



## Project Summary

# Evaluation of the High Volume Collection System (HVCS) for Quantifying Fugitive Organic Vapor Leaks

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Fugitive volatile organic compound emissions associated with gas and/or petroleum processing facilities have historically been difficult and expensive to measure accurately. A measurements technique has recently been developed that offers the potential for providing an easy-to-use and cost-effective means to directly measure organic vapor leaks. The method, called the High Volume Collection System (HVCS), uses a high volume sampling device and a portable flame ionization detector (FID) for field analysis. The HVCS can obtain direct measurements of mass emission rates without the need for tenting and bagging. This study of HVCS method performance included both field and laboratory testing. Laboratory evaluation of HVCS results closely matched EPA method results with a difference in total measured emissions of only about 3%. In one field test, the HVCS matched the EPA estimate of total facility emissions within about 4%. In the other field test, the HVCS measured approximately 18% more emissions than the EPA method. However, the bias was present only early in the test. Later in the test, after efforts were made to identify and correct its source, HVCS bias was essentially zero. With some physical and procedural enhancements, the HVCS may be offered to EPA for approval as an acceptable alternative to the EPA protocol bagging method with gas chromatographic analysis.

*This Project Summary was developed by EPA's National Risk Assessment*

*Research Laboratory, Research Triangle Park, NC, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).*

### Introduction

Fugitive emissions of methane and other organic vapors from leaking pipelines, valves, flanges, and seals associated with natural gas, petroleum, and chemical production and processing facilities are an important source of methane and other organic emissions to the atmosphere. Such emissions have historically been difficult and expensive to measure accurately. EPA Reference Method 21, "Determination of Volatile Organic Compound Leaks," describes instruments and procedures that can be used to locate and assess the magnitude of such leaks. However, Method 21 does not provide a direct measure of the mass emission rate. According to the current EPA protocol, the mass emission rate is arrived at by associating plant/component specific information and instrument screening values (per Method 21) with published EPA emission factors or correlation equations. These emission factors and correlations were developed over the last 15 years, based on field studies at petroleum refineries, gas plants, and Synthetic Organic Chemical Manufacturing Industry plants. In these studies, screening measurements based on Method 21 were associated with direct measurements of mass emissions obtained by isolating leaking components and measuring the pollutant concentration in a

known flow of carrier gas (*i.e.*, tenting and bagging the leak).

A measurements technique has recently been developed as a result of work sponsored by the Gas Research Institute. The method, known as the High Volume Collection System (HVCS), uses a high volume sampling device in front of a portable flame ionization detector (FID) (Foxboro OVA Model 108 portable FID). The HVCS uses a battery-powered pump to draw air across a leaking component at rates between 10 and 500 standard cubic feet per hour (scfh<sup>1</sup>). Flows are metered using three calibrated rotameters (100-1000, 10-50, and 2-20 scfh). The FID is used to measure the hydrocarbon concentration in the collected air. Hydrocarbon mass emission rates are determined from the measured airflow rates and hydrocarbon content in the flow. The success of the method depends on capturing all of the leaking gas from a component in the flow entering the sample inlet. The inlet is constructed to enhance this capture (the inlet is shaped like the mouthpiece of a snorkel). Diffuse leaks from larger components (such as a large flange) are captured by wrapping the component in polyethylene wrap so that the air flow passes over the entire leaking surface. A flexible spring coil (toy slinky) is used to prevent the wrapping from obstructing the leak or inhibiting the airflow across the component.

The HVCS was designed to obtain direct measurements of mass emission rates without the need for tenting and bagging and offers the potential for providing an easy-to-use and cost effective means to measure organic vapor leaks from gas, oil, and chemical industry sources. The HVCS has the potential to provide accurate and cost effective emissions data compared to the current EPA protocol methods. It provides a direct measurement of emissions at the source and is simple and inexpensive to operate. These capabilities also provide the means to effectively evaluate alternative inspection and maintenance programs and select the program that provides maximum control and minimum cost.

## Project Objectives and Scope

The purpose of this study was to complete a detailed evaluation of HVCS method performance over the wide range of leak sizes, component types, and operating conditions characteristic of natural gas production in the U.S. The focus of this evaluation is direct comparisons of HVCS results versus controlled leak rates

(laboratory) and EPA protocol "tent and bag" method results (field). Consideration is also given to the broader issue of whether the HVCS can be used to accurately determine total emissions from a facility. The report presents results from each of these points of view.

