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GUIDELINES FOR RECIRCULATION OF EXHAUST AIR

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The use of exhaust air recirculation to conserve energy was analysed. Recirculation decision logic, design and assessment, worker exposure, and system evaluation were outlined. Recirculation without premixing, air recirculation system monitoring, and recirculation air bypass were described. Costs, safe exposure concentrations, dilution, monitoring devices, systems flexibility, airflow rates and patterns, ventilation, and air cleaner efficiency calculations were discussed. The authors conclude that adherence to these guidelines is necessary, and caution that if the air contains human carcinogens, recirculation should not be attempted.

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INTRODUCTION

A common and effective engineering approach to the control of airborne contaminants in the working environment is the use of exhaust ventilation systems. These systems remove contaminated air from the workplace and, following appropriate cleaning, discharge it outdoors. They are usually complemented by a makeup air supply system which replaces the exhausted air with air from outside the building. Where the outside air temperature varies from the required inside temperature, it must be heated or cooled. The cost associated with tempering large volumes of makeup air is significant and of great concern to industry, especially due to costs, shortages or nonavailability of fuel. Consequently, there has been considerable interest in techniques which will reduce the energy requirements associated with makeup air.

Recovery or conservation of the heat energy in a ventilation exhaust air stream can provide a significant reduction in energy requirements and plant operating costs. There are a number of heat recovery methods available which can effectively be used in conjunction with industrial exhaust systems. These methods may transfer heat directly from the exhaust air stream to the makeup air stream or in some cases may recover the exhaust air energy for process or heating requirements. While there are some exceptions, these methods require a reasonably high temperature differential between the exhaust and makeup air. Many exhaust streams do not, however, have a sufficiently high temperature. In such cases recirculation of the exhaust air after thorough cleaning may be a feasible approach.

Recirculation in the context of these guidelines refers to any ventilation system in which contaminated exhaust air is removed from one location in the work environment, cleaned, and reintroduced to either the same or other plant location. A schematic representation of one possible recirculation system configuration is shown in Figure 1. Exhaust air recirculation, as an energy conservation method, differs from heat recovery methods that utilize heat transfer principles in that the exhaust air stream is returned to the workplace rather than discharged outside.

