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Safe transport of cyanamide

Klaus-Dieter Wehrstedt [a,*], Werner Wildner [b], Thomas Güthner [c], Klaus Holzrichter [c], Bernd Mertschenk [c], Armin Ulrich [d]

[a] BAM Federal Institute for Materials Research and Testing, Division II.2 "Reactive Substances and Systems", Unter den Eichen 87, D-12205 Berlin, Germany
[b] AQura GmbH, Rodenbacher Chaussee 4, D-63457 Hanau-Wolfgang, Germany
[c] AlzChem Trostberg GmbH, Dr.-Albert-Frank-Straße 32, D-83308 Trostberg, Germany
[d] BAM Federal Institute for Materials Research and Testing, Division III.2 "Tanks for Dangerous Goods and Accidental Mechanics", Unter den Eichen 44-46, D-12203 Berlin, Germany

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In memory of Dr. Chester M. McCloskey (1918–2009).

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ABSTRACT

For many years cyanamide (CAS no. 420-04-2) was not commercially available due to its unstable nature. Since about 1965 the former "Süddeutsche Kalkstickstoffwerke AG" (current name: AlzChem Trostberg GmbH) developed a special stabilizing system. It was to be investigated to which Class (e.g. "Corrosive Substances", Class 8) or Division (e.g. "Self-reactive Substances", Division 4.1) of the International Regulations for the Transport of Dangerous Goods cyanamide (pure or as a 50% solution in water) should be assigned and based on this which maximum quantities are allowed to transport e.g. in tanks. Cyanamide is used for the synthesis of pharmaceutical and agrochemical actives, biocides, dyestuffs and fine chemicals.

During the last years cyanamide was tested at BAM and AQura. The results and an appraisal are presented in this paper. Thus, cyanamide should be classified according to the UN Recommendations on the Transport of Dangerous Goods in Class 8, UN number 2922 (50% solution in water) and UN number 2923 (pure substance) respectively, packaging group III, danger labels 8 + 6.1. Cyanamide, 50% solution in water, can be transported in portable tanks under specific conditions.

1. Introduction

Cyanamide (Fig. 1) was first obtained by Bineau [1] from cyanogen chloride and ammonia in 1838. The first real source for cyanamide was found by Caro and Frank [2] by developing a process for calcium cyanamide starting from calcium carbide in 1895. However, the problem of low stability of aqueous cyanamide solutions (Cyanamide L 500) was first solved by Süddeutsche Kalkstickstoffwerke AG, Germany (current name: AlzChem Trostberg GmbH), 1965 in technical scale [3,4]. Some years later a technical process for stabilized solid cyanamide (Cyanamide F 1000), was established and its stability increased continuously.

Cyanamide is shipped and used worldwide in large quantities and therefore the riskless transport is important for quality and safety reasons. According to the UN Recommendations on the Transport of Dangerous Goods [5] no person may offer or accept dangerous goods for transport, unless those goods are properly classified, packaged, marked, labeled, placarded, described and certified on a transport document, except if otherwise provided in these regulations. Consequently, it had to be decided whether the previous assignment of cyanamide as merchandise to Class 8 is still possible or is a classification as a self-reactive substance of Division 4.1 more appropriate and under which conditions the transport is safe particularly in tanks. The UN Manual of Tests and Criteria [6] contains a number of test methods to determine the hazard potential (e.g. explosive properties, thermal stability and vent sizing test) of a substance or formulation. On the basis of the obtained test results a final decision was made. The object of this paper is to give information about the properties of cyanamide and the correct classification according to the UN Recommendations on the Transport of Dangerous Goods.

2. Test samples and test procedure

2.1. Test samples

2.1.1. Cyanamide, technically pure (>99%, stabilized), trade name: Cyanamide F 1000, AlzChem Trostberg

The following relevant data characterize the substance:

Colorless, deliquescent crystals, melting point (46 °C), boiling range (132–138 °C, 16 hPa, decomposition), vapor pressure (0.005 hPa, 20 °C), density (1.28 g/cm^3, 20 °C), bulk density

* Corresponding author. Tel.: +49 30 8104 1220; fax: +49 30 8104 1227.
E-mail address: klaus-dieter.wehrstedt@bam.de (K.-D. Wehrstedt).

