The study of Influencing Maintenance Factors on Failures of Two gypsum Kilns by Failure Modes and Effects Analysis (FMEA)

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ABSTRACT

Developing technology and using equipment in Iranian industries caused that maintenance system would be more important to use. Using proper management techniques not only increase the performance of production system but also reduce the failures and costs. The aim of this study was to determine the quality of maintenance system and the effects of its components on failures of kilns in two gypsum production companies using Failure Modes and Effects Analysis (FMEA). Furthermore the costs of failures were studied.

After the study of gypsum production steps in the factories, FMEA was conducted by the determination of analysis insight, information gathering, making list of kilns' component and filling up the FMEA's tables. The effects of failures on production, how to fail, failure rate, failure severity, and control measures were studied. The evaluation of maintenance system was studied by a check list including questions related to system components. The costs of failures were determined by refer in accounting notebooks and interview with the head of accounting department.

It was found the total qualities of maintenance system in NO.1 was more than NO.2 but because of lower quality of NO.1's kiln design, number of failures and their costs were more. In addition it was determined that repair costs in NO.2's kiln were about one third of NO.1's. The low severity failures caused the most costs in comparison to the moderate and low ones.

The technical characteristics of kilns were appeared to be the most important factors in reducing of failures and costs.

Key words: FMEA, Safety, Kiln, Maintenance system

INTRODUCTION

Rapid development of technology and requirement of equipment and machineries performance improvement led to automation. Automation causes the reduction of work- labors hence, increasing the workforces involving maintenance in different industries. As the automation requires a large investment for buying new machinery and equipment, the managers naturally have to designate sufficient budget to maintain the machineries. Generally maintenance system led to improve the buildings and property conditions, maximize the use of machineries and reduce the non-production periods, control and direct the workforces, increase the equipment reliability, reduce the waste materials, keep records of costs and evaluate equipment performances for future considerations.

Gypsum is one of the oldest materials which was used for construction. For instance, the gypsum was used in Egyptian triple pyramids in 2700 B.C. [1]. Gypsum mines is found in Iran in a large amount, most of them are located in eastern of Tehran, Semnan, Shiraz, Kerman and Hormozgan provinces. Totally, there are 260 gypsum mines in Iran from which approximate 14 million tons of stones are extracted annually [2]. In gypsum industries row material, is dehydrated in kiln by heating and converted to calcined gypsum. Considering the high investment in gypsum industries and prevention of the failures of machinery, it is critical to study the maintenance system of kilns.

The first step of accident prevention is identification of failures. Failures (accidents) identification and evaluation are conducted by different methods such as FMEA (Failure Modes and Effects Analysis), HAZOP (Hazard and Operability study) and FTA (Fault Tree Analysis) [3]. FMEA method mainly aims to prevent the accidents in a process or product. The FMEA optimize the production process and reduce the costs which nowadays is used for choosing proper machineries and equipments, as well as in selection of the proper production technology [4]. In addition, the FMEA is a useful technique to manage and conduct the preventive maintenance that is used in different industries [5]. A survey was conducted in 120 industries in UK and 120 failures caused by fatigue and other influencing factors were investigated [6]. In addition of its industrial applications, the FMEA is an effective technique in improving of patients' conditions and emergency response [7, 8].

The aim of this study was to compare the maintenance system components and its effects on failures of kilns of two companies. The identification and evaluation of failures of kilns was conducted by FMEA and costs of failures were determined.

Materials and Methods

Company no.1 was founded in 1975. The constructional operations were begun by German Company of BAU-Verlag from 1973. The nominal production amount was 1100 ton per day, which produced by two revolving 400 and 700 ton kilns. The row material of gypsum stone ($CaSO_4$, $2H_2O$) (9), was prepared from the gypsum mine which located at 2 Km from the factory.

Company no.2 was located in eastern south of Tehran. The constructional operations of this company were begun from 1971 by the German Company of Gebr.pfeiffer and finalized in 1972. The nominal production was 1000 ton per day, produced by two triplex kilns. The technical characteristics of two companies' kilns are presented in table1.

Table 1: The technical charactristics of two companies' kilns

Kiln	Nominal production(T/D)	Diameter(m)	Length(m)	Number of rings	Motor power (KW)	Kiln revolution (RPM)	Motor revolution (RPM)	Kiln temperature ○(C)
No.1	700	2.5	30	2	40-120	2.14	500-1500	600
No.2	1000	5	6.3	1	69	2.5	1000	600

The production processes in two companies were nearly the same. The most important difference between them was the relevant to kilns types which were direct revolving and triplex in no.1 and no.2, respectively. Gypsum stones were transferred to factory and then shoot to special screens for separation the proper size and convert to them hammer crusher. After crushing, the materials transferred to kilns for cooking. The construction of kilns of no.1 and no.2 are presented in Figures 1 and 2.