The study included both field and laboratory testing. The field testing assessed the accuracy of the HVCS method relative to an EPA protocol emissions measurements method. The goal was to challenge HVCS performance over the range of leak rates, component types and sizes, and operating conditions characteristic of U.S. natural gas production. A major focus of the study was to develop performance criteria for field use of the HVCS method. This included identifying strengths and weaknesses of the prototype HVCS system, making recommendations for improvement, identifying conditions under which best and worst HVCS performance is achieved, and recommending procedures for obtaining optimum results. The laboratory testing was conducted to establish the accuracy and precision of the EPA protocol (bagging) and HVCS methods compared to controlled leak rates. This testing provided necessary support to the field test results by examining the performance of both methods under controlled conditions. In the laboratory, many of the sources of uncertainty associated with field testing were eliminated; the most important source is that the true leak rate in the field is unknown.

A detailed Quality Assurance Project Plan (QAPjP) was prepared, reviewed, and approved, prior to beginning any actual testing. This plan served as a guide throughout the field testing and final data analysis.

## Summary of Testing and Results

Laboratory testing was completed before the field testing and consisted of EPA method and HVCS measurements on 134 constructed leaks (75 HVCS and 59 EPA) representing a range of leak rates and component types typical of natural gas production. The EPA protocol vacuum method was selected for the study based on results of preliminary testing with both EPA protocol methods. Field testing was conducted at two gas production fields: one in South Texas and one in West Texas. A total of 135 paired EPA and HVCS quantifications were obtained in the field studies (56 in South Texas and 79 in West Texas). The field sites were selected to represent "typical" facilities where one would expect to find leaking components.

This profile required an average facility age of 15 or more years, moderate operating pressures (< 1000 psi<sup>2</sup>), low hydrogen sulfide levels, and no active leak detection and repair program. The sites had to contain a sufficient number of wells, compressor stations, and other installations located in a small enough area to permit cost effective screening and quantification. Leaks were identified with soap solution, and selected leaks were quantified by both the EPA and HVCS methods. Gas composition was determined in the field by gas chromatography (GC) for each bag sample.

## Laboratory Test Results

The EPA and HVCS methods were both evaluated in laboratory studies. Since the EPA method, like any measurement, is subject to imprecision and bias, quantification of these data quality indicators was essential before the EPA method could reliably be used in the field as a measure of HVCS performance. Only limited controlled testing of EPA protocol method performance has been conducted previously, and this did not include treatment of errors associated with the total sampling system, including the "bag" or component enclosure.

The laboratory tests conducted for this study were devised to represent "real world" components and leak types so that overall errors (including total sampling errors) are represented. Actual pipeline components were assembled in such a manner that induced leak rates could be carefully controlled and accurately metered against a primary flow standard. Components tested included a 2 in.<sup>3</sup> gate valve, a 4 in. threaded coupling, a 6 in. pipe flange, and a 1/2 in. pump shaft. These represent component types and sizes that are typically encountered at natural gas production and processing facilities. Details of the laboratory test bench setup and test matrix are given in the QAPjP. Laboratory test procedures were identical to the field test procedures. Leak rates induced in the laboratory study span 4 orders of magnitude and are representative of the range of leaks likely to be encountered at actual gas and oil production facilities. Induced leak rates ranged from 0.02 to 20 standard liters per minute (slpm) (.04 to 40 lb/day as methane<sup>4</sup>).

Laboratory test results are summarized in Table 1. Percentage differences are

<sup>1</sup> 1 scfh = 0.0283 std m<sup>3</sup>/sec.

<sup>2</sup> 1 psi = 6.89 kPa.

<sup>3</sup> 1 in. = 2.54 cm.

<sup>4</sup> 1 slpm = 2 lb/day (this converts the metric standard liter per minute leak rate to the nonmetric pounds per day mass equivalent of the principal gas, methane).

