Estimation of Operation Time for Soil Vapor Extraction Systems

David L. Barnes, P.E., M.ASCE

Abstract: Soil vapor extraction (SVE) has become an acceptable method of removing volatile organic compounds from soil. However, determining the length of time these systems should operate has been historically difficult. This paper presents a procedure for determining this length of operation. The procedure incorporates principles of uncertainty analysis, contaminant transport, and decision theory. An example is provided to illustrate the use of the procedure. Additional analysis of the results shows that a simple calculation can be made that will determine if a SVE system that has been operating for a period of time and is in the later stages of contaminant removal should continue to operate. This calculation consists of dividing the cost of treating the remaining contaminated soil with an alternative method (e.g., ex situ biological treatment) by the annual operation and maintenance cost and comparing this ratio to the inverse of the interest rate. If this ratio is less than the inverse of the interest rate the system should be shut off.

DOI: 10.1061/(ASCE)0733-9372(2003)129:9(873)

CE Database subject headings: Soil gas; Volatile organic chemicals; Soil treatment; Extraction procedures.

Introduction

In recent years soil vapor extraction (SVE) has become an accepted method for VOC removal from contaminated unsaturated soils. This is an in situ technology that uses flowing air (soil gas) created by vacuum blowers attached to extraction wells installed and screened in the unsaturated zone to volatilize VOCs contained in contaminated soil, thus removing the contaminant from the soil. The soil gas containing the VOCs is subsequently treated aboveground to remove the VOCs, allowing the treated air to be discharged to the atmosphere. The system may contain multiple wells, either horizontal or vertical, with each well connected in parallel to the vacuum blower system.

Others have shown with field and laboratory tests that the mass removal rate of VOCs by SVE systems slows significantly with increasing operation time (Crow et al. 1987; Ho and Udell 1992). This decrease in removal rate usually results in inefficient removal of the remaining mass of VOC in later stages of operation. Since the inception of SVE as a viable contaminated soil restoration strategy, designers and operators of these systems have struggled with determining the best date to terminate operation of their systems. Due to the heterogeneous nature of soil permeability and associated uncertainty in the spatial distribution of this soil property, SVE systems designers are unable to accurately predict the VOC mass removal rate a priori. System operators are challenged to justify the expense of continued operation of SVE systems that have low mass removal rates but have not removed sufficient amounts of VOCs from the contaminated soil to satisfy a regulatory clean-up standard.

This paper presents a procedure for estimating the length of time a SVE system should operate. Principles of soil-gas flow and vapor transport, uncertainty analysis, and economics are incorporated in the procedure.

Method

The fact that most SVE systems show a decline in mass removal rate was established by Crow et al. (1987). A typical graph of the relationship between mass remaining and time for removal of VOCs by SVE systems in heterogeneous soils operating at constant extraction rates will be similar to the graph shown in Fig. 1. The result of decreasing mass removal rates on the cost of operating SVE systems can be illustrated by considering VOC removal cost as a function of time. If the operation and maintenance (O&M) cost to operate a SVE system over a set period of time, say one year, is divided by the amount of VOC mass removed during the one-year operating period, then a ratio of the cost per mass removed results. Comparing this cost over the life of an operating SVE will result in a relationship with the general trend shown by the mass removal cost curve in Fig. 1. This curve shows a sharp increase in cost per mass removed during later stages of SVE operation. From an operational viewpoint the longer a SVE system operates the more costly it becomes. In this latter stage of SVE operation, where the removal process has become inefficient, if the mass of VOC in the soil has not been reduced to the clean-up standard then an analysis should be done to determine if the SVE system can be redesigned to increase efficiency or if the SVE system should be shut off and treatment continued using an alternative treatment process.

A flowchart outlining the procedure for such an analysis is presented in Fig. 2. Each of the key models in the procedure is shown in the figure along with required data sets. The three models (uncertainty, simulation, and decision) are described subsequently.
Fig. 1. Relationship between fraction of volatile organic carbon remaining in soil with time and mass removal cost with respect to time for typical operating soil vapor extraction

Referring to this flowchart, an uncertainty model is first developed with knowledge of key soil property data (permeability statistical values and the magnitude and location of measured permeability values). Given a statistical description of the spatial distribution in permeability (mean, variance, and correlation length), the uncertainty model uses geostatistical techniques to develop a number of equally likely representations (realizations) of the spatial distribution of permeability.

