A Heat Engine Has An Efficiency Of 35.0% And Receives 150 J Of Heat Per Cycle.(a) How Much Work Does

A Heat Engine Has An Efficiency Of 35.0% And Receives 150 J Of Heat Per Cycle.(a) How Much Work Does this question involve understanding the fundamental principles of thermodynamics, particularly the concepts of heat transfer, work output, and efficiency of heat engines. This problem is a classic example used in physics and engineering to illustrate how energy conversion works in practical systems such as engines, refrigerators, and power plants. To answer it thoroughly, we need to delve into the definition of efficiency, the relationship between heat input and work output, and how these ideas are applied in real-world scenarios.

Understanding the Basics of Heat Engines

What Is a Heat Engine?

A heat engine is a device that converts heat energy into mechanical work. It operates between two reservoirs at different temperatures: a hot reservoir that supplies heat and a cold reservoir that absorbs waste heat. The core principle behind a heat engine is the transfer of heat from the hot source to do work, with some heat inevitably lost to the cold sink due to the second law of thermodynamics.

Efficiency of a Heat Engine

Efficiency (η) is a measure of how well a heat engine converts the heat it receives into useful work. It is defined as:

$$
\eta = \frac{\text{Work output}}{\text{Heat input}}
$$

Expressed as a percentage, efficiency indicates the proportion of input energy that is transformed into work, with the remainder typically lost as waste heat.

Analyzing the Given Data

The problem states:
- Efficiency, $\eta = 35.0\% = 0.35$
- Heat received per cycle, $Q_{in} = 150\, \text{J}$

Given this information, our primary goal is to determine the work done per cycle, denoted as W.

Calculating the Work Done per Cycle

Using the Efficiency Formula

Since efficiency relates work output to heat input:

$$
\eta = \frac{W}{Q_{in}}
$$

Rearranging to find W:

$$
W = \eta \times Q_{in}
$$

Substituting the known values:

$$
W = 0.35 \times 150\, \text{J}
$$

$$
W = 52.5\, \text{J}
$$

Therefore, the heat engine performs 52.5 Joules of work per cycle.

Understanding the Significance of the Results

Efficiency in Real-World Engines

An efficiency of 35% is typical for many practical engines, such as internal combustion engines, which often operate within the 25-40% range. This means that a significant portion of the heat energy is not converted into work but is lost to the environment, primarily as waste heat.

Implications of Work Output

The work output per cycle, 52.5 J, signifies the useful energy produced in each operational cycle of the engine. This value is essential for engineers and designers to assess the performance and power of engines in applications like vehicles, power plants, and industrial machinery.

Additional Concepts Related to Heat Engines

Second Law of Thermodynamics

The second law states that no heat engine can be 100% efficient because some energy will always be lost as waste heat. This law sets an upper limit on efficiency, known as the Carnot efficiency, which depends on the temperatures of the hot and cold reservoirs.

Carnot Efficiency

The maximum theoretical efficiency, given by the Carnot cycle, is:

$$
\eta_{max} = 1 - \frac{T_{cold}}{T_{hot}}
$$

where T_{hot} and T_{cold} are the absolute temperatures of the hot and cold reservoirs, respectively. Real engines operate below this maximum efficiency due to practical limitations.

Practical Applications and Considerations

Designing Efficient Engines

Engineers aim to maximize efficiency while balancing factors like cost, size, and material limitations. Improving thermal insulation, optimizing combustion processes, and using advanced materials are some strategies to enhance efficiency.

Environmental Impact

Higher efficiency engines produce less waste heat and consume less fuel for the same amount of work, reducing environmental pollution and conserving resources. This is especially important in the context of sustainable energy practices.

Energy Conversion and Sustainability

Understanding the principles of heat engine efficiency helps in developing renewable energy technologies, such as solar thermal plants and geothermal systems, which rely on converting heat into usable energy efficiently.

Summary and Final Thoughts

In conclusion, given a heat engine with an efficiency of 35.0% that receives 150 Joules of heat per cycle, the work output per cycle can be calculated straightforwardly using the efficiency formula. The work done is 52.5 Joules, indicating the useful energy produced during each cycle. This calculation not only demonstrates core thermodynamic principles but also highlights the importance of efficiency in energy conversion systems, impacting everything from engine design to environmental sustainability.

