# Thermodynamics
# ME 1229
# Credit: 3.0

## First Law of Thermodynamics


Presented By

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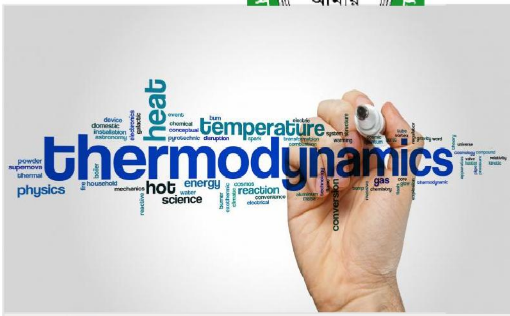
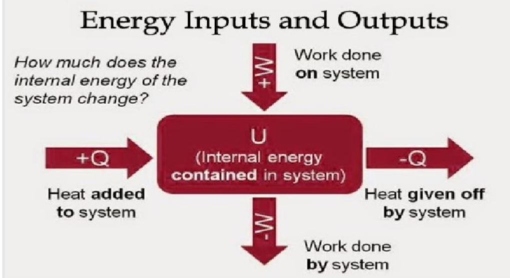
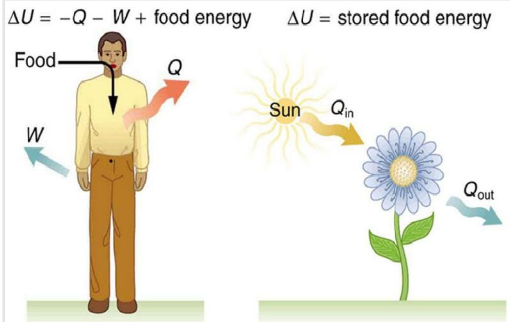


# First Law of Thermodynamics

- This law may be stated as follows:

(a) "*The heat and mechanical work are mutually convertible*". *(for* System Undergoing a Cycle*)*

(b) "*The energy can neither be created nor destroyed though it can be transformed from one form to another*". (for System Undergoing a Change of State)

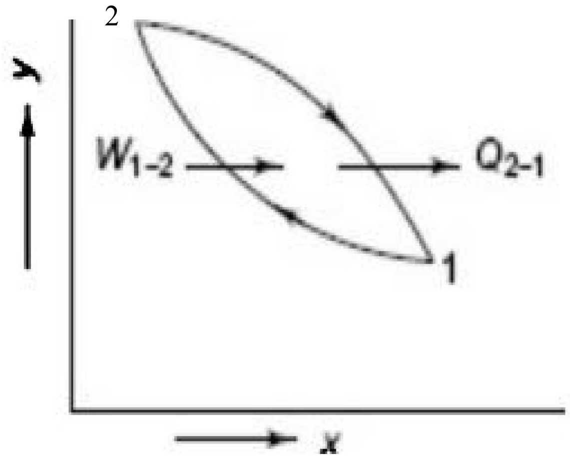
# First Law For A Closed System Undergoing A Cycle

- Energy which enters a system as heat may leave the system as work, or energy which enters the system as work may leave as heat.
- According to first law, when a closed system undergoes a thermodynamic cycle, the net heat transfer is equal to the net work transfer.

$$\oint \delta Q = \oint \delta W$$

- If the cycle involves many more heat and work quantities, the same result will be found. Expressed algebraically.

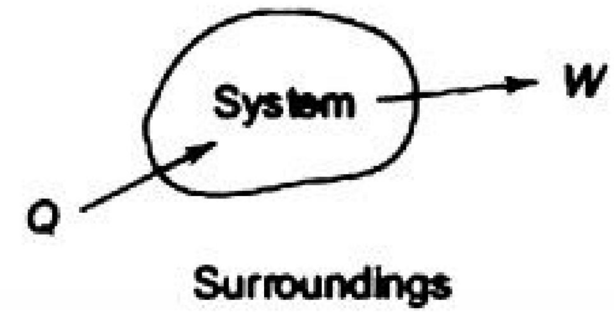
$$\left(\sum W\right)_{cycle} = \left(\sum Q\right)_{cycle}$$



