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Dynamic Optimization of Air Treatment Systems for Fundries

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ABSTRACT: One major branch in mathematical sciences, which recently has been given especial attention, is optimization, including various methods such as linear programming, integer programming, and dynamic programming. Due to the unique characteristics of air treatment systems, specifically multistage nature of such systems, dynamic programming has been widely applied. The purpose of this paper is to find the best cost effective way to treat the waste gas stream from industries, such as foundries, which contains different kinds of pollutants. To attain this goal in dynamic programming, it is necessary to determine the cost of each system in various conditions. The dynamic programming procedure determines the optimum system. Iran Khodro Co. was considered as the case study of this investigation. The cost of each treatment unit calculated under the special conditions of the study. In order to minimize the emissions from foundries, Cyclone has been found to be the most optimum system to collect particulate matters, and as for controlling volatile organic compounds, Carbon Adsorber found to be the most optimum device

Key words: Foundry, Air Pollution Control, Dynamic Programming, Dynamic Optimization

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INTRODUCITION

Considering the rapid development of industries and also the environmental regulations, the industries are obliged to obey the standards of the quality of their exhaust gas and also the air quality of the working place. Due to high costs in order to reach the desired level of air quality standards, it is necessary to choose the appropriate way which has the lowest price. In order to minimize the cost of the treatment systems, the optimization process takes place. The systems that are being studied in this paper are different kinds of dust collectors as well as different devices to treat the pollutants which are in the form of gas such as volatile organic compounds (VOC's). Pretreatment systems consist of the devices which can eliminate dust from the waste gas stream. The process of dust and particulate matters in the stream may have negative effect on the structure and the operation of the VOC treatment systems, and can damage those filtration devices. Each filtration system has its own advantages and disadvantages. Systems that are described below can be considered as air filtration units. The first category consists of pretreatment systems and dust collectors.

There are different types of devices available in order to eliminate dust from gas stream. These are as follows:

- Condensation scrubber
- Cyclones
- Dry Electrostatic Precipitator (ESP)-Wire-Pipe Type
- Dry Electrostatic Precipitator (ESP)-Wire-Plate Type
- Wet Electrostatic Precipitator – Wire-Pipe Type
- Wet Electrostatic Precipitator-Wire-Plate Type
- Elutriators
- Fabric Filter - reverse air cleaning type
- Fabric Filter - Mechanical Shaker cleaning type
- Fabric Filter - Pulse Jet Cleaning type
- Settling chambers
- Momentum Separators
- Mechanically Aided Separators
- Paper Filters-Cartridge Collector type with pulse-jet cleaning

- High Efficiency Particle Air (HEPA) Filter
- Ultra Low Penetration Air (ULPA) Filter
- Mechanically-Aided scrubber
- Spray Chamber/Spray-Tower Wet Scrubber
- Venturi Scrubber
- Orifice Scrubber
- Packed – Bed/Packed- Tower Wet Scrubber
- Fiber – Bed Scrubber
- Impingement –Plate Scrubber

These systems will be installed down stream of dust collectors, and will decrease the gas form pollutants to the standard level. These devices are as follows:

- Different types of Scrubbers
- Catalytic Incinerator
- Thermal Incinerator
- Incinerator – Recuperative Type
- Regenerative Incinerator
- Flare
- Carbon Adsorbers
- Refrigerated Condensers

Good control of pollution from foundry processes not only enables companies to comply with legislative requirements, but also:

- prevents nuisance to neighbours
- improves the internal work atmosphere and reduces risks to worker health
- minimises the environmental impact of the operations
- improves the company image.

MATERIALS & METHODS

Evaluating the cost of air treatment devices is difficult and also limited to a short period of time due to the economic conditions and the exchange rate fluctuations, the need of technology from other countries and also the need for using different materials which are being produced inside or outside the country for air treating. Further, bank's financial interest rate for industries has been included in calculations. The systems operating period should be considered as well. In order to economically compare different methods of filtration and to make final decision, it is necessary to make all the costs uniform. For this reason, capital cost and operating and maintenance costs have to be converted to annual costs. This is done by equation (1). According to past experiences the operating period of the devices is assumed to be 10 years, and the financial interest rate is assumed at 24 per cent according to Parsian bank policies.

$$P = A[i(1+i)^n/((1+i)^n - 1)] \qquad (1)$$

Where:
P= Capital cost
A= Annual cost
i= Financial interest rate
n= operating period

RESULTS & DISCUSSION

Iran Khodro Co. filtration systems have been studied. Inlet air flow to these devices are 5000, 10000 and 15000 cfm. The pollutant loading assumed to be in three different concentrations (Table 1).