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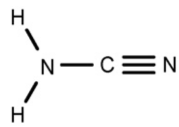

Fig. 1. Cyanamide.

(700–800 kg/m^3), constant pressure heat capacity c_P (1.86 J/(g K) [7]), heat of fusion (208.5 J/g), heat of reaction to form dicyandiamide (1161 J/g, exothermic).

2.1.2. Cyanamide, 50% solution in water, stabilized, trade name: Cyanamide L 500, AlzChem Trostberg

The following relevant data characterize the substance:

Bluish, slightly turbid solution, concentration (50–51% cyanamide), pH-value (4.5, 20 °C), freezing point (−8 °C), density (1.06 g/cm^3), dynamic viscosity (1.026 mPa s, 20 °C), constant pressure heat capacity c_P (3.5 J/(g K)).

2.2. Test methods

The procedures and criteria of the test methods used are fully described in literature [6,8]. Therefore, the test methods used to determine the explosive properties are not described here again. The recommended test methods to determine the so-called self-accelerating decomposition temperature (SADT) and for vent sizing are also accurately described in literature [6]. Details concerning the parameters used are included in chapter 3.

3. Results and discussion

3.1. Explosive properties

The test results obtained for solid cyanamide and cyanamide, 50% solution in water, are summarized in Table 1. The investigated test samples are not able to propagate a detonation or a deflagration and the explosive power is insignificant according to the criteria as defined [6]. Under defined confinement where high heating rates are used the effects are low or medium. This is not a surprise if the effect of heat to cyanamide is considered. Cyanamide is able to dimerize and polymerize, respectively. At temperatures below approx. 150 °C the “polymerization” stops at the dimer level (dicyandiamide) (Fig. 2). At higher temperatures (starting at about 180 °C) the “polymerization” of cyanamide and dicyandiamide may progress further to the trimer melamine (Fig. 3). Above 300 °C melamine produces the 1,3,5-triazines melam, melem and melon (Fig. 4) which have only recently been structurally characterized [10].

Thus the observed effects in the heating under defined confinement tests E.1 and E.3 are explainable by the “polymerization” particularly because only a continuing rise of an adiabatic self-heating produces steam (in case of aqueous cyanamide solution) and gaseous ammonia, which may build up pressure. According to the UN Recommendations [4] self-reactive substances are thermally unstable substances liable to undergo a strongly exothermic decomposition even without participation of oxygen (air). Such substances normally have heats of decomposition, as measured with differential scanning calorimetry (DSC), equal or higher than 300 J/g. Also cyanamide shows an exothermal heat (DSC) of about 1360 J/g but this is owing to the dimerization/trimerization. Cyanamide as well as aqueous solutions of it therefore should not be assigned to the group of self-reactive substances according to the transport regulations.

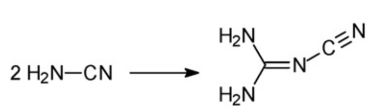

Fig. 2. Dimerization of cyanamide.

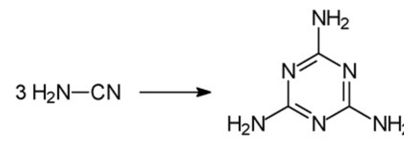

Fig. 3. Trimerization of cyanamide.

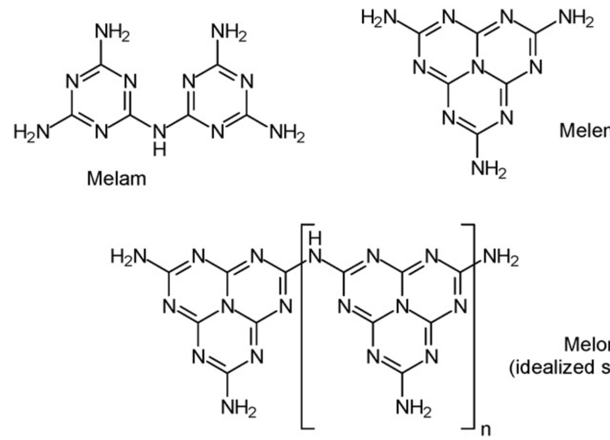

Fig. 4. 1,3,5-Triazines melam, melem and melon.

