



Audibility Assessment of Fire Alarm System Sound Level for Industrial Processes

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Abstract

Fire alarm systems are the first stage of fire evacuation. The audibility of the fire alarm is of vital importance. In industrial buildings, there is almost continuous occupational noise. Variables such as duration, frequency, level and frequency range of this noise may vary depending on the work performed. In this study, the audibility of the fire alarm when it sounds during the process is evaluated. Audibility is based on the sound level. Sound levels for various processes were obtained from the literature.

In our country, the sound levels of audible fire alarm systems are specified in the “Regulation on Fire Protection of Buildings”. According to this, the lowest alarm level is 65 dB(A), and the maximum total is 75 dB(A) with +10 dB(A) in places characterized as “noisy”. The maximum sound level allowed by the regulation is 120 dB(A). The sound level generated in the environment was calculated by calculating the fire alarm sound level and the sound levels of the processes together. Looking at the audibility of the fire alarm with sound levels based on processes, it was observed that the alarm was generally masked at low sound levels and the process was masked at high sound levels. In other words, the results show that the fire alarm sound level at the lower limit is not sufficient for process noise, while the fire alarm level at the upper limit corresponds to the “pain threshold”.

1. INTRODUCTION

Fire is one of the most frequent catastrophic event [1]. Fire accidents can cause major loss of life, economic and ecological damage [2], [3], [4], [5]. Reducing risks is necessary to ensure safety of life and property [6]. Fire safety of buildings and reduction of fire risk are ensured by design or performance-based methods. The “Regulation on the Protection of Buildings from Fire” (BYKHY) in force in our country (BYKHY) [7] is based on the provision and is mandatory [8]. Specify what the measures are and how to implement them [5]. The Regulation describes how the building should be rather than how the building should behave [8], [9]. Article 81 of the BYKHY sets out the limits on fire alarms. Article 81-(5) of the Regulation: “Audible warning devices shall be placed throughout the building, measured at a height of 150 cm from the ground and the sound level shall be at least 15 dBA above the average ambient sound level. In sleeping areas, bathrooms and showers, the sound level must be at least 75 dBA. Audible warning devices must have a sound level of at least 75 dBA and at most 120 dBA at a distance of 3 m. It is not necessary to install a siren system in the volumes with an emergency announcement system speaker.” [7].

Separate attention should be paid to fire safety in the design, implementation and operation phases of buildings. Each stage needs separate safety measures [10]. Fire alarm systems are one of the fire safety measures that initiate the escape and the designed fire scenario used in the operation phase of buildings. Fire alarms with different features can be preferred according to the intended use and intensity of use of the building. “Fire alarm system is a system that includes signal-alarm devices that automatically detect and transmit the fire situation.” is designed to work in different environments. [11]. They usually consist of thermally sensitive materials that can detect heat. The material senses the heat and converts it into an

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electrical signal and triggers the fire alarm system [11], [12]. The system may give an audible or light warning [12].

Audible warning systems may not always be sufficient in case of fire. Even if the sound is heard and attracts attention, people may ignore the warning [13]. In the literature, the terms “unwanted alarm”, “false alarm”, “malicious alarm” and “unknown alarm” are used for alarms that sound in a situation that does not require danger or warning: “unwanted alarm”, ‘false alarm’, ‘malicious alarm’ and ‘unknown alarm’. False alarms occur frequently in automatic fire alarm systems. Because of this, people tend to ignore alarms. This has even been identified as a potential hazard by the US National Fire Protection Association (NFPA) [14]. For these reasons, the detection and alarming scenario should be designed and implemented to minimize error. However, the opposite is also true. Even if the fire or hazard alarm works correctly, people may not recognize or hear the alarm and the evacuation process may be delayed. The background noise level of the environment is one of these factors. It can make alarms difficult to hear and pose a safety hazard [15]. Noise is common in environments where industrial activities take place. It is one of the most serious risk factors in industrial environments. Noise control is of great importance for human life [16], [17]. Hearing loss from occupational exposures accounts for around a third of all occupational diseases in Europe [18], [19]. The level and duration of occupational noise exposure is limited in many parts of the world [20]. The American Occupational Noise Exposure Regulations set the noise exposure of industrial workers at 90 dB for 8 hours [20], [21]. In Europe, this value is recommended at 85 dB for 8 hours [22], [23]. Türkiye is in the category of developing countries, and workers and people living near industrial facilities throughout the country are exposed to noise ranging from 70 to 100 dB(A). [24], [25], [26], [27]. These values are higher than the values stipulated in national and international regulations and directives [24], [28].

Industrial plants are a source of noise both internally and for the environment [29], [30]. They may cause various occupational noises depending on the working area and hours. These occupational noises can be constant, intermittent or fluctuating, except for frequency ranges [24], [31]. It can also be defined as regular and irregular according to the number of repetitions and duration of the noise. Each type of noise has a different definition and impact on humans [32]. The production and process in the industrial plant is the main determinant of the type of noise [33]. When there is more than one sound source, the dominant source may overpower or mask the other source [34]. Therefore, the identification of the temporal and physical variables of the noise type plays an important role in characterizing process noise and occupational noise. Several studies have been carried out on the identification of industrial noise and its propagation according to the room in which the process is carried out [35], [36], [37], [38]. The models developed are limited to predicting noise levels only. However, room dimensions, absorption of materials and the reflection time of the room, surface forms and room shapes can affect and change the noise level, frequency ranges and duration of noise to which the worker is exposed [35].

Noise in the low frequency range (LFN) makes up most of the naturally or artificially generated noise we are exposed to in everyday life [24]. Wind noise, sea waves, airport, highway and industrial noise can fall into this category. Industrial areas and activities, compressors, pumps, diesel engines, ventilation and air conditioning systems and many industrial machines are considered sources of LFN [24], [39], [40]. According to the World Health Organization (WHO): “...health effects from low-frequency components in noise are generally estimated to be more severe than those from community noise.” Since the early 2000s, studies have recognized LFN as a serious public health problem [41].

Studies on LFN can be limited starting from the lowest audible frequency (16 Hz) [24], [42]. In some cases, the lower limit may be started at 10 Hz for operational sensitivity and to calculate the total exposure [24], [39], [43], [44]. As an upper limit, the frequency range of the noise under investigation is considered. Generally, above 310 Hz can be considered as the upper limit of the LFN as it is considered a mid-frequency. However, depending on the noise spectrum, this upper limit can be increased up to 500 Hz. [24]. LFN type noises can reach farther distances than high frequency noises (due to high wavelength and high energy), less loss when passing through any wall [24], [45], [46], is likely to cause further damage to the wall. LFN noises can generate mechanical vibration. It can be categorized as both air-born and solid-born noise. LFN is less conspicuous than high-frequency noise, causing a feeling of relaxation

when the sound stops [24]. It can cause serious health problems in humans and animals. While studying the condition of animals exposed to LFN, Cavacas found severe tooth wear in rats regularly exposed to cotton fabric production process noise (industrial, occupational noise) in a textile factory [47].

This study was conducted to examine the audibility status of the minimum sound level specified in the “TS EN 54-3+A1:2019” standard (TSE 2019) and “TS EN 54 - 14” (TSE 2018) standard, which fire alarm systems must comply with according to the “Regulation on the Protection of Buildings from Fire” (T.R. Presidential Regulation 2007) dated 19/12/2007 official gazette.

2. METHOD

Within the scope of the study, various types of industrial facilities were identified and their existing background noises according to their production processes were obtained from the literature. The sound levels generated in the environment were calculated when the fire alarm in TS EN 54-3+A1:2019 and TS EN 54 - 14 standards operate at minimum sound levels while production continues in the facility (when background noise is present). The “audibility” assessment of the sound levels was made by comparing the results obtained.

3. TYPES OF INDUSTRY AND OCCUPATIONAL NOISE LEVELS

10 industrial types in Türkiye were analyzed. These are: Wood, energy, food, pharmaceutical, construction, chemical, mining, machinery, automotive and textile industries. For each of these industry types, 2 processes were selected.

The wood industry is a long and complex industry, from the extraction of raw materials to the final product. Wood is a biodegradable, renewable, recyclable material. So it is one of the sectors where waste generation is relatively low (compared to plastics or cement, for example) [48]. Production and marketing of raw wood or wood-based products for paper, construction and fuel [49], [50], [51]. In the wood industry, the sound level for the “carpentry” process is between 83.2 - 105.8 dB(A) [52], [53], [54]. The “compressed air blowing” process has a sound level of 104 dB(A) [52], [55].

The energy industry consists of a well-established industrial chain. It mainly consists of mining, processing and chemical industries [56]. It involves different types of processes depending on the raw materials used. Energy is an essential need for large masses of people. Today, China is the world's largest energy consumer [57]. The energy produced by renewable and non-renewable energy sources is transmitted in various ways to living spaces, industrial facilities and areas in need of energy and is used by converting it into different types of energy such as electricity, water and movement. The energy sector is one of the most renovated sectors. Various renovations are needed for both raw materials and the way energy is produced (process) [58], [59]. Energy reform, accelerating the energy transition, reducing the carbon footprint are crucial for the energy industry and economy [56]. In the energy industry, “water treatment” and “generator” processes were evaluated. In water treatment plants, the processes work together in an open area since the flow and progress of water in the plant does not require separate spaces. For this reason, the sound level of the entire water treatment plant was evaluated, not a specific process. Occupational sound level in the water treatment plant is in the range of 60 - 94 dB(A) [60]. Generators are mechanisms that convert energy generated from fossil or renewable energy sources into electrical energy. It has shown many changes and developments until today. Generators are usually operated for certain periods of time. For this reason, the noise level of a generator can be evaluated separately in the start-up phase and separately in the operating phase. The highest noise levels in generators usually occur during the start-up phase. The initial noise level varies between 96.5 and 105 dB(A) [61]. The process noise level evaluated for the generator within the scope of the study is 86 - 105 dB(A).

The food industry is a branch of industry that includes the process from raw material extraction to final product packaging. It is one of the most important business items in our country and in the world. Periodic increase and decrease in production may occur according to raw material density and season. There may be different material productions according to the region where the facility is located. It may

include a different number of processes according to the end product. The duration, sequence, volume and cost of these processes depend on the type of raw material and end product. Closely related to the agriculture sector [62]. The processes “margarine production line with churn, pasteurizer and cooler mixer” for the food industry and “packaging” for the brewery were chosen. The sound level of the margarine production line process is 93 - 95 dB(A) [63], beer packaging sound level is in the range of 60.1 - 61.7 dB(A) [64].

The pharmaceutical industry is one of the fastest growing industries in our country and in the world. It was formed as a sub-branch of the chemical industry and over time became an industry type in its own right. Medicinal chemistry origin [65]. It has an intensive capital. It is an industry with intensive production in both developed and developing countries. [66]. Closely linked to the health sector [67]. Growing in direct proportion to global investments in healthcare [66]. For the pharmaceutical industry, “homogenization” (homogenizer machine) and “packaging” processes were preferred. The sound level of the homogenization process is in the range 73 - 78 dB(A) [63], the sound level of the packaging process is 74.6 - 76.5 dB(A) [64].

The construction industry is a sector where activity intensity and costs increase with population growth [68]. It has a long history [69]. It has a large share of production and consumption in our country and in the world. The construction sector is highly dependent on resource inputs, meaning that activity in the industry depends on regular production [70]. It is one of the largest sources of greenhouse gas emissions worldwide. It consumes 40% of the world's raw materials and accounts for 50% of carbon emissions [69]. It is an area where noisy processes take place at many stages such as demolition, production, logistics, where most of the work is physical [54], [71], [72]. In the current Industrial Revolution 4.0 (IR 4.0) period, technological developments and digital transformations in the construction sector are aimed to create developments [73]. It is aimed to reduce manual work, increase efficiency throughout the sector, and identify equipment, procedures and operations with fewer failure problems [69]. Some processes in the sector are planned to be advanced with artificial intelligence: For example, modular and prefabrication production [74]. In this way, occupational health and safety risk factors in the processes can be reduced and any harmful effects in the work process can be reduced to lower levels (including the noise factor). In the construction industry, the sound level for the on-site production process (workshop) is between 61.9 - 91.2 dB(A) [19], [28], [52], [75]. The “packaging machine” process in the cement production plant, one of the construction materials, is 85 dB(A) [76].

The chemical industry is a sector in which various compounds that cannot be decomposed or are difficult to decompose are produced or used as raw materials [77]. It is closely related to many sectors such as food, cleaning, pharmaceuticals, defense [78]. It is also a sector that uses fossil fuel as raw material [79]. Chemical and pharmaceutical industries are the two most inefficient sectors in terms of carbon recycling [67]. The chemical industry can lead to serious environmental problems and has an impact on the increase of environmental pollutants [80]. Causes direct and indirect emissions [81]. In terms of controlling environmental pollution in chemical industry plants, various process additions can be made for the transformation of waste products: Heavy metal separation process, fenton process for wastewater treatment [80], [82]. “Centrifugal pump” process and “granulator” process were preferred in the chemical industry. The double suction volute pump has a sound level of 60 - 75 dB(A) depending on the speed at which it is operated. [83], granulator has a sound level range of 73 - 79 dB(A) [63].

The mining industry is an old industrial branch that proceeds by obtaining raw materials (minerals), processing them and delivering them to the market [84]. Classified as underground and surface mining [85], [86]. The main objective of the sector is to provide raw materials for other types of industry. It also contributes to the national economy by creating new employment areas in rural areas [87]. Mining is a sector closely linked to the supply chain [84]. Arbitrary and unplanned mining activities have led to environmental problems. Examples include topsoil degradation, atmospheric pollution, release of toxic substances, water pollution, vibration [84]. For the mining industry, “ball mill” and “coal mill” processes were preferred from the coal processing stages. The sound level of the ball mill process is 96 dB(A) [88] the coal mill is 102 dB(A) [76].

The machinery industry is a field closely related to almost all sectors where basic actions such as manufacturing, automation and production take place [89]. The products coming out of production are used both in other industries and as end products. Industrial Revolution 4.0 has brought serious developments to the machinery industry [90], [91]. Connectivity and communication standardization in particular have come a long way. Modern industrial machines, devices and processes are equipped with communication systems that support such processes [90]. In the machinery industry, the “annealing furnace and finishing” and “exhaust system” processes were selected for the manufacture of parts for plumbing equipment. The sound level of the annealing furnace and finishing process is 88.7 dB(A) [92], exhaust system (for standard screwdriver) sound level is 96 -108 dB(A) [15].

The automotive industry is one of the largest sub-branches of the manufacturing sector. It is formed by the combination of different sub-disciplines such as mechanics, electricity, materials, logistics and engineering. It has a wide range of human resources [93]. The automotive industry is a complex sector with different processes by which different parts are manufactured and assembled. The automobile industry is important for the development of the country, supporting economic and social progress. Automobile production is very high, especially in developed countries. Some of the materials used in production are serious pollutants for the environment (e.g. paint) [94]. Various research are being carried out to recycle the residual products [95]. In this way, it is planned to increase efficiency and reduce carbon footprint in the automotive industry in the Industrial Revolution 4.0 [93]. According to a sound measurement and calculation study conducted in an automotive factory in Mexico, the sound level for the “wiring harness assembly” process for the automotive industry is 99.41 dB(A) [96]. 95 dB(A) is assumed for the air compressor process [76].

The textile industry is one of the most important manufacturing industries in the world [97]. It includes the processes from raw material to fabric production to the final production. It is known that textile production and trade has been carried out in Anatolia for more than 3000 years. It is one of the sectors with high employment and export capacity in our country. [98]. It consists of three sub-branches: Apparel, home and technical textile [99]. The production process consumes large amounts of water and energy [97], [100]. The rapid expansion of the textile industry and the growth of the market have led to more intensive energy consumption. Accordingly, care is taken to adopt clean production (CP, cleaner production) in the sector. Efforts are made to reduce the carbon footprint of processes [97]. The textile industry is one of the most organized and fastest sectors. Its contribution to the growth of the country's economy is quite high [101]. Accordingly, it is a sector with a high employment and labor force ratio. Due to the use of different chemicals, their transformation and different processes, the majority of textile industry workers are exposed to high noise levels [102], [103]. In the textile industry, 2 processes were selected which are included in the home textile. The sound level of the “weaving loom” process is in the range 85.5 - 98.1 dB(A) [104]. These sound levels are in different ranges for different types of fabric and product weaving. For example, the sound level of the towel loom process is 88 - 95 dB(A), the sheet weaving process is 80 - 87 dB(A) [105]. Conditions such as modification and maintenance of benches may cause changes in sound levels [104].

4. INDUSTRIAL FACILITY INDOOR NOISE LEVELS DURING FIRE ALARM SYSTEM OPERATION

According to TS EN 54-3 + A1: 2019 and TS EN 54 - 14, the minimum sound level for fire alarm systems is 65 dB (A) [106], [107]. This value can be increased by +10 dB(A) for noisy areas. In other words, the minimum sound level for noisy areas can be increased up to 75 dB(A). The maximum sound level is determined as 118 dB(A) in TS EN 54 - 14 [106]. Industrial facilities are categorized as high noise areas [108]. Therefore, in this study, both 65 dB(A), 75 dB(A) and 120 dB(A) were calculated separately as minimum levels.

The sound level resulting from sound emitted simultaneously from two separate sources: It is calculated by the difference in sound level (SPL) between the sources. Accordingly, if the SPL difference between the sound sources is between 0 and 1 dB, 3 dB is added to the larger one, between 2 and 4 dB, 2 dB is added to the larger one, between 5 and 8 dB, 1 dB is added to the larger one, and between 9 and 10 dB,

0.5 dB is added to the larger one to obtain the total sound level. If the difference between them is more than 10 dB, the sound of the source with the lower sound level is masked [109]. Masking: The phenomenon whereby the sound of one of two simultaneously existing sound sources prevents the other from being heard. A sound with a low volume is not heard. In other words, it can be defined as an increase in the lower threshold of hearing [110]. Furthermore, the higher the level of the masking sound, the wider the frequency range in which it is effective.

Table 1 shows the sound levels that occur during the process and the sound levels that occur when the fire alarm operates at the same time. The cases where the sound with a small sound level cannot be heard are written as “masked”. It is written according to the masking of the alarm or process. In Table 1, blue and orange colors are used according to the dominance of the alarm sound and process sound. In cells with color transition, the audible dominant sound changes in the process.

Table 1. Industry Types, Processes, Sound Levels and Sound Levels When the Fire Alarm Sounds (A. Masked: Alarm Sound Masked, P. Masked: Process Sound Masked, *: alarm sound dominant, **: process sound dominant)

Industry Type	Process	Sound Level (dB(A))	Volume When Fire Alarm Sound (dB(A))		
			Alarm: 65 dB(A)	Alarm: 75 dB(A)	Alarm: 120 dB(A)
wood industry	carpentry	83.2 – 105.8	A. Masked	84.2** – A. Masked	P. Masked
	compressed air blowing	104	A. Masked	A. Masked	P. Masked
energy industry	water treatment plant	60 – 94	66* – A. Masked	P. Masked – A. Masked	P. Masked
	generators	86 – 105	A. Masked	A. Masked	P. Masked
food industry	margarine production line	93 – 95	A. Masked	A. Masked	P. Masked
	beer packaging	60.1 – 61.7	66* – 67**	P. Masked	P. Masked
pharmaceutical industry	homogenization	73 – 78	74** – A. Masked	77* – 80**	P. Masked
	packaging process	74.6 – 76.5	75.1** – A. Masked	78* – 79.5**	P. Masked
construction industry	on-site production	61.9 – 91.2	67* – A. Masked	A. Masked – P. Masked	P. Masked
	cement packing	85	A. Masked	85,5**	P. Masked
chemical industry	double suction volute pump	60 – 75	66* – 75.5**	P. Masked – 78**	P. Masked
	granulator	73 – 79	74** – A. Masked	77* – 81**	P. Masked
mining industry	ball mill	96	A. Masked	A. Masked	P. Masked
	coal mill	102	A. Masked	A. Masked	P. Masked
machinery industry	annealing furnace and finishing	88.7	A. Masked	A. Masked	P. Masked
	exhaust system	96 – 108	A. Masked	A. Masked	P. Masked
automotive industry	wiring harness assembly	99,41	A. Masked	A. Masked	P. Masked
	air compressor	95	A. Masked	A. Masked	P. Masked
textile industry	towel loom	88 – 95	A. Masked	A. Masked	P. Masked
	sheet weaving process	80 – 87	A. Masked	81** – A. Masked	P. Masked

4.1 Evaluation

In workplaces, audible warnings are used to warn of dangerous situations. Audibility is therefore of vital importance, playing a role in ensuring safety [111]. Reducing noise levels to reasonable levels in production facilities will improve ergonomics and contribute to the audibility of fire and danger signals [112]. If this cannot be done, workers should be protected against noise with personal protective equipment. However, such measures also prevent the audibility of auditory warning systems. The audibility assessment of alarms and background noise varies according to frequency ranges. In this study, the average values of the sounds in the frequency octave band range were used. The rhythm, level and frequency values of the fire alarm to be used affect the audibility because the frequency range in which

the sound is effective increases as the level of the sound increases. Accordingly, the type of industry and process sound (physical condition) should be well evaluated when planning.

All processes in Table 1 except water treatment (energy), packaging (food), homogenizer (pharmaceutical), packaging (pharmaceutical), in-plant production (construction), centrifugal pump (chemical) and granulator (chemical) are fully masked by the fire alarm (65 dB(A)), which sounds at a minimum level while work is in progress. Of these processes, the alarm sound could be louder than the process sound in the water treatment, packaging, in-plant production and centrifugal pump processes. In all other processes, the process sound is dominant. When the processes are compared with the alarm of 75 dB(A), which is the highest value of the minimum sound level according to TS EN 54, masking occurs in all processes except carpentry (wood), water treatment (energy), homogenizer (pharmaceutical), packaging (pharmaceutical), in-plant production (construction), cement packaging (construction), centrifugal pump (chemical), granulator (chemical) and sheet loom (textile) processes. In water treatment and in-plant production there is a range of sound levels where both sounds can be heard (around 75dB(A) both sounds can be heard separately). Only in the packaging (food), water treatment, homogenizer, homogenizer, packaging, in-plant production and granulator processes is the alarm sound more dominant. All processes are masked at an alarm level of 120 dB(A), the maximum value recommended by the regulation for the alarm sound level. However, this sound level is too high for humans and is referred to in the literature as the “pain threshold” [110]. It should be taken into account that this sound level poses a risk to the auditory health of people both inside and near the building and may cause temporary hearing loss.

4. CONCLUSION

The results in Table 1 show that even the sound level of the basic processes in industrial production is higher than the sound levels specified in the “TS EN 54-3+A1:2019” and “TS EN 54-14” standard, which fire alarm systems must comply with according to the “Regulation on Fire Protection of Buildings” (BYKHY). The minimum alarm sound level is insufficient for the processes. Therefore, even if a fire alarm is sounded while the plant is in operation (or while the processes are being processed), the resulting sound level is insufficient in terms of audibility and warning. For this reason, various standards accepted in the world and in our country can also be used when planning the fire alarm.

TS EN ISO 7731: 2008 standard (Ergonomics - Hazard signals for public and work areas. Auditory danger signals) can be considered [113], this can also be included in the current regulation. However, the sound levels determined and recommended by this standard should also be evaluated for each line of work and applied with various limitations and conditions in the regulation. For example, ISO 7731 requires a 15 dB(A) difference between alarm and background noise at A-weighted sound level [111], [113]. Although this difference covers all volume levels, it causes an unnecessary loudness at high background volume. The standard also recommends audible alarms at this level as “sufficient but not always necessary”, leaving the door open for other warning methods. In addition to dominating methods, performance-based methods can also be used to enhance the audibility of the alarm sound. One of these is scenario design. By determining different scenarios for the processes in industrial buildings, the alarm sound level can be regulated or alternative solutions can be produced for the most plausible and most risky ones. Thus, fire and alarm levels specific to the structure and process can be obtained and evacuation stages can be facilitated in case of fire. Both audible and visual warning systems can be developed. Such performance-based solutions can be added to or suggested in the regulation for industrial buildings. Such measures can accelerate evacuation in case of a disaster and reduce the loss of life to lower levels. In this context; the audible alarms recommended by the regulation should be reconsidered, further elaborated, limited and, if necessary, developed with other warning systems, especially for workplaces where physical production takes place.

It should be noted that this study was conducted solely on sound levels. It should be noted that audibility decreases at higher frequencies and that the audible frequency range varies with age[114]. Therefore, standards that may be included in the regulations should consider factors such as age and gender on a sectoral basis.

CONFLICTS OF INTEREST

No conflict of interest was declared by the authors.

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