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UNITED STATES DISTRICT COURT
SOUTHERN DISTRICT OF NEW YORK

IN RE M/V MSC FLAMINIA

12-cv-8892 (KBF)

OPINION & ORDER

KATHERINE B. FORREST, District Judge:

On July 14, 2012, the M/V MSC FLAMINIA (the "Flaminia") was crossing the Atlantic Ocean bound for Antwerp, Belgium. The vessel had departed from New Orleans, Louisiana fourteen days earlier and it was loaded with cargo. Early that morning, alarms began to sound, followed shortly thereafter by an explosion. Three members of the crew were killed, thousands of container cargos were destroyed, and the vessel was seriously damaged. A number of lawsuits followed, seeking compensation for death, bodily injury, loss of cargo, and damage to the vessel. Many of the original claims have been settled, including those alleging wrongful death and bodily injury. What remains are a host of claims relating to cargo losses and vessel damage.

The Court has split the trial into three phases: a trial on causation in "Phase 1," to be followed by trials establishing fault and damages. The Phase 1 bench trial was conducted from September 11, 2017 through September 19, 2017, with closing arguments on September 26, 2017.

At trial, three sets of parties presented related but materially different theories of causation. All agree that the explosion occurred as a result of runaway auto-polymerization of 80% grade divinylbenzene ("DVB80")[1] that was contained in ISO containers[2] aboard the Flaminia. The manufacturer and shipper of that cargo, Deltech Corporation ("Deltech") and Stolt Tank Containers B.V. ("Stolt"), respectively, assert that runaway auto-polymerization would not have occurred absent the storage conditions on the dock at the New Orleans Terminal ("NOT") (where the DVB80 was stored before being loaded onto the ship) and aboard the vessel. In contrast, Container Schiffahrts-GMBH & Co. KG MSC "FLAMINIA" and NSB Niederelbe Schiffahrtsgesellschaft MBH & Co. KG (together, "Conti"), which owned and operated the Flaminia, and MSC Mediterranean Shipping Company, S.A. ("MSC"), the time-charterer, assert that the cause of the auto-polymerization was Deltech's failure to deliver fully oxygenated DVB80 to the dock at NOT. The last party that presented a causation theory was Chemtura Corporation ("Chemtura"), a shipper of another chemical contained in cargo aboard the vessel, diphenylamine ("DPA"). Chemtura argued that in all events, the DPA was not a substantial factor contributing to the conditions that caused the explosion.

The parties have spent an enormous amount of time litigating this case. The discovery was, by any measure, extensive. Each group of parties retained experts, resulting in a classic "battle of the experts." The Court carefully studied the experts' work, listened to their testimony, and poked and prodded them with

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[1] DVB is a chemical used for the synthesis of ion-exchange resins, an important component of water purifiers. These water purifiers create clean drinking water as well as clean water for use by nuclear power plants. DVB may also be used in the production of adhesives and polymers.

[2] ISO containers—sometimes referred to as "ISO tanks"—are receptacles that can be filled with liquid. The Court discusses the characteristics of the ISO containers further below.

questions. According to the Stolt/Deltech experts, the DVB80 was fully oxygenated and only excessive heat conditions caused the auto-polymerization. The Conti/MSC experts argue the opposite.

It is clear that neither the experts nor the Court will ever be absolutely certain as to what caused the DVB80 to auto-polymerize and what ignited the explosion. But this is a civil case—one in which the standard of proof is not certainty, but a "preponderance of the evidence." Based on that standard, the Court finds that that the DVB80 was delivered to NOT in an appropriately oxygenated state. However, the choice of NOT as the port of embarkation was a fatal one. Together, the extended, stagnant storage under a hot sun at NOT, followed by high ambient temperatures in the hold of the Flaminia, caused the DVB80 to auto-polymerize. The Court also finds that the heated DPA, which had been placed in containers adjacent to those filled with DVB80 at NOT and in the hold of the vessel, was a substantial contributing factor in the auto-polymerization.

As the auto-polymerization progressed aboard the Flaminia, a white cloud of venting DVB80 gases triggered alarms. The crew missed a final opportunity to prevent the explosion when, lacking information as to the conditions in the hold and instructions as to how much carbon dioxide ("CO_2") to release, it failed to inert the venting gases. The reasonable crew response to what crew members believed was an ongoing fire then created a spark that triggered the explosion.

The Court's findings of fact and conclusions of law are set forth below.

I. THE PARTIES

Dozens of parties have, at various points, been involved in these proceedings. For purposes of this Phase 1 causation trial, the notable players consist of the following groups: first, the "ship interests," Conti and MSC; second, the parties that manufactured and shipped the three ISO containers of DVB80, Deltech and Stolt; and third, the companies connected to ten ISO containers of DPA. This last group is comprised of Rubicon LLC ("Rubicon"), the manufacturer; Chemtura, the owner and shipper; and Bulkhaul Ltd. and Bulkhaul (USA) Inc. (together, "Bulkhaul"), which provided the ISO containers in which the DPA was stored. (Stipulated Facts at 9, ¶ 66.)[3]

II. THE BATTLE OF THE EXPERTS

A total of 54 witnesses testified at trial: 35 by deposition designation; 13 by trial declaration, live cross-examination, and live redirect; and six by trial declaration only (because the parties waived cross-examination (see Trial Tr. at 101–03)).[4] The Court also received into evidence over one hundred documents and a videotape.

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[3] Several other companies produced other chemicals being transported on the Flaminia—by the time of trial, these materials had been absolved of blame. Monsanto Company ("Monsanto") was the manufacturer of glyphosate intermediate ("GI") carried in 30 twenty-foot dry van containers aboard the vessel on July 14, 2012. (Stipulated Facts at 12, ¶ 1.) BASF Corporation ("BASF") was the manufacturer of four ISO container shipments of dimethylethanolamine ("DMEA") carried aboard the vessel on July 14, 2012. (Stipulated Facts at 13, ¶ 3.) Suttons International, Ltd. and Suttons International (N.A.) Inc. (collectively "Suttons") were the providers of the ISO containers utilized for carriage of the Flaminia shipments of DMEA aboard the vessel. (Stipulated Facts at 14, ¶ 13.)

[4] This last group includes Leon Nell (ECF No. 1292), Gerry Walsh (ECF Nos. 1294, 1334), Robert Cohen (ECF No. 1298), Ian Wadsworth (ECF No. 1300), Tommy Sciortino (ECF No. 1302), and David Hughes (ECF No. 1292).

A number of intelligent, articulate, and talented experts in their fields testified at trial. Each of the individuals who testified as an expert was truly an expert; the fact that the Court credits certain conclusions over others does not suggest otherwise. Ultimately, the Court credits the testimony of the experts representing Stolt and Deltech over the experts representing MSC, Conti, and/or Chemtura.[5] The Court was highly impressed with the credentials of the Stolt/Deltech experts, as well as the engagement, rigor, and consistency with which they approached their work and opinions; Stolt and Deltech's experts were the most persuasive.

While relatively early in this Opinion and technically complex, in order to set the stage for the Court's findings that follow and which rely heavily on the experts, the Court now provides a brief overview of their work. The technical details will be explained more thoroughly in the relevant sections of this Opinion.

A. Dr. Scott G. Davis

Scott G. Davis, Ph.D., testified extensively at trial. The Court was very impressed by him. Dr. Davis has all the expertise a court could wish for: extraordinary credentials, engagement with his assignment, and a careful, forthright, and clear manner. The Court was particularly persuaded by the careful scientific work that he did which reinforced many of his opinions. Dr. Davis was not

[5] Stolt proffered Anand Prabhakaran to conduct a thermal analysis of the maximum temperature the DVB80 could have reached in the ISO containers. While the Court found his analyses interesting, and supportive of heat contributions from the DPA and solar radiation, it ultimately does not rely on him. Certain of his analyses changed between his deposition and trial and while the Court credited his explanations, it ultimately need not delve into his analyses to reach its conclusions herein.

relying solely on theory—he and the company with which he is associated, GexCon US, Inc. ("Gexcon"), performed modeling and testing that provide a strong, independent basis for crediting his views. The Court relies heavily on his opinions. He did not overreach.

A summary of certain of Dr. Davis's qualifications are as follows: he holds a Masters of Science and a Ph.D. in mechanical and aerospace engineering from Princeton University. Dr. Davis is a registered professional engineer in California and New York, a licensed engineer in Texas, and an authorized professional engineer in Maryland and Pennsylvania. He is a certified fire and explosion investigator with the National Association of Fire Investigators National Certification Board. He has also completed a "fire cause and origin investigation" training with the California Office of State Fire Marshal, hazardous waste operations and emergency training in accordance with Occupational Safety and Health Administration ("OSHA") standards, and confined space entry training also in accordance with OSHA. (Davis Trial Decl., ECF No. 1304, at 1, ¶¶ 3–6.) Dr. Davis has authored numerous scientific and academic publications. (Id. at 1, ¶ 7.) He is President and Principal Engineer at Gexcon, where he is responsible for fire and explosion related assignments. (Id. at 1, ¶¶ 1, 8.) This includes post-incident investigative work, worldwide training and experimentation, risk assessments, and safety studies for petrochemical facilities and other industries. (Id. ¶ 8.) At Gexcon, he has performed numerous explosion risk assessments, blast and venting analyses, assessment of combustible dust explosions, toxic/flammable gas releases and dispersion, hydrogen safety, ventilation, detector placement, and carbon monoxide dispersion. (Id. at 2, ¶ 9.)

Dr. Davis is a member of Gexcon's "docents group," which delivers industrial seminars all over the world on the hazards associated with gas explosions. (Id. at 2, ¶ 10.) He has expertise in the investigation and prevention of fires, explosions, and dispersion hazards such as flammable vapors, as well as extensive experience evaluating the cause, origin, and dynamics associated with fires and explosions, principally as they relate to ignition, flame propagation, chemical kinetics, and fluid dynamic processes associated with combustion and explosion events. (Id. at 2, ¶¶ 11, 12.) Dr. Davis has been the lead investigator on hundreds of fire and explosion incidents, including chemical and industrial facilities and equipment, dust explosions, natural gas and propane explosions, above-ground storage tanks, unintentional ignition including thermal runaway, and residential and commercial fires. (Id. at 2, ¶ 13.) Prior to joining Gexcon, his research focused on heat and flow processes in fires, chemically reacting flows, flame dynamics, and combustion phenomena in high-pressure burners and reactors. (Id. at 3, ¶ 16.) As part of his professional experience, he has developed large-scale experiments to understand the explosion phenomena of deflagration to detonation. (Id. at 3, ¶ 17.)

Deltech retained Dr. Davis to conduct and lead a comprehensive scientific investigation into the cause and origin of the explosion and fire that occurred aboard the Flaminia on the morning of July 14, 2012. (Id. at 10, ¶ 1.) His investigation and work on this case lasted over two and a half years. (Id. at 12, ¶

14.) As part of his work, Dr. Davis and others from Gexcon visited the Deltech facility in Baton Rouge, Louisiana where the DVB80 at issue in this case was manufactured and filled into ISO containers for transport. (Id. at 10, ¶ 3.) He reviewed the records of DVB80 production and storage and measured the dissolved oxygen saturation levels at various stages of Deltech's DVB80 manufacturing, storage, and transport process. (Id. at 10, ¶¶ 4–5.) Dr. Davis performed detailed computational fluid dynamic ("CFD") analysis of the mixing and storage of DVB80 in Deltech's main cooling and storage tanks. (Id. at 10, ¶ 6.)

The Court found Dr. Davis's mathematical heat transfer models particularly compelling. He created and used these models to ascertain the magnitude of heat transferred to the DVB80 ISO containers during the time they were stored at NOT aboard the Flaminia. (Id. at 10, ¶ 7.) This analysis included evaluating the combined effects of the ambient air temperature, solar radiation on the dock, thermal radiation from neighboring ISO containers of heated DPA, the ambient air temperature in the hold where the containers of DVB and DPA were stored ("Hold 4"), the impact of ventilation (or lack thereof), and the heated bunker fuel wing tanks adjacent to Hold 4. (Id. at 10–11, ¶ 7.) Dr. Davis's heat transfer model allowed him to estimate the approximate time it took the DVB to begin auto-polymerizing. (Id. at 11, ¶ 8.)

As part of his work on the case, Dr. Davis performed thermal accelerated rate calorimetry tests ("ARC" tests) of DVB80 to determine the time to onset of an exothermic reaction (discussed below), which indicates the onset of polymerization;

tests to determine the flammability characteristics of DVB80; and tests relating to venting and peak temperature rise under certain conditions. (Id. at 11, ¶ 9.) Further, he used advanced computational fluid analyses as well as an analytic model of CFD dispersion to evaluate the effectiveness of the CO_2 system, the dispersion of venting DVB80 within the cargo hold, and explosion modeling. (Id. at 11, ¶¶ 11–12.)

In addition to all of this, Dr. Davis created a full-scale model to test certain temperature conditions. He placed an ISO container with characteristics as similar as possible to one of the ISO containers (Tank I) aboard the Flaminia, filled with DVB80, and placed it within a specially built structure (the "Full-Scale Test"). The Full-Scale Test allowed Dr. Davis to establish with a high and persuasive degree of scientific certainty: (1) the representative UA (relating to thermal resistance) of the Stolt ISO containers filled to 80% capacity with Deltech's DVB80; and (2) the minimum expected time it took to auto-polymerize, or the shelf life of Deltech's DVB80 as prepared and shipped aboard the Flaminia. (Id. at 11–12, ¶ 13.)

Dr. Davis's conclusion, with which the Court agrees, is that Deltech's DVB80 would not have auto-polymerized and undergone the thermal runaway reaction it did on July 14, 2012, if it had not sat still in the sun at NOT, if it had not been stored next to heated DPA both on the dock at NOT and in Hold 4, and if Hold 4 had been properly ventilated and had not had high ambient temperatures. (Id. at 13–14, ¶¶ 1–6.) In addition, even when thermal runaway had been achieved, an explosion was not a foregone conclusion; additional deployment of CO_2 could have rendered the gas inert, and in the absence of an ignition event—a spark—no explosion would have been triggered. (Id.)

B. Dr. Deborah Kaminski

The Court was also highly impressed by Deborah Kaminski, Ph.D., another expert retained by Stolt and Deltech. Dr. Kaminski provided a number of opinions relating to heat transfer—an area particularly important in this case, as the parties are litigating whether, how, and to what extent heat transferred into or out of the containers in which the DVB and DPA were stored (the "ISO containers") contributed to runaway auto-polymerization. Dr. Kaminski is another true expert, with decades of relevant in-depth experience.[6]

A summary of Dr. Kaminski's credentials are as follows: she is a Professor Emerita of Mechanical Engineering at Rensselaer Polytechnic Institute ("RPI"). (Kaminski Decl., ECF No. 1303, at 2, ¶ 3.) She earned her Bachelor of Science in physics from RPI in 1973; her Masters of Science in Chemical Engineering from RPI in 1976; and her Ph.D. in Mechanical Engineering from RPI in 1985. (Id. at 2, ¶ 4.) Prior to obtaining her doctorate, she spent five years at General Electric Research and Development Center, working on heat transfer. (Id. at 2, ¶ 5.) Her doctoral research was on computational fluid dynamics in free convection. (Id. at 2, ¶ 6.) Dr. Kaminski was the Associate Technical Editor for the Journal of Heat Transfer from 1998–2001, and she was named a Fellow in the American Society of Mechanical

[6] The Court was also impressed by the fact that Dr. Kaminski is not a professional testifying expert—this was the first case in which she provided testimony in court. (Tr. at 930:16-18.)

