THE INCOMPATIBILITY OF A STACK DESIGN TO THE EQUIPMENT IT SERVES

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ABSTRACT

A chimney that is not properly designed can be very dangerous.
Described below is a chimney recently investigated.

1. INTRODUCTION

The stack is 87 m high located in the Middle East. It is situated on site behind a sulfur incinerator unit. This stack should be capable of running continuously under the incinerator normal operating conditions. Last summer, a sudden increase of pressure at the stack base was reported and the process was completely stopped resulting in the total unit shutdown. As usual a unit shutdown is very expensive and immediate action was required. The stack liner was completely molten and the Tuned Mass Damper was found broken: it was decided to replace them identically.

2. GENERAL DESCRIPTION OF THE ORIGINAL EQUIPMENT.

The equipment consisted of an 87 m high steel stack with a stainless steel liner and a tail gas incinerator. The incinerator mainly consists of a burner , incineration chamber, air dilution damper and cooling chamber. The incinerator was supposed to burn tail gas most of the time. In the original design the possibility of burning disulfide was taken into consideration. In that case the temperature was expected to be much higher and a cooling chamber was inserted between combustion chamber and stack. A circular air dilution damper was erected between the combustion chamber and cooling chamber. Opening and closing of this damper was done manually. For tail gas incineration, the air dilution damper has to be closed as per original design. It is to be noticed that the air combustion is introduced at the burner location only by natural draft.

2.1 Stack general view

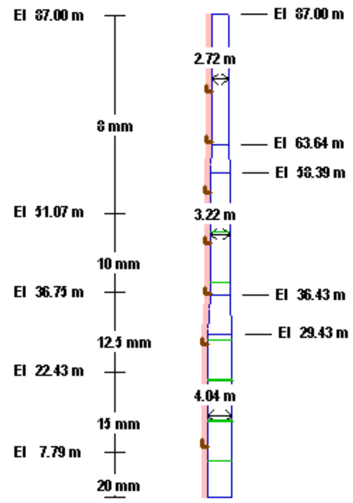


Figure 1 : stack view.

The stack is equuipped with a Tuned Mass Damper fittied with thres hdraulic daspots.

2.2 Incinerator

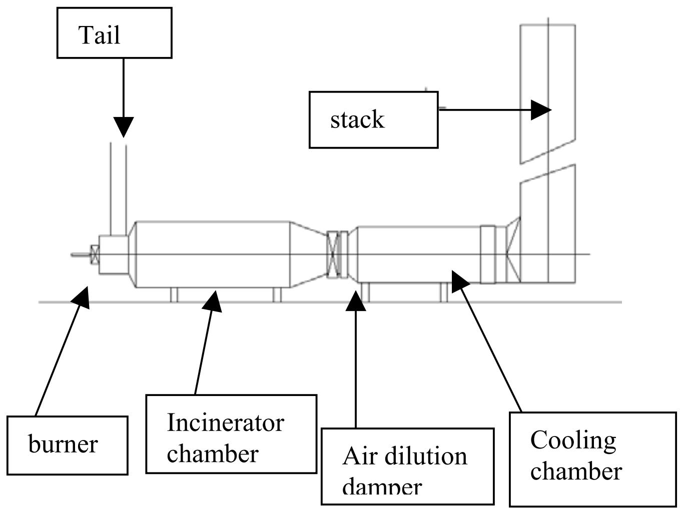


Figure 3:géneral view of the incinerator

3. SOME FACTS AND PHOTOS

3.1 Photos

Photo 1 :view of one segment of the liner after partial dismantling

Photo 2 :detail of liner from outside

Photo 3 :detail of liner from inside.

It was clear that the failure occurred due to the smoke temperature being to high. To find the reason of this accident an investigation concerning the whole process was necessary.

