MODELING THE SEATTLE STEAM CO. DISTRIBUTION SYSTEM WITH RELAP5-3D©

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ABSTRACT

Steam generation is a major component of US industry. INEEL, a DOE national laboratory, is working with Seattle Steam Co. to increase their system's operational efficiency. Seattle Steam Co, which has over 18 miles of pipelines, needs a means: to obtain scoping calculations on potential design changes, to optimize their operational efficiency, and to investigate limiting transients. INEEL is assisting Seattle Steam by: modeling their steam distribution system with RELAP5, benchmarking the model using data specifically measured for this purpose, and performing a typical design calculation to assist Seattle Steam to improve and enlarge their system in an efficient manner. Calculations to date match the available data at steady-state conditions. The calculated behavior of a typical condensate trap under steady-state conditions was modeled. Rupture of a 14-inch diameter trunk line just north of Interstate 5 in downtown Seattle was also modeled to demonstrate the limiting transient capability of RELAP5-3D.

INTRODUCTION

All industrialized nations have extensive steam systems. From their most basic uses as steam utilities to the most sophisticated uses where steam systems are designed as the framework on which to build industrial processes, large steam systems exist throughout the United States. Steam is such big business that the Department of Energy has instituted a number of programs that address the operational efficiency of steam systems on a national basis. A program, devoted exclusively to increasing the operational efficiency of online steam systems is: *Steam Challenge.* However, industrial steam systems are also studied in DOE's *Industries of the Future Program, Vision 21 Program,* and others that are aimed at industries such as steel, chemical, petroleum, and forest products.

INEEL, as a DOE national laboratory, is taking part outside of these programs, by cooperating with the Seattle Steam Co to assist them in increasing their operational efficiency and to streamline their design procedures. INEEL is working with other commercial organizations to be included directly in DOE's ongoing programs.

The Seattle Steam Co. Distribution System: The steam distribution system consists of high pressure piping that is pressurized to a maximum of 150 psia and low pressure piping that operates at a maximum pressure of 25 psia. In total, the system has about 18 miles of pipeline (Seattle Steam, 1999) that ranges in size from large mains (14-inch diameter and 12-inch diameter pipes) to 1 to 1 ½-inch delivery lines. The high pressure system, which has been modeled using RELAP5-3D is a total of about 6 miles and is shown in Figure 1.

The steam distribution system is straightforward in concept. Seattle Steam Co. has five boilers located at the Western Ave. boiler plant and one boiler located at the Post St. boiler plant.
The two boiler plants are connected by a 12-inch diameter header pipe so the company has the flexibility to operate using either plant or with some combination of the two plants. The steam provided by the boilers is fed into the main trunk lines along Seneca St. and Cherry St for distribution to their forty-eight business customers and numerous smaller accounts.

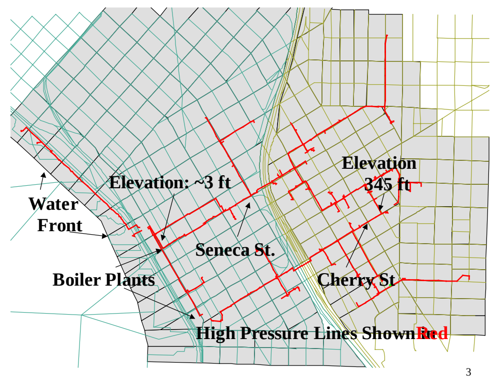

Figure 1. Map showing location of Seattle Steam Co. high pressure lines.

The steam lines are encased in insulation and are buried, beneath the streets of the City of Seattle. Typical dimensions are shown in Figure 2. The pipes are covered with calcium silicate that is wired and blocked (Loper, 1964) followed by direct concrete encasement.