Engineers in recognition of her work in radiation heat transfer. (Id. at 3, ¶¶ 7–9.) In 1995–96 she served as the Program Director of Thermal Transport and Thermal Processing at the National Science Foundation. (Id. at 3, ¶ 10.) She has also co-authored a book on thermal engineering, published in 2004, and has written 82 articles in peer-reviewed publications as well as 11 additional publications in the areas of thermal engineering and heat transfer. (Id. at 3, ¶ 11.)

Dr. Kaminski was retained to determine the temperature history and polymerization of the DVB80 containers from the time they were filled at Deltech's Baton Rouge manufacturing facility until the time the first alarm went off aboard the Flaminia on July 14, 2012. She also computed the temperature of the DPA and measured its contribution to heat conditions within the hold where the containers of DVB80 and DPA were stored.

Dr. Kaminski created reliable experimental and theoretical estimations of the thermal resistance of the relevant ISO containers. She then predicted the temperatures of the liquid DVB80 and heated DPA while the ISO containers were at NOT and examined the influence of the heated DPA on the DVB80. She discussed the heat transfer that occurred at NOT—where one ISO container filled with DVB80, an unstable and heat-sensitive mixture, was stored facing three neighboring containers filled with heated DPA; two additional containers of DVB80 were on top of the stack. Her analysis determined that all of the DVB80 containers were affected by solar radiation, infrared radiation, and proximity to neighboring

DPA containers. Her opinions in this regard were rigorous, based in evidence, clearly explained, and persuasive.

In addition, Dr. Kaminski modeled the temperatures of the DVB80 containers while they were in the hold of the Flaminia for 14 days, considering a number of different air temperature scenarios. She then predicted the induction time for the three ISO containers of DVB80. Her conclusions agree with those of Dr. Davis on which the Court relies, finding thermal runaway following from the combined conditions of heat at NOT and both heat and poor ventilation in Hold 4.

C. Dr. Hans Fauske, D.Sc.

A third expert upon whom the Court relies is Dr. Hans Fauske. He was retained by Deltech to testify regarding the thermal stability of DVB80. His testimony was ultimately narrow—providing experimental results that allowed for a mathematical calculation predicting the time necessary to achieve runaway auto-polymerization. Dr. Davis was persuaded as to the reliability of these equations, and so was the Court.

Dr. Fauske is the founder, Emeritus President, and Regent Advisor of Fauske and Associates, LLC, a world leader in nuclear, industrial, and chemical processes, and now a wholly-owned subsidiary of Westinghouse Electric Company. He obtained a Masters in Science in Chemical Engineering from the University of Minnesota in 1959 and a Doctorate of Science from the Norwegian Institute of Technology in 1963. After completing his graduate education, Dr. Fauske joined the staff of the Argonne National Laboratory, an entity managed by the University of

Chicago. In 1972, he became a Senior Chemical Engineer at the lab (the equivalent of a full professor of the University of Chicago). In 1975 he was awarded the University of Chicago Medal for Distinguished Performance. He has won a number of awards and recognitions from organizations and academic institutions worldwide, has published more than 200 scientific articles, and holds numerous patents in the areas of nuclear and chemical safety.

Dr. Fauske believes strongly in the benefits of experimental results to inform his conclusions. He presented compelling testimony regarding testing that he conducted for this matter. Dr. Fauske also ran a series of ARC tests, Thermal Activity Monitor ("TAM") tests, and Vent Sizing Package Calorimeter ("VSP2") testing. In his opinion, TAM tests are the most accurate means to determine the shelf life of DVB80. (Fauske Decl. at 27, ¶ 79.) He was persuasive in this view. Based on these experiments, Dr. Fauske was able to derive "Arrhenius equations" that predict the "shelf life" (that is, the "induction time" or time to auto-polymerization) of Deltech's DVB80 as a function of its temperature. (Fauske Decl., ECF No. 1290, at 5, ¶¶ 37–38.) "Arrhenius equations" are mathematical calculations that can account for chemical reactions occurring at increased temperatures. (Id. at 6, ¶ 41.)

Dr. Fauske determined an Arrhenius equation applicable here based on guidelines for the DVB published by Deltech and Dow Chemical Company ("Dow"). (Id. at 6–7, ¶ 44.) Notably, the Arrhenius equations that he derived from the TAM testing (assuming no headspace in the ISO container) and from the guidelines provided by Deltech and Dow predicted the shelf life of the DVB80 used in the Full-Scale Test conducted by Dr. Davis. In addition, based on his testing, Dr. Fauske was able to conclude that the DVB80 sample he received from Deltech, which had been manufactured in the same manner as that which filled the ISO containers aboard the Flaminia, was adequately saturated with oxygen. According to his Arrhenius equations, under normal conditions, the upper bound of the shelf life for DVB80 manufactured according to the same process as that aboard the Flaminia was 64.9 days. (Id. at 37, ¶ 94.) This means, under normal conditions, the DVB80 aboard the Flaminia should have made it safely to port in Antwerp, Belgium.

The Court was persuaded by Dr. Fauske that the Arrhenius equation he developed allows for a determination of how long Deltech's DVB80 would remain stable at various temperatures, and provides the approximate shelf life of the DVB80.

D. Plaintiffs' Experts

With regard to the plaintiffs' expert witnesses, the Court again notes that all were impressively credentialed and deserving of the title "expert." However, for the reasons set forth here and throughout this opinion, the Court was not persuaded by their testimony that Deltech did not adequately oxygenate the DVB80, or that anything other than crew activity ignited the explosion.

Plaintiffs retained Dr. Paul Beeley, a forensic investigator who specializes in fires and explosions. Dr. Beeley presented four possible sources of ignition for the Flaminia fire and explosion including: a spark involving the electrical system inside

Hold 4; crew activity on deck; discharge of static electricity; and thermal runaway of the DVB leading to auto-ignition. (Beeley Decl. ¶ 8.) At trial, though, Dr. Beeley could not identify any physical evidence supporting one source of ignition over another, and he did not assign a relative probability to any of the sources. (Tr. at 774:4–6; id. at 775:3–6; id. at 788:4–16.) Further, he did not perform an independent investigation of the ship's electrical systems, but instead relied on another expert's opinion regarding the equipment.[7] As such, Dr. Beeley's testimony cannot be relied on to prove anything beyond the fact that the explosion was triggered in one of at least four ways. The Court's task in this Phase 1 trial is to determine whether these possibilities can be measured—and they can.

Plaintiffs also retained Edward Hammersley, another fire and explosion investigator and a chemistry expert, and David Robbins, a forensic investigator and specialist in fires and explosions. The Court found Hammersley and Robbins similarly credible, but was still unpersuaded that auto-polymerization occurred as a result of a flaw in Deltech and/or Stolt's manufacturing and/or transport processes.[8]

Hammersley's declaration focused on testing of samples of materials from Hold 4 of the Flaminia, which, he concluded, demonstrated that the DVB shipments had undergone auto-polymerization that resulted in venting of DVB80 polymer. (Hammersley Decl. at ¶¶ 8, 44–49, 74–75, 99–100.) He also determined that no

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[7] Dr. Beeley relied on David Robbins, whose testimony is discussed below.

[8] Both Hammersley's and Robbins's declarations focused, in large part, on the fact that the explosion derived from auto-polymerization that occurred in the tanks of DVB80. The facts that auto-polymerization had occurred and that the DVB80 exploded were no longer in dispute at the time of the Phase 1 trial.

other cargo was involved in the explosion, and that there was not a fire in the hold prior to the release of CO_2. (Id. at ¶¶ 9–10.) With regard to the induction time to auto-polymerization, while Hammersley testified that Dr. Fauske's Arrhenius equations resulted in a "prediction contrary to scientific expectation," he was not persuasive in this view. (Hammersley Decl. at ¶¶ 113, 116, 127.) And at trial, Hammersley conceded that Dr. Fauske's equations set forth a conservative view of temperature conditions (that is, a view favorable to the plaintiffs' interests). (Tr. at 1397:4–1400:14.) Hammersley did not perform any TAM tests of his own. (Id. at 1405:9–10.)

Robbins similarly concluded that the fire and explosion were caused by the DVB80's auto-polymerization and ignition due to a discharge of static electricity. He analyzed previous incidents involving auto-polymerized DVB as well as the preferred and calculated temperature and storage conditions for the Flaminia DVB80. Like Hammersley, Robbins ruled out alternative sources of a fire, such as other cargo. (Robbins Decl. ¶ 172.) Overall, the Court was not persuaded that Hammersley's and Robbins's explanations supported a theory that auto-polymerization occurred due to a flaw in Stolt and Deltech's processes.

Finally, plaintiffs retained Dr. Brian Ott, a chemical engineer who opined that it was "more likely than not that the subject DVB shipments were not fully saturated with oxygen when they were delivered" to NOT. (Ott Decl. ¶ 17.) The Court was not persuaded. Though Dr. Ott opined that the liquid DVB80 was not sufficiently oxygenated, he neither modeled its mixing within the storage tank nor tested the oxygen saturation levels of DVB during Deltech's manufacturing process. The Court is also unpersuaded by Dr. Ott's calculation of the relevant UA values; Dr. Davis's values were based on direct measurement through his Full-Scale Test, while Dr. Ott's were reverse-engineered and based on an incorrect assumption regarding the oxygen saturation in one of the tanks used during manufacturing. Additionally, his model failed to incorporate the influence of solar radiation and DPA on the containers while they sat on the dock.

Further, Dr. Ott critiqued Dr. Davis's computation of what is referred to as the cumulative Fraction of Inhibitor Life Consumed ("FILC") measure. Dr. Ott contends that because Dr. Davis's calculations depend on precise knowledge of the oxygen concentration and temperature of the subject DVB shipments—which is unattainable—they are necessarily unreliable. (Ott Decl. at ¶¶ 179–80, 186.) This position is unpersuasive. While there is uncertainty, that does not address Dr. Davis's careful, reasoned conclusions based on certain known facts, principles, modeling, and experiments. In addition, Dr. Ott's model of the DVB's shelf life is itself flawed. It derived a UA value based on incorrect assumptions, used an unrealistic temperature contribution from the DPA on the ambient air, and failed to account for diffusion from the headspace. (Davis Decl. at 100, ¶ 3.)

The Court also viewed Dr. Ott as overreaching in his answers at trial. For instance, he posited assumptions that, if credited, (1) would support a scenario in which most, if not all, of Deltech's DVB shipments are so unstable that venting and even explosions should occur frequently on trans-Atlantic voyages (and they do not);

and (2) predicted auto-polymerization of the Flaminia shipments almost a week before it actually occurred. Furthermore, Court found Dr. Ott unnecessarily argumentative, distracting from any persuasive force in his arguments.

E. Chemtura's Expert

Chemtura presented one witness at trial, Douglas Carpenter, a mechanical engineer who was retained to determine what DPA's role might have been in the fire and explosion. The Court found Carpenter credible but was not ultimately persuaded by his views. He principally opined that the DPA did not make a "thermal contribution" (that is, contribute to heat) in the adjacent DVB containers. Carpenter opined that the source of heat for the DVB containers may have been re-radiation from other cargo exposed to solar radiation or the pavement; notably, however, he did not adequately explain why these sources would not have also re-heated the DPA. (And no other expert pointed to these sources as heavily influencing the DVB's temperature.) Simply put, the weight of evidence throughout trial is against Carpenter's conclusions, and thus the Court does not rely on them.

III. FINDINGS OF FACT[9]

A. DVB's Chemical Properties

The parties largely agree on the basic chemical properties of DVB80 that are are at the heart of this case. The core disagreement relates to whether the

[9] The Court makes its findings of fact by a preponderance of the credible evidence. This Opinion contains some citations to evidence; these are example citations only. The Court has not attempted to exhaustively recite all supportive citations in the record.

manufacturing process failed to adequately oxygenate the DVB80, or whether the terminal and vessel storage conditions triggered auto-polymerization.

DVB is an "enhanced performance aromatic monomer" produced by Deltech to include para-methylstyrene ("PMS"), vinyltoluene ("VT"), and tertiary-butylstyrene ("TBS"). (Cooper Decl., ECF No. 1295, ¶ 8.) Deltech produces DVB in two grades: 80% ("DVB80") and 63% ("DVB63"). The DVB that shipped aboard the Flaminia was DVB80. DVB80 is a monomer that, depending on exposure conditions, can undergo heat-initiated free radical[10] polymerization. (Davis Decl. at 28, ¶ 61.) When exposed to heat, the DVB monomer molecule becomes unstable and forms a reactive, free radical. This molecule can then react with another DVB molecule to start a polymer chain. (Id. at 28, ¶ 62.) This is referred to as "polymerization."

The "polymerization" of DVB is an "exothermic" reaction. That is, energy (heat) is released when DVB monomer molecules combine to form DVB polymer. (Stipulated Facts at 1, ¶ 6.) Thus, once started, the process generates its own heat, which results in additional polymer formation; once begun, the polymerization process is self-sustaining. This, in turn, gives rise to "auto-polymerization." (Id. at 1, ¶ 7; Davis Decl. at 29, ¶ 65.) In scientific terms, the "exothermic reaction" is "self-promoting" and "auto-accelerating." (Stipulated Facts at 1, ¶ 8; Davis Decl. at 29, ¶ 66.) Polymerized or polymerizing DVB is not a desired condition.

[10] The term "free radical" is a technical name for a molecule that has one or more unpaired electrons. (Davis Decl. at 28, ¶ 63.)

Polymerizing DVB is unstable and potentially dangerous. Customers order DVB in its monomer form, without high polymer content.

When the heat generated by the exothermic auto-polymerization reaction exceeds the heat lost to the environment, the reaction is said to have reached "thermal runaway"; at this point, polymerization increases exponentially. (Davis Decl. at 29, ¶ 67.) If the runaway reaction generates temperatures and pressure that exceed the capacity of the equipment in which the product is stored (for instance, an ISO container), a pressure relief valve is required to vent accumulated gases. (Id. at 29, ¶ 68.) A white, smoky cloud of gas may be emitted. If exposed to an ignition source and a specific amount of oxygen (discussed below), the DVB gas may explode. Deltech's manufacturing process is designed with these chemical characteristics in mind.

TBC and oxygen halt polymerization (that is, the formation of DVB polymer) by creating a chain-terminating reaction sequence (that is, TBC and oxygen can stop the formation of polymer chains and thus prevent the exothermic reaction that can lead to thermal runaway). (Id. at 29–30, ¶¶ 71–72.) During the manufacturing process, Deltech oxygenates and adds TBC to the DVB liquid to inhibit polymerization. (Id. at 29, ¶ 70.)

A major issue in this Phase 1 trial is the time it took the DVB80 aboard the Flaminia to begin to auto-polymerize, referred as the "induction time" of DVB or its "shelf life." The induction time or shelf life of DVB liquid is the time it takes to deplete the inhibiting materials (that is, the oxygen and TBC) below a threshold value, allowing the auto-polymerization reaction to commence. (Id. at 30, ¶ 73.) The induction time depends on the temperature of the liquid, which dictates the consumption rate of the inhibiting material (that is, the consumption rate of oxygen and TBC). (Id. at 30, ¶¶ 73–74, 76.)[11] Once the TBC or oxygen is depleted below a certain threshold, the chain-terminating path no longer exists and polymerization can occur. (Id. at 30 ¶ 77.)[12] Thus, the oxygen saturation level, the amount of TBC, and temperature play a significant role in the stability of DVB80.