3.2. Thermal stability

The UN Manual of Tests and Criteria [6] recommends four different tests in test series H for the determination of the SADT in dependence of the net mass and the packaging used for transport. In this study the tests H.1 (United States SADT test, a test with the original package), H.2 (adiabatic storage test, a small-scale Dewar test under adiabatic conditions) and H.4 (heat accumulation storage test, a small-scale Dewar test under quasi-adiabatic conditions) are used.

Remark: The term “SADT” is used in the UN Recommendations [5,6] also for thermally instable substances which are not organic peroxides or self-reactive substances even if the critical starting temperature for an exothermic reaction is not implicitly a decomposition but e.g. a polymerization.

Table 1
Test data.

Time/pressure test UN C.1	Deflagration test UN C.2	Koenen test UN E.1	US Pressure vessel test UN E.3
No (overall evaluation)		Medium (overall evaluation)	
No (overall evaluation)		Low (overall evaluation)	

Table 2
Heat loss and SADT values for Cyanamide L 500 based on a test H.2.

Packaging/tank parameter	Heat loss (mW/kg K)	SADT (°C)
Drum, 60 l	71	55
Drum, 200 l	44	55
Tank, 24 m^3, insulated	1.7	35

Table 3
H.1 and H.4 results for Cyanamide L 500.

Test	Packaging	Storage temperature (°C)	Evaluation
H.1	Drum, 200 l	50	Stable, SADT = 55 °C
H.1	Jerrican, 60 l	55	Not stable
H.1	Jerrican, 60 l	50	Stable, SADT = 55 °C
H.1	Drum, 200 l	55	Not stable
H.1	Drum, 200 l	50	Stable, SADT = 55 °C
H.4	Dewar, 500 ml	50	Stable, SADT ≥ 55 °C

3.2.1. Cyanamide, 50% solution in water, stabilized (Cyanamide L 500)

The heat loss values of the usual types of packagings were determined either by recording the cooling curves of aqueous cyanamide solution in jerricans (60 l) and drums (200 l) or by calculation taking into account geometry and material (24 m^3 tanks). Based on adiabatic storage tests in a 1 l spherical Dewar vessel the SADT values were determined according to the test method H.2 (Table 2). Table 3 shows the results of the tests H.1 and H.4.

The drums used had the following coding:

3H1/X1.3/250/.. ../BAM 9240-M H2 (plastic jerricans, non-removable head, volume 60 l) and
1H1/X1.6Y1.9Z1.9/250/.. ../BAM 5402-MARMOR (plastic drum, non-removable head, volume 200 l).

The spherical Dewar vessel used for the H.4 test had a half-time of cooling of 19.43 h in relation to $c_P = 3$ J/(g K) and thus a heat loss value (L) of 29.7 mW/(kg K) (compared with a 60 l plastic jerrican: half-time of cooling 8 h, $L = 71$ mW/(kg K), and 200 l plastic drum: half-time of cooling 13 h, $L = 44$ mW/(kg K)). The heat loss of the Dewar vessel is much lower as required but on the safe side.

The SADT for a 24 m^3 tank (insulated) was determined to be 35 °C. This leads to a control temperature of 25 °C and an emergency temperature of 30 °C for Cyanamide L 500. If such a tank is filled with Cyanamide L 500 with an initial temperature of 18 °C, the approximate time until the ambient temperature of 30 °C, which is assumed to be constant, is reached, based on a model calculation by AQura, would be 60 days (Fig. 5a). In the same model an assumed ambient temperature of 40 °C would be reached in approx. 47 days (Fig. 5b). The assumption of a constant ambient temperature without day–night-cycles is ultraconservative.

To show that cyanamide, 50% solution in water, stabilized, is long-time stable also in large containers storage tests with an ISO portable tank (net mass of solution 20 ton) and a railway tank wagon (50 ton) were carried out under Bavarian summer conditions with the result that neither a significant temperature increase nor a decrease of percentage of cyanamide was observed (Tables 4 and 5). Comparable results were obtained during sea transport in insulated ISO portable tanks (net mass of solution 20 ton) from Trostberg, Germany, to West Virginia, USA, transport time about 1 month as shown in Table 6. In the current operating instruction of AlzChem the requirement is defined that filling of tanks is not allowed at temperatures higher than 18 °C. So the transport of the solution in tanks is safe with regard to thermal stability.