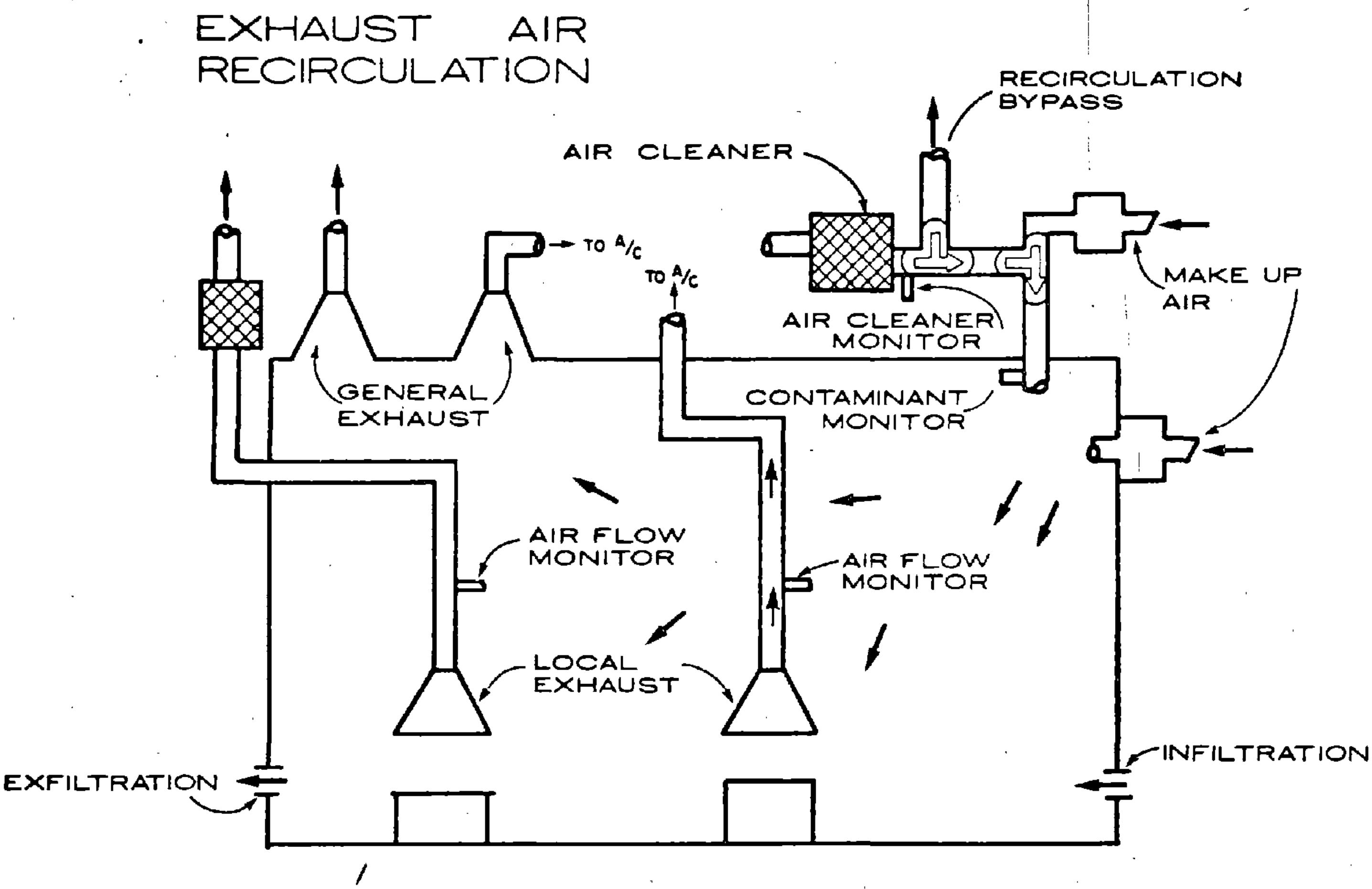


Figure 1. Schematic representation of a recirculation system.

This tends to concentrate the chemical agents that may be found in the exhaust air stream. The potential health hazards that could result mandates that recirculation must not be indiscriminately applied. It should be considered only after careful evaluation of the technical and economic factors of a non-recirculating approach.

RECIRCULATION GUIDELINES

There has been some documentation of recirculation systems and system elements.[1,2,3,4] These have, however, been presented relative to a very specific application or system element. The feasibility of a recirculation system and its final design depend on many factors, and will require a unique determination for each application. The interdependence and variability of these factors render a specific or "cookbook" design approach inappropriate. Rather, a general design approach utilizing a decision logic in conjunction with a mathematical recirculation model is recommended to provide the proper guidance to a design team. The use of a decision logic will assure that the appropriate industrial hygiene and engineering factors are adequately addressed to assure protection of the worker. The recirculation model will assure that these factors are properly integrated with the recirculation system design factors to result in a safe recirculation system. A recommended decision logic is presented in Figure 2.

