Performance analysis of inert gas systems in main distribution board room using fire dynamics simulation

Nummon Rattananon¹,* and Supat Patvichaichod²

¹Safety Engineering and Environmental Management Program, Kasetsart University Sriracha Campus, Chonburi, Thailand.
²Department of Mechanical Engineering, Safety Engineering Research Group, Kasetsart University Sriracha Campus, Chonburi, Thailand.

*E-mail: blue_biot@hotmail.com

Abstract. This study focused on the fire-extinguishing performance of inert gas in main distribution board room using fire dynamics simulator. The study included 4 types of inert gas: Nitrogen, Argon, Argonite and Inergen. The simulation was done in a 1 meters wide x 2.1 meters height x 1 meters deep main distribution board. In simulation, according to each type of inert gas, 3405.0 kW/m² heat release rate of electrical wires with ramp-up time at 492.0 second using concentration of inert gases based on NFPA 2001 standard. With initial concentration of Nitrogen at 41.9%, Argon 52.9%, Argonite 42.7% and Inergen 38.5% and also simulated the incidents when increased safety factor of Class C fire to 50% and 100% respectively in all 4 experimental gases which divided into 12 cases. The results showed that different types of inert gases did not affect the fire-extinguishing performance caused by the same fuel in the same environment. And the increasing of safety factor of Class C fire by 50% and 100% respectively in all 4 types of inert gas did not improve their fire-extinguishing performance.

1. Introduction
Fire accident is one of a disaster causing severe damage to lives and properties. It can happen anywhere and anytime, unavoidable. Because fire or heating is a part of our day to day life and this can be a source of fire hazard [1]. Most of fire accidents caused by electrical systems, some examples of those accidents described as follows: A fire accident in electrical control room in Patong’s water quality improvement plant. Before the incident a loud explosion occurred, then the flame was spotted in the room. After the situation was controlled, the inspector found electrical devices in the control room received heavy damage, assuming a short circuit. Another example from a fire accident occurred in electrical control room in Khon Kaen airport; a thousand of passengers riotously attempted to flee from the building. After the incident they found major damage only in the control room area causing airport shutdown. As we can see that electrical production and control system not only improves everyday life, industry and economy but also can cause severe damage to lives and properties as well. As the system has to operate all the time; which can result in heat accumulation, damaging the equipment and lead to fire hazard.

From the above accidents, this should be taken into account, fire detection and suppression systems should be installed in the electrical control room. As a fire-control system, inert gas fire-extinguishing
is one of an interesting option. Since inert gases are in the atmosphere, no production is needed, do not break down to toxic gas. Not conductive and do not have environmental impacts. Plus, it does not damage electrical equipment and also save cleaning time (after used) due to no chemical residue [2].

2. Theories

2.1. Inert gas fire-extinguishing system

Inert gas fire extinguisher or specifically referred as clean agents (from NFPA 2001 standard). It is one of the gas-type fire extinguishers that was invented to replace Halon. As it is environmentally friendly, inert gas has 0 ODP and GWP values. It is also low toxicity, non-corrosive and naturally available. The gases which are utilized as a fire extinguisher are nitrogen and argon, available in both single and mixed compound as show in table 1. The main fire extinguishing mechanism is to reduce oxygen content; by releasing the gas to the area, making the oxygen content below 12%; then the fire will be extinguished [3].

| Type of Inert gas | Components |
|------------------|------------|
| IG-100 (Nitrogen) | N₂ 100%    |
| IG-01 (Argon)    | Ar 100%    |
| IG-541 (Inergen) | N₂ 52%, Ar 40% and CO₂ 8% |
| IG-55 (Argonite) | N₂ 50% and Ar 50% |

2.2. Fire dynamics simulator (FDS)

FDS is a study of the model of fire with a computer, developed by the NIST (National Institute of Standard and Technology) in the United States to illustrate flame’s behavior in a simple way. The system will predict movements of smoke or the flow of hot air caused by fire, also including ventilation system, wind force and other factors, by using fire and combustion mechanisms tools. With the smoke view added to the system, make it easier for demonstration [4].

The idea of FDS to divide buildings or rooms into small sections called computational cell in order to calculate density, pressure, temperature, speed and concentration of the gas in each cell using law of conservation of energy and mass. Various properties of materials such as decoration materials, walls, floors and ceilings will be taken into account in order to simulate fire-accident scenarios. Number of the cells is major factor to determine the time used in data processing of the scenario and simulation details [5]. And it can be derived from the optimum mesh matching with the simulation details and preferred processing time according to UT Fire research group’s recommendations.

\[
D* = \left( \frac{\dot{Q}}{\rho_c c_p T_\infty \sqrt{g}} \right)^{2/5} \tag{1}
\]

where \( D* \) = Characteristic Fire Diameter, \( \dot{Q} \) = Heat Release Rate, \( \rho_c \) = Density, \( c_p \) = Specific Heat, \( T_\infty \) = Ambient Temperature and \( g \) = Gravity. To create the most realistic fire simulation, \( t \)-squared Fire Ramp can be calculated according to UT Fire research group’s guidelines [6].

\[
\dot{Q} = \alpha t^2 \tag{2}
\]

where \( \dot{Q} \) = Heat Release Rate (kW), \( \alpha \) = Fire Growth Coefficient (kW/s²), \( t \) = Time (s).

3. Methods
Create a model of main distribution board room (MDB) with MDBs cabinet located in the middle of the room. Then installed 4 types of inert gas fire-extinguishing systems, i.e., IG-100, IG-01, IG-541, and IG-55. Finally, simulate the scenario using FDS with concentration and volume of substances based on NFPA 2001 standard [3].

3.1. Create a modeling
We have prepared a questionnaire in order to gather detailed information about MDB room, including size of the room and MDB, location of MDB, thickness and materials used in making the MDB, floors, walls, ceilings, ventilation system etc. Then analyzed the obtained data to determine optimum parameters in order to create a model as an example of modern MDB room and its equipment. MDB in this study is studied is a 3-section interior MDB with 3 meters wide, 1 meter deep, 2.1 meters high, with side vents. MDB’s frame and floor are made of 3 mm thick steel, side-cover and doors are made of 1.5 mm thick steel. It is located in the middle of the 3.2 meters wide x 5.2 meters length x 3 meters high room, derived from the size of the MDB plus working space according to the EIT standards [7].

We determined contacting surface of the room model as follows: concrete for the room, steel for the MDB and PVC for electrical cord. The electrical cord is the source of fire with the maximum heat release rates 3,405 kW/m² according to Warehouse Materials table from NFPA 72 standard [8]. And we used 492.0 s for the ramp-up time according to UT Fire research group’s calculation [6] as shown in figure 1.

![Figure 1. Model of main distribution board.](image)

3.2. Determine the size of Fire Mesh
Fire mesh’s size, 3.2 meters wide x 5.2 meters length x 3 meters high, was calculated according to UT Fire research group. The grid’s size used in the model was 0.15 x 0.15 x 0.15 m which is a moderate.

3.3. Installing a gas nozzle and determining the concentration of inert gas
Create one nozzle was installed in the middle of the room above the MDB. The required nozzle must be able to inject solid particles for 60 s in a circular shape with the volume of inert gas derived from equation as follows [3]:

\[
X = 2.303 \left\{ \frac{V}{S} \right\} \log_{10} \left\{ \frac{100}{100 - C} \right\}
\]  
(3)

when \(X\) = Volume of inert gas added at standard conditions per volume of hazard \([\text{ft}^3/\text{ft}^3(\text{m}^3/\text{m}^3)]\), \(V_s\) = Specific volume of inert gas at 70°F (21°C) \([\text{ft}^3/\text{lb}(\text{m}^3/\text{kg})]\), \(S\) = Specific volume of the inert gas at 1 atmosphere and temperature \([\text{ft}^3/\text{lb}(\text{m}^3/\text{kg})]\), \(C\) = Agent design concentration. The gas’s flow rate can be calculated from equation as follows:

\[
M = \frac{\rho V}{S}
\]  
(4)

when \(M\) = Mass flow rate \((\text{kg}/(\text{m}^2\cdot\text{s}))\), \(\rho\) = Density \((\text{kg}/\text{m}^3)\), \(V\)=Volume of agent \((\text{m}^3)\), \(S\)=Time of injection agent \((\text{s})\). The simulation was divided into 12 cases according to the type and concentration of
inert gas which NFPA 2001 recommended. And we also simulated scenario when the safety factor of Class C fire increased by 50% and 100% respectively as shown in table 2.

**Table 2.** Show all case for simulation.

| Case | Agent  | Design Concentration | Flow rate (kg/(m²·s)) |
|------|--------|-----------------------|------------------------|
| 1    | IG-100 | 41.9 %                | 0.527                  |
| 2    | IG-100 | 46.5 %                | 0.606                  |
| 3    | IG-100 | 62 %                  | 0.938                  |
| 4    | IG-01  | 52.9 %                | 1.036                  |
| 5    | IG-01  | 58.8 %                | 1.21                   |
| 6    | IG-01  | 78.4 %                | 2.109                  |
| 7    | IG-541 | 38.5 %                | 0.471                  |
| 8    | IG-541 | 42.75 %               | 0.541                  |
| 9    | IG-541 | 57 %                  | 0.819                  |
| 10   | IG-55  | 42.7 %                | 0.767                  |
| 11   | IG-55  | 47.4 %                | 0.884                  |
| 12   | IG-55  | 63.2 %                | 1.376                  |

5 Thermocouples were installed over the ceiling area for monitoring of temperature change in each section of the room as shown in figure 2.

![Figure 2. Show the location of the Thermocouples.](image)

We simulated the fire scenario by setting the fire at power line below, inside the MDB. The flame has 0.3 x 0.3 x 0.05 meters in dimension.

**4. Results**

The results from each scenario are as written below:

4.1. First, second and third cases

In these cases, we used IG-100 as a fire suppressor with percentage of concentration from NFPA 2001 recommendation and also varied according to the safety factor of Class C fire which increased by 50% and 100% respectively. The results from all 3 cases showed that when IG-100 was released, it cannot suppress the fire within 60 seconds. Plus, the increased concentration did not help reducing (or just insignificantly reducing) the temperature inside the room as shown in table 3. The temperature inside the MDB remained at 42.0 °C as shown in figure 3.

**Table 3.** The results of the simulation of IG-100.

| Case | Safety Factor    | Concentration | Temperature room |
|------|------------------|---------------|------------------|
| 1    | NFPA recommended | 41.9 %        | 23.70            |
| 2    | increase 50 %    | 46.5 %        | 23.70            |
| 3    | increase 100 %   | 62 %          | 23.60            |
4.2. 4th, 5th and 6th cases

IG-01 was used for these cases, with the concentration from NFPA 2001 recommendation and also varied according to the safety factor of Class C fire which increased by 50% and 100% respectively. The results from all 3 cases showed that when IG-01 was released, it cannot suppress the fire within 60 seconds. Plus, the increased concentration did not help reducing (or just insignificantly reducing) the temperature inside the room as shown in table 4. The temperature inside the MDB remained at 42.0 °C as shown in figure 4.

Table 4. The results of the simulation of IG-01.

| Case | Safety Factor       | Concentration | Temperature room |
|------|---------------------|---------------|-----------------|
| 4    | NFPA recommended 35%| 52.9 %        | 23.50           |
| 5    | increase 50 %       | 58.8 %        | 23.60           |
| 6    | increase 100 %      | 78.4 %        | 23.10           |

4.3. 7th, 8th and 9th cases

In these cases, we used IG-541 as a fire suppressor with percentage of concentration from NFPA 2001 recommendation and also varied according to the safety factor of Class C fire which increased by 50% and 100% respectively. The results from all 3 cases showed that when IG-541 was released, it cannot suppress the fire within 60 seconds. Plus, the increased concentration did not help reducing (or just insignificantly reducing) the temperature inside the room as shown in table 5. The temperature inside the MDB remained at 42.0 °C as shown in figure 5.

Table 5. The results of the simulation of IG-541.

| Case | Safety Factor       | Concentration | Temperature room |
|------|---------------------|---------------|-----------------|
| 7    | NFPA recommended 35%| 38.5 %        | 23.80           |
| 8    | increase 50 %       | 42.75 %       | 23.80           |
| 9    | increase 100 %      | 57 %          | 23.70           |
4.4. 10th, 11th and 12th cases
IG-55 was used for these cases, with the concentration from NFPA 2001 recommendation and also varied according to the safety factor of Class C fire which increased by 50% and 100% respectively. The results from all 3 cases showed that when IG-55 was released, it cannot suppress the fire within 60 seconds. Plus, the increased concentration did not help reducing (or just insignificantly reducing) the temperature inside the room as shown in table 6. The temperature inside the MDB remained at 42.0 °C as shown in figure 6.

Table 6. The results of the simulation of IG-55.

| Case | Safety Factor | Concentration | Temperature room |
|------|---------------|---------------|------------------|
| 10   | NFPA recommended 35 % | 42.7 % | 23.70 |
| 11   | increase 50 % | 47.4 % | 23.70 |
| 12   | increase 100 % | 63.2 % | 23.50 |

5. Conclusion
From the study of fire-extinguishing model with 4 types of inert gas in MDB room. It was found that the fire-extinguishing performance of inert gas: Nitrogen, Argon, Inergen and Argonite. The experimental gases had initial concentration using NFPA 2001 recommendation and varied concentration according to the safety factor of Class C fire which increased by 50% and 100%. The results showed that the increased concentration did not (or insignificantly) help reducing or extinguishing the fire caused by the same fuel in the same environment. In addition, when compared the fire-extinguishing performance between all 4 types of inert gas with the concentration according to NFPA 2001, the results showed that all 4 types of inert gas had no significantly difference in fire-extinguishing performance.

Therefore, we can conclude that in order to install a fire-extinguishing system with inert gas in the model environment; regardless of which type of inert gas is used, it will yield the same fire-extinguishing performance. And the concentration according to NFPA 2001 is recommended for
all 4 types of the inert gas. The recommended concentration is the most cost-effective because it requires lesser amount of substances, though giving the same fire-extinguishing performance.

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