The stabilization of the solution by phosphate buffer (optimum quantity about 0.5%, by mass) is secured as long as segregation e.g. by excessive cooling is prevented. Therefore, a minimum temperature limit of −8 °C is recommended.

3.2.2. Cyanamid, stabilized (Cyanamide F 1000)

Crystalline cyanamide is – in a pure, not stabilized form – a relatively unstable compound which tends to dimerization. Freshly sublimated cyanamide melts at 47–48 °C. At 143–144 °C pure cyanamide has a vapor pressure of 18 Torr and sublimation is possible under precautionary measures [9].

Cyanamide is thus similar to a reactive monomer, which polymerizes under heat influence whereby in the adiabatic case the polymerization turns into a cracking process.

3.2.2.1. Stabilization effect. The task of the stabilizer of solid cyanamide consists in preventing the production of alkaline substances, which catalyze the dimerization, as well as in absorbing traces of moisture that might cause a hydration of cyanamide to form urea.

The stabilization of Cyanamide F 1000 is carried out in two ways. On one hand it is produced by gentle evaporation of Cyanamide L 500, which had been stabilized by phosphate buffer. The adherent parts of phosphate buffer ensure a sufficient stabilization for drying the crystalline product as well as for in-house handling.

After drying an “extra stabilizer” is added to Cyanamide F 1000 before the product will be shipped. This proprietary formic acid ester has the function to absorb traces of moisture, to neutralize alkaline traces (NH_3) as well as to release continuously small amounts of formic acid.

Thus Cyanamide F 1000 gets an excellent long-term stability. Typical results of isothermal storage tests are shown in Table 7. Each charge destined for shipment has to undergo a quick quality test to eliminate any error in the manufacturing process that might have an effect on its stability. In this test a sample of 50 g is stored during 24 h at 60 °C (i.e. in the molten state). Then the increase of the concentration of dicyandiamide is measured. A shipment is possible only, if the formation of dicyandiamide does not exceed 3.0%. Experiences over many years show that the measured values are mostly far below the limiting value.

3.2.2.2. SADT values. The methods H.2 and H.4 were used to determine the SADT of Cyanamide F 1000 with the results that in both cases a SADT of 45 °C was detected for a package containing 50 kg substance which leads formally to a maximum allowed temperature for transport of 35 °C (“control temperature”). This temperature is also sufficiently low regarding to the melting point, because this one is a strong “endothermic barrier” in case of a possibly starting dimerization. According to the UN Recommendations [5], chapter 7.1.6, a substance needs to be transported under temperature control if the addition of a chemical stabilizer does not lead to a SADT higher than 50 °C.

3.3. Tank transport of cyanamide, 50% solution in water, stabilized

In chapter 3.2.1 it is concluded that the transport of Cyanamide L 500 in tanks (insulated and non-insulated) is safe regarding to thermal stability. But it is also important to investigate the pressure relief capacity of such insulated tanks particularly in case of a full fire engulfment. Therefore, pressure relief tests in model tanks were carried out according to the UN Recommendations [5,6]. The tests were conducted with thermally induced decomposition of the Cyanamide L 500 solution in a 1.3 l and a 10 l model tank, whereby the pressure and temperature curves were recorded. The tests in the 1.3 l model tank were for purposes of preliminary orientation, since no experimental data had been gathered on such formulations. The tank characteristics were at first based on the specifications in

