

Liquid Stabilizing Device

Field of Technology

The present invention relates to a device for stabilizing liquid contained in a tank, more particularly but not limited to, liquefied natural gas (LNG) tanks, so as to suppress
5 sloshing of the liquid in the tank.

Background

Being the cleanest among fossil fuels, the use of natural gas has rapidly increased as an important energy source globally. In its liquid state at approximately -162°C ,
10 liquefied natural gas (LNG) is easier to transport and store than in its gas state. To meet the growing demand, many LNG ships and terminals have been built. For example, Singapore is building a LNG terminal costing about S\$1.5 billion. There is a trend towards the use of membrane tanks instead of self supporting storage systems, mainly due to the fact that membrane tanks utilize the hull shape more efficiently.
15 Maximizing space utilization is an important design consideration for sea vessels.

Generally, a membrane-type tank of prismatic shape is more compatible with the shape of ship hull than other shapes such as sphere. The cost of building a membrane-type LNG ship is up to 160~200 million US dollars. Lower cost of sea transport and re-
20 gasification plants has also helped to boost the manufacture of larger LNG carriers with larger LNG tanks. Good thermal insulation is required to minimize the loss of LNG through evaporation. The insulation wall of the tank typically consists of two layers of membranes and two layers of insulation materials, with the inner most layer being a layer of membrane.

Considering the large size of LNG tank, sloshing in a partially filled tank during rough sea motion can be severe and can cause damage to the thin membrane layer. In particular, the violent sloshing movement of free surface and pressure oscillation would increase fatigue and is detrimental to the membrane tank. If unchecked, sloshing would
5 also contribute to the instability of the vessel in severe sea states. Due to the increasing need for larger LNG tanks and greater flexibility in operation, the problem of LNG sloshing, particularly in partially filled tanks, has to be addressed to reduce its effects in terms of damaging the tank wall and adversely affecting the vessel stability.

10 There are several patent applications proposed to solve the sloshing problem, examples are WO/2009/072681 and JP2009018608.

In the patent application WO/2009/072681 filed by Jin (2009), sloshing is to be reduced by separating the whole space of LNG tank into several small compartments. The idea
15 is that sloshing in each small compartment is less severe than in a big tank. This design requires building partition walls inside the LNG tank, and addition of bulkheads and stool parts. Each bulkhead partitions the space of LNG tank into left and right spaces to reduce sloshing. The stool part is used to fasten the bulkhead to the first insulation layer of LNG tank. Hence, the design necessitates significant modification of
20 the tank's structure and layout. Furthermore, the partitioned walls in contact with the supporting ship hull will cause significant thermal leak problem (i.e. heat transfer from external to internal).

The patent application JP2009018608 filed by Shinkichi (2009) aims to mitigate LNG
25 sloshing by keeping prismatic tanks under the fully loaded condition. That is, the filling level of the membrane-type LNG tank is always kept at greater than 95 percent of the tank height. When the filling level decreases, LNG stored in a special tank will be

transferred to the membrane-type tank to recover the level to greater than 95 percent of the tank height. The special tank is of spherical shape and is hence better in coping with sloshing than the prismatic tank. However, this design requires the addition of a spherical tank and substantial modification of ship's structure or layout. In addition,
5 additional piping system is required to transfer LNG from each of the rectangular tank to the special spherical tank.

The present invention proposes a solution for stabilizing the liquid contained in a tank while alleviating at least one of the problems above.

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Summary of Invention

In general terms, the invention provides a liquid stabilizing device to suppress sloshing
15 by confining the liquid free surface under a floating baffle and a constraint to prevent the baffle from moving uncontrollably.

In a first aspect, the invention provides a device for stabilizing liquid in a tank, the device comprising a baffle arranged to float on a free surface of the liquid; and a
20 constraint for coupling the baffle and the tank so as to restrain the baffle against tilting relative to the tank.

