Proceedings of the 2014 Winter Simulation Conference
A. Tolk, S. Y. Diallo, I. O. Ryzhov, L. Yilmaz, S. Buckley, and J. A. Miller, eds.

CASE STUDY: THERMODYNAMIC STEAM CYCLE SIMULATION USING SIMIO - EXTENDED ABSTRACT -

Dave Marquis

Solosi Pty Ltd
32C Talbot Avenue
Como Western Australia 6152

For over a century and a half, man has used water in industrial applications including mining, power generation, chemical processing, etc. The energy transfer properties of water have been understood and utilized since the early 1800s when Scottish civil engineer William John Macquorn Rankine became fascinated with the thermodynamics. His work culminated in the development of the steam cycle bearing his name: the Rankine cycle. Figure 1 shows a typical (academic) representation of a Rankine steam cycle, which in its simplest form incorporates processes of *heat in* (boiler), *heat out* (condenser), *work in* (pump), and *work out* (turbine). For this model, *throttling* (valve) is added for completeness.

The detailed mathematical representations of the states of steam, including its energy carrying abilities, viscosities, mass properties, etc. were not fully defined until 1976, during extensive testing conducted by the *National Bureau of Standards* (now *NIST*). These tests provided the basis for the steam charts, which have been used extensively during the development of modern power plants, etc. And, with the ever-expanding utility of computer technology, the equations can be used directly in the development of design simulations, automated controller development, etc. Since 1995, the *International Association for the Properties of Water and Steam* has continued this work and publishes industrial formulations of the water/steam equations: iapsws.org.

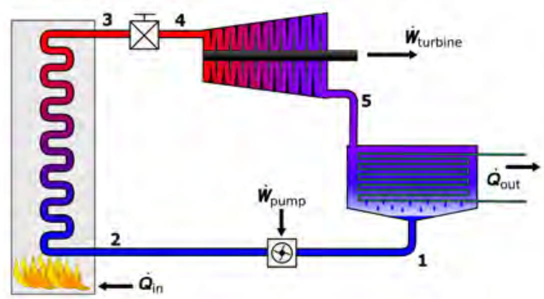

Figure 1: Rankine Cycle

Each component shown in Figure 1 is represented by the general thermodynamic equation:

$$\sum \dot{Q} + \sum \dot{W} + \sum_{in} \dot{m}e - \sum_{out} \dot{m}e = \frac{dMe}{dt},$$

where $\dot{Q}$ is the heat *flux*, $\dot{W}$ is the work "flux", $\dot{m}$ is the mass flowrate, e is the specific (i.e. per unit mass) energy of the fluid and M represents the mass contained within the component. The left-hand side of the equation represents the flow/flux of mass-energy *across the boundaries* of the device, while the right-hand side is the change in mass-energy *inside* the device.

The challenge for implementing these types of system processes is determining out-going states (temperature, pressure and quality, if necessary) as a function of incoming states and work/heat fluxes. Since the steam equations are provided as functions of temperature and pressure (and quality), and deriving the inverse equation set is not practical, a series of searching algorithms is developed for implementation in a hybrid simulation package: Simo.

Typical event-driven simulation software targets purely discrete systems, such as manufacturing, material handling (bulk and discrete), services, and flows that exhibit *if-then* behavior only;

978-1-4799-7486-3/14/$31.00 ©2014 IEEE

i.e. systems that can be reduced to discrete items or quasi-homogeneous properties encountering discrete events, where variability is approximated through statistical distributions.

At the other end of the simulation spectrum, continuous systems have governing equations that are full differential equations, with continuously varying states. Steam equations fall under this category; all that is necessary is event-driven controls.

Fortunately, Simio bridges the two by providing mechanisms for combining the differential continuous system with discrete-events and controls.

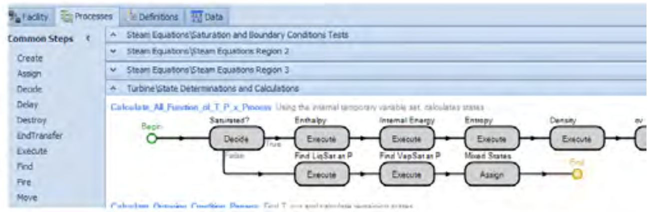

Figure 2: Processes

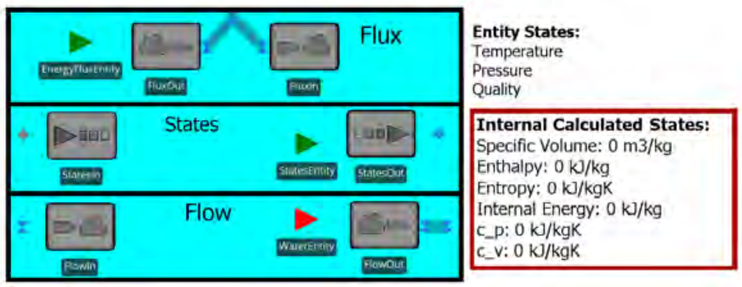

Figure 3: Typical Steam Component Internals

The equations are built into a "base" model using Simio's *Processes*, with pre-compiled *steps* as shown in Figure 2. The interface for this base model is shown in Figure 3, which becomes the uniform building block, through *subclassing*, for the cycle components.

In the model, there are five interface connections: *energy in* or *out* (not both), *mass flow in* and *out* (need both), and *states in* and *out* corresponding to the mass flows. Calculations are triggered by entities crossing the boundaries and internal state-change events (matching the equation above).

With the foundation of Figure 3, the components are built with their respective custom processes and connected in the Rankine cycle, as shown in Figure 4. External controls for energy fluxes and work transfers are constructed. Gauges and numerical displays show the dynamics of the system, while pop-up boxes show additional details not constaintly visually necessary.

While the running system shows fluid flowing through the flow connectors, the green triangles indicate new states being transported from one component to the next.

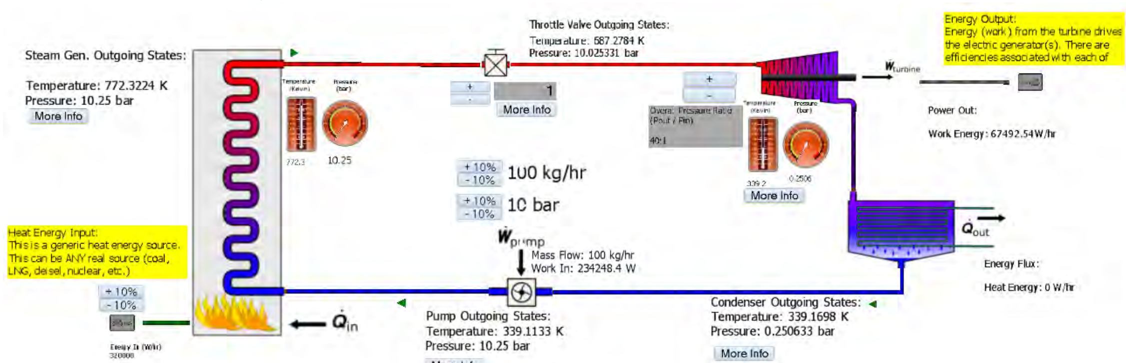

Figure 4: Running Rankine Cycle

This model can be implemented *as-is* within a variety of power generation systems (e.g. different fuels) or modified with multiple parallel/series components to study design concepts, overall functionality/stability, variability, and in operational planning and maintenance exercises.

This case study demonstrates that a single simulation package can be used to study real-world continuous systems with discrete controls and events.