Even polymerized or auto-polymerized DVB80 does not explode without some external ignition source and just the right amount—no more, no less—of oxygen. To reach the point where a spark may ignite the liquid requires that the temperature of the DVB80 liquid reaches what is referred to as its "flashpoint." (Id. at 25, ¶ 51.) DVB80 has a flashpoint of between 156.2–170°F (69–76.7°C). Its auto-ignition temperature (that is, the point at which it ignites without an external ignition source) is far higher—470°C. (Id. at 26, ¶ 54.)

Additionally, in order for DVB80 vapor to ignite (assuming a temperature level at or above the flashpoint), the concentration of DVB80 vapor and air (oxygen) must be within narrow limits; the DVB vapor can only be between 1.1% and 6.2% of

[11] Deltech has a Material Safety Data Sheet ("MSDS") for DVB80. The MSDS contains certain hazard, firefighting, transport, regulatory, stability, handling, and storage information for DVB80. The MSDS states that DVB80 is a reactive monomer with a melting point of -126.4°F (-88°C). The MSDS also indicates that for ignition of DVB vapor to occur, the DVB in the air must be between 1.1–6.2%. (Deltech Trial Ex. 46.) Deltech has also created a Technical Bulletin for DVB. (Deltech Trial Ex. 111.) The Technical Bulletin states that DVB80 has a boiling point of 392°F (200°C).

[12] During the manufacturing process, Deltech adds more TBC than is chemically necessary to ensure complete inhibition. Thus, the limiting factor in a closed system such as an ISO container is the oxygen concentration level. (Id. at 31, ¶ 78.)

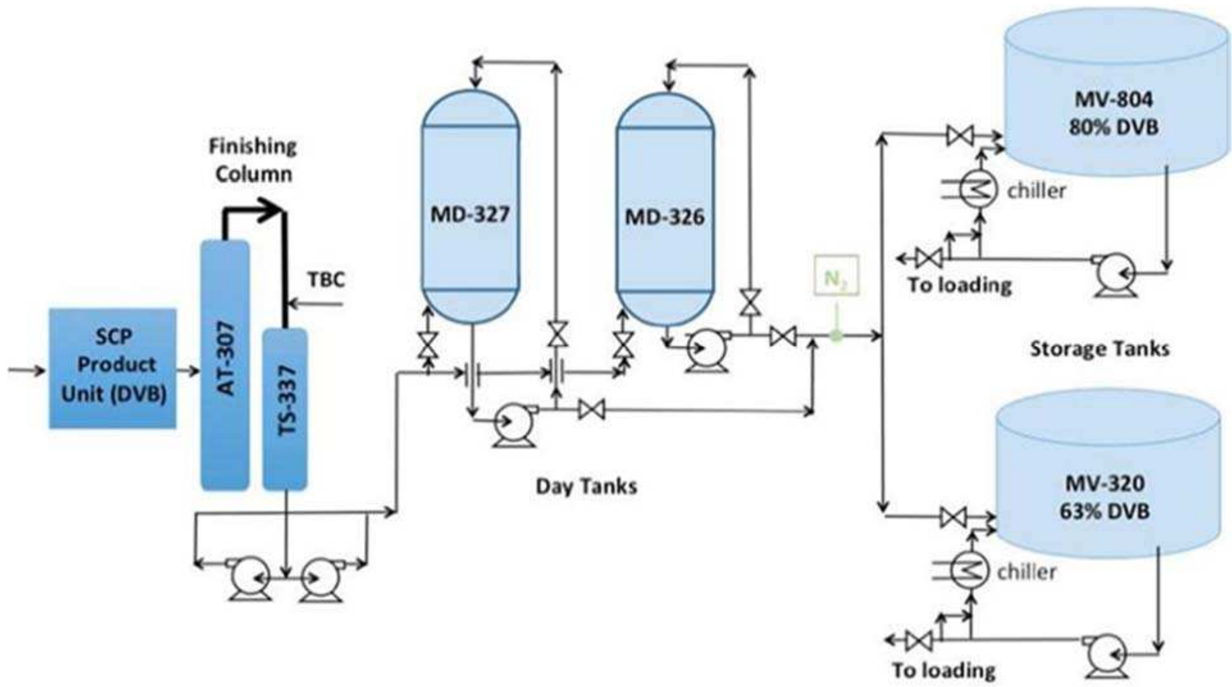
the combined vapor/air mixture. If the concentration is below 1.1% DVB80 vapor per unit volume of air (that is, too much air dilutes the vapor), or more than 6.2% DVB80 vapor (that is, not enough air), ignition is impossible. (Id. at 25, ¶¶ 48–50.) Thus, the window for ignition of DVB80 is relatively narrow. In addition, even when these conditions are met, an external ignition source is required (such as a spark) to trigger a fire or explosion. Here, as discussed below and based on the evidence at trial, the Court is persuaded that the DVB80 did not auto-ignite, but rather that the crew lifted the lid covering the access point to Hold 4 as part of its response to the fire alarms in order to insert a hose. Such lifting caused friction, resulting in a spark that triggered the explosion.

B. Deltech's DVB Manufacturing Process

Deltech's process of manufacturing DVB80 includes sufficient chilling, oxygen saturation, and TBC to ensure safe trans-Atlantic shipment under typical storage, temperature, and transport conditions (including typical voyage length).

The pertinent aspects of the process are as follows: Deltech manufactures DVB80 at its Baton Rouge facility in batches or campaigns based on customer demand. The following figure depicts the process:

Figure 1.



(Stipulated Facts at 3, ¶ 19; Davis Decl. at 32, ¶ 80.)

The DVB80 is manufactured in numerous distillation columns. (Stipulated Facts at 3, ¶ 20.) While in the columns, oxygen exposure is minimal because the columns operate under a vacuum. (Id. at 3, ¶ 21.) TBC is added in the overhead vapor line that connects the top of AT-307 to the TS-337 condenser and, at this point in the process, the DVB mixture is cooled to the cooling tower water temperature which is near ambient. (Id. at 3, ¶ 22.)

The DVB80 is then pumped from the finishing column to one of the day tanks (MD-326 and MD-327), where it is circulated to ensure product uniformity prior to sampling. (Id. at 4, ¶ 23.) After approximately twenty-four hours of production (depending on the production rate), the flow of DVB80 from the column is redirected into the other day tank. (Id. at 4, ¶ 25.) The DVB80 is then circulated and a sample is taken from the day tank for analysis in the lab. (Id. at 4, ¶ 26.) If the sample meets specifications, the product in the day tank is transferred into a storage tank, the MV-804. (Id.)

The MV-804 storage tank plays a key role in this case, as it is the location in which the bulk of the chilling and oxygenation of the DVB80 occurs. The MV-804 is a cylindrical tank (30' tall, 30' diameter), with a capacity of 155,000 gallons. (Id. at 4, ¶ 31.) Since at least 2012 to the present (and during the production campaign relevant here), the MV-804 storage tank is filled only at or below 80% capacity. This allows for 20% headspace in the MV-804. Headspace, in turn, allows for the presence of air (i.e., oxygen) above the liquid. This allows for diffusion of the oxygen into the DVB80 while in the MV-804 tank. The tank also has a vent allowing oxygen into the tank, as well as a circulation loop that allows the DVB to be continuously circulated through a chiller (at a rate of 34 gallons/minute). (Id. at 4, ¶ 27; see also Davis Decl. at 33, ¶¶ 87–88; Sciortino Decl., ECF No. 1302, ¶ 16.)[13] The chiller unit in the MV-804 storage tank is equipped with a permanent fixed piping system and pump that takes DVB from the tank, runs it through an external chiller, and then delivers it back into the MV-804 tank.

Prior to June 21, 2012, several containers were filled with DVB80. This decreased the level of liquid in the MV-804, increasing the headspace. The DVB80

[13] Tommy Sciortino is employed by Deltech as a "Loader" of DVB product and Shipping Coordinator. He is knowledgable about Deltech's manufacturing process. (Sciortino Decl. at 1–2, ¶¶ 4–7.)

ultimately destined for the Flaminia continued to circulate within the MV-804 tanks for several additional days, continuing to be oxygenated and chilled.

The temperature of the MV-804 storage tanks is monitored daily by Deltech personnel. (Sciortino Decl. ¶ 14.) In addition, a sample from the MV-804 storage tank is taken once per week for analysis by Deltech's Quality Control Laboratory. The testing checks TBC levels. (Cooper Decl. ¶ 102.)[14] Deltech maintained records of the temperatures for the product storage tanks for the period from June 18–22, 2012. (Sciortino Decl. ¶¶ 29–32.) On June 21, 2012 (the day the DVB80 was loaded into the containers destined for the Flaminia), the temperature of the DVB80 in the MV-804 storage tank was 44°F—a temperature well within typical and safe limits. (Id. ¶ 34, fig. 5.)

Due to changes in the level of DVB liquid within the storage tank, DVB residue may adhere to the walls of the tank. Lowering tank levels (for instance, when ISO containers are filled) may leave a thin layer of liquid DVB on the tank walls. As the liquid layer vaporizes, some DVB is left behind. In addition, stalactites (solid formations of DVB) may be formed on the roof of the tanks. Stalactites are removed during cleaning but sometimes fall into the liquid DVB and, depending on the presence of factors that may have allowed it to polymerize, can cause the polymer content of the DVB to increase.[15]

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[14] Greg Cooper has been a Senior Process Engineer at Deltech for over eight years. He is responsible for quality control, including evaluating and improving Deltech's manufacturing processes for DVB. (Cooper Decl. at 1–2, ¶¶ 2, 6.)

[15] This point is, by analogy, useful to refer to when explaining a higher than expected polymer content of DVB80 shipped aboard a different vessel, the Ludovica, just prior to the Flaminia in June 2012. Persuasive evidence was presented at trial that the polymer content of that shipment was

C. Filling into a Storage Receptacle

The next step in Deltech's manufacturing process is filling a receptacle with DVB. Two aspects of this process have particular importance in this case: first, the oxygenation (via diffusion) that occurs during and as a result of the passage of the liquid through the air and splashing into the containers that occurs during the fill process itself; and second, the physical characteristics of the container, such as whether it is an uninsulated drum or an insulated ISO container. The temperature of the stored DVB product in an ISO container is impacted by the type and placement of insulation, vents, and the surface area exposed to heat sources.

Tommy Sciortino, a "loader" employed by Deltech, testified by declaration at trial and all parties waived cross-examination. Sciortino personally filled the three ISO containers of Deltech's DVB80 that were shipped aboard the Flaminia. (Sciortino Decl. ¶ 7.) For the purposes of this litigation, the three ISO containers destined for the Flaminia have been designated as Tanks I, J, and K. (Id. ¶ 46.) While Sciortino does not recall filling these precise containers, he followed the same procedures for all loading. Deltech creates a Product Transfer Sheet for product that will be filled into containers for a customer. The Product Transfer Sheet for Tanks I, J, and K, which Sciortino completed on June 21, 2012, identified the TBC level within the expected range of 1000–1,100 ppm. (Id. ¶ 42.)

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based on the formation of stalactites and soluble polymer in the ADPO storage tank. (ADPO is a storage facility for, inter alia, liquids in ISO containers. Deltech shipments are received at the Port of Antwerp and then trucked to ADPO's facility in Kallo, Belgium. (Jodlowski Dep. Tr. at 12:16–16:23.))

ISO containers, including Tanks I, J, and K here, are filled one at a time. Deltech uses "loading racks" for this purpose. (Id. ¶ 75.) The loading racks are free-standing and consist of a metal staircase with a platform on top. When a truck pulls up to the loading rack, the loader drops a moveable walkway above the ISO container. The walkway rests on the container's frame and provides the loader with access to its top. The walkway allows the loader to walk onto a container and to open and close the lid on its top—referred to as a "manlid." (Id. ¶ 76.) The manlid is the opening through which product is filled. (Id.) Prior to filling a container, the loader runs through a standard "pre-filling" checklist and visibly inspects the container for cracks, dents, or damage, the container's temperature gauge, the dome gasket that seals the manlid for proper fit, and the container's seal to ensure it is properly fitted and undamaged. (Id. ¶ 79.) As reflected in the checklist retained in Deltech's files, Sciortino performed the typical pre-loading checks for Tanks I, J, and K. (Id. ¶¶ 81–83.) No defects or problems were detected with any of these ISO containers. (Id.)

The filling process itself takes 35–40 minutes. The loader inserts a 12-foot gauge stick into an empty tank. (The stick has markings to identify the fill point.) The loader then extends the loading arm out over the tank's manlid, which was previously opened during the inspection process. (Id. ¶¶ 89–90.) The loader then lowers the loading arm through the manlid; the end of the nozzle extends approximately 30 inches below the manlid opening. (Id. ¶ 91.) The DVB80 pours out of the loading arm, falls through the air and splashes into and around the inside of the ISO container. (Id. ¶ 97.) This process further oxygenates the liquid as it falls or splashes into the container. (Davis Decl. at 46, ¶ 135.) The loading arm remains above the liquid level of the DVB in the ISO container for the majority of the filling process; it is typically submerged for about three minutes during the entire 35–40 minute process. (Sciortino Decl. at ¶ 97.)

When filling is almost complete, the loader inserts a thermometer into the DVB liquid in the container to determine the temperature of the product. (Id. ¶ 104.) A sample of the DVB is taken and tested by Deltech's Quality Control Laboratory. (Id. ¶¶ 86, 104.) Samples from each of Tanks I, J, and K indicated TBC concentration levels within the expected range of 1000–1,100 ppm and polymer concentration at an expected level of less than 5 ppm. (Id. ¶¶ 115–118.) The Deltech "Loading Sheet" records the temperature of the DVB after filling. The Loading Sheets for Tanks I, J, and K indicate that the DVB80 had a temperature of 44°F. (Id. ¶¶ 129–133.) This is consistent with the temperature in the MV-804 storage tank and corroborates Deltech's position that the manufacturing process employed for the DVB80 here was its typical process.

After an ISO container has been filled, Deltech's loaders then perform a post-inspection of the truck, its chassis, and the filled ISO container. During this post-filling inspection, the loaders ensure, inter alia, that there are no leaks and that the chains on the caps, plugs, and safety valves are secure. No defects or problems for Tanks I, J, or K were noted during this post-filling check process. (Id. ¶ 107.) After the post-filling inspection, the truck then pulls away from the loading dock.

In July 2016, one of Dr. Davis's Gexcon colleagues observed the filling process. (Id. ¶¶ 155–156.) His observations confirmed the points in the process during which oxygen saturation and the addition of TBC occurred, as well as the loading protocol. No other expert observed the process.

D. Manufacturing and Filling the Flaminia Shipment

At issue in this trial is the cause of the auto-polymerization of DVB80 in Tanks I, J, and K. The DVB80 in each of those containers was manufactured by Deltech pursuant to the above process, and filled into three ISO containers provided by Stolt. Plaintiffs argue that the lack of adequate oxygenation of the DVB80 caused it to auto-polymerize aboard the Flaminia. The Court here describes the particular facts relating to the manufacturing and filling process relevant to these three containers, based on the process set out above.

At trial, the parties focused on whether Deltech's manufacturing process for the DVB80 shipped aboard the Flaminia allowed for sufficient oxygen saturation and chilling of DVB80. If not, then the DVB80 may have been doomed to auto-polymerize because its inhibitors (TBC and oxygen) would have been depleted before successful completion of the voyage; but if the DVB80 was adequately oxygenated and had enough TBC, then external conditions must have played the causal role.