The next step in the process consists of supplying the simulation model with parameters characteristic of the design configuration (number and location of extraction wells, size of blower, etc.). These parameters are provided as input into a numerical soil-gas flow and vapor transport model such as the numerical model VapourT, which is used in this study (Mendoza and Frind 1990). VapourT is a two-dimensional finite element model that incorporates a number of assumptions; first, equilibrium phase partitioning for the transport processes is assumed. By making this assumption the diffusion of contaminant through the soil water and the kinetically limited desorption of contaminant from the soil particles are not accounted for by the model. However, the condition for nonequilibrium transfer will most likely occur predominantly in the area around the extraction well, with the effect being less at distances away from the pressure sinks. Johnson et al. (1990) showed with a simplified example that, under typical SVE conditions, equilibrium is reached in a distance of several pore diameters from the extraction well.

An assumption of incompressible soil-gas flow is also made in the model. Massman (1989) showed that for soil-gas flow modeling the assumption of incompressible flow is valid for pressure drawdowns of up to approximately 0.2 atm. Thus, the assumption should not be a limiting factor for most applications.

A static soil-water system is assumed in the numerical model. Not only will infiltrating water and a fluctuation groundwater table invalidate this assumption, but a reduction in the air pressure caused by the creation of a vacuum at the extraction well will also cause movement of soil water. This effect will be minimized if the screened portion of the extracting well is placed at elevations that have low soil-water content.

The simulation model requires a spatial distribution of the contaminant in the porous medium as well as some physical and chemical properties of the contaminant. Once the appropriate number of permeability realizations is generated and all input values for the simulation model have been determined, a Monte Carlo analysis is performed. The output from the simulation of VOC removal from each realization by SVE is compared to the clean-up standard.

From this comparison a probability of failure (ratio of the number of realizations that failed to reach the clean-up standard to the total of the number of realizations) as a function of time is calculated for the SVE system being analyzed. The probability of failure is defined as the probability that the SVE system will be unable to remove a sufficient amount of VOC mass such that the clean-up standard is met. Barnes and McWhorter (2000) discuss the method of calculating the probability of failure in more detail.

Results from the Monte Carlo analysis are incorporated into the decision model as a probability of failure. Included in the decision model are the annual O&M cost and a cost of failure. These costs along with the probability of failure and a utility function are combined in a function called the operation objective function

\[ \Phi_T = \sum_{t=1}^{T} \frac{1}{(1+i)^t} [P_f(t) \gamma(C_f) C_f(t)] \]

\[ C_f(t) = \frac{A_{t+1}}{(1+i)^t} \quad t = 1,2,3,...,T-1 \]  
\[ C_f(T) = C_f \]

In Eq. (1), \( \Phi_T = \) operation objective function value for a SVE system operating until the end of year \( T \) (the end of the final year of SVE operation); \( i = \) discount factor; \( A = \) annual O&M cost; \( P_f(t) = \) probability of failure at time \( t \); \( \gamma(C_f) = \) utility factor; \( C_f(t) = \) cost of failure at any time prior to the final year of opera-
tion; and $Cf_T$ = cost of failure if the system is not able to achieve the clean-up standard by the end of the final year of operation. The product of $P_f(t)\gamma(Cf)$, and $Cf(t)$ is a measure of the risk of incurring additional costs should the system fail to meet the clean-up standard. This term is defined as the expected costs associated with the probability of failure (Freeze et al. 1990).

In Eq. (1), the cost of failure is defined as the cost associated with the inability of a design alternative to reach the clean-up standard. This cost may include such items as the cost associated with regulatory fines, or the cost associated with the loss of an opportunity to sell the property. An additional cost of failure may be the cost of designing, installing, and operating an alternative treatment method such as ex situ bioremediation or even the cost of excavation and proper disposal of the remaining contaminated soil. Cost of failure prior to the final year of operation will be the cost of designing, installing, and operating an alternative treatment method (to include excavation and disposal). It is assumed that the SVE system will need to be operated for at least one year, resulting in removal of the first year’s operation cost.

