A STUDY ON DEVELOPMENT OF STEAM GENERATOR FOR DOMESTIC STEAM CLEANER

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The steam generation mechanism is the key technology of the domestic steam cleaner. Not only the weight and the price of the steam cleaner but also the performance of the steam generation mechanism should be considered to improve the competitive power of the products. In this study, a steam generator which is called coaxial steam generator was recommended for compensating the drawback of the spray boiling steam generator. At first, the safety of the coaxial steam generator was studied for checking the possibility of developing a high performance coaxial steam generator. Furthermore, an analysis of the eccentric steam generator was carried out for improving the safety of the coaxial steam generator. The steam generator will be highlighted in the field of the domestic steam cleaner because of its many merits shown in this paper.

Keywords: Steam Generator; Heat Transfer; Computer Aided Analysis.

1. Introduction

The volume change can be obtained by changing water to steam. The engines such as piston type engines and steam turbines can obtain mechanical work by using the volume change from water to steam. From the industrial revolution, piston type steam engines played a central role to modern steam turbines [1, 2]. They are used to generate about 90% of all electricity.

Besides power generation, steam is also used in cleaning process like clinical applications in the hospital as a steam cleaner. Steam cleaners are cleaning appliances or devices that use steam to clean and sanitize surfaces. The process is very efficient to disinfect or even sterilize the surfaces. Steam is produced in a boiler that heats tap water to high temperatures to produce low-pressure steam. The cleaning ability of steam is based on its heat. Steam is applied to cleanable surfaces to break soil bonds and release contaminants into water suspension, after which they can be easily removed.

Environmental surfaces in health care have been often contaminated by microorganisms. These surfaces are commonly associated with disease

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transmission [3-5], and environmental cleaning is critically important to reduce the risk of infection. Traditional cleaning methods can involve detergents and disinfection with chemicals. Liquid chemical disinfectants are usually used to decontaminate environmental surfaces. These compounds are often inefficient in eradicating biofilms and toxic to humans, or require long contact times for disinfection. Thermal disinfection with steam technology has been used to sterilize critical medical devices.

Gillespie et al. [6-8] have introduced microfiber and steam technology adopting chemical free cleaning and improve operating room cleaning outcomes. The benefits include that the overall water use was reduced by 90% for each ward, measurements using bioluminescence before and after cleaning are significantly reduced, and reduced cost of cleaning, allowing for expansion of cleaning activity without the need for additional human resources.

To investigate the disinfection efficacy of dry steam against biofilms, Song et al. [9] have developed different bacterial strains on polycarbonate coupons, then disinfected with the steam vapor device for a few seconds. All test biofilms were killed rapidly through steam vapor generated from the device. They also compared disinfection efficacy by dry steam and chemical disinfectant against biofilms. From the results, only 1 second of steam vapor disinfection was required to reach using 10-minute 10-ppm sodium hypochlorite treatment of disinfection.

Therefore, steam cleaner need to be widely studied as domestic cleaning because of steam vapor's ability to kill germs and in some cases disinfect without the use of chemical disinfectants. Steam is also effective in killing dust mites in carpet, bedding, and upholstery. For the family use, the steam cleaner should have an effective steam generator. But most of the literature focuses on steam generators in power plants about their design, calculation methods and characteristics [10–13].

The study on the steam generator based on spray boiling has been widely researched in order to shorten the warm-up time and minimize the content of dirt in vapor. The warm-up time can be remarkably shortened because the little water which has been sprayed on a hot surface of over 100 ℃ is quickly vaporized. Also, the content of dirt in vapor can be remarkably minimized because the heater just has a contact with water under the condition of generating vapor [14-16]. Figure 1 shows the structure of a spray boiling steam generator used to a domestic steam cleaner.

Not only a spray boiling steam generator but also a pump for supplying water and a water tank are assembled in a domestic steam cleaner. Therefore, the structure becomes complicate due to the necessary components. Also, the weight and volume become larger. The weight and volume of the steam generator need to be reduced for easier handling.

In this study, a coaxial steam generator was recommended for compensating the drawback of the spray boiling steam generator. The characteristics of the coaxial steam generator was analyzed using numerical method.