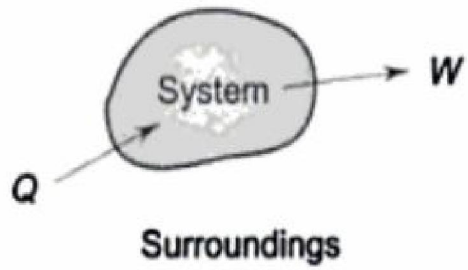
# First Law For A Closed System Undergoing A Change Of State

- The expression $(\sum W)_{cycle} = (\sum Q)_{cycle}$ applies only to systems undergoing cycles, and the algebraic summation of all energy transfer across system boundaries is zero.
- But if a system undergoes a change of state during which both heat transfer and work transfer are involved, the net energy transfer will be stored or accumulated within the system.
- If Q is the amount of heat transferred to the system and W is the amount of work transferred from the system during the process, the net energy transfer (Q - W) will be stored in the system. Energy in storage is neither heat nor work, and is ***given the name internal energy or simply, the energy of the system.***

Therefore, $Q - W = \Delta E$

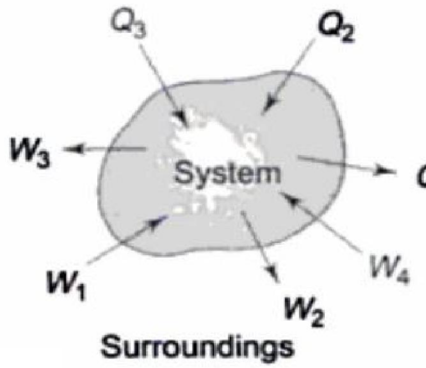


# First Law of Thermodynamics for Closed System




*Heat and work interactions of a system with its surroundings in a process*

$$Q - W = \Delta E$$




*System-surroundings interaction in a process involving many energy fluxes*

$$Q_2 + Q_3 - Q_1 - W_2$$
$$-W_3 + W_1 + W_4 = \Delta E$$

# Stored Energy and Internal Energy

- **Stored Energy:** The sum of potential energy, kinetic energy and several other forms of energy such as due to magnetic, electrical, solid distortion and surface tension effects can be estimated as the stored energy.
- Difference of heat and work interactions yield the stored energy as given below; $E = Q - W$.
- **Internal Energy:** If the energy at macroscopic level could be separated from the total stored energy E, then the amount of energy left shall be called internal energy. Mathematically,

*Internal energy, U = (Stored energy) – (Kinetic energy) – (Potential energy) – (Magnetic energy) – (Electrical energy) – (Surface tension energy) – (Solid distortion energy).*

$$E = U + KE + PE \text{ (when Other energies are negligible)}$$

$$e = u + \frac{c^2}{2} + gz \quad (\text{unit mass basis})$$

# Energy - A Property Of The System

- Consider a system which changes its state from state 1 to state 2 by following the path A, and returns from state 2 to state 1 by following the path B(Fig). So the system undergoes a cycle.

Writing the first law for path A.

$$Q_A = \Delta E_A + W_A$$

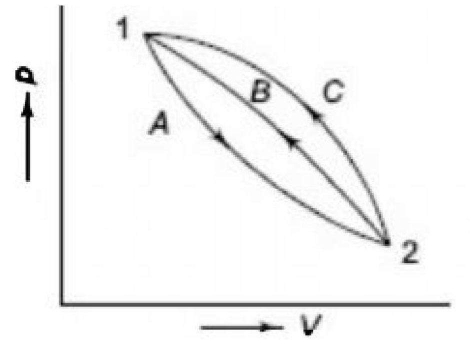
and for path B

$$Q_B = \Delta E_B + W_B$$

The processes A and B together constitute a cycle, for which

$$\left(\sum W\right)_{cycle} = \left(\sum Q\right)_{cycle}$$

$$W_A + W_B = Q_A + Q_B$$
$$Q_A - W_A = W_B - Q_B$$




*Energy—A property of a system*

# Energy - A Property Of The System
(Cont..)

From above equations

$$\Delta E_A = -\Delta E_B$$

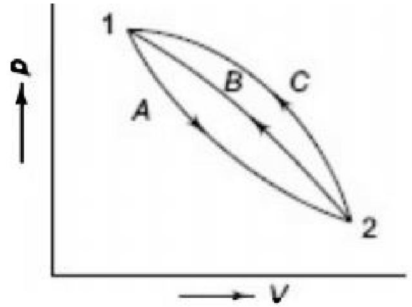
Similarly, had the system returned from state 2 to state 1 by following the path C instead of path B

$$\Delta E_A = -\Delta E_C$$

From above two equations

$$\Delta E_B = \Delta E_C$$

Therefore, it is seen that the change in energy between two states of a system is the same, whatever path the system may follow in undergoing that change of state. Therefore, energy has a definite value for every state of the system. Hence, it is a point function and a property of the system.