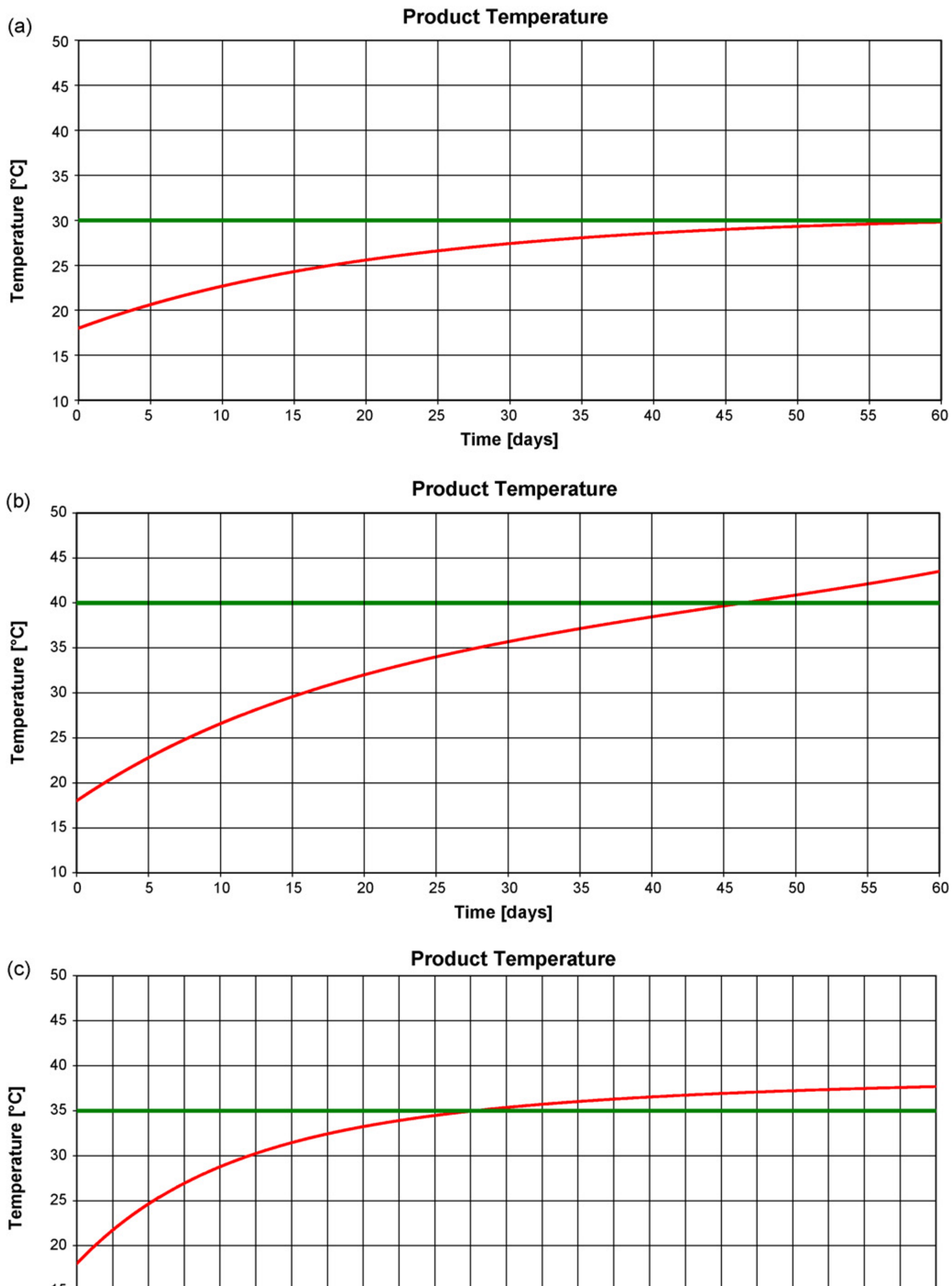

Fig. 5. Product temperature (red) of Cyanamide L 500 in an insulated 24 m^3 tank vs. time: filling temperature 18 °C, constant ambient temperature (green) 30 °C (a), 40 °C (b), 35 °C (c) (heat transfer coefficient: 0.7 W/(m^2 K), half-time of cooling: 340 h; kinetics: reaction order 0, pre-exponential factor 1.06×10^{22}, activation energy 162.5 kJ/mol). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of the article.)

Appendix 5 of the UN Recommendations on the Transport of Dangerous Goods, Manual of Tests and Criteria, for an insulated tank (model calculation of heating application rate to be applied).

Characterization of the tank containers:

- Their volume V is approx. 24 m^3, degree of filling maximum 90%;
- Insulation as per the example in Appendix 5 (UN Test Manual);
- Test pressure of 6 bar (explosion pressure shock resistance up to 10 bar);
- Size of the pressure relief surface (frangible disc(s)) to be determined in tests;
- Ratio A/V, also to be determined in tests.

The testing technique necessitated higher heating rates than those determined on the basis of the UN Recommendations on the Transport of Dangerous Goods.