The utility factor in the decision model is a measure of the decision maker’s aversion to risk, or, as applied here, a decision maker’s aversion to incurring additional risk. The utility is equal to unity for a risk-neutral behavior. For a risk-averse behavior, the utility is greater than unity. The utility is described in detail by Massman and Freeze (1987) and Freeze et al. (1990).

The use of this decision model to determine the length of time a SVE system should operate requires the assumption that a point in time will be reached such that the cost of operating and maintaining the system outweighs the benefit of operating the system. If this assumption holds true then at this point it seems reasonable that operation of the SVE system should be terminated. If the clean-up standard has not been met by the time operation of the SVE system has been terminated, then an alternative treatment method will be required as previously discussed. It may also be possible that a change in the design configuration could improve the probability that the clean-up standard will be met. The analysis can be repeated with a different design specification.

The procedure is suitable for determining the length of operation for any SVE system including systems that operate in a pulse or on-off-on fashion to reduce O&M costs. Of course, operating in a pulse fashion will prolong the length of time necessary to treat the soil to the clean-up standards. Accepting the premise that diffusion is the dominant transport mechanism for contaminants migrating between areas of relatively low soil permeability and areas of relatively high soil permeability during SVE operation, then the fact that pulsing a SVE system prolongs the time of operation is attributed to the driving force for diffusion, which is the concentration gradient. As long as a SVE system is kept operating, the concentration gradient between the areas of differing soil permeability will be at a maximum for the system. Once the SVE system is shut off, stopping the induced flow of soil gas, the concentration gradient will tend toward a minimum until a flow of soil gas is reestablished. Thus, if the goal is to expediently reduce the mass of contaminant in the soil, then the SVE system should remain operating.

Analyzing pulse style operation by this procedure requires a numerical model that can incorporate the resulting spatial distribution of VOCs formed during this phase of operation is then incorporated into the next “on” phase of the simulated pulsed operation. The numerical model VapourT used in this study can be operated in this fashion (Mendoza and Frind 1990). Referring to Eq. (1), $P_f(t)$ is calculated in the same manner as described previously; however, $Cf(t)$ is proportioned accordingly to account for the fraction of the year the system will not be in operation.

After performing the necessary calculations for any particular SVE system to determine $P_f(t)$, as described previously, the operation objective function value ($\Phi_f$) is calculated for each year of simulated operation. The length of time a SVE system should operate corresponds to the year of operation with the minimum operation objective function value.

### Results

In comparing the value of $\Phi_f$ for consecutive years of simulated operation, if the calculated objective function for year $T$ is greater than the objective function for year $T+1$ ($\Phi_f > \Phi_{f+1}$), then the operation of the SVE system should continue in the next year (year $T+1$). In other words, continued operation of the SVE system results in a decrease in the risk that the system will fail to meet the clean-up standard. Conversely, if calculation of the objective function for year $T$ and year $T+1$ results in $\Phi_f \leq \Phi_{f+1}$, then operation of the SVE system should be discontinued since the cost of operating the system for an additional year outweighs the risk of failing to meet the clean-up standard.

Restating the conditions for terminating SVE operation as $\Phi_f - \Phi_{f+1} \leq 0$ and substituting the definition of the operation objective function (assuming risk neutral behavior) results in the following:

$$\sum_{t=1}^{T} \frac{1}{(1+i)^t}[P_f(t)Cf(t)] - \sum_{t=1}^{T+1} \frac{1}{(1+i)^t}[P_f(t)Cf(t)]=0$$

Substituting annual operation cost adjusted to present worth for $Cf(t)$ (cost of failure prior to the final year of operation) in Eq. (2) and assuming that the terminal cost of failure $Cf_T$ is the same if the system operation is discontinued in the year $T$ or in the year $T+1$, then the following results:

$$\frac{1}{(1+i)^T}[P_f(T)Cf_T] - \frac{1}{(1+i)^T}(P_f(T)\frac{A}{(1+i)}) + \frac{1}{(1+i)^{T+1}}[P_f(T+1)Cf_T]\leq0$$

