Consequences Modeling of the Akçagaz Accident through Land Use Planning (LUP) Approach

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ABSTRACT: *In the study, consequences analysis of Akçagaz LPG Facilities accident was conducted. The consequences analysis, modeling studies were performed by the use of EFFECTS 10.0 Software over two liquefied gas LOC (Loss of Containment) scenarios. One of the scenarios was G1: Instantaneous release corresponding to BLEVE (Boiling Liquid Expanding Vapor Explosion) and the other was G2: Release in 10 min corresponding to UVCE (Unconfined Vapor Cloud Explosion). The highest threat zone distance (1kW/m^2 heat radiation distance) was determined as 1699 m, the lethal burn distance as 377 m and distance from the center cloud to threshold overpressure as 342.46 m with the G1 scenario. French, Italian and Austrian methodologies relating to LUP (Land Use Planning) context of the Seveso Directive, which was not implemented in Turkish legislation, were evaluated for BLEVE of The Akçagaz Accident. Three different modeling approaches for BLEVE including static, dynamic and rupture of the vessel were used and the results were compared to the LUP methodology. The value (height of the fire ball: 273m) closed to the actual accident situation (height of the fire ball:200-300m) was obtained with the use of the static modeling approach. The distance access to fragments of the tank was calculated as 409 m with the use of rupture of vessel modeling approach which was compatible with the actual accident value (~500m). High lethality, the beginning of lethality, irreversible effects, indirect/reversible effects radius of The Akçagaz Accident were calculated for each country LUP methodology. The determined distances with the use of static BLEVE model correlation were obtained at the highest value again. High lethality radius was determined for French and Italian as 173.37 m and 86.13 m, respectively. The LUP methodology used in France is said to be more restrictive based on the large impact distances. On the other hand, when the TOTAL specifications (GS EP SAF 253& 262) are considered, which are dependent on demand but very important, the threshold values for health effects are seen to be much more stringent.*

KEYWORDS: *LPG; BLEVE; VCE; Consequences analysis; The Akçagaz accident; LUP (Land Use Planning).*

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INTRODUCTION

Nowadays, an increasing number of large and small-scale industrial accidents has occurred especially in the petrochemical industry and refineries. Many major industrial accidents have happened in the establishment processes, especially containing a large amount of LPG (liquefied petroleum gas) and other highly flammable products. According to the international disaster database (EM-DAT), 1427 major industrial accidents were recorded in the world between 1900 and 2016 [1]. As a result of these accidents, there were 57568 deaths and 221654 injuries in all around the world. 26 of the accidents (including 1239 deaths, 534 injuries) occurred in Turkey. The biggest industrial accident in Turkey after the fire of TÜPRAŞ (Turkish Petroleum Refineries Corporation) originating from the Kocaeli Earthquake in 1999 is The Akçagaz Accident. No detailed report has been released on this accident. In the accident occurred in Akçagaz LPG filling plant in Turkey on 28 July 2002, two people were injured, property damage occurred on a large scale and it was returned from a major disaster. Many industrial plants have been built close to densely populated areas without taking the risk of industrial accidents into account. The basic implementation of the Seveso III Directive in the European Union has not included a predetermined risk analysis methodology for LUP (Land Use Planning) and the European Union member states use their own methodology for LUP. In Turkey, "Regulation on Prevention of Major Industrial Accidents and Mitigation of Impacts" was prepared by harmonizing Seveso II Directive to the legislation of Turkey with a commission created by Environment and Urban Ministry and The Ministry of Labor and Social Security and the Regulation went into effect as of 30th of December in 2013 [2]. The aim of the regulation is to prevent major industrial accidents in establishments that contain hazardous substances, to minimize possible accidents' dangerous effects on people and the environment and to determine principles and procedures related to necessary measures in order to ensure effective and continuous protection at a high level. Regulation has been started to apply in Seveso establishments where in particular the names and quantities of hazardous substances. In Turkey, the concept of LUP has not been included in the relevant regulations. As a priority of infrastructure a study needs to be done about it.

In the literature, there have been studies on the LUP methodology development. Different approaches for LUP around chemical areas were compared on a factory in Greece by Palazoglou et al. It was determined that the results evaluated together with LTD (Land Development Types) gave a more preferable solution [3]. LUP procedures for planning authorities and establishment operators were discussed to determine a rational approach taking into account the major accident hazards [4]. In another study conducted by *Christou et al.*, the criteria of the European Union for LUP were focused and information about the procedures applied by other countries was given. Approaches for LUP were evaluated in three categories: "real distance", "consequence-based methods" and "risk-based methods" [5]. A methodology on analysis of plant area for quantitative risk assessment depending on the domino effect was developed by *Antonioni et al.* Domino package of Aripar-GIS software was used in the recombination of the risk [6]. In literature, a subject on the Seveso Directive's important implementation steps which are risk analysis and public information activities in the threat zone have been located. Requirements for Security Management System Integration of chemical plants in the concept of clustering were determined by *Reniers et al.* [7]. *Vinnem* studied on issues related to the operational requirements, deviations from technique, risk communication, risk evaluation depending on risk acceptance criteria for LNG (Liquefied Natural Gas) facilities in Norway. It was stated that risk-based law enforcement was a fragile system [8]. The subject of public participation in the LUP in the seven community in the UK was investigated by *Walker et al.* [9]. In a study conducted by *Taveau*, new risk analysis approaches (benefit, challenges, and limits of semi-quantitative and quantitative assessment methods and risk analysis in the nuclear industry) prepared by France Environment Ministry were disclosed. It was indicated that an appropriate national matrix had to be established for effects on humans of accidents outside the facility, had to be developed a common risk methodology, and feedback between national institutions should be organized [10].

