Boiling Heat Transfer of Low GWP Refrigerants: A Review

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Abstract - The boiling heat transfer of low GWP (global warming potential) refrigerants, which are more environmentally benign, is studied in this work. Low GWP applications allow for greater freedom in the choice of suitable working fluids based on application and necessity. Human comfort demands increase as a result of the rapid pace of climate change in order to adapt to its negative effects. HVAC&R (Heating, Ventilation, Air Conditioning, and Refrigeration) is crucial for preserving the level of climate comfort in a closed space and its surrounds by using eco-friendly refrigerants. The purpose of this review is to provide a summary of significant studies on the application of low GWP refrigerants in boiling heat transfer, as well as a background on refrigerants and their many subtypes. Along with explaining the impacts of vpour quality, heat flux, and mass flux on pressure drop, this also discusses the implications of heat flux, mass flow, saturation temperature, and the heat transfer mechanism on the heat transfer coefficient.

Keywords - **eco-friendly, refrigerants, boiling, HVAC&R, GWP.**

INTRODUCTION

The goal of all nations is to have zero global warming potentials (GWP) and ozone depletion potentials in order to control the uneven effects and hazards of climate change (ODP) [1]. There is a significant shift taking place in the replacement of refrigerants and refrigeration systems in order to meet the condition of carbon neutrality and demand for refrigerants in order to achieve the target range of low carbon energy transformation determined by the Paris Agreement for global warming. There is a significant shift taking place in the replacement of refrigerants and refrigeration systems in order to meet the condition of carbon neutrality and demand for refrigerants in order to achieve the target range of low carbon energy transformation determined by the Paris Agreement for global warming [2]. Boiling is crucial for the heat transfer of low GWP refrigerants in the heating, ventilation, air conditioning, and refrigeration (HVAC&R), thermal and nuclear power engineering, space and aviation, food, chemical industry, cryogenic, and other industries [3]. This study contains descriptive information on a number of topics, including refrigerant development, a review of the literature on different types of boiling heat transfer, a summary of the main findings, and so forth. Boiling is essential for the heat transfer of low GWP refrigerants in the heating, ventilation, air conditioning, and refrigeration (HVAC&R), thermal and nuclear power engineering, space and aviation, food, chemical industry, cryogenic, and other industries.

BOILING HEAT TRANSFER

When a liquid receives heat from a submerged solid surface that is warmer than the liquid's saturation temperature, a portion of the liquid undergoes a phase transition and turns into vapour. A liquid becomes a vapour when it is heated to the boiling point. In general, boiling is a physical transformation as opposed to a chemical one. Classification of boiling under various situations was depicted in Fig.1 as follows:

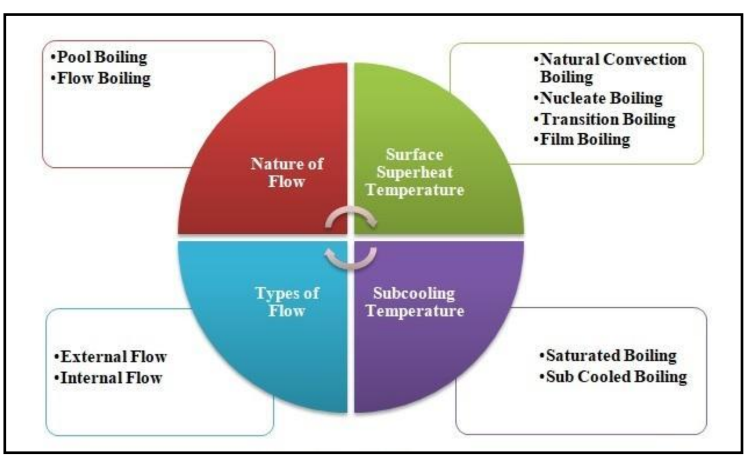

Fig. 1. Types of Boiling Heat Transfer [4,6].