**Table 1.** Laboratory Results Summary

Method Bias	Mean (MVU) <sup>a</sup>	Lower 95% Limit	Upper 95 % Limit	No.
EPA Method Bias vs. Induced	-7.4%	-9.7%	-5.0%	55
HVCS Bias	-8.3%	-12.0%	-4.3%	32/55 <sup>b</sup>
HVCS Relative Bias	0.3%	-9.0%	8.5%	9/22 <sup>b</sup>
HVCS "True" Bias	-7.1%	-15.7%	0.5%	9/22 <sup>b</sup>

  

Difference in Total Emissions	Leak (slpm)	Result (slpm)	Diff (%)	No.
EPA Method vs. Induced	96.1	90.4	-5.9	55
HVCS Method vs. Induced	175.1	164.5	-6.1	55
EPA vs. HVCS	25.1 (EPA)	24.4 (HVCS)	-2.8	22

<sup>a</sup> MVU = Minimum variance unbiased.

<sup>b</sup> Summary results are calculated using only data that are unaffected by a bias caused by the position of the FID probe in the HVCS exhaust. This bias was discovered during the laboratory study, and measures were taken to prevent the bias from occurring during the field study.

used as the measure of bias in four cases: (1) EPA results versus known leak rates, (2) HVCS results versus known leak rates, (3) HVCS versus EPA results (HVCS relative bias), and (4) HVCS versus bias corrected EPA results (HVCS "True" bias). The EPA bias correction is -7.4%, as determined in these studies. HVCS "true" bias is a useful measure of field performance, since it compares the HVCS results to an estimate of actual emissions (as estimated from the EPA method results), rather than relative to another measurement (the EPA method).

Results are summarized in terms of a minimum variance unbiased estimator of the mean, lower 95%, and upper 95% confidence interval limits. These summary statistics were selected based on the natural log-normal distribution of the percentage difference used to measure bias.

In the laboratory study, the HVCS and EPA methods gave very similar results (relative bias is 0.3%). Both methods showed a moderate negative bias (7 to 8%) compared to the known leak rates. For the EPA method, the negative bias is probably due to incomplete mixing in the bag, so that outside air is taken up preferentially to the leaking gas. For the HVCS method, the negative bias is probably due to incomplete leak capture, or failure of the HVCS system to fully capture the leaking gas in the slipstream of air pulled in around the component. In the laboratory study, the components were not fully en-

closed during HVCS sampling. In the field study, however, components were thoroughly wrapped in polyethylene film during HVCS sampling. This appeared to improve leak capture.

To assess the ability of the HVCS to quantify total facility emissions, total emissions from all leaking components in the laboratory test results may be viewed as total facility emissions. The total induced leak rate from all components tested by the HVCS method was 175.1 slpm (84.6 lb/day). The total leak rate measured by the HVCS method was 164.5 slpm (79.5 lb/day), for an overall difference of -6.1%. The total induced leak rate from all components tested by both the HVCS and EPA methods was 26.1 slpm (54.0 lb/day). The total leak rate measured by the EPA method was 25.1 slpm (52.0 lb/day), and the total leak rate measured by the HVCS method was 24.4 slpm (50.5 lb/day). The overall difference between the EPA and HVCS methods was -2.5%. The total induced leak rate from all components tested by the EPA method was 96.1 slpm (198.9 lb/day). The total leak rate measured by the EPA method was 90.4 slpm (187.1 lb/day), for an overall difference of -5.9%.

### Field Test Results

To locate leaks for the study, over 21,000 components were screened at two gas production facilities located in separate areas (South Texas, and West Texas).

Table 2 summarizes the number and type of components screened and leaks found at each location.

Table 3 summarizes the field study results using summary statistics as described for the laboratory study.

At the South Texas site, measured leak rates ranged from less than 0.01 to more than 9 slpm as measured by the EPA method. Some larger leaks were not measurable by the EPA method. The HVCS method measured leak rates up to 13 slpm. The average leak rate was about 1.2 slpm, with a median of 0.25 slpm. Total measured emissions (EPA method) were about 70 slpm, or about 140 lb/day, representing most of the leaks in two of three gas fields served by the facility. There appears to be a positive bias in the South Texas field data compared to the laboratory results; however, a statistical comparison ("t" test) gives a probability that the means are different by about only 65 to 75%. That is, given the variability in the data, the means cannot be distinguished with a very high level of statistical significance. In terms of an inventory, the relative bias overstates the difference between the two methods. Overall measured emissions (final validated data only) are 58.2 slpm (about 120 lb/day) for the HVCS method and 55.8 slpm (about 115 lb/day) for the EPA method, an overall difference of only 4%. The reason for the overstatement is that small differences in measurements of small leaks often yield large percentage differences. The negative bias observed in the laboratory studies was probably eliminated by the additional "wrapping" of components that was routinely performed in the field.