In this study, consequences analysis was performed for The Akçagaz Accident, on which there is neither published work nor data, using EFFECTS 10.0 Software. The implementation of three different BLEVE models with static, dynamic and rupture of vessel correlations The Akçagaz Accident and comparison of the obtained results considering LUP context were also conducted. The analysis was made considering threshold values belonging to LUP methodologies of French, Italian and Austrian regulations were considered, and it was aimed to determine a more suitable one for Turkey. Total Exploration&Production specifications (GS EP SAF 253[11] and GS EP SAF 262[12]), not retroactive and apply to new installations and to major modifications or extensions of existing installations, were also evaluated with an engineering approach for The Akçagaz Accident.

THE AKÇAGAZ ACCIDENT

Akçagaz LPG filling facility (Fig. 1), established for the filling and stocking work in Körfez district of İzmit province, has 900 tons LPG stock capacity and 100 tons/day filling capacity. It is established for_dealership nets mainly in İstanbul, Bursa, and İzmit in Marmara Region. The plant operates in the fields of filling LPG tubes, filling of LPG to tanks, discharging of LPG, tube control. At the Akçagaz facility, filling and discharge operations are performed with bulk gas treatment. This procedure is based upon the principle of gas transportation to the existing storage tanks in a facility with the trucks arriving at the facility. Filling of the gas cylinder with house type (12 kg), picnic (camping) type (2 kg) and industrial type (45 kg) is performed and the trucks that will be sent from LPG storage tanks to LPG gas stations are filled in the facility.

The facility consists of several sections including truck filling unit, a sandblasting unit, a gas cylinder filling ramp and painting unit, a sealing control and a gas cylinder discharging unit, a utility unit, a weighbridge for trucks and a transformer unit. In the truck filling unit, with the system connected to the storage tanks, LPG is supplied the storage tanks from the filled trucks coming into the facility and also the trucks to be sent to LPG gas stations are filled. In case of emergency, there is a tank for fire water transport and fire prevention on pipelines belonging to this unit. The blasting unit is the place where the surface cleaning of the incoming cylinders is carried out using a sanding machine. Scales in the cylinder filling ramp and filling and weight control of cylinders with chain structure with cylinders and dyeing of cylinders requiring paint in the dyeing unit are performed. The LPG cylinders, successfully passing through the weight control, come to the test chamber of the cylinder for leak tightness control, where it is checked if there is any leakage in the valve and welding points of the cylinders. In the utility unit, necessary water for operation, air conditioning, distribution of electricity and operation of the fire system is performed. As well, the installation and labeling of PVC flaps are carried out in the same unit. The filled trucks and gas cylinders are passed from the weighbridge for weight control based on traffic and environmental safety. The facility is supplied by the transformer unit with electricity.

Fig. 1: The Akçagaz LPG filling plant (2016, Google Earth).

In Akçagaz LPG filling facility, one km away from TÜPRAŞ İzmit Refinery, the fire caused by an explosion due to compression during gas filling of a tanker on Sunday, 28th of July in 2002, at about 8:15 a.m. was started and subsequently 100 tons of LPG tanks was burned. The fire was kept under control in approximately two and a half hours. Since the accident occurred at weekend larger losses were fortunately prevented.

In Fig. 1, it is seen that the facility, which is located on the coast of the Sea of Marmara to the south with the Gulf of İzmit, is close to the densely populated settlements and also other industrial establishments.

The Akçagaz Accident Precautions

An alarm was given in filling plants and industrial organizations in the region mainly TÜPRAŞ (Turkish Petroleum Refineries Corporation), PETKİM (Petrokimya Holding Corporation), İGSAŞ (Istanbul Fertilizer Industries, Inc.) and Navy. Thirty people from the city of Sakarya and eleven people from the city of İzmit of The Civil Defense Team provided support. Teams experienced in petroleum fires were dispatched to the filling plant, all surrounding firefighter teams were also provided to reach the fire place by creating a crisis center. Power in the region was cut, the D-100 highway was closed to traffic and train services were cancelled. Measures were taken to prevent the spread of fire on the environment instead of interfering with plant resort to intervention by firefighters in the region.

Effects and Consequences of The Akçagaz Accident

9 LPG tanks became unusable in the facility and the total loss reached 3 trillion Turkish Liras (approximately 850000$), nearly 1 trillion for 800 tons of LPG, nearly 2 trillion for the facilities. The mineral oil storage facility of neighbor OPET Petrol Office burned. BİLYAP Construction Industry&Trade with environmental facilities and residential areas were severely damaged by the explosion and the fire effects. Two people (guard and tanker driver) were injured. Because the accident occurred at a very close point to the city center (living in Barbaros and Güney Neighborhood) 5000 people were evacuated from their homes, the upper floors of the house up to ten were found to be unusable as a result of leaping flames from the explosion.