Tables 8 and 9 contain the most important test results in which the following symbols are used:

Table 4
Long-time storage Cyanamide L 500 (railway tank wagon, 50 ton).

Days	Date	Cyanamide tank wagon (%)	*T*, tank wagon (°C)	*T*, ambient 7-day-mean (°C)	Dicyandiamide tank wagon (%)	Urea tank wagon (%)	pH tank wagon
0	21.06.2001	50.1	15.9	18.9	1.04	0.3	4.27
7	28.06.2001	49.9	17.9	19	1.06	0.3	4.35
14	05.07.2001	49.9	20.2	19	1.07	0.3	4.45
21	12.07.2001	50.1	21.3	19.7	1.1	0.35	4.52
28	19.07.2001	49.8	21.3	16.7	1.13	0.4	4.54
35	26.07.2001	49.9	22.5	18.7	1.18	0.4	4.52
42	02.08.2001	49.8	23.9	22.7	1.2	0.43	4.57
49	09.08.2001	50.2	24.3	18.9	1.24	0.43	4.61
56	16.08.2001	50	24.1	18.7	1.3	0.46	4.64
63	23.08.2001	50.2	24.8	19.3	1.37	0.5	4.72
70	30.08.2001	50.1	24.6	18.7	1.36	0.6	4.83
77	06.09.2001	50	22.7	13.5	1.44	0.55	4.94
84	13.09.2001	50	20.6	11.4	1.46	0.6	4.97
91	20.09.2001	49.8	18.4	10	1.5	0.65	4.97

Table 5
Long-time storage of Cyanamide L 500 (ISO portable tank, 20 ton).

Days	Date	Cyanamide ISO tank [%]	*T*, ISO tank (°C)	*T*, ambient 7-day-mean (°C)	Dicyandiamide ISO tank (%)	Urea ISO tank (%)	pH ISO tank
0	21.06.2001	50.3	13.3	18.9	0.93	0.25	4.21
7	28.06.2001	50	16.3	19	0.95	0.25	4.32
14	05.07.2001	50	17.3	19	0.96	0.25	4.44
21	12.07.2001	50.2	18.7	19.7	0.98	0.3	4.51
28	19.07.2001	50.1	18.6	16.7	1	0.3	4.59
35	26.07.2001	50.2	19.2	18.7	1.05	0.3	4.7
42	02.08.2001	50	20.9	22.7	1.06	0.34	4.72
49	09.08.2001	50.2	21.1	18.9	1.1	0.35	4.74
56	16.08.2001	50	20.8	18.7	1.15	0.34	4.76
63	23.08.2001	50.4	20.9	19.3	1.22	0.4	4.82
70	30.08.2001	50.4	21.2	18.7	1.19	0.4	4.87
77	06.09.2001	50.3	18.7	13.5	1.24	0.4	4.9
84	13.09.2001	50.4	16.1	11.4	1.23	0.45	4.92
91	20.09.2001	50.3	14.2	10	1.28	0.5	4.93

Table 6
Temperature development in ISO portable tanks during sea transport of Cyanamide L 500.

Container no.	Ex works	Filling temperature (°C)	Arrival	Arrival temperature (°C)
VOSU9212309	22.06.1994	<18	18.07.1994	23.1
PCVU1893849	08.06.1994	Ditto	11.07.1994	21.9
SECS8931083	10.06.1994	Ditto	07.07.1994	20.6
TOLU94719092	10.06.1994	Ditto	29.07.1994	22.0

A/V: ratio of pressure relief area to volume
dT/dt: heating rate before occurrence of measurable self-heating
P_{Resp}: frangible disc response pressure
P_{Rmax}: maximum pressure caused by substance decomposition

All pressure values were measured against atmospheric pressure.

The tests reveal that the tanks/containers require an A/V ratio of $4.1 \times 10^{-3}\,m^{-1}$, i.e. for a $24\,m^3$ tank, two frangible discs with a diameter of 25 cm each are required. The test pressure of the tanks should be 6 bar, operating pressure 4 bar and the set pressure for the frangible discs approx. 6 bar. Experience has shown that the set pressure of the frangible discs drops to approx. 4–4.5 bar in cases of longer heat load exposure of a tank with an ambient fire. Further, the intended tanks have two safety valves with frangible discs in front of them that respond at 4.84 bar. The above test results can be considered representative of these stipulations.

