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Subject: Fitting Wind Speed Correction Factor for External Floating Roof Tanks
EPA Contract No. 68-D2-0159; Work Assignment No. 2-02
MRI Project No. 4602-02

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I. Introduction

The purpose of this memo is to document our recommendations on incorporating the fitting wind speed correction factor into the Organic Liquid Storage Tanks section of AP-42. Evaporative loss from external floating roof tanks (EFRT's) has been shown to be wind dependent. The EFRT fitting loss estimating equation in previous versions of AP-42 Section 7.1 included the assumption that the wind speed across the deck is equivalent to the local ambient wind speed. It is known from field experience, however, that the shell of the tank partially shields the floating roof from the wind. Therefore, the fitting wind speed correction factor has been added to the EFRT deck fitting loss equation to account for the reduction in wind speed across the floating roof as compared to the ambient wind speed. This addition results in the following form of the loss estimating equation:

$$K_F = K_{Fa} + K_{Fb}(K_v v)^m$$

where:

K_F = loss factor for a given deck fitting, lb-mole/yr
K_{Fa} = zero wind speed loss factor, lb-mole/yr
K_{Fb} = wind speed dependent loss factor, lb-mole/mph^m-yr
K_v = fitting wind speed correction factor, dimensionless
v = average wind speed at tank location, mph
m = deck fitting loss exponent, dimensionless

While this shielding effect was previously a known occurrence, no data were available to quantify the reduction in wind speed across the deck. Therefore, to evaluate the actual reduction, wind tunnel testing, a roof height survey, and an evaluation of field data were conducted by API.

II. The API's Development of the Wind Speed Correction Factor[1-2]

The CPP wind tunnel test program modeled EFRT's of 48, 100, and 200 feet in diameter, with the floating roof positioned at three different heights in each tank. The roof heights chosen were grouped to result in three ranges of roof height as follows:

$$0.35 \le R/H \le 0.75$$
$$0.80 \le R/H \le 0.90$$
$$R/H = 1.0$$

(The ratio R/H is the ratio of the floating roof height to the tank shell height.)

Average horizontal wind speeds were calculated for each roof height range at 28 locations across each floating roof. The test program concluded that a single factor could reasonably be used to account for the reduction in wind speeds for all areas of the floating roof, at all roof heights and tank diameters. This factor was determined by calculating separate correction factors for each of the roof height ranges and then calculating a weighted average of these three factors based on an assumed distribution of time that the floating roof would spend in each range. The distribution was based on a complete cycle of a floating roof, where the tank begins empty, rises through each height range, and then empties back through each range. This assumption results in the following distribution:

$0.35 \le R/H \le 0.75$	40%
$0.80 \le R/H \le 0.90$	40%
$R/H = 1.0$	20%

This test program determined that the wind speed at the floating roof is about 0.4 times the ambient site wind speed in the first two height ranges, but increases to about 0.7 at the third roof height. Although the third roof height (R/H = 1.0) is not a position that occurs in the normal operation of storage tanks, it was conservatively included in the calculation of the weighted average correction factor. The approach, or site, wind speed used in this study is analogous to a National Weather Service (NWS) wind speed measurement taken in an open field. This wind speed is applicable to an isolated tank condition, but the wind speed at a tank farm is expected to be only about 80 percent of the NWS measured wind speed due to shielding effects.

To investigate the reasonableness of the assumption regarding roof height distribution, a survey of roof heights was conducted. Forty tanks were evaluated based on 12 consecutive monthly records of liquid level. These liquid levels were then compared to the height of the tank shell, and the ratio of liquid level to shell height was determined. Each ratio was then assigned to one of the height ranges from the wind tunnel study, with any readings not falling within a range being assigned to the next higher range. This approach resulted in tanks over 0.9 being assigned to the R/H = 1.0 range. The resulting height distribution was as follows:

Assigned Range	Assumed Distribution	Actual Distribution
$0.35 \le R/H \le 0.75$	40%	77.7%
$0.80 \le R/H \le 0.90$	40%	15.6%
$R/H = 1.0$	20%	6.7%

While the weighted average single factor had assumed the floating roof to be at the top of the tank shell 20 percent of the time, in the survey it was found to be in the top 10 percent of the shell height only 6.7 percent of the time. The distribution assumed in the wind tunnel test study was therefore conservative compared to the distribution determined from this survey. From the data collected in these two studies, CPP developed an average fitting wind speed correction factor of 0.52.