Barbaros Neighborhood located next to TÜPRAŞ as well as other petroleum and LPG filling and storage companies in the district of Kocaeli Gulf has been declared as “risk area” that survived the danger of fire and explosion many times. Council of Ministers Decision (Decision number: 2013/5318) on the newspaper (October 6, 2013 and 28787 official numbered) was stated as “the area shown the border and coordinates listed with attached sketch in Kocaeli Province, District of Gulf, located within Barbaros Neighborhood was declared as “risk area” according to writing (15.08.2013 dated, 5019 numbered) and the law (6306 numbered, second article) on Transformation of Area Under Disaster Risk of Environment and Urban Ministry on 23.08.2013”. The attached sketch is given in Fig. 2.

The first application on the scope of Transformation of Area under Disaster Risk Law has been started in Kocaeli began in the Gulf District as a result of The Akçagaz Accident. It was stated that TOKİ (Public Housing Authorities Presidency)’s subsidiary of Emlak Konut would build new housing for rights holders living in the neighborhood of Barbaros on TEM highway.

Measures Taken After The Akçagaz Accident

It was explained that the distance between the tanks should have been 125 meters. It was indicated that the arrangements should be made for closure of the other valves, tanks and the main valves with an automatic gas detection system when the fire started in a tank. After the accident, Kocaeli Governor's Office prepared a 10-point package of emergency measures on a meeting headed by TÜPRAŞ with fuel and LPG distribution companies and the experts in order to prevent potential disasters for Gulf District. Requests located on the 10-point package of measures were given below.

1. The implementation of a fire-fighting force and to conduct a joint action plan,
2. The establishment of a school for fire-fighting training,
3. Connections of the safety valves to the torch system will be installed,
4. Establishment of fire water tanks and pressurized fire water network (with pressure 8 kg / cm^2),
5. Strict adherence to the rules of private safety distance of TÜPRAŞ (200 meters for land, 400 meters for sea),
6. Reducing the number of plants and closure of the areas around the facilities at least 500 meters to reconstruction and resettlement,
7. Adherence to safety regulations at the facility of the settlement and determination and rehabilitation of transport to be used in an emergency,
8. Introduction of an upper limit on the level of stocks of LPG and petroleum products will be kept in the region (14 thousand tons totally according to the calculations),
9. Separation of tank and filling site within the plant,
10. Decreasing the number of tanks in the safety region.

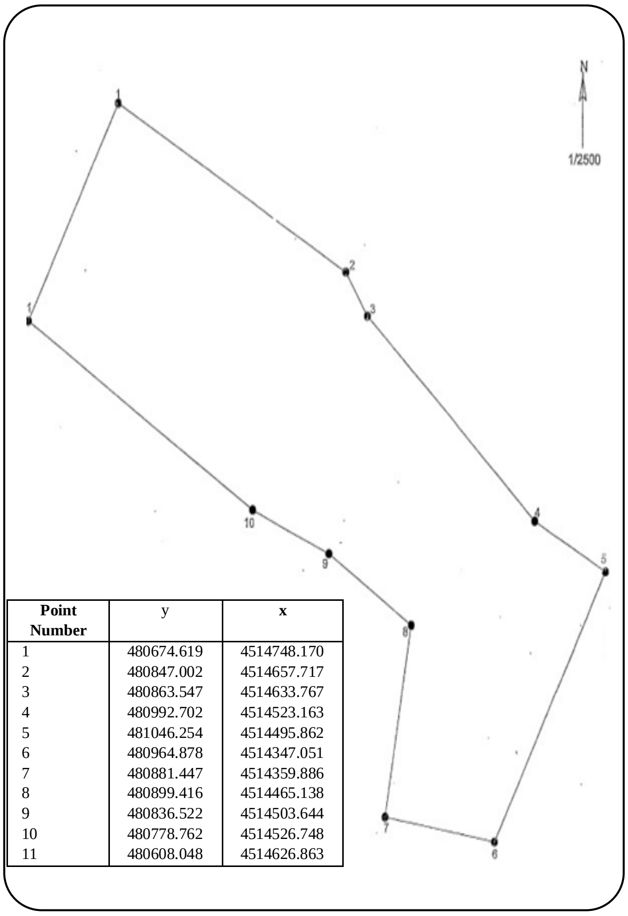
LAND USE PLANNING VIEWS

The Land Use Planning Guide developed by the European Union Joint Research Center describes four basic methods for risk analysis [13]:

1- Consequence-based methods

2- Risk based methods

3- Deterministic approach method with the implicit judgment of risk



Point Number	y	x
1	480674.619	4514748.170
2	480847.002	4514657.717
3	480863.547	4514633.767
4	480992.702	4514523.163
5	481046.254	4514495.862
6	480964.878	4514347.051
7	480881.447	4514359.886
8	480899.416	4514465.138
9	480836.522	4514503.644
10	480778.762	4514526.748
11	480608.048	4514626.863

Fig. 2 Risk area for the city of Kocaeli in Gulf District.

4- Hybrid methods

The consequence-based method listed above was taken into consideration for the case study of The Akçagaz Accident. BLEVE models of static, dynamic and rupture of the vessel were considered for the accident. Land Use Planning is used to mean the determination of threat zones on the basis of the health effects of various accidents. In this connection, three different LUP methodologies were identified and were compared with each other considering the threshold values of the methodologies wherein Table 1.