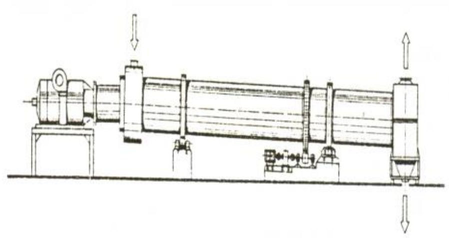

Fig. 1: Construction of longitudinal kiln of company No.1

The maintenance system for two companies' kilns was evaluated by preparing and filling out a check list about components of this system [10]. Maintenance system components were determined as programming (15 Items), control (6 Items), manager and personnel (8 Items), improving of maintenance system (16 Items), machineries characteristics (6 Items), logistic (15 Items), determining of maintenance cost (6 Items), personnel safety (3 Items) and training (3 Items) [10]. The total score of any components was indicated the quality of maintenance system. The probable failures of kilns were studied by the FMEA which was conducted in four steps as follows:

1. Determining the analysis scope; which indicates boundary and limits of the system (kilns),
2. Information gathering; which have been done through available documents in operation manuals, catalogues, and interview to engineers and maintenance men,
3. Preparing a list of kilns' components; which was conducted via using gathered information from step number 2 and also the operational conditions of kilns, such as temperature and pressure,
4. Filling out the FMEA's tables; the ratio of numbers of failures in 1 year was considered as failure rate.

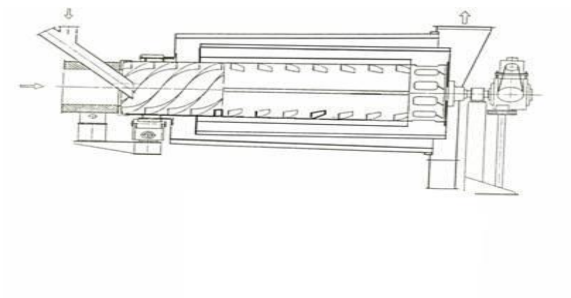

Fig. 2: Construction of triple layer kiln of company No.2.

The total failure costs were computed from wage, material, and non-productive period costs by referring to equipments and spare parts discharge data sheets and accounting department. The wage of repairers was computed as a product of the person-hour of each fails by the average of wage for any hour. The non-productive period costs were computed from the following formula:

*Non-productive period cost = the price of one ton gypsum * failure rate * repairing period of any fails * (daily production/24)*

The price of one ton gypsum at the time of conducting the study was considered 51500 and 51000 Rials for company no.1 and company no.2, respectively.

RESULTS

The scores of any components of maintenance system are presented in Table 2.

The kilns' failures (in terms of failure rate) and their costs in no.1 and no.2 companies are presented in tables 3 and 4 respectively.

Table 2: The score of components of maintenance system of both companies

Maintenance systems' components	programming	Control	Managers and personnel	Maint.sys. improving	Technical characteristic	Logistics support	Costing	Safety	Training	Total scores
No.1	15	7	7	16	3	10	6	4	2	70
No.2	10	5	6	14	10	7	6	1	0	59

Table 3: No.1 kilns' failures and their costs

Priority in terms of failure rate	Type of fails	Annually cost (Rials)	Failure rate (Annually)
1	Crack and deformation of kiln seals	104,248,000	24
2	Falling of kiln bricks	3,118,000,000	5
3	Burning of bricks	18,708,000	3
4	Sharpening of the kiln main gear teeth	11,657,333	2
4	Burning of burner tips and nuzzle	110,776,000	2
5	Kiln fuels cut off	9,857,333	1
5	Obstruction of fuel pips	12,021,666	1
5	Chipping the main gear teeth	5,828,666	1
5	Incomplete connection of electrometer's brush	4,310,166	1
5	Shortening of electrometer's brush	4,410,166	1
5	Liners loss in kiln	60,360,000	1
6	Compotator damage and scratch	2,164,333	0.500
7	Abnormal wear in bearing surface	206,753,910	0.330
7	Cracks of kiln shell upon welding junction underneath tire.	1,428,460	0.330
7	Kiln shell spot	5,194,400	0.330
8	Wear on lifting roller surface	75,597,000	0.250
8	Cracks of kiln shell underneath tires.	1,082,166	0.250
9	Contacts on kiln drive	95,683,540	0.235
9	Tearing out of ball bearing of motor's gearbox	9,654,500	0.235
10	Fracture of bearing shaft	48,668,710	0.176
11	Rubbing and tearing of inside surface of ring	703,786	0.160
12	Kiln shell deformation	194,199,850	0.117
12	Cracks on roller shell	1,519,325	0.117
13	Kiln exit stretch	5,194,400	0.100
14	Breakage of kiln gearbox	23,576,585	0.058
14	Cracks on junction of main gear	251,043	0.058
14	Contact between rotor and stator	24,775,470	0.058
14	Shrink of kiln shell near tire.	15,321,280	0.058
14	Excessive rubbing and deformation of ring	64,179,990	0.058
14	Fracture of lifting roller shaft	11,158,430	0.058
14	Increase of temperature of kiln bearing brush	1,295,043	0.058

