3. DEVELOPING THE SYSTEM PROCESS FLOW DIAGRAM

Now since provided with a firm foundation in the fundamentals of Thermodynamics and Mollier's T – S Diagram for water, it is time to create our system's Process Flow Diagram (acronymed PFD). In our Rankine Cycle system, there will be four distinct steps, which are:

1. Pressurize Saturated Water with a centrifugal Pump to the working pressure of our nuclear Reactor. The Pump will be *assumed* to be 100% efficient,
2. Add heat to the pressurized water within the Reactor to completely vaporize it to Saturated Steam,
3. Direct the Saturated Steam to a Turbine, which will extract the energy in the steam as useful work. The Turbine will be *assumed* to be 100% efficient,
4. Direct the energy-depleted fluid discharged by the Turbine into a Condenser, which will remove residual latent heat until the fluid is in a Saturated Water state. Direct this liquid to the inlet of the Pump in Step #1.

For clarity, two separate, but interrelated, system cycle diagrams will be used. The first, Figure 5, will be, as just stated, a *physical model* PFD within which individual simplistic icons will be used to identify the equipment associated with each of the four process steps. In addition, a second, Figure 6, *logical model*, will be used, Mollier's T – S Diagram, so that each step can be tracked and the fluid's Thermodynamic properties can be definitively established. Each diagram will correspond to the other. Both diagrams are key to the understanding of Thermodynamic processes, whether they are the simple case discussed in this paper, or that of Thermodynamic systems involving multiple interacting Thermodynamic Cycles. As this paper progresses, more and more 'reality' of the actual components involved in a Nuclear Power Plant will be revealed, with the hope that in doing so the reader will gain a better appreciation for the immensely complex Engineering that is involved in conceptualizing, constructing and operating such a facility. However, irrespective of how simplistic or complex one's Thermodynamic Cycle and Process is, everything begins with what is to be shortly presented, namely simplistic *physical* and *logical* models of the process of concern. This is certainly true of a Nuclear Power Plant. As proof of this fact, a very early stage *physical model* PFD of an actual BWR Nuclear Power Plant will be included in this paper as a future illustration, the facility of which it conceptualizes has been subsequently built and it remains in operation to this day!

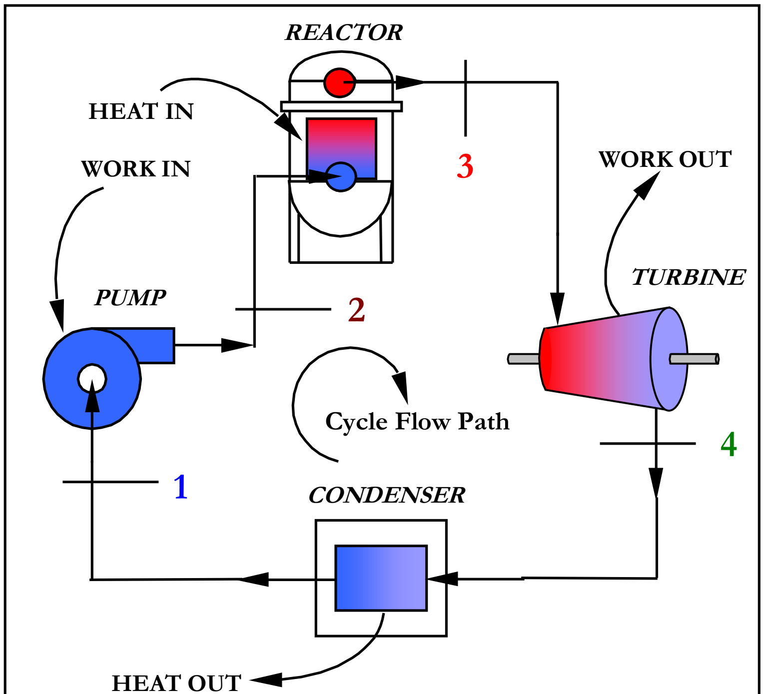

Figure 5 ***Simplified*** **Rankine Cycle PFD**

In Figure 5, a new color code is used for each starting and ending point of the four legs of the Process. These new colors correspond to those which are used in the *logical* diagram of the same Rankine Cycle overlain onto Mollier's T – S Diagram in Figure 6. To illustrate the <u>actual</u> Cycle as an Engineer initially designing this system would visualize, the T – S Diagram of Figure 1 will be used in Figure 6. The *approximate* values of various Thermodynamic properties at each of the four reference points as could *reasonably* be discerned using Mollier's T – S Diagram are included in Figure 6.