Table 1 shows that both the overpressure effects and the thermal radiation effects were considered together to develop the methodology of the countries. However, in the current legislation, the safety distances have been determined usually taking into account the thermal radiation hazard range [14, 15]. The facilities containing, using and storing LPG also take more strict measures than the LUP approach in order not to meet to an industrial accident or to keep the effects of accidents (loss of life, property, and prestige) to a minimum. Especially for this purpose, special specifications are used in companies.

The general specifications (GS EP SAF 253 and GS EP SAF 262) of TOTAL Exploration&Production were also evaluated by engineering approach in the study. The purpose of the GS EP SAF 253 specification is to define the safety requirements for the partition of oil and gas production installation and the zone surrounding it into the impacted area, restricted area, and fire zones. A deterministic approach is used to delimit fire zones, impacted and restricted areas in GS EP SAF 253 specification. A list of possible incidents is established from a hazard identification table applicable to oil and gas production and processing installations. This list of applicable incidents comprises however only events whose probability to occur and/or magnitude of consequences have been deemed sufficiently high by Company and/or Authorities Having Jurisdiction. Restricted area is the area within the boundaries of the installation and hence under the control of the Company. Impacted area is accessible to the public as a consequence its control cannot be placed under the responsibility of the Company but shall be agreed with Local Authorities. Fire zones are areas within the installation were equipment are grouped by nature and/or by the homogeneous level of risk attached to them. The restricted area is further divided into fire zones but this partition only functional. People do not undergo more troubles than those inherent to any other human activities outside the impacted area. The probability to be injured is low and the risk of remaining permanently incapacitated is negligible inside the impacted area but outside the restricted area. The consequences of an incident or from the normal operation can be severe enough to cause permanent prejudice to human beings shall, therefore, be off-limited to the public inside the restricted area. The resulting summary table for BLEVE and UVCE scenarios is given in Table 2.

When Table 1 and Table 2 are compared with each other, it is seen that threshold values of heat radiation and overpressure in the specification are more strict than the threshold values of the LUP methodologies. The minimum heat radiation value (3 kW/m^2) is approximately 18times higher than the threshold value of BLEVE in a restricted area.

Table 1: Threshold Values of the LUP Methodologies of the BLEVE.

LUP Methodology	***High lethality***	***Beginning of lethality***	***Irreversible effects***	***Reversible effects***	***Indirect effects***	***Domino effects***
The French methodology (Ministry of Ecology, 2010)	8 kW/m^2	5 kW/m^2	3 kW/m^2	-	-	-
Heat load	1800 [(kW/m^2)$^{4/3}$]xs	1000 [(kW/m^2)$^{4/3}$]xs	600 [(kW/m^2)$^{4/3}$]xs	-	-	-
Overpressure effects	200 mbars	140 mbars	50 mbars	-	20 mbars	-
The Italian LUP Normative (Ministry of Public Works, 2010)						
Thermal radiation effects	Fireball Radius-%100 lethality	350 kJ/m^2	200 kJ/m^2	125 kJ/m^2	-	-
Thermal radiation effects (limits for stationary heat radiation mentioned in the Guidance SFK/TAA GS-1, Federal Ministry of Environment, 2010)	12.5 kW/m^2	7 kW/m^2	5 kW/m^2	3 kW/m^2	-	12.5 kW/m^2
Overpressure effects (Federal Ministry of Environment, 2010)	300 mbars	140 mbars	70 mbars	30 mbars	-	300 mbars Domino effects from projected fragments: 200-800m
The Austrian Permanent Seveso Working Group recommends guidance values for the calculation of LUP distances for BLEVE events with LPG						
Thermal radiation effects	-	-	-	-	-	12.5kW/m^2-2kW/m^2 (LUP)
Overpressure effects	-	-	-	-	-	100mbars-25mbars (LUP)

Table 2: The resulting summary table for BLEVE and UVCE scenarios [11].

Scenario	Impacted area	Restricted area	Fire zones
BLEVE	2nd degree burns 1500 BTU/sqft/hr for one minute exposition (0.08 kW/m^2)	0% lethality 3000 BTU/sqft/hr for one minute exposition (0.16 kW/m^2)	9.7 kW/m^2
UVCE	50mbar	170mbar	170mbar buildings, storage, process. 300mbar piping.

It is very important to design the plant according to the safety considerations for the prevention of an industrial accident. Another useful specification used for this purpose is GS EP SAF 262 that defines safety requirements for the design of the pressure protection and relief and the hydrocarbon disposal systems suitable for production, processing, transportation and storage in the oil and gas industries [12]. Hydrocarbon disposal systems are the systems to dispose of vapors or liquid hydrogen by burning or venting to the atmosphere during normal operation, abnormal operation and emergencies. The specification is not also retroactive. Flare, burn a bit, catch pit, vent, liquid burners are used as release systems in the oil and gas industry. As a general rule toxic gas containing more than 0.5% H_2S shall be flared for the protection of personnel. The public shall in no case be exposed to radiation level exceeding 1.6 kW/m^2, over a sustained period of time and 2 kW/m^2, for periods shorter than 15 minutes according to the specification.