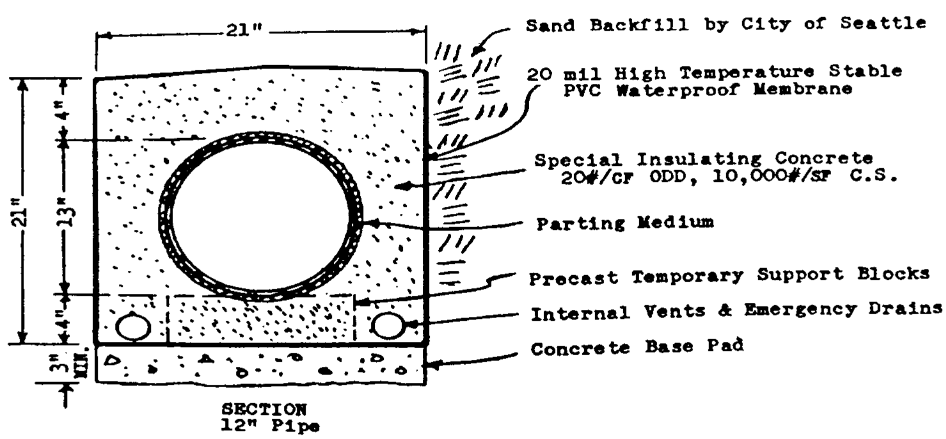

Figure 2. Typical steam line installation—cross -section of 12-inch diameter trunk line including insulation

The system usually provides between 300,000 lb/hr and 350,000 lb/hr of saturated steam, on a typical winter day, for use by their customers. About 31,000 lb/hr is provided to the low pressure steam system

The steam from the boilers enters the steam piping at saturated conditions. Due to environmental heat losses, condensate collects throughout the system and must be removed from the system to maintain an efficiently operating system and also to prevent safety hazards (to mitigate the possibility of condensation-induced water hammer). This function is provided by condensate traps (also called steam traps). Seattle Steam Co typically uses an inverted bucket steam trap built by Armstrong (see Figure 3). When condensate is present above a preset height in the trap, it forces the bucket down and opens the discharge valve. In the case of the Seattle Steam Co system, the condensate is discharged into the city sewer system. Traps are located every 1000 ft or so, depending on the local geometry of the piping system and the grade.

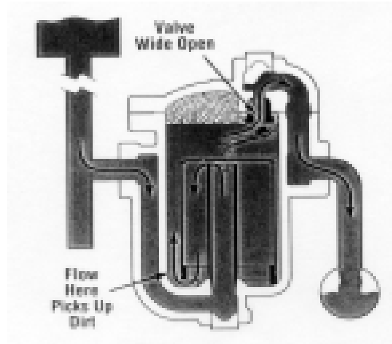

Figure 3. Typical condensate trap—showing condensate flowing from distribution system line into sewer (Armstrong, 1998).

Needs: Seattle Steam Co has a number of requirements that are fulfilled by using RELAP5-3D. Their needs can be placed in three categories:

1. ***Design Requirements:*** Seattle Steam Co often is required to perform scoping calculations on possible design changes, expansions, or improvements on their system. For example, to increase their customer base, Seattle Steam Co may be solicited to provide an estimate for meeting the steam requirements of a new customer such as a hospital. To provide steam for heating, for autoclaves, and a number of other needs, Seattle Steam would have to assess the capabilities of their existing system, design the new main feedline for the hospital, and then perform parametric studies on a number of pipeline routings and sizes to both meet the hospital's needs and operate their system at is optimum efficiency level.
2. ***Optimize Operational Efficiency at Different Operating Conditions:*** Changes in the operating patterns of Seattle Steam Co's customer base sometimes shift and cause the operational steam flows through the main trunk lines to undergo large changes. Therefore, Seattle Steam Co is required to define their operational envelope as a function of customer needs according to the season.
3. ***Investigation of Limiting Transients:*** Seattle Steam Co has several limiting transients that occasionally require analysis. These transients usually fall into the category of scenarios that may be investigated to minimize the company's litigation exposure. Examples inlcude:
   a. Pipe rupture: Determine the system behavior following an inadvertent pipe rupture. This question arises in conjunction with heavy equipment causing a breach in the piping network during normal operating conditions.
   b. Rapid cooldown: Past history has shown that when other utilities operate equipment near the steam distribution system, water mains have been inadvertently ruptured. The presence of cold water adjacent to a steam main will cause unnaturally large steam condensation with the potential for overloading the available condensate trap. This scenario leads to the presence of highly subcooled water in the presence of saturated steam—a precursor to condensation-induced water hammer.

Prior to working with RELAP5, Seattle Steam Co had not been successful at finding a tool that was capable of analyzing their steam system because available software is aimed at analyzing: (i) single-phase incompressible transient flow (thus steam-water phenomena are not analyzed correctly) or (ii) two-phase steady-state compressible flow (so multiphase flow dynamics are not properly treated). RELAP5 has been found to meet the needs of the Seattle Steam Co.

