ASME231 Atmospheric Thermodynamics NC A&T State U
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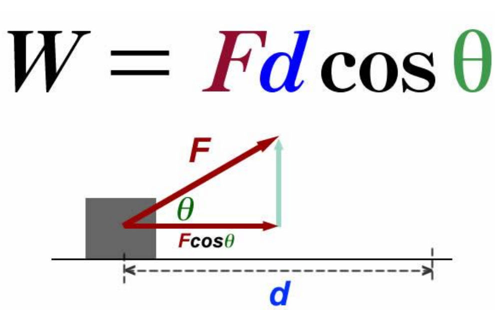
Lecture 5

(Chap. 3: First Law of Thermodynamics)

3.1 Work

Definition of work: The amount of work W done by a force F, which displaces a mass over a distance d in the direction of the force is $Fd \cos \theta$. The symbol θ denotes the angle between the direction of actual displacement and the force.

Figure 6.1:



Thus the amount of work dW done by a constant force F, which displaces a mass over a small distance ds is

$$dW = Fds = F\, ds \cos \theta. \tag{3.1}$$

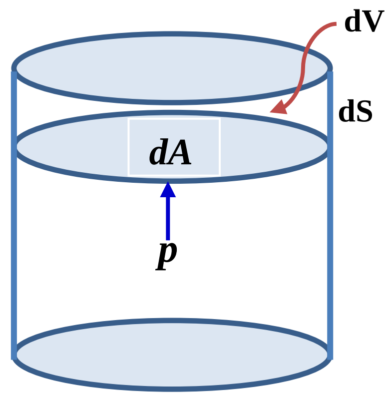
Integrating (3.1) from initial to final state gives $W = Fd \cos \theta$. For the work done in a gas, we normally use the concept of work of expansion, which is defined as the work done by a force in gas expansion, as shown in the sketch below. The work of expansion is often represented by pressure since it is much easier to measure for fluid. Since pressure is defined as the force per unit area ($p = F/dA$), the force of expansion may be written as $F = p\,\mathrm{d}A$.

Thus, the work of expansion can be expressed as

$$dW = Fds = p\,dA\,ds = pdV, \qquad (3.2)$$

where dV is the volume element given by the cylinder swept by dA in the direction of F.

Figure 6.2:



Divide Eq. (3.2) by the mass of the fluid system m, we obtain

$$dw = \frac{dW}{m} = \frac{pdV}{m} = p\,\frac{dV}{m} = pd\alpha, \text{ i.e. } \quad dw = pd\alpha, \qquad (3.3)$$

where $d\alpha$ is the specific volume and $dw=dW/m$ is called the specific work and the sign of dw is defined as follows:

$dw > 0$ if the system expands and does work on its environment;

$dw < 0$ if the system is compressed by an external pressure force.

For a finite expansion,

$$w = \int_i^f p d\alpha \tag{3.4}$$

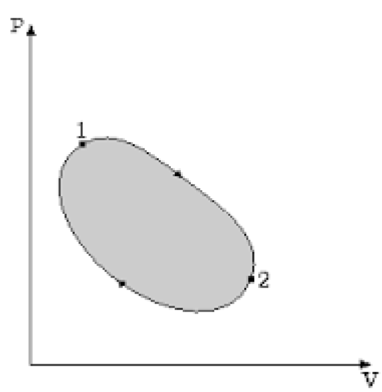
where subscripts i and f stand for the initial and final states, respectively.

For a cyclic process as shown in the figure (in α-p space),

$$w = \oint p d\alpha = \int_1^2 p d\alpha + \int_2^1 p d\alpha$$

Mathematically, w is the area enclosed by the curve and $w > 0$ if the curve is clockwise.

Figure 6.3:



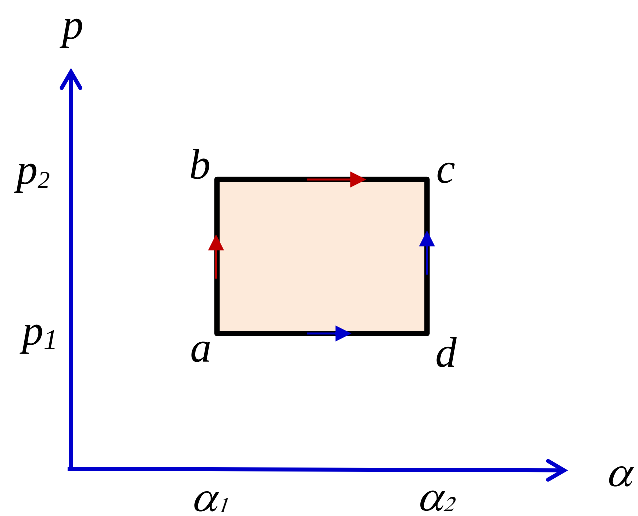
The work of expansion is the only work we shall consider in our atmospheric system.

In an isobaric process, p is a constant. Thus, the total work done can be computed from Eq. (3.4): $\Delta w = p(\alpha_f - \alpha_i)$.

In an isothermal process, p is only a function of α. Thus, the total work done can also be computed from Eq. (3.4).

In an isosteric process, there is no change in volume (no expansion or $d\alpha = 0$). Thus, the work done is zero.

Example: Consider the following processes (Fig. 6.4)



Path A ($a \to b \to c$): The system goes through an isobaric expansion from a to b (e.g., heating the cylinder with constant), and then goes through an isosteric pressure increase from b to c (e.g., heating the cylinder with the piston fix at the same location).

The work done is

$$W_A = p_2(\alpha_2 - \alpha_1)$$

Path B ($a \to d \to c$): The system goes through an isosteric pressure increase from a to d (e.g. heating the cylinder while fix the piston) followed by an isobaric expansion from *d to c (e.g. heating the cylinder with constant pressure)*.

The work done is

$$W_B = p_1(\alpha_2 - \alpha_1)$$

Thus, the work done depends on the process (i.e., path on a *α-p* diagram).

Path C: For a cyclic process ($a \to b \to c \to d \to a$), the work done can be calculated

$$W_A = p_2(\alpha_2 - \alpha_1) - p_1(\alpha_2 - \alpha_1) = (p_2 - p_1)(\alpha_2 - \alpha_1)$$

Thus, work done may not be zero for a cyclic process.

In summary,

(1) *w* depends on the path of the process ($w_1 \neq w_2$).

(2) *w* may be non-zero even for cyclic processes.