RESULTS AND DISCUSSIONS

Consequence Analysis of The Akçagaz Accident

It was attempted to determine the physical effect distances via the EFFECTS 10.0 software for The Akçagaz Accident considering the LPG properties. Liquefied gas LOC scenarios, which were G1: instantaneous release and G2: release in 10 min., were performed with the software. G1 was considered to be

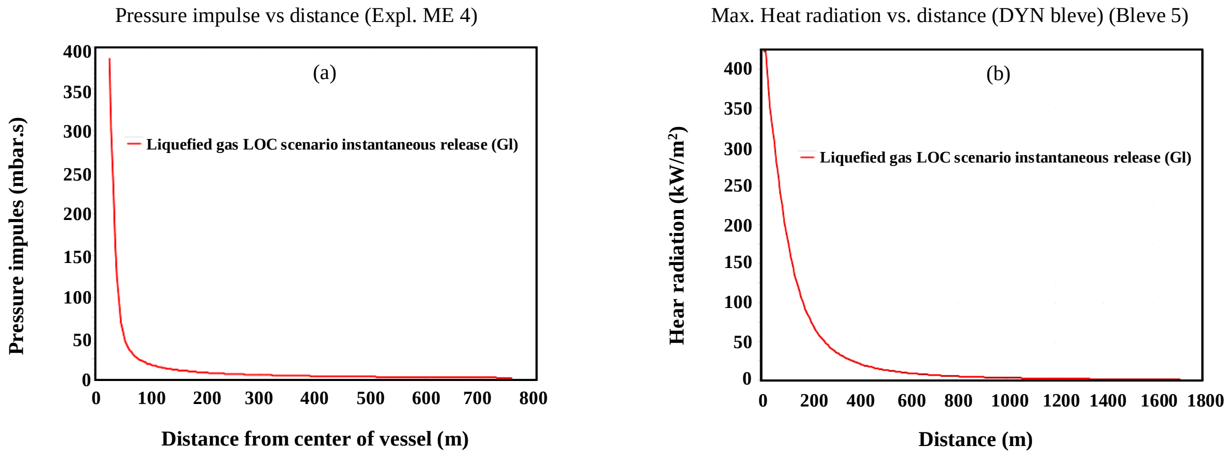


***Fig. 3:** Variation of and pressure impulse (a) and heat radiation (b) with distance obtained by the G1 scenario.*

BLEVE (Boiling Liquid Expanding Vapor Explosion), G2 was considered to be UVCE (Unconfined Vapor Cloud Explosion). G1 scenario was based on Dynamic BLEVE model whereas G2 was based on Pool Fire-Yellow Book Model. BLEVE means that the flame impingement caused rupture of a liquefied flammable gas pressure vessel, producing a fireball and usually, rocketing fragments. When a flammable vapor is released, its mixture with air will form a flammable vapor cloud. In UVCE, if the flammable cloud ignited, the flame speed may accelerate to high velocities and produce significant blast overpressure. LPG and air mixture just explodes at the range 2% to 10% of LPG in the air [16]. Considering one of the LPG tanks infiltrated in The Akçagaz Accident, the same amount (180m^3) of the LPG sample was modelled over the scenarios, separately. This approach was followed since the operation of the model by EFFECTS Software for tanks at close distances was the intersection of the similar effect distance instead of giving larger impact distances. 80% of tank filling and pressure inside the vessel corresponding to vapor pressure were assumed. It is known that effect distances are particularly influenced by Pasquill atmospheric stability classes, especially in the toxic zone [17]. Atmospheric stability is defined by the Pasquill model, which is divided into 6 classes. Very unstable atmospheres are classified as A, B; neutral atmospheres are classified as C, D, and very stable atmospheres are classified as E, F. F atmospheric stability class selection was made considering the worst-case scenario in the modeling studies. For the other atmospheric input parameters of the EFFECTS Software, the average conditions of the Kocaeli province, where The Akçagaz Accident occurred, were taken into consideration.

The graphs showing the variation of the pressure impulse and heat radiation versus distance obtained by the G1 scenario are given in Fig. 3.

Fig. 3 showed that the heat radiation and pressure impact distance increased as the hazard source was approached. There was an inverse relationship between them. The variation of the heat load and high pressure effects of the G2 scenario with distance are given in Fig. 4.

From Fig. 4 it was seen that there was an inverse relationship between the heat load and overpressure effects with distance in a similar way to the G1 scenario. Impact distances were found to be very much higher in the G1 scenario. Heat flux received by the objects depended on the distance between the center of the fireball and the object. As the distance is increased the heat flux tends to decreased [18]. The effect distances obtained as a result of the G1 and G2 scenarios are presented in Table 3.

When Table 3 was examined, the thermal radiation distances and the burn distances were found to be close to each other for the G2 scenario, whereas the burn distances were determined to be 2-3 times less than the thermal radiation distances for the G1 scenario. The diameter of the jet/cloud was 0.68 m and the length of the flammable cloud was determined as 342 m for the G2 scenario. The distance from center cloud to threshold overpressure was calculated as 181.91m for G2 scenario and 342.46 m

Table 3: The effect of distances obtained by the G1 and G2 scenarios (EFFECTS Software).

