1.0 EXECUTIVE SUMMARY

On March 17 & 18, 2020, The Stack Test Group, Inc. performed volatile organic compound (VOC) removal efficiency and emissions testing on the Line #1 and Line #2 absorber systems and VOC emissions testing on the two vacuum pumps (PV101 & PV102) at the LG Chem facility located in Holland, MI. VOC testing was conducted on absorber inlet and outlet simultaneously on each unit. Three one-hour tests were conducted on these sources. Presented below are the average results of these tests.

Line #2:

VOC Inlet Concentration:	1770.1 ppm as propane
VOC Inlet Emissions:	470.108 lb/hr as propane
VOC Outlet Concentration:	1.3 ppm as propane
VOC Outlet Emissions:	0.322 lb/hr as propane
VOC Removal Efficiency:	99.93 percent

Line #1:

VOC Inlet Concentration:	1191.0 ppm as propane
VOC Inlet Emissions:	361.983 lb/hr as propane
VOC Outlet Concentration:	1.8 ppm as propane
VOC Outlet Emissions:	0.452 lb/hr as propane
VOC Removal Efficiency:	99.88 percent

PV101:

VOC Outlet Concentration:	2.1 ppm as propane
VOC Outlet Emissions:	5.78×10^{-5} lb/hr as propane

PV102:

VOC Outlet Concentration:	3.6 ppm as propane
VOC Outlet Emissions:	5.13×10^{-4} lb/hr as propane

INTRODUCTION

On March 17 & 18, 2020, The Stack Test Group, Inc. performed volatile organic compound (VOC) removal efficiency and emissions testing on the Line #1 and Line #2 absorber systems and VOC emissions testing on the two vacuum pumps (PV101 & PV102) at the LG Chem facility located in Holland, MI. VOC testing was conducted on the two absorber inlet and outlet ducts/stacks simultaneously. Testing was performed to verify the removal efficiency and emissions of the absorbers and the vacuum pumps per the permit requirements.

Testing was conducted while LG Chem personnel operated the two lines associated with the absorbers at normal rate and normal conditions.

Testing was supervised by Mr. Bill J. Byczynski of the Stack Test Group, Inc. Testing was coordinated by Mr. Matthew Kwiatkowski of ERM. Testing was witnessed by Mr. David Paaterson and other representatives from the EGLE.

All testing followed the guidelines of U.S. EPA Reference Methods 1 through 4, and 25A. This report contains a summary of results for the above mentioned tests and all the supporting field, process, and computer generated data.

3.0 SAMPLING AND ANALYTICAL PROCEDURES

3.1 Exhaust Gas Parameters

3.1.1 Traverse and Sampling Points

Testing was conducted on the inlet and outlet ducts/stacks associated with the Line 1 and Line 2 aborbers. The number of velocity traverse and sample measurement points for each duct/stack was determined using EPA Method 1.

Line #1 Inlet:
The Line #1 inlet duct inside diameter measured 50 inches. The test ports were located approximately 10 feet (greater than 2.0 equivalent diameters) downstream and 12 feet (greater than 0.5 equivalent diameters) upstream of the nearest flow disturbances. Velocity measurements were taken at each of 16 points, 8 points in each of the two ports set at 90° to each other.

Line #1 Outlet:
The Line #1 exhaust stack inside diameter measured 45 inches. The test ports were located approximately 15 feet (greater than 2.0 equivalent diameters) downstream and 30 feet (greater than 0.5 equivalent diameters) upstream of the nearest flow disturbances. Velocity measurements were taken at each of 16 points, 8 points in each of the two ports set at 90° to each other.

Line #2 Inlet:
The Line #1 inlet duct inside diameter measured 50 inches. The test ports were located approximately 9 feet (greater than 2.0 equivalent diameters) downstream and 15 feet (greater than 0.5 equivalent diameters) upstream of the nearest flow disturbances. Velocity measurements were taken at each of 16 points, 8 points in each of the two ports set at 90° to each other.