Table 4: No.2 kilns' failures and their costs

Priority in terms of failure rate	Type of fails	Annually cost (Rials)	Failure rate (Annually)
1	Crack and deformation of kiln seals	70,992,000	16
2	Burning of bricks	222,880,000	4
3	Incomplete connection of electrometer's brush	8,537,000	2
4	Sharpening of the kiln main gear teeth	5,787,000	1
4	Obstruction of fuel pips	11,917,500	1
4	Chipping the main gear teeth	5,787,000	1
4	Deviation of torch	1,067,125	1
4	Shortening of electrometer's brush	4,368,500	1
4	Burning of burner tips and nuzzle	54,888,000	1
4	Falling of kiln bricks	55,720,000	1
5	Commotator damage and scratch	2,143,500	0.500
6	Cracks of kiln shell upon welding junction underneath tire.	857,400	0.200
7	Cracks on roller shell	2,263,536	0.176
8	Shortcut Circuit in motor of kiln	60,849,600	0.150
9	Fracture of bearing shaft	27,627,700	0.100
9	Increase of temperature of kiln bearing brush	2,212,000	0.100
9	Breakage of kiln gearbox	38,643,050	0.100
10	Contact between rotor and stator	21,283,200	0.050
10	Contact between stator and motor shell	11,072,200	0.050

It is worth to mention that because of proper designing and construction of kilns and using of esteemed materials in construction of kilns' parts, the failure rate of many fails were found equal to zero (F.R.=0). The failure rate, for instance, of wrapping of kiln trunk, cracks near the welded parts, and inside corrosion of No.1's and No.2's kilns were zero. In addition, it was found that many failures of No.2's kiln were zero meanwhile the relevant amounts were higher than zero in No.1 (Table 3).

The study of maintenance cost showed that the total cost of No.1's and No.2's kilns were 160,732 and 60,082 million Rials, respectively. Figure 3 shows the contributions of equipment, wage and non-productive time in total cost of No.1 and No.2. The maintenance cost (million Rials) in terms of failure severity is shown in figure 4.

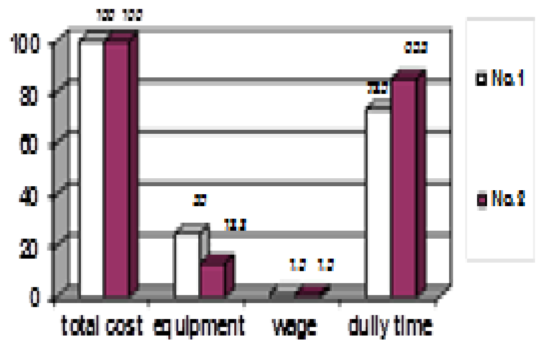

Fig. 3: Contribution of equipment, wage and non-productive time to total cost of No.1 kilns' failures

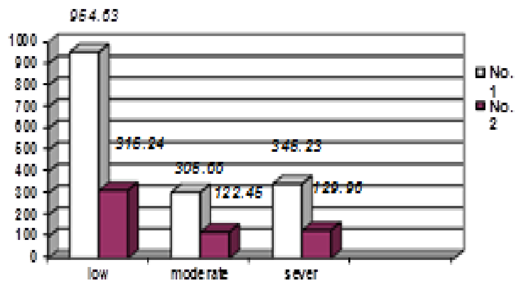

Fig. 4: Maintenance cost in terms of severity of failures

DISCUSSION AND CONCLUSION

Failure Modes and Effects Analysis (FMEA) is a design tool that mitigates risks during the design phase before they occur. Although many industries use the current FMEA technique, it has many limitations and problems. Risk is measured in terms of Risk Priority Number (RPN) that is a product of occurrence, severity, and detection difficulty. Measuring severity and detection difficulty is very subjective and with no universal scale. RPN is also a product of ordinal variables, which is not meaningful as a proper measure [11].

Table 2 shows that all components of maintenance system of No.2 company (exception kiln) has lower scores than No.1's. In each two companies, the further study of maintenance system and its improvement was necessary in order to reduce the cost of fails. In both considered companies the non-production time for each fail were indicated but time analyses were not conducted. In both companies one of the most important reasons for increasing of non-product time was implementation of the periodical maintenance rather than the replacement of spare parts [12]. Several operations, such as cutting, welding and grinding can led to wasting time and increasing the cost.

The control of maintenance system was performed by service request papers in two companies. In addition the performance of kilns was tested during the operation and after repair which is the best way to identify the fails before increasing the severity of the fails. Unfortunately it was not possible to determine the skill and experience level of personnel in maintenance departments but in regarding the interview, it seemed that the personals of No.1 Company had higher skill level than No.2.

It is found that the most important difference between maintenance system components in two companies was related to kiln's features (table 2). These different features lead to the diversity of the severity, type and failure rate in two kilns. The main differences between two kilns were as follows:

- The rotation of kilns caused to the torque of kilns. The torque of NO.1's kiln was more than NO.2's because of its higher length.
- Because of the less longitudinal expansion and less torque of NO.2's kiln, slipping effect (the slip of kiln because of angle between kiln longitudinal axes and horizontal line) was negligible. This phenomenon was so low that there was no necessity to use lifter and therefore there were no failures of rubbing and tearing of lifting roller surface and fracture of roller’s shaft.
- The thermal efficacy of kiln NO.2 was higher than NO.1's because the NO.2 kiln was built up from concentric three cylinders. The heat was transferred from inner cylinder to the outer ones and therefore the heat loss was kept as low as possible. Because of high thermal efficiency and shorter length of NO.2 kiln, the failure rates of Kiln shell deformation, Shrink of kiln shell near tire, Kiln exit stretch, cracks on junction of main gear, falling of kiln bricks, Kiln shell spot were zero.
- The disadvantage of NO.2 kiln from NO.1's was the lack of quick access to inner parts of kiln for inspection and maintenance operations. It was impossible watching out inner parts and it was necessary to use some monitors for inspection.

Table 3 shows that the maximum failure rate was related to crack and deformation of kiln seals (F.R= 24). The main reason of that was improper distance between torch and entrance part of the kiln. The kiln may be elongated and shrink due to the heat. The distance was adjusted by the lifter. If for any reasons the mentioned distance was not adjusted, the fails of Crack and deformation of kiln seals and Cracks of kiln shell upon welding junction underneath tire were occurred.

This study shows that any fail can cause to another sever fails. The most important following fail was separation of brick which had second priority in order to F.R (Table 3). Considering the fails shows that the deformation of kiln, wrinkle of kiln near ring, wideness of extranet part of kiln, cracking on kiln surface near ring, red-hot making surface and cracking of roller led to fail on bricks.

In general, using proper material in kilns construction led to reducing the failure rate to zero of many fails. In addition working process of production was steady and therefore operational conditions (such as temperature, pressure) of kilns were monotonous; so fluctuating tension was not occurred on kilns that caused to reduce the failure rate.

It must be remember that one of the reasons for the low amount of failure rate was the lack of inefficacy of the record keeping system. For reduction of maintenance cost failure rate must be reduced. With reduction of failure rate not only the cost of equipment replacement was reduced but also the cost of wage and non-product times were also declined significantly. Meanwhile, the burden cost such as transportation and administration costs were omitted. The best way of cost reduction is conducting preventive maintenance. The regular and planned inspections for determining the performance status of kilns and prevention of fails are essential. Unfortunately in none of the companies the inspection was conducted regularly.

The falling of kiln brick and burning of bricks are the first priorities of fails in order to cost in NO.1 and NO.2 companies, respectively (Tables3 and 4). The reason of this difference was the higher length and to be one layer of NO.1 kiln. On the other hand the most cost of fails was due to non-productive time (Figure 3). The results of this study showed that 10 percent of fails was included 43% and 49% of cost in NO.1 and NO.2 companies, respectively.

Considering the relation between repair cost and severity of fails showed that the low severity fails had the most cost (Figure 4). One of the most important reasons for this issue was neglecting the low severity fails by personnel and using the improper material equipment in reparation. Finally this study showed that the design and construction of kilns are most important variables in reduction of fails.

The further studies on this issue are recommended.

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