DESIGN AND FLOW CONTROL OF SUBSURFACE INJECTION SYSTEM FOR MOBILE OIL TANKS

Zhang Shujing, Gu Xiujuan
(Shanghai Fire Research Institute, 601 Zhong Shan Nan Er Road, Shanghai 200032, China)

1. INTRODUCTION

There are more than fifty oil tanks of various sizes in Hainan Province, although its petrochemical industry is less advanced than some other provinces. Among these oil tanks, Haikou Oil Tanks and Lin Shui Estate Oil Tanks are both of a considerable scale. Evidently it is not enough to just maintain a few fire extinguishers in the oil tanks . What is more, Hainan is a typical heavy-thunderstorm area, with long sunshine period and high temperature. All these mean very great fire hazards. In view of such conditions the fluoroprotein foam subsurface injection fire extinguishing system is adopted by Mobil Oil Tanks in Hainan Province. In China the design of such a system is yet a comparatively new technique, which involves a number of crucial problems not fully solved. In this paper, the writers explore preliminarily the design and flow control of this system as used in the fire protection engineering of Mobil Oil Tanks in Hainan.

Usually, in order to determine the flow of the foam solution in such a system, the designer takes the nominal flow value of the foam generator as the basis of his calculation and takes it as a fixed value. He would consider that the foam generated is only related to the foam expansion, as is also so stated in the instruction book of the high back pressure foam generator. A back pressure control valve is therefore fixed to the outlet of the foam generator to compenste for the effects of the change of the liquid level in the oil tank (i.e., the change in the static pressure of oil in the tank), so that the quantity of the flow generated and the speed at which the foam flows into the oil may be regulated. But it has to be pointed out that the key to controlling the flow of the system does not lie in regulating the back pressure of the foam generator. Regulating the back pressure often brings about changes in all the working parameters. Therefore, in order to control the flow of the system, there should be a comprehensive control of all the main working parameters of the system. These include parameters of the pump outlet pressure, the foam generate inlet pressure, foam solution concentration, foam solution supply intensity, quantity of foam generated, speed of foam flowing into the oil, speed of extinguishment of the fire, etc. The usual method a designer uses consists of the following:

(a) Ascertain the maximum area to be protected by the system.
(b) Calculate the quantity of foam required for the protection of the area.
(c) Choose the type of high back pressure foam generator, basing on the required quantity of the foam and the flowing speed of the foam solution
(d) Choose the type of proportioner and fire pump, basing on the quantity of the foam solution.

(e) Calculate the quantity of foam liquid actually required.
In selecting the right type of equipment, it is often nigh impossible to find a piece of equipment whose nominal value corresponds with the design parameters.It often happens that "One is not enough and two are too many."The usual approach to this problem is let there be a surplus,which means an excessive safety coefficient and a waste .Yet the designers of the subsurface injection system for Mobil Oil Tanks have realized the comprehensive control of the working parameters with due consideration for safety as well as economy.

2.THE METHOD FOR BASICALLY CONTROLLING THE WORKING PARAMETERS OF THE SUBSURFACE INJECTION FIRE EXTINGUISHING SYSTEM

As is characteristic of the petrochemical industry,in the Mobil Oil Tanks subsurface injection system there are pipes and valves of many types and specifications,beside the fire pumps,the proportioners and the high back pressure foam generators.It is easily understandable that a functional relation exists among the parameters of the outlet pressure of the fire pump,the flow of the foam solution,the density of the foam solution,the resistance of the pipe to the foam solution,the inlet pressure of the foam generator,the quantity of the foam generated,the resistance of the pipe to the foam,the speed of the foam flowing into the oil,the speed of fire extinguishment and other working parameters.This means the designer may effect a comprehensive control of the working parameters by choosing the suitable types of equipment and regulating the valves.

(1) High Back Pressure Foam Generator:
This is the key equipment of the subsurface injection fire extinguishing system.While designing the system people often take the nominal flow of the high back pressure foam generator as a fixed one.Actually the flow is not unchangeable,because a change in either the inlet pressure or the back pressure of the foam generator can cause a change in the flow.But the difference between the effects caused by the inlet pressure and the back pressure is quite big.

(2) Regulation of The Back Pressure of The Foam Generator:
It is clearly stated in the instruction book of the foam generator that within the limitation of the nominal flow,the flow of the system may be regulated through regulating the back pressure regulating valves.Such regulation however,is in our opinion of little importance,since it is very limited.The reasons of the limitation are:

(a) Mainly,the regulation of the back pressure is to compensate the changes in the static pressure of the oil.The magnitude and range of the change of the back pressure are approximate to that of the static pressure of the oil contained in the tank,always within the range of 0-0.15 MPa.

(b) In this system,the foam solution becomes foam after passing through the foam generator.As the sum of the amounts of the foam solution and the expansion is equal to the amount of the foam,so,when the back pressure of the foam generator changes,the flows of the foam solution and the foam,as well as the expansion,change correspondingly,too.Figure 1 illustrates this relation.

