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ANNOYANCE AND ITS SOLUTION (AN APPROACH TO ELIMINATE TONAL NOISE FROM A CENTRIFUGAL FAN)

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1. INTRODUCTION

As is well known, the effect of sounds on people consists of multiple factors of physical matters shown as sound pressure and psychological matter which depends on the state of people. The psychological effects are varied with personal characteristics such as situation, psychological condition, age, sex, etc., so the noise problems become more complex.
Meanwhile, industrial noise control in Japan started as the establishment of Noise Regulation Law in 1968 and Environmental Quality Standard for Noise in 1971. The aim of these law and standard was environmental pollution control specifying the noise limit at the property fence of plant site, that is, the quantitative regulations.
However, recently the environmental noise has been become not only a quantitative problem but a qualitative problem due to the increase of people's concern for pleasant environment.
The noise problem discussed in this paper highlights both public nuisance and the pursuit of a comfortable life.

2. BACKGROUND

The oil refinery is located in an industrial area but it faces a residential area. The community residents had a large concern for environmental pollution, so a special agreement for environmental pollution control has been concluded between the residents and the companies.
In this surroundings, a centrifugal type induced-draft fan (ID fan) revamping was carried out accompanied by the enhancement of a up-stream fired heater of a catalitic cracking reformer plant.
During the plant start-up period, abnormal sounds having tonal components was emitted from the top of the stack at 60 metres in height above ground (see Fig.1, Fig.2). This tonal noise was not

eliminated when the plant operation become steady, so it affected the residential area and led to complaints by residents.
Although the overall sound levels had satisfied the noise limitation of a local agreement, quick investigation and mitigation were requested to take a look at environmental conservation in compliance with the refinery manager's policy.

3. INVESTIGATION OF CAUSES

Under the limited period of time and plant operating conditions, an auditory check, sound pressure level measurement at possible locations, narrow-band analysis, and detailed investigation of fan revamping were conducted.
The results had suggested tone emission relevant to the blade passing frequency of the ID fan (rpm x no. of blade /60 = 247.5Hz) and the existence of mechanisms to excite the tonal noise on the way from the fan-discharge to the stack-end.

The flow scheme to find the cause of tonal noise is presented in Fig.3 in consideration of the gap decreasing between the impeller and the fan casing due to fan revamping, and the existence of the cavity at the exhaust stack bottom.

Possible causes are summarized as the following three points:

(1) Sound pressure level of the blade passing frequency component had increased due to a decrease in tongue clearance as the result of the impeller diameter extension to the existing fan casing.

(2) A standing-wave coincident with the blade passing frequency built up at the cavity of the stack bottom (note), so that the acoustic resonance had occurred.

(note)Wave length (λ) calculated with the ID fan design specifications(i.e. molecular weight M =27.35, specific heat ratio κ =1.38 and flue gas temperature θ =170℃) and the equation below is 1.75 metres.

sound velocity : $a = 91.1 \{ \kappa (273+\theta) / M \}^{1/2}$ (m/s)

wave length : $\lambda = a / f$ (m)

1.31 metres of 3/4 λ nearly coincides with the depth of the cavity which is 1.35metres, so the standing wave build up is possible.

(3) Gas flow came off at the upstream edge of the cavity so that vortices had occurred. Due to the breakaway of these vortices, pressure fluctuation occurred in the cavity and cavity noise was generated.

4. MITIGATION MEASURES

Several mitigation measures to reduce the tonal noise were discussed from the viewpoints of effect, schedule, workability and cost (see Table

1).Two type of mitigation measures were finally selected and decided upon to be conducted.

(1)Step-1 (mitigation measures conducted under a plant in service)
To preserve the occurrence of a standing-wave or vortices, the cavity of the stack bottom is filled up with raschig rings. A raschig ring has a cylindrical shape of 25 mm dia., 25 mm length and 1 mm thickness, and is made of stainless steel.

(2)Step-2 (mitigation measures conducted during minimum plant shutdown period)
An adequate designed absorptive silencer is equipped at the top of the stack for maintenance ability.The silencer is designed to reduce not only the pure tone component of a 247.5 Hz but also the overall sound level.

- Required insertion loss of a silencer:
  Minimum 15 dB at 247.5 Hz
  Minimum 10 dB at all pass
- Allowable pressure drop : 20mm H_2O
- Configuration of silencer : see Fig.4

As an alternative, the adoption of an active silencer was investigated and was eventually given up. The advantages of an active silencer were no pressure drop and to control the attenuate of the specific frequency component. However, the system also had the disadvantages such as durability to corrosive flue gas and high initial and running cost.

5. RESULTS OF MITIGATION MEASURES

(1) After mitigation of Step-1
Tonal noise of 247.5 Hz had attenuated at 5 dB, but the effect to the residential area still remained. It was suggested that the filling up the cavity with raschig rings contributes to preserve the excited component due to standing-wave or vortices. However, the energy of the 247.5 Hz component generated and transmitted from the ID fan had dominated the overall tonal noise.

(2) After mitigation of Step-2
After an installation of a silencer, the sound pressure level of the tonal frequency component (247.5Hz) measured at 20 metres horizontally from the top of the stack had decreased from 81.6 dB to 63.6 dB. This was dramatic, so the tonal noise component was not recognized. Auditory check and measurement with instruments at the residential area also showed the disappearance of the tonal component. Thereafter, the residents which had complained consented to the results.

6. CONCLUSION

This case history was not a legal question. It was not a matter that the emitted noise exceeded the local regulation of noise but it was a matter that the surpassed tonal noise annoyed community residents. It was a case of complaints by residents. It was a unique phenomenon of noise as a psychological matter.
Meanwhile, the correspondence of the refinery manager suggests that the desirable corporate attitude is to consider the co-existence of enterprises and community residents.
Simultaneously, things which should be done now are the practice of human oriented engineering based on the philosophy that equipment facilities are in existence for human beings which should be changed from the current philosophy of facility orientation (see Fig.6).

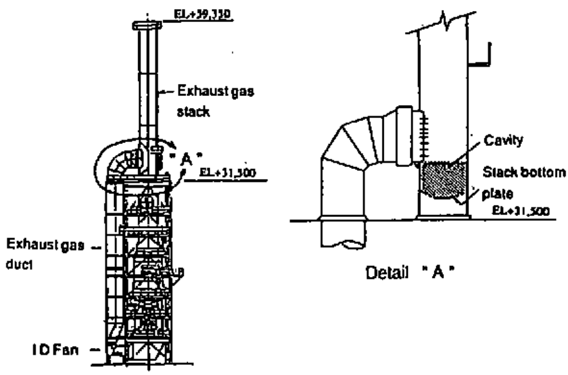


Fig. 1. Scheme of exhaust duct and stack

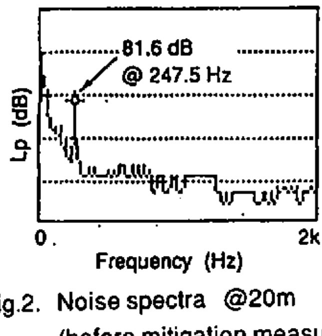
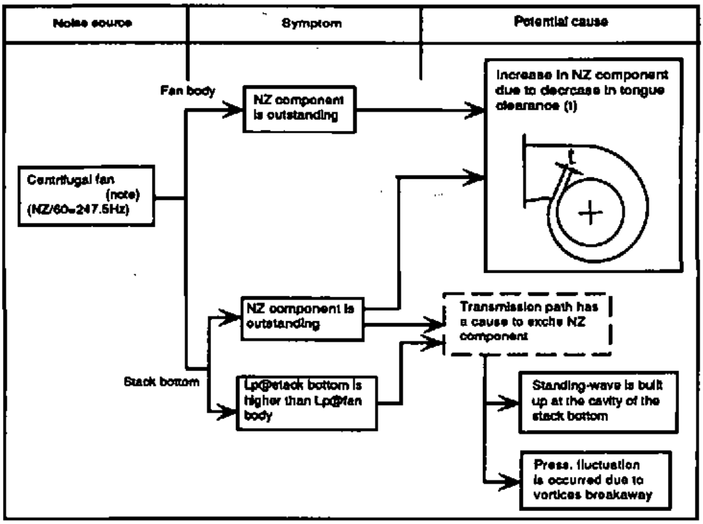


Fig.2. Noise spectra @20m
(before mitigation measures)



(note) Number of revolution N:1485 RPM, Number of blade Z:10

Fig.3. Flow scheme to find the cause of tonal noise

Table 1. Proposed mitigation measures to reduce the tonal noise

Part to be mitigated	Mitigation measures	Action propriety during plant operation	Evaluation (Expected effect···○ : large, × : small)
1. Noise source (ID Fan)	① Reshaping impeller and/or casing · Widen tongue clearance · Increase skew ratio	NO	○ · Essential measures to reduce NZ component · Problem is modification period and cost
2. Transmission path (Stack)	② Install silencer	NO	○ · Effective measures to reduce NZ component and overall noise level
	③ Install barrier on stack outlet (Directivity)	NO	× · Small effect due to limited space
	④ Fill up the cavity of stack bottom	YES	○ · Effective measures to break standing-wave and to avoid vortex generation
	⑤ Install active noise control system	NO	○ · Effective measures to eliminate NZ component · Problem is period and cost

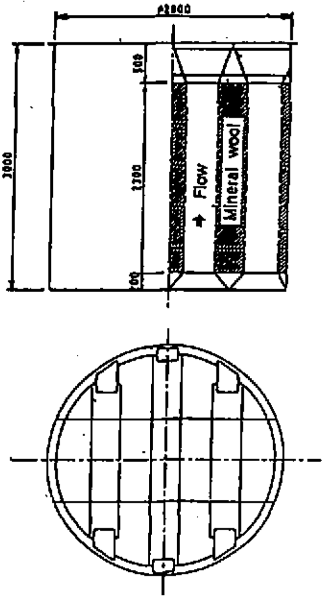


Fig.4. Configuration of silencer

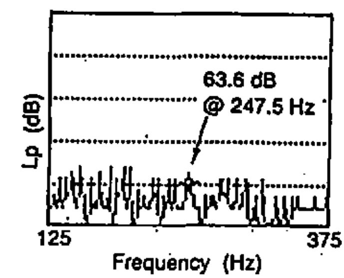


Fig.5. Noise spectra @20m
(after mitigation measures)

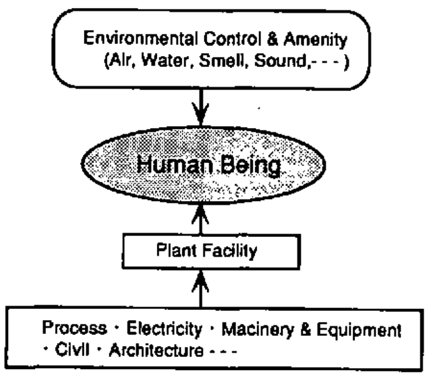


Fig. 6. Concept of Human
Oriented Engineering