Results	G1 scenario	G2 scenario
Peak overpressure (mbar)	9.16	5.14
Distance from center cloud to threshold overpressure (m)	342.46	181.91
1 kW/m^2 heat radiation distance (m)	1669	286
3 kW/m^2 heat radiation distance (m)	1011	180
10 kW/m^2 heat radiation distance (m)	576	110
%1 first degree burns distance (m)	590	159
%1 second degree burns distance (m)	389	113
%1 third degree(lethal) burns distance (m)	377	111

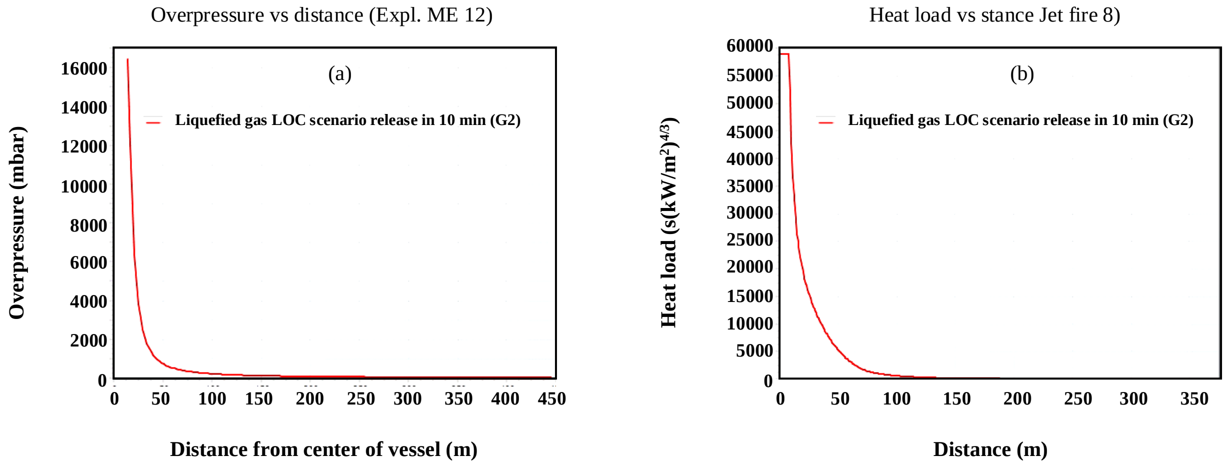


Fig. 4: Variation of overpressure (a) and heat load (b)) with distance obtained by the G2 scenario.

for the G1 scenario, respectively. It was obtained that the overpressure effects coming from beside thermal radiation decreased the effects of distances for the G1 scenario. It was also seen that the values of the burns distances obtained for the G1 scenario were about 3-4 times higher than the values obtained for the G2 scenario. The change in the ratio of the lethal burns with a distance of the LOC scenarios is given in Fig. 5. For the G2 scenario, the lethal burns effect distance was determined to be 62.5% of the total impact distance, while the impact distance for the G1 scenario in Fig. 5 was very much higher. The lethal burns effect distance for the G1 scenario determined as 35% of the total impact distance. A large part of the deaths resulting from the BLEVE was due to the overpressure effect. The pressure effects have high danger range values and cover the thermal hazard range [14]. According to the hazard identification of the specification (GS EP SAF 253), BLEVE can occur in impacted and restricted areas while UVCE can occur in fire zones. When the G1 and G2 scenarios were evaluated with the LUP approach in terms of health effects, according to French LUP methodology ($3kW/m^2$), irreversible effect distances were determined as 1011m for G1 scenario and 180m for G2 scenario, respectively. The same distance values were evaluated as reversible effects in Italian LUP methodology. As a result, BLEVE was particularly found to have impacting effect on the community outside the facility, and it was determined that the LUP approach was more appropriate for this G1 scenario.

BLEVE Models

The LUP methodology was adapted to BLEVE, because of the determined widest impact distances

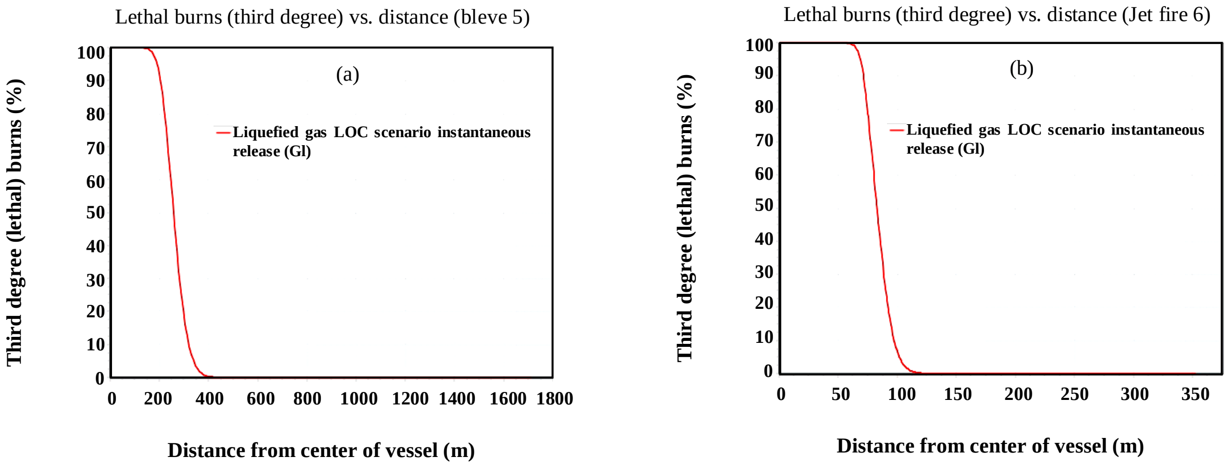


Fig. 5: Variation of lethal burns with distance (a) G1 scenario (b) G2 scenario.