Line #1 Outlet:
The Line #1 exhaust stack inside diameter measured 45 inches. The test ports were located approximately 18 feet (greater than 2.0 equivalent diameters) downstream and 25 feet (greater than 0.5 equivalent diameters) upstream of the nearest flow disturbances. Velocity measurements were taken at each of 16 points, 8 points in each of the two ports set at 90° to each other.

PV101 Outlet:
The PV101 exhaust stack inside diameter measured 1 inch. The test ports were located approximately 8 inches (greater than 2.0 equivalent diameters) downstream and 4 inches

(greater than 0.5 equivalent diameters) upstream of the nearest flow disturbances. Velocity measurements were taken at each of 16 points, 8 points in each of the two ports set at 90° to each other.

PV102 Outlet:
The PV102 exhaust stack inside diameter measured 3 inch. The test ports were located approximately 10 inches (greater than 2.0 equivalent diameters) downstream and 6 inches (greater than 0.5 equivalent diameters) upstream of the nearest flow disturbances. Velocity measurements were taken at each of 16 points, 8 points in each of the two ports set at 90° to each other.

3.1.2 Velocity Traverse
Velocity measurements were performed during each VOC destruction efficiency test in accordance with EPA Method 2. An "S" type Pitot Tube with an attached type "K" thermocouple was used to conduct the velocity traverse.

3.1.3 Gas Composition
Gas composition for oxygen, carbon dioxide, and nitrogen was determined employing EPA Method 3. An integrated gas sample was collected during each VOC efficiency test. Gas analysis was conducted using a calibrated Servomex Model 1440C O_2/CO_2 analyzer.

3.1.4 Moisture Content
The RTO exhaust gas moisture content was determined using EPA Method 4 for all tests. Moisture content was determined by drawing the gas sample through four impingers in the sample train. Volumetric analysis was used to measure the condensed moisture in the first three impingers while gravimetric analysis of silica gel was used to measure moisture collected in the fourth impinger.

3.3 VOC REMOVAL EFFICIENCY AND EMISSIONS TESTING
3.3.1 Sample Collection
Testing on the two absorber inlet and outlet ducts for the removal efficiency and emissions was performed using U.S. EPA Reference Method 25A. A J.U.M. Model 3-300 Flame Ionization Detector (FID) was used to determine the emission concentrations at each location. A sample was transported through a heated Teflon line from the exhaust stack and inlet duct to the FIDs which analyzed the samples continuously. The output signal from the FIDs were then recorded at one minute averages throughout the test. Copies of this data may be found in Appendix E.

At the beginning of the test series, the analyzers were calibrated and then checked for calibration error by introducing zero, low-range, mid-range and high-range calibration gases to the back of the analyzers. Before and after each individual test run, a system bias was performed by introducing a zero and mid-range propane calibration gas to the outlet of the probes. Calibration gases used were U.S. EPA Protocol 1 certified.

3.3.2 Sample Duration and Frequency
The Method 25A train samples were collected in triplicate with each test lasting sixty minutes in duration.

3.3.3 Calibrations
All sampling equipment was calibrated according to the procedures outlined in EPA Reference Method 25A. Copies of the FID calibrations are included in Appendix D.

4.0 TEST RESULTS
Presented in this section are the results of this test series. Test results are reported in Tables 4.1 through 4.6. Table 4.1 reports the Line #2 inlet results for the VOC testing including stack gas temperature, percent carbon dioxide and oxygen, percent moisture, molecular weight of the stack gas dry and wet, velocity in feet per second (fps), and flow rate in actual cubic feet per minute (acfm), standard cubic feet per minute (scfm), and dry standard cubic feet per minute (dscfm).

Tables 4.1 also presents the VOC results for the Line #2 inlet. The VOC results are presented in terms of parts per million as propane and lb/hr as propane.

Table 4.2 presents the results for the Line #2 outlet. The results are presented in the same manner and format as Table 4.1. The removal efficiency is presented in terms of percent.

Table 4.3 and 4.4 present the results for the Line #1 absorber in the same manner and format as Tables 4.1 and 4.2.

Table 4.5 and 4.6 present the results for PV101 and PV102 respectively and in the same manner and format as Table 4.1.