Field wind speed data also were evaluated in the analysis of the fitting wind speed correction factor. Measurements of wind speed were taken at two external floating roof tanks at a petroleum refinery over an eleven month period. Site wind speed was measured at a platform located at the top of the shell of one of the tanks. Wind speeds across the floating roofs were measured at two locations on the deck, one near the perimeter and one near the center of the deck. Both horizontal and vertical wind speed components were measured. Approximately 30 readings were taken per day.

Five months worth of data from one of these tanks were evaluated. Daily average wind speeds were determined at each of the two locations on the floating roof, as well as at the platform. However, only the horizontal wind speed measurements were used in this evaluation. Due to some interruptions in the data, only 142 days were included in the evaluation. The wind speeds were summed for each of the three measurement locations, and the ratio of floating roof to ambient wind speed was calculated for the two deck locations. The resulting ratios were

0.45 for the outer area of the deck and 0.53 for the inner area. The resulting average, 0.49, corresponds well with the value of 0.52 calculated for the single factor in the wind tunnel test program. A factor of 0.5 was adopted by API and published in their preliminary draft of Chapter 19, Section 2 of the Manual of Petroleum Measurement Standards.

III. Evaluation of Data

The single wind speed correction factor developed by API in the wind tunnel test program was determined using generally conservative procedures. As stated, the correction factor for the highest roof position was weighted at 20 percent, while the roof height survey indicated that the roof would be at this height less than 10 percent of the time. Further, the factor was developed based on wind speed at an isolated tank. For a tank farm scenario, the wind speed at the tank is expected to be only 80 percent of the site ambient wind speed.

The field data were evaluated and used by API to compare to the wind speed correction factor developed from the wind tunnel study. The field data were also evaluated by MRI; during MRI's review, several questions were raised. Those questions and MRI's evaluation of the field data are discussed in the following paragraphs.

During the wind tunnel study performed to determine evaporative loss rates from deck fittings, only a horizontal wind speed component was measured; however, the total wind speed was equal to the horizontal wind speed (i.e., there was no vertical component). The wind tunnel turbulence was much less than that expected on an actual tank (7 percent in the tunnel versus 20-100 percent expected). Although the effect of turbulence on evaporative loss from fittings is unknown, the CPP report indicates that an increase in turbulence may cause an increase in evaporative loss. During the testing, the wind speed in the tunnel was held as constant as possible to reduce variability in loss rates and provide a stable estimate of the rate at each test condition. Also, only the horizontal wind speed vector was measured during the wind tunnel study performed to determine the fitting wind speed correction factor, although a vertical wind speed component may have been present. Development of the wind speed correction factor by API was based on the wind tunnel data and, consequently, only a horizontal wind speed vector.

The factor API developed from their analysis of the field data agrees well with the factor they developed from the wind tunnel study. However, both horizontal and vertical wind speed vectors were measured in the field study. Questions regarding what effect the vertical vector of the wind speed has on emissions and whether the vertical component should be incorporated into the calculation of the wind speed correction factor were raised during MRI's analysis. Since no data exists on the effects of the vertical component of wind speed on evaporative loss, it is difficult to assess whether that component should be included in the calculation of the wind speed correction factor.

Another issue concerns the accuracy of the field data. For example, there are some measurements of deck wind speed that are more than 10 times the ambient wind speed. In addition, no information was provided concerning the accuracy of the measurement devices. The field data were used as a validation of the wind tunnel study, but it is unclear whether or not the data are accurate. Since the accuracy of the field data is unknown, and since the field data represent only one test condition, basing the factor on these data may not be fully warranted.