When floating on the free surface of the liquid, the baffle may be partially or fully submerged in the liquid.

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With the constraint, the baffle is prevented or constrained from moving uncontrollably in the container. In particular, the tilt movement of the baffle is limited such that lateral surging of liquid is suppressed by the baffle.

- 5 Further, lateral drifting movement of the baffle may also be limited, and the baffle may be prevented from impacting the sidewall of the tank.

In a first embodiment, the constraint may comprise a linking member having a first end connected to the baffle while preventing the baffle from rotating with respect to the first
10 end; and a second end connected to an anchor, said anchor point may be at the bottom of the tank or the tank walls or other internal face of the tank, or other such convenient reinforceable location so as to prevent damage or failure to the anchor point.

In a second embodiment, the linking member may comprise a plurality of cables having
15 first ends connected to a plurality of points on the baffle so as to constrain the baffle in substantially the horizontal plane.

The constraint may further comprise height adjustment means for adjusting the length
20 of the cables so as to adapt the baffle to different level of liquid.

The height adjustment means may, for instance, comprise a device to allow adjustment
of the second end of the cables from the anchor point. Such a device may include a
block and pulley, a rope clutch turning block or a cable tensioner. The anchor point
may comprise a pulley directing the second end of the cables upward through an
25 aperture in the baffle to the top of the tank; and the height adjustment means
comprises a device for pulling the second end of the cables from the top of the tank.

In a third embodiment, the constraint may further comprise auxiliary cables anchored at the top of the tank or other tank walls so as to fix the baffle in position, thereby limiting or preventing the baffle from hitting an inner surface of the tank.

5 In a fourth embodiment, the linking member may comprise two sets of fixed-length cables having first ends of each set connected to a plurality of points on one baffle. The other ends of the first set of cables are connected to anchor points on the bottom of the tank, whereas the other ends of the second set of cables are connected to anchor points on the top of the tank. In this embodiment, the baffles are fixed in position in the
10 tank, and no adjustment of cable length may be required. The two sets of cables also prevent the baffle from hitting the internal surface if the motion is large under extreme condition. In this alternative of fixed length cables, two or more baffles can be used in the same tank if necessary. In this case, the baffles can be parallelly placed and connected with cables providing preset gap between one another.

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The baffle may be in the form of a flat member. It may be of a dimension covering a substantial portion of the horizontal cross-section area of the tank. More particularly, the baffle may cover approximately 50% of the free surface of the liquid.

20 The flat member may comprise a metal frame. Interstitial space in the frame may be filled with material of density lower than that of the liquid. Alternatively, the flat member may be a framed mesh having an array of apertures through which the liquid may flow and consequently dissipate energy, or a polystyrene plate with metal frame.

25 A further variation may include several baffles as distinct from a single baffle. Effectively, the tank area is divided into several sub-areas, each of which will have a baffle for stabilizing the liquid. This will reduce the cable tension and its size. This

embodiment may be particularly useful where the tank is very large, and so avoiding the need to construct a similarly large baffle.

Brief Description of Drawings

It will be convenient to further describe the present invention with respect to the
5 accompanying drawings that illustrate possible arrangements of the invention. Other arrangements of the invention are possible, and consequently the particularity of the accompanying drawings is not to be understood as superseding the generality of the preceding description of the invention.

10 Figure 1 is a perspective view of a typical LNG tank and a liquid stabilizing device according to a first embodiment of the invention.

Figure 2A is a top view of the device and the tank shown in Figure 1.

15 Figure 2B is a section view of the device and the tank along line A-A' of Figure 2A.

Figure 3 shows an example of the construction of the baffle.

Figure 4A shows an arrangement of height adjustment means according to a second
20 embodiment of the invention.

Figure 4B shows an arrangement of auxiliary cables as well as height adjustment means according to a third embodiment of the invention.

25 Figure 4C shows an example of baffle arrangement with fixed length cables according to a fourth embodiment of the invention. In this figure, two baffles are shown for illustration.