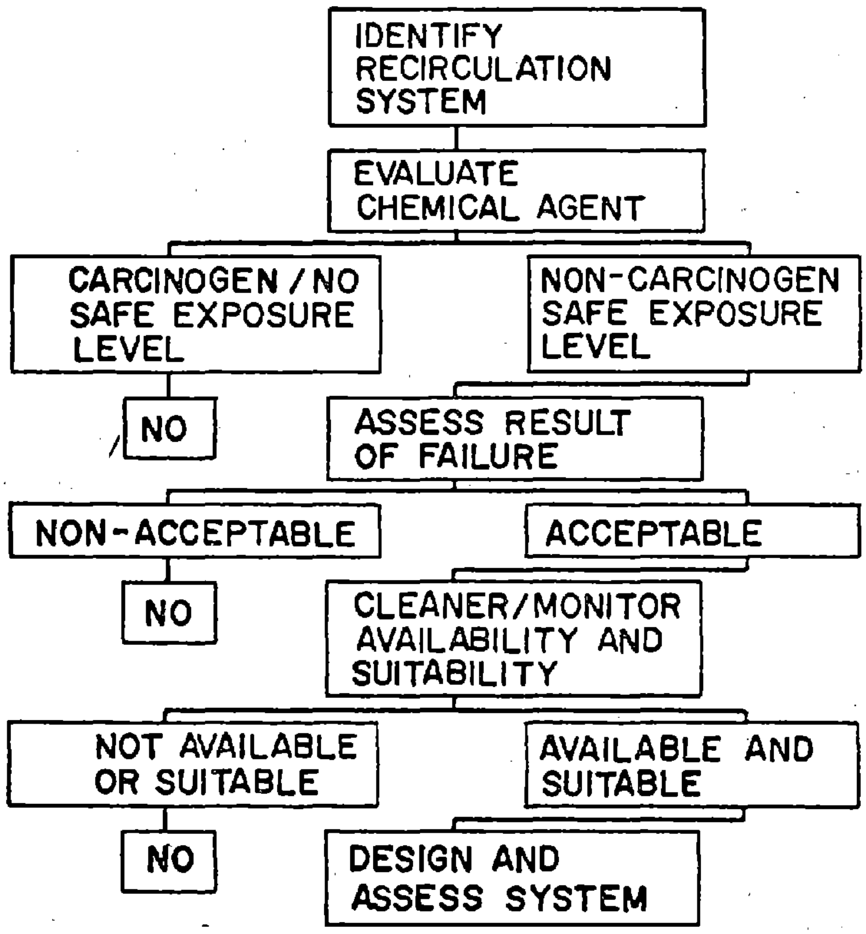
The first step for any recirculation attempt is to analyze all options available for energy recovery. Identify the recirculation system processes: exhaust hoods, duct work, fans, component locations, and interactions with other exhaust systems. Closely allied with this step is the review of local, state, and federal regulations regarding recirculation. Regulations may restrict or prohibit recirculation in some cases.

The chemical, physical, and toxicological characteristics of the chemical agents in the potentially recirculated air stream must next be identified and evaluated. If the agent is an identified human carcinogen, recirculation should not be attempted. Chemical agents whose toxicity is unknown or for which there are no established safe exposure levels likewise should not be recirculated. Ventilation systems with chemical agents to which these restrictions do not apply may be considered as potential recirculation candidates.

Having determined and evaluated the characteristics of the system chemical agents, the result of failure of the recirculation system must be evaluated. If the failure of the system would result in exposure levels which could cause serious worker health problems, recirculation should not take place. This assessment must consider the physical parameters of the proposed recirculation system as well as the characteristics of the chemical agent. For example, a low-flow rate recirculation system with a highly toxic chemical agent in a plant with a high total airflow relative to the recirculation flow may not create any significant problems upon failure due to dilution. Conversely, a high-flow rate system with a low toxicity chemical agent and with a high

