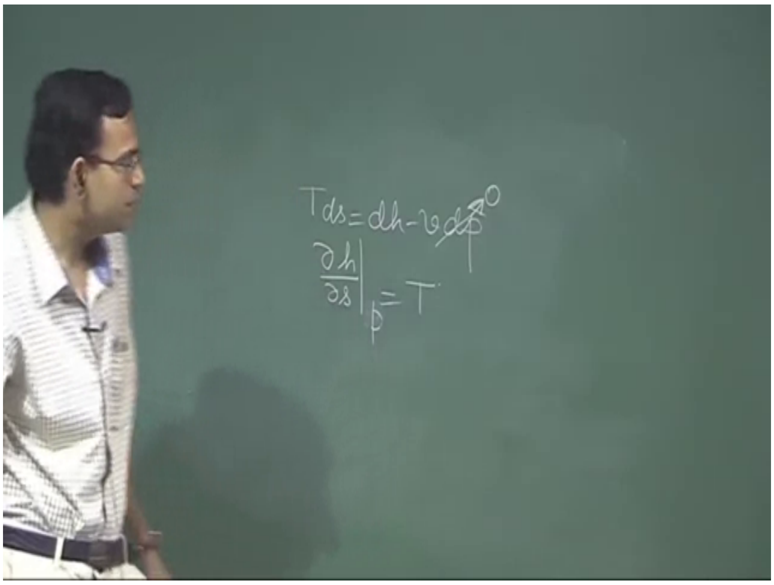

So, we will use that T d s equal to d h minus v d p. For a phase change process of a simple compressible pure substance this is 0. So, phase change of a pure substance takes place at constant pressure. So, del h del s at constant temperature constant temperature or at constant pressure rather, constant pressure here means constant temperature also that is T. So, this does not depend on the dryness fraction or quality, it depends only on the absolute temperature. So, because the absolute temperature is same during the phase change process, the slope remains constant during the phase change process. So, it is a essentially a straight line.

Now, the final question; this is the final question of this particular session, heat is transferred from a heat source at 1000 Kelvin to a simple compressible system with a system boundary temperature of 500 Kelvin. During this process there is a total heat transfer of 1500 kilo Joule to the system entropy of the system increases by 5 kilo Joule per Kelvin, an internal energy increases by 100 kilo Joule. The system mass is 1 kg state whether the following is true or false the work done equal to integral p d v equal to 500 kilo Joule and entropy generation due to external irreversibility is 2 kilo Joule per Kelvin. So, let us see whatever whether these statements are correct or not.

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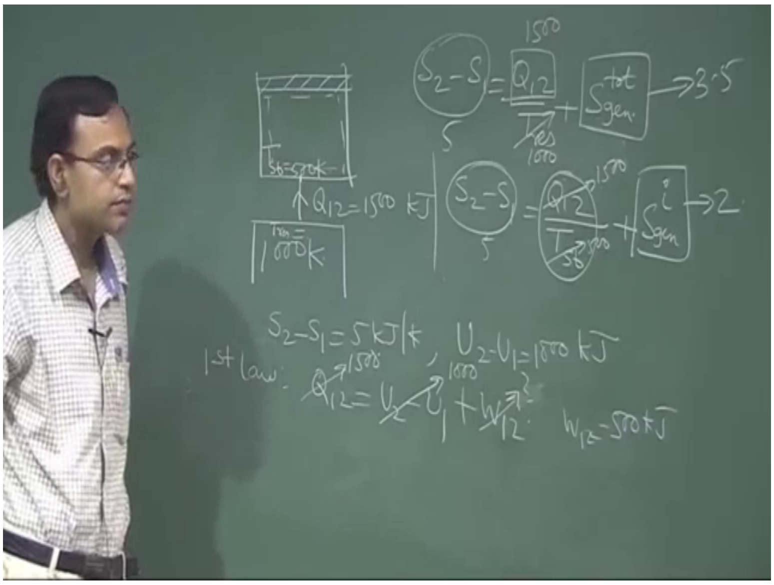

So, let me try to draw a schematic of this. Heat is transferred from a heat source at 1000 Kelvin to a system with a system boundary temperature of 500 Kelvin. So, this is T system boundary this is T reservoir. There is a total heat transfer of 1500 kilo Joule. During the process entropy of the system increases by 5 kilo Joule per Kelvin and internal energy of the system increases by 100 kilo Joule sorry 1000 kilo Joule. So, 1st law if you apply Q 1 2 is equal to U 2 minus U 1 for the system, this is the system let us say plus W 1 2 it may be a piston system arrangement.