Table 7
Typical results of isothermal storage tests with Cyanamide F 1000.

Storage conditions	Production of dicyandiamide (%)
360 days at 20 °C	0.5–0.7
90 days at 30 °C	0.5–0.7
14 days at 40 °C	0.5–0.9

3.4. Skin tolerance of Cyanamide L 500

Testing of this substance was done with New Zealand White rabbits (six animals) via application on the intact or abraded skin using an occlusive patch. The duration of exposure was 4 h. After this period, the treated skin areas showed slight to severe erythema and oedema. After 52 h, these skin changes were more pronounced. Necroses formed within one week. According to these findings Cyanamide L 500 is to be considered strongly irritant to corrosive [11]. Practical experience has shown that following accidental contact, human skin shows effects mainly on unprotected and sweaty parts of the body. Depending on the exposure time and concentration, effects from reddening of the skin to severe dermal inflammations with blistering are possible. Having consulted the German Federal Institute for Risk Assessment, the classification of Cyanamide L 500 in Class 8, UN number 2922, packaging group III, secondary risk 6.1, is confirmed. Cyanamide F 1000 should be classified in Division 8, UN number 2923, packing group III, danger labels 8 + 6.1.

Table 8
Cyanamide L 500, 1.3 l model tank, 90% degree of filling.

No.	$A/V\ (10^{-3} \times m^{-1})$	dT/dt (K/min)	P_{Resp} (bar)	P_{Rmax} (bar)	Remarks
1	15.5	5	3.0	6.3	P_{Rmax} reached after approx. 150 s.
2	15.5	2.5	3.7	7.7	P_{Rmax} reached immediately after the frangible disc response.
3	15.5	1.0	3.4	–	P_{Rmax} not reached until after heating rate was raised after a longer period.

Table 9
Cyanamide L 500, 10 l model tank, 90% degree of filling.

No.	$A/V\ (10^{-3} \times m^{-1})$	dT/dt (K/min)	P_{Resp} (bar)	P_{Rmax} (bar)	Remarks
1	15.5	1.0	4.3	–	No further pressure increase
2	5.0	0.52	4.6	8.1	–
3	5.0	0.36	4.4	5.0	–
4	4.1	0.3	2.8	≤2.8	The early response of the frangible disc is due to the very long heat-up time and the thermal load on the frangible disc (low strength level). After response of the frangible disc the pressure in the container dropped very slowly.
5	4.1	0.3	4.2	5.3	After response of frangible disc pressure falls to approx. 3.4 bar, then rises to P_{Rmax} and then falls again very slowly, making very loud outflow noises.

4. Conclusions

Based upon the described test results, the following conclusions were drawn:

4.1. Cyanamide L 500

The substance being assessed here is a 50% solution of cyanamide in water, stabilized with about 0.5% phosphate buffer, by mass. On the basis of the test results BAM specifies that the formulation is to be classified in Class 8, UN number 2922, packaging group III, danger labels 8 + 6.1. Classification as a self-reactive substance in Division 4.1 is not required because the formulation does not have the characteristic properties of such a substance. Under a pronounced thermal load, the formulation can produce heat, but does not thereby release gas generated by thermal decomposition. What may result is a dimerization or polymerization, whereby naturally certain amounts of heat are produced, which, if not released, would result in an increase in the temperature in the shipping unit. To prevent these reactions, the formulation is stabilized with additives in the form of chemical inhibitors. The effect of these additives is to prevent the formulation in shipping units up to 200 l of content volume of heating up dangerously under "normal" ambient temperatures of <50 °C within a period of 7 days. The SADT for Cyanamide L 500 in packaged units up to 200 l is >50 °C as shown in tests with the original transport containers according to the UN-Test H.1. According to the criteria, formulations stabilized by chemical inhibitors so that the SADT is >50 °C need not be transported in accordance with the recommendations specified under 7.1.6 [5]. This applies initially only to packaging units containing cyanamide, 50% in water, stabilized, up to 200 l of content volume.