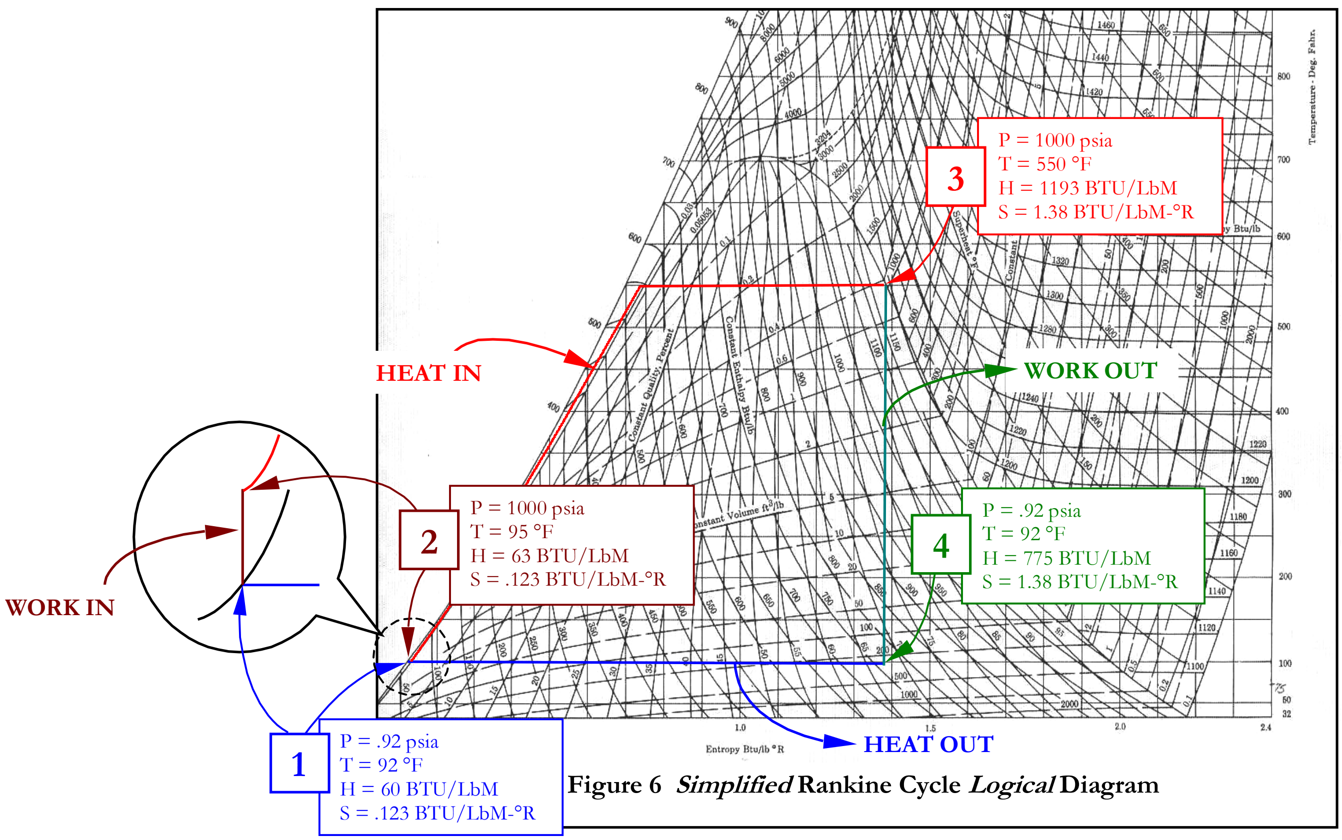

Figure 6 ***Simplified*** **Rankine Cycle** ***Logical*** **Diagram**

In order to assure a full understanding of Figures 5 & 6, a complete understanding of the *Simplified Rankine Cycle* illustrated, and the significance of all of the Thermodynamic Property values shown, the reader is asked to devote an additional amount of time than was done reviewing previous Figures. To underscore key information included in the Figures, the following summary is provided:

- Beginning at Point #1 (the entrance to the Reactor Feed Pump(s)), the fluid is by definition *Saturated Liquid* and has an Enthalpy of 60 BTU/LbM. The liquid Temperature is 92° F, and the inlet entrance Pressure is .92 psia. The entrance fluid's Entropy value is .123 BTU/LbM-° R.
- Because the Pump is *assumed* to be 100% mechanically efficient (which is impossible in practice), the Pump's fluid's exit Entropy at Point #2 is exactly the same value as the entrance (.123 BTU/LbM-° R), which makes the path from Point #1 to Point #2 easy to define - a straight vertical line. The Pump Work in, equal to the increase in the fluid's Enthalpy (63 BTU/LbM minus 60 BTU/LbM or 3 BTU/LbM), is very small in comparison to other Point values, and this energy is all it takes to raise the fluid's Pressure from .92 psia to 1000 psia, and raises the fluid's Temperature slightly to 95° F.
- The amount of Heat added by the Reactor between Point #2 and #3 (the increase in the fluid's Enthalpy) is extraordinary large and is equal to the Reactor fluid's exit Enthalpy at Point #3, 1193 BTU/LbM, minus the Reactor liquid's entrance Enthalpy at Point #2, 63 BTU/LbM, which equals 1130 BTU/LbM.
- The Reactor's fluid's exit state (Point #3) is a *Saturated Gas* (*steam*), meaning that the *liquid* supplied to the Reactor by the Pump was completely vaporized into *steam* in the Reactor. Though not specifically identified in Figure 6, but which the reader can verify by inspecting the path from Point #2 to #3, is that of the total energy added to the Process fluid in the Reactor 57.5% of this energy was used just to change the state of the fluid in the Reactor from *liquid* water to *steam*. This value is equal to the Enthalpy of *steam* at Point #3 (1193 BTU/LbM) minus the Enthalpy of *Saturated Water* at the same Temperature as Point #3 (543 BTU/LbM) divided by the total energy added to the fluid from Point #2 to Point #3 (which is 1130 BTU/LbM).
- Since 57.5% of the total energy added to the fluid by the Reactor goes into changing its state from a *Saturated Liquid* to a *Saturated Gas*, that means that the remainder of the energy, 42.5% (480 BTU/LbM) goes into raising the fluid's Temperature from 95° F to 1000° F.

- Similar to the Pump, the Turbine is also *assumed* to be 100% mechanically efficient (and similarly, impossible in practice), which by *definition* prescribes that the change of Enthalpy of the Process path from Point #3 to Point #4 is zero and is a straight vertical line down. The quantity of energy as useful Work extracted from Point #3 to Point #4 by the Turbine is equal to the difference in the Points' Enthalpies (1193 BTU/LbM – 775 BTU/LbM), which equals 418 BTU/LbM.
- The amount of energy as useful Work extracted from the System, 418 BTU/LbM, represents 36.9% of the total energy inputted into the System. This value is equal to the energy extracted by the Turbine divided by the total energy added to the System. The total energy inputted into the Pump (the difference in Enthalpies between Point #1 and #2), is 3 BTU/LbM, while the Heat energy added to the fluid by the Reactor, is 1130 BTU/LbM (from a previous bullet calculation). Adding these two values represents the total energy added into the System as shown, 1133 BTU/LbM. Thus, the percent of this total energy extracted as useful Work is equal to 418 BTU/LbM / 1133 BTU/LbM, or 36.9%.
- By comparison, the amount of energy discarded from the System by the Condenser, equal to the difference is Enthalpies between Point #4 and #1, equates to 715 BTU/LbM (775 BTU/LbM – 60 BTU/LbM, or 715 BTU/LbM). This value represents 63.1% of the total energy inputted into the System. Stated differently, of all of the energy inputted into the System and with the Processes *assumed* to be 100% efficient [9], only 36.9% of this energy is extracted as useful Work, while 69.1% of it is discarded, as waste, into the atmosphere!
- Finally, an actual Nuclear Power Plant possesses an efficiency, in practice, of 34% (as was stated on page 3 of this paper). This is *only* 2.9% below the greatest possible theoretically perfect efficiency of the *Simplified* Rankine Cycle that was just analyzed. Being just below that which is the best possible performance that *could exist* for this Cycle means that the Engineers who designed and constructed power plants based upon this Thermodynamic model did a phenomenal job.

[9] System efficiency as defined in this document not only includes perfect thermal & mechanical efficiency of all PFD equipment, but also includes zero heat loss from all plant piping, 100% efficient insulation, thermal rejection plant wall paint, no plant personnel A/C & no energy lost due to sound or sonic process fluid flow.