Figure 5 illustrates the flow of the liquid under the effect of the liquid stabilizing device shown in Figure 1.

5 Figures 6A to 6F are snapshots of the liquid being excited under various experimental conditions.

Figures 7A and 7B are waveforms of the pressure on the bottom of the tank under various experimental conditions.

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Detailed Description of Embodiments

A constrained floating baffle (CFB) according to one embodiment of the invention is illustrated in Figure 1. The floating baffle is located within a prismatic typical LNG tank 1.

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A prismatic LNG tank 1 comprises a floor 2, sidewalls 4 and a roof 6 all formed of insulation wall. The width and height of a LNG tank may be around 30m. The insulation wall may be formed of a primary membrane, a primary insulation layer, a secondary membrane and a secondary insulation layer. Each membrane is made from Invar-steel
20 sheet of thickness of 1 mm or less. The insulation box is typically made of plywood and filled with perlite. As an example, the total thickness may be approximately 0.5m.

The liquid stabilizing device may comprise a baffle 10, and a constraint, in this case a plurality of cables 20 connecting the baffle 10 to an anchor point 30. The cables 20 and
25 the anchor point 30 forms a linking member of the constraint for exerting a force on the baffle against tilt movement of the baffle or undesired large motion relative to the tank 1.

The linking member connects the baffle 10 to the tank 1. A top view of the device is

shown in Figure 2A, and Figure 2B shows a sectional view along the line A-A' of Figure 2A.

The baffle 10 may be made of suitable material with sufficient stiffness and strength. It may be made of solid material or a shell filled with air or light material so as to achieve an effective density less than that of the liquid. This allows the baffle 10 to be partially submerged or, if deemed beneficial as an alternative, fully submerged below the free surface in the liquid with the constraint provided by cables 20.

10 The geometry, dimension and material used in the embodiment are for the purpose of illustration only, and may vary depending on the actual application. The baffle 10 is in the form of a flat member. A plate-like baffle 10 floating on the free surface is constrained at four points of the baffle 10 via cables 20 to an anchor point 30.

15 The term cable may refer to wires, chains or similar tension lines. The anchor point 30 may be a cable holder, or stub, or more if required at the bottom of the tank, preferably on the floor 2.

The floating baffle 10 forces the liquid free surface to conform to its flat shape. The cables 20 provide the necessary constraint to prevent the baffle 10 from tilting caused by the rise of liquid at a side of the tank. In the meanwhile, it also prevents the baffle 10 from moving laterally uncontrollably and hitting the sidewall 4 of the tank as well.

One example of the baffle is shown in Figure 3. In the design of baffle 10, one consideration is to avoid the impact between the baffle 10 and the sidewalls 4 of LNG tank 1 when sloshing occurs. Hence, the dimension of the floating baffle 10 is smaller than the horizontal cross-sectional area of the tank 1. The baffle 10 have a sufficient

dimension to cover a substantial portion of free surface of the liquid, or the horizontal cross-sectional area of the tank, so as to suppress sloshing of the liquid effectively. As an example, the floating baffle is a rectangular plate of 18 m by 24 m and thickness 0.5 m for a typical prismatic LNG tank as shown in Figure 1. To restrict the motion of baffle

5 10 if expected to be too large, the cables 20 can alternatively be crossed supported and connected to more than one anchor points 30. The plate could be hollow depending on the material used so as to have an overall density lower than that of the LNG for making it float on the surface.

10 Liquefied natural gas (LNG) consists primarily of methane (CH_4) which has a boiling point of around -162°C . Thus, another design consideration is the material for constrained floating baffle to provide sufficient stiffness and strength under cryogenic temperature. As an example, aluminum alloy is used since this material has relatively stable physical properties in a cryogenic environment. Aluminum alloy may be used to

15 construct a frame or the outer boundary 12 of the baffle 10 as shown in Figure 3.