Copies of the calculations used to determine these emission rates may be found in Appendix A. Copies of the field data sheets are presented in Appendix B. Copies of equipment calibrations are presented in Appendix D.

Table 4.1

VOC Results
LG Chem
Holland, MI
03/17/20
Line #2 Absorber Inlet Duct

Test No:	T1	T2	T3	Avg.
Start Time:	09:00 AM	10:45 AM	12:20 PM	
Finish Time:	10:00 AM	11:05 AM	01:20 PM	
Stack Gas Temperature, °F:	142.1	142.6	142.5	142.4
% Carbon Dioxide:	0.0	0.0	0.0	0.0
% Oxygen:	20.5	20.5	20.5	20.5
% Moisture:	2.40	2.30	2.40	2.37
Molecular Weight dry, lb/lb-Mole:	28.82	28.82	28.82	28.82
Molecular Weight wet, lb/lb-Mole:	28.56	28.57	28.56	28.56
Velocity and Flow Results:				
Average Stack Gas Velocity FPS:	53.68	53.60	54.09	53.79
Stack Gas Flow Rate, ACFM:	43,932	43,866	44,267	44,022
Stack Gas Flow Rate, SCFM:	38,680	38,590	39,040	38,770
Stack Gas Flow Rate, DSCF/HR:	2,265,076	2,262,139	2,286,176	2,271,131
Stack Gas Flow Rate, DSCFM:	37,751	37,702	38,103	37,852
VOC Results:				
PPM as Propane:	1779.1	1858.0	1673.1	1770.1
LBS/DSCF:	2.03E-04	2.12E-04	1.91E-04	2.02E-04
LBS/HR (as Propane):	471.506	491.274	447.544	470.108

Table 4.2

VOC Results
LG Chem
Holland, MI
03/17/20
Line #2 Absorber Exhaust Stack

Test No:	T1	T2	T3	Avg.
Start Time:	09:00 AM	10:45 AM	12:20 PM	
Finish Time:	10:00 AM	11:05 AM	01:20 PM	
Stack Gas Temperature, °F:	92.2	92.2	92.4	92.3
% Carbon Dioxide:	0.0	0.0	0.0	0.0
% Oxygen:	20.5	20.5	20.5	20.5
% Moisture:	1.80	1.90	1.90	1.87
Molecular Weight dry, lb/lb-Mole:	28.82	28.82	28.82	28.82
Molecular Weight wet, lb/lb-Mole:	28.63	28.61	28.61	28.62
Velocity and Flow Results:				
Average Stack Gas Velocity FPS:	54.17	58.98	58.98	57.38
Stack Gas Flow Rate, ACFM:	35,882	39,068	39,068	38,006
Stack Gas Flow Rate, SCFM:	33,324	36,282	36,269	35,292
Stack Gas Flow Rate, DSCF/HR:	1,963,421	2,135,585	2,134,812	2,077,939
Stack Gas Flow Rate, DSCFM:	32,724	35,593	35,580	34,632
VOC Results:				
PPM as Propane:	1.4	1.3	1.3	1.3
LBS/DSCF:	1.60E-07	1.48E-07	1.48E-07	1.52E-07
LBS/HR (as Propane):	0.320	0.323	0.323	0.322
Removal Efficiency, %:	99.93	99.93	99.93	99.93

Table 4.3

VOC Results
LG Chem
Holland, MI
03/18/20
Line #1 Absorber Inlet Duct

Test No:	T1	T2	T3	Avg.
Start Time:	08:40 AM	09:55 AM	11:20 AM	
Finish Time:	09:40 AM	10:55 AM	12:20 PM	
Stack Gas Temperature, °F:	175.8	176.0	176.0	175.9
% Carbon Dioxide:	0.0	0.0	0.0	0.0
% Oxygen:	20.5	20.5	20.5	20.5
% Moisture:	2.30	2.20	2.10	2.20
Molecular Weight dry, lb/lb-Mole:	28.82	28.82	28.82	28.82
Molecular Weight wet, lb/lb-Mole:	28.57	28.58	28.59	28.58
Velocity and Flow Results:				
Average Stack Gas Velocity FPS:	63.67	64.14	63.20	63.67
Stack Gas Flow Rate, ACFM:	52,108	52,492	51,723	52,108
Stack Gas Flow Rate, SCFM:	44,372	44,685	44,074	44,377
Stack Gas Flow Rate, DSCF/HR:	2,601,078	2,622,136	2,588,879	2,604,031
Stack Gas Flow Rate, DSCFM:	43,351	43,702	43,148	43,401
VOC Results:				
PPM as Propane:	1264.9	1051.4	1256.6	1191.0
LBS/DSCF:	1.44E-04	1.20E-04	1.43E-04	1.36E-04
LBS/HR (as Propane):	384.564	321.913	379.472	361.983

Table 4.4

VOC Results
LG Chem
Holland, MI
03/18/20
Line #1 Absorber Exhaust Stack

Test No:	T1	T2	T3	Avg.
Start Time:	08:40 AM	09:55 AM	11:20 AM	
Finish Time:	09:40 AM	10:55 AM	12:20 PM	
Stack Gas Temperature, °F:	106.5	106.8	106.8	106.7
% Carbon Dioxide:	0.0	0.0	0.0	0.0
% Oxygen:	20.5	20.5	20.5	20.5
% Moisture:	2.10	2.10	2.00	2.07
Molecular Weight dry, lb/lb-Mole:	28.82	28.82	28.82	28.82
Molecular Weight wet, lb/lb-Mole:	28.59	28.59	28.60	28.60
Velocity and Flow Results:				
Average Stack Gas Velocity FPS:	59.75	60.33	60.18	60.08
Stack Gas Flow Rate, ACFM:	39,578	39,963	39,863	39,801
Stack Gas Flow Rate, SCFM:	36,482	36,816	36,725	36,674
Stack Gas Flow Rate, DSCF/HR:	2,142,938	2,162,594	2,159,421	2,154,984
Stack Gas Flow Rate, DSCFM:	35,716	36,043	35,990	35,916
VOC Results:				
PPM as Propane:	1.9	1.6	1.9	1.8
LBS/DSCF:	2.17E-07	1.83E-07	2.17E-07	2.06E-07
LBS/HR (as Propane):	0.475	0.404	0.478	0.452
Removal Efficiency, %:	99.88	99.87	99.87	99.88

Table 4.5

VOC Results
LG Chem
Holland, MI
03/18/20
PV101 Exhaust Stack

Test No:	T1	T2	T3	Avg.
Start Time:	01:00 PM	02:20 PM	03:30 PM	
Finish Time:	02:00 PM	03:20 PM	04:30 PM	
Stack Gas Temperature, °F:	89.4	89.0	89.3	89.2
% Carbon Dioxide:	0.0	0.0	0.0	0.0
% Oxygen:	20.5	20.5	20.5	20.5
% Moisture:	1.60	1.60	1.60	1.60
Molecular Weight dry, lb/lb-Mole:	28.82	28.82	28.82	28.82
Molecular Weight wet, lb/lb-Mole:	28.65	28.65	28.65	28.65
Velocity and Flow Results:				
Average Stack Gas Velocity FPS:	6.81	7.16	6.81	6.93
Stack Gas Flow Rate, ACFM:	4	4	4	4
Stack Gas Flow Rate, SCFM:	4	4	4	4
Stack Gas Flow Rate, DSCF/HR:	229	241	229	233
Stack Gas Flow Rate, DSCFM:	4	4	4	4
VOC Results:				
PPM as Propane:	2.1	2.4	1.9	2.1
LBS/DSCF:	2.40E-07	2.74E-07	2.17E-07	2.44E-07
LBS/HR (as Propane):	5.58E-05	6.71E-05	5.05E-05	5.78E-05

Table 4.6

VOC Results
LG Chem
Holland, MI
03/18/20
PV102 Exhaust Stack

Test No:	T1	T2	T3	Avg.
Start Time:	01:00 PM	02:20 PM	03:30 PM	
Finish Time:	02:00 PM	03:20 PM	04:30 PM	
Stack Gas Temperature, °F:	69.8	69.0	69.0	69.3
% Carbon Dioxide:	0.0	0.0	0.0	0.0
% Oxygen:	20.5	20.5	20.5	20.5
% Moisture:	1.50	1.40	1.50	1.47
Molecular Weight dry, lb/lb-Mole:	28.82	28.82	28.82	28.82
Molecular Weight wet, lb/lb-Mole:	28.66	28.67	28.66	28.66
Velocity and Flow Results:				
Average Stack Gas Velocity FPS:	7.90	6.68	6.68	7.09
Stack Gas Flow Rate, ACFM:	24	20	20	21
Stack Gas Flow Rate, SCFM:	23	20	20	21
Stack Gas Flow Rate, DSCF/HR:	1,381	1,171	1,170	1,241
Stack Gas Flow Rate, DSCFM:	23	20	20	21
VOC Results:				
PPM as Propane:	2.5	3.9	4.5	3.6
LBS/DSCF:	2.85E-07	4.45E-07	5.14E-07	4.15E-07
LBS/HR (as Propane):	4.00E-04	5.29E-04	6.10E-04	5.13E-04

APPENDIX A

SAMPLE CALCULATIONS

SAMPLE CALCULATIONS

The tables presenting the results are generated electronically from raw data. It may not be possible to exactly duplicate these results using a calculator. The reference method data, results and all calculations are carried to sixteen decimal places throughout. The final table is formatted to an appropriate number of significant figures.

1. Volume of water collected (wscf)

$$V_{wstd} = (0.04707)(V_{lc})$$

Where:

V_{lc}	total volume of liquid collected in impingers and silica gel (ml)
V_{wstd}	volume of water collected at standard conditions (ft^3)
0.04707	conversion factor (ft^3/ml)

2. Volume of gas metered, standard conditions (dscf)

$$V_{mstd} = \frac{(17.64)(V_m)\left(P_{bar} + \frac{\Delta H}{13.6}\right)(Y_d)}{(460 + T_m)}$$

Where:

P_{bar}	barometric pressure (in. Hg)
T_m	average dry gas meter temperature (°F)
V_m	volume of gas sample through the dry gas meter at meter conditions (ft^3)
V_{mstd}	volume of gas sample through the dry gas meter at standard conditions (ft^3)
Y_d	gas meter correction factor (dimensionless)
ΔH	average pressure drop across meter box orifice (in. H_2O)
17.64	conversion factor (°R/in. Hg)
13.6	conversion factor (in. H_2O/in. Hg)
460	°F to °R conversion constant

SAMPLE CALCULATIONS (CONTINUED)

3. Volume of gas metered, standard conditions (dscm)

$$V_{mstd(m)} = \frac{\left(V_{mstd(ft)}\right)}{35.35}$$

Where:

$V_{mstd(ft)}$	volume of gas sample through the dry gas meter at standard conditions (ft^3)
$V_{mstd(m)}$	volume of gas sample through the dry gas meter at standard conditions (m^3)
35.35	conversion factor (ft^3 to m^3)
13.6	conversion factor (in. H_2O/in. Hg)

4. Sample gas pressure (in. Hg)

$$P_s = P_{bar} + \left(\frac{P_g}{13.6}\right)$$

Where:

P_{bar}	barometric pressure (in. Hg)
P_g	sample gas static pressure (in. H_2O)
P_s	absolute sample gas pressure (in. Hg)
13.6	conversion factor (in. H_2O/in. Hg)

5. Actual vapor pressure (in. Hg)[1]

$$P_v = P_s$$

Where:

P_v	vapor pressure, actual (in. Hg)
P_s	absolute sample gas pressure (in. Hg)

6. Moisture content (%)

$$B_{wo} = \frac{V_{wstd}}{V_{mstd} + V_{wstd}}$$

Where:

B_{wo}	proportion of water vapor in the gas stream by volume (%)
V_{mstd}	volume of gas sample through the dry gas meter at standard conditions (ft^3)
V_{wstd}	volume of water collected at standard conditions (ft^3)

[1] For effluent gas temperatures over 212°F, P_v is assumed to be equal to P_s.

SAMPLE CALCULATIONS (CONTINUED)

7. Saturated moisture content (%)

$$B_{ws} = \frac{(P_v)}{(P_s)}$$

Where:

B_{ws}	proportion of water vapor in the gas stream by volume at saturated conditions (%)
P_s	absolute sample gas pressure (in. Hg)
P_v	vapor pressure, actual (in. Hg)

Whichever moisture value is smaller is used for B_{wo} in the following calculations.

8. Molecular weight of dry gas stream (lb/lb·mole)

$$M_d = M_{CO_2}\frac{(CO_2)}{(100)} + M_{O_2}\frac{(O_2)}{(100)} + M_{CO+N_2}\frac{(CO+N_2)}{(100)}$$

Where:

Md	dry molecular weight of sample gas (lb/lb·mole)
M_{CO_2}	molecular weight of carbon dioxide (lb/lb·mole)
M_{O_2}	molecular weight of oxygen (lb/lb·mole)
M_{CO+N_2}	molecular weight of carbon monoxide and nitrogen (lb/lb·mole)
CO_2	proportion of carbon dioxide in the gas stream by volume (%)
O_2	proportion of oxygen in the gas stream by volume (%)
$CO+N_2$	proportion of carbon monoxide and nitrogen in the gas stream by volume (%)
100	conversion factor (%)

9. Molecular weight of sample gas (lb/lb·mole)

$$M_s = (M_d)(1 - B_{wo}) + (M_{H_2O})(B_{wo})$$

Where:

B_{wo}	proportion of water vapor in the gas stream by volume
M_d	dry molecular weight of sample gas (lb/lb·mole)
M_{H_2O}	molecular weight of water (lb/lb·mole)
M_s	molecular weight of sample gas, wet basis (lb/lb·mole)

SAMPLE CALCULATIONS (CONTINUED)

10. Velocity of sample gas (ft/sec)

$$V_s = (K_p)(C_P)(\sqrt{\Delta P})\left(\sqrt{\frac{(\overline{T_s}+460)}{(M_s)(P_s)}}\right)$$

Where:

K_p	velocity pressure coefficient (dimensionless)
C_p	pitot tube constant
M_s	molecular weight of sample gas, wet basis (lb/lb·mole)
P_s	absolute sample gas pressure (in. Hg)
T_s	average sample gas temperature (°F)
V_s	sample gas velocity (ft/sec)
$\overline{\sqrt{\Delta P}}$	average square roots of velocity heads of sample gas (in. H_2O)
460	°F to °R conversion constant

11. Total flow of sample gas (acfm)

$$Q_a = (60)(A_s)(V_s)$$

Where:

A_s	cross sectional area of sampling location (ft^2)
Q_a	volumetric flow rate at actual conditions (acfm)
V_s	sample gas velocity (ft/sec)
60	conversion factor (sec/min)

12. Total flow of sample gas (dscfm)

$$Q_{std} = \frac{(Q_a)(P_s)(17.64)(1-B_{wo})}{(\overline{T_s}+460)}$$

Where:

B_{wo}	proportion of water vapor in the gas stream by volume
P_s	absolute sample gas pressure (in. Hg)
Q_a	volumetric flow rate at actual conditions (acfm)
Q_{std}	volumetric flow rate at standard conditions, dry basis (dscfm)
T_s	average sample gas temperature (°F)
17.64	conversion factor (°R/in. Hg)
460	°F to °R conversion constant

SAMPLE CALCULATIONS (CONTINUED)

13. VOC concentration (lb/scf)

$$E_{lb/scf} = \frac{(ppm)(MW)}{(385.3 \times 10^{6})}$$

Where:

$E_{lb/scf}$	emission rate
C_{ppm}	measured concentration in the gas stream (ppm_v)
MW	molecular weight of Methane (16)
385.3	conversion factor

14. VOC emission (lb/hr)

$$E_{lb/hr} = (lb/scf)(60)(scfm)$$

Where:

$E_{lb/hr}$	emission rate
$E_{lb/scf}$	concentration
SCFM	flow rate
$60_{min/hr}$	conversion factor