4. THE INCINERATION PROCESS

Limited information was available; the key data being :

- The smoke composition and flow rate
- The required natural draft at the burner location to feed the necessary amount of combustion air
- The required temperature for incineration : 600°C
- The temperature measurements at the end of combustion chamber , end of dilution and stack top

	Vol mass kg/Nm3	flow rate Kmole/hr	Cp Kcal/Nm3	flow Kg/h	flow Nm3/h
H2S	1.52	12.04	0.3690	410	270
SO2	2.86	6.01	0.4555	385	135
H2O	0.804	488.69	0.3569	8 806	10 953
N2	1.25	868.34	0.3148	24 331	19 465
S1		1.18	0.0000	38	
H2	0.0899	25.41	0.3057	51	570
CS2	3.41	0.59	0.4860	45	13
COS	2.69	0.78	0.4500	47	17
CO	1.25	27.36	0.3133	767	613
CO2	1.977	599.88	0.4194	26 419	13 363
		2 030.27		**61 299**	**45 399**
				kg/hr	**Nm3/hr**

table 1: smoke composition

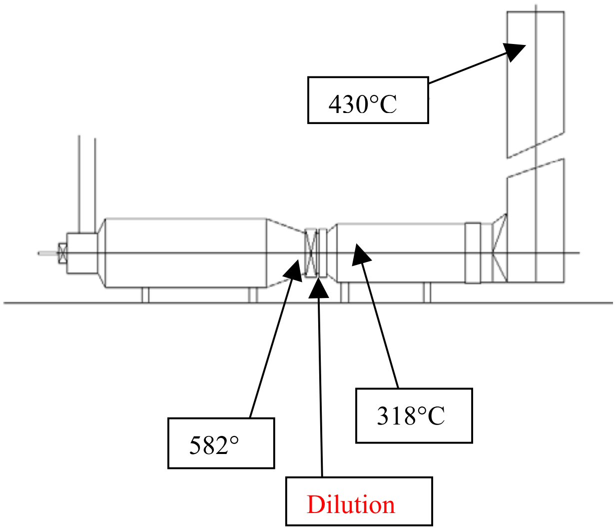


Figure4: measured temperature

It should be observed that the smoke temperature at the stack top is 112°C above the temperature at stack base.

4.1 Calculation of the theoretical incineration process

In order to check the process it was necessary to estimate the quantity of combustion air required for the burner. This air was supposed to be fed only by natural draft.

The summary of our calculation follows

- required quantity of combustion air : 16 021 Nm3/hr
- smoke temperature at the end of combustion chamber : 603°C
- O2 content in the smoke after combustion>1%
- Natural draft at burner –48 mm WG

All of these results were in strict accordance with the original specification; the incineration temperature was in accordance with the specification, the natural draft was sufficient to allow air combustion in sufficient quantity in the burner and the O2 content was also sufficient to insure a full incineration.

Conclusion: the normal operating temperature was checked and confirmed to be 600°C. The stack liner made of SS 304 was not suitable for continuous operation. This kind of steel could withstand 600°C for a short duration but the creep stress is not acceptable.

As the incinerator was only burning tail gas the air dilution damper should have been closed but it wasn't. At first this was supposed to be on the safe side because it resulted in reducing the temperature in the stack liner.

It was necessary to estimate the quantity of air dilution arriving at the air dilution damper location.

4.2 Estimation of the amount of air dilution.

The amount has been estimated by two different solutions

- By considering the temperature just before and just after dilution and having the tail gas and the air combustion flow rate

- By considering the fact that the all combustion process was supposed to occur somewhere between the burner and the stack top. We have estimated the required excess air so that the average temperature is just above 430°C at the stack top.