The density of LNG is roughly 0.41 kg/L to 0.5 kg/L, depending on temperature, pressure and composition. The interstitial space 14 of the metal frame or outer boundary 12 may be filled with light material having a density lower than that of the

20 liquid, such as foamed polystyrene. In this way, the overall density of the constrained floating baffle can be designed to be less than the density of LNG so that it would float on the free surface of LNG.

Based on the geometry and the size of the tank, various different design of the floating

25 baffle 10 could be used; and variances of the constraint are also possible. Depending on the actually shape of the floating baffle 10, it may be more proper, or necessary, to

connect only three points, or more than four points, of the baffle 10 to the anchor point 30 with cables.

5 In a further alternative, one or more points of the baffle 10 may be connected to a first end of a rigid linking member while preventing the baffle from rotating with respect to the first end, and a second of the linking member is connected to the anchor point 30. The rigid linking member may be rotatable with respect to the anchor point 30.

10 In a still further alternative, the constraint may comprise a rod projecting upright from the floor 2 of the tank and the baffle 10 having an aperture which allows the rod to extend through while the baffle 10 is floated on the surface of the liquid. The rod and aperture may be arranged such that, once the baffle 10 is tilted to a certain degree, the rod exerts a force on the baffle 10 against any further tilt movement of the baffle. In the meanwhile, if the baffle 10 laterally drifts away from the center to a certain distance, the
15 constraint may also exert another force on the baffle 10 against any further lateral movement of the baffle on the free surface of the liquid.

In practice, the insulation wall of the tank cannot provide perfect insulation, and so the liquefied natural gas is constantly boiling during the voyage. Typically, an estimated
20 0.1% - 0.25% of the cargo converts to gas each day, depending on the efficiency of the insulation and the roughness of the voyage. Thus, in a typical 20-day voyage, 2% - 6% of the total volume of LNG originally loaded may be lost. In addition, the depth of LNG would vary to facilitate greater flexibility in operation.

25 Accordingly, the cable length should be adjusted to allow the floating baffle to adapt to different level of liquid in the tank. In a second embodiment of the invention, there is provided a height adjustment means for adjusting the length of the cables so that the

cables would remain sufficiently taut at a given LNG depth. Two ways of adjusting the height of the baffle are as follows, and variations are possible to suit the tank geometry and other constraints.

5 In a first approach, there is provided a means for pulling the second end of the cables 20 from the anchor point 30 in the bottom of the tank 1. As illustrated in Figure 2B, the adjustment is from the tank bottom below the anchor point area and locked by some mechanical means, such as a winch. This would be the only thermal leak path and this thermal leak can be reduced by using good insulation material to wrap around the stub
10 and winch area.

In a second approach, if adjustment from the tank bottom is not desired due to space constraint, it can be done from the tank top. As illustrated in Figure 4A, the anchor point may comprise a pulley 32 directing the second end of the cables upward through an
15 aperture 40 in the baffle 10 to the top of the tank 1; and there is provided a means for pulling the second end of the cables 20 from the top of the tank 1. The cables 20 may be locked at the top. The presence of relatively small hole in the middle of constrained floating baffle 10 would not compromise its effectiveness since sloshing motion is larger at the sides than the middle.

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Auxiliary cables anchored at the top of the tank or other tank walls can be used to prevent the baffle from impacting the inner surface of the tank. An example arrangement is shown in Figure 4B. The anchor point on top of the tank may comprise a pulley 33 directing the second end of the auxiliary cables 50 upward, similar to cables
25 20. If the liquid depth is low (sloshing is insignificant) and the baffle 10 is near the tank bottom, the lengths of cables 50 are fixed so that the baffle will not be in contact with the tank bottom.