Finally, the fitting loss factors in AP-42 Section 7.1 are applicable only for wind speeds up to 15 miles per hour. Average ambient wind speeds during the field test were generally low, with a maximum wind speed of about 6 m/s (13 mph). However, CPP's wind tunnel tests were conducted at wind speeds of greater than 6 m/s (13 mph).

Analyses of the field data were conducted by MRI to replicate API's analysis and to determine the value of the wind speed correction factor when the vertical wind speed component is included. The first analysis replicated API's analysis, using only the horizontal wind speed measurements. A correction factor of 0.5 resulted. The second analysis used both the horizontal and vertical vectors of the wind speed measured on the floating deck. Daily average wind speeds were calculated for the five month period used in the API analysis. A vector addition ($Horiz^2 + Vert^2 = Total^2$) was then performed to determine a total deck wind speed vector for each daily average at both inner and outer locations. The ratio of deck to ambient wind speed was calculated for each data point and measurement location. An average ratio was then determined for the inner and the outer locations. These two ratios were then averaged and an average fitting wind speed correction factor of 0.69 was calculated. A summary of the data is attached.

IV. Summary and Recommendations

The field data indicate that a vertical wind speed component is present at the deck surface on an EFRT. However, no data are available to evaluate the effect of a vertical wind speed component on evaporative loss. Further, no wind tunnel data are available that quantify a vertical wind speed component for different tank configurations.

API has recommended a wind speed correction factor of 0.5 based on their analyses of the wind tunnel and field data. Due to the fact that no data are available on the effects of the vertical wind speed component on evaporative loss, the most conservative approach is to use the factor developed by MRI from the field data. Therefore, the fitting wind speed correction factor that MRI recommends is 0.7.

V. References

1. Cermak, Peterka, Peterson, Inc., Wind Tunnel Testing of External Floating Roof Tanks, CPP Project Nos. 92-0869 and 93-0934. Prepared for the American Petroleum Institute, Washington, DC. 1993.

2. Ferry, Robert L., Documentation of the Fitting Wind Speed Correction Factor for the Manual of Petroleum Measurement Standards, Chapter 19, Section 2. Prepared for the American Petroleum Institute, Washington, DC. March 1995.

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Attachment 1. Wind Speed Correction Factor Data Analyses

Outer Horiz	Inner Horiz	Outer Vert	Inner Vert	Ambient	Total Outer	Total Inner	Outer Ratio	Inner Ratio	
2.00	1.40	2.52	2.29	4.44	3.22	2.69	0.73	0.60	January
1.66	1.09	1.99	1.63	3.76	2.59	1.96	0.69	0.52	
1.73	0.75	1.74	1.37	3.55	2.45	1.56	0.69	0.44	
1.87	1.14	2.55	2.20	4.62	3.16	2.47	0.68	0.54	
0.93	0.71	1.67	1.51	2.57	1.91	1.67	0.74	0.65	
0.81	0.63	0.74	0.72	1.97	1.10	0.95	0.56	0.48	
1.47	1.33	1.43	1.36	3.02	2.05	1.90	0.68	0.63	
1.58	1.29	1.72	1.62	2.41	2.33	2.07	0.97	0.86	
0.70	0.87	0.68	0.51	1.14	0.98	1.01	0.86	0.89	
1.14	0.63	1.13	0.91	2.09	1.61	1.11	0.77	0.53	
1.76	1.05	2.31	1.98	4.13	2.91	2.24	0.70	0.54	
0.55	0.41	1.06	0.93	1.12	1.20	1.01	1.07	0.90	
0.50	0.36	0.61	0.55	1.24	0.79	0.66	0.63	0.53	
0.49	0.32	0.92	0.83	1.48	1.04	0.89	0.71	0.60	
0.43	0.40	0.60	0.57	1.18	0.74	0.70	0.63	0.59	
1.06	0.99	1.49	1.34	2.80	1.83	1.66	0.65	0.59	
0.37	0.26	0.57	0.56	0.70	0.68	0.62	0.97	0.89	
0.38	0.27	0.58	0.53	1.22	0.69	0.59	0.56	0.49	
0.44	0.36	0.49	0.43	1.08	0.66	0.56	0.61	0.52	
0.80	0.72	0.89	0.83	2.28	1.20	1.10	0.53	0.48	
0.93	0.76	0.78	0.72	1.87	1.22	1.04	0.65	0.56	
0.77	0.54	0.55	0.54	1.67	0.95	0.76	0.57	0.46	
0.67	0.29	0.45	0.44	0.67	0.81	0.53	1.21	0.79	
0.56	0.33	0.72	0.63	1.73	0.91	0.71	0.52	0.41	February
0.86	0.50	0.90	0.76	2.01	1.25	0.91	0.62	0.45	
1.28	1.02	1.98	1.79	2.98	2.35	2.06	0.79	0.69	
0.76	0.57	1.42	1.29	1.80	1.61	1.40	0.90	0.78	
0.42	0.28	0.77	0.69	1.04	0.88	0.75	0.85	0.72	
0.93	0.78	1.24	1.12	2.14	1.55	1.36	0.72	0.64	
0.79	0.38	1.00	0.85	1.92	1.27	0.93	0.66	0.48	
0.86	0.68	0.95	0.82	2.08	1.28	1.06	0.62	0.51	
1.35	1.33	1.12	1.02	2.23	1.75	1.67	0.79	0.75	
1.51	1.29	1.37	1.22	3.04	2.04	1.77	0.67	0.58	
1.14	0.64	1.28	1.09	2.86	1.71	1.26	0.60	0.44	
0.97	0.67	0.85	0.78	2.32	1.29	1.03	0.56	0.44	
1.82	1.70	1.40	1.31	2.61	2.30	2.15	0.88	0.82	
1.61	1.55	1.41	1.34	3.01	2.14	2.04	0.71	0.68	
0.96	0.74	1.19	1.15	2.22	1.53	1.37	0.69	0.62	
1.20	1.23	2.35	2.25	3.88	2.64	2.57	0.68	0.66	
0.34	0.20	0.52	0.47	0.79	0.62	0.51	0.79	0.64	
0.23	0.10	0.46	0.38	0.46	0.51	0.40	1.11	0.86	
0.25	0.14	0.52	0.47	0.60	0.58	0.50	0.96	0.82	
0.24	0.13	0.42	0.38	0.67	0.49	0.40	0.73	0.60	
0.67	0.38	0.85	0.75	1.62	1.08	0.84	0.67	0.52	
1.36	1.06	1.17	1.13	2.92	1.79	1.55	0.61	0.53	
1.59	1.53	1.96	1.74	4.04	2.53	2.32	0.62	0.57	
1.34	1.22	1.17	1.11	2.17	1.78	1.65	0.82	0.76	
0.78	0.67	1.00	0.90	2.45	1.26	1.12	0.52	0.46	
1.20	1.08	0.88	0.88	2.50	1.49	1.39	0.60	0.56	
0.83	0.72	0.78	0.76	0.44	1.14	1.05	2.60	2.39	
0.74	0.55	0.68	0.74	1.41	1.01	0.92	0.71	0.65	
0.93	0.95	0.72	0.88	2.38	1.18	1.29	0.50	0.54	March
1.38	1.30	1.66	1.55	3.48	2.16	2.02	0.62	0.58	
1.08	0.80	1.83	1.73	2.64	2.13	1.90	0.81	0.72	

Attachment 1. Wind Speed Correction Factor Data Analyses

Outer Horiz	Inner Horiz	Outer Vert	Inner Vert	Ambient	Total Outer	Total Inner	Outer Ratio	Inner Ratio	
0.45	0.39	0.48	0.47	0.83	0.66	0.61	0.79	0.73	
0.88	0.93	0.61	0.74	2.14	1.07	1.19	0.50	0.56	
1.28	1.35	1.11	1.22	2.55	1.70	1.82	0.66	0.71	
1.05	1.01	0.70	0.98	2.67	1.26	1.41	0.47	0.53	
1.01	1.08	0.80	0.92	2.05	1.29	1.42	0.63	0.69	
1.15	1.21	1.15	1.05	2.26	1.63	1.60	0.72	0.71	
1.80	1.92	1.73	1.65	4.12	2.50	2.53	0.61	0.61	
1.15	0.67	1.28	1.08	2.67	1.72	1.27	0.64	0.48	
1.56	1.17	1.61	1.40	3.44	2.24	1.83	0.65	0.53	
1.55	1.00	2.27	1.97	3.53	2.75	2.21	0.78	0.63	
1.38	1.08	2.47	2.24	3.36	2.82	2.48	0.84	0.74	
0.79	0.60	1.44	1.30	1.92	1.64	1.44	0.85	0.75	
0.49	0.30	0.83	0.75	1.32	0.97	0.81	0.73	0.61	
1.11	0.93	0.83	0.81	2.41	1.39	1.23	0.58	0.51	
1.17	0.97	0.90	0.88	2.47	1.48	1.31	0.60	0.53	
1.61	1.40	1.43	1.33	3.83	2.15	1.93	0.56	0.50	
0.92	0.70	0.78	0.69	2.05	1.21	0.98	0.59	0.48	
0.88	0.70	0.74	0.60	1.65	1.15	0.92	0.70	0.56	
1.04	0.62	0.96	0.94	1.35	1.41	1.13	1.05	0.84	
1.30	0.75	1.51	1.47	2.08	1.99	1.65	0.96	0.79	
0.93	0.66	1.52	1.52	2.25	1.78	1.66	0.79	0.74	
0.61	0.51	0.59	0.53	1.06	0.85	0.74	0.80	0.69	
1.05	1.02	0.84	0.75	1.70	1.34	1.27	0.79	0.74	
0.83	0.73	0.73	0.64	1.53	1.10	0.97	0.72	0.63	
0.71	0.46	1.14	1.08	1.68	1.34	1.18	0.80	0.70	
0.41	0.23	0.68	0.59	0.91	0.79	0.64	0.87	0.70	
0.51	0.24	0.80	0.78	0.83	0.95	0.82	1.14	0.98	
1.15	0.63	1.15	1.11	1.40	1.62	1.28	1.16	0.91	
1.12	0.89	2.15	2.02	2.60	2.43	2.21	0.94	0.85	April
0.91	0.78	1.46	1.34	2.35	1.72	1.55	0.73	0.66	
0.45	0.33	0.71	0.62	1.19	0.84	0.70	0.70	0.59	
0.26	0.13	0.41	0.32	0.53	0.48	0.35	0.91	0.66	
0.26	0.09	0.45	0.34	0.52	0.52	0.35	1.01	0.68	
0.49	0.42	0.50	0.34	0.92	0.70	0.54	0.76	0.58	
0.56	0.50	0.56	0.44	1.27	0.79	0.66	0.62	0.52	
0.28	0.15	0.55	0.44	0.72	0.62	0.46	0.86	0.64	
0.23	0.09	0.41	0.35	0.49	0.47	0.37	0.96	0.74	
0.84	0.79	0.75	0.63	1.80	1.12	1.01	0.62	0.56	
0.56	0.39	0.56	0.46	1.18	0.79	0.60	0.67	0.51	
0.91	0.86	0.81	0.72	1.97	1.21	1.12	0.62	0.57	
1.13	0.87	1.21	1.06	3.07	1.66	1.37	0.54	0.45	
0.98	0.78	1.19	1.05	2.96	1.55	1.31	0.52	0.44	
1.07	1.00	1.85	1.76	3.27	2.13	2.03	0.65	0.62	
0.87	0.71	1.47	1.42	2.31	1.71	1.58	0.74	0.68	
0.50	0.33	0.66	0.59	1.18	0.83	0.68	0.70	0.57	
1.66	1.49	1.97	1.76	4.10	2.58	2.30	0.63	0.56	
2.29	1.07	2.52	2.24	3.58	3.41	2.48	0.95	0.69	
0.93	0.74	1.75	1.61	2.11	1.98	1.78	0.94	0.84	
0.46	0.30	0.93	0.87	1.37	1.04	0.92	0.76	0.67	
0.68	0.31	0.76	0.72	1.06	1.02	0.79	0.96	0.74	
0.57	0.39	0.63	0.56	1.01	0.85	0.68	0.85	0.68	
0.98	0.97	0.89	0.81	1.84	1.32	1.26	0.72	0.69	
1.56	1.45	1.55	1.39	3.05	2.20	2.01	0.72	0.66	
1.26	1.18	1.26	1.12	2.58	1.78	1.63	0.69	0.63	