At the West Texas site, measured leak rates ranged from less than 0.01 to more than 20 slpm. The average leak rate was about 1.2 slpm, with a median of 0.7 slpm. Total measured emissions (EPA method) amounted to about 130 slpm (about 260 lb/day). Most of the measurements were obtained in a gas processing plant (51/79); the remainder were collected at well heads and in a propane storage area. There is a very significant positive HVCS bias in the overall West Texas results. The probability that the mean bias is the same as in the laboratory studies is very small (0.4%). The probability that the mean bias is the same as in the South Texas data is also small (0.9%). For the validated data, the HVCS method measured a total of 93.9 slpm (194 lb/day), while the EPA method came up with only 79.2 slpm (164 lb/day). This difference in total emissions is significant (18.6%) but not far outside acceptable limits for field emis-

**Table 2.** Component Screening and Leak Identification

<i>Component</i>	<i>South Texas</i>		<i>West Texas</i>	
	<i>Screened</i>	<i>Leaks</i>	<i>Screened</i>	<i>Leaks</i>
<i>Flanges</i>	889	0	1401	1
<i>Threaded Connectors</i>	3733	12	8010	11
<i>Tube Connectors</i>	931	3	982	0
<i>Valves</i>	1785	25	2901	79
<i>Open-End Lines</i>	216	8	55	0
<i>Miscellaneous</i>	74	11	94	7
<i>Total</i>	7628	59	13443	98

sions measurements. It is notable that the bias occurred only early in the study. Before September 26, the difference in total emissions was 47.1%, and after this date the difference was essentially zero (-1.5%). This is significant, as some operational and procedural changes were made in the field after September 26 in an attempt to improve results.

The bias in the West Texas results was immediately noted in the field. The field crew conducted numerous quality control and operational checks to determine the source of the bias. The HVCS and bag sampling apparatus were carefully leak-checked, and additional flow calibrations were performed. The OVA was calibrated before and after each HVCS quantification, using the same methane standards used to calibrate the GC. Controlled leak tests and other special tests were also conducted in an attempt to isolate the source of the bias.

After efforts early in the study failed to eliminate the bias, a concentrated effort was made on September 26 to isolate and eliminate the bias, if possible. This included controlled leak tests, equipment checks and cleaning, and minor changes in operating procedures. A hypothesis that the apparent positive HVCS bias may have actually been due to a negative bias caused by dilution in the EPA sampling apparatus was also investigated. Unfortunately, this effort failed to identify and explain the exact source of the bias; however, after this date, the bias was no longer present in the results.

Two additional possibilities that could explain the apparent HVCS bias were identified: (1) high background hydrocarbon levels and (2) analytical bias of the OVA versus the GC. Background hydrocarbon concentrations can produce a positive

HVCS bias since the background concentration is multiplied by the higher HVCS flow rate to obtain the emission rate (i.e., the HVCS result is more strongly influenced by background levels than the EPA vacuum method, even though both use the air surrounding the leaking component as dilution gas). Note, however, that observed background hydrocarbon concentrations were, in most cases, not sufficiently high to have produced the observed HVCS bias. Although both the GC and the OVA use FID, an analytical bias could result from differences in instrument design that make the OVA response sensitive to sample contaminants, sample gas composition, and possibly environmental effects such as pressure. The possibility that an analytical bias was present was suggested by field efforts to identify the source of the bias.

In addition to the possible effect of operational changes that were implemented after September 26 (the pump was cleaned and an extension tube was added to the EPA apparatus), the improvement in HVCS results after September 26 may be related to a combination of two other factors. First, as part of efforts to determine and eliminate the source of the bias, measuring in areas with high background levels was avoided after that date. Earlier in the study, most of the measurements were obtained from dense clusters of leaking components where there were potentially high background levels. At the South Texas site, background levels were minimal (samples were obtained in remote, open areas and wind speeds were very high). Second, the average leak rate after September 26 (1.8 slpm) is larger than the average leak rate before that date (1.2 slpm). This would reduce an HVCS bias related to background hydrocarbon

since such a bias is less significant for larger leaks.

After the field studies, additional laboratory studies were conducted to confirm the field tests that suggested an analytical bias and to identify the source of the bias. For these tests, five gas samples were obtained in pressurized stainless steel sample canisters from the West Texas plant. The samples were collected progressively through the gas processing stages and represent the areas in the gas plant where leaks were quantified. In addition, the same OVA used in the study was obtained for comparative tests with the GC. The laboratory testing was designed to compare the response of the OVA and the GC under more controlled conditions, to identify a contaminant in the gas samples, and/or to identify an unidentified compound that could have produced the observed bias.

No evidence was found in the laboratory tests to confirm a positive analytical bias of the OVA versus the GC. In addition, no contaminants or excess compounds were identified that could have produced such an analytical bias. The only identified factors that were not investigated in these tests are environmental; e.g., the difference in atmospheric pressure due to the high altitude of the West Texas site (about 3500 ft<sup>5</sup> above mean sea level compared to near sea level elevations for the laboratory and South Texas studies). While the OVA response is known to be sensitive to sample inlet pressure, this should not effect the results since the OVA was calibrated at the pressure at which it was used.

## Conclusions

As demonstrated in the laboratory study and by the South Texas results, the HVCS is capable of accurately quantifying fugitive leaks over a wide range of leak sizes, and component types and sizes. On the other hand, the West Texas results revealed an important limitation of the system.

- Laboratory evaluation of HVCS performance was very favorable. The HVCS results closely matched EPA method results with a difference in total measured emissions of only about 3%. The HVCS also reproduced a wide range of known leak rates with an average bias of -8.3%. The negative bias is probably due to incomplete leak capture. In the laboratory tests, HVCS leak capture depended solely on the ability

<sup>5</sup> 1 ft = 0.3 m.

**Table 3.** Field Study Results Summary

Method Bias	Mean (MVU) <sup>a</sup>	Lower 95% Limit	Upper 95% Limit	No.
South Texas HVCS Relative Bias	15.2%	4.1%	29.8%	48
South Texas HVCS "True" Bias	6.6%	-3.6%	20.2%	48
West Texas HVCS Relative Bias - Overall	44.5%	34.3%	56.7%	66
West Texas HVCS "True" Bias - Overall	33.8%	24.4%	45.1%	66
West Texas HVCS Relative Bias - On or Before September 26	67.0%	56.5%	84.8%	40
West Texas HVCS "True" Bias - On or Before September 26	54.7%	44.9%	71.1%	40
West Texas HVCS Relative Bias - After September 26	5.7%	-0.4%	18.6%	26
West Texas HVCS "True" Bias - After September 26	0.0%	-7.3%	9.8%	26

  

Difference in Total Emissions	EPA (slpm)	HVCS (slpm)	Diff. (%)	No.
South Texas	55.8	58.2	+4.3	48
West Texas - Overall	79.2	93.9	+18.6	66
West Texas - On or Before September 26	32.7	48.1	+47.1	40
West Texas - After September 26	46.5	45.8	-1.5	26

<sup>a</sup> MVU = Minimum variance unbiased.

of the HVCS to capture all of the leaking gas in the slipstream of dilution air entering the HVCS inlet. No enclosures were constructed to shield components and direct gas into the HVCS inlet.

- The HVCS also performed very well in the South Texas field study. The HVCS matched the EPA estimate of total facility emissions within about 4%, similar performance to that obtained in the laboratory studies. In the field, enclosures were constructed to shield components from wind and assist in directing leaking gas into the HVCS inlet.
- Early in the West Texas study, an apparent positive bias was observed in the HVCS results. On and before September 26 (about midway of the study), the HVCS measured 47.1% more total emissions than the EPA method. After this date, no appreciable bias was observed. After the entire study, the HVCS measured 18.6% more emis-

sions from the facility than the EPA method. The source of the early study bias is unclear; however, results suggest that some operational problems may have been overcome as a result of efforts undertaken in the field. Other factors that may have contributed to the changed results include (1) efforts that were made to avoid sampling in areas with potentially high background concentrations that could cause a positive bias in the HVCS results and (2) the fact that average leak rates were higher later in the study, which would lessen the effect of background interference on the HVCS quantifications.