*Energy—A property of a system*

# Enthalpy

- **Enthalpy (H)** of a substance at any point is quantification of energy content in it, which could be given by summation of internal energy and flow energy. Enthalpy is very useful thermodynamic property for the analysis of engineering systems. Mathematically, it is given as,

$$H = U + PV$$

- On unit mass basis, the specific enthalpy could be given as,

$$h = u + pv$$

# Specific Heats And Their Relation With Internal Energy And Enthalpy

- **Specific heats** of the substance refer to the amount of heat interaction required for causing unit change in temperature of the unit mass of substance.
- This unit change in temperature may be realized under constant volume and constant pressure conditions separately.
- Therefore, the above heat value obtained with heat interaction occurring under constant volume conditions is called specific heat at constant volume, denoted as $c_v$.
- Whereas the above heat value obtained with heat interaction occurring under constant pressure conditions is called specific heat at constant pressure, denoted as $c_p$.

# Specific Heats And Their Relation With Internal Energy And Enthalpy

For isochoric conditions

$$Q_v = m \cdot c_v \cdot \Delta T$$

and for isobaric conditions

$$Q_p = m \cdot c_p \cdot \Delta T$$

Again difference of specific heats at constant pressure and volume is equal to the gas constant for an ideal gas.

$$c_p - c_v = R$$

Also the ratio of specific heats at constant pressure and volume could be given as γ,

$$\frac{c_p}{c_v} = \gamma$$

Combining above two relations of $c_p$ and $c_v$ we get,

$$c_p = \frac{\gamma . R}{(\gamma - 1)}, c_v = \frac{R}{(\gamma - 1)}$$

# Problems

**Prob-1:** Given, m=4kg, Q=300 kJ at constant volume, ΔT=80 K

a. $C_v = ?$
b. If $\gamma$=1.55 find $C_p$ & R

**Sol:**

$$Q = mC_v(T_2 - T_1)$$

$$300 = 4 * C_v * 80$$

$$C_v = 0.9375 \frac{kJ}{kg.K}$$

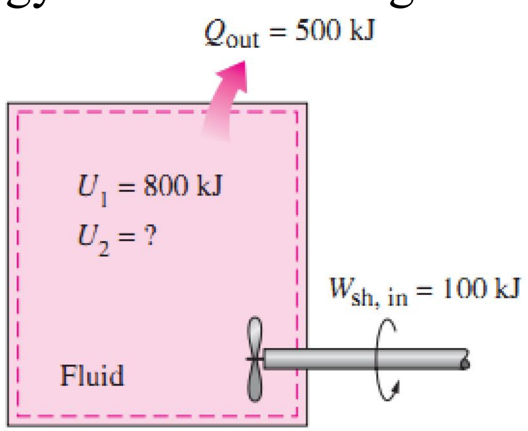
$$C_p - C_v = R$$

$$C_p = \gamma C_v = 1.55 * 0.9375 = 1.4531$$

$$C_p - C_v = R = 1.4531 - 0.9375 = 0.5156 \frac{kJ}{kg.K}$$

# Problems

❑**Prob-2:** A rigid tank contains a hot fluid that is cooled while being stirred by a paddle wheel. Initially, the internal energy of the fluid is 800 kJ. During the cooling process, the fluid loses 500 kJ of heat, and the paddle wheel does 100 kJ of work on the fluid. Determine the final internal energy of the fluid. Neglect the energy stored in the paddle wheel.




❑**Prob-3:** A stationary mass of gas is compressed without friction from an initial state of 0.3 $m^3$ and 0.105 MPa to a final state of 0.15 $m^3$ and 0.105 MPa, the pressure remaining constant during the process. There is a transfer of 37.6 kJ of heat from the gas during the process. How much does the internal energy of the gas change?