RECIRCULATION DECISION LOGIC

I. INITIAL DECISION



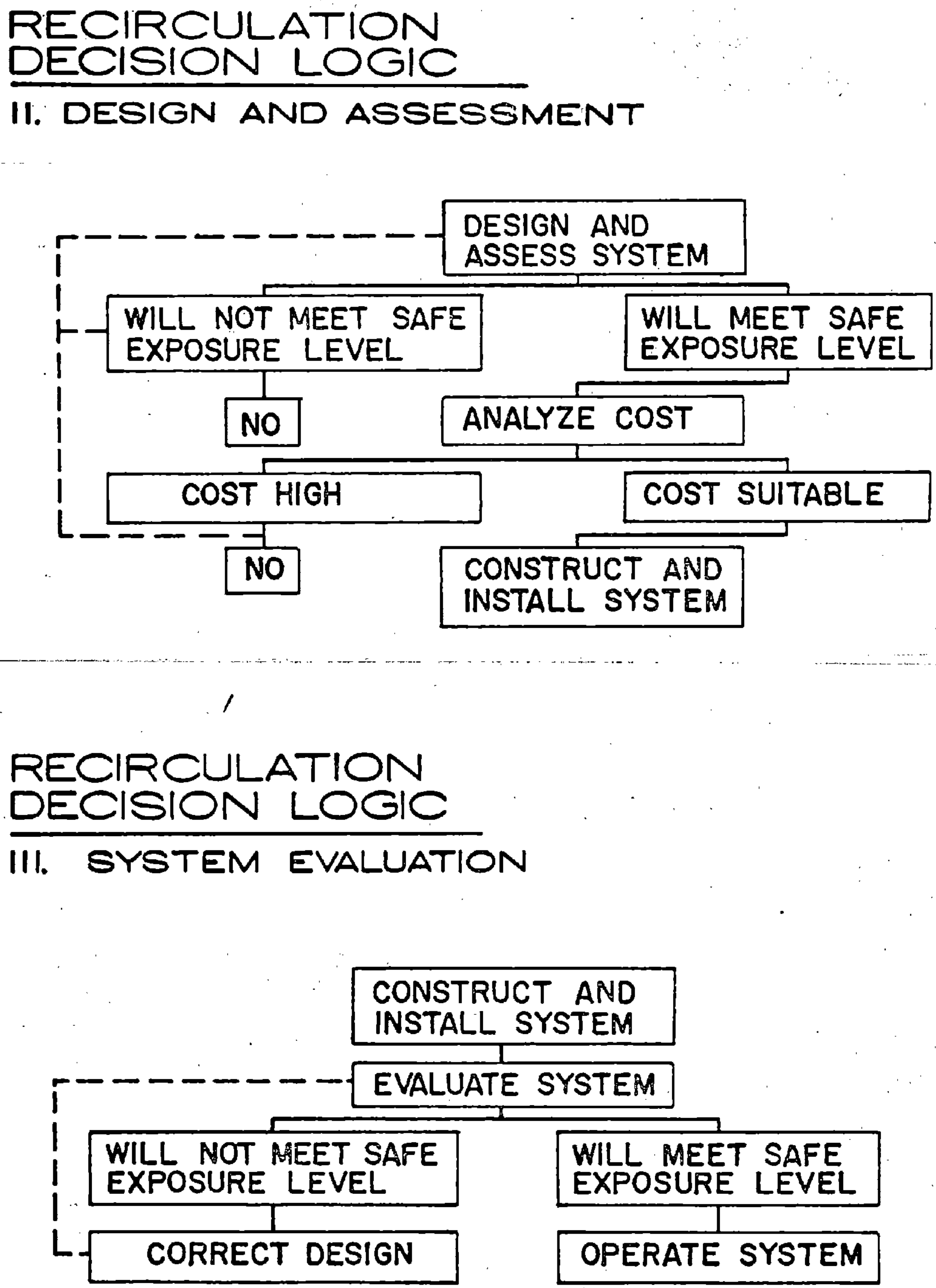


Figure 2. Recirculation decision logic (cont'd).

recirculation to total ventilation flow ratio may not be adequately diluted, and as such, may present an exposure problem.