Attachment 1. Wind Speed Correction Factor Data Analyses

Outer Horiz	Inner Horiz	Outer Vert	Inner Vert	Ambient	Total Outer	Total Inner	Outer Ratio	Inner Ratio	
0.88	0.56	0.86	0.74	1.87	1.23	0.93	0.66	0.50	
1.35	1.35	1.16	1.09	2.67	1.78	1.74	0.67	0.65	
0.59	0.38	0.99	0.82	1.92	1.16	0.91	0.60	0.47	
1.42	1.20	1.26	1.17	3.03	1.90	1.68	0.63	0.55	
1.93	1.85	1.66	1.60	3.89	2.55	2.44	0.65	0.63	May
1.29	1.09	1.36	1.22	2.96	1.87	1.64	0.63	0.55	
0.61	0.37	0.79	0.68	1.73	1.00	0.77	0.58	0.45	
0.66	0.34	0.96	0.80	1.70	1.16	0.87	0.69	0.51	
1.45	1.52	1.33	1.17	2.92	1.97	1.92	0.68	0.66	
0.98	0.70	1.65	1.48	2.48	1.92	1.64	0.77	0.66	
0.53	0.34	0.90	0.78	1.32	1.04	0.85	0.79	0.64	
0.32	0.19	0.50	0.44	0.66	0.59	0.48	0.89	0.72	
0.45	0.30	0.42	0.36	0.92	0.62	0.47	0.67	0.51	
0.80	0.60	0.63	0.55	1.76	1.02	0.81	0.58	0.46	
0.78	0.66	0.65	0.56	1.35	1.02	0.87	0.75	0.64	
0.62	0.55	0.53	0.43	0.86	0.81	0.70	0.94	0.81	
0.78	0.68	0.71	0.62	1.66	1.06	0.92	0.63	0.55	
0.53	0.29	0.61	0.54	1.17	0.80	0.62	0.69	0.53	
0.66	0.47	0.73	0.65	1.45	0.99	0.80	0.68	0.55	
0.77	0.40	0.83	0.79	1.30	1.13	0.89	0.87	0.68	
0.65	0.30	0.83	0.78	1.23	1.06	0.84	0.86	0.68	
0.60	0.37	0.87	0.79	1.27	1.06	0.87	0.83	0.68	
0.76	0.51	0.88	0.78	1.57	1.16	0.93	0.74	0.59	
0.49	0.35	0.64	0.55	1.18	0.80	0.65	0.68	0.55	
0.61	0.37	0.61	0.55	1.45	0.86	0.66	0.59	0.46	
					Average of Ratios:		0.75	**0.64**	
					Single Correction Factor:			**0.69**	

Outer Horiz = Daily average horizontal wind speed at outer measurement location, m/s
Inner Horiz = Daily average horizontal wind speed at inner measurement location, m/s
Outer Vert = Daily average vertical wind speed at outer measurement location, m/s
Inner Vert = Daily average vertical wind speed at inner measurement location, m/s
Ambient = Daily average wind speed measurement at gauger's platform, m/s
Total Outer = Outer location wind speed vector = sqrt (Outer Horiz^2 + Outer Vert^2)
Total Inner = Inner location wind speed vector = sqrt (Inner Horiz^2 + Inner Vert^2)
Outer Ratio = Total Outer / Ambient
Inner Ratio = Total Inner / Ambient
Average of Ratios = avg(Total Outer) and avg(Total Inner)
Single Correction Factor = average of avg(Total Outer) and avg(Total Inner)