# In a Pot Without a Lid, Steam Adds to the Least Power That Can Boil, and the Better the Insulation the More a Lid Matters

— heat lost from the water surface rises steeply toward boiling, and its value at 100 degrees adds directly to the least power that can boil —the separator is whether heat loss rises in proportion to the temperature difference or steeply toward the boiling point — [Paper 965]

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*— From thinking to syncing. —*

**Abstract**

**The efficiency of boiling water is set by the ratio of power to heat loss rather than by the appliance, and weaker heat wastes more (Paper 883), but that paper left out heat lost in steam and the lid.This paper adds to the model of Paper 883, which heats 1 kg of water from 20 to 100 degrees, the heat lost by evaporation from the water surface (saturated vapor density from the Antoine equation; area and mass-transfer coefficient set), treats a lid as stopping evaporation, and compares the least power that can boil, the time and the energy used.No new theorem or law is claimed. First, heat lost from the water surface rises steeply toward boiling: the heat carried off by evaporation was 3.113036 W at 20 degrees, 43.616210 W at 60, 101.751082 W at 80 and 209.656699 W at 100** (Section 2). **Second, without a lid, the evaporation heat at 100 degrees is added to the least power that can boil: for wall loss coefficients of 1, 3 and 6 W/K, the least power was 80, 240 and 480 W with a lid and 289.656699, 449.656699 and 689.656699 W without** (Section 2). **Third, the better the insulation, the more a lid matters: the ratio of least power without a lid to with a lid was 3.620709, 1.873570 and 1.436785 for coefficients 1, 3 and 6 W/K. At 3 W/K and 300 W, the lidded pot boiled in 2245.702 s, and the open pot stopped at 82.5639 degrees** (Section 3). **Fourth, even when both boil, weaker heat makes the energy difference larger: at 3 W/K, the energy ratio without to with a lid was 1.510276 at 500 W and 1.023265 at 3000 W. At 1 W/K and 300 W, 0.129147 kg of water evaporated before boiling** (Section 3). **Fifth, the separator is whether heat loss rises in proportion to the temperature difference or steeply toward the boiling point: heat lost through the wall is proportional to the temperature difference, reaching the coefficient times 80 at 100 degrees. Heat lost from the surface is proportional to the saturated vapor density, rising from 43.616210 W at 60 degrees to 209.656699 W at 100. That addition does not depend on the insulation of the vessel** (Section 4).
**Keywords**: evaporation, lid, heat transfer, saturated vapor pressure, Antoine equation, boiling water.

**Scope of this paper (scope note)**: **No new theorem or law is claimed**: **that evaporation of water carries heat, the mass-transfer formula taking the evaporation rate as proportional to the difference between saturated vapor at the surface and vapor in the air, the Antoine equation for saturated vapor pressure, and that a lid stops steam and boils water faster, are all known in heat transfer and everyday experience.These are set values**: **a surface area of $0.02$ m², a mass-transfer coefficient of $0.008$ m/s, a latent heat of $2.26 \times 10^6$ J/kg (constant) and an ambient humidity of $0.5$ are set here. The coefficients and powers of Paper 883 are used as they are. They correspond to no pot or kettle.Boiling itself is not treated**: **the flow of vapor pushing air away near boiling, bubbles, heat lost through the lid and the heat capacity of the lid are not included. A lid is taken only to stop evaporation.Nothing is recommended**, **which appliance or lid should be used is not stated.Relation to earlier papers**: **Paper 883, in its scope note, did not include combustion and evaporation, leaving out the fraction of heat passing from a gas flame to a pot, the lid, heat lost in steam and the heat capacity of the vessel; this paper sits in the seat of the lid and heat lost in steam** (no earlier occupant).**Paper 883 showed that the efficiency of boiling water is set by the ratio of power to heat loss and that weaker heat wastes more**. **Here the steam heat, which rises steeply with temperature, is added to that heat loss, and how the least power that can boil changes with and without a lid is counted.Paper 392 showed that the boiling point is a property of substance and pressure together, and gave the vapor pressure at 100 degrees as $760.0864$ mmHg from the Antoine equation**. **Here the same equation gives the saturated vapor density at the water surface.**What is added: **computing the heat lost by evaporation at each temperature**, **comparing the least power that can boil with and without a lid**, **showing that this ratio is larger for better insulated vessels**, **setting out energy and evaporated water**, and **placing the separator on "proportional to the temperature difference, or steep toward boiling"**.

## 1. Notation and the Question

**Setting**: **as in Paper 883, heating $1$ kg of water (heat capacity $4186$ J/K) from $20$ to $100$ degrees takes $334880$ J, with power $P$ and wall heat loss $h(T-20)$. This paper adds the heat lost by evaporation from the water surface.**

$$E(T) = L\,\beta\,A\,\big(\rho_s(T) - \phi\,\rho_s(20)\big), \qquad \rho_s(T) = \frac{p_s(T)\,M}{R\,(T+273.15)}$$

**The saturated vapor pressure $p_s$ follows the Antoine equation (mmHg, degrees)**
$\log_{10} p_s = 8.07131 - 1730.63/(233.426 + T)$, **giving $760.0864$ mmHg at 100 degrees and $17.4733$ mmHg at 20 degrees, and saturated vapor densities of $0.588412$ and $0.017218$ kg/m³. $A = 0.02$ m², $\beta = 0.008$ m/s,**
$L = 2.26 \times 10^6$ **J/kg and $\phi = 0.5$ are set values. The water temperature $T$ and mass $m$ follow**

$$m\,c\,\frac{dT}{dt} = P - h(T-20) - E(T), \qquad \frac{dm}{dt} = -\frac{E(T)}{L}$$

**with $E = 0$ under a lid. If the water falls below half, the run is stopped (not counted as boiling).**

**Question**: **how much do the least power that can boil and the energy to boil change with and without a lid?**

## 2. Steam Heat and the Least Power That Can Boil

**Computation 2.1**: heat lost by evaporation is $3.113036$ W at 20 degrees, $43.616210$ W at 60, $101.751082$ W at 80 and $209.656699$ W at 100.

