The Science

Thermal Dynamics and Ultra-High-Pressure (UHP) Applications During Transitional Fire Attack (TFA)

The goal in this section is to give the science behind the actions. This sectionm explains the thermal dynamics principles that govern fire behavior and how Ultra-High Pressure (UHP) water-fog systems exploit those principles during Transitional Fire Attack (TFA). Understanding this science allows firefighters to apply UHP effectively, safely, and consistently under modern fire conditions.

Over the past 100 years, fire behavior has changed significantly due to the introduction of:

- Synthetic fuels and furnishings
- Lightweight construction
- Open floor plans
- Increased fuel load and faster heat release rates

Fire Profile – Definition
A fire profile describes the overall characteristics and behavior of a fire at a given moment, including:

- Flame size and heat release rate (HRR)
- Smoke production and gas temperature
- Fuel type, arrangement, and load
- Air movement and ventilation conditions
- Stage of fire development

Understanding the fire profile allows firefighters to predict fire behavior, select appropriate tactics, and make critical safety decisions.

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1. TACTICAL IMPLICATIONS

As the fire profile changes, firefighting tools and tactics must adapt. The primary objectives remain:

1. Firefighter safety
2. Rapid fire stabilization
3. Control of the interior fire environment

UHP water-fog systems address these objectives by leveraging fundamental thermal dynamics rather than relying solely on water volume.

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2. THERMAL DYNAMICS PRINCIPLES APPLIED TO UHP

Fire suppression using UHP is governed by enthalpy, entropy, and stoichiometric combustion, supported by sensible heat absorption and latent heat of vaporization.

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3. HEAT TRANSFER MECHANISMS IN UHP FIREFIGHTING

Total Heat Absorbed by Water

The total heat absorbed by water during fire suppression is defined as:

$$Q = m c \Delta T + m h_{fg}$$

Where:

- Q = Total heat absorbed (kJ)
- m = Mass of water (kg)
- c = Specific heat of water (≈ 4.18 kJ/kg·°C)
- ΔT = Temperature increase of water (°C)
- $h_{(fg)}$ = Latent heat of vaporization of water (≈ 2260 kJ/kg)

3.1 Sensible Heat Absorption (Gas Cooling)

Sensible heat is the energy absorbed as water droplets increase in temperature without changing phase.

- Occurs as UHP droplets rapidly heat from ambient temperature toward 100°C
- Primary mechanism for hot gas cooling
- Reduces upper layer temperatures and slows fire growth

UHP advantage:

- Extremely fine droplets provide high surface-area-to-mass ratio
- Rapid heat absorption from superheated gases

3.2 Latent Heat of Vaporization (Phase Change)

Latent heat is absorbed when water changes phase from liquid to vapor at 100°C.

- Each kilogram of water absorbs ~2260 kJ during vaporization
- This phase change removes massive amounts of energy from the fire environment

UHP advantage:

- Droplets vaporize almost instantly
- Maximizes latent heat absorption per gallon applied

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4. ENTROPY AND STEAM EXPANSION

When UHP droplets flash to steam:

- Liquid water becomes water vapor
- Entropy increases (greater molecular disorder)
- Water expands approximately 1,500–1,700 times its original volume

Tactical Effect:

- Steam expansion displaces oxygen-rich air
- Reduces oxygen concentration in the flame zone
- Suppresses combustion without relying solely on fuel wetting

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5. STOICHIOMETRIC COMBUSTION DISRUPTION

Stoichiometric Combustion – Definition

Fire burns most efficiently when fuel and oxygen are present in near-ideal proportions.

UHP Impact:

- Steam dilutes oxygen concentration
- Cooling lowers fuel pyrolysis rates
- Turbulent mixing is disrupted

Result:

- The fire environment is pushed away from stoichiometric balance
- Heat release rate drops rapidly
- Flame stability is lost

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6. COMPARISON: UHP VS. TRADITIONAL LOW-PRESSURE ATTACK

Traditional Low-Pressure Firefighting

- Large droplets
- Low surface-area-to-mass ratio
- Slower heat absorption
- Minimal immediate steam generation
- Primary mechanism: surface cooling and fuel soaking

UHP Water-Fog Firefighting

- Extremely fine droplets
- Rapid sensible heat absorption
- Immediate latent heat absorption via vaporization
- Significant steam expansion
- Active oxygen displacement
- Immediate combustion disruption

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7. APPLICATION DURING TRANSITIONAL FIRE ATTACK (TFA)

During TFA, UHP:

- Rapidly cools hot gases (sensible heat)
- Removes massive energy through vaporization (latent heat)
- Expands into steam, displacing oxygen (entropy)
- Disrupts fuel-air balance (stoichiometry)

This combination results in fast fire stabilization prior to entry, reducing interior thermal insult to crews.

✅In Summary:

Ultra-High-Pressure water-fog systems suppress fire by maximizing heat absorption efficiency, not water volume. By combining:

- Sensible heat absorption
- Latent heat of vaporization
- Steam expansion and oxygen displacement
- Stoichiometric combustion disruption

UHP excels in Transitional Fire Attack by rapidly stabilizing modern, high-energy fire environments.

🔑 Key Takeaways

- Faster heat absorption due to ultra-fine droplets
- Maximum energy removal through latent heat of vaporization
- Rapid steam generation for oxygen displacement
- Immediate disruption of efficient combustion
- Reduced water usage and runoff
- Improved visibility and faster knockdown
- Increased firefighter safety