The availability of a suitable air cleaner must be evaluated. An air cleaning device capable of providing an effluent air stream contaminant concentration sufficiently low so as to achieve design workplace concentrations must be available. If not, recirculation should not be attempted. Most existing air cleaners were designed to comply with outdoor air quality standards. Recirculation may require effluents with much lower contaminant concentrations. To assure the suitability of an air cleaner for a recirculation application, a pilot scale testing program would yield valuable information. A mobile recirculation van incorporating several pilot scale air cleaning devices could be used to reduce the cost and time required to perform such a pilot study.[4]

Mixing of a cleaned discharge air stream with a makeup air supply, placement of recirculation return air outlets, amount of recirculation air bypass, and recirculation to total ventilation flow rates are major items which must be considered in determining the suitability of the air cleaner.

Recirculation systems must incorporate a monitoring strategy which will provide adequate warning of a failure or malfunction. The prime requisite for the monitoring strategy is that it provide an accurate warning or signal which will initiate corrective action, or process shutdown before a harmful concentration of the recirculated chemical agent occurs in the workplace. On-line continuous monitoring devices would be ideal, and should be used wherever the result of failure of the recirculation system has been determined to be potentially severe.

Where the result of failure is not severe, reliable and enforced monitoring techniques other than continuous monitoring could be considered. If a monitoring strategy meeting this requirement is not viable, recirculation should not be attempted.

Assuming the foregoing decisions have been positive, the system should be designed, assessed, and cost analyzed. Wherever possible, excess capacity should be included in the design to permit adjustment of the installed system.

Assuming the design phase produces a technically and economically feasible design, the system may be constructed and installed. If possible, a pilot system should be constructed to verify design. This may not be possible for a single system. However, where several systems are anticipated, it could be instrumental in achieving efficient designs.

The "logic" approach does not offer a "cookbook" solution to recirculation design, nor should it, given the current state-of-the-art of exhaust air recirculation. Each situation must be evaluated individually and will require expertise in the area of industrial hygiene and engineering to make the appropriate and correct decisions to protect the worker's health. It is also imperative that the decision be made by personnel adequately skilled in the industrial hygiene and engineering fields.

There are two factors which require further discussion: "system failure exposure levels" and "design workplace levels." Recirculation system components should be as reliable as possible. However, failure or malfunctions may, and probably will, occur. Therefore, careful attention must be given to the chemical agents in the recirculation system and to the workplace level which would result if a failure occurred. Two criteria should be followed. The exposure level resulting from the recirculation system failure should be no greater than the level that would result from a non-recirculating ventilation system failure on the same process. Secondly, the failure exposure level should cause no harm to the worker beyond slight inconvenience or discomfort. This can be assured by proper screening of permissible chemical agents for recirculation, proper design of system return ducts, and use of an effective monitoring strategy.

The selection of a contaminant concentration level in the breathing zone of the worker is a key point in the design of a recirculation system. This level is unique to each specific system, and is a function of the existing level with the non-recirculating system and the contaminant itself. Assignment of a hard and fast rule, e.g., 20 percent of the permissible exposure limit, is not appropriate. Assigning such a number hampers the flexibility in tailoring the system design to a specific situation. This level should be chosen as one chooses the design level of a non-recirculating system. The system should be designed to achieve the lowest possible contaminant level within practical constraints of equipment availability and economics; this level must be lower than the level in which there are known adverse human health effects.

SYSTEM DESIGN

Use of these decision criteria does not provide a specific design, but rather will assure that the factors critical to a safe recirculation system are considered. The actual system design must consider the effects and interrelationship of a variety of parameters directly associated with the workplace and the proposed recirculation system. These parameters are summarized in Table 1 and are more fully described in reference 5. The parameters as listed and discussed herein apply to conversion of an existing ventilation system. For a new system they may be estimated from analogous systems in operation.

Table 1. Recirculation and workplace parameters.