Understanding these concepts is crucial for scientists, engineers, and policymakers working toward more efficient and sustainable energy solutions in a world increasingly dependent on reliable and eco-friendly power sources.

Frequently Asked Questions

What is the work output of a heat engine with an efficiency of 35.0% receiving 150 J of heat per cycle?

The work output is 52.5 J.

How do you calculate the work done by a heat engine given its efficiency and heat input?

Work done = Efficiency × Heat input, so multiply the efficiency (as a decimal) by the heat received.

If a heat engine's efficiency is 35.0%, what is the heat rejected per cycle when it receives 150 J of heat?

The heat rejected is 97.5 J, calculated by subtracting work output from heat input.

Why is the efficiency of a heat engine always less than 100%?

Because some energy is always lost as waste heat, preventing perfect conversion of heat into work.

What does an efficiency of 35.0% imply about the energy conversion in the heat engine?

It means that 35% of the heat energy is converted into work, while 65% is lost as waste heat.

How can the work output of a heat engine be increased without changing the heat input?

By increasing the efficiency, such as through improved engine design or better heat management.

What is the significance of the efficiency value in evaluating a heat engine's performance?

Efficiency indicates how effectively the engine converts heat into useful work, with higher efficiency being more desirable.

Can the work output of this heat engine be greater than 52.5 J with the given heat input?

No, because the maximum work output is limited by the efficiency and heat input; for 35%, maximum work is 52.5 J.

If the heat input increases while efficiency remains the same, what happens to the work output?

The work output increases proportionally with the heat input.

What assumptions are typically made when calculating work done by a heat engine in such problems?

Assumptions include idealized conditions, no energy losses outside of specified efficiencies, and perfect heat transfer.

Additional Resources

Heat Engines and Efficiency: An In-Depth Analysis of Work Output

Understanding the fundamental principles of heat engines is essential for grasping how energy conversion works in real-world systems, from automobile engines to power plants. In this detailed review, we will explore the scenario of a heat engine with a given efficiency and heat intake per cycle, providing comprehensive insights into how to determine the work output per cycle, alongside a broader discussion of the thermodynamic principles involved.

Introduction to Heat Engines

A heat engine is a device that converts heat energy into mechanical work. It operates between two thermal reservoirs — a hot source and a cold sink — absorbing heat from the hot reservoir, performing work, and releasing some heat to the cold reservoir.

Key concepts:

- Heat input (Q_{in}): The heat energy absorbed from the hot reservoir.
- Work output (W): The useful mechanical energy produced.
- Heat rejected (Q_{out}): The heat expelled to the cold reservoir.
- Efficiency (η): The ratio of work output to heat input, expressed as a percentage.

Mathematically:

$$
\eta = \frac{W}{Q_{in}} \times 100\%
$$

Efficiency of a Heat Engine: Understanding the Basics

The efficiency of a heat engine is a crucial parameter, defining how effectively it converts heat into work. The maximum theoretical efficiency is dictated by the Carnot efficiency, which depends on the temperatures of the hot and cold reservoirs:

$$
\eta_{Carnot} = 1 - \frac{T_{cold}}{T_{hot}}
$$

However, real engines operate below this maximum due to irreversibilities and practical limitations.

In our case, the efficiency is given as 35.0%, which indicates that only 35% of the heat energy supplied is converted into work, with the remaining 65% expelled as waste heat.

Given Data and Problem Statement

Let's restate the problem details:

- Efficiency, $\eta = 35.0\%$
- Heat received per cycle, $Q_{in} = 150\,J$

The question posed is:

(a) How much work does the heat engine produce per cycle?

Step-by-Step Calculation of Work Output

To determine the work output, W, per cycle, we use the fundamental relationship between efficiency, work, and heat input:

$$
\eta = \frac{W}{Q_{in}}
$$

Rearranged to solve for W:

$$
W = \eta \times Q_{in}
$$

Note: Since efficiency is given as a percentage, convert it to decimal form:

$$
\eta = \frac{35.0}{100} = 0.35
$$

Now, substitute the known values:

$$
W = 0.35 \times 150\,J = 52.5\,J
$$

Result: The heat engine produces 52.5 Joules of work per cycle.