## Problems

**Prob-4:** A gas undergoes a thermodynamic cycle consisting of three processes beginning at an initial state where $p_1$ = 1 bar, $V_1$ = 1.5 $m^3$ and $U_1$ = 512 kJ. The processes are as follows:

(a) Process 1-2: Compression with pV = constant to $P_2$ = 2 bar, $U_2$ = 690 kJ

(b) Process 2-3: $W_{23}$ = 0, $Q_{23}$ = -150 kJ, and

(c) Process 3-1: $W_{31}$ = + 50 kJ. Neglecting KE and PE changes, determine the heat interactions $Q_{12}$ and $Q_{31}$.

(Ans. 74 kJ, 22 kJ)

# Problems

**Prob-5:** A gas undergoes a thermodynamic cycle consisting of the following processes:

(i) Process 1-2: Constant pressure p = 1.4 bar, $V_1 = 0.028$ $m^3$, $W_{12} = 10.5$ kJ,

(ii) Process 2-3: Compression with pV = constant, $U_3 = U_2$,

(iii) Process 3-1: Constant volume, $U_1 - U_3 = -26.4$ kJ.

There are no significant changes in KE and PE.

(a) Sketch the cycle on a p-V diagram,

(b) Calculate the net work for the cycle in kJ.

(c) Calculate the heat transfer for process 1-2

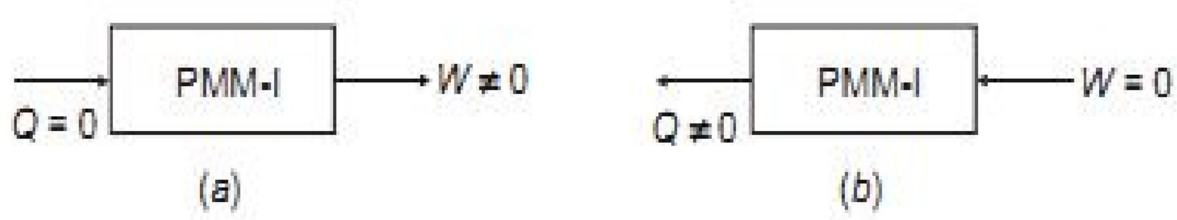
(d) Show that $\sum_{cycle} Q = \sum_{cycle} W$

# Perpetual Motion Machines

- Any device that violates either law is called a perpetual-motion machine, and despite numerous attempts, no perpetual-motion machine is known to have worked. But this has not stopped inventors from trying to create new ones.
- A device that violates the first law of thermodynamics (by creating energy) is called a perpetual-motion machine of the first kind (PMM1), and
- a device that violates the second law of thermodynamics is called a perpetual-motion machine of the second kind (PMM2).

# Perpetual Motion Machine of the First Kind (PMM1)

- Perpetual motion machine of the first kind (PMM-I) is a hypothetical device conceived, based on violation of First law of thermodynamics. Let us think of a system which can create energy as shown below.




- Here a device which is continuously producing work without any other form of energy supplied to it has been shown in (a), which is not feasible. Similarly a device which is continuously emitting heat without any other form of energy supplied to it has been shown in (b), which is again not feasible.
- Above two imaginary machines are called Perpetual Motion Machines of 1st kind.

# Limitation of "FIRST LAW"

- 1st law of thermodynamics has certain limitations as given below:

(i) First law of thermodynamics does not differentiate between heat and work and assures full convertibility of one into other whereas full conversion of work into heat is possible but the vice-versa is not possible.

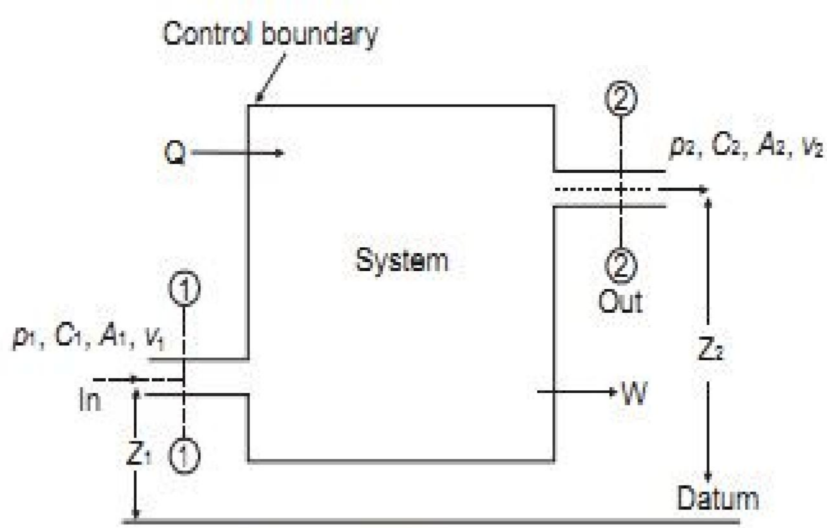
(ii) First law of thermodynamics does not explain the direction of a process. Such as theoretically it shall permit even heat transfer from low temperature body to high temperature body which is not practically feasible. Spontaneity of the process is not taken care of by the first law of thermodynamics.

# Steady and Unsteady Flow System

- **Steady flow** refers to the flow in which its properties at any point remain constant with respect to time. Steady system is the system whose properties are independent of time, i.e. any property at a point in system shall not change with time.
- **Unsteady Flow System**: There exist a number of systems such as filling up of a bottle or emptying of a vessel etc. in which properties change continuously as the process proceeds. Such systems can not be analyzed with the steady state assumptions. Unsteady flow processes are also known as transient flow processes or variable flow processes.

# Steady Flow Energy Equation

- Let us take an open system having steady flow. Figure shows steady flow system having inlet at section 1–1, outlet at section 2–2, heat addition Q and work done by the system W.




*Steady flow system*

# Steady Flow Energy Equation

- We know, the energy balance when applied to open system results in

$$Q + m_1(e_1 + p_1v_1) = W + m_2(e_2 + p_2v_2)$$

Substituting for $e_1$ and $e_2$

$$Q + m_1\left(u_1 + \frac{c_1^2}{2} + gz_1 + p_1v_1\right) = W + m_2\left(u_2 + \frac{c_2^2}{2} + gz_2 + p_2v_2\right)$$

and from definition of enthalpy,

$$h_1 = u_1 + p_1v_1$$
$$h_2 = u_2 + p_2v_2$$

therefore,

$$Q + m_1\left(h_1 + \frac{c_1^2}{2} + gz_1\right) = W + m_2\left(h_2 + \frac{c_2^2}{2} + gz_2\right)$$

Above equation is known as steady flow energy equation (S.F.E.E.).

# Steady Flow Energy Equation

- If the mass flow rates at inlet and exit are same, i.e. $m_1 = m_2 = m$

$$Q + m(h_1 + \frac{c_1^2}{2} + gz_1) = W + m(h_2 + \frac{c_2^2}{2} + gz_2)$$

or, on unit mass basis the S.F.E.E. shall be;

$$q + h_1 + \frac{c_1^2}{2} + gz_1 = w + h_2 + \frac{c_2^2}{2} + gz_2$$

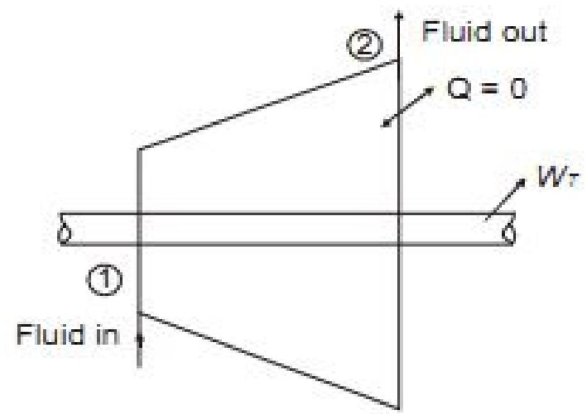
where $q = \frac{Q}{m}, \; w = \frac{W}{m}$