	Estimated air dilution flow Nm3/hr	Total estimated smoke flow in the stack Nm3/hr
1 st solution	48 063	93 580
2 nd solution	51 000	112 536
average	49 531	103 059
To be compared with the original design	0	61 538

Table 2: estimation of smoke flow in the stak

Opening the air dilution damper results in an increase of the smoke quantity from 61 538 Nm3/hr (+67%) and of a decrease of the average smoke temperature within the stack from 603°C down to 374 °C. As a result the natural draft of the stack is greatly affected. The natural draft at the burner location has been reduced from – 48 mm WC to 30 mm WC << the minimum required by the specification.

4.3 Conclusion for the incinerator

The new operation conditions generated by opening the air damper results in in-sufficient natural draft at the burner; as a result, the combustion is not fulfilled in the combustion chamber. At the air dilution damper location , additional air was introduced by natural draft : a post combustion process was likely to occur in the stack

Opening the air dilution damper (which was supposed to be opened only in case of burning disulfide) to reduce the temperature in the stack because of inadequate material for the liner results in fact in post combustion with an extremely high temperature.

5. STACK AND DAMPER

5.1 Tuned Mass Damper

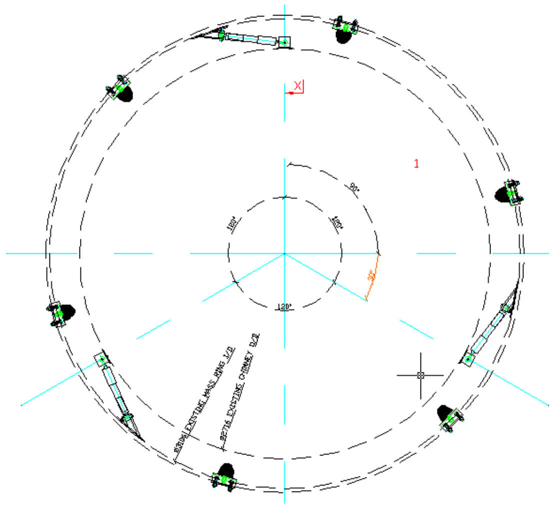


Figure 1 : plan view of the damper

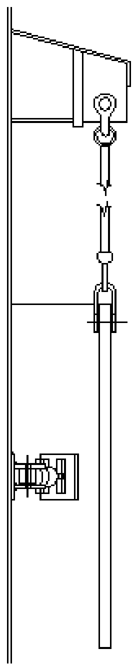


Figure 2 : damper sectionnal view

The stack design has been checked using different codes: STS 1-2000, Bs 4076 and Eurocode..

The main results were :

The stack is properly designed for along wind for the three Codes

The stack would have vibration problems and require a damper system

STS 1-2000 and BS 4076 permit only a conclusion for the first mode.

Eurocode was used for prediction with the first and second mode

	First mode	Second mode
frequency	0.57 Hz	2.42 Hz
Max top deflection without damper	0.45 m	0.55 m
Critical wind speed	7.9 m/s	33.4 m/s
Max stress amplitude for fatigue	136 Mpa	888 Mpa
Number of vibration cycle over 10 years with Vo=7 m/s	38.4 e6	2

Table 3: estimation of number of vibration cycles

So the number of cycles over a period of 10 years is huge due to the fact that the critical wind speed is small . The three dashpots of the damper were found completely broken which is not surprising because dashpots of any kind have a guarantee of 1 e6 cycles. Of course the life span is bigger than the guarantee and these dashpots could be used for perhaps 2 or 3 e6 cycles. Above this number of vibration cycles everything is dependent upon the maintenance period

The second vibration mode occurs with a critical wind speed of 33.4 m/s which is below the design wind speed. So it might occur even if the probability remains small. For vibration with the second mode the forces, stresses and deflection would be much higher than those resulting from the first mode and in any case above the allowable value.