COOPERATIVE EFFORT

The cooperative effort between Seattle Steam Co and INEEL consists of the following elements:

1. Construct a RELAP5 model of the Seattle Steam Co high pressure system.
2. Benchmark the model using data recorded on site to determine typical friction factors of the pipelines.
3. Perform a typical design calculation as a demonstration of capability.
4. Create a "Deck-Builder" to enable an engineer, not intimately familiar with RELAP5, to perform design calculations and limiting calculations.

Phase 1 is completed and Phases 2, 3, and 4 are underway.

RELAP5 MODEL OF SEATTLE STEAM CO DISTRIBUTION SYSTEM

The RELAP5 model is shown in Figure 4 (RELAP5-3D Development Team, 2000). The model was constructed using only the PIPE, BRANCH, VALVE (motor operated), SNGJUN, TMDPJUN, and TMDPVOL components. For now the boilers are represented by time dependent volumes. The condensate traps are located on the bottom of the pipeline and represented by vertical volumes that contain a representative volume for a typical trap. The trap volumes are linked to valves that are controlled to open and close based on the quantity of liquid present in the trap volume. Steam bleeds, sized to represent the average steam flow requirement for a representative quantity of Seattle Steam Co's customers, are represented by choked orifices.

Environmental heat losses were modeled by using heat slabs on all pipe sections. The insulation shown in Figure 2 was modeled with an outer pipe boundary condition that consisted of a constant temperature sink of 50 °F. The insulation thermal resistance was estimated on the basis of Seattle Steam Co's estimate of the quantity of condensate that is present in their distribution system for a standard operating condition.