# First Law Applied To Engineering Systems

- **Turbine:** It is the device in which the high temperature and high pressure fluid is expanded to low temperature and pressure resulting in generation of positive work at turbine shaft. Thus, turbine is a work producing device.
- Assuming change in kinetic energy, potential energy to be negligible, the steady flow energy equation can be modified and written between 1 and 2 as,

$$0 + mh_1 = W_T + mh_2$$

$$W_T = m(h_1 - h_2)$$

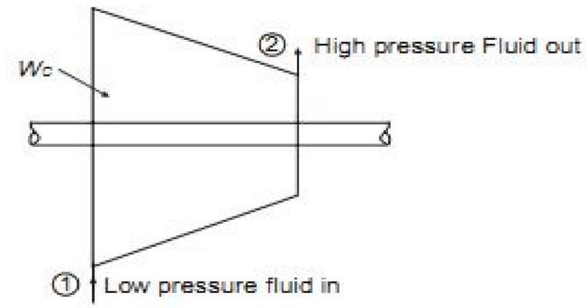


# First Law Applied To Engineering Systems

- Similarly applying steady flow energy equation in compressor

$$mh_1 = -W_c + mh_2$$

$$\text{or } W_c = m(h_2 - h_1)$$

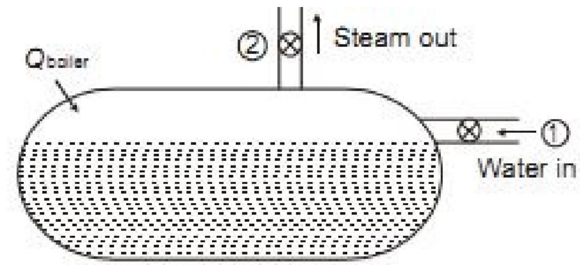



- For boiler

$$Q_{boiler} + m(h_1) = m(h_2)$$

$$\text{or } Q_{boiler} = m(h_2 - h_1)$$

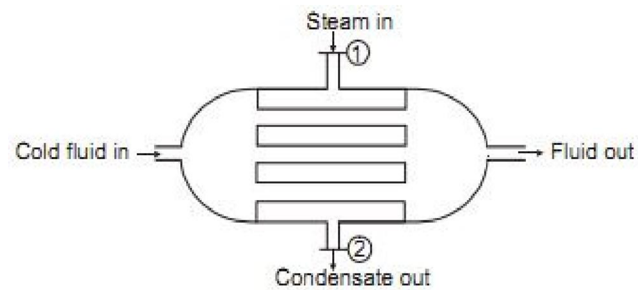
$$= mc_p(T_2 - T_1)$$




- For Condenser

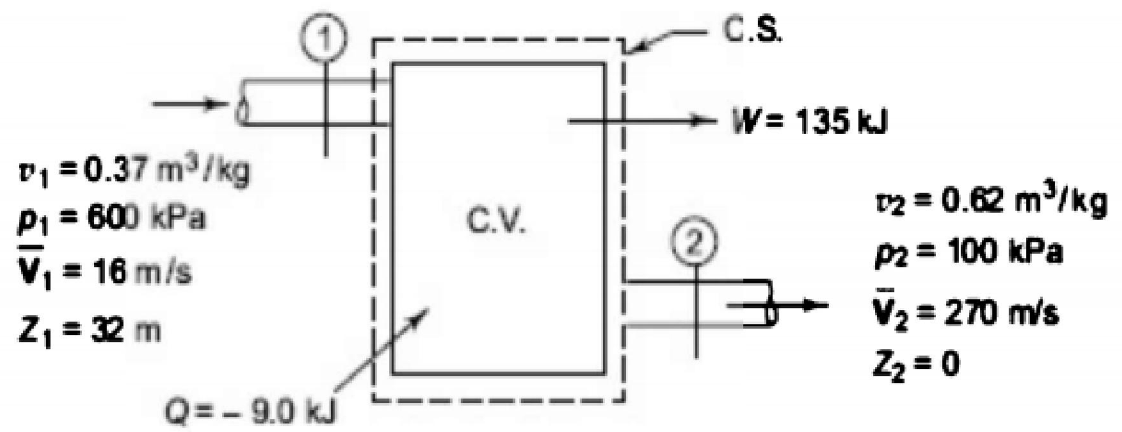
Heat lost by steam,

$$Q = m(h_1 - h_2)$$



# Problem

- In a steady flow apparatus, 135 kJ of work is done by each kg of fluid. The specific volume of the fluid , pressure, and velocity at the inlet are 0.37 $m^3/kg$ , 600 kPa, and 16 m/s. The inlet is 32 m above the floor, and the discharge pipe is at floor level. The discharge conditions are 0.62 $m^3/kg$, 100 kPa, and 270 m/s. The total heat loss between the inlet and discharge is 9 kJ/kg of fluid. In flowing through this apparatus, does the specific internal energy increase or decrease, and by how much?



# Thank You