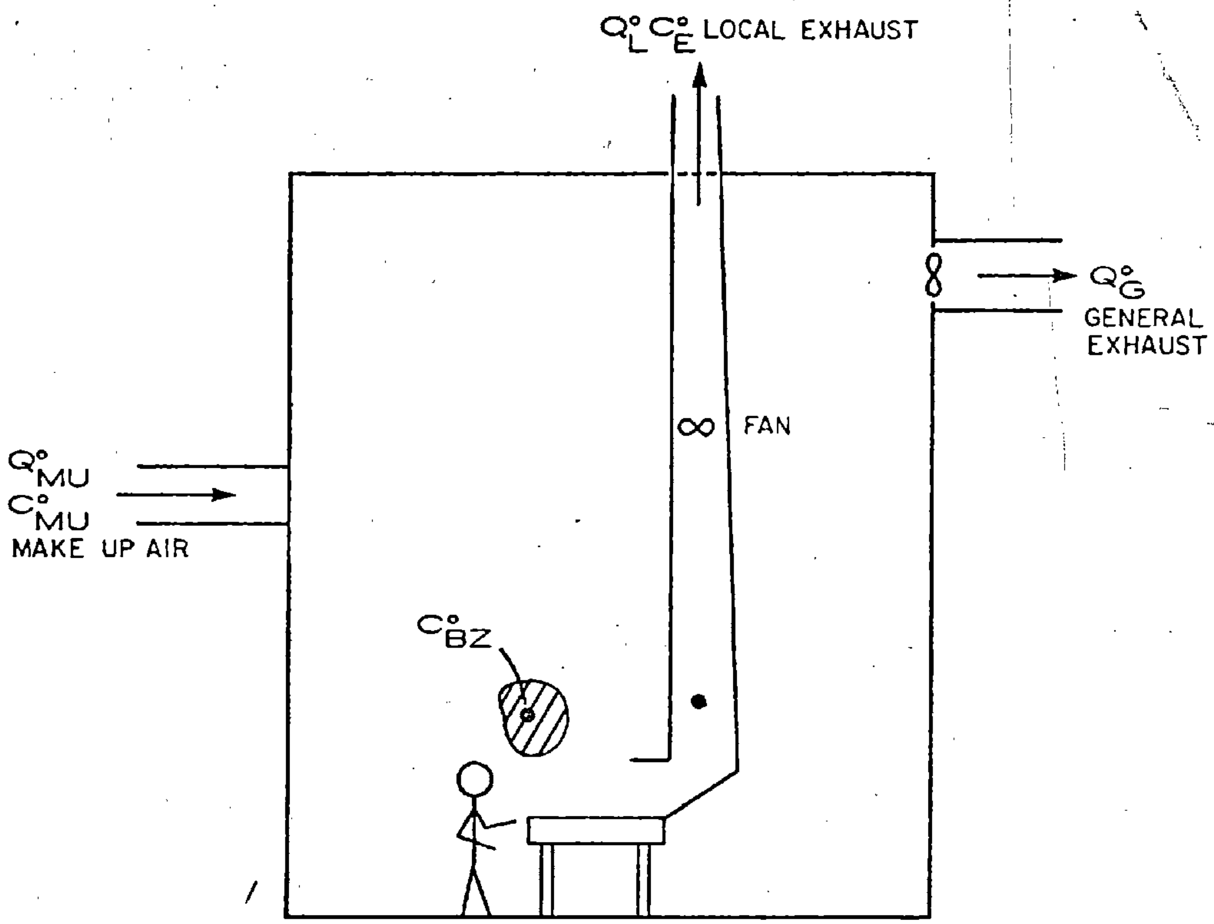
- Process Characteristics
- Makeup air quantity and quality
- Local exhaust airflow rates
- General exhaust airflow rates
- Recirculation airflow rates
- Workplace contaminant concentration
- Recirculation airflow concentration
- Recirculation airflow patterns
- Air cleaner efficiency
- Recirculation air bypass
- Recirculation/makeup air mix
- System maintenance plan
- System monitoring strategy
- Air tempering costs

The physical design of the system will utilize the same guidelines and practices as for an industrial ventilation exhaust and air cleaning system.[6] The basic difference will be the possible selection of a more efficient air cleaning device, the careful placement of return air ducts, and the inclusion of monitoring devices.