Solving for the ratio $Cf_T/A$ results in the following:

$$\frac{Cf_T}{A} = \frac{P_f(T)}{(1+i)P_f(T) - P_f(T+1)}$$

In some cases, predominantly in the later stages of system operation, the $P_f$ will not be reduced from one year to the next [$P_f(T)=P_f(T+1)$]. In these cases Eq. (4) reduces to

$$\frac{Cf_T}{A} = i^{-1}$$

Thus, if for any year of SVE operation the ratio of the ultimate cost of failure of a SVE system to the annual cost of operating the SVE system is less than or equal to $P_f(T)/(1+i)P_f(T) - P_f(T+1)$, or in special cases [i.e., $P_f(T)=P_f(T+1)$] the reciprocal

---

JOURNAL OF ENVIRONMENTAL ENGINEERING © ASCE / SEPTEMBER 2003 / 875
of the interest rate, then the continued operation of the SVE system is not economically justified. At this point the system should be shut off and the soil tested to determine if the clean-up standard has been reached. If the clean-up standard has not been reached, then the alternative method of treating the soil should be employed.

Another important conclusion comes from this analysis. Comparing Eqs. (4) and (5) results in the following inequality:

\[ i^{-1} \geq \frac{P_f(T)}{(1+i)P_f(T) - P_f(T+1)} \] (6)

Noting that the maximum value that \( C_f/A \) can attain is \( i^{-1} \), if for any SVE system this ratio exceeds \( i^{-1} \), then there is no economical justification (according to this analysis) to shut off the system unless the SVE system is able to remove the VOC down to the clean-up standard. For future discussion, the ratio \( P_f(T)/[(1+i)P_f(T) - P_f(T+1)] \) will be referred to as \( \beta_f \) and \( i^{-1} \) as \( \beta_f^\text{max} \).

Knowing \( \beta_f \) for each year of simulated operation and the total cost of an alternative treatment (\( C_f \)), the optimum length of time a SVE system should operate can be determined. To make this decision, a maximum cost of failure is first calculated (\( C_f^\text{max} = \beta_f \times A \)) for each year of operation. The present cost of installing and operating an alternative treatment method (\( C_f^\text{T} \)) is compared to the calculated \( C_f^\text{max} \) for each year of operation. If the total cost of an alternative is less than \( C_f^\text{max} \) for any year of SVE operation, then the SVE system should be shut off and the soil tested to determine if the clean-up standard has been met. The alternative treatment method would be put in place if the SVE system fails to remove a sufficient mass of VOCs to meet the clean-up standard. The limitations of this procedure can largely be attributed to the limitations of the numerical model chosen for the soil-gas flow and vapor transport. An example to illustrate how the procedure can be used to estimate the length of time a SVE system should operate follows.

Example

To investigate the validity of the procedure, consider a typical but hypothetical soil contamination scenario. In this scenario, the source of contamination is an evaporation lagoon that in the past has accepted a trichloroethylene (TCE) waste stream. The surface of the lagoon measures 26 m\(^2\) x 30 m. After approximately one year of service, the lagoon was found to be discharging TCE to the subsurface. A two-well horizontal SVE system has been installed. The original lagoon has been removed and the ground surface capped with a low permeable soil.

It is well known that SVE systems do not perform in the capillary fringe area of the unsaturated zone. Thus, it seems reasonable that SVE systems should be designed to remove the VOCs from the zone above the capillary fringe leaving the contaminant removal from this zone to other techniques such as vacuum enhanced liquid recovery. For modeling purposes, the top of the capillary fringe is considered the lower boundary (no flow) in the modeled region. In a soil with heterogeneous permeability one can envision that the distance from the groundwater table to the top of the capillary fringe is spatially dependent. Barnes and McWhorter (2000) derive an equation that can be used to estimate the height of the capillary fringe in heterogeneous porous media. The resulting equation is used for this study.

A cross section of the contaminated area and the dimensions of the SVE system are shown in Fig. 3. The contaminated region shown in Fig. 3 contains liquid phase TCE. Table 1 lists the logarithmic permeabilities for each datum point. The porous medium properties and relevant properties of TCE are provided in Table 2. A spherical variogram was assumed for this example.

For this example the yearly cost of operating the SVE system is $25,000, which is a typical O&M cost for SVE systems operating in Alaska (Mark Prieksat, personal communication, August 7, 2000). The interest rate is assumed to be 6%.

Referring to Eq. (5), given an annual O&M cost (\( A \)) of $25,000, if the cost of an alternative treatment method, should the SVE system fail to reach the clean-up standard, exceeds $417,000, then according to the analysis method described here, the length of system operation will be controlled by the time required for the system to reach the clean-up standard.