The damper has to be replaced by another type of damper able to withstand a high number of cycles. An estimation of the number of vibration cycles has been made in order to have an idea of the filed of application of this damper system. This estimation has been made using the formula given in the DIN 4133 Code. The number of vibration cycles are dependant on the stack location. If the stack is in a very windy location, one could expect a large number of vibration cycles. We have taken Vo=5 m/s for a non windy area and Vo=7 m/s for a windy area. To summarize the results we have made an estimation of number of vibration cycles as a function of the critical wind speed for some common stack diameters. Varying from 1 m to 4 m. The red line represents 3 million cycles of vibration over a period of 10 years .If the critical wind speed is below the red curve then the number of vibration cycles is lower than 3 million and as a result a dashpot system is acceptable.

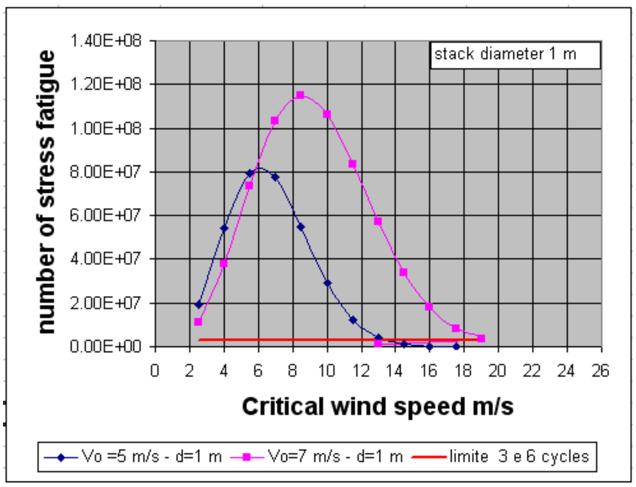


Figure5: number of vibration cycles versus crtitical wind speed for a 1 m diameter stack

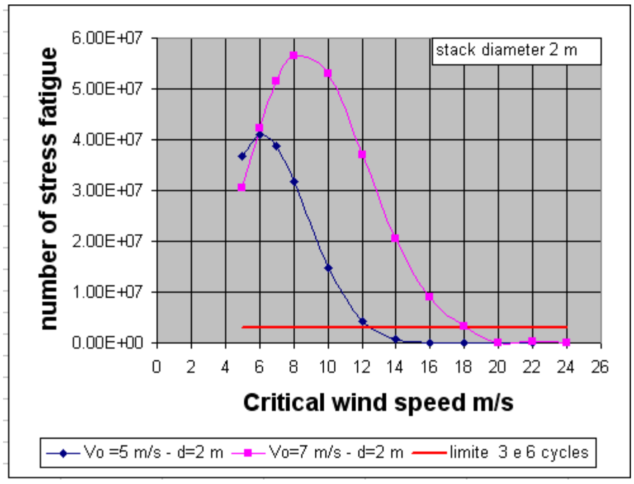


Figure6: number of vibration cycles versus crtitical wind speed for a 2 m diameter stack

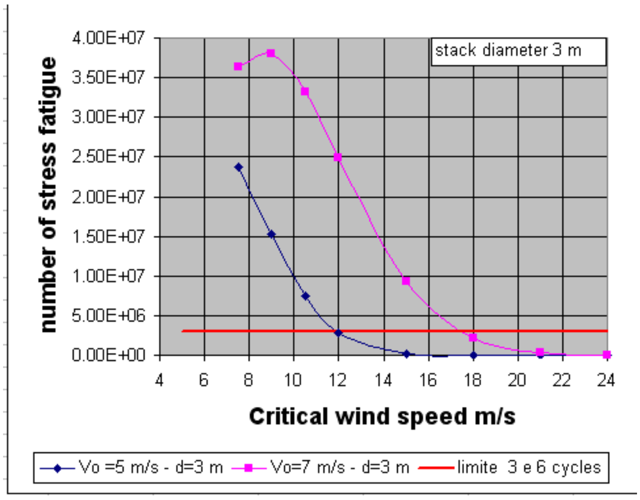


Figure7: number of vibration cycles versus crtitical wind speed for a 3 m diameter stack

In our case study, the stack diameter is about 3 m and critical wind speed is about 8 m/s; it is quite normal that the damper system has failed.

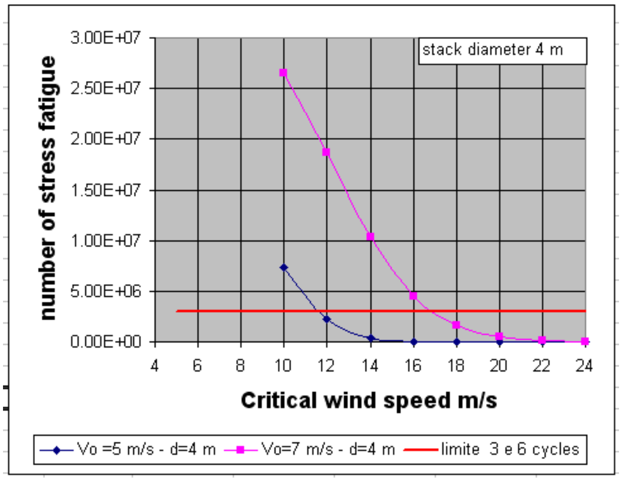
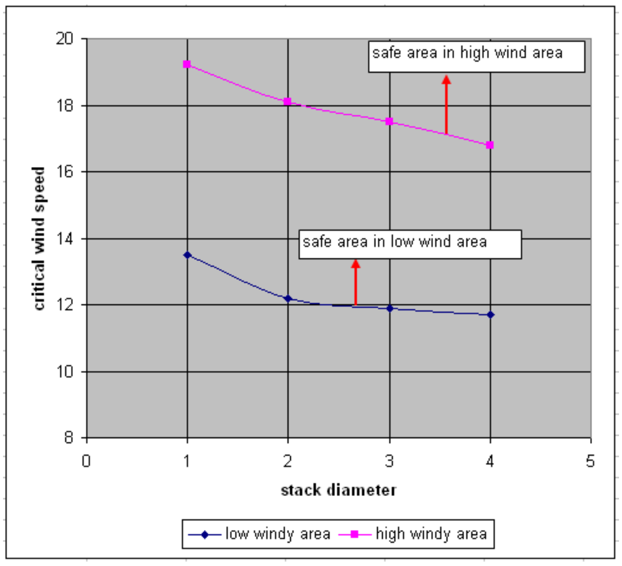


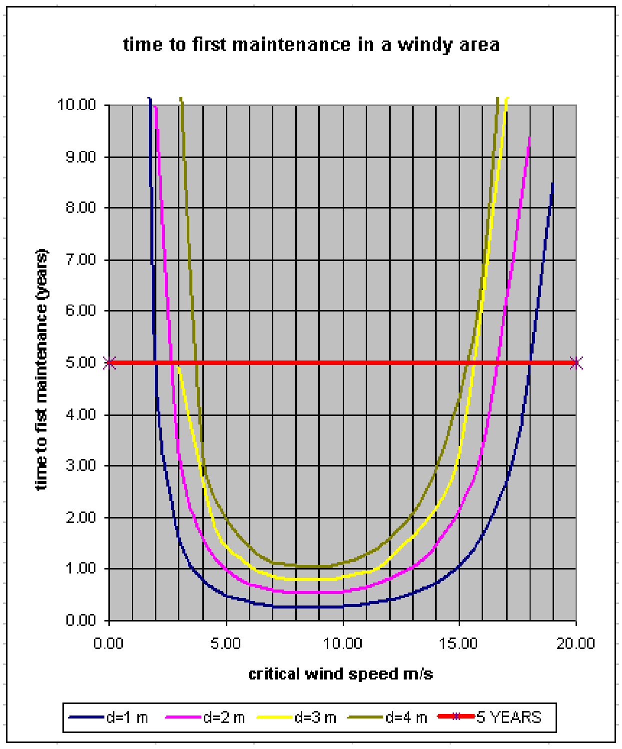
Figure8: number of vibration cycles versus crtitical wind speed for a 4 m diameter stack

In some extreme conditions a broken damper could also affect the liner fatigue resistance.

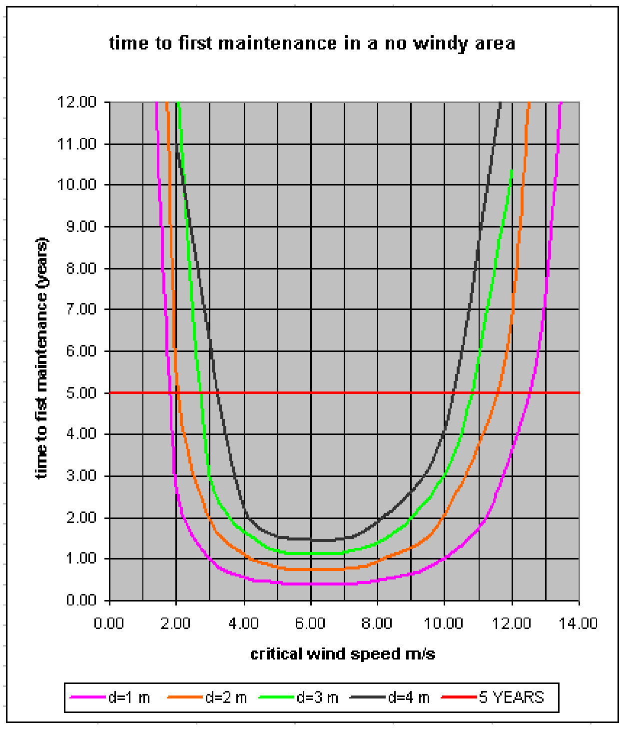


As a conclusion this type of damper is suitable for critical wind speeds above 12 m/s in low wind areas and above 17-18 m/s in windy areas.

Due to the need of preventive maintenance it is now requested to have an estimation of the duration of the TMD/dashpot system. Below we have considered a minimal 5 years maintenance period based on 3 e6 cycles lifespan for the dashpots.



In a windy area and with a stack of 4 m diameter, the critical wind speed has to be above 15 m/s in order reduce the maintenance period to 5 years. If the critical wind speed is between 8 to 13 m/s then the maintenance period is smaller than 2 years. If the stack has a diameter of 1 m then the critical wind speed has to be above 18 m/s to keep this 5 years maintenance period.



In a no windy area and with a stack of 1 m diameter, the critical wind speed has to be above 12 m/s in order reduce the maintenance period to 5 years. If the critical wind speed is between 4 to 8 m/s then the maintenance period is smaller than 2 years

In our case the critical wind speed was 8 m/s and the stack diameter at top about 3 m. It is clear from the attached curves that the maintenance period was expected to be very small and it is not surprising to have found the dashpot broken . As an approximation, with TMD other damping devices than dashpots have to be taken into consideration when critical wind speed is less than 16 m/s in a windy area and 11 m/s in a no windy area.

6. CONCLUSION

There was an error or misfit between the original specification for the stack and the original specification for the incinerator due to the fact that the max temperature of the stack liner was in fact the normal operating temperature for the incinerator and the SS304 material is not suitable for continuous use at 600°C

Trying to solve the problem by opening an air dilution damper post combustion has generated the causes resulting in the full smelting of the liner

The damper type was not properly chosen and was not in operation after a few years, due to its short term failure the stack shell and also the liner would have also failed by fatigue if no other event such as the post combustion problem had occurred.

The second vibration mode could produce much higher stresses than the first mode; even with small probability the risk does exist.

In order to reduce the maintenance period to industrial acceptable practice other damping devices than dasphot have to be investigated when the critical wind speed is smaller than 11 m/s in a no windy area and smaller than 16 m/s in a windy area