So, the heat transfer is 1500 and work is 1000 sorry change in internal energy is 1000. So, what is the work that is 1500 minus 1000. So, that is 500 kilo Joule. Now, let us do a 2nd law analysis and check the entropy generation. So, we can write S 2 minus S 1 is equal to Q 1 2 by T plus entropy generation, S 2 minus S 1 is given as 5. Question is what T U will substitute here. It depends on as I told are you interested to calculate only the internal irreversibility, the related entropy generation or total entropy generation. If you are interested to calculate the total entropy generation, then this should be the temperature of the reservoir.

And if you are interested to calculate only the entropy generation due to internal irreversibility, then this is the temperature of the system boundary, S gen due to internal irreversibility. So, this is Q 1 2 is what Q 1 2 is 1500 and the reservoir temperature is 1000 right. So, this is 1500 by 1000, so, 1.5 5 minus 1.5 that is 3.5 I am not writing the units, for this is 5 this is 1500 and temperature of the system bounded is 500. So, this is 3, 5 minus 3 this is 2.

So, what is the heat transfer? What is the entropy generation due to external irreversibilities? This is the total entropy generation; this is the entropy generation due to internal irreversibilities. So, the remaining entropy generation is due to external irreversibilities; so, 3.5 minus 2 that is 1.5 kilo Joule per Kelvin. So, the part b of the answer is given entropy generation due to external irreversibility is 2 kilo Joule per Kelvin that is wrong, it should be 1.5 kilo Joule per Kelvin.

And the first question W1 2 is equal to integral p d v equal to 500. See this is a very typical critical question W1 2 is equal to 500 kilo Joule this is correct, but it is not equal to integral p d v because it is not a quasi-equilibrium process. How do you know that it is not a quasi-equilibrium process? See there is entropy generation due to internal irreversibilities.

What is a quasi-equilibrium process? It is such a slow process that the process must be internally reversible. If it is internally reversible the entropy generation due to internal irreversibility must be 0. So, had this been 0; that means, you could have use the formula p d v for the work, but because it is not 0 you cannot use the p d v formula for the work. So, all though the work is equal to 500 kilo Joule, but it is not equal to integral p d v. So, the first answer is also not correct.

So we have come to the end of this course we have to summarize we have discussed various laws of thermodynamics, to begin with we have discussed the sum of the basic considerations like system control volume, the concept of macroscopic and microscopic approach, then properties, processes, states, then pure substance, phase, concept of thermodynamic equilibrium, simple compressible substance, quasi equilibrium process all these concepts we have developed. Using this concepts we try to understand how to specify properties of pure substances how to fix a properties of how to fix up states of pure substances using the property data or equations of state.

And then using that building block we have learnt various laws of thermodynamics. So, the preliminary law that we have understood through the concept of thermal equilibrium is the 0th law of thermodynamics, then we have studied the 1st law of thermodynamics, then we have studied the 2nd law of thermodynamics and eventually the 3rd law of thermodynamics.

And we have worked out various problems to illustrate these laws of thermodynamics and these are very critical, because no matter whatever is the branch of science and engineering you are talking about or even it is biological sciences or chemical sciences or physical sciences or mechanical sciences whatever or metallurgical and materials sciences.

The basic building blocks of thermodynamics remain to be the basic laws of thermodynamics. So, that was the agenda of this course, I believe it was enjoyable for all of you to go through this course, it was a pleasure on my personal behalf to deliver lectures in this course and I wish all of you a great time ahead.

Thank you very much.