(physical and also burns/health effect distances) that could affect society and the values close to the real accident data. BLEVE was studied in the scope of the consequence-based procedure. Static, dynamic and rupture of vessel models for BLEVE were considered n the study. (Table 4)

The radius of the fireball, R_{FB} (m) can be calculated over a static BLEVE model using the number of flammable materials in a fireball, M_{FB} (kg). Constant c_3 in Eqn.3 depends on the vapor pressure before release, P_{Sv} in (N/m^2), and it is characterized in terms of the fraction of liberated combustion energy through radiation [19].

Experimental researches were made in order to determine the time dependency of the fireball. It was found that the fireball reached the maximum diameter during the first third of the total duration and after that it remained constant until it dissipated. The center height of the fireball, H_{FB} was also time dependent and could be described with Eqs. (8) and (9) according to the experimental observations [20].

The fragment velocity, v_i could be calculated using Baum's empirical formula using Eqn.11. The fraction of liberated energy, A_{kd} (-), in case of a BLEVE was estimated at 4% of the total energy [21]. There have been no methods to estimate the number of fragments that may be thrown into the air in the case of a BLEVE. In the literature, there have been many estimates based on accident investigations. The number of fragments based on the type of vessel in case of overpressure: for cylinders at 2 or 3 pieces, for spheres at 10–20 pieces. The mass of the pieces, M_V in (kg) could be estimated using the average mass in case of more fragments.

Values seen in Table 5 were calculated using the correlations of the three different BLEVE models for The Akçagaz Accident. It was assumed that 100 ton of LPG caused to the fire in calculations. 8 bar of vapor pressure inside the tank and the ambient temperature was assumed for the related tank according to the average values of LPG tank storage conditions, since there were no data available on the accident situation [22].

Table 5 showed that the values determined by the static model and the rupture of the vessel model were compatible with the value detected for The Akçagaz Accident. The diameter, duration, and height of the fireball were expected to vary in direct proportion to the amount of the combustible material [18]. It was determined that the values of the static BLEVE model were a bit higher than the values of the dynamic BLEVE model. Standard techniques used in BLEVE modeling base on static models evaluating heat radiation. The main property of the static model is that the radiant heat flux is constant over the duration of the fireball, mostly between 5s and 30s, depending on the quantity involved [15]. The techniques used in the most recent period has been started to use dynamic model approach. Dynamic model, taking into account the time evolution of thermal radiation generated by the fireball and the change in the shape and power of the blast wave, leading to a more realistic assessment of threat zones associated with burn and overpressure injuries [23, 24].

Table 4: BLEVE models.

Static Model	Dynamic Model	Rupture of Vessel Model
The radius of fireball: $R_{FB}(m) = c_1 x M_{FB}^{0.325}$ (1) where $c_1 = 3.24(\frac{m}{kg^{0.325}})$ Duration of the fireball: $t(s) = c_2 x M_{FB}^{0.26}$ (2) $c_2 = 0,852(\frac{s}{kg^{0.26}})$ The intensity of heat radiation: $F_s(-) = c_3 x (P_{sv})^{0.32}$ (3) where $c_3 = 0.00325((N/m^2)^{0.32})$ The center height of the fireball: $H_{BLEVE}(m) = 2xR_{FB}$ (4)	The duration of combustion for the fireball: $t_d(s) = 0.9xM_{FB}^{1/4}$ (5) The growing of the fireball: $D(t)(m) = 8.664xM_{FB}^{1/4}xt^{1/3}$ (6) for $0 \leq t \leq 1/3t_d$. The maximum diameter: $D_{max}(m) = 5.8xM_{FB}^{1/3}$ (7) for $1/3t_d \leq t \leq t_d$. The center height of the fireball: $H_{FB}(t)(m) = \frac{D(t)}{2}$ (8) for $0 \leq t \leq 1/3t_d$ $H_{FB}(t)(m) = 3x\frac{D_{max}(t)}{2}xt_d$ (9) for $1/3t_d \leq t \leq t_d$.	The total liberated energy: $E_{av}(J) = e_{av} x M_{fl}$ (10) where e_{av} (J/kg): specific work done by an expanding fluid M_{fl} (kg): mass of released phase The fragment velocity: $v_i(m/s) = \sqrt{\frac{2xA_{kd}xE_{av}}{M_v}}$ (11) where A_{kd} (−): fraction of liberated energy M_v (kg):mass of the pieces

Table 5: Duration, height and radius of fireball according to different BLEVE models.