Table 1. Concentration of pollutants

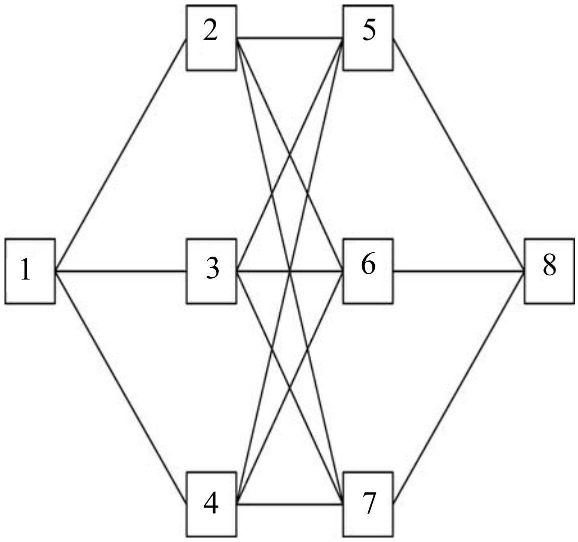
Concentration Pollutant	High	Medium	Low
PM	15 g/m^3	10 g/m^3	5 g/m^3
Triethylamine	70 ppm	62 ppm	54 ppm

Six different systems have been chosen to reach the desired air quality. All these systems will be studied in 3 different air flows and concentrations as stated previously. Two categories or stages of filtration can be used. Finally the optimized system will be selected. At the first step, it is necessary to calculate the cost of each system, including capital cost, annual cost and operating and maintenance cost. It is necessary to draw a chart for the dynamic programming problem. The chart and all its relations in different stages is shown in Fig. 1. Each node in the picture shows an air treatment unit and the relation between these nodes is the cost for each system. The costs are calculated and shown in Table 2.

Table 2. The filtration cost in 5000 cfm air flow for medium concentration of pollutants

From node	To node	Annual Cost ($)
1	2	63800
1	3	74510
1	4	187000
2	5	166000
2	6	241740
2	7	73040
3	5	166000
3	6	241740
3	7	73040
4	5	166000
4	6	241740
4	7	73040
5	8	0
6	8	0
7	8	0

* 9200 Rials = 1 US$



1- Waste gas stream
2- Cyclone
3- Fabric filter – Pulse jet
4- Venturi scrubber
5-Catalytic incinerator-Fixed bed
6- Packed bed scrubber
7- Carbon adsorber
8- Clean air

Fig. 1. Dynamic programming chart for a foundry air treatment system

According to Fig. 1, this problem has 3 stages, 21 relations and 8 nodes. Now the problem will be solved using 3 stage procedure of dynamic programming as shown in Fig. 2.

The first step is to solve the equation (2).

$$\underset{d_1}{Min}\ [r_1(S_1, d_1)] = f_1{*}(S_1) \qquad (2)$$

As the result, Table 3 can be drawn. In the second step equation (3) is solved.

$$\underset{d_2}{Min}\ [r_1(S_2, d_2) + f_1{*}(S_1)] = f_2{*}(S_2) \qquad (3)$$

The third step was done according to the third step shown in Fig. 2. Thus we arrive at (Table 5):

$$\underset{d_3}{Min}\ [r_3(S_3, d_3) + f_2{*}(S_2)] = f_3{*}(S_3) \qquad (IV)$$

So the air treatment system would be a combination of following devices:

$d_3{*} = 2$, $d_2{*} = 7$, $d_1{*} = 8$

Therefore the filtration process may be done using a Cyclone as dust collector and Carbon Adsorber as VOC eliminator from waste gas stream. Total annual cost for this process would be US$ 136742.