A clean-up standard of 20 kg of TCE remaining in the soil has been assumed in this example. For each realization, the two-dimensional soil-gas flow and vapor transport model VapourT (Mendoza and Frind 1990) was used to model passive migration of TCE vapors for a simulated period of one year, establishing the initial conditions for simulations of SVE performance. At the end of one year, removal of the TCE vapors by SVE was modeled for a simulated period of 15 years. The Monte Carlo analysis consisted of 150 realizations. Fig. 4 shows the average mass of VOC remaining as a function of time. The calculated annual probability of failure, the associated ratio \( \beta_f \), and the maximum costs of failure (\( C_f^\text{max} \)) are shown in Table 3.

*Table 1. Logarithms of Permeabilities for Each Datum Point Shown in Fig. 3*

<table>
<thead>
<tr>
<th>Datum point</th>
<th>Log (permeability)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>−28.6</td>
</tr>
<tr>
<td>2</td>
<td>−30.0</td>
</tr>
<tr>
<td>3</td>
<td>−28.5</td>
</tr>
<tr>
<td>4</td>
<td>−27.7</td>
</tr>
<tr>
<td>5</td>
<td>−29.1</td>
</tr>
<tr>
<td>6</td>
<td>−27.8</td>
</tr>
<tr>
<td>7</td>
<td>−30.8</td>
</tr>
<tr>
<td>8</td>
<td>−31.4</td>
</tr>
<tr>
<td>9</td>
<td>−28.3</td>
</tr>
<tr>
<td>10</td>
<td>−29.5</td>
</tr>
</tbody>
</table>
From the example results in Table 3, different alternatives can be compared. For example, if the SVE system is unable to reach the clean-up level by the end of year 6, and a treatment technology that has a better probability of reducing the mass of VOC to the clean-up standard or the remaining contaminated soil can be excavated and properly disposed costs less than approximately $202,500, then the SVE system should be shut off and the alternative method put in place. Arbitrarily setting the final cost of failure at $202,500 the objective function for each year of simulated operation can be calculated for each year of simulated operation. The results of this calculation are shown in Fig. 5. As expected, the minimum value of the objective function is found in year 6.

Table 2. Porous Media and Chemical Properties Used in Example Problem

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Porous medium property</td>
<td></td>
</tr>
<tr>
<td>Mean permeability</td>
<td>$7 \times 10^{-13}$ m$^2$</td>
</tr>
<tr>
<td>Mean natural logarithm of permeability</td>
<td>-29.0</td>
</tr>
<tr>
<td>Permeability variance</td>
<td>$3.05 \times 10^{-24}$ m$^4$</td>
</tr>
<tr>
<td>Variance in natural logarithm of permeability</td>
<td>2.0</td>
</tr>
<tr>
<td>Horizontal correlation length</td>
<td>10 m</td>
</tr>
<tr>
<td>Vertical correlation length</td>
<td>2 m</td>
</tr>
<tr>
<td>Porosity</td>
<td>0.40</td>
</tr>
<tr>
<td>Longitudinal dispersivity</td>
<td>1.0 m</td>
</tr>
<tr>
<td>Transverse dispersivity</td>
<td>0.1 m</td>
</tr>
<tr>
<td>Fraction of organic carbon</td>
<td>0.005</td>
</tr>
<tr>
<td>Residual soil-water saturation</td>
<td>0.04</td>
</tr>
<tr>
<td>Bulk density</td>
<td>$1.59$ g/cm$^3$</td>
</tr>
<tr>
<td>Brooks-Corey pore size distribution index</td>
<td>2.0</td>
</tr>
<tr>
<td>Capillary fringe height</td>
<td>2.13 m</td>
</tr>
<tr>
<td>Relevant TCE chemical property</td>
<td></td>
</tr>
<tr>
<td>Viscosity</td>
<td>$9.4 \times 10^{-6}$ Pa\cdot s</td>
</tr>
<tr>
<td>Molecular weight</td>
<td>131.4 g/M</td>
</tr>
<tr>
<td>Gaseous diffusion coefficient</td>
<td>$6.9 \times 10^{-6}$ m$^2$/s</td>
</tr>
<tr>
<td>Aqueous diffusion coefficient</td>
<td>$3.0 \times 10^{-10}$ m$^2$/s</td>
</tr>
<tr>
<td>Henry’s law constant</td>
<td>0.42</td>
</tr>
<tr>
<td>Organic carbon partitioning coefficient</td>
<td>125 mL/g</td>
</tr>
</tbody>
</table>