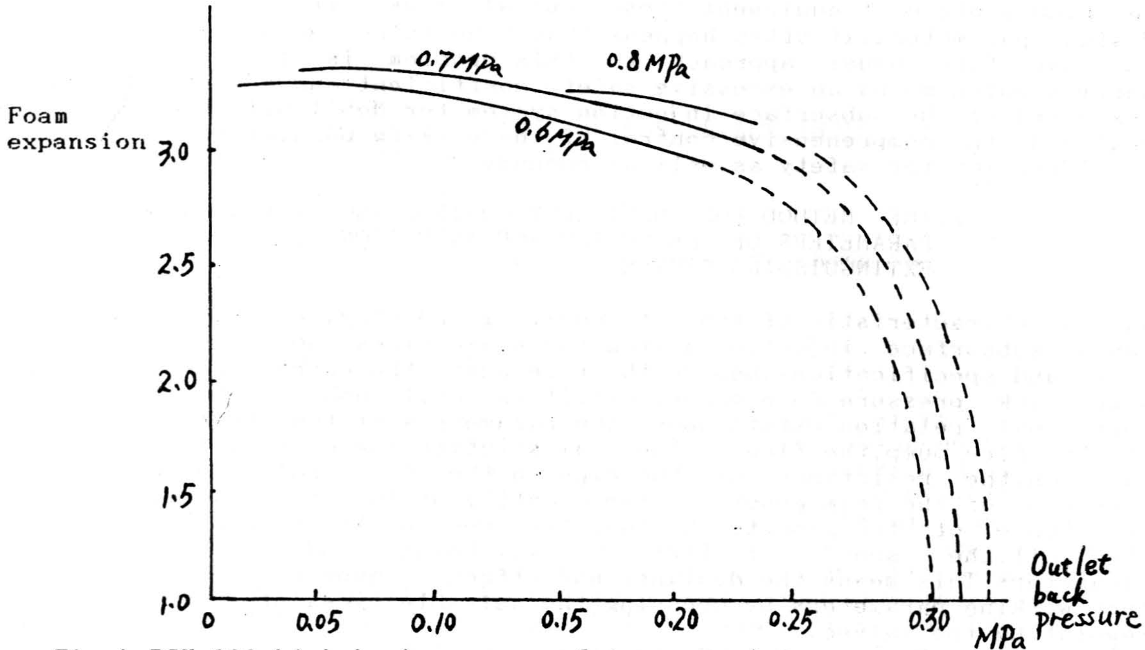

Fig.1:PCY 900 high back pressure foam generator--
curves showing relation between expansion and
outlet back pressure

Within the limited range of the back pressure regulation,the change in foam expansion is insignificant and it is quite unnecessary to regulate the back pressure of the foam generator.

(3) Regulation of The Inlet Pressure of The Foam Generator:
The subsurface injection system requires a sufficient supply of foam solution in quantity and in speed.At the same time it requires that the flow of the foam into the oil tank be of limited speed.Since the two requirements hold each other in check,the change in the flow of the foam solution has to be limited to a very small scope to effect only a targeted control.Otherwise the following conditions will appear:

(a) A big change in the magnitude and speed of the flow will cause a change in the concentration of the foam solution,affecting the foam quality and the efficiency of fire extinguishing.

(b) A big change in the magnitude and speed of the flow will cause pressure change and pressure loss in the pipes.Especially,when the flow-increase is too big,a reverse-flow back pressure may be reached,making the foam generator unable to absorb air and produce foam,thus losing its fire extinguishing power.

The regulation of the inlet pressure of the foam generator has a great effect on the working parameters of the whole system,as shown in Fig 2.

When the inlet pressure undergoes a change of 0.4 MPa during normal operation,the change of the flow will be more than 30%,which must not be taken lightly.