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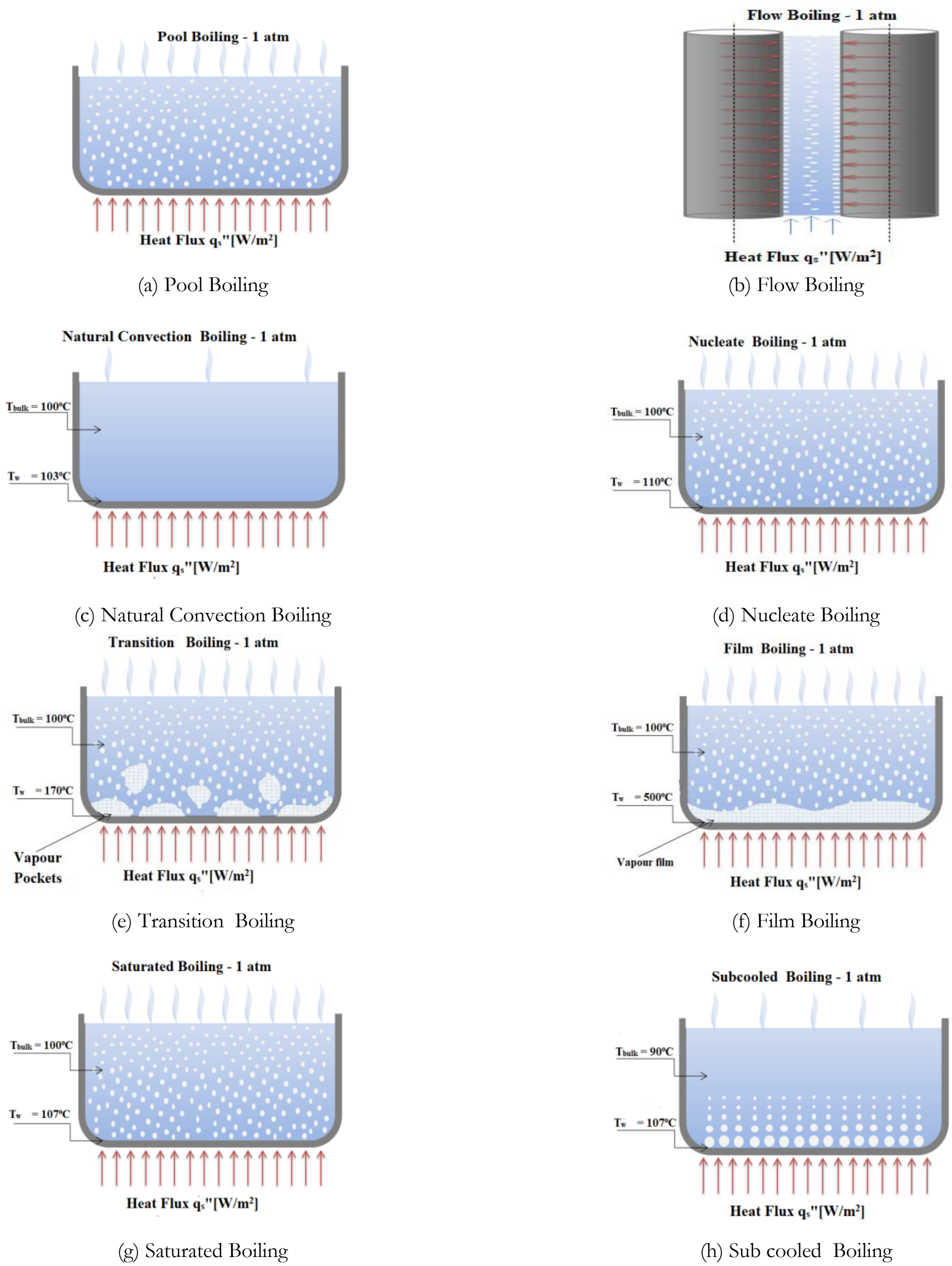
Nature of Flow

Pool Boiling: One of the boiling processes involves a pool of liquid coming into touch with the heat flux in a sealed container with just natural convection, as shown in Fig. 2 (a).



(a) Pool Boiling

(b) Flow Boiling

(c) Natural Convection Boiling

(d) Nucleate Boiling

(e) Transition Boiling

(f) Film Boiling

(g) Saturated Boiling

(h) Sub cooled Boiling

Fig. 2. Types of boiling [4].

Flow Boiling: It is a boiling process in which a pump or other external source is utilized to forcefully move the liquid as "Forced convection" heat transmission and nucleate boiling occur simultaneously as illustrated in above Fig. 2. (b).

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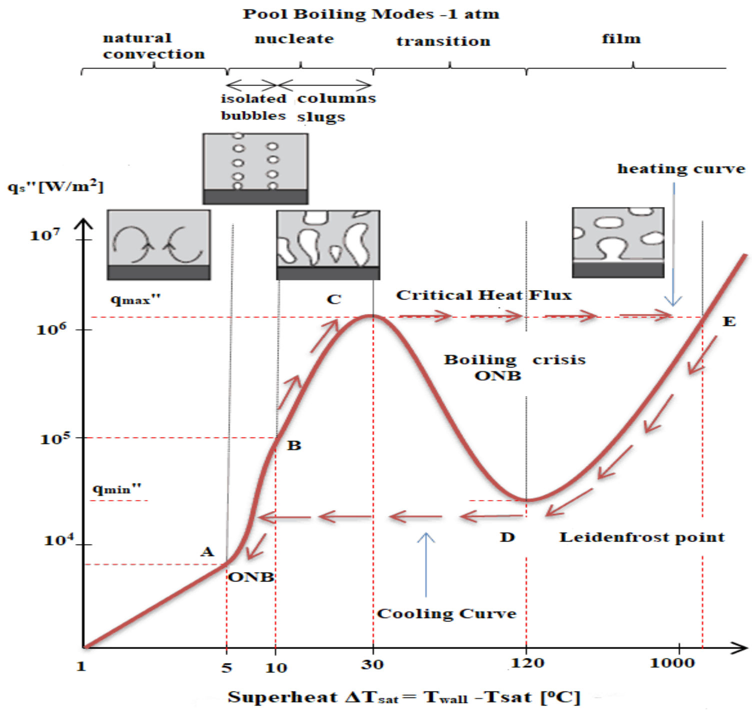

Fig. 3. Pool Boiling Curve [4].