The various airflow and contaminant concentrations can vary considerably because of the particular operating configuration of any given plant. Many of the parameters can be varied to optimize overall recirculation system performance. However, the inter-relationship of the parameters cannot be easily determined without use of mathematical procedures. A mathematical model developed in terms of these parameters has been developed.[5] An example follows which will demonstrate how the recirculation model may be used to quantify design parameters and predict post-recirculation conditions.

A simple non-recirculating exhaust system is depicted in Figure 3. This system has 4.72 m^3/s (10,000 cfm) local exhaust and 4.72 m^3/s (10,000 cfm) general exhaust airflows. The makeup airflow is 9.44 m^3/s (20,000 cfm). A single gaseous contaminant is present with concentration of: 10 mg/m^3 in the makeup air, 75 mg/m^3 at the work station, 40 mg/m^3 in the general room air, and 1,000 mg/m^3 in the exhaust duct.

In this case 4.72 m^3/s (10,000 cfm) of the local exhaust is to be recirculated in a manner described in Figure 4 thus reducing the fresh makeup air quantity required by an equal amount. To predict the air cleaner discharge, recirculation return, and worker breathing zone concentrations one would use the following model equations.[5]



$Q^{\circ}_{MU} = Q^{\circ}_{L} + Q^{\circ}_{G}$

Figure 3. Process before recirculation of local exhaust.

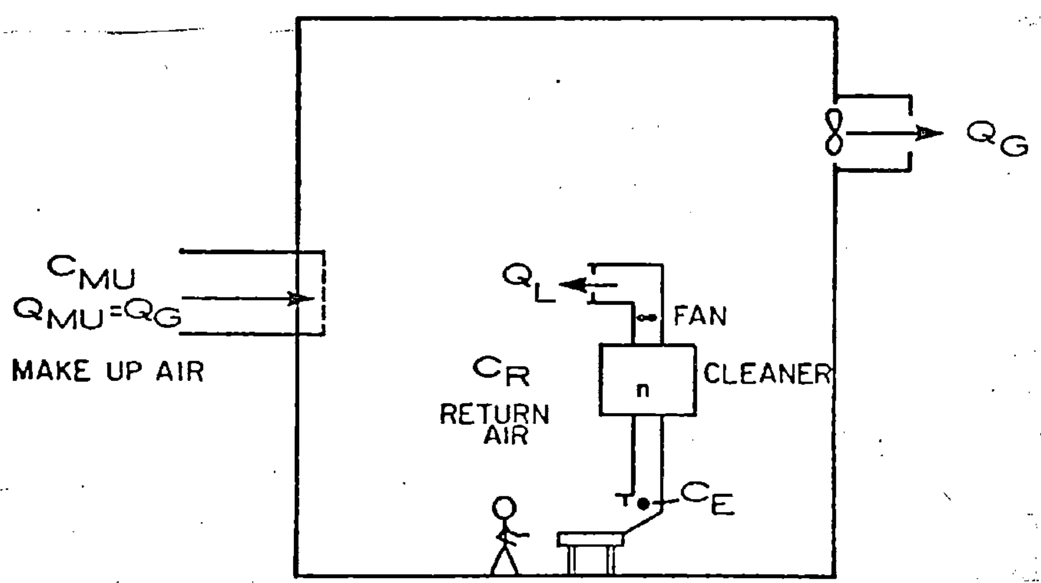


Figure 4. Recirculation without premixing.