After filling on June 21, 2012, Deltech tested Tanks I, J, and K for TBC levels and polymer content. As stated above, the test results showed that the TBC and polymer content were within specification levels. Evidence amply supports the

Court's finding that the DVB80 filled into Tanks I, J, and K had a high level of oxygen saturation from: (1) the mixing in the MV-804 storage tank for at least ten days since the end of the production run, and for over six days after the headspace in the storage tank had additional fresh air in it; and (2) agitation from the fill process itself, from truck transport on the road, and in connection with the process at NOT during which cargo containers were stacked. Under normal transit time and temperature conditions, this level would have allowed for a safe arrival in Antwerp.

The DVB80 in the ISO containers aboard the Flaminia was manufactured as part of a production campaign that started on May 19, 2012 and ended on June 11, 2012. (Stipulated Facts at 5¸ ¶ 35; Davis Decl. at 34, ¶ 93.) During this manufacturing campaign, the levels of DVB80 in the various tanks (including the MV-804) rose and fell. In general, the higher the liquid level, the less oxygen can saturate the product (as there is less room for the product to move around, allowing for mixing with the oxygen). Before filling Tanks I, J, and K on June 21, 2012, Deltech filled ISO containers to be shipped aboard another ship, the Ludovica, on June 15 and June 18. This reduced the level of DVB80 in the storage tank, allowing more oxygen to mix with the remaining product, at least some of which was eventually shipped aboard the Flaminia. (Davis Decl. at 37, ¶¶ 105–06.) The DVB80 that eventually filled the ISO containers destined for the Flaminia spent several additional days in the tank, allowing for more chilling and additional oxygenation compared with the Ludovica shipments (which in all events made the trans-Atlantic voyage safely). (Stipulated Facts at 37, ¶ 110.)

The Flaminia DVB80 and the Ludovica DVB80 were produced during the same manufacturing campaign. The Ludovica departed for Europe shortly before the Flaminia.[16] The circumstances relating to the Ludovica shipment provide further evidence that the DVB80 manufactured by Deltech from May 19–June 11 had been sufficiently oxygenated and chilled. The key fact is that the DVB80 aboard the Ludovica did not achieve runaway polymerization en route.

Three ISO containers filled by Deltech on June 15 and June 18, 2012 were shipped out of NOT aboard the Ludovica. These ISO containers were shipped aboard the Ludovica eight days before the shipment aboard the Flaminia. The ISOs aboard the Ludovica had 20% headspace, a measured temperature at filling of 44–46°F (6.67–7.8°C), and a TBC concentration of 1020–1077 parts per million ("ppm"). They had also been provided by Stolt. They were loaded onto the Ludovica on June 23, 2012. The total duration of the voyage was about 29 days. But, none of these containers underwent thermal runaway. The Ludovica DVB was added to the ADPO storage container, causing the level of the ADPO storage tank to reach its highest level of the year.

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[16] The Court also notes that the Ludovica was one of <u>five</u> ships—not including the Flaminia—that carried Deltech's DVB80 from New Orleans to Europe during the summer of 2012. All carried DVB80 manufactured between May 3 and June 18, 2012. None of the shipments, other than that aboard the Flaminia, underwent thermal runaway, and none was above 25°C upon arrival at the storage facility (ADPO) in Belgium. (Johnson Decl. ¶¶ 136–37.)

Dr. Davis found the Ludovica shipment especially informative. (Davis Decl. at 57, ¶ 187.) The Court agrees. The DVB80 was manufactured during the same campaign as that shipped aboard the Flaminia, yet it was shipped to France without reaching thermal runaway. In fact, given its shipment dates, the Ludovica DVB80 had five fewer days to chill and oxygenate in the MV-804 storage tanks than did the Flaminia DVB80. (Id.)[17]

E. Dr. Davis's Tests of the Mixing in the MV-804 Tank

Dr. Davis performed various tests to determine the oxygen saturation level in DVB80 achieved by Deltech's DVB80 manufacturing process—the same process used for the May 19–June 11, 2012 campaign. The Court found this testing rigorous and persuasive. Dr. Davis performed CFD modeling to determine how the oxygen and TBC would mix in the DVB80 liquid within the MV-804 storage tank. (Davis Decl. at 38, ¶ 113.) In his trial declaration, and as further explained during live examination, he presented a persuasive set of models that showed the flow pattern and velocity at which the oxygen mixed into the DVB fluid.

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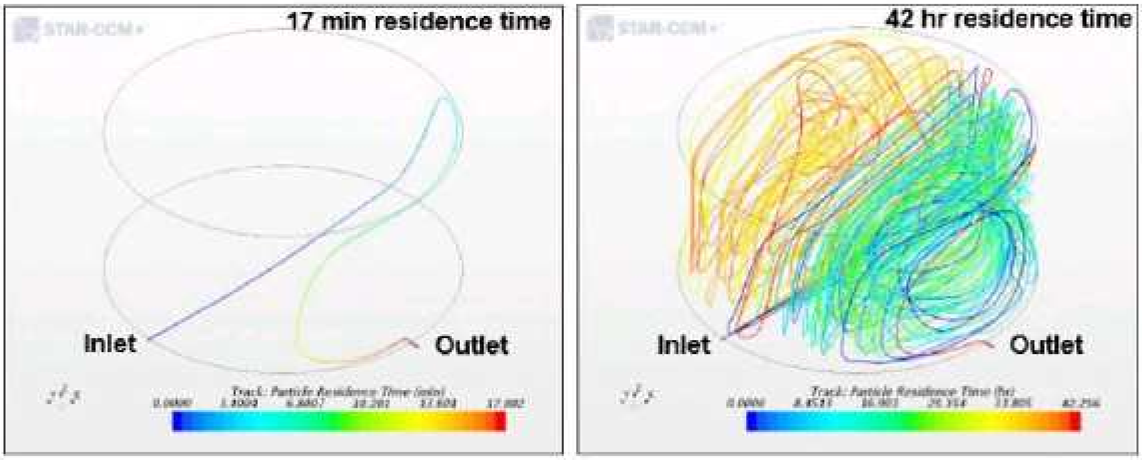
[17] Additionally, Dr. Ott, plaintiffs' expert, agreed that the Ludovica shipments were less oxygenated than the DVB80 shipped in containers aboard the Flaminia. (Tr. at 226:3–8.)

Some polymer was detected in the ADPO storage tank after the arrival of the Ludovica shipment. The amount detected was well below the specification values of 50 ppm for quality assurance standards. (Davis Decl. at 57, ¶¶ 187–189.) The low level of polymer detected in the storage tank at ADPO is not indicative of the onset of polymerization during the Ludovica shipment. A more likely explanation is that the formation of polymer occurred in the ADPO storage tank over time above the liquid surface, and when the levels within the storage tank reached their highest levels that year with the infusion of the Ludovica liquid, the polymer that had formed on the sides of the tank washed into the tank itself. (Id. at 57, ¶¶ 190–91.) The Court is persuaded by this explanation. Dr. Davis, who had the requisite expertise, describes the way in which monomer vapor could polymerize on the side of the tank and form a soluble layer, and explains that there might also be stalactites on the sidewalls and roof of the tank. (Id. at 57–58, ¶ 191.)

Figure 2.



(Id. at 40–41, ¶ 119.) Figure 2 depicts the path and residence time of massless tracer particles.[18] (Id.) The left diagram depicts the path of the tracer particle that stayed in the tank for the shortest amount of time, 17 minutes; the right diagram depicts that path of the tracer particle that stayed inside the tank for the longest amount of time, 42 hours. From this experiment, Dr. Davis concluded that particles in the MV-804 tank completely mix from top-to-bottom in the tank and that there is no evidence of stagnant layering (that is, no DVB80 liquid remaining in one place without mixing with TBC and oxygen). The mixing ensured that there were near homogenous oxygen levels at all layers (that is, heights within the tank), and that DVB80 was also periodically rising to the surface and mixing with air. (Id. at 41, ¶¶ 120–123.)

[18] These particles have no physical effect on the liquid inside the tank, but they follow the flow and allow analysts—and the Court—to visualize flow paths within the storage tank. (Davis Decl. at 40, ¶ 119.)

When he visited Deltech's facilities, Dr. Davis also used detectors[19] to measure the concentration of oxygen in the headspace of the MV-804 storage tank, the recirculation line, and the ISO container after filling. (Id. at 43–53, ¶¶ 131–165.) These measurements confirmed that DVB80 liquid is exposed to oxygen during the manufacturing process, and that oxygen saturation is at the predicted levels at each step. In addition, Dr. Davis found that additional oxygen continued to be mixed into the liquid after it had been filled into the ISO container and during transport. Such additional mixing (and thus additional oxygenation) resulted from the fact that, as stated above, as of 2012 and thereafter, Deltech only fills containers to near or at 80% capacity, leaving approximately 20% headspace that fills with oxygen. The liquid can thus "slosh around" (not a technical term) and mix with that oxygen in the headspace, providing for additional oxygenation.

Dr. Davis's testing confirmed that the DVB80 in Tanks I, J, and K was delivered to NOT for loading onto the Flaminia in what the Court considers a fully saturated condition—that is, at 94–95%. He testified that this was a minimum and likely conservative oxygen saturation level. The Court agrees. In particular, the Court is persuaded that the manufacturing process generally used by Deltech, and pursuant to which hundreds of voyages had been successfully completed without incident, was utilized here.

On the morning of June 21, 2012, Tanks I, J, and K were filled with DVB80. After being filled with DVB80, Tank I had 20.2% headspace; Tank K had 17.5%

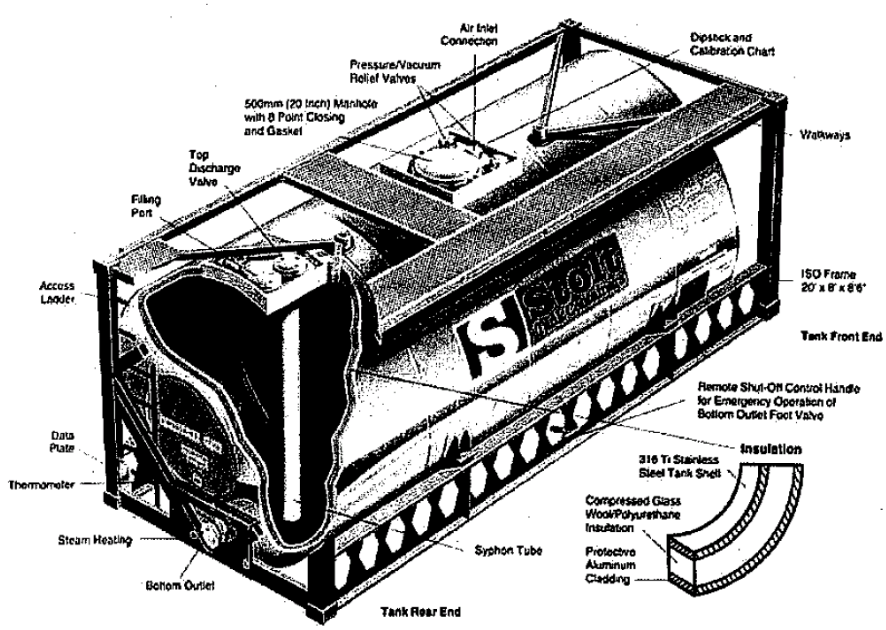
[19] These detectors had not been available in 2012.

headspace; and Tank J had 17.8% headspace. (Stipulated Facts at 7–8, ¶¶ 47, 53, 59.)

F. Filling Tanks I, J, and K

Stolt provided Tanks I, J, and K. An ISO container is a cylinder-shaped tank fixed into a 20-foot long, 8-foot wide, 8.5-foot high rectangular frame. (Nell Decl., ECF No. 1296, ¶ 5.) ISO containers are made to certain standards and the containers that were shipped aboard the Flaminia were similar to one another. (Id. ¶ 6.) The bodies of the tanks were constructed of stainless steel, then covered by a layer of insulation and a protective cladding. (Id. ¶ 8.) The containers have a top-side manhole, a pressure relief valve, a top discharge valve, a thermometer on the lower portion of the rear-side of the tank, and a bottom discharge outlet on the rear-side of the tank. (Id.)

Figure 3.



Each of Tanks I, J, and K had been periodically inspected and found to be in working order. (Id. ¶¶ 14–17.) Through the date of the incident, the containers had been regularly serviced and maintained. (Id. ¶ 17.) Each of Tanks I, J, and K were set in a rectangular frame made of carbon steel. Because the frame is necessarily larger than the container itself, when two containers are stacked on top of one another, the space between the top of the frame on the lower tank and the bottom of the frame on the upper tank is only approximately 3.1 inches. (Id. ¶ 9.) Under certain conditions, such as occurred at NOT and aboard the Flaminia, this proximity allows for radiative and convective heating.[20]

If and how heat can enter or exit an ISO container (that is, how well the ISO container absorb and/or emit heat) is highly relevant to the causation issues before the Court. Given oxygen saturation, the next question is whether heat conditions in and outside of the ISO containers of DVB (and DPA) contributed to polymerization. To understand this, the Court next turns to a discussion of "UA" values of the ISO containers. The UA value is the overall heat transfer coefficient, a measure of the ability to transfer heat into and out of an ISO container. Mathematically, it is the inverse of thermal resistance. Therefore, if an ISO container has a higher UA value, this indicates that heat is more easily transferred into or out of it (i.e., that the container has a lower thermal resistance). (Davis Decl. at 60, ¶ 2(a).) Thermal resistance of the relevant ISO containers—or, their ability to insulate DVB80—is a

[20] Convection is the transfer of heat by movement, or circulation, of liquids or gases. Radiation is energy emitted from a surface as particles or waves; it does not require a medium (such as a liquid or gas) to transfer heat.

key parameter in predicting the temperature history of the DVB80. There are various ways to measure UA values for ISO containers. Ultimately, the Court credits that performed by Dr. Davis, which was adopted by Dr. Kaminski.[21]

Dr. Davis arrived at a UA value of 39 W/K for Tank I. This was calculated through a Full-Scale Test (described below) using an ISO container of the same make and model as Tank I. (Davis Decl. at 63, ¶ 10.) Dr. Davis examined the average DVB80 temperature measured by four thermocouples (that is, a device that acts as a thermometer), which yielded a UA value of 36 W/K. The two thermocouples deepest in the tank, however, yielded an average UA value of 39 W/K for Tank I—this represents a conservatively high estimate of the overall coefficient, as well as the shortest induction time to auto-polymerization. (Id. at 67, ¶¶ 20–21.) Gexcon calculated the UA values for Tanks J and K as approximately 48 W/K. (Id. at 60, ¶ 2(a).)

Dr. Kaminski work examined the methods proposed by various experts in the case, and carefully and thoroughly analyzed whether their predicted thermal resistance values were supportable. Ultimately, she determined that the "full scale value of 39 is likely to be the most accurate because the container measured was made on the same assembly line as Tank I of the incident voyage, was the next container manufactured after Tank I, and closely resembles it physically." (Kaminski Decl. at 15, ¶ 39.) When combined with other measurements and

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[21] The Court agrees with the criticisms of Drs. Davis and Kaminski of Dr. Ott's work. Dr. Ott arrived at a UA value of 70 W/K, but this was derived using inaccurate assumptions such as 26,000 liter tanks (as opposed to 25,000 liter tanks) that were 70% (as opposed to 80%) filled. (Ott Decl. ¶ 102.)

modeled, these UA values support the Court's findings as to heat contributions into Tanks I, J, and K.