**Computation 2.2**: the least power that can boil is where power balances losses at 100 degrees: $80h$ with a lid and $80h + E(100)$ without.

| coefficient $h$ (W/K) | with lid (W) | without lid (W) | without / with |
|---|---|---|---|
| 1 | 80.000000 | 289.656699 | **3.620709** |
| 3 | 240.000000 | 449.656699 | 1.873570 |
| 6 | 480.000000 | 689.656699 | 1.436785 |

At 3 W/K without a lid, the least power found without the formula, by narrowing the heating model, was $449.657$ W, within 1 W of the formula.

> **Observation 2.3**
>
> steam heat adds directly to the least power that can boil.The addition of $209.656699$ W is the evaporation heat at 100 degrees and does not depend on the wall coefficient: the smaller the wall loss of a vessel, the larger that addition was in proportion.

## 3. Time and Energy to Boil

**Computation 3.1**: time (s) and energy (kWh) at 3 W/K.

| power | with lid | without lid | evaporated water (kg) |
|---|---|---|---|
| 300 W | 2245.702 s, 0.187142 | stops at 82.5639 degrees | (none) |
| 500 W | 912.445 s, 0.126729 | 1378.044 s, 0.191395 | 0.061703 |
| 1000 W | 382.931 s, 0.106370 | 419.659 s, 0.116572 | 0.013649 |
| 2000 W | 178.370 s, 0.099095 | 185.044 s, 0.102802 | 0.005566 |
| 3000 W | 116.345 s, 0.096954 | 119.052 s, 0.099210 | 0.003504 |

All lidded times agreed with the closed form of Paper 883 within 0.05 s. The energy ratio without to with a lid was, at 1 W/K, 1.963091 at 300 W, 1.208163 at 500 W, 1.076679 at 1000 W, 1.034103 at 2000 W and 1.021942 at 3000 W; at 3 W/K, 1.510276 at 500 W, 1.095914 at 1000 W, 1.037417 at 2000 W and 1.023265 at 3000 W; at 6 W/K, 1.154048 at 1000 W, 1.043786 at 2000 W and 1.025577 at 3000 W. At 6 W/K, 500 W stopped at 83.7519 degrees without a lid, and 300 W stopped at 70.0000 degrees with a lid and 62.0232 degrees without. At 1 W/K and 300 W without a lid, boiling took 2548.698 s with water loss included (evaporating 0.129147 kg) and 2663.933 s with the water held at 1 kg.

> **Observation 3.2**
>
> even when both boil, weaker heat makes the lid matter more.At 3 W/K the energy ratio fell from 1.510276 at 500 W to 1.023265 at 3000 W: near the least power that can boil, the open pot takes longer, and steam heat keeps escaping all that time.

## 4. The Separator

> **Observation 4.1**
>
> the separator is whether heat loss rises in proportion to the temperature difference or steeply toward the boiling point.Heat lost through the wall is proportional to the temperature difference and reaches $80h$ at 100 degrees: heat lost from the surface is proportional to the saturated vapor density and rose from 43.616210 W at 60 degrees to 209.656699 W at 100. This addition does not depend on the wall coefficient, so for a well insulated vessel (1 W/K) the least power that can boil became 3.620709 times as large.

**Observation 4.2**

**what is not said.Values for real pots or kettles, the flow of vapor near boiling, bubbles, heat lost through the lid, the fraction of flame heat reaching the pot, and which appliance to use are not treated. What is shown is how far, in a model adding steam heat with set area and mass-transfer coefficient, a lid changes the least power that can boil and the energy used.**

## 5. Roll Call and Closing

1. **two heat losses, wall and surface** (Section 1): **saturated vapor from the Antoine equation.**
2. **evaporation heat at 100 degrees 209.656699 W** (Computation 2.1): **steep toward boiling.**
3. **least-power ratios 3.620709, 1.873570, 1.436785** (Computation 2.2): **larger for better insulation.**
4. **at 3 W/K and 300 W the open pot stops at 82.5639 degrees** (Computation 3.1): **the lidded pot boils.**
5. **energy ratio from 1.510276 (500 W) to 1.023265 (3000 W)** (Computation 3.1): **weaker heat, larger difference.**
6. **proportional to the temperature difference, or steep toward boiling** (Observation 4.1): **the separator; the scope note of Paper 883.**

**Closing: In a pot without a lid, steam adds to the least power that can boil, and the better the insulation the more a lid matters.Adding surface evaporation to the model of Paper 883, the heat lost reached 209.656699 W at 100 degrees, and the least power that can boil without a lid became 3.620709, 1.873570 and 1.436785 times that with a lid for coefficients 1, 3 and 6 W/K: at 3 W/K and 300 W, the lidded pot boiled and the open pot stopped at 82.5639 degrees. Even when both boiled, the energy ratio was 1.510276 at 500 W.The separator is whether heat loss rises in proportion to the temperature difference or steeply toward the boiling point.Placed among the earlier papers: to the efficiency that Paper 883 counted with wall loss alone, the steam and lid that Paper 883 did not include were added, with vapor from the same Antoine equation as Paper 392.To be honest: the area and mass-transfer coefficient are set values, and vapor flow near boiling is not included. With steam heat added, where the lid matters, and no further.**

## References


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