Discussion

Comparing the curves for $P_f(t)$ and fraction of mass remaining with time shown in Fig. 4, a similar trend between the two curves is noted—the rate of change for each function tends to decrease with time. This similarity indicates that, for any typical VOC contaminated soil clean-up activity being attempted with a SVE system, as the total VOC mass remaining in the soil tends toward a minimum, the minimum probability that the system will fail to achieve the clean-up standard is being reached as well. From this comparison one can assume that in this later stage of SVE system operation the conditions for use of Eq. (5) are being approximated.

During the operation of a SVE system samples of off gas from the system are typically gathered at certain time intervals. These samples are measured for VOC concentration. A graph of off-gas concentration versus time for any typical SVE system will show the same general trend as the graph of fraction of mass remaining versus time shown in Fig. 4. The similarity between concentration versus time and the probability of failure versus time indicates that it is possible to use Eq. (5) during the later stages of SVE operation to make a determination as to the continued operation of a system. If the cost of an alternative treatment system is less than the yearly operation cost divided by the interest rate, then the
system should be shut down and the soil tested to determine if the clean-up standard has been met. Failing to meet the clean-up standard suggests that the SVE system has become inefficient from an operations perspective and should be replaced with an alternative method in order to finish the clean-up activity. The procedure for making the decision on continued operation of an operating SVE system can be summarized as follows:

- Determine an appropriate 
  \( C_f T \);
- Collect SVE off-gas samples over time and measure VOC concentration;
- With each new sample result, determine the rate of change in VOC concentration for the interval between sampling (change in off-gas VOC concentration over sample time interval);
- If the rate of change for several sample periods tends toward zero, then compare \( C_f T / A \) to \( i^{-1} \);
- Shut off the system if \( C_f T / A < i^{-1} \);
- Sample soil to determine if the clean-up standard has been met.

The risk in making a decision based upon this approximate method is the possibility that with additional time the SVE system could have reached the clean-up standard. However, given the historically slow mass removal rates due in the later stages of SVE operation, this approximate method of determining if a SVE system should remain in operation should be viable. With the results from this study, operators of SVE systems should now be able to make economically based decisions concerning the continued operation of their systems using data that are already being regularly collected.

Conclusions

A large amount of uncertainty exists when designing and operating a SVE system to reduce the mass of VOCs contained in a contaminated soil. This uncertainty is partially due to the lack of complete knowledge concerning the soil properties, the spatial distribution of permeability in particular. Because of this uncertainty, many SVE systems are designed without knowing how long the system should operate. This condition provides a challenge to designers of these systems to develop a cost-effective system with incomplete knowledge. To aid designers of SVE systems, a procedure for estimating the length of time that is economically justifiable for a SVE system to operate has been presented. The procedure takes into account uncertainty in the soil properties and the economics of operating a SVE system. The procedure has been described and an example provided. Results from the analysis show that for operating SVE systems in the later stages of operation a simple calculation can be made to allow an economics based decision on continued system operation.

Acknowledgments

The Alaska Science and Technology Foundation and U.S. Army Alaska funded this study. The writer thanks these agencies for their support.

Notation

The following symbols are used in this paper:

\[ A = \text{annual operation and maintenance cost}; \]
\[ C_f = \text{cost of failure}; \]
\[ i = \text{discount factor}; \]
\[ P_f = \text{probability of failure}; \]
\[ T = \text{end of final year of SVE operation}; \]
\[ t = \text{time}; \]
\[ \beta = \text{probability of failure ratio}; \]
\[ \gamma = \text{utility factor as function of cost of failure}; \]
\[ \Phi = \text{operation objective function}. \]

Subscripts

\[ T = \text{end of final year of SVE operation corresponding to cost of failure}; \]
\[ T_{\text{max}} = \text{maximum probability of failure ratio}; \]
\[ t + 1 = \text{time corresponding to annual operation and maintenance cost}. \]

References