Deeper Insight into the Work Output

While the calculation is straightforward, it’s instructive to analyze what this means in the broader thermodynamic context.

2.1 Energy Balance in a Heat Engine

The energy flow in each cycle can be summarized as:

- Input heat energy: $Q_{in} = 150\,J$
- Work output: $W = 52.5\,J$
- Heat rejected to cold reservoir: Q_{out}

Applying the energy conservation principle:

$$
Q_{in} = W + Q_{out}
$$

Rearranged to find Q_{out}:

$$
Q_{out} = Q_{in} - W = 150\,J - 52.5\,J = 97.5\,J
$$

This indicates that, per cycle, the engine expels 97.5 Joules of heat to the cold reservoir.

2.2 Efficiency and Thermodynamic Limits

The efficiency of 35% is typical for many real-world engines, which are inherently less than ideal due to friction, turbulence, and other irreversibilities.

The maximum efficiency theoretically achievable between two reservoirs is the Carnot efficiency, which depends on the temperature difference:

$$
\eta_{Carnot} = 1 - \frac{T_{cold}}{T_{hot}}
$$

Since our engine operates at 35%, it is well below the Carnot limit, reflecting practical constraints.

Implications and Practical Considerations

2.1 Energy Conversion and Waste Heat

The fact that only 35% of the heat input is converted into work emphasizes the importance of waste heat management. The remaining 65% of heat must be expelled, often necessitating cooling systems that prevent overheating and maintain operational stability.

2.2 Efficiency Improvements

Enhancing the efficiency involves:

- Increasing the temperature difference between the hot and cold reservoirs.
- Reducing irreversibilities within the engine.
- Utilizing advanced materials to minimize friction and heat losses.

2.3 Real-World Applications

Understanding efficiency and work output is vital in designing engines for:

- Electricity generation
- Transportation (cars, ships, aircraft)
- Industrial processes

Optimizing these parameters can lead to significant energy savings and reduced environmental impact.

Extended Analysis: Beyond the Basic Calculation

While the primary question was about work output, a comprehensive understanding includes exploring related factors:

3.1 Power Output and Cycle Time

If the cycle duration were known, the power output could be calculated:

$$
\text{Power} = \frac{W}{\text{time per cycle}}
$$

This is crucial for applications where energy generation rate matters.

3.2 Impact of Changing Heat Input

Suppose the heat input changes; the work output scales linearly with Q_{in}:

$$
W' = \eta \times Q_{in}'
$$

This linearity underscores the importance of maximizing heat intake without compromising efficiency excessively.

3.3 Thermodynamic Efficiency under Different Conditions

The efficiency is influenced by:

- Reservoir temperatures
- Engine design
- Operating conditions

Research continues into innovative engine cycles, such as combined cycles, that aim to surpass traditional limitations.

Conclusion: Summarizing the Insights

To conclude:

- The heat engine, with an efficiency of 35%, converts 150 Joules of heat per cycle into 52.5 Joules of work.
- The remaining heat, 97.5 Joules, is expelled as waste heat.
- Improving efficiency involves increasing the temperature differential and

minimizing irreversibilities.
- Practical applications require balancing efficiency, work output, and heat rejection for optimal performance.

This scenario exemplifies fundamental thermodynamic principles, especially the relation between heat, work, and efficiency, which underpin modern energy systems. Understanding these concepts enables engineers and scientists to design better engines and energy conversion devices, contributing to sustainable and efficient energy utilization.

Additional Resources:
- Thermodynamics textbooks (e.g., "Fundamentals of Engineering Thermodynamics" by Moran and Shapiro)
- Online courses on heat engines and thermodynamic cycles
- Research articles on advanced engine technologies

In summary, the calculation of work output based on efficiency and heat input is a core skill in thermodynamics, providing insights into the capabilities and limitations of real-world engines. Continuous improvements in this domain are crucial for advancing sustainable energy solutions worldwide.

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