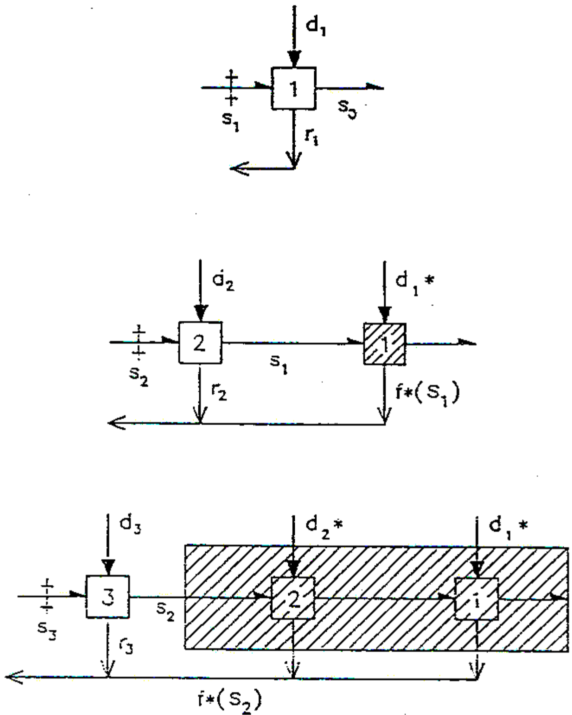


Fig. 2. Sequences of sub-optimization

Table 3. Results of the first step

$r_1(S_1, d_1) + f_0^*(S_0)$, d_1 =			
S_1	8	f_1^*	d_1^*
5	0	0	8
6	0	0	8
7	0	0	8

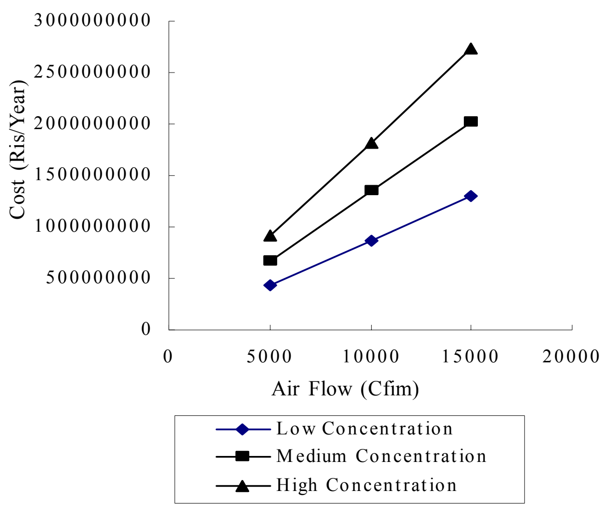


Fig. 3. Cost variation of a Cyclone unit by air flow in different concentrations

Table 4. Results of the second step

S_2	$r_2(S_2, d_2) + f_1^*(S_1), d_2 =$ 5	6	7	f_2^*	d_2^*
2	1526534422	2222306627	671484299	671484299	7
3	1526534422	2222306627	671484299	671484299	7
4	1526534422	2222306627	671484299	671484299	7

9200 Rials=US$ 1

Table 5. Results of the third step

S_3	$r_3(S_3, d_3) + f_2^*(S_2), d_3 =$ 2	3	4	f_3^*	d_3^*
1	1258034471	1356454729	2391172844	1258034471	2

9200 Rials=US$ 1

CONCLUSION

Same procedure was carried out for the air flows of 10000 cfm and 15000 cfm. In all cases the optimized system consists of a Cyclone for dust collecting and a carbon adsorber in order to adsorb VOC's from the gas stream. The cost variations for all devices in different air flows with different levels of concentration were calculated and have been shown in Figs. 3 to 8 (In Figs. 3 to 8, Rials 9200=US$ 1). The annual cost for the optimized combination of filtration devices, based on the air flow and pollutants' concentrations level have been shown in figures 9 to 11(9200 Rials = 1US$). There are few foundries in Iran which use air filtration systems. By neglecting the pollutants concentration in the air stream, these industries are putting every one's health and the environment in danger. Therefore, the use of appropriate systems for dust collecting and also for VOC's filtration is necessary for these kinds of industries.