G. Prior DVB Incidents

Much of the foregoing discussion indicates to the Court that the DVB80 was sufficiently oxygenated and chilled when it left Deltech's facility—as such, something else must have caused the DVB80 to auto-polymerize and achieve thermal runaway aboard the Flaminia. But in addition, the parties spent substantial time at trial delving into previous incidents (all in 2006) that resulted in auto-polymerization of Deltech's DVB63 and DVB80. Stolt and Deltech argue that these incidents are informative because, afterward, Deltech changed its manufacturing process for DVB80 by, inter alia, increasing the amount of headspace in ISO containers to about 20%; since these changes, Deltech shipped DVB63 and DVB80 hundreds of times without incident. Plaintiffs, however, point to at least two of these incidents (Chauny and Grangemouth) as useful analogies; they attempt to draw out similarities between these incidents and what occurred aboard the Flaminia.

Ultimately, the Court is persuaded by Deltech and Stolt. As the Court will explain, each 2006 incident (described below) is distinguishable from the Flaminia incident. Moreover, between 2006 (when Deltech changed its procedures)[22] and 2012 (when the incident occurred aboard the Flaminia), none of the ISO containers filled by Deltech underwent thermal runaway.

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[22] Deltech's changes are described in more detail below.

Travis Johnson, Deltech's Quality Assurance and Laboratory Manager, testified at trial. Following the incident aboard the Flaminia in July 2012, Johnson was tasked with investigating whether the DVB shipped aboard the Flaminia had been filled in ISO containers in a manner consistent with Deltech's ISO container filling procedures. (Johnson Decl., ECF No. 1305, ¶ 13.) He was also responsible for ensuring that those practices had been consistent over time. (Id.) These assignments fell squarely within his duties and responsibilities in Quality Assurance. As part of his investigation, Johnson reviewed documents maintained in Deltech's files and was able to provide information regarding Deltech's history of manufacturing and shipment of DVB. The Court found Johnson credible and relies on his testimony.

Deltech commenced manufacturing and shipping DVB80 in 2006. It had begun manufacturing and shipping a lower grade of DVB—DVB63—in 2005. (Id. ¶ 15.) In 2006, at a time when shipping DVB was still relatively new for Deltech, Deltech experienced instances of shipments auto-polymerizing or product arriving at their destinations with elevated polymer content (a cause for concern as the formation of polymers happens with increases in temperature; and as set forth above, polymers beget polymers, hence the "runaway" polymerization risk).

Following these incidents in 2006, DVB made changes to its manufacturing and shipment procedures. First, prior to loading, Deltech chilled the DVB at a lower temperature than it had previously. Second, Deltech increased the empty headspace between the liquid DVB in an ISO container and the top of the tank from

10% to 20%. (Id. ¶ 17.) Headspace fills with oxygen, and when the tanks are moved (whether due to transport by truck or shifting during voyage), the oxygen then mixes with the liquid, allowing for additional oxygenation. Until 2012, Deltech had not had additional incidents involving polymerization following these changes. In 2006, changes in the manufacturing process were implemented.

Since Deltech first began manufacturing DVB in 2005, it has made almost 800 overseas shipments without incident. (Id. ¶¶ 24, 117 tbl. 2.) Among all of the hundreds of shipments Deltech has made, the only shipment that underwent thermal runaway reaction during an ocean crossing was that aboard the Flaminia in 2012. (Id. ¶ 25.) As set forth below, however, during the first summer that Deltech shipped DVB80 in 2006, there had been several incidents. But all involved a manufacturing process different from Deltech's procedures in 2012, and certain of them involved DVB in uninsulated drums (versus insulated ISO containers).

A lack of insulation fails to provide protection against heat. (Kaminski Decl. at 22, ¶ 2.) If drums containing DVB are left in the sun, the steel drums will absorb heat, which will easily and readily be transferred to the DVB. If left unabated, runaway polymerization can occur. (Id.) In addition, drums have a lower capacity than ISO containers and thus, when filled, hold a lesser amount of liquid. This would impact the time to auto-polymerization or induction time because the more DVB in a container, the more DVB there is to absorb energy. Further, drums have less surface area, increasing the ratio of the surface area to mass of the DVB in the container. Because heat is transferred where the container's surfaces come into contact with the DVB, the greater the surface area ratio (as in a drum versus in an ISO), and the faster heat will be absorbed by the DVB, causing its temperatures to increase. (Id. at 23, ¶ 4.)

Dr. Kaminski finds, and the Court agrees, that five of the seven incidents discussed below are not as analogous as plaintiffs claim. (Id. at 24, ¶ 7.) The remaining two incidents—the “Chauny” and “Grangemouth” incidents—are useful, and they support the view that the Flaminia DVB80 cargo would have completed the voyage safely under normal conditions.

1. Lanxess

On July 3, 2006, Deltech shipped an ISO container of DVB80 trans-Atlantic, to its customer Lanxess Deutschland GmbH (“Lanxess”). The ISO container had been filled to 90% capacity. Its temperature at filling was 60°F (15.5°C). The product did not vent during the voyage.

The ISO containers were delivered to Lanxess on July 31, 2006. Lanxess notified Deltech that the shipment had elevated polymer levels. (Johnson Decl. ¶ 31.) In fact, DVB polymer clogged the discharge valve. Despite this, the customer (Lanxess) was able to filter the polymer product and use it. (Id.) Deltech determined that the product that had been sent to Lanxess had spent very little time mixing and chilling in the MV-804 storage tank. (Id. ¶ 34.)

The Court finds that the Lanxess incident is not analogous to the DVB80 aboard the Flaminia. The DVB shipped to Lanxess had been subjected to different chilling and fill level procedures than the product aboard the Flaminia.

2. Rohm & Haas

The second DVB shipment with polymerization issues occurred only three days later, on August 3, 2006. On June 15, 2006, Deltech had filled an ISO container shipment of DVB63, in an ISO container with a 90% fill level bound for its customer, Rohm & Haas, located in Chauny, France. (Id. at 8–9, ¶¶ 40–42.) The ISO container of DVB63 was transported by truck to NOT. At the terminal, it was exposed to average daily temperatures of 83°F (23°C). It took 30 days for the shipment to reach Chauny. Upon arrival on August 3, 2006, it had elevated polymer levels. However, it had not achieved thermal runaway.

The Court does not find that this incident is analogous to what occurred aboard the Flaminia. First, the product had a higher fill level (and therefore less headspace) in the ISO container, and second, it had not been chilled to the same extent in the MV-804 tank as the DVB80 shipped aboard the Flaminia.

3. Ashland/Amwar in Brook Park, Ohio

Also on August 3, 2006 (the same day as the Rohm & Haas shipment above), Deltech's customer, Ashland, Inc. ("Ashland") in Brook Park, Ohio, reported to Deltech that a shipment was undergoing polymerization. Ashland had received twenty uninsulated drums of DVB80. (Id. at 10, ¶ 48.) When the drums were filled with the DVB80, the temperature measured 54°F (18°C); this is 10°F higher than was the Flaminia DVB80 when it was initially filled into Tanks I, J, and K. The drums were also filled to 90% capacity. From July 13–18, the drums were trucked from Baton Rouge to Ohio. Sixteen days later, on August 3, 2006, Deltech received notification that the drums were undergoing polymerization. Deltech did not receive information regarding storage conditions between July 18 and August 3.

The Court does not find the circumstances of the Ashland shipment relevant to the DVB80 aboard the Flaminia. First, the DVB80 was at a higher initial temperature when it was filled into uninsulated drums, not insulated ISO containers. In addition, the lack of information regarding storage conditions eliminates the Court's ability to draw conclusions regarding the cause of the polymerization.

4. Whitehall Township, PA

On July 10, 2006, at its facility in Baton Rouge, Deltech filled four, uninsulated 55 gallon drums with DVB63 for its customer, Bowden Chemical Ltd. ("Bowden"). Bowden arranged for the transport of the drums and did not pick them up for nine days—that is, until July 19, 2006. (Id. at ¶ 54.) The temperature in the truck in which the drums were shipped was measured at 120°F (48.9°C)—far higher than the recommended 85°F. On August 6, 2006, Deltech received notice that the product shipped to Bowden auto-polymerized.

The Court does not find that the circumstances with regard to the Bowden product are relevant to those at issue here. First, the product was filled into uninsulated drums, and shipment temperatures were higher than they should have been. However, it is unclear how those truck conditions compared to temperatures at NOT (influenced by solar radiation) aboard the Flaminia.

5. Chauny, France

The parties spent significant time at trial on the circumstances relating to this shipment, referred to as the "Chauny" incident. This incident relates to another shipment of DVB product to Deltech's customer Rohm & Haas. (Id. at 12, ¶ 57.) The salient facts relating to this incident are as follows: Deltech filled an ISO container with DVB80 on July 3, 2006. At the time of filling, the temperature of the DVB80 was measured as 60–61°F (15.5–16.1°C). The DVB80 had been mixed and chilled in the product storage tank for, at most, five days. These two facts—from the start—distinguish this shipment from Tanks I, J, and K aboard the Flaminia. The fill temperature was 16°F higher than Tanks I, J, and K, and the Chauny tanks had spent five to six fewer days mixing with oxygen and chilling in the MV-804 tank.

After filling, the Chauny ISO container was transported by truck to Houston, Texas. It sat on the dock in Houston for an additional 12 days—from July 4–15, 2006. The average temperature during that period was 85°F (29.4°C); certain days experienced high temperatures of over 95°F (35°C). This was two days longer on the dock than Tanks I, J, and K (with somewhat similar ambient temperatures), but there is no indication that on the dock, this tank was proximate to tanks of heated DPA. The ISO container was then loaded onto a vessel for trans-Atlantic shipment. The voyage carrying this ISO container lasted 17 days—from July 15 to August 1, 2006. Upon arrival, the container sat for several additional days until it began the final leg of its trip to Chauny, France. On August 7, 2006, and while en route to

Chauny, the ISO container began to vent. It was determined that the DVB80 was experiencing auto-polymerization. It never exploded.

There are certain notable similarities between the Chauny incident and that onboard the Flaminia. Both products sat on a dock with ambient temperatures in excess of 80 degrees for a period of days prior to loading, and the voyages on both trips were a similar duration. These similarities are of particular interest insofar as the Chauny product made it safely across the ocean, and only began to vent once en route to Chauny. Moreover, it never exploded. Additionally, the Flaminia product auto-polymerized in 22.75 days, versus the 36 days that it took for the Chauny product to achieve runaway auto-polymerization.

There are, however, significant differences. It is significant that again, the fill and chill conditions during the loading and manufacturing processes were different: the Chauny product was chilled in the day tank for fewer days than that shipped aboard the Flaminia and it was filled to 90% in the ISO container. Also, the Chauny product was loaded aboard the vessel 12 days after initially being filled—two days longer than the product onboard the Flaminia.

6. Grangemouth, Scotland

Another auto-polymerization event that received extensive attention during the trial occurred in Grangemouth, Scotland. An ISO container was filled with DVB63 on June 23, 2006. (Id. at 15, ¶ 74.) Sixty-two days later, on August 23, 2016, it achieved thermal runaway. The temperature at the time the ISO container was filled was 48°F and it was filled to 90% capacity. At the time of filling, the product had only chilled for a few days (fewer than the 10 allowed for Tanks I, J, and K). After filling, the tank was then transported to NOT, where it sat for 11 days. That is to say, it was not loaded onto the ship until 12 days after it had been filled (one day longer than the ISOs destined for the Flaminia sat at NOT). During the time at NOT, the average daily temperature was 85°F (29.4°C); again, during the day, certain temperatures exceeded that by several degrees. The container was then loaded onto a vessel and successfully completed a trans-Atlantic voyage.

It arrived in Antwerp, Belgium on July 4, 2006; it was then transported to the Netherlands before being placed aboard another vessel for transport to Scotland. (Deltech Ex. 152 at 1.) During this period, the ISO container was exposed to high ambient temperatures between 85–100°F (29.4–37.8°C). On August 23, 2006, 41 days after it had been off-loaded from its trans-Atlantic voyage, the DVB63 tank achieved thermal runaway in Grangemouth.

There are notable differences and some similarities between the Grangemouth incident and what occurred aboard the Flaminia. In terms of the similarities, the Court notes that the Grangemouth ISO container sat at NOT for a period of time, exposed to ambient temperatures in excess of 80 degrees prior to loading. But the differences must not be ignored. As already discussed, the filling and chill procedures were different. Additionally, the Grangemouth shipment completed the trans-Atlantic voyage without incident.

7. Rohm & Haas Incident #3

The final auto-polymerization incident that occurred in 2006 related to product again destined for Deltech's customer Rohm & Haas. This incident did not result in thermal runaway, but in elevated polymer levels rendering the product delivered to Rohm & Haas "off-specification." (Johnson Decl. at 18, ¶ 93.) Here, again, there are differences between these circumstances and what occurred aboard the Flaminia. First, the chill and fill procedures were different—the DVB63 chilled for fewer days and the ISO container was filled to 90%. The ISO container made the trans-Atlantic crossing without incident. It was subsequently off-loaded and stored in a depot in the Netherlands for 41 days. On August 23, 2006, 63 days after filling, the ISO container was delivered to Rohm & Haas. That same day, Rohm & Haas informed Deltech that the DVB had elevated polymer levels and was off-specification.

The Court finds that this incident is not analogous to what occurred aboard the Flaminia. The product had the same differences in chilling and fill level as discussed elsewhere, it made the trans-Atlantic voyage successfully, sat at a depot in unknown conditions for 41 days, and even then, never achieved thermal runaway.

8. Changes to the Manufacturing Process After the 2006 Incidents

The above incidents confirm the Court's view that what occurred aboard the Flaminia was unusual and not the result of the Deltech manufacturing process. These incidents reveal what occurs when the manufacturing process has issues: all of the incidents occurred during a 24-day period in 2006, and none occurred in the years after Deltech changed its manufacturing and fill process.

Following the 2006 incidents described above, Deltech changed certain aspects of its manufacturing and fill processes. In 2007, Deltech roughly doubled the amount of headspace in its shipments (from 10% headspace to approximately 20% headspace), allowing more oxygen into the tank to mix with the product. Deltech also implemented additional chilling procedures. It began chilling the DVB80 to cooler temperatures: from about 61°F (16.1°C) to 45°F (7.2°C). This increases the time that it would take to heat up the product and thus increase the time to polymer formation or thermal runaway. When product arrives at the storage facility in Belgium ("ADPO"), its temperature is measured and is consistently below 25°C. A report of the temperature of the Deltech DVB product measured at ADPO for 2012 does not show any product above 25°C. ADPO also measures polymer levels of the Deltech DVB product. Other than the Flaminia shipment, none of the 300 shipments that ADPO has measured experienced a thermal runaway or were found to have polymer levels elevated above the customer's specification.

The Court also finds persuasive evidence that shows that other containers of DVB80, filled in approximately the same timeframe as the Flaminia's containers, did not experience thermal runaway. Between May 3, 2012 and June 18, 2012, Deltech filled thirteen other ISO containers with DVB80. These tanks were destined for shipments aboard five other vessels, also departing from NOT. When the contents of these ISO containers were transferred to the ADPO storage tanks, the DVB within the storage tank was within specification.

H. The Conditions at New Orleans Terminal

After being filled with DVB 80 on June 21, 2012, Tanks I, J, and K were trucked to NOT.[23] In light of other factors, Deltech's fateful decision to ship Tanks I, J, and K out of NOT—as opposed to a more northern port—was a substantial contributing factor in the auto-polymerization event aboard the Flaminia. (Stipulated Facts at 16, ¶ 1.)