Overall, these results are within acceptable limits for field emissions measurements. With some physical and procedural enhancements, the HVCS should offer an acceptable alternative to the EPA protocol bagging method with GC analysis.

- Special precautions must be taken to obtain accurate HVCS quantifi-

cations where there may be elevated background concentrations, such as in confined areas, or where there are dense clusters of leaking components or very large leaks. The simplest approach is to attempt to quantify background levels with the OVA and apply an appropriate correction to the results. This must be done very carefully since background levels in such areas have been observed to range widely in small areas and change very rapidly. An alternative method for determining the background level has been suggested that, in some instances, could provide a useable correction, even when background levels cannot be practically measured. The limitation of this method is that one must be certain that changes in HVCS outlet concentration are due solely to changes in HVCS flow; i.e., total leak capture must be attained at all HVCS flows.

- Improved HVCS flow capacity, control, and metering are needed to enhance leak capture and provide greater reliability and ease of use in the field. With the current rotameter set-up, the capacity could be doubled by simply increasing pump capacity. Power requirements would also be increased, but the unit could still be battery-operated (a 12-V pump could reach near 1000 scfh). Much larger flows would require more power, decreasing portability, and the metering system would also have to be modified substantially to handle the higher flows. Increased flow capacity would also increase the size of leaks that could be quantified without the need for a dilution probe, or other alternative to extend the range of the portable hydrocarbon monitor. Enhanced leak capture might also make it possible to measure leaks from larger components without the need for auxiliary bagging. This could decrease the time required for each measurement.

- Increased range and enhanced stability of the portable hydrocarbon monitoring device used with the HVCS are also needed. The portable hydrocarbon monitor used with the HVCS needs greater range and reliability than the Foxboro OVA Model 108 that is currently used. The OVA's upper range is at 10,000 ppm, or 1%. This can be extended to perhaps 15,000 ppm using the

direct voltage output from the OVA; however, precision rapidly deteriorates at this upper end. In the field, Foxboro's dilution probe was used to extend the quantification range, with generally good results; however, the use of the dilution probe adds a degree of complexity. The OVA is also very sensitive to sampling conditions, contaminants, battery levels, and other factors. The OVA requires frequent calibration, which adds significantly to the expense and level of uncertainty associated with its use in quantitative applications. The OVA is very sensitive to sample gas composition since the detector is exposed to the entire sample stream at once and uses sample stream air as combustion air for the FID. The OVA exhibits varying responses to different hydrocarbons, and sometimes radical responses to "contaminants" (water, dust, and

gases—e.g., excess hydrogen—that affect the response of the FID). Some research is needed to identify and test alternative analyzers with greater range and stability than the OVA. This might include infrared devices and electrochemical sensors. In addition, there has been some preliminary development of a catalytic combustor that would determine hydrocarbon concentration by stoichiometry, using measurements of oxygen and carbon dioxide at the entrance to and exit from the combustor.

The HVCS may have a very significant role to play in applications where rapid, cost effective, on-site leak quantifications are important.

- With the HVCS, a single operator can quantify approximately 30 leaks per day. With the EPA bagging method, approximately 10 leaks can be sampled per day with additional time and expense required for GC analysis.

- The HVCS could be very useful in evaluating the effectiveness of different inspection and maintenance programs, and determining the most cost effective approach for maintaining emissions below a given level.
- The HVCS would also be useful for emissions inventory and compliance testing activities related to federal and state air permit requirements.
- In addition, the HVCS may be valuable in evaluating the performance of optical-sensing-based techniques for determining fugitive emission rates under real world conditions. Such methods are currently under development at EPA and may soon be tested under actual site conditions. For these tests, there will be a need to independently determine leak rates from multiple fugitive sources as a basis for evaluating the performance of the optical-sensing-based methods.

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**Charles C. Masser** is the EPA Project Officer (see below).

*The complete report, entitled "Evaluation of the High Volume Collection System (HVCS) for Quantifying Fugitive Organic Vapor Leaks," (Order No. PB96-136395; Cost: \$27.00, subject to change) will be available only from*

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