Besides adjustable baffles, fixed baffles at preset positions can be an alternative which avoids the need of cable length adjustment. Figure 4C illustrates an example of the arrangement. Two baffles (or more if required) are placed parallel to each other with
5 certain gap in between by using equal-length cables 60. The cables 20 and 50 are anchored at the bottom and top surfaces of the tank respectively. The vertical positions of the two baffles can be preset such that the sloshing waves at any filling depth can be optimally mitigated. For example, filling depths from 10%H to 70%H (where H is the tank height) are prohibited due to large sloshing phenomena, in accordance with the
10 Lloyd's Register guidance. Therefore, the two baffles may be placed at positions about 20%H and 60%H so as to mitigate sloshing under different filling depths as much as possible.

Figure 5 illustrates the flow of the liquid under the effect of the constrained floating
15 baffle in the tank. During transportation of a partially filled tank, instability of the vessel or vehicle introduces lateral forces on the liquid and causing the liquid to flow inside the tank. At one point of time, the liquid flows from one side of the tank to the other side, and rises in the other side of the tank. However, the surface of the constrained floating baffle 10 causes the liquid flow to be reflected as shown in arrowed curves 5.

20 While the liquid flow is reflected, the flow shown in arrowed curves 5 applies an upright force on the right hand side of the baffle 10 that would cause the baffle 10 to tilt, and horizontal force on the baffle 10 that would cause the baffle 10 to drift to the right. The constraining cables 20 exert a force on the baffle 10 against the tilt and the lateral
25 drifting, so as to maintain the baffle 10 in substantially the horizontal plane and maintaining it adjacent to the centre of the surface of the liquid.

Experimental Results

A small-scale experimental test involving a partially filled water tank on a shake table was carried out to demonstrate the underlying principles of the constrained floating baffle in a rectangular tank of plan dimensions 0.53 m x 0.4 m and height 0.6 m. The tank contained partially filled water, which was dyed for better visualization. The depth of water was 0.3 m. The constrained floating baffle was made of Styrofoam and constrained by steel wires having a diameter of 1.5 mm, and with a dimension of 0.26 m x 0.335 m.

The cables or wires were anchored to a Perspex stub on the tank bottom by means of hooks. The hook connection was adopted in the experimental study for simplicity. In the case of real LNG tank, the constrained floating baffle connection could be different and can be covered by the same insulation material as required for the tank wall to reduce thermal leak.

In one of the experimental case, a piece of Perspex plate was added on the top of the baffle as an added mass, while in another experimental case, the constrained floating baffle was provided without the added plate. The mass of the baffle is hence adjustable in the experimental study.

In order to demonstrate the liquid sloshing and its mitigation by the constrained floating baffle, a sinusoidal excitation was used as an input to the shake table supporting the tank. Two different excitation amplitudes, i.e. 2 mm and 4 mm, were used. The sloshing problem became worse when the excitation frequency was close to the natural frequency of liquid in tank.

Based on the above setup, a series of experiments were carried out. For comparison purpose, four cases under the same excitation frequency, which is equal to the first natural frequency of sloshing in tanks (without baffle), were studied. The maximum wave amplitudes, or sloshing amplitude, were estimated from video image captured.

5 Some snapshots of the wave motion are shown in Figures 6A to 6E.

In Case 1, no baffle was used. Figures 6A and 6B are snapshots of the liquid without baffle under excitation amplitudes of 2 mm and 4 mm respectively. The liquid sloshing motion was large.

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In Case 2, a floating baffle was used but not constrained. Figures 6C and 6D are snapshots of the liquid under the effect of an unconstrained floating baffle under excitation amplitudes of 2 mm and 4 mm respectively. The baffle is capable of free movement following the flow of the liquid. The mitigation effect was not significant.

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In Case 3, a constrained floating baffle was used without added weight. Figures 6E and 6F are snapshots of the liquid under the effect of a constrained floating baffle under excitation amplitudes of 2 mm and 4 mm respectively. The mitigation effect was significant for both excitation amplitudes. The sloshing amplitude was reduced by 2.8 to

20 9 times compared to Case 1.