For transport in tanks, from the point of view of safety, the items under 7.1.6 of the UN Recommendations [5] are to be applied accordingly. It is stated that the SADT for the formulations to be evaluated was formally 35 °C. According to the regulations, that would result in a control temperature of 25 °C and an emergency temperature of 30 °C. It was also shown that the temperature of the formulation in an insulated tank (heat loss approx. 1.7 mW/(kg K)) cannot rise dangerously even after transports of longer duration. A precondition is, however, a maximum filling temperature not exceeding 18 °C. According to the valid AlzChem operating instructions for tank truck loading of cyanamide formulations, 50% in water, stabilized, the maximum filling temperature of 18 °C must not be exceeded. Observing the temperature curves in the insulated 24 m^3 tank at various (constant) ambient temperatures, beginning at a fixed filling temperature of 18 °C, reveals the following:

- Not until an ambient temperature of 40 °C is reached, assuming this temperature to apply constantly day and night and after a period of 3 months, does the initial sign of a self-accelerating reaction situation manifest itself.
- Assuming a critical (ambient) temperature of 35–36 °C a temperature of 42 °C (6 K criterion) is not even reached within 6 months (Fig. 5c). Compared with the criterion of the H.1 and H.4 tests a period of only 7 days is assessed as a stable result if the substance temperature does not exceed a value of six degrees above the ambient (storage) temperature whereat the start time for this period is taken when the substance temperature reaches two degrees below the ambient temperature.
- As the result of the simulation calculations carried out, it can be said that the tank SADT of 35 °C for Cyanamide L 500 according to the H.2 method is quite conservative.

This leads to the conclusion that, in the view of the BAM, transport under temperature control is not required. The existing insulation of the tank effectively prevents the formulation from heating up to temperatures exceeding 25 °C (see also measuring results, Table 6). Even assuming unusually high and unrealistically constant ambient temperatures, the critical temperatures (SADT and higher) are hardly reached and only after months. This does however, assume that the maximum filling temperature is strictly observed. The applicant bears responsibility for ensuring that strict organizational measures apply on this point at all times.

The conducted study leads also to the conclusion that for the transport of such substances in tanks the absolute SADT is not a realistic but rather a conservative value. In fact, the specification of a minimum loading temperature associated with a defined maximum transport time would be more appropriate and should be discussed further in competent bodies (e.g. the IGUS EOS working group [12] and the UN Sub-Committee of Experts on the Transport of Dangerous Goods).

By BAM, in agreement with the relevant dangerous goods regulations, and on the basis of the pressure relief tests, the following tank data were specified:

Permissible total mass:	36 000 kg
Volume:	24 m^3
Material:	1.4401/1.4404 EN 10028-7 (equal to stainless steel 316 or 316L)
Diameter:	2350 mm
Maximum allowable working pressure (MWP):	4 bar
Test pressure:	6 bar
Explosion pressure shock resistant:	Up to 10 bar

Insulation with special steel cover should be used.
Bottom discharge, 3 closures.
All gaskets made of PTFE.
Safety equipment:

two safety valves, 4.4 bar,
two frangible discs, 25 cm in diameter each, set pressure 6 bar, distributed over the 1st and 3rd thirds.

The U.S. Department of Transportation as the competent authority of the United States has issued the approval CA2005020018 for the transport of Cyanamide L 500 on basis of the above-mentioned test results and the recommendations of BAM.

4.2. Cyanamide F 1000

Considering the a.m. properties and test results the authors conclude that cyanamide, pure and stabilized (Cyanamide F 1000), is not a self-reactive substance of Division 4.1 of the dangerous goods regulations. The effects noticed in the tests are mainly due to a dimerization/polymerization of the cyanamide at elevated temperatures and not to a self-reaction due to gas release. Cyanamide F 1000 is to be classified in Class 8, UN number 2923, packaging group III, danger labels 8 + 6.1. The proper shipping name of the good (technical name) should be: "CORROSIVE SOLID, TOXIC, N.O.S., STABILIZED (CYANAMIDE)"

The company states that the transport of the substance is carried out in metal drums with PE-in liners, filled with a maximum net mass of 50 kg substance. On short distances (within the EU) the transport does not need to be refrigerated due to the relative low averaged temperatures around the clock, the strong "endothermic barrier" of the melting point and the long induction time. On longer transports by sea the transport is carried out in reefer containers. Nevertheless, BAM recommends strictly the compliance of a maximum temperature of 40 °C during transport in all cases. Carriage by rail is not permitted.

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