SURFACE SUPERHEAT TEMPERATURE

According to Fig.2 and Fig.3, pool boiling can be divided into the following categories: (a), (c), (d), (e), and (f).

Natural Convection*:* As seen in Fig. 2(c) and Fig. 3, the liquid is in a metastable state in this situation and evaporates when it reaches the free surface layer. Normal convection currents are used in this situation to create fluid flow, and heat is captured by the fluid and transmitted from the heating surface by natural convection.

Nucleate boiling: The creation of bubbles begins at point A in this instance, which is a unique location on the heating surface of the boiling curve, as seen in Fig. 2(d) and Fig. 3. Since there are more nucleation sites as one moves from point A to point C on the boiling curve, the creation of bubbles increases. The nucleate boiling regime showed two distinct circumstances. In the first instance, A-B, isolated bubbles form on the heated surface at a specific nucleation spot. Once they separate from the surface after a while, the created bubbles will eventually turn into liquid. A significant quantity of heat flux and heat transfer coefficient is produced in this region of nucleate boiling by stirring and agitation. The heater temperature changes significantly from B to C, and due to the abundance of nucleation sites that are available in the layer of vapour into the liquid, bubbles arecreated at a high pace. In this area, a bubble will form and rise to the surface, where it can burst and release its vapour-holding capacity. Huge amounts of heat fluxes are present in this region as a result of the joint effects of liquid entrainment and evaporation.

Transition Boiling: As seen in Fig. 2(e) and Fig. 3, nucleate and film boiling coexists fairly in this section of the boiling curve, with film boiling completely replacing nucleate boiling at point D, which was at point C.

Film Boiling: As seen in Fig. 2(f) and Fig. 3, in this instance, the entire region is covered by a continuous, stable vapour film that extends to a point known as the Leiden frost point (point D), where the heat flow reaches its lowest value and slowly evaporates liquid droplets because of the presence of a hot surface. Due to the presence of a vapour layer between the heater surface and liquid, the heat transmission rate during film boiling is poor in this area.

SUB COOLING TEMPERATURE

Saturated Boiling: As seen in Fig. 2(g), during the boiling process, the fluid temperature is much higher than the saturation temperature of the fluid, and the bubbles that were created as they entered the cooled channel merged to form bubbles of a larger size. The buoyant forces from the surfaces move this large bubble.

Sub cooled Boiling: As seen in Fig. 2(h), during the boiling process, the fluid temperature will always be lower than the saturation temperature at different parts of the fluid, which causes bubbles to develop on the heating surface and become condensed in the fluid

TYPES OF FLOW

External Flow: It is a technique that primarily uses heat surfaces and is closely connected to pool boiling due to fluid movement near the heating surface, a huge HTC of the system, and the need for larger heat flux than in pool boiling.
Internal Boiling: Two-phase flow was seen during the boiling process, primarily through the pipe and duct. It is complicated since there is no open surface for the release of vapour, and Fig. 4 illustrates diverse flow regimes in horizontal tubes and vertical tubes including bubbly, slug, and churn as well as annular observed inside an upward flow in vertical tubes along with bubbly, plug, stratified, wavy, slug, and annular flow.
Bubbly Flow: It develops in a limited volume, somewhat fast-moving gas fraction flow where a bubble breaks off and transitions to a steady liquid stage.
Plug Flow: Long-lasting bubbles appeared throughout this flow.
Wavy Flow: It develops at large gas volume ratios, although the phase crossing point exhibits volatility because of very high flow velocities.
Slug Flow: As a result of the bubbles coalescing during this passage, the sizable bubbles those were almost the same diameter as the tube took the form of a bullet.
Annular Flow: A film of liquid flows continuously downs the tube wall during this flow, whereas unbroken droplets of liquid continuously develop in the gas phase [5].

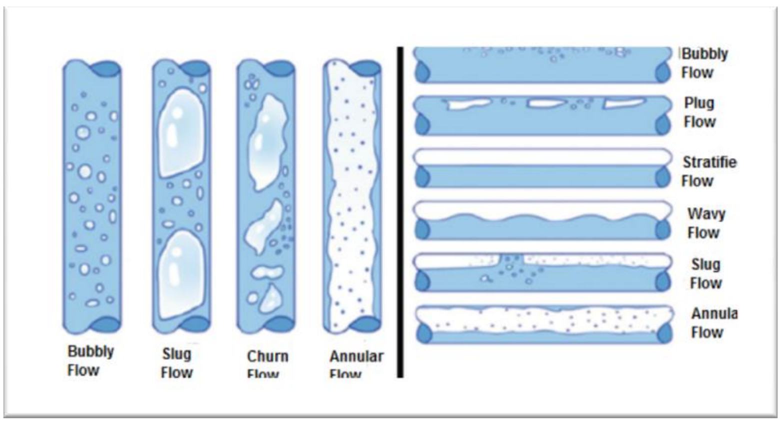

Fig. 4. Flow Regimes (a) Upward Vertical Flow, (b) Horizontal Flow [25].

CONