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Study on Fire Risk and Disaster Reducing Factors of Cotton Logistics Warehouse Based on Event and Fault Tree Analysis

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Abstract

Cotton logistics warehouses have increased unceasingly along with the development of society. Firstly, referring to a hundred cotton logistics warehouse fires, based on the relevant provisions of the cotton logistics warehouse, and fire safety issues are summarized in this paper. Secondly, according to the physical and chemical characteristics of cotton, the fire risk of cotton logistics warehouse is analyzed, and the fire hazard sources are identified. Thirdly, Event and Fault Tree Analysis (EFTA) is used to explore the disaster mechanism of cotton logistics warehouses to obtain disaster reducing factors. In the end, based on the above analyses, a set of fire prevention measures against the cotton logistics warehouse are put forward. The result shows that the probability of moisture absorption and heat release is the highest of all causes of smoldering fire, so it is essential to control the temperature below 343K and the humidity below 70% when keeping in storage. Lacking of spaces between shelves is an important factor leading to the spread of fire. In the process of fire fighting, water supply is the key factor, so appropriate water storage facility for fire-fighting is necessary before the establishment of the cotton logistics warehouse.

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Keywords: cotton logistics warehouse; fire risk; event and fault tree analysis; disaster reducing factors

1. Introduction

The logistics warehouse spread to China in the 1980s [1]. In general, logistics refers to storage, transportation, loading, unloading, packing, and processing between the production and consumption for commodity [1], as shown in Figure 1, instand of simply storing. China has become the largest cotton production and consumption country all over the world, and cotton products have become the indispensable household in Chinese families, while its production-transportation line also becomes the important part of national livelihood, so developing modern cotton logistics is the best way to reduce the cost of cotton circulation and improve the competitiveness of Chinese cotton.

Cotton is natural fiber which is identified as flammable goods, while there are massive reserves in logistics warehouse, once they are ignited, fires will develop quickly to hundred square meter in few seconds and cause inestimable loss. However, the fire safety status of cotton logistics warehouses is not optimistic because lots of property damages have been caused due to fires in cotton logistics warehouses for recent years.

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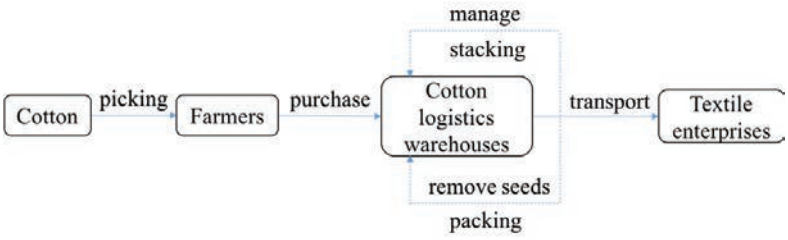

Figure 1 Service process of cotton logistics warehouse

A lot of scholars have done the analysis and research on the current situation of cotton logistics. ZANG Li [2] analyses the current situation of cotton logistics storage, pointing out that the warehouse facilities are too simple and the manual operation mode is backward. YUAN Jin [3] analyses the difference between the concept of cotton circulation and cotton logistics, emphasizing that fire protection plays an important role of cotton storage. TAN Yan [4] puts out the countermeasures based on the analysis of the characteristics of the cotton warehouse fire. ZHANG Jing [5] establishes evaluation index system of cotton transport warehouse by using fuzzy comprehensive analysis method and analytic hierarchy process(AHP). However, there are less study on cotton fire safety problems and the disaster mechanism. Above all, it is urgent to understand comprehensively its fire risk and put forward targeted disaster reducing factors. In additional, the frame structure of the article is shown in Figure 2.

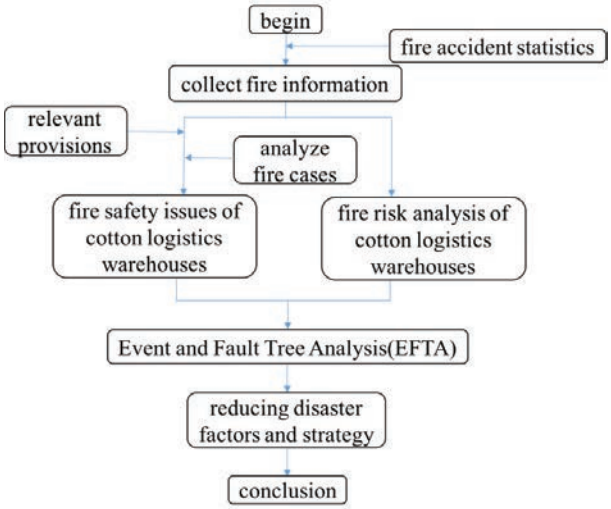

Figure 2 The frame structure of the article

2. Fire Safety Issues of Cotton Logistics Warehouses

In recent years, there are hundreds of cotton logistics warehouse fires, which are collected to find the fire safety issues, combined with *Fire-protection Code of Building Design*. 3 typical fire cases are chosen to add up to the issues, all of them are shown in Table 1, which are Minhang"11•13" fire in Shanghai, Houma"7•1" fire in Shanxi Province, Jinyuan"12•31" fire in Jiangxi Province.

1) Fire resistance classification of structures are unqualified. According to *Fire-protection Code of Building Design*, the rule 3.3.10 provides that the storage hazard of cotton belongs to hepatitis C, and the warehouse fire resistance couldn't below class three. However, simple steel structure is widely used to cotton warehouse because of less costs, which is violation behavior. Once a fire happens on the warehouse, it is easy to be collapsed and pose a threat to the safety of firefighters. According to statistics of hundreds of fire cases, the warehouses were collapsed fully or partially in more than 80% fire cases. In February 31th, 2010, there was a fire in one cotton logistics warehouse in Qingdao, Shandong Province because of spontaneous ignition of cotton, and the warehouse, which was color steel plate structure, happened collapse after half an hour, and the fire led to loss more than one billion RMB. On April 22th, 2010, there was a fire in another warehouse in Jiaonan, Shandong Province because of spontaneous ignition of cotton, which led to one hundred ton of cotton burned and one million RMB economic loss at least, the warehouse was built by frame structure, so it happened collapsed partially just after one

quarter of an hour. In recent period, on October 31th, a cotton logistics warehouse, belongs to troops in Xinjiang Province happened an emergency fire because the worker smoked illegally in warehouse and the smoldering cigarette butt ignited cotton, and firefighters had been fighting with the great fire 12 hours at least. According to the report, the warehouse on fire was simple steel plate which was built to stock cotton for a short time, and it was collapsed fully after one and half an hour, unfortunately, a firefighter was in the warehouse at that time. In the end, two thousand tons of cotton was ignited in 5000m^2 and one firefighter was died.

2) Fire load density is too large. According to *Fire-protection Code of Building Design*, the rule 4.5.1 provides that the largest reserves of per inflammable materials (cotton, fibers, silk and fur etc.) open or half open pit yards should below 5000t. However, many of cotton logistics warehouses improve the reserves in order to decrease the site area and increase freight transportation volume. The warehouse on fire of Minhang"11•13" fire in Shanghai was applied for stacking cotton about 4000t~5000t imported from the United State and Sudan, but the reserves had surpassed two times in fact, and there even had 3440t just in third floor. The warehouse on fire of Houma"7•1" fire in Shanxi Province, stored illegally in open pit yard, and its height of stacking exceeded in the height of the lightning rod which was the direct cause of fire. In addition, the preliminary development phase of fire developed rapidly and stacks were on fire in few minutes one after another because of the lack of space between two. The warehouse on fire of Jinyuan"12•31" fire in Jiangxi Province stored seed cotton, which was as tall as the roof.

3) Fire protection facilities are not installed comprehensively or not maintained timely. According to *Fire-protection Code of Building Design*, there must have installed automatic fire alarm system, automatic sprinkler system (we call them as "double automatic systems" in the next), hydrant system indoor and outdoor when the building area of a cotton logistics warehouse exceeds 1000m^2. Also, *Warehouse Fire Safety Management Rules* requires that fire hydrant, fire pool, fire extinguishers and other fire protection facilities should be tested per week to ensure in good condition. However, according to statistics, more than 50% cotton logistics warehouses don't install all kinds of facilities because the building area of warehouses are short of several square to standard, while more than 70% cotton logistics warehouses couldn't maintain the fire protection facilities in time, which makes them no sense. The warehouse on fire of Minhang"11•13" fire in Shanghai had set automatic fire alarm system but no automatic sprinkler system which was violated because its area had surpassed 1000m^2. After the investigation of fire department lively, fire hydrants outdoor just installed three and that indoor couldn't be used as same as automatic fire alarm system, also the high elevated water tank, the volume of which was 30t, had no water too long time. Firefighters had to find extinguishment water far away from the warehouse. The warehouse on fire of Houma"7•1" fire in Shanxi Province was also found that there was no "double automatic systems", as well as the number of fire hydrants was inadequate, which led initial phase of fire grew so quickly that it was too difficult for firefighters to control ignited area. The warehouse on fire of Jinyuan"12•31" fire in Jiangxi Province only installed four indoor fire hydrants and fire pool without water. All above these was the key factors leading to fire grow.

4) Potential risk of fire hasn't been corrected. According to *Fire-protection Code of Building Design*, the rule 3.3.10 provides that the maximum building area of logistics warehouses (goods except cotton and cotton products) can enlarge three times of normal warehouses but cotton logistics warehouses should be the same as normal warehouses, and the rule 3.3.2 provides that the maximum allowable area of the fire compartment of warehouses is 6000m^2. It is known that the building area of the warehouses of three cases were more than one fire compartment, while all of them didn't divide reasonably. Moreover, in many of cotton logistics warehouses, plenty of bales of cotton are stacked in the corridor which is quite dangerous if a fire happens, because it will be the fuse to ignite cotton in another warehouse and the consequence would be unimaginable.

5) Personnel fire safety consciousness is poor. *Warehouse Fire Safety Management Rules*, the fourteen rule requires that there must be one duty in warehouse every day or night. Minhang"11•13" fire in Shanghai was found by a fisherman when the fire had grown half an hour while the warehouse duty was sleeping. Houma"7•1" fire in Shanxi Province was caused by ignited cigarette butt from illegally smoking of workers. The windows of warehouse on fire of Jinyuan"12•31" fire in Jiangxi Province were closed so that heat released from the ignition of cotton was accumulated to more than 873.5K which is the condition of flashover.

Analysis above all indicates that the cotton logistics warehouse exists many fire safety issues. Potential risk and poor consciousness of personnel fire safety may trigger a fire. Imperfect fire protection facilities will not control the spread of fire effectively. For fire fighting, massive goods with higher fire load density and lacking of space between shelves may means that it is difficult to aim at the ignition point, transport the goods, even lead to the growth of fire from one stacking to another in few minutes. And if the fire resistance structure of warehouse is unqualified or the fire continues too long time, it is possible to collapse to threat to firefighters fighting in warehouses. In the end, the fire will make enormous economic loss for country and entrepreneurs, even causes casualties. So, these issues cannot be ignored, and it is necessary to study on disaster reducing factors.

Table 1 3 typical cases of cotton logistics warehouses

Contents	The typical cases of cotton logistics warehouses		
Name	Minhang "11•13" Fire in Shanghai	Houma "7•1" Fire in Shanxi Province	Jinyuan "12•31" Fire in Jiangxi Province
Time	Nov.13, 2000 00:45	Jul.1, 2013 18:00	Dec.31, 2014 19:27
Floor	5	2	1
Building structure	Reinforced concrete frame structure	Reinforced concrete frame structure	Reinforced concrete frame structure
Cause of the fire	Smoking illegally by workers	Lightning	Spontaneous Combustion
Construction area	17640 m^2（10 warehouses）	unknown	22528 m^2
Fire protection design	Automatic fire alarm system, 20 indoor fire hydrants, 3 outdoor fire hydrants, 252 fire extinguishers, 30 t of head water tank, 2 fire pumps, and Huangpu River is near	8 Outdoor fire hydrants, 3 indoor fire hydrants, automatic sprinkler system	4 outdoor fire hydrants, fire pool (no other fire extinguishing facilities)
Burned area	unknown	10500 m^2	3600 m^2
Reasons for spreading	1) excessive reserves 2) dense stacking 3) automatic fire alarm system in disrepair 4) all windows of the warehouse were closed 5) dry weather in winter	1) illegal outdoor storage 2) the space between stacking was narrow 3) the height of the stacking was over that of lightning rod 4) without automatic fire alarm system 5) stormy weather	1) without fire departments in warehouse 2) a lot of lint cotton were stored illegally in the gallery between warehouse and workshop
Mobilization of forces	52 fire engines and more than 800 fire fighters	5 fire brigades, 56 fire engines and 334 fire fighters	8 fire brigades, 10 fire engines and 70 fire fighters
Handling time	37 hours	68 hours	46 hours
Tactical of firefighting	First, cracked the glass of 3,4,5 layer, with shooting water towards the fire floor, fire fighters entered the warehouse to attack the point origin one by one. Meanwhile, structure was strengthened to prevent collapse, and firefighters still stock to their positions to prevent resurgence.	Water supplied inside and outside, and stacking near the fire was evacuated prevent jump fire, meanwhile firefighters were pushing, picking or turning the stacking to exclude recrudescence.	Fire origins were found by fire investigation, and glasses were cracked to strengthen ventilation. Firefighters tried to use dynamite to prevent the fire spread to workshop.
The collapse of the case	Partial collapse	Partial collapse	cracks on the wall and collapse
Losses	2109 t cotton was burned and the economic losses were about 3.63 million RMB	24,600 t cotton was burned and the economic losses were about 48,387,300 RMB	More than 500 t cotton was burned and the economic losses were 15 million RMB
Fire safety issues	1) fire department area is excessive 2) the warehouse changed stacking material unauthorizedly 3) attendant was off-site 4) the number of outdoor fire hydrants were insufficient	1) the number and water pressure of outdoor fire hydrants were insufficient 2) extinguishment water source was 1000m away from the warehouse 3) fire protection facilities were in vain 4) hidden security risks were not timely certificated	1) the pressure of outdoor fire hydrants were insufficient 2) extinguishment water volume was not enough 3) automatic fire alarm system and automatic sprinkler system were not set in the warehouse

3. Fire risk of cotton logistics warehouses

Cotton logistics warehouses was identified as the great fire risk area by fire departments. Cotton is not classified as dangerous goods, but when confronted with the fire, it actually caused such a serious loss, which is due to the special physical and chemical properties of cotton, so higher storage requirements, in particular fire protection requirements, are needed. Therefore, it is necessary for fire safety countermeasures to analysis the fire risk of cotton logistics warehouses.

3.1 The physical and chemical characteristics of cotton

Cotton is inflammable. The 90% of the main component of cotton is natural fiber, carbon, oxygen content exceeding 45%, which makes cotton become inflammable substance. Because of strong hygroscopic of cotton fiber, when the cotton moisture, ambient temperature and humidity is appropriate, heat from microbial fermentation, the oxidation process of cottonseed absorbent will be issued. Since the cotton fibers radiating ineffective, cotton is easy to accumulate internal heat, so cotton is not only easily ignited, but also easy to combust spontaneously.

Cotton is easy to be smoldering. The texture of cotton is osteoporosis, even porosity of highly compacted bales still is more than 70%. When sparks fall into bales or physicochemical heat to ignite cotton, due to lack of oxygen in the cotton, the combustion mode will change to smoldering and last up to several days without being discovered.

3.2 Environmental influence to cotton logistics warehouses

Because spontaneous combustion and smoldering happen frequently based on physicochemical properties of cotton, the temperature of cotton logistics warehouses is generally kept below 303K and the maximum of it should not exceed 308K, as well as relative humidity may not exceed 70%. According to the temperature and humidity requirements, the advent of rain, summer, lightning, high winds and other adverse environmental factors are likely to cause natural variation of the cotton.

Depending on the degree of processing of cotton, cotton storage can be divided into the unginned cotton cargo area, lint cargo area, cottonseed area and cotton reservoir area. The unginned cotton is not off of seed, and lint refers processed cotton which is off of seed. Cottonseed means seeds that separated out from cotton with a short fiber, which accounted for 60% of the weight of the unginned cotton. The requirements of temperature and humidity of different kind of cotton are different in the Cotton national standard, so there is the difficulty in the management of the warehouse environment. For example, it sets forth in moisture regain of cotton is 8.5%, maximum amount being 10%. Here, cotton refers to raw cotton, but for seed cotton and cottonseed, its internal water is higher than the cotton as being new picked soon. For example, at the environment where a relative humidity is 70%, moisture content of cottonseed is 12%.

As for the precise control of temperature and humidity, it requires on-duty warehouse inspectorate view records of temperature and humidity daily. Because of too much human factors and uneven personnel safety awareness level, the warehouse temperature and humidity cannot be completely controlled.

3.3 Complicated Fire sources

Cotton logistics warehouse contains processing, storage, transportation, and these processes have many fire hazards. There are seeded cotton processing, pressing, packing. Spark may be the dangerous source of fire which is caused by the using of embossing machines, balers, triboelectrification by breaking of baling wire and electrical fault during the cotton processing (pressing and packing). In the process of cotton warehousing, it will ignite cotton that the lighting being too close with stacked or too big wattage. In the transportation of cotton, it becomes dangerous sources of fire for ignition cotton that sparks of engine of the car battery, forklifts, and the hot air of the exhaust pipe.

There are also many external fire sources. The ignition sources that is carried by personnel, such as unburned cigarette butts, lighters. It also comes from needful hot work such as welding cutting jobs. Furthermore, due to the low awareness of security, somebody may use the fireworks and stoves around the warehouse, the behaviors of which are likely to become dangerous sources of cotton logistics warehouse fire. In conclusion, it can be seen that the sources of cotton warehouse fire are complicated.

4. Event and Fault Tree Analysis(EFTA) of Cotton Logistics Warehouses

As fires occur repeatedly in recent years, the fire safety analysis of cotton logistics warehouses obtains progressively attention. By analyzing the fire cases, Tan Yan [4], Zhu Jiang [6], Zhu Hailong [7] and GUO Jian-feng [8] summary that the fire characteristics of cotton logistics warehouses are that there are several ways for fire to spread, including spread between

stacking, spread from inside and outside of stacking, surface spread, jump fire spread, and it is difficult to evacuate goods and extinguish the fire, as well as high recrudescence possibility. However, the research on the disaster mechanism of cotton logistics warehouses also is superficial. Through the analysis of fire development process, it can put forward some disaster reducing factors and corresponding measures for the theoretical basis of fire prevention.

4.1 Event and Fault Tree Analysis(EFTA)

In order to analyze the cotton logistics warehouse fire development, and disaster factors comprehensively and scientifically, the Event Tree and the Fault Tree are combined to be called Event and Fault Tree Analysis (EFTA), which can not only demonstrate the process of the fire spread of cotton logistics warehouses, but provides a way for analyzing different causes about different false events. Moreover, it is also significance to find out disaster mechanism and disaster reducing factors, which is the basis of formulating fire safety measures on cotton logistics warehouses. The procedure of EFTA is shown in Figure 3.

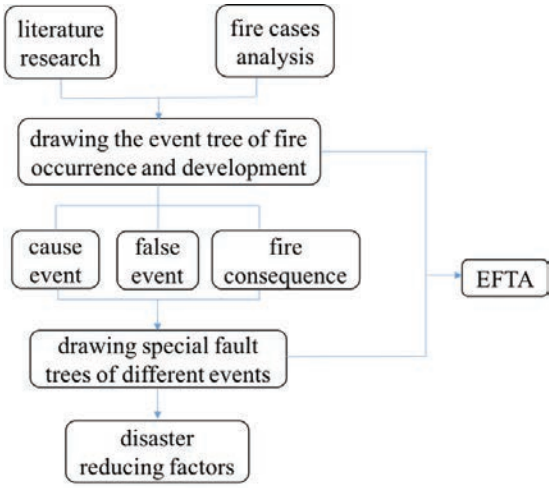

Figure 3 The procedure of EFTA

4.2 Event and Fault Tree of cotton logistics warehouses

Spontaneous combustion often happens on cotton through heat release from moisture absorption, fermentation and oxidation, as well as higher environment temperature, and it may go on by smoldering generally. If the smoldering spread to the surface of cotton, given enough oxygen around the space at the same time, it will turn into combustion with flame, which may cause a disaster. Here is Event and Fault Tree of cotton logistics warehouses as shown in Figure 4. It describes the development of cotton fire in Event Tree and the basic event of fire cause, process of fire spread, fire consequence in Fault Trees.

4.3 Fault Tree Analysis

According to Fault Tree Analysis, effectively fire safety measures may be figured out by analyzing the cause of the fire, spread reason and cause of the accident through the analysis of disaster mechanism of cotton logistics warehouses.

1) Spontaneous combustion

Through the Fault Tree analysis, the minimal cut sets is as follows:

$$\{X1,X4\}\ \{X2,X4\}\ \{X3,X4\}\ \{X5,X6,X7\}\ \{X8,X9\}\ \{X10,X11,X12\}$$

Structure importance is as follows:

$$I(X4)>I(X9)=I(X8)=I(X3)=I(X2)=I(X1)>I(X12)=I(X11)=I(X10)=I(X7)=I(X6)=I(X5)$$

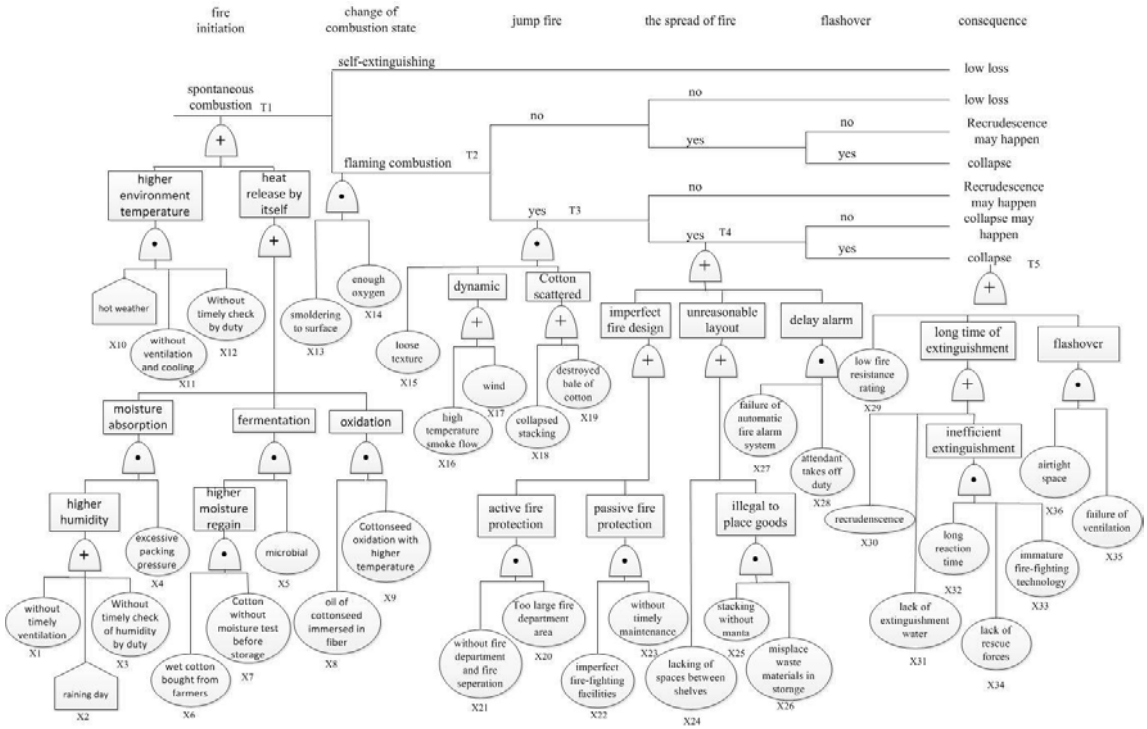

Figure 4 Event and Fault Tree of cotton logistics warehouses

It can be seen in all causes of cotton smoldering, the possibility of heat release from moisture absorption and oxidation is much higher; the overpressure of cotton packing is the vital factor of smoldering because heat of moisture absorption cannot be diffused which lead to the temperature of the fire origin raise. Thus, moderately pressure along cotton packing, and strictly temperature and humidity control of cotton logistics warehouses are both significant.

2) The spread of fire

Through the Fault Tree analysis, the minimal cut sets is as follows:

$$\{X20,X21\}\ \{X22,X23\}\ \{X24\}\ \{X25,X26\}\ \{X27,X28\}$$

Structure importance is as follows:

$$I(X24)>I(X28)=I(X27)=I(X26)=I(X25)=I(X23)=I(X22)=I(X21)=I(X20)$$

It can be seen that inadequate space between shelves, which means large fire load density, is the main factor in the spread of cotton logistics warehouses fire. This is because that the density of cotton would increase when it meets water, and the outside water cannot damage to internal fire origin, so that the fire extinguishing effect of fire protection facilities, such as the automatic sprinkler system will be reduced. So it is necessary to keep reasonable space between cotton shelves.

3) Collapse

Through the Fault Tree analysis, the minimal cut sets is as follows:

$$\{X29\}\ \{X30\}\ \{X31\}\ \{X32,X33,X34\}\ \{X35,X36\}$$

Structure importance is as follows:

$$I(X31)=I(X30)=I(X29)> I(X36)=I(X35) >I(X32)=I(X33)=I(X34)$$

It is known that the higher the building fire resistance rating is, the less prone it collapses. In extinguishing process, adequate extinguishment water source can continuously blow burning cotton to decrease the temperature and reduce the

probability of recrudescence which may cause the second accident. So there need to ensure adequate fire hydrants and enough effective extinguishment water source around cotton logistics warehouses within close range, which is vital for fire fighting.

5. Fire protection measures of Cotton Logistics Warehouses

For cotton logistics warehouse fire, the main policy of "Putting prevention first, combining prevention and fire-fighting" should be implemented. Therefore, according to the EFTA of cotton logistics warehouses, fire protection measures should be proposed.

5.1 Temperature and humidity control on cotton logistics warehouses

According to the known physical and chemical characteristics of cotton, it is inflammable because of heat release through moisture absorption, microbial fermentation, oxidation of cottonseed, and its flash point is low. When the outside temperature is above 308K or humidity over 70%, cotton would mutate. Therefore, it must be equipped with thermometer and hygrometer inside cotton warehouse to keep the temperature below 308K and the humidity below 70%. Furthermore, warehouse administrators should check the temperature and humidity every day, and take ventilation scattered wet or closed warehouses and other measures in a timely manner in accordance with changes in the weather.

5.2 Moderate pressure of cotton packing and sufficient space between shelves

When lint cotton is in packaging with over pressure, it will be excessively tight, which may lead to inside cotton ignition because of the accumulation of heat. Thus, in the cotton packing process, we should not only pay attention to the rational use of strapping wire but adjustable pressure as well.

Meanwhile, it is better to divide fire department according the rules in Fire-protection Code of Building Design, which has clearly defined about the warehouse fire department area and fire separations, otherwise it provides the conditions for the large range spread of cotton logistics warehouse fires. However, in the same fire department, if the spaces of shelves or stacking are too narrow, fire will suddenly extend to the entire region in just a few minutes before breaking through the fire department in the early phase of fire. It will not only cause significant economic losses, but also make the rescue work difficult. In general, stacking shelves should be spaced not less than 2 m and the width of other channel should be not less than 1.5 m. The pile should be away from the wall not less than 0.5 m and be away from the column not less than 0.2 m, both of which can minimize the directly baking to walls, columns and roofs and reduce the collapse probability of cotton logistics warehouses.

5.3 Control of fire sources and integrated fire safety facilities

Since the inner cotton logistics warehouse includes kinds of processes, it is very important that the staff carry kindling fire exclusion. It is the essential way to prevent the fire source from warehouses through personnel management and fire protection to technology. First of all, the provisions of individual security check must be strictly implemented in order to forbid fire source, whatever who wants to enter the warehouse. Secondly, transportation vehicles, storage vehicles, equipment in warehouses must install flameproof enclosure or choke to ensure no sparks. Meanwhile, it is forbidden to do hot work around the cotton logistics warehouse without the permission of the fire department, dangerous goods should not be carried into reservoir as well.

However, it isn't simple to guarantee the control of fire source perfectly, so fire-fighting facilities is the second line of defense, those of which should be installed and maintained in daily life, so that sudden fire can be found in time by automatic fire alarm system and control the spread of the fire or even extinguish fire by automatic sprinkler system. Additionally, extinguishment water plays an important role all times during fire fighting. Once the water closures, smoldering cotton will soon spread to the surface, causing the recrudescence of secondary disasters, which delays the best time to fire fighting and causes serious property damage. Thus it would better to find water source before building a cotton logistics warehouse.

6. Conclusion

The article sums up the fire safety issues of cotton logistics warehouses at present by analyzing the physical and chemical characteristics of cotton and analyzing typical fire cases, combined with national standard of fire regulations and fire accidents statistics, which include the excess fire load, incomplete fire-fighting devices, violated stacking and other illegal fire safety hazards. According to the properties of the process of cotton and equipment in warehouses, fire risks of cotton logistics

warehouses including complicated fire source, difficulty of controlling the temperature and humidity of the warehouse, which provide a basis for establishing Event and Fault Tree and analyzing the disaster mechanism.

Through the EFTA, it is known that the possibility of smoldering by heat released from moisture absorption is much higher, and the narrow space between stacking has a great impact on the spread of fire. In general, the fighting duration of cotton logistics warehouse fires is quite long, so whether the warehouse collapses depend on the fire resistance classification of the warehouse, and extinguishment water source is indispensable in the process of fire fighting. From the study above, we can summarize the disaster reducing factors as temperature and humidity of warehouses, pressure of cotton packing, space of shelves, fire resistance classification and extinguishment water. Fire protection measures can be put forward including: control the temperature below 305K and humidity below 70%; adjustable pressure of cotton packing; keep the space between shelves more than 2 m; fire resistance rating shouldn't below class three; extinguishment water must be found near the warehouse.

According to the above analysis, the combination of Event Tree and Fault Tree can solve the question dynamically and statically to achieve the target to find fire safety issues and promote fire safety design scientifically and reasonably.

References

[1] WU Jian-qiang, ZHANG Lei, ZHU Guo-qing, 2011. "Performance-based Evaluation on the Logistics Warehouse" Procedia Engineering-Proceedings of the 5th Conference on Performance-based Fire and Fire Protection Engineering, p. 522-528.
[2] ZANG Li, 2015. The Study on the Domestic Cotton Logistics. Journal of Chinese Mark Logistics Management 822, p. 19-19.
[3] YUAN Jin, 2006. The Study on Current Situation and Countermeasures of Cotton Logistics. Journal of Chinese Cotton Processing 5, p. 5-6.
[4] TAN Yan, 2005. Firefighting Technology of Cotton Warehouses. Journal of Chinese Inspection of Fiber 2, p. 55.
[5] ZHANG Jing, 2012. Fire Safety Assessment on National Cotton Logistics Warehouse, Journal of Fire Protection Technique and Production Information 8, p. 81-84.
[6] ZHU Jiang, 2014. Fire-fighting Technology of Cotton Stacking Based on the Example of National Cotton Warehouses Fire, Journal of Chinese People's Armed Police Force Academy 30, p. 27-29.
[7] ZHU Hai-long, 2001. The Study on Causes of Cotton Enterprises and Fire Protection Measures, Journal of Chinese Fluid Circulation Economy 3, p. 31-32.
[8] GUO Jian-feng, 2013. The Study on the Development of Chinese Cotton Industry Warehousing, Journal of Chinese Cotton Processing 3, p. 36-37.