Deltech utilizes various ports and routes for shipping its product overseas. Shipping via NOT at New Orleans takes longer to reach Antwerp than do other routes. (Deltech Trial Ex. 139 at 18.) Based on its investigation into other auto-polymerization events that had occurred in 2006, Deltech understood that the combination of time-to-destination and temperature exposure risked the stability of the product. As it was summer (June 2012), temperatures at NOT could have almost certainly been expected to be higher than the recommended maximum of 85°F. The choice to ship from NOT therefore risked (1) a longer time-to-destination, and (2) higher NOT exposure temperatures than a more northern port (such as Newark's).

A Deltech document set forth transit times as follows:

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[23] This transport process would have additionally oxygenated the DVB80 as it "sloshed" around the tank. (See Kaminski Decl. at 34, ¶ 10.)

Table 1.

Route	Range Number of Days in Transit	Median Number of Days in Transit	Maximum Number of Days in Transit
New York to Antwerp	7–12	9.5	13
Charleston to Antwerp	11–13	12	16
New Orleans to Antwerp	15–17	16	31

(Id.) In fact, after the 2006 auto-polymerization incidents, Deltech implemented a policy of shipping DVB80 to Europe only through Newark during the hottest time of year: April 16 to November 14. (Pl.'s Ex. 59 at 2–3.)

In March 2012, when a Deltech employee was consulted about shipping DVB80 from NOT to Antwerp, he stated: "Since we have no control of the container once it leaves the plant and the possibility of sitting on a dock at 100 F, I vote no." (Pl.'s Ex. 141 at 2.) Then, forty minutes later: "If I understand the transit route the shipment from NO [New Orleans] goes south and exposure time to heat is much longer. We changed to the NJ route to avoid that exposure in the summer." (Id. at 1.) When asked at his pre-trial deposition whether it was safer to ship out of Newark, the same employee unequivocally answered "Yes." (Fluharty Dep. Tr. at 224:19–23.) He also stated, "If we were going to ship out of New Orleans? That [sic] we probably should ship in refrigerated containers in hot weather conditions." (Id. at 222:19–23.) Based upon a desire to fulfill a customer order as soon as possible, however, Deltech's owner and President, Bob Elefante, nonetheless decided to ship from NOT. (Levine Dep. Tr. at 106:4–9; id. at 237:2–18; id. at 240:19–25; id. at 241:2–16.)

Tanks I, J, and K arrived at NOT on June 21, 2012 and sat still on the dock until July 1, 2012, when they were loaded aboard the Flaminia. A principal question in this Phase 1 trial is whether this 10-day period of storage at NOT substantially contributed to the auto-polymerization of the DVB80 on July 14, 2012. The Court finds that there is convincing evidence that it did.

As discussed below, several aspects of the storage at NOT lead to this conclusion. First, once on the dock, the liquid became still—previously, it had been circulated in a tank and sloshed around in a truck. This diminished ongoing oxygen diffusion. Deltech had previously recognized such circumstances as having been a contributing factor to the 2006 auto-polymerization events. (Pl.'s Ex. 113 at 3.) In a Deltech email analyzing the cause(s) of such events, an employee noted:

> One thing that all of our DVB polymerization incidents had in common besides temperature was that they were held quite still for some days or weeks. As the temperature of the bulk liquid rises, the rates of TBC and oxygen consumption rise. If the solution is still, then the only method for oxygen to be distributed through out the bulk liquid is diffusion. Diffusion is not a very fast method of transportation and so it is possible that at some temperature, the oxygen is being consumed faster than it can diffuse into the entirety of the liquid. The implications of this are simple: for a container sitting still at an average temperature, if the oxygen is consumed at the bottom of the container, where it is farthest away from the headspace air, then the inhibition is lost in the bottom of the container, and thus the polymerization could begin unchecked by TBC.

(Id.)

In addition, at NOT, the DVB80 containers were stored outdoors and exposed to consistently warm ambient temperatures. On June 21, the high daytime temperature was 92°F (33.3°C), and the average temperature was 85°F (29.4°C).

On June 26, 27, 28 and 29, the high temperature reached 96–98°F (35.5–36.6°C). (Earle Decl., ECF No. 1289, ¶ 3.)

Chemtura's expert, Douglas J. Carpenter, also testified that while at NOT, the DVB containers were subjected to temperatures substantially higher than the recommended 65°F (18°C). (Carpenter Decl., ECF No. 1293, ¶ 43.) He further stated:

> the DVB containers exposed to the sun at NOT also would have received thermal energy from the uninsulated spill box manlid on the top of the shilling containers. This exposed section of the tank can transfer more thermal energy since it is not thermally insulated. This is especially true in the scenario where an ISO container is located on the top of the pile with exposure to direct thermal radiation from the sun for an extended period of time (in this case, approximately 10 days).

(Id. ¶ 44.) He added, "This solar contribution would be analogous to having a heated plate inside the container with a surface temperature of 90°F to heat the vapor space and ultimately the DVB liquid in the container." (Id.)

Based on its prior investigations into the 2006 auto-polymerization incidents, Deltech recognized that exposure to high temperatures was a contributing factor. For instance, a Deltech "Root Cause Analysis and Corrective Action Report" stated:

> Root Cause 1
> Shipping:
> The product was left still and unmonitored in Antwerp for 30 days, which is not recommended. The weather in Antwerp was not above the temperatures that Deltech normally stores its DVB, but the fact that the materials was [sic] not handled, circulated, aerated or sampled AND had seen about 15 days of temperatures in the 80's leads us to believe that the material could have had significant polymer formation during shipping and handling. Other incidents with DVB . . . lend support to the main cause as improper handling leading to polymerization.

(Pl.'s Ex. 85 at 2.) Another "Root Cause Analysis" for a separate incident found similarly:

> Root Cause 1
> Polymer formation during shipping and handling:
> The product was held in ambient conditions unsuitable for storage of the material for 66 days. The most likely cause of this autopolymerization is the consistent elevated temperature.

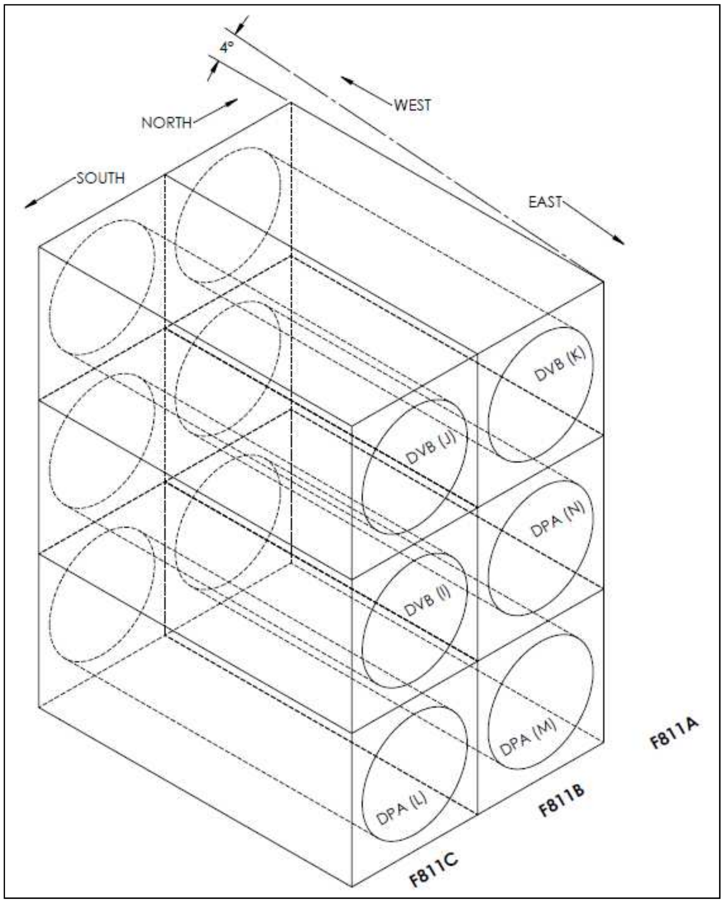
(Pl.'s Ex. 87 at 2.) An additional Deltech study concluded that DVB transportation times needed to be kept to 15–20 days, and less if the temperature was greater than 85°F:

> The conclusion is simple and inconsistent with current handling and storage procedures included in either Deltech or Dow's MSDS or product bulletins. We believe that DVB has to be handled in a controlled environment where periods without direct care are kept to a minimum typically less than 15–20 days. The 15–20 days is based upon the product being exposed to average daily temperatures in the 75-85 degrees F. Should temperatures exceed 85°F then this time without direct care needs to be shortened. When temperature exposure is less than 75°F then the time without direct care can increase. However, we do not recommend leaving the product without direct care for more than 35 days.

(Deltech Ex. 139 at 3.)

Third, at NOT, the DVB80 containers were adjacent to containers of heated DPA and other cargo. The following diagram shows the arrangement of the DVB80 containers (Tanks I, J, and K) and the relevant DPA containers (Tanks L, M, and N):

Figure 4.



(Davis Decl. at 17, ¶ 9.) As evidenced from the diagram, while on the dock at NOT, Tank I was exposed to thermal radiation from three neighboring ISO containers filled with heated DPA: Tanks L, M, and N.

It must be kept in mind that the ISO containers are 20 feet long and thus "border" adjacent containers in close proximity for a full 20 feet. The DVB80 ISO container on the top left, designated Tank J, was exposed to solar radiation and had a narrow line of exposure to one neighboring ISO container filled with heated DPA (Tank N); Tank K, on the top right, was exposed both to direct solar and thermal radiation from the heated DPA in the ISO container beneath it, Tank N; and Tank

I, in the middle on the left, was exposed to direct solar and thermal radiation from two heated DPA containers, Tanks N and L, as well as Tank M through a narrower line of exposure. (See Kaminski Decl. at 17, ¶ 42.)

I. Measuring the Effect of the Conditions at NOT on Tanks I, J, and K

To analyze the effect of these conditions on the temperature of the DVB80 and DPA while they sat at NOT for 10 days, Dr. Kaminski performed various simulations. She broke the ISO container's thermal resistance down into "internal thermal resistance" and "external thermal resistance." (Kaminski Decl. at 18, ¶ 44.) Internal thermal resistance consisted of natural convection of DVB80 with the inside wall of the container, conduction through the container wall and various support members, and conduction across the insulation. External thermal resistance consisted of natural convection and radiation from the outer surface of the 20-foot container. Both resistance values are needed to determine the surface temperature of the container. (Id.)

At the time the ISO containers were filled, as set forth above, the DVB80 in the ISO containers was measured at 44°F (6.67°C), with the appropriate amount of TBC. Dr. Kaminski considered the particular position of each container, the average air temperature at NOT, and the temperature of the DPA. She included the absorption of solar energy by the ISO container while at NOT. (Id. at 19, ¶ 48.) She calculated the absorbed solar flux on an hour by hour basis and considered any portions of the ISO containers exposed to the sun, including ends and flat panels.

(Id.) She also took into account the angle at which the sun struck the surface of the container. (Id.)

While the ISO containers were stored at NOT, there was also metal grating above them. Dr. Kaminski took this structure into consideration in her analysis by considering that the metal grating on top of Tanks J and K acted to partially block the incoming sunlight. (Id. at 19, ¶ 49.) Her model further accounted for the varying position of the sun, the night sky temperature, and the absorptivity of the paint on the exterior of the container itself. (Id. at 19, ¶¶ 49–51.)[24]

J. Properties and Loading Condition of DPA Shipments

The DPA has a melting point of 125.6°F (53°C). (Stipulated Facts at 9, ¶ 65.) It is solid until heated. To fill an ISO container with DPA, the DPA is first heated to a level above its melting point. On June 21–25, 2012, as they were filled with DPA, Tanks A–F, L, M, N, and P, had temperatures between 71–74°C. (Stipulated Facts at 9–11, ¶¶ 67–76.)

On cross-examination, Chemtura's expert, Douglas J. Carpenter, agreed that while stored on the dock at NOT, the ISO containers of heated DPA would have made a thermal contribution to the temperature of the adjacent ISO containers of DVB. (Tr. 1198:9–18.) He agreed that the pavement underneath the ISO containers, as well as the ambient temperature in the hold, may have caused the

[24] The Court agrees with Dr. Kaminski's criticisms of the work of Dr. Ott regarding the impact of solar radiation on the liquids in the ISO containers. She correctly points out that his work does not include a radiation model, the solar radiation that follows from the exposure of portions of an ISO container to the sun, and the liquid capacity of the container and its impact on absorptivity. (Kaminski Decl. at 20, ¶ 54.)

DPA to increase or maintain its temperature. (Tr. 1189:20–22, 1190:1–3, 1196:10–1197:1.)[25] Carpenter also acknowledged that ISO containers could receive thermal energy from the uninsulated spill box and manlid. (Carpenter Decl. at 18–19, ¶ 44.) While he was positing that this would have led to thermal energy heating the DVB, his conclusion in this regard is applicable to the ISO containers that were filled with DPA. In addition, he opined that when ISO containers are stacked on one another—as was the case here with the DPA and DVB containers at NOT—solar radiation of one container could, by radiative heating and/or convection, contribute to the temperature of the contents of an adjacent tank. (Id.) He gave this testimony in connection with opinions regarding the effect of solar radiation hitting a tank, and then being emitted from an uninsulated spill box or manlid. However, the evidence at trial supported solar radiation hitting certain ISO containers along the sides and ends, as well as the tops. In these circumstances, which Carpenter did not specifically address in his report, his conclusions are applicable to ISO containers of DPA impacted by solar radiation, and emitting heat through the uninsulated spill box and manlid to the adjacent containers of DVB.

In sum, the ISO containers of DPA arrived at NOT in a heated, liquid state, with a temperate above 125.6°F (53°C). The DPA was itself then further exposed to warm ambient temperatures, solar radiation, radiation from the pavement, and

[25] In his trial declaration and at various points during his examination, Carpenter opined that the casualty would have occurred independent of the presence of the DPA. (See, e.g., Carpenter Trial Decl. at 15, ¶ 38 et. seq.) The weight of the evidence is to the contrary. Indeed, statements made by Carpenter at trial, as recited herein, are supportive of the opposite conclusion.

radiative heat and convection from each other, which prevented the DPA liquid from cooling as rapidly as it otherwise would have. As a result, the ISO containers of DPA emitted heat through their tank walls, uninsulated manlids, and spill boxes, contributing to the temperature of the liquid DVB80 in the adjacent containers. The Court finds that given their proximity in storage, the ISO containers filled with heated DPA were a substantial factor in the heat conditions that led to DVB runaway polymerization.

Chemtura commissioned a study from Willbros Engineers LLC (the "Willbros Study"). The purpose of the study was to determine how quickly DPA filled into an ISO container at 175°F (79°C) would cool to its melting point, and to show that sufficient cooling would have occurred to eliminate any temperature contribution to the DVB80. (Carpenter Decl. at 21, ¶ 59; Carpenter Decl., Ex. C, ECF 1293-3 ("Willbros Study").) The Court is not persuaded that this study was sufficiently close to actual conditions to have utility. In the Willbros Study, an ISO container was filled with heated DPA (with a measured temperature of 175°F) and placed in a warehouse. The warehouse did not have mechanical ventilation, but from photographs it is clear that it was far roomier open than the Flaminia and had a large garage door that opened to the outside.

The DPA was 10°F (6°C) hotter than that in the ISO containers loaded aboard the Flaminia. After seven days, the DPA had cooled to 127°F (53°C). The exterior shell of the ISO container in the Willbros Study also never reached more than 18°F (10°C) above ambient temperature.

