Thermodynamics for Biological Systems: Classical and Statistical Aspects

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Lecture - 3
Need for Analysis

Let us begin today by looking at the need for analysis of a biological system. As we all know, engineers are typically introduced to the information or the knowledge; they understand the knowledge toward analysis and design of the relevant system. Taking that view for biological engineering, we can look at getting the information first, understanding that, and using that to analyse and design systems of biological importance. To understand this a little better, let us first consider bio-process industry; you know in the bio process industry, products of biological relevance or using biological systems are made for the use of mankind.

In a biological process, it is easy to imagine or let us imagine that a liquid needs to be moved from one place, A, to another place, B; typically this movement occurs through pipes of different sizes. And deciding on what pump to use to move the fluid from say point A to point B is a very important design aspect in a bioprocess. As you will learn later, or … you may have already done fluid flow courses; if you have done fluid flow courses, you would already know this. One of the important aspects in deciding what pump size to use is to know the type of flow that happens in the pipe. There are two major types of flows; one is the laminar flow, in which it is an ordered flow in layers, and the other is a turbulent flow, where pockets of fluid tumble over each other and flow through a pipe.

The power requirement depends on what kind of flow we have in the pipe, to move the fluid from one place to another. Let us say that we do not have any information about whether the flow is laminar or turbulent; and let us say that we do not really know how to decide whether the flow is laminar and turbulent. The way to go about, or the approach would be to visualize a flow in some fashion with itself it is quite difficult; you need transparent pipes and so on and so forth, which may not be suitable for all fluids that are applicable. We need to look at, what all aspects would change the type of flow involved. Do experiments one after another to figure out, what kind of flow exists in a particular piping system. We don't even know what decides the kind of flow that happens in a piping system.

Luckily for us, a lot of work has been done earlier starting from the 1900s; in 1883 Reynolds did the flow visualization experiment, where he, as a result of which, we know that there are four parameters that decide whether the flow is going to be laminar or turbulent. The four parameters are the density of the fluid, the velocity of the fluid, the diameter of the pipe through which the fluid is flowing, and the viscosity of the fluid. These four parameters decide on the nature of flow. Suppose we did not know this at all, we did not have to do experiments one after another may be thousands of experiments to arrive at the same information.

Somebody has done this, somebody has used the intuition to come up with, what you may already know as a Reynolds number, which is nothing but the (density x velocity x diameter)/ (viscosity), or (rho v D)/mu.

$$N_{Re} = \frac{\rho\, v\, D}{\mu}$$

In a pipe flow situation, you may know that if the Reynolds number is less than about 2000 or 2100, the flow is going to be laminar, otherwise the flow is ... or above 4000 let us say, in a pipe, the flow is going to be turbulent. What information we could get out of thousands and thousands of experiments, is all compressed into this one single beautiful relationship; it is called the Reynolds number. And that is the advantage in analysing something, and coming up with a useful parameter.

We are in the process of understanding biological systems better, and we are nowhere near that level of completeness in the case of a biological system.

Let me present something else to you to understand the need for analysis, so that the design can be much better. And, also analysis has its own benefits in terms of better and better understanding of the system. To do that, I am going to read out parts of a paper, this paper is titled, `Can a biologist fix a radio or what I learnt studying apoptosis'. This paper is authored by a person called Yuri Lazebnik. He is from the Cold Spring Harbour lab, which is a very prestigious lab. This was published in Cancer Cell in 2002. I am going to read out parts of a paper.

Yuri Lazebnik considers the transistor radio, something that existed a long time ago, but I guess, he relates to that a lot better. He considers a transistor radio to be equivalent to the cell. The particular aspect that he is going to consider is an old broken transistor radio. And the objective here is to fix the radio or to repair the radio, so that it functions properly. Therefore, we can consider this radio to be equivalent to a human being or a cell to begin with; something is wrong, and we need to fix it, so that it functions properly.

Reading from this paper, some parts of it: conceptually, a radio functions similarly to a signal transaction path way in a cell, in that both convert a signal from one form to into another. A radio converts electromagnetic waves into sound waves. The radio has about a 100 various components such as resistors, capacitors and transistors, which is comparable to the number of molecules in a reasonably complex signal transduction pathway in a cell. If we take a biological way of looking at things right now, the way a biologist would look at it; he gives the … some of the ways, in which a biologist would approach this problem.

Biologist as – I am talking of a classical experimental biologist. I am sure a lot of people work in interdisciplinary areas now, but a classical biologist will approach it a certain way.

And eventually all the components will be catalogued; connections between them will be described, and the consequences of removing each component or their combinations will be documented. Can the information that we accumulated help us to repair the radio? The information itself is wonderful; it helps, it gives a lot more inside into what is happening, but is it good enough to repair the radio, is the question. The answer is, most likely no; unless there is a certain piece of luck that helps you in setting right the radio or the cell.

Coming back to this paper, yet we know with near certainty that an engineer could fix the radio; what makes the difference? I think it is the languages that these two groups use. It is common knowledge that the human brain can keep track of only so many variables. It is also common experience that once the number of components in a system reaches a certain threshold understanding the system without formal analytical tools requires geniuses, who are so rare even outside biology. In engineering, this scarcity of geniuses is compensated, at least in part, by a formal language that successfully unites the efforts of many individuals, thus achieving the desired effect.

Very nicely put here; let me read it again. In engineering, the scarcity of geniuses is compensated, at least in part by a formal language that successfully unites the efforts of many individuals, thus achieving a desired effect. The language that is relevant is mathematics; and the tools that are relevant for understanding the systems, as we are going to look at are thermodynamics, may be transport aspects, fluxes and forces and so on, and other relevant things. In this course, we will, of course, look at one aspect of thermodynamics, which can be used to analyse biological systems.

When we finished up in the last class, we had reviewed some of the principles that we already knew some of the concepts that we already knew in thermodynamics, from your earlier classes may be in your school or in the first year of engineering.

And we are going to take things further here. And one of the important things that we considered was classical thermodynamics versus statistical thermodynamics. We said that classical thermodynamics is very good to apply in the continuum regime, where individual molecules are not really important; whereas statistical thermodynamics is a lot more complete, and it gains better relevance, when it is applied to non continuum systems.

See you in the next class.