In Case 4, the constrained floating baffle was used with an added plate (to increase the mass) and the mitigation effect was similar to Case 3. The reduction in the sloshing amplitude was 3.1 to 14 times.

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Results of the experimental Cases 1 to 4 are summarized in Table 1.

Table 1 - Maximum wave elevations of water in various experimental cases

		Excitation ampl. = 2 mm	Excitation ampl. = 4 mm
Case	Baffle Type	Maximum wave elevation	Maximum wave elevation
1	No baffle	140 mm	220 mm
2	Unconstrained floating baffle (0.1 kg)	140 mm	160 mm
3	CFB without added plate (0.1 kg)	15 mm	80 mm
4	CFB with added weight (1.2 kg)	10 mm	70 mm

A pressure sensor was installed on the wall near the bottom of the tank to measure the pressure. Figures 7A and 7B show the pressure time histories of the four cases, from Case 1 to Case 4, under 2-mm and 4-mm excitation amplitudes, respectively.

In Cases 1 and 2, both Figures 7A and 7B show large pressure variation, where were resulting from large sloshing motion. In Cases 3 and 4, the use of constrained floating baffle reduced the pressure variation significantly. The pressure mean and variance are summarized in Table 2.

Table 2 - Pressure variations for the experimental cases

Case	Baffle Type	Excitation ampl. = 2 mm		Excitation ampl. = 4 mm	
		Mean (Pa)	Variance (Pa ²)	Mean (Pa)	Variance (Pa ²)
1	No baffle	2849	25,980	2848	41,770
2	Unconstrained floating baffle	2855	25,760	2858	41,690
3	CFB	2893	1508	2881	3788
4	CFB with added weight	2968	2077	2967	3562

The mean pressure was about the same for all four cases as it is mainly depended on the average liquid depth. The pressure variance reflected the dynamic component induced by sloshing fluctuation and it was evidently reduced by the presence of constrained floating baffle. This reduction is important since a smaller dynamic component means a lower risk of fatigue-induced damage to the membrane tank and a lesser effect on vessel instability.

- 10 The present invention is based on the concept of having a floating baffle constrained from uncontrolled free movement. It can be seen from the experimental results that by constraining the floating baffle, it effectively suppresses the sloshing of the liquid in the tank. It should be appreciated that variations of the actual design of the baffle and constraint are possible within the scope of the concept of the present invention defined
- 15 in the claims.

CLAIMS

1. A device for stabilizing liquid in a tank, the device comprising:
a baffle arranged to float on a free surface of the liquid; and
5 a constraint for coupling the baffle and the tank so as to restrain the baffle against tilting relative to the tank.
2. A device according to claim 1, wherein the constraint comprises a linking member, the linking member comprising a plurality of cables having first ends
10 connected to a plurality of points on the baffle so as to constrain the baffle in substantially the horizontal plane.
3. A device according to claim 2, wherein the constraint further comprises height adjustment means for adjusting the length of the cables so as to adapt the
15 baffle to different level of liquid.
4. A device according to claim 3, wherein the height adjustment means comprises a device to allow adjustment of the second end of the cables from the anchor point.
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5. A device according to claim 3, wherein the anchor point comprises a pulley directing the second end of the cables upward through an aperture in the baffle to the top of the tank; and the height adjustment means comprises a device for pulling the second end of the cables from the top of the tank.
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6. A device according to any one of claim 2 to 5, wherein the baffle is in the form of a flat member of a dimension covering a substantial portion of the horizontal cross-section area of the tank.
- 5 7. A device according to claim 6, wherein the flat member comprises a metal frame.
8. A device according to claim 7, wherein the flat member is a framed mesh.
- 10 9. A device according to claim 7, wherein the flat member is a polystyrene plate with metal frame.
10. A device according to claim 7, wherein an interstitial space in the frame includes material of density lower than that of the liquid.