3.7 Processes

3.7.1 The northern mill engine Society crossfield mill beam engine

Beam engines were the earliest form of stationary steam engine and this is certainly the oldest engine in the Northern Mill Engine Society's collection, believed to date from about 1840.

The engine was rebuilt in about 1893 with a new high-pressure cylinder and worked until 1953, lying derelict until 1967 when the Society acquired it from the Crossfield Mill at Wardle near Rochdale. The cylinders are 12" and 20" diameter and the stroke is 3ft 6ins. The maker is unknown.

http://www.youtube.com/watch?v=kfrZjFNCn0w

3.7.2 Outline

The concept of a state diagram and properties has previously been introduced. In this unit we will now consider moving from one point to another on a state diagram, a so-called process.

We will introduce a process and define a process path.

We will define the criteria to describe a process completely and introduce a very important definition, that of a quasi-equilibrium process.

We will question whether thermodynamic properties do depend upon the actual process path.

We will introduce the terms isobaric, isochoric, isothermal and adiabatic and finally define a cyclic process.

3.7.3 Double acting stationary engine

Let’s start by looking at the relatively familiar sight of a steam engine piston and valve mechanism. You might not be familiar with the details, but will recognise the key features.

In the animation to the right we can see a common single cylinder mill engine from the mid-19th century. Look closely and you can see the drive cylinder, the moving piston and the sliding valve, where steam is alternatively introduced and exhausted from the drive cylinder.

On the left is an indication of how the pressure varies within the drive cylinder, suggesting regions of high pressure and flow pressure. Traditionally, this sort of diagram is referred to as a pressure indicator diagram. The diagram already provides some sort of indication that there is a change in pressure within the cylinder according to the position of the piston.

Let's look at this in greater detail.

3.7.4 Pressure indicator diagram

The pressure indicator diagram illustrates the variation of pressure within the drive cylinder over a single cycle and suggests that this cycle will be repeated over and over again. Later you will see how we can refer to this as a cyclic process.

Notice how the diagram illustrates pressure on the vertical axis against position of piston on the horizontal axis. So for a given diameter cylinder, this is effectively a pressure-volume diagram, just like the pressure-volume state diagrams we have already seen.

Here is a real-world application of some of the concepts introduced earlier.

3.7.5 Steam locomotive

The importance of the steam locomotive in enabling the development of our modern technological society cannot be underestimated. Today they often invoke emotions and memories of a bygone age.

There are vast number of resources to explore should you be interested.

This detailed graphical illustration shows a 4-6-2 Pacific class locomotive built by the American Locomotive Company, New York in 1911. The engine was built for passenger service. It was fired by a mechanical stoker, the tender held 12,000 gallons of water and 17.5 tons of coal. With a working pressure of 200 psi it could pull up to 18 passenger cars and could reach 80 mph.

Look carefully at the illustration and you should be able to identify the basic processes for steam generation. Take a moment to read the labels.

Label 8 shows the firebox in which the coal is burnt, the resulting hot combustion products pass through the flue gas tubes, label 19, and exhaust through the chimney stack.

Meanwhile liquid water flows from the tender into the boiler, saturated steam is produced, which rises in the boiler and collects in the steam dome, label 13.

In this relatively modern engine, the saturated steam is then taken from the steam dome and passed back through superheater tubes, label 20, before being routed to the drive cylinders, label 25.

The spent steam finally exhausts through the chimney stack.

3.7.6 WP 4-6-2 locomotive

The WP 4-6-2 is considered by some to be one of the most graceful steam locomotives designed and operated anywhere in the world. The bullet shaped giants evoke nostalgic memories of a bygone era and are adored by railway enthusiasts worldwide.

WP were designed by Indian Railways design office and Baldwin locomotive Company in the USA. From 1947 until 1967 over 755 locomotives were built, remaining in service until 1994.

This is a fantastic Flash-based animation, to find out more, why not visit the archived website yourself.

http://www.oocities.org/wp_loco/wp_sheeju.swf

3.7.7 Processes and cycles

We have seen in the pressure indicator diagram that pressure within the drive cylinder of an engine varies with the stroke.

In thermodynamic terms, we might say that the pressure is changing from one state to another state by following a process path. This is schematically illustrated here, where property A and property B can be any two independent properties, such as pressure and volume. Remember that pressure and temperature are not independent when phase change occurs and so cannot be used in such circumstances.

Formally, any change that system undergoes a change from one equilibrium state to another is called a process. The series of states, through which a system passes during the process, is called the path of the process.

To completely describe a process we must specify the initial and final states of the process, the path it follows, and any interactions with the surroundings, such as work output or heat transfer.

Hopefully you can see now how the pressure indicator diagram represents a process path, even if rather complex, in terms of the thermodynamic properties, pressure and volume.

3.7.8 Independent paths

As you might imagine, every steam engine will most likely have a different pressure indicator diagram, therefore, in thermodynamic terms, we must consider each different pressure indicator diagram to represent a different process.

Formally we would state that every path is a different process, shown here by the three arbitrary paths A, B and C.

Notice how the thermodynamic properties, at the initial state 1 and the endpoint, state 2, are totally independent of the path taken during the process.

We will explore this later, but for now remember that thermodynamic properties are used to define points, or states, on a state diagram. They are completely independent of the path taken during the process. You will see later how other derived quantities, such as work and heat transfer, do depend upon the actual path taken.

3.7.9 Quasi equilibrium

When a system is in thermodynamic equilibrium there is no change in the value of any thermodynamic property, that is no temperature, pressure or mixture concentration gradients remain and there is no remaining interaction across the system boundaries.

Of course, in such a state, the piston illustrated in the diagram on the right would not move and all forces would be in mechanical equilibrium.

Now imagine a process which we will allow to change in such a manner that the system remains infinitesimally close to an equilibrium state at all times. We will call such a process a quasi-static or quasi equilibrium process.

During a quasi-equilibrium process a system will pass through an infinite number of equilibrium states and thermodynamic properties can be defined for each one of these states. You may imagine that for this to occur the piston must move extremely slowly, such that we are infinitely close to an equilibrium condition at all times. In a later unit we will revisit this topic and introduce the additional concept of a reversible process.

We can represent the variation of thermodynamic properties for each one of these equilibrium states on a state diagram. We will refer to such a change in equilibrium properties as a process path.

In a real engine the mixing inside a cylinder may not be perfect, there may be variations in temperature or even composition within the cylinder. We will explore the impact of these nonuniformities in a later module when considering reversible and irreversible processes. For now, to allow us to proceed further, let us assume that we will always have a quasi-equilibrium process.

3.7.10 Process diagram

As we have seen, process diagrams, plotted by employing thermodynamic properties as coordinates, are very useful in visualising a process. Now remember that for a simple compressible system only two independent thermodynamic properties are required to represent the state of the system.

Common properties include temperature, pressure, volume, or specific volume, or new properties that we have not yet seen such as enthalpy or entropy.

Typically we will refer to a state diagram, making reference to the thermodynamic properties at the initial state and the thermodynamic properties of the final state.

Remember thermodynamic properties are always independent of the process that is, the state of a system does not depend on the path taken. This is important because later we will see that other functions such as work and heat transfer do depend on the path that is actually taken during the process.

3.7.11 Process type

We have already met a number of easily defined processes and these are listed here again.

An adiabatic process when no heat passes through boundaries of the system.

An isothermal process when the temperature remains constant during the process.

An isobaric process when the pressure remains constant during the process and an isochoric process when the volume remains constant during the process.

As indicated to the right, for an ideal gas, the ideal gas equation of state always applies and may be used to relate pressure, temperature and volume at one state to pressure, temperature and volume at any other state.

3.7.12 Process type

In general, there may be any number of different processes of any arbitrary type.

Here, for example, is a sequence of four different processes,

an isochoric, or constant volume, process from 1-2,

an isobaric, or constant pressure, increase in volume 2-3,

an isothermal, or constant temperature, increase in volume, 3-4

and finally an isobaric, or constant pressure, reduction in volume, 4-1.

This is just an example illustrating how we may have any sequence of processes from one to another.

3.7.13 Cyclically process

As in the previous example a system is said to have undergone a cycle if it returns to its initial state at the end of the process. That is, for a cycle, the initial and final states are identical.

Returning now to the pressure indicator diagram and you can see that this does indeed represent a cyclic process. This is very much in line with everyday experience of a reciprocating piston engine in not only steam engines, but also in the petrol and diesel engines in our cars.

3.7.14 Carnot cycle

To conclude this unit, this animation illustrates the cyclic nature of a Carnot cycle, an idealised cyclic process that we will introduce later. The Carnot cycle is represented by four sequential processes, adiabatic compression, isothermal expansion, adiabatic expansion, and finally isothermal compression.

Later you will see, how, using your knowledge of the ideal gas equation of state, you will be able to follow such a cyclic process and determine pressure, temperature and volume at each along each path. Assuming, of course, quasi equilibrium processes.