Model	Radius of fireball	Duration of the fireball	Height of the fireball	Accident value
Static Dynamic	136.62m 106.46m (Max. 129.50m)	16.99s 16.01s	273m 106.46m (0≤*t*≤1/3*t*d) 3886.15m (1/3*t*d ≤*t*≤*t*d)	Height of the fireball: 200-300m Fragment to distance: 500m
Rupture of vessel	-	-	14.8t fragment to distance of 409.22m	

LUP Approach

The values of high lethality, beginning of lethality, irreversible effects, indirect/reversible effects radius calculated considering the threshold values of LUP methodologies of French, Italian and Austrian for BLEVE are given in Table 6.

From Table 6, it can be said that the values obtained by French threshold limits affected the larger health effect distances and enforced more. The overpressure effects were found at lower health effect distances than the thermal radiation effects. In case of a using BLEVE model, the health effects of the fireball were more severe than the effects of the blast wave [25]. Safe separation distance and the probability of injuries and death were expected to vary depending on the amount of LPG [18]. Minimum separation distances between vessels are generally arranged by regulations. They are important from the point of view of thermal radiation and particularly to avoid direct contact between the flames from the fire in one piece of equipment and the wall of another vessel. They do not guarantee protection, however, in the case of an explosion [15]. Since no data were available on the negative health effects of The Akçagaz Accident, no comparison was made with the actual situation.

Table 5 also showed that as the threshold value intensity (heat radiation, overpressure) increased, possible health effect distances decreased. When the threshold values for BLEVE scenario in the specification (GS EP SAF 253) were taken into consideration, the health effect distances reached very high values (> 10000 m). Such high distances for the LUP approach may lead to difficulties in legislation studies and practice in terms of Authorities. For plants, specifications with more stringent thresholds on a scenario basis should be used so that the possible effects (loss of life, property, and prestige) of

Table 6: Determined physical effect distances considering to LUP Approach in different methodology.

Methodology	Model	High lethality radius (m)	Beginning of lethality radius (m)	Irreversible effects radius (m)	Indirect/reversible effects radius (m)
French	Static model	173.37	221.92	369.87	-
	Dynamic model	86.80	138.89	231.48	-
	Rupture of vessel	20.07	28.67	80.29	200.72
Italian	Static model	86.13	153.79	221.92	369.87
	Rupture of vessel	13.38	28.67	57.35	133.81
Austrian	Static model	-	-	538.28	-
	Rupture of vessel	-	-	-	160.58

the accidents will be reduced to a minimum and the plant settlement will be designed to be more secure. The application of these standards is primarily under the responsibility of the Company and the operating conditions are provided according to the threshold values and the impact distances are not assessed in the specification. The LUP approach, which provides more flexible thresholds, should be assessed in the responsibility of the Authorities. While the LUP approach for the country is being developed, the concept of the impacted area, which is included in the specification, must be considered even so.

It is aimed at reducing the effects of on-site accidents and preventing the effects of the accident from reaching the facility boundary in the specifications. LUP, on the other hand, develops its own methodologies, taking into account possible accident effects on the community outside the facility, and the impact distances calculated by taking the threshold values determined by them into account, are applied in land use.

The toxic emission, which is the result of an industrial accident, is not evaluated since it gives a wide impact range in the LUP approach. For this reason, the threshold values (exposure times and the concentration of the relevant toxic chemical) specified in the specifications in terms of health effects should be used effectively. Authorities introduce a number of obligations to the operator with environmental legislative regulations for toxic emissions.

CONCLUSIONS

First, The Akçagaz Accident was modeled on possible scenarios for LPG using EFFECTS Software. Threat zone areas were obtained over G1 and G2 LOC scenarios of liquefied gas using simple inputs. Physical impact distances (>500m) and burn distances (>350m) were assessed and it was determined that the G1 scenario gave wide impact distances and serious health effects. Then, The Akçagaz Accident was studied by using three different BLEVE models. The values of fireball duration, the radius of the fireball and heat radiation with the use of static and dynamic models and the values of the tank fragments reach distance and overpressure effects with the use of rupture of vessel model were obtained. Height of the fireball (273m) determined by the static model and the fragment to distance (409m) determined by the rupture of the vessel were found to be similar to the actual accident values. The impact distances obtained with these different BLEVE models were evaluated through the LUP approach. Only irreversible effects (538m) and indirect/reversible effects (160m) distances were identified in the Austrian methodology. In France methodology, the maximum health effect distances were determined, and the values determined by the static model were determined to be about twice the values determined by the dynamic model. Italy's methodology gave the lowest health effect distances within the LUP approach. It was seen that the LUP approach applied in France found to be more restrictive considering thresholds of the other countries LUP methodologies. Results were also assessed over TOTAL specifications, an important source document in LPG installations and threshold values of the specifications were found to be much more strict than the LUP approach. Particularly in the gas industry, it is extremely important to take measures to protect human health with this specification approach. The LUP methodology applies more flexible threshold values due to country policies. The facilities will take precautionary measures for human health beyond the LUP when they adopt their own safety measures according to the specifications. The highest physical and health effect distances are experienced in BLEVE explosions after the toxic emission physical and health effects considering the major industrial accidents. It has emerged that the facilities containing, storing and using of LPG have to be substituted far away from the public spaces once again with The Akçagaz Accident.

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