Equation 1:

$$C_D = C_R = \frac{(1-n)(C_E^o - k_R C_{MU})}{1-k_R(1-n)}$$

Equation 2:

$$C_{BZ} = \frac{Q_T^o}{Q_T}(C_{BZG}^o - C_{MU})(1-f) + (C_{BZL}^o - C_{MU})f + k_{BZ}C_R + (1-k_{BZ})(C_{MU})$$

where

C_{BZG}^o = TWA breathing zone concentration in the general room areas before recirculation-mg/m^3

C_{BZL}^o = TWA breathing zone concentration at work station influenced by large volume local exhaust hood before recirculation-mg/m^3

C_E^o = local exhaust duct concentration before recirculation-mg/m^3

C_D = air cleaner discharge concentration after recirculation-mg/m^3

C_{MU} = makeup air concentration-mg/m^3 (assumed constant)

C_R = recirculation return concentration-mg/m^3

n = fractional air cleaner efficiency (assumed constant)

Q_G = general exhaust airflow after recirculation-m^3/s (cfm)

Q_L = local exhaust airflow-m^3/s (cfm)

Q_T^o = total ventilation airflow before recirculation-m^3/s (cfm)

Q_T = total ventilation airflow after recirculation-m^3s (cfm)

f = factor which represents the fraction of time the worker spends in the influence of a strong exhaust hood (range 0 to 1.0)

k_{BZ} = factor which represents the fraction of the workers breathing air that is composed of recirculation return air (range 0 to 1.0)

k_R = factor which represents the fraction of the recirculated exhaust stream that is composed of the recirculation return air (range 0 to 1.0)

TWA = the 8-hour time weighted average

C_{BZ} = TWA breathing zone concentration the worker sees after recirculation

These equations are based on a chemical agent mass or volume balance and an airflow balance.

As an example of how these equations are used, assume that a worker is continually stationed at the high concentration work station near a large exhaust hood, and that the recirculation air is returned directly to the work station. The model parameters become:

$C^{o}_{BZL} = 75\ mg/m^3$

$C^{o}_{BZG} = 40\ mg/m^3$

$Q_G = 4.72\ m^3/s$ (10,000 cfm)

$Q_L = 4.72\ m^3/s$ (10,000 cfm)

$Q_{MU} = 4.72\ m^3/s$ (10,000 cfm)

$C^{o}_{E} = 1000\ mg/m^3$

$C_{MU} = 10\ mg/m^3$

$k_{BZ} = 1.0$

$k_R = 1.0$

$f = 1.0$

$n = 0.95$

Since there is no premixing of makeup with return air, the recirculation return concentration, C_R, equals the air cleaner discharge concentration, C_D, and is determined by equation 1.

$$C_R = C_D = \frac{(1-0.95)(1{,}000-1x10)}{1-(1.0)(1-0.95)}$$

$$C_R = 52.1\ mg/m^3$$

The TWA breathing zone concentration, C_{BZ}, is determined by equation 2:

$$C_{BZ} = \frac{9.44}{9.44}(40-10)(1-1)+(75-10)(1) + (52.1)(1) + (1-1)(10) = 117.1\ mg/m^3$$

If the design C_{BZ} had been selected at 100 mg/m^3, this configuration would have been unsatisfactory.

However, if the recirculation return could be relocated to reduce the amount of return air introduced into the worker's breathing zone, and the work could be scheduled to minimize the worker's need to stay continuously in the high level area near the hood, some improvements could be achieved. Assuming k_R, k_{BZ}, and f were lowered to 0.5, the C_{BZ} would equal 78.6 mg/m^3

In providing a worker breathing zone level below the design level of 100 mg/m^3, this design relies on better mixing of the air streams entering the room along with movement of the work stations. Further improvement in the reliability of the estimates could be achieved by insuring perfect mixing of the recirculation return air with the make-up air. This case, premixing of return air, is covered in detail in reference 5.

CONCLUSIONS

The continuing need for energy conservation may result in application of exhaust air recirculation in many industrial areas. The potential for worker exposure and the complex interrelationship between the wide range of engineering and industrial hygiene parameters mandate a formal, logical approach to the decision required in implementing a recirculation system. The use of system modeling is also necessary to account for the effects of system parameter variation and to assure optimum system performance. Adherence to the design and decision guidelines presented herein will provide the logical approach necessary.

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