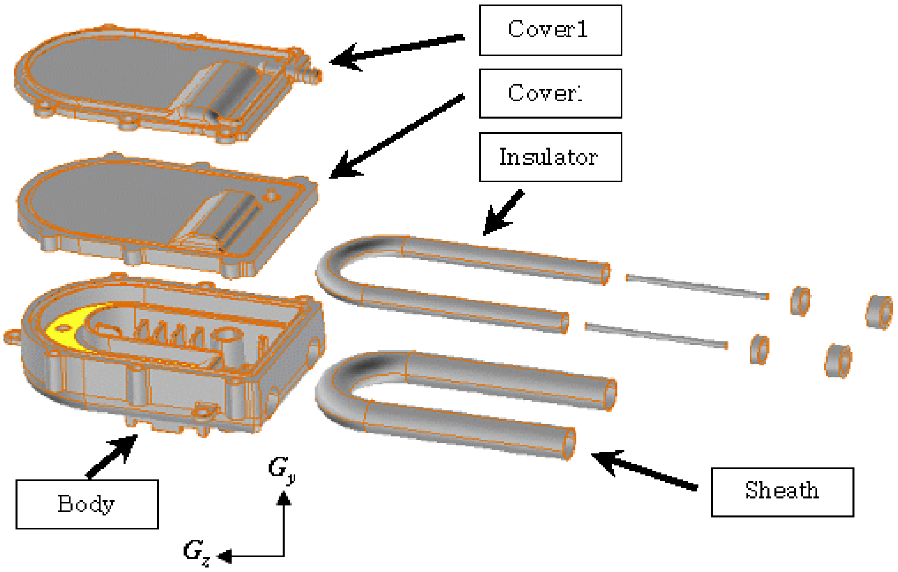

Fig. 1. Spray boiling steam generator using a sheath heater

2. Coaxial Steam Generator.

In order to develop a high performance, low cost steam generator, a coaxial steam generator shown in Fig. 2 was recommended. The coaxial steam generator is composed of the sheath heater and the cover.

The warm-up time can be minimized because the coaxial steam generator allows the sheath heater a direct contact with water [17]. Because of relatively low temperature of the steam generator's cover, the insulator packaging the steam generator can be deleted.

The main drawback of the coaxial steam generator is the safety because the sheath heater is not always in contact with water. Also, the cover of the coaxial steam generator cannot be used to control the temperature of the sheath heater because the cover is not sufficiently responsive to show the temperature variation of the sheath heater.

2.1 Heat Transfer Theory

Heat transfer is the exchange of thermal energy between objects or media. The rate of heat transfer depends on the temperature differences between the objects and their material properties. Conduction, convection and radiation are 3 basic modes of heat transfer. Heat transfer is a process by which a system's internal energy is changed. The direction of heat transfer is from a region of high temperature to another region of lower temperature, which increases the entropy of systems. Heat transfer ceases when thermal equilibrium is reached.

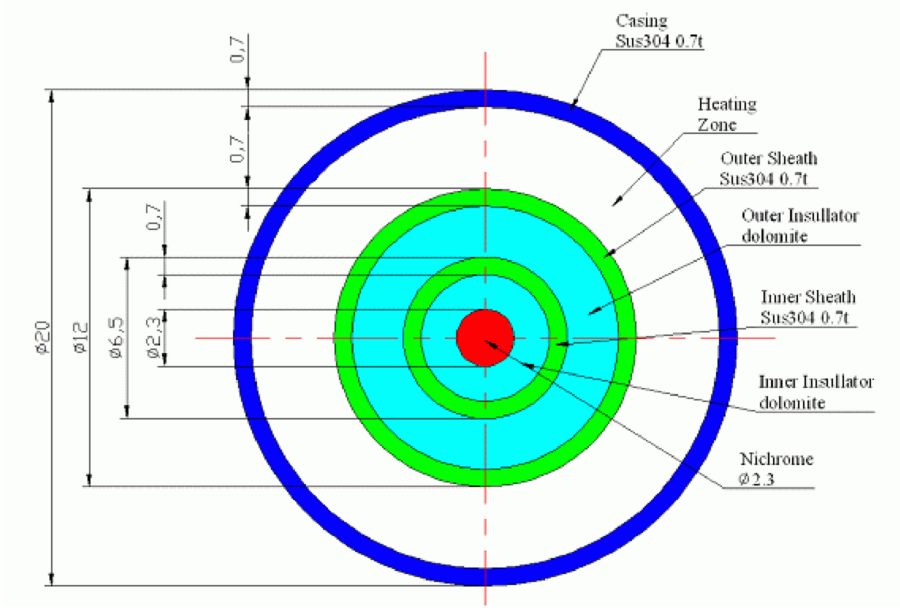

Fig. 2. Coaxial steam generator

On a microscopic scale, heat conduction happens as hot, rapidly moving or vibrating atoms and molecules interact with neighboring atoms and molecules, transferring some energy to these neighboring particles. In other words, energy is exchanged by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is very popular type of exchanging heat within a solid or between solid objects. Fluids and gases are less conductive.

The fluid flow may be forced by external processes, or sometimes by buoyancy forces caused when thermal energy expands the fluid, thus affecting its own transfer. The latter process is named natural convection. The processes of convection also move heat partly by diffusion, as well. Another form of convection is called forced convection. In this case the fluid is forced to flow using a pump, fan or other devices.

Thermal radiation happens through a vacuum or any transparent medium. Radiation can move energy using photons in electromagnetic waves. Radiation is energy emitted by matter as electromagnetic waves, due to the pool of thermal energy in all matter with a temperature above absolute zero. Radiation propagates without the presence of matter through the vacuum of space.

Vaporization of an element or compound is a phase transition from the liquid phase to vapor. There are two types of vaporization: evaporation and boiling. Evaporation is a surface phenomenon, whereas boiling is a bulk phenomenon. Evaporation is a phase transition from the liquid phase to vapor (a state of substance below critical temperature) that occurs at temperatures below the boiling temperature at a given pressure. Evaporation occurs on the surface. Evaporation only occurs when the partial pressure of vapor of a substance is less than the equilibrium vapor pressure. Boiling is also a phase transition from the liquid phase to gas phase, but boiling is the formation of vapor as bubbles of vapor below the surface of the liquid. Boiling occurs when the equilibrium vapor pressure of the substance is greater than or equal to the environmental pressure. The temperature at which boiling occurs is the boiling temperature, or boiling point. The boiling point varies with the pressure of the environment.

2.2 Safety Analysis about Burning Out

The operation of the steam generator used to the domestic steam cleaner is time-dependent, so it can not be sure that the sheath heater is always in contact with water. The left and right figures in Fig. 3 show the cases that the sheath heater is in contact with water or not, respectively. The sheath heater can be over heated because of the low heat transfer coefficient of air or steam in the right case shown in Fig. 3. In order to investigate the two cases, an analysis was carried out using FLUENT which is one of the commercial codes used to simulate the thermal and fluid systems [18, 19].

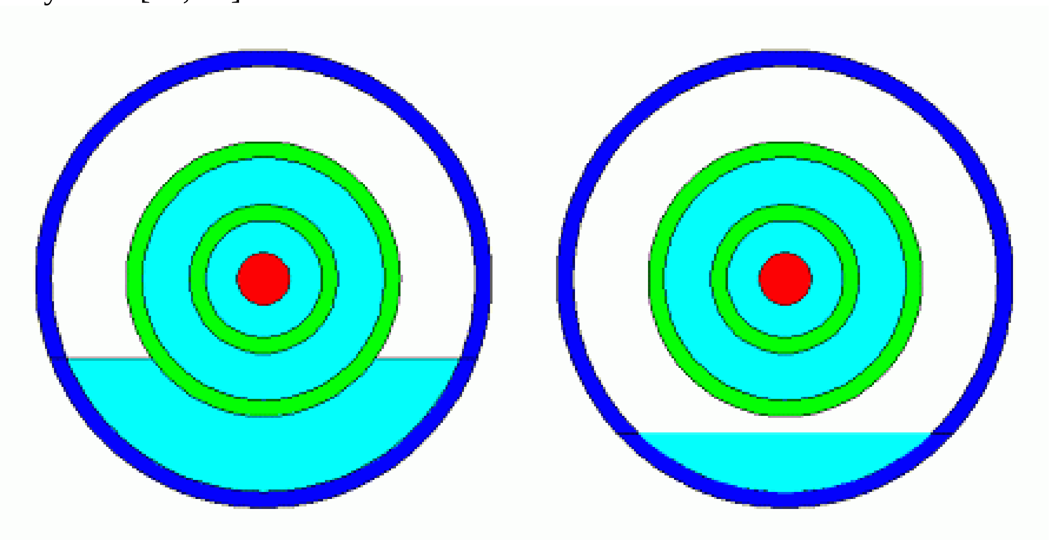

Fig. 3. Analysis cases

In this analysis, a steady-state simulation was carried out for checking the safety of the coaxial steam generator using 2D model. The heat transfer happened in the coaxial steam generator was considered for obtaining the temperature distribution [19, 20]. The materials shown in Table 1 were used in this analysis.

Table 1.

Properties of each material

Item	Nichrome (80%Ni, 20% Cr)	SUS304	Dolomite (CaO-MgO_2CO_2)
Density(kg/m3)	8400	7900	2872
Specific Heat(J/kg.K)	420.1	477.1	910
Thermal Conductivity(W/m.K)	12	14.9	1.75

The schematic of the coaxial steam generator was shown in Fig. 2, and the power of the sheath heater was set as 700 W. The mass flow rate of water was 15.5 cc/min, and water was sprayed continuously. In this simulation, Water was handled as a heat sink under the condition of considering that 25 ℃ water has been changed into 100 ℃ steam. The boundary condition of the cover was the condition of natural convection.

As we konw, the heat due to phase change is much larger than the heat due to the temperature increasement, so it has the significant effect on the accuracy of the simulation. For the heat sink sink due to evaporation and the temperature increasement can be expressed by Eq. (1). Where Q is total heat sink due to evaporation and the temperature increasement, m is mass flow rate of water, C_p is the specific heat of water, T_1 is the initial temperature, T_2 is the final temperature, and h_{fg} is thecoefficient of latent heat from water to vapor.

$$Q=mC_p(T_2- T_1)+mh_{fg} \tag{1}$$

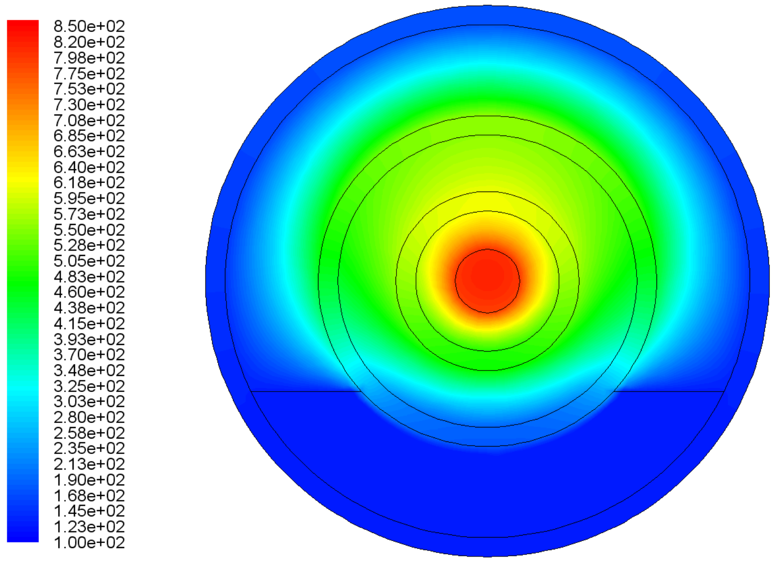

Fig. 4(a). Temperature contour of the steady-state analysis (in contact with water)

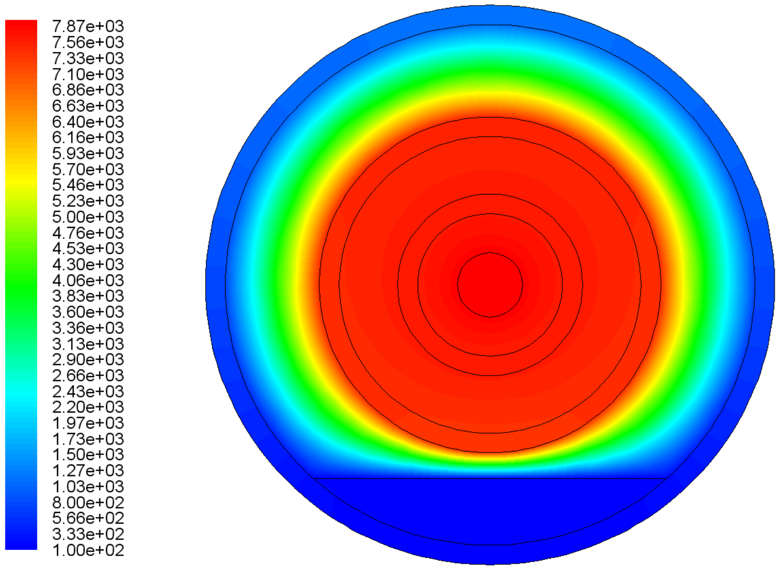

Fig. 4(b). Temperature contour of the steady-state analysis (not in contact with water)

The temperature of the cover in the 2 cases keeps about 100 ℃ as shown in Fig. 4. The temperature of the NiCr wire in the case that the sheath heater was in contact with water was about 820 ℃, but the temperature in the other case was 7800 ℃. It means that the sheath heater had been damaged when the sheath heater was not in contact with water. In a word, the sheath heater should be in contact with water for improving the safety of the coaxial steam generator.

2.3 Method for improving safety.

An analysis of a eccentric steam generator shown in Fig. 5 was carried out in order to improve the safety of the coaxial steam generator. The analysis condition was the same as the analysis in the previous simulation. Figure 6 shows the contour of velocity field due to the natural convection and temperature field. As shown in the analysis result, the safety of the steam generator can be improved because the eccentric steam generator can be in contact with water more sufficiently under the condition that there is just a little water in the steam generator.

In a word, the safety of the coaxial steam generator can be improved by adjusting the position of the sheath heater in the steam generator, but the coaxial steam generator need to be controlled using the temperature of the NiCr wire directly for considering the case that there is no water in the steam generator.

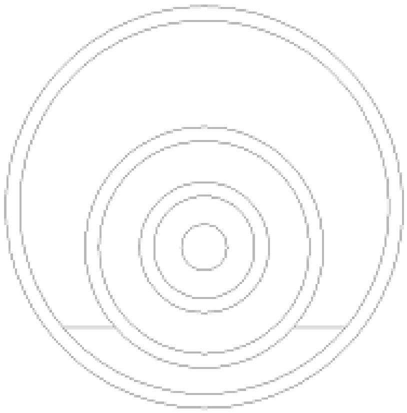

Fig. 5. Schematic of the eccentric steam generator

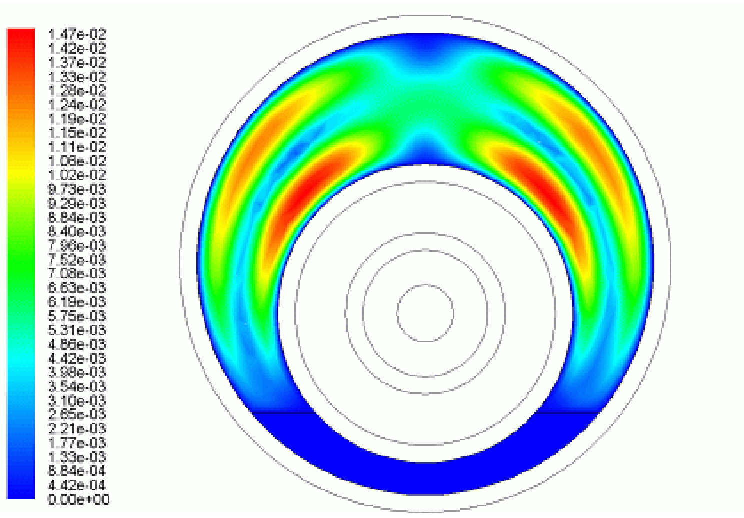

Fig. 6(a). Contour of the velocity field (analysis result of the eccentric steam generator)

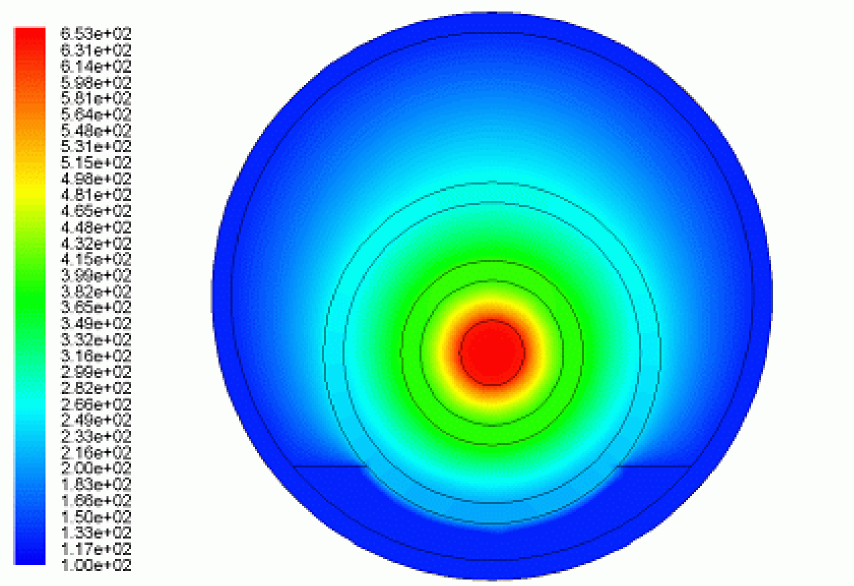

Fig. 6(b). Contour of the temperature field (analysis result of the eccentric steam generator)

3. Conclusions

The characteristics of the coaxial steam generator including the safety was discussed in order to check the possibility of developing a high performance, low cost steam generator for a domestic steam cleaner. The coaxial steam generator has many merits compared to the spray boiling steam generator, but main drawback of the type should be improved for mass production. The coaxial steam generators will be highlighted in the field of the domestic steam cleaner because of many merits under the condition of minimizing the drawbacks.

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