The conditions in which the ISO container in the Willbros Study was placed did not approximate those at NOT or aboard the Flaminia. First, and most significantly, the ISO container was never placed out in the open, where solar radiation would directly hit a portion of the container, and the container would be exposed to ambient temperatures that fluctuated into the 90s (Fahrenheit). Second, when in the warehouse, the container with DPA was not proximate to any other containers with heated DPA that might have emitted some heat. When both on the dock at NOT and in storage aboard the Flaminia, the ISO containers filled with DPA were proximate to one another. For instance, DPA (N) was directly below DVB (K), and directly adjacent to DVB (I). DVB (I) was also directly above another container with DPA, DPA (L). DPA (M) and DPA (N) were each diagonal from DVB (I) and (J), respectively. (See fig. 4.)

Finally, there was no evidence that the ambient temperatures in the warehouse would have been similar to the ambient temperatures in Hold 4 of the Flaminia. Indeed, the photographs of the Willbros Study show a large, garage-like door that opened into the outside, suggesting a level of ventilation that was not present within Hold 4. (Willbros Study at 18–20.) Taken together, the Court is not persuaded that the conditions in the Willbros Study were sufficiently similar to those at NOT or aboard the Flaminia to provide meaningful information regarding the speed of cooling. Accordingly, the Court draws no conclusions based upon the results of the Willbros Study.

Carpenter testified that the DVB was sufficiently saturated with oxygen that but for the addition of heat, it would have arrived safely at its destination. (Tr. 1151:4–11; Carpenter Decl. ¶ 52.)

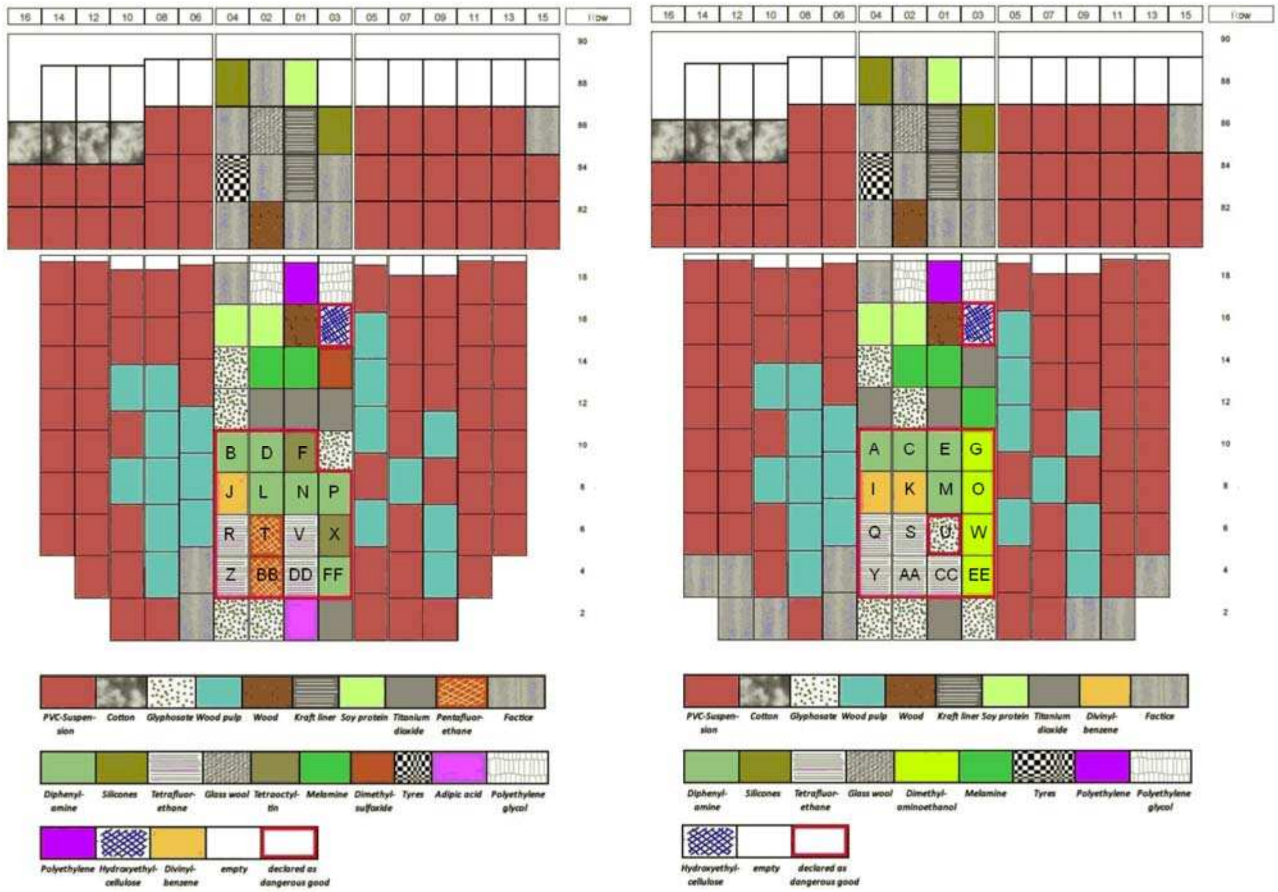
K. Stowage and Conditions in Hold 4 of the Flaminia

The cargo was loaded aboard the Flaminia on July 1, 2012. (Stipulated Facts at 18, ¶ 16.) Hold 4 was one of the holds designated for dangerous cargo. The containers with the DVB and DPA were loaded into this hold. Including the containers of DVB80 and DPA and the other cargo, 262 containers were stored below deck in Hold 4.[26]

Below is a diagram showing the arrangement of the relevant cargoes in Bays 29 and 31 of Hold No. 4 of the vessel:

[26] The other cargoes stowed in Cargo Hold 4 on the Flaminia played no role in causing the DVB80 to undergo a thermal runaway reaction and there is no evidence that they contributed to the explosion and fire that occurred on July 14, 2012.

Figure 5.



(Id. at 22, ¶ 31.) This diagram shows that in Hold 4, Tank J was surrounded on two sides by Tanks B and L, and diagonal to Tank D, all of which contained DPA. Similarly, Tank A—of heated DPA—was stored directly on top of the least insulated portion of Tank I, and Tank C was diagonal to it; Tank K had top, side, and diagonal DPA containers.

The Flaminia was propelled by heavy fuel oil or diesel oil stored in wing tanks along the port and starboard sides spanning from cargo hold 3 to cargo hold 7. (Id. at 23, ¶ 2; see also Davis Decl. at 18, ¶ 11.) Wing tanks were therefore located on either side of one of the holds designated for dangerous cargo, and the hold which the heat-sensitive DVB80 was stored, Hold 4. The wing tanks were equipped with heating coils, which were heated by steam generated in the engine room. (Stipulated Facts at 31, ¶ 33.) The fuel oil is heated during the voyage (and was during the voyage at issue here) in order to lower its viscosity so that it can be more easily pumped. (Davis Decl. at 18, ¶ 12.) Dr. Davis, Dr. Kaminski, and Carpenter all agreed that the fuel tanks adjacent to Hold 4 contributed to ambient temperatures in the hold. (Id. at 100–01, ¶ 4; Kaminski Decl. at 27, ¶ 3; Carpenter Decl. ¶ 49.)

Hold 4 was comprised of two principal compartments, or hatches, each of which was approximately forty feet long and had multiple cells. (Stipulated Facts at 28, ¶ 15.) Each cell was capable of holding two twenty-foot containers or, alternatively, one forty-foot container lengthwise. (Id.)

The hold also had three mechanical exhaust ventilation fans to accomplish at least two air changes per hour based on the volume of air in the hold when empty of cargo, with all three fans being operated simultaneously. (Id. at 29, ¶ 19.) Under normal circumstances, the nozzles and piping continuously sampled the air in the holds, drawn by fans, as a smoke detection system. (Id. at 29, ¶ 20.)

During the Flaminia's voyage, ambient outside temperatures were generally in the 80s (from July 2–9), with one day in the 60s (July 12), and three days in the 70s (July 10, 11, and 13). (Earle Decl. ¶ 11.) The average daily temperature during the Flaminia's voyage was higher than that for the five previous trans-Atlantic DVB shipments. (Id. ¶ 19.)

L. The Temperature Inside the Hold

The containers of DVB80 loaded into Hold 4 had already sat—motionless—on the dock at NOT for ten days, exposed to summer ambient heat, solar radiation from the sun, and thermal radiation from adjacent DPA containers. Neither the temperature of the DVB80 liquid nor its polymer content were measured when Tanks I, J, and K were loaded into Hold 4. No measurements were taken of the ambient temperature or the cargo in Hold 4. Accordingly, the parties in this matter presented expert opinions as to temperature based on known, likely, and theoretical conditions. The most significant expert opinions combined the manufacturing process, conditions at NOT, and conditions in Hold 4 to explain the likely cause of runaway polymerization.

All parties prepared models based on the fact that on the day of the explosion, July 14, 2012, Tanks I, J, and K had been in transit for 23 days. Notably, this was already three days beyond the 15–20 day preferred transit time and known ambient temperature conditions had, at times, exceeded the recommended maximum of 85°F. (Deltech Ex. 139.) Apart from these known conditions, the parties agree on little. Their respective experts offered substantially different opinions as to whether at the time Tanks I, J, and K were loaded into Hold 4, they were already doomed to auto-polymerize, (see Ott Decl., ECF No. 1306, at 4–9, ¶¶ 10–37), or whether the ambient conditions in Hold 4 were a necessary contributing factor.

The Court has already found that but for the extended storage at NOT, the auto-polymerization event would not have occurred. But it also would not have occurred but for higher than normal temperatures in Hold 4. The auto-polymerization resulted from a "perfect storm" of combined circumstances. Below, the Court first sets forth its findings with regard to the temperature in the hold. Following that, it turns to the expert modeling it finds most persuasive with respect to the onset of auto-polymerization and thermal runaway.

The temperature in the hold was influenced by a number of factors. First, ambient temperatures. During the Flaminia voyage at issue, the outside air temperatures were in the 80s Fahrenheit from July 2–9, in the 70s on July 10 and 11, and in the 60s on July 12 and 13. (Earle Decl. ¶ 11.) Both Dr. Davis and Dr. Kaminski found that the difference between the outside air temperature and that inside the hold was strongly dependent on whether the ventilation system was working, its capacity, and whether the ventilation flaps to the outside were open. Dr. Davis's modeling, which the Court found persuasive, demonstrated that even assuming ventilation, by July 7, 2012, the air temperature within the hold would have been 8.3°F higher than the outside air temperature. (Davis Decl. at 78, ¶ 5(a).) But if, as Dr. Kaminski assumed, the ventilation flaps to the outside were closed or the ventilation system was not operating, the temperature would have been higher. According to Dr. Davis, without ventilation, the hold temperatures would have been 11.2°F higher than outside ambient air temperatures.

Ventilation (or a lack thereof) would have exerted additional influence on the hold's temperature. MSC's Dangerous Cargo Manager, Dirk Vande Velde, testified that the ambient air temperature within a ship's hold is maintained by the ship's ventilation system. (See also Tr. at 1060:15–20.) There is mixed evidence as to whether the ventilation flaps were open but, on balance, the Court is persuaded that they were closed. All experts agree that if they were closed, the hold temperature was likely higher than it would have been if they were open. (See, e.g., Tr. at 624:24–25 (Davis); id. at 1055: 9–16, 1060:21–1061:6 (Kaminski); id. at 1256:17–23 (Robbins); Ott Decl. ¶ 146.) A crew member reported to the Captain that on the morning of July 14, 2012, the flaps on the hatch covers for the passive ventilation were found to have already been in the closed position when the crew arrived to close them in preparation for deployment of CO_2; the captain testified that he was "astonished" when he heard this. (Langer Vol. 1 Dep. Tr. at 72:22–73:12; 203:8–16.)[27] The third engineer confirmed that all four flaps for the passive ventilation were already closed at the time he arrived to close them. (Deltech Ex. 306 at 2.) Moreover, had the ventilation flaps been open, crew should have observed "smoke" (or venting DVB gas) emitting from them prior to the explosion; they did not. (Casandra Dep. Tr. at 100:4–102:17; id. at 105:10–106:5; id. at 112:2–13.)

[27] The Court here relies on certain designated deposition testimony, portions of which was objected to by one or more parties. The Court overrules those objections. Here, for instance, the shipping parties made a hearsay objection. However, the testimony fits comfortably within Federal Rule of Evidence 803(3).

The closed ventilation flaps meant that the mechanical ventilation fans had not been in use—as the flaps must be open for that to occur. (Dalomias Dep. Tr. at 108:6–8.) Further, crew testimony indicated that it was standard operating procedure for the Flaminia to use mechanical ventilation only while in port, not while at sea. (Tr. at 1255:1–7.) The Court finds that during the Flaminia's voyage from NOT en route to Antwerp, the mechanical ventilation for Hold 4 was not being operated.

Additional conditions added to the temperature within the hold: the heated wing tanks, (Davis Decl. at 100–01, ¶ 12), and the DPA. The fuel oil was heated to a temperature between 113–140°F (45–70°C). (Kirstein Dep. Tr. at 187:1–188:2; id. at 216:12–23); Tarnowski Dep. Tr. at 33:24–34:2; Langer Vol. 1 Dep. Tr. at 188:9–16.) Based upon usage, the fuel in the wing tank adjacent to Hold 4 would have been heated a day before it was needed, or by July 5, 2012. (Pokusa Dep. Tr. at 197:21–199:9; id. at 231:5–13.) As of July 13, 2012, the wing tanks adjacent to Hold 4 were almost empty. Thus, the heated wing tanks increased the temperature in Hold 4. (See Tr. at 990:13–18.)

And finally, as depicted in Figure 5 above, ten ISO containers of heated DPA were stowed in Hold 4: Tanks A, B, C, D, E, L, M, N, P, and FF. As described in more detail above, the three containers I, J, and K were therefore surrounded by containers of DPA. The DPA containers contributed to an increase in both the ambient air temperature in the hold and, via radiative heat, in the adjacent tanks themselves. (See Davis Decl. at 94, ¶ 48; id. at § 6.4; Kaminski Decl. at 17, ¶ 42.)

Dr. Davis persuasively modeled the influence of the DPA and found that between the DPA and reduced ventilation, the DVB80 liquid temperature would have risen to between 87.4–90.7°F (30.8–32.6°C). (Davis Decl. at 80, ¶ 9.)[28]

M. Measuring the DVB80's Shelf Life Aboard the Flaminia

As discussed above, an Arrhenius equation predicts the rate at which the polymer inhibitors are consumed as a function of temperature. (Davis Decl. at 98, ¶ 1(b).) Based on the temperature of the DVB80, the Arrhenius equation therefore predicts the fraction of inhibitor life depleted in the DVB80 liquid, and hence the amount of shelf life that remains for the liquid. (Id.)

1. Dr. Fauske's and Dr. Kaminski's Arrhenius Equations

Dr. Fauske, using his TAM tests, developed one Arrhenius equation for DVB in a container with no headspace (a conservative and restrictive estimate) and another for DVB in a container with 20% headspace. (Fauske Decl. at 8, ¶ 45.) Dr. Kaminski derived her Arrhenius equation based on data from the Chauny DVB80 incident, in which a shipment of DVB80 auto-polymerized in 2006. The DVB80 containers in the Chauny incident had 10% headspace. She used the UA value of 39 W/K, as determined by Gexcon's Full-Scale Test, and assumed the air temperature in the hold was 31°F (another conservative estimate), as put forth by plaintiff's expert, Robbins. (Kaminski Decl. at 35–36, ¶ 23.)

[28] Dr. Davis's modeling accounted for both convective and radiative heating from the containers of DPA.

Dr. Kaminski calculated the thermal history and “fraction of life consumed” by the DVB80 during the 14 days of the voyage. She used a model to simulate the heat transfer to the DVB80 from the containers filled with DPA, and she compared the Arrhenius equations put forth by Drs. Fauske and Ott to her own. According to her analysis, which the Court credits and found both thorough and persuasive, the temperature of the air in the hold was affected by many factors. These included the ambient air temperature, the sea temperature, the temperature of the heated fuel in the wing tanks, heat transfer from and to all of the containers in the hold, and the status of the ventilation fans and passive ventilation flaps. (Id. at 27, ¶ 3.)

Dr. Kaminski utilized these three equations to calculate the shelf life of the DVB80 aboard the Flaminia. She concluded that the Arrhenius equations that account for the DPA from the nearby ISO containers predict auto-polymerization on July 14, 2012 only if the ship’s ventilation had also been sufficiently impaired.

2. Dr. Davis’s Full-Scale Test

Dr. Davis performed the Full-Scale Test with an ISO container filled with DVB80 exposed to certain heat conditions. This test provided him—and the Court—with further support for his opinion as to what is likely to have occurred aboard the Flaminia and why. Gexcon’s Full-Scale Test allowed Dr. Davis to test his views with regard to the UA value for the ISO container, the induction time necessary to deplete the inhibitor and oxygen during thermal exposure, and various aspects of auto-polymerization reaction in an ISO container.

Gexcon applied the ambient temperatures at NOT to the ISO container used for the Full-Scale Test. (Davis Decl. at 68, ¶ 23.) He started with DVB80 at 6.7°C. To take into account the time at NOT, the exposure to the DPA, and the time spent in the hold, Gexcon would increase the exposure temperature to accelerate the induction time. Dr. Davis assumed that the DPA had a temperature of 71–73°C. Storage of the DVB ISO containers in proximity to these temperatures raised their temperature to between 24.1–24.9°C. (Id. at 74, ¶ 38.) The heated DPA increased ambient temperatures by approximately 2.9°C. (Id. at 74, ¶ 40.)

Dr. Davis used the Full-Scale Test to make predictions about the induction time (i.e., shelf life), accounting for the number of air changes per hour. Like Dr. Kaminski, he determined that the DVB80 shipments aboard the Flaminia would not have undergone thermal runaway unless the hold was excessively hot. He also determined that, accounting for the DPA and reduced ventilation, the DVB80 would likely auto-polymerize around July 14, 2012. If the ventilation system was completely off, auto-polymerization was predicted to have occurred on July 14, 2012—the precise day of the incident.

3. Dr. Ott's Calculations

The Court agrees with Dr. Davis's criticisms of Conti/MSC's expert, Dr. Brian Ott. Dr. Ott's principle opinion was that if the DVB80 had been properly oxygenated, then the other heat sources would not have caused run away auto-polymerization. He reached this conclusion without, however, ever visiting Deltech's manufacturing facility and without doing any of the sorts of measurements undertaken by Dr. Davis at that facility. Dr. Ott opined on the UA value of the ISO containers without running any actual tests on an ISO container.

Notably, Dr. Ott agreed that: the DPA would have added to ambient temperatures; solar radiation would have increased the heat of the DVB liquid by at least 1°C; the combination of ambient air and solar radiation would have increased the temperature from 6.7°C to 24 or 27°C; and the wing fuel tanks would have contributed to the temperature in the hold. He also agreed that the DVB80 liquid filled into the ISO containers destined for the Flaminia would have had 5–6% more oxygen saturation than the DVB liquid transported by the Ludovica.

Dr. Ott's assumptions, put into Dr. Davis's model, result in a prediction that auto-polymerization would have occurred after 15.7 days—almost a week earlier than it did occur. Moreover, Dr. Ott's own prediction uses an assumption that the oxygenation level is at 94%; if it were lower, as Dr. Ott claims it was, auto-polymerization should have occurred even sooner than his 15.7 days. (Davis Decl. at 110–11, ¶ 48.) In the end, a fundamental problem with Dr. Ott's oxygenation theory is that, unlike those of the Stolt/Deltech experts, it is entirely unsupported by any actual testing.

N. The Alarms, CO_2 Discharges, and Subsequent Explosion

The Flaminia is fitted with a smoke detection system. This system monitors the air in the cargo holds. (Stipulated Facts at 33, ¶ 43.) The system is located in the CO_2 room and to the right of the three-way valve manifold for the CO_2 system for the cargo holds. (Id. at 33, ¶ 44.) The cargo hold smoke detection alarm is linked to the ship's main monitoring and alarm system. (Id. at 34, ¶ 49.) The output from the smoke detection system to the main monitoring and alarm system, whether indicating a fire or a fault, is in the form of one alarm channel stating "SMOKE DETEC. CARGO SYS FAIL." (Id.)

At approximately 5:42 in the morning on July 14, 2012, the smoke detector alarm activated on the bridge of the Flaminia. (Id. at 35, ¶ 56.) At approximately 6:00 a.m., the Chief Officer sounded the general alarm and announced on the public address system that a fire had been detected in Cargo Hold 4. (Id. at 35, ¶ 60.) At 6:42:27 a.m., the door for the cabinet containing the master release ball valve for the cargo hold CO_2 system was opened. (Id. at 35, ¶ 63.) The second release of CO_2 to the cargo hold commenced at 7:07:52 a.m. as confirmed by the machinery monitoring system alarm log: CO2 BOTTLE CO2 LEAKAGE ALM ALARM M2 07:07:52 B. (Stipulated Facts at 36, ¶ 67.)

At 7:40 a.m., the Captain sent an email message to NSB headquarters that read:

> vessel in position
> 048 13 N / 027 59 W
> fire in hatch NO 4
> fire not under control
> stopped engine, used CO2 to destinguish (sic) the fire without result.
> Crew is ok

(Id. at 36, ¶ 69.) Sometime shortly after 8:00 a.m., the Chief Engineer was ordered to release additional CO_2 into Cargo Hold 4. (Id. at 36, ¶ 70.) The third release of CO_2 to the cargo hold commenced at 8:06:32 a.m. (Id. at 36, ¶ 71.)

The Flaminia was equipped with a fixed gas fire extinguishment system, a fire detection system, an alarm system, and a water supply fire main system with two fire pumps. (Id. at 32, ¶ 34.) The Flaminia's fixed High Pressure Carbon Dioxide Gas ("CO_2") System was intended to protect the engine room and all cargo holds and included 330 cylinders of CO_2, each of which contained 45 kilograms of CO_2; these were stored in the CO_2 Room. (Id. at 32, ¶ 35.) According to the vendor drawing, the quantity of CO_2 carried onboard was intended to ensure that the largest volume compartment requiring protection receives a sufficient concentration of CO_2 to suppress a fire. (Id. at 32, ¶ 36.)

Release of CO_2 into a cargo hold requires manual opening of the individual cylinders. The number of CO_2 cylinders released into the cargo holds varies by the size of the specific hold and the volume of cargo containers carried in the hold. (Id. at 33, ¶ 40.) The parties spent substantial time at trial on the questions of (1) whether the CO_2 release was inadequate, and (2) whether the DVB80 vapors could have been rendered inert and the explosion avoided if more tanks had been released.

The explosion occurred one to two minutes after the Chief Engineer finished opening the CO_2 cylinders for a third release of CO_2. (Id. at 36, ¶ 72.) The Chief Engineer was alone in the CO_2 room when the explosion occurred. (Stipulated Facts at 36.) The explosion occurred in the vicinity of Hold 4. (Id. at 36, ¶ 74.) After the explosion, on deck, the Second Officer looked back in the direction of Cargo Hold 4 to see a large amount of dense black smoke on the upper deck, containers falling into the sea, and, eventually, flames. (Id. at 37, ¶ 75.) After the explosion, witnesses on the bridge saw dense black smoke, containers in the sea, and flames coming from the area of Cargo Hold 4. (Id. at 37, ¶ 76.) At 8:08 a.m., the Captain sent another email message to NSB headquarters that included the original language from the prior message sent at 7:40 a.m. and the additional text:

> CARGO HOLD four ecxploded (sic)
> container over board will lesave (sic) the vessrel (sic)

(Id. at 37, ¶ 77.)

After the Flaminia incident, its CO_2 system was found to have been defective. (Paffenhoff Dep. Tr. at 21:18–21.)[29] Immediately after the incident, an engineer from NSB determined that piping leading to a booster unit (designed to assist in the release of CO_2) was incorrectly installed. This resulted in an activation of levers triggering an alarm and an unexpected shutdown of engine room equipment. (Dehde Dep. Tr. at 48:17–49:13; id. at 84:25–85:24; id. at 109:17–111:6; id. at 133:9–135:7; Deltech Ex. 315; Deltech Ex. 316.)

The Flaminia had four sets of instructions stating four difference sets of numbers regarding how many CO_2 cylinders needed to be released immediately and how many were to be released at 30-minute intervals. Two sets (a Fire Control and Safety Plan and the Nautical Audiovisual Emergency Control Support) both advised

[29] The Court in this Section cites the deposition transcripts of a number of plaintiffs' employees, some of whom were Flaminia crew members: Pompeyo Dalomias was an electrical engineer aboard the Flaminia; Joerg Dehde and Joerg Erdtmann are both project engineers for NSB; Lars Paffenhoff was a fleet engineer for NSB at the time of the Flaminia incident; Maciej Pokusa was a second engineer on the Flaminia; Steve Sabandal was a fitter on the Flaminia; Janusz Tarnowski was an engineer aboard the Flaminia.

an initial release of 189 cylinders, with 32 cylinders every 30 minutes thereafter. (Erdtmann Dep. Tr. at 75:17–76:14; Hall Dep. Tr. at 207:10–211:10[30]; Deltech Ex. 266; Deltech Ex. 318; Deltech Ex. 319.) Additional instructions directed that only 31 cylinders should be released immediately into the hold, and 31 additional cylinders every 30 minutes thereafter. (Tarnowski Dep. Tr. at 69:25–70:8; Deltech Ex. 265; Deltech Ex. 320; Deltech Ex. 330.)

The evidence supports confusion surrounding the releases of CO_2. Several individuals testified that they were involved in the manual opening of CO_2 cylinders, but were not sure how many. (See, e.g., Dalomias Dep. Tr. at 65:3–23; id. at 78:13–15; Sabandal Dep. Tr. at 22:6–20; id. at 51:6–11); Pokusa Dep. Tr. at 36:12–14; id. at 38:2–4.) The weight of the evidence supports fewer than 30 cylinders having been released during the first release. Following the first release of CO_2, the Flaminia's main engine room shut down. (Tarnowski at 194:6–15.) The vessel's electrician was able to restart the auxiliary boiler only shortly before the explosion. (Dalomias Dep. Tr. at 58:11–59:13; id. at 60:1–61:5.) And as noted above, a second release of CO_2 cylinders did occur at 7:07 a.m.—but again, none of the personnel employed in the task could recall how many cylinders were operated. (Tarnowski at 126:4–14; id. at 198:23–199:2; id. at 229:14–19.) The evidence supports a release of only 7 cylinders during the second release. (Davis Decl. at 134–36, § 9.2.3.)

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30 Brian Hall was employed by the Merchant Marine Academy and was retained as an expert in shipboard firefighting.

As noted earlier, the Court is persuaded that the DVB80 did not auto-ignite—rather, crew activity led to a spark that caused the explosion and fire in Hold 4. The parties agree that the thermal runaway of the DVB80 led to the discharge of flammable vapors into the hold. (See, e.g., Davis Decl. at 121, ¶ 1; Ott Decl. at 54, ¶ 199.) Then, the Court finds, the explosion was ignited when the crew opened the manlid to insert firehoses.

Opening the access point would have allowed more oxygen into the hold, which likely brought the DVB80 vapor within the narrow concentration range (1.1–6.2%) that allows it to ignite. A spark was then created through the opening of an access point or by dropping a metal object into Hold 4. The physical act of opening an access point—which can be heavy and "track back when you open" it—can create a spark. (Tr. at 826:3–6.) And while there is uncertainty as to whether hoses were inserted into the hold—the hoses were certainly being prepared and positioned—the Court is persuaded by Dr. Beeley's testimony that, when he examined the Flaminia, he found evidence of burnt hoses that had been attached to the hydrants, such as the remains of the spigot and burnt bits of hose. (Id. at 834:1–16; id. at 826:22–827:4; Robbins Decl. ¶ 50; Langer Dep. Tr. at 135:2–23.) The insertion of the hoses itself could also have initiated the spark. Thus, the Court finds that this crew activity—again, in response to what crew members believed was an ongoing fire—created a spark that triggered the explosion.

IV. CONCLUSIONS OF LAW

The parties agreed that the Court's primary task in Phase 1 of this multi-phase trial is factual: the Court is to decide what occurred during the production and transport of the DVB80, and which external conditions ultimately contributed to the explosion and fire aboard the Flaminia. The conclusions of law discussed herein are therefore limited to very basic concepts of causation.

In order for a party to be found liable on any of the claims against it, the claimants must establish causation. See In re M/V DG Harmony, 533 F.3d 83, 96 (2d Cir. 2008) ("In addition to proving duty and breach, the plaintiff must prove causation. . . . [and] show that the dangerousness of the cargo . . . caused the harm."). Causation requires claimants to prove both cause in fact as well as legal cause. See Jurgens v. Poling Transp. Corp., fa113 F. Supp. 2d 388, 397 (E.D.N.Y. Sept. 19, 2000) ("To prevail on a claim for negligence under the general maritime law, the burden is on the plaintiff to establish duty, breach of duty, causation (both cause in fact and proximate cause) and damages." (internal quotation omitted).

The fire and explosion that occurred aboard the Flaminia on the morning of July 14, 2012 were caused by a number of factors. All parties agree that the DVB80 onboard underwent auto-polymerization, which led to thermal runaway. The Court now finds that the following were substantial contributing factors that led to the DVB80's auto-polymerization:

- The decision to ship the DVB80 out of NOT, which necessitated a longer voyage than would have a more northeastern port and exposed it to undesirable conditions;
- The fact that the DVB80 was left still on the dock at NOT for 10 days in the sun, in hot weather, and next to a number of tanks of heated DPA[31];
- The placement of the DVB80 in Hold 4, where it was stored next to containers of heated DPA and near the ship's heated fuel tanks; and
- The lack of proper ventilation, leading to hotter-than-typical ambient temperatures in Hold 4.

The Court additionally finds that the DVB80 was adequately oxygenated and chilled when it left Deltech's facility, and that it did not auto-ignite aboard the ship. Rather, crew activity—through, inter alia, opening the access point to Hold 4—created a spark that ignited the fire.

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[31] Dr. Davis specifically estimates that the storage conditions at NOT subjected the DVB to "a needless and avoidable 2.5°C increase in the bulk liquid temp of the DVB80 at loading." (Davis Decl. at 77, ¶ 1.)

V. CONCLUSION

Based on the Court's decision as to Phase 1, the parties are to confer on the timing for Phases 2 and 3. The Court believes that those phases can be combined. The parties shall consult and provide proposed dates (with expected duration) in a letter to the Court filed **not later than December 15, 2017**.

SO ORDERED.

Dated: New York, New York
November 17, 2017

KATHERINE B. FORREST
United States District Judge