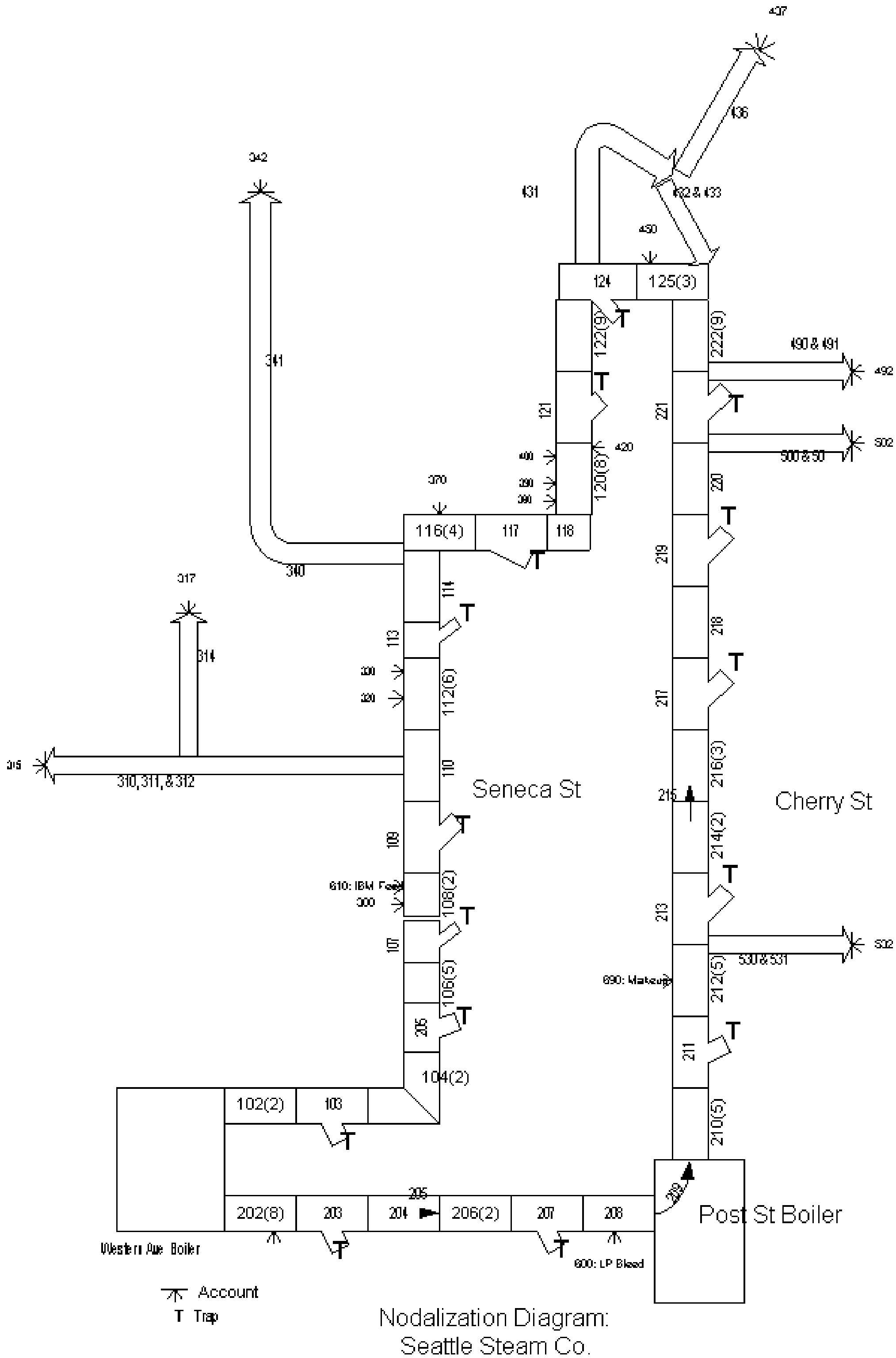

Figure 4. RELAP5 Nodalization of Seattle Steam Co Distribution System

ANALYSES

Steady-State Calculations: Steady-state calculations have been performed to compare the calculated and measured pressures at the distribution system's farthest extremity (at the Swedish Hospital) for the standard winter operating condition with a 75% plant production supply flow. Seattle Steam Co's data indicates:

- Supply pressure = 155 psia
- ΔP_{loss}=27 psi
- Heat losses ~5%.

The calculated pressure at the Swedish Hospital is shown in Figure 5 and is a good match to the data.

Also shown is a typical fill-empty cycle for one of the condensate traps (No. 810). The cycle length is approximately 16 minutes.

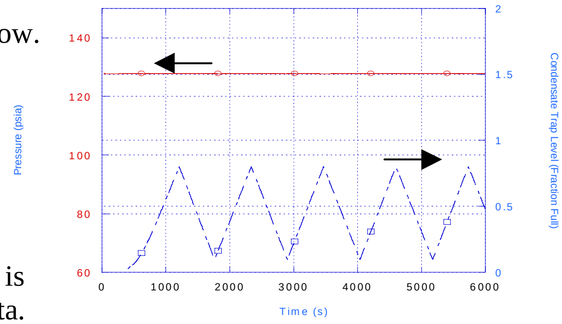

Figure 5. Steam distribution system steady-state calculation: pressure @ Swedish Hospital & condensate trap fill-empty cycle rate.

Pipe Rupture at Interstate 5: A 14-inch diameter pipe rupture just north of Interstate 5 was simulated. The results indicate the line pressure dropped from 131 psia to 47 psia in about 40 s. The calculated depressurization does not include the effect of the boiler dynamics—since only a time dependent volume/junction was used to model its presence. These results are shown in Figure 6.

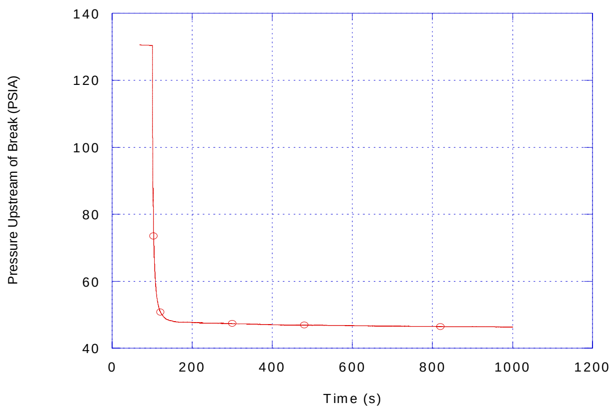

Figure 6. Depressurization resulting from 14-inch diameter pipe rupture north of Interstate 5

STATUS & FUTURE PLANS

The cooperative effort between Seattle Steam Co and INEEL is demonstrating the feasibility and usefulness of modeling steam distribution systems to streamline the design process, to enable the calculation of system optimization to become a reality, and to produce credible calculations of system limiting transients. Future work will focus on linking the dynamics of typical boiler systems with the steam distribution system behavior. One of the ways this can be done is to link codes that are boiler model specific to RELAP5. Realization of this objective will allow interactions between the combustion process ongoing in the boiler and the steam production process to be linked. Thus reaction kinetics models, simulating the interplay between the variables that influence combustion process emissions, can be coupled with the steam system demand and models of the control systems that are required to maintain the boiler at its peak operational efficiency.

REFERENCES

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