The Sticky Spring. We use the sticky spring to model real spring behavior by accounting for a friction component $F_s = K(X_s - X_{s,o}) \pm \delta F_s$. The irreversible work is found to be $đW^i_{irr} = |\delta F_s dX_s|$. Thus the mechanical production is

$$dS_m = \frac{|\delta F_s dX_s|}{T_{eq}} \geq 0$$

Viscous Fluid Flow. The motion of a viscous fluid during compression work produces pressure drop and irreversible work

$$dS_m = \frac{|(p_B - p_{eq})dV|}{T_{eq}} \geq 0$$

Electric Resistance. Entropy is generated at a rate that is proportional to the current squared.

$$\frac{dS_m}{dt} = \frac{I^2 R}{T_{eq}} \geq 0$$

The sources of mechanical entropy production arise due to friction within a specific intrinsic work mode. The following example shows, more specifically, the effect of production on a practical system.

Example 6. A large ship requires a propulsive force of 8000 lb_f to realize a speed of 20 knots (approx. 23 mph). This energy is dissipated into the ocean, primarily in wave making (but with some surface friction) as the ship moves. Calculate the rate of increase of the entropy of the ocean as a result of the ship's passing. (The local ocean temperature is 520 R.)

For purposes of analysis, choose the ocean as the system. Using the intrinsic form of the first law on a rate basis, we have

$$\frac{dU}{dt} = \cancel{\frac{đQ}{dt}} + \frac{đW^i_{irr}}{dt} + \cancel{\frac{đW^i_{rev}}{dt}}$$

The water is a simple compressible substance and its volume does not change; so the intrinsic reversible work is zero. The transfer mechanism of the propulsive energy from the ship to the water is force acting through a resistance; hence, it is irreversible work, not heat. We have

$$\frac{dU}{dt} = \frac{đW_{irr}}{dt} = 8000\ lb_f \cdot 23\ mil/hr \cdot 5280\ ft/mil = 9.7 \cdot 10^8\ ft\ lb_f/hr$$

The rate of increase of the entropy of the ocean (and the universe, since the ship is in steady state $(ds/dt)_{ship} = 0$), can be determined from eqn. IIIS-7.

Ans. 4. (a) $ds = \frac{du - \mu_o v\bar{H} \cdot d\bar{M}}{T}$	(b) $ds = \frac{du - v\bar{E} \cdot d\bar{P}}{T}$	(c) $ds = \frac{du + pdv - \sigma da}{T}$

Ans. 5. The Gibbs equation is applicable between equilibrium states. The entropy of an isolated system increases until it reaches equilibrium. After that $dS|_{isol} = 0$. There is no inconsistency in the statements.