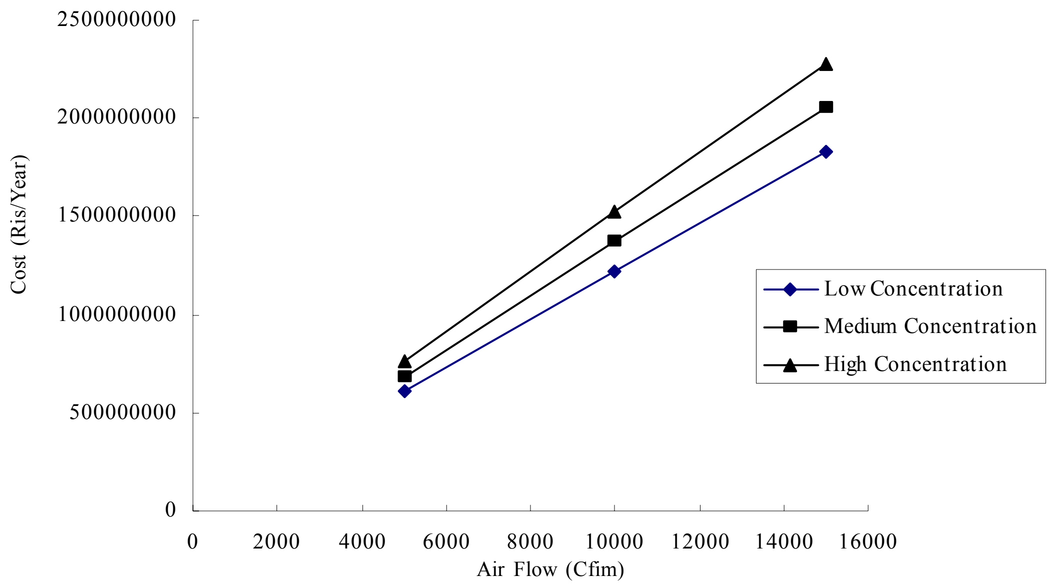


Fig. 4. Cost variation of a Baghouse-Pulse jet unit by air flow in different concentrations

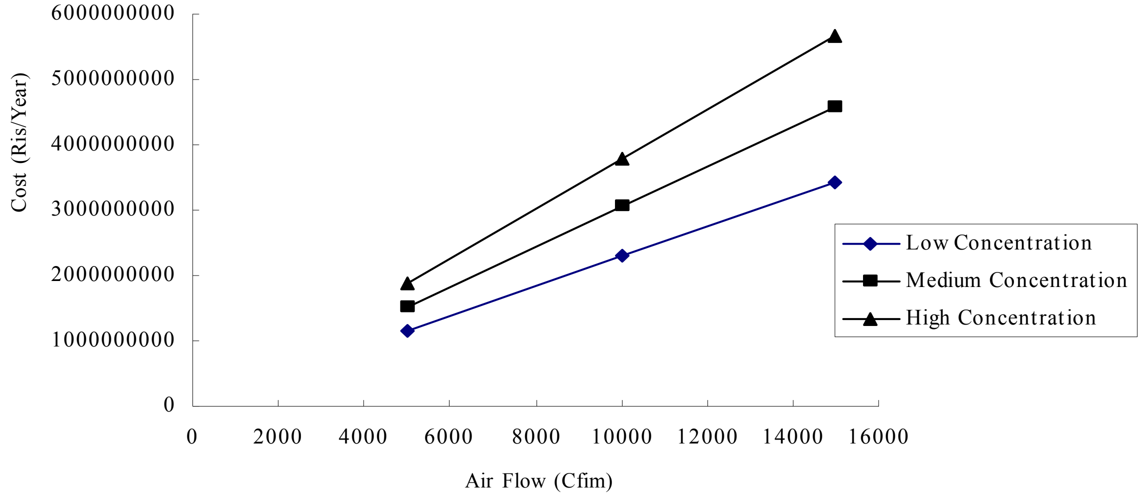


Fig. 5. Cost variation of a Venturi scrubber unit by air flow in different concentrations

