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Simulation of super-heated steam generator for performance analysis

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ABSTRACT

This paper presents bond graph simulation, analysis and experimentation of super-heated steam generator on 20sim software. A cylindrical tank of 4 liters capacity with inlet, outlet and drain plug mounted with pressure sensor acts as boiler shell designed to be charged to 80% with coal heating and generates the steam inside the shell. When the pressure crosses 4 bar absolute then pressure operated NRV on outlet opens, the steam thus enters into copper tube of 12mm diameter, where it is superheated. The output of this pipe is designated to operate turbine developed for the cause. The bond graph model of this setup is the objective of this dissertation. Wherein pressure in tank, mass flow rate and pressure of superheated steam are estimated, which are validated on the experimental setup fabricated. The power variables of interlinked thermal, mechanical and thermal domain are mapped.

Keywords— **Analysis of steam generator, Bond graph modelling, Superheated steam.**

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I. INTRODUCTION

Wet steam, i.e. steam containing water droplets, is extremely common even in piping used for processes that run 24/7.When steam isn't kept dry, system is more likely to encounter problems due to scale and other foreign matter. This is because the water droplets entrained in the steam can break off hard pieces of foreign matter such as dirt from the pipe walls, which then flow downstream. High concentrations of solidified conditioning agents used in boiler feed water can also cause problems. These can severely affect equipment service life and diminish productivity because of product quality problems. So there is a need to generate superheated steam.

Mostly a heat exchanger consisting of a number of straight-through, once through, or U-shaped tubes is used to exchange the heat between a primary coolant circulating through the reactor core and a secondary coolant that is converted to steam. The tubes are relatively simple to manufacture and install using mechanical methods of connecting the tubes to a tube sheet. By expanding of the tubes, deformation occurs, that leads to a weakened state of the tube wall and is a point of failure.

The proposed system consists of a cylindrical tank of 4 litters capacity with inlet, outlet and drain plug mounted with pressure sensor,acts as boiler shell designed to be charged to 80% with coal heating and generates the steam inside the shell. When the pressure crosses 4 bar absolute then pressure operated NRV on outlet opens, the steam thus enters into copper tube of 12mm diameter, where it is superheated. The output of this pipe is designated to operate turbine developed for the cause. The advantage of coiled tubes is that they can be used to pack more surface area in a small volume. The superheated steam thus generated is used to drive the turbine. Coiled tubes also have better heat transfer coefficient and residence time distribution. The simulation of this system is done in 20Sim software's bond graph modelling. Bond graphs are representative graphs for a system. Bond graph modelling is dependent on power variables which are interlinked and mapped. The system is validated on the experimental setup. The section III presents the details of designing of the superheated steam generator.

The section IV presents the bond graph modelling of system, which is the objective of this dissertation. The Section V presents the experimental and simulation results. The section IV presents the conclusion obtained.

II. LITERATURE REVIEW

Optimization and payback period of steam production by biomass combustor for Agro-industry,increases efficiency and reduces the cost [].Modeling of Power Plant Superheated Steam Temperature Based on Least Squares Support Vector Machines shows that, the controlling system can be adapted to the variation of the object characteristic well with strong non linearity and large time varying characteristics rapidly[].A nonlinear model of heat exchanger for steam superheating unit is a part of 250MW power station, is composed of three heat exchangers with front-end spray attemperator. This modeldevelops control algorithms and verifies existing algorithms, too [1]. A numerical method to determine the proper rate of spray water mass flow to be supplied to an injection attemperator keeps the steam temperature of the superheated outlet at a constant level, when the parameters of steam at the inlet to the attemperator and combustion gases at the inlet to the super heater vary. [2]Theoretical study of direct steam generation in two parallel pipes shows that RELAP is able to get the most stable solutions. It was found that for symmetric solar heating, asymmetric flow distribution solutions may be present in the system. Also, for asymmetric heating the mass flow rate is larger in the pipe with smaller heating. This is an unfavorable condition under a practical point of view. [3].Control of water level strongly affects nuclear power plant. The control is difficult due to the nonlinear plant dynamics and the non-minimum phase plant characteristics. It has been seen that in the case of nonlinear processes, the approach using fuzzy predictive control gives very promising results [4].

III.LAYOUT SYSTEM

The stream generator generates dry steam at high temperature.

Water is fed into the tank and is heated by coal till steam is generated to the desired pressure. When desired pressure is reached the valve opens and steam flows into the super-heater, there it is heated again to generate superheated steam. The block diagram of the system is shown in fig 3.1.

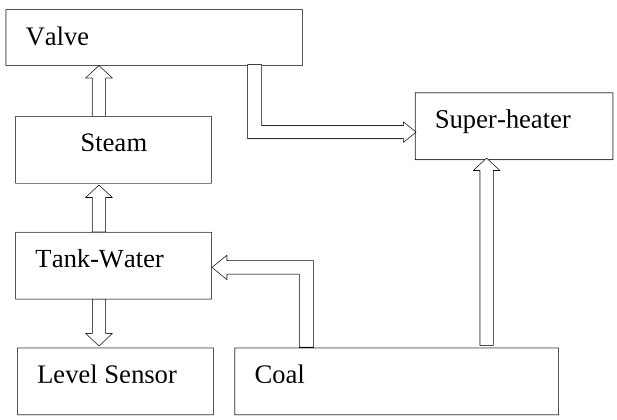

Fig. 1 Block diagram of the system

A. TANK

A tank with capacity of 4 litters is selected. The tank has diameter of 150cm and 400cm height. The tank is made up of MS steel and has flanges outside. Pressure gauge, level sensor and pressure relief valve are mounted on the tank. This tank has inlet for water to enter into the tank, outlet for water to flow into the next section and drain for excess water to drain off. The water is fed into the tank. The level sensor senses the level of water and stops filling water when the desired level is reached. This tank is filled upto 80% with water.This tank is heated to generate steam.

B. LEVEL SENSOR

The level sensor is mounted on the tank. Level sensor senses the water level in the tank. Water is filled in the tank till the desired level is reached.

C. VALVE

The tank has a pressure relief valve mounted on the top. This pressure relief valve is mounted to discharge steam at desired pressure .The pressure relief valve is set to open at 4 bar gauge pressure.

D .HEATER

The heating is done by burning coal. The coal has calorific value of 4180J/s. 0.5 kg of coal is burnt in a try. This tray has holes from where the ash drops into the tray bellow and the ash is collected there.

E. COPPER TUBES

The copper tube of 12mm diameter is selected. These tubes are bent to form open loops. Each loop has a turning radius of 127mm and length of 100mm.Layers of such loops are formed. Each layer contains 3 open loops. The bending of pipes in such manner is done to increase the area occupied by the steam.

IV. WORKING OF THE SYSTEM

The working of the system is shown in fig.4.1

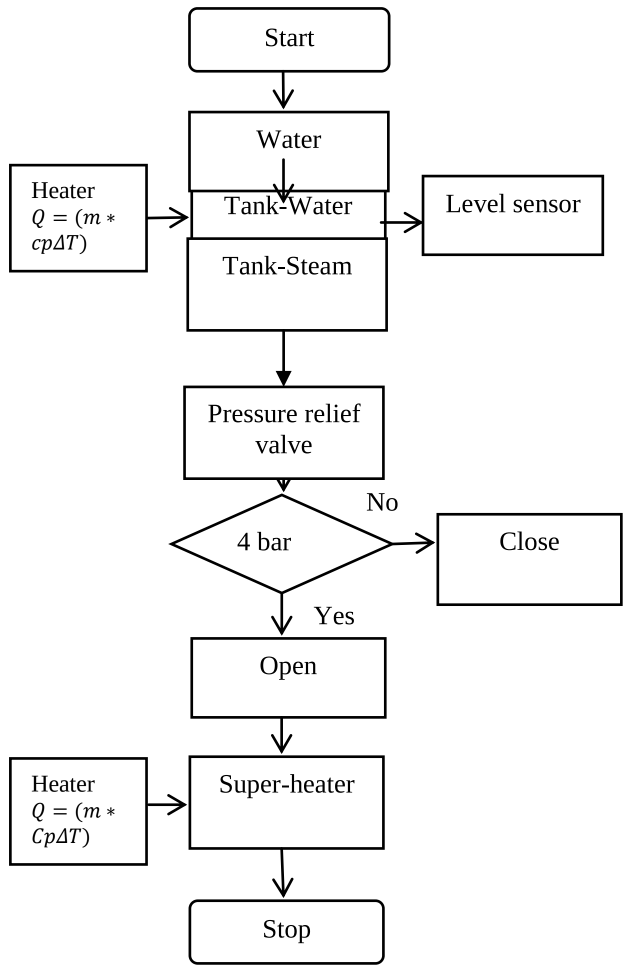

Fig. 2 Flow chart of the system

Water flows into the tank and is filled up to 370cm, as indicated by level sensor. The water is then heated by coal. The heat supplied is given by

$$Q = (\mathrm{m} * \mathrm{Cp}\Delta\mathrm{T})$$

Where,
Q=heat supplied
m=mass =1Kg
Cp= specific heat=4180 KJ/s
ΔT=Change in temperature = $T_2 - T_1$
T_1=$25^0 C$

Heat supplied, mass and specific heat and ambient temperature is known.So, T_2 can be calculated.The steam generated due to the heat supplied occupies the remaining volume of the tank. The temperature goes on increasing up to the saturation temperature i.e.$100^0 C$ is reached. After the saturation temperature is reached, the pressure of steam generated goes on increasing. The pressure of steam is calculated by following equations.

$$\dot{Q} = C_d * A * v \quad \text{.....} \quad (1)$$

$$\dot{Q} = m/\rho \quad \text{.....} \quad (2)$$

$$v = \sqrt{2 * g * h} \quad \text{.....} \quad (3)$$

Where,
$\dot{Q}$=Volumetric flow rate
C_d=Coefficient of discharge
m=mass of water
A=Surface area of tank
h=Height
ρ=Density

The dryness factor is calculated by:
$$x = (h - h_{fg})/h_{fg} \quad \text{.....} \quad (4)$$
Where,
h_{fg} =specific enthalpy
The specific volume of dry steam is calculated by:
$$V_f = V/m \quad \text{.....} \quad (5)$$
The specific volume of wet steam is calculated by:
$$V_{fg} = x * V_f \quad \text{......} \quad (6)$$
The pressure corresponding to V_{fg} is found from the steam table. When pressure reaches to 4bar, the pressure relief valve opens and steams flows into the super-heater. The steam flowing into the super-heater is heated again by heater. The flowing has very small mass flow rate and thus is heated efficiently in small time span. The temperature of steam rises and the water content present in it gets evaporated. Thus, superheated steam is generated.

V. BOND GRAPH MODELLING

Bond graph modelling is based upon the energy flows between the ports of the components. The nodes of a bond graph have power ports. Bond graph nodes are multiport. Energy can either exit or enter from the ports. Specific representations for nodes of graph are used in iconic diagrams.

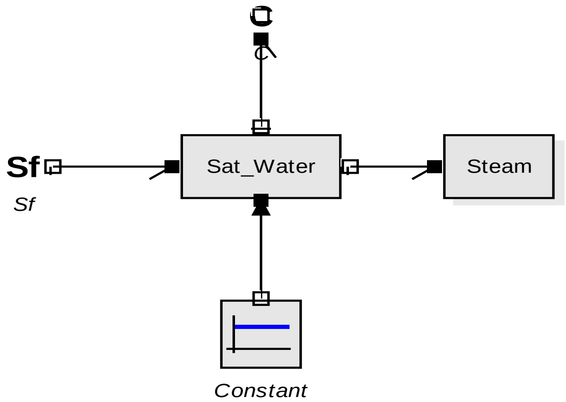

Fig. 3 Complete model

Sf

In Sf element flow rate is given. Sf has causality of fixed flow out. It is connected to submodel- sat_water by bonding. The output of this element is effort.
parameters
real flow = 9722;
variables
real effort;
equations
p.f = flow;
effort = p.e;

1. C

The C element integrates the flow and gives effort. Causality of the element is preferred effort out.
parameters
    real global Tatm = 25;
    realCp = 4180;
    real global mw = 1;
variables
    real global mw_rem;
    real global Tsat;
equations
state = int(p.f);
p.e = Tatm + (state / (mw * Cp));

2. Sat_Water
   This block calculates the saturation temperature. 1 bar pressure is given as input in the constant block and signal C is given as input to the sat_water.

variables
    real global TSat;
equations
    TSat=((6e-16)*(p^3))-((7e-10)*(p^2))-(0.0004*p)+67.756;
    if p2.e <TSat then

```
        p2.f = p1.f;
        p1.e = p2.e;
        p3.f = 0;
else
        p2.f = 0;
        p3.f = p1.f;
        p1.e = p3.e;
        p2.e = TSat;
end;
```

3. Steam

This block calculates the pressure of steam, the mass of water left and mass of steam. Sat_water’s output is fed to this block. The pressure calculated is fed to the constant block and Tsat is re-estimated.

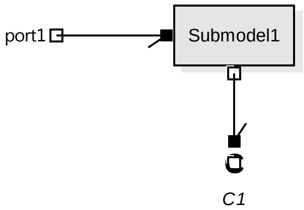

Fig. 4 Sub model

```
Submodel1
parameters
        real global Tank_Vol = 0.003925;
        real global mw;
        real R = 8314;
variables
        real global TSat;
        realSteam_Mass;
        realSteam_Vol;
        realMass_Water_Left;
        realWater_Vol;
        real vg, vf, hfg;
        realvsf;
        realsteam_pressure;
        real p;
        real x;
initialequations
        Steam_Mass = 0;
        vsf = 2;
        steam_pressure = 101300;
equations
        vg = (-0.028 * TSat + 4.442);
        vf = (9e-07 * TSat + 0.001);
        hfg = (-2838 * TSat + 3e06);
        p2.f = p1.f;
        Water_Vol = mw * vf;
        Steam_Vol = Tank_Vol - Water_Vol;
        Mass_Water_Left = mw - Steam_Mass;
        x = (p2.f / (hfg * Mass_Water_Left));
        Steam_Mass = x * mw;
        ifSteam_Mass> 0 then
                vsf = Steam_Vol/Steam_Mass;
                ifvsf< 2 then
                        vsf = 2;
                end;
                ifvsf> vg then
                        steam_pressure = 101300;
                        p3.e = steam_pressure;
                        p3.f = 0;
                        steam_pressure = (17555 * (vsf^-1.06));
                        p3.e = steam_pressure;
                        p3.f = 0;
                        TSat = 99.79 * steam_pressure^(0.264);
                        end;
        end; */
        p1.e = TSat;
```

VI..EXPERIMENTAL SETUP

The fig 6.1 shows the experimental setup of the system. Water is fed in to the tank. The tank capacity is 4 litters. The tank has flanges at top and bottom. A level sensor is mounted on the tank to check the level. The tank is filled utpo 80% with water. The remaining volume is occupied by the steam generated. Heating is done by burning coal. The generated steam is stored in the top of the tank. When 4 bar pressure is reached, the pressure relief valve mounted on the top opens and steam vents.

Fig 5 Experimental setup

Fig 6 Flanges and pressure gauge

The steam flows into the copper tubes and there it is reheated to generate superheated steam.

VII.RESULTS

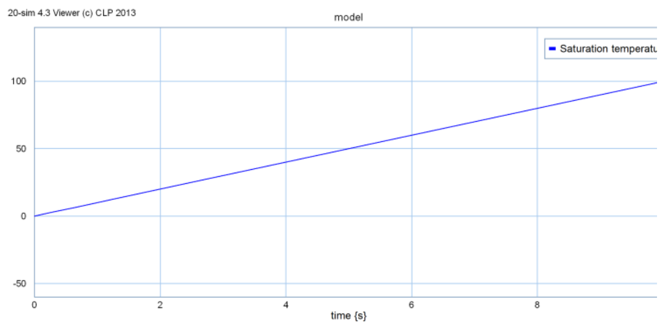

Fig. 7 Saturation temperature

The saturation temperature is at $100^0 C$.after which steam is generated. This is the output of sub model. The saturated temperature obtained by bond graph modelling and by that of experimental validation is the same.

VIII..CONCLUSION

The superheated steam generator is simulated in 20sim software's bond graph modelling. The performance of the system is analysed. The validation is done on the experimental setup. This system is small in size. The system generates superheated steam at very low cost. The analysis is adaptable to changes in the sizes. The steam generated by this system is used to drive the turbine.

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