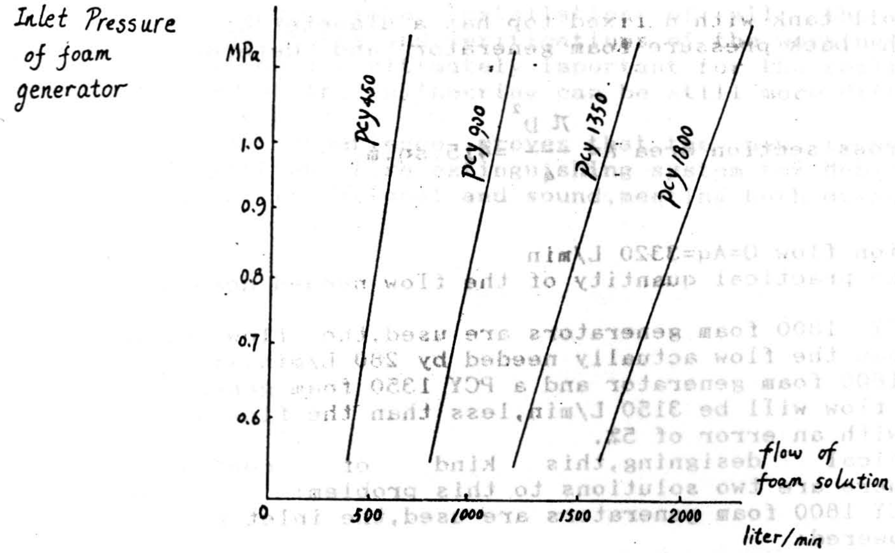

Fig.2 Characteristic curves of flows in high back pressure foam generators

3.SIMPLIFIED CALCULATION IN FLOW CONTROL DESIGNING

In designing the subsurface injection system,a great many complicated calculations are involved,because many working parameters are interrelated and mutually checking.

In practice,basing on experimental data and curves of the high back pressure foam generator,we find:

(1) Foam solution flow quantity (Q) of the foam generator is directly proportional to the square root of the inlet pressure (P).Viz,$Q=K\sqrt{P}$

The flows of the various types foam generators manufactured in China are all integral multiples of the flow of the smallest generator (under the same pressure).Thus:

PCY 450	$Q_1=K_1\sqrt{P}$
PCY 900	$Q_2=K_2\sqrt{P}=2K_1\sqrt{P}$
PCY 1350	$Q_3=K_3\sqrt{P}=3K_1\sqrt{P}$
PCY 1800	$Q_4=K_4\sqrt{P}=4K_1\sqrt{P}$

In the above equations,when P is in MPa,Q is in L/min.

Through a series of experiments,data processing,analyses,tests and verifications we find $K_1=581$

The values derived from the tests conducted by other scientists are very approximate to the value so calculated.

Making use of these findings it is now much easier to solve the problem of calculation and selection of the foam generators to be used in large numbers and in combination in the subsurface injection system.

4.FLOW CONTROL OF SUBSURFACE INJECTION SYSTEM FOR MOBILE OIL TANKS

In designing the subsurface injection system for Mobil Oil Tanks, the usual problem of "One is not enough and two are too many" rises.But using the simplified calculation method,this problem is easily solved by the experienced designers.

Example:

A 5000 T oil tank with a fixed top has a diameter of 23 m. Choose the type of high back pressure foam generator and determine the inlet pressure.

$$\text{Oil tank cross section area } A = \frac{\pi D^2}{4} = 415 \text{ sq.m.}$$

Foam solution flow Q=Aq=3320 L/min

This is the practical quantity of the flow needed determined through calculation.

If two PCY 1800 foam generators are used,the flow will be 3600 L/min.more than the flow actually needed by 280 L/min.with an error of 8%.If a PCY 1800 foam generator and a PCY 1350 foam generator are used together,the flow will be 3150 L/min,less than the flow actually needed by 170 L/min,with an error of 5%.

In practical designing,this kind of contradiction is unavoidable.There are two solutions to this problem:

(a) If two PCY 1800 foam generators are used,the inlet pressure should be suitably lowered:

$$\because \quad Q = K\sqrt{P}$$

$$\therefore \quad P = \frac{Q^2}{K^2} = \frac{(3320/2)^2}{2324^2} = 0.510 \text{ MPa}$$

This will be the inlet pressure in the case of two PCY 1800 foam generators being used.

(b) If one PCY 1800 foam generator and one PCY 1350 foam generator are used together,the inlet pressure should be suitably raised:

$$\because \quad Q = K\sqrt{P}$$

$$P = \frac{Q^2}{K^2} = \frac{3320^2}{(2324+1743)^2} = 0.666 \text{ MPa}$$

This is the inlet pressure in the case of one PCY 1800 and one PCY 1350 foam generators being used together.

On the basis of the above calculations,it can be seen that theoretically ,either method is feasible,with the inlet pressures regulated respectively at 0.510 MPa and 0.666 MPa.In both cases the flow needed will be available.However,inpractice it is necessary to consider fully the characteristics of the pumps and the foam generators,the pressure loss in the foam generators,and the diameters and lengths of the pipes.Only after comprehensive consideration and balancing the advantages and disadvantages can a right choice be made from the two solutions.That choice can ensure safety as well as economy.

5.CONCLUSIONS

(1) For the subsurface injection system for Mobil Oil Tanks not just the designing,but the tests and verifications of the system are of crucial importance.

(2) In designing the system,to make precise calculations of the working parameters,to carry out comprehensive analyses, and to choose the right type of equipment are a complicated and difficult process.But the

correct and appropriate installation of all the equipment,and particularly the tests and verifications of the working of the system after installation,are ultimately important for the realization of the design.This part of the engineering can be still more difficult and must be done carefully.

(3) The working experience proves that the new technique for the subsurface injection fire extinguishing system for Mobil Oil Tanks in Hainan Province is rational and sound,meeting both demands for safety and economy.