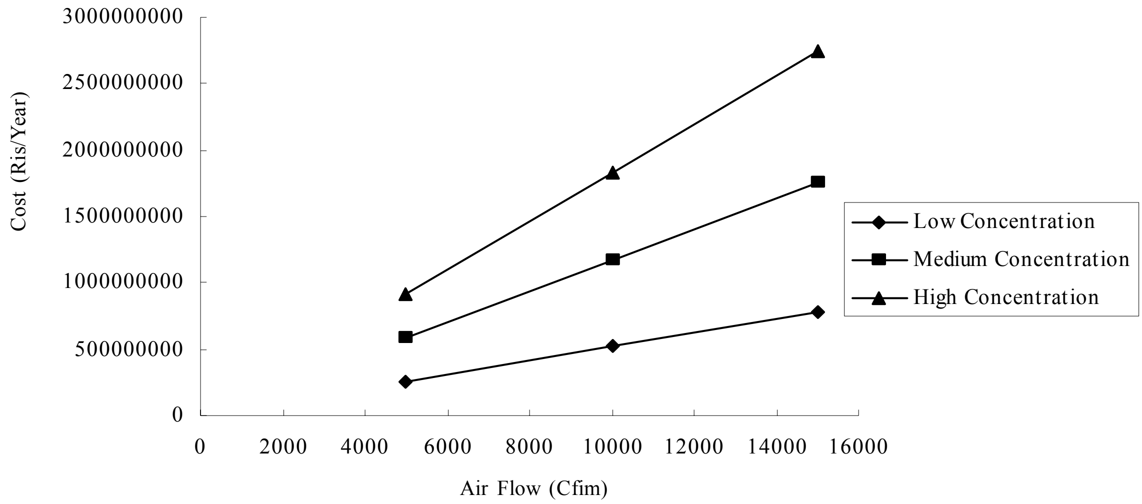


Fig. 6. Cost variation of a Catalytic incinerator unit by air flow in different concentrations

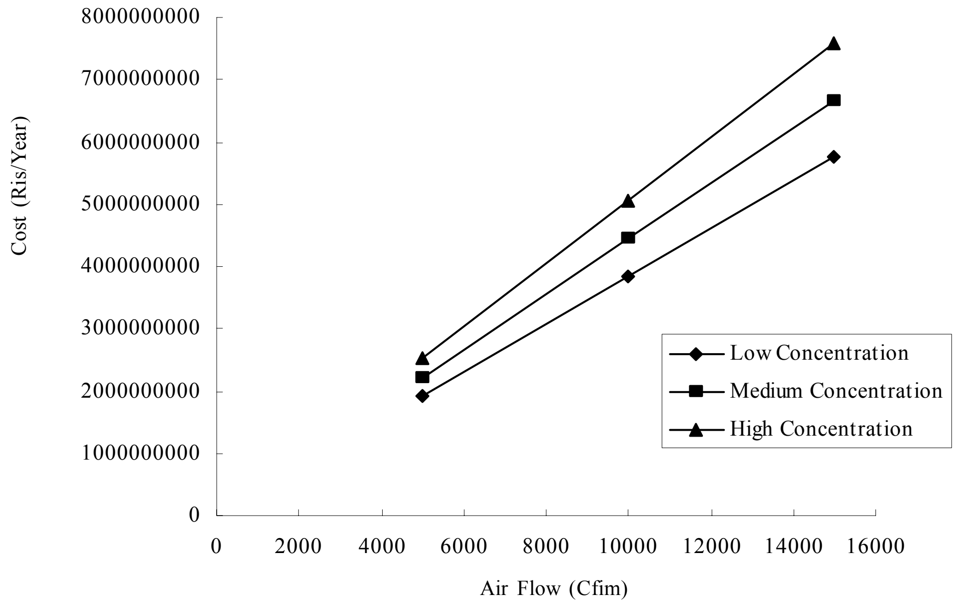


Fig. 7. Cost variation of a packed bed scrubber unit by air flow in different concentrations

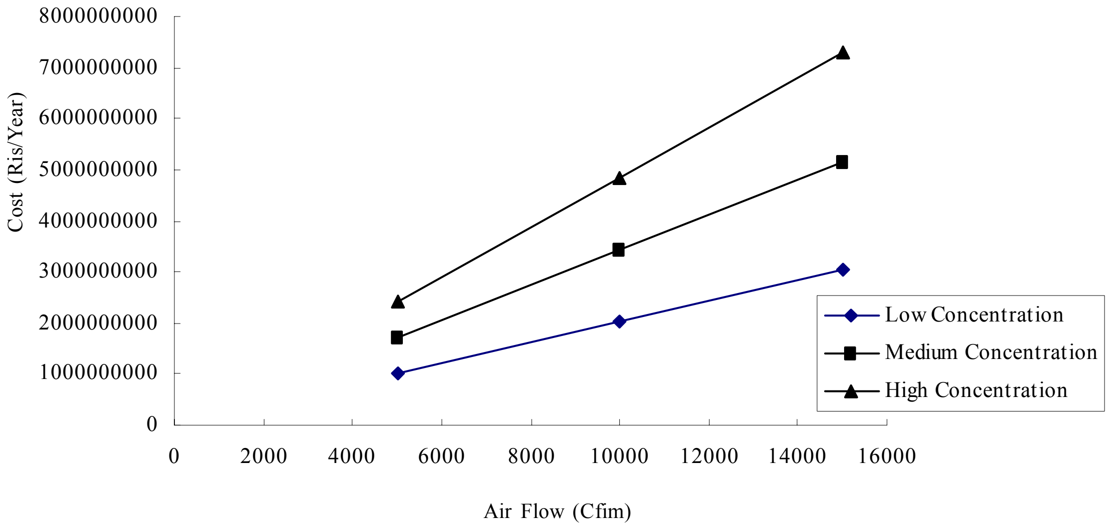


Fig. 8. Cost variation of a Carbon adsorber unit by air flow in different concentrations

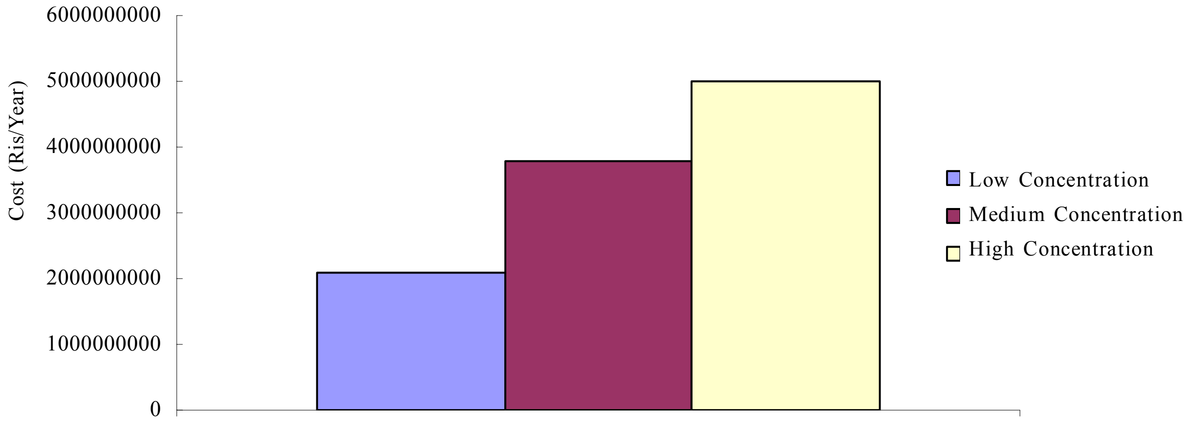


Fig. 9. The cost of optimized system for different concentrations with 5000 cfm air flow

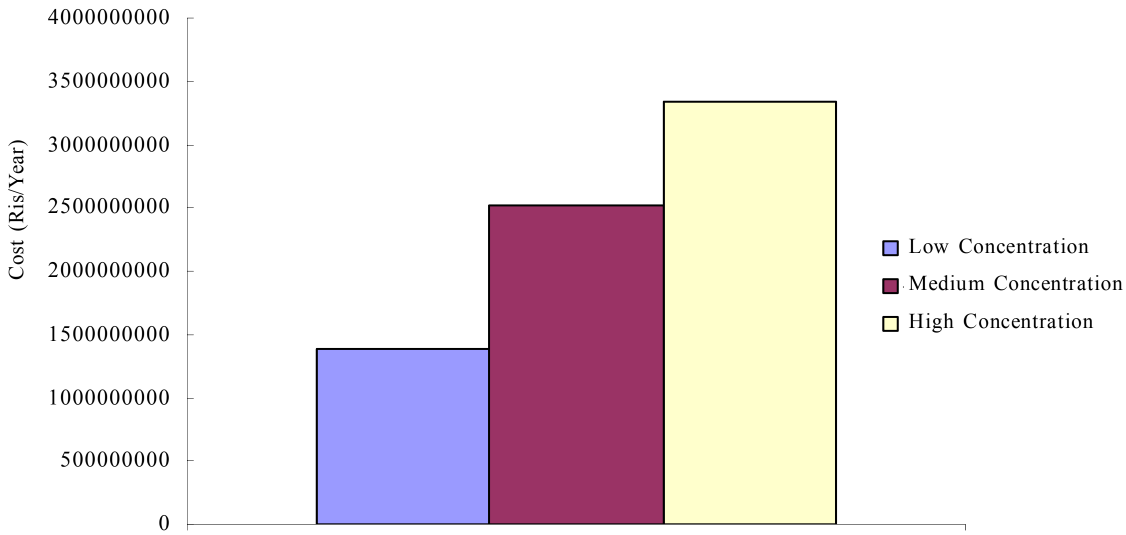


Fig. 10. The cost of optimized system for different concentrations with 10000 cfm air flow

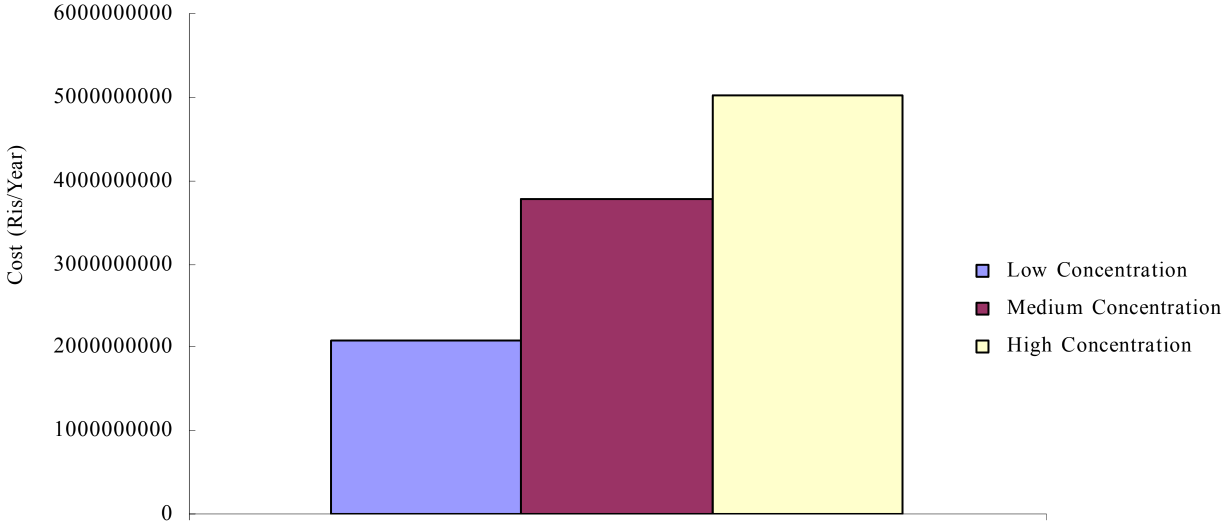


Fig. 11. The cost of optimized system for different concentrations with 15000 cfm air flow

Although VOCs are considered to be the source of significant environmental problems, it is not considered cost-effective to capture or abate the VOCs produced from most foundry processes. One of the main sources in foundries is the casting process, and, in jobbing foundries in particular, containment of such emissions is impractical. There is usually more than one way of eliminating or reducing emissions of particulates and VOCs, and it does not always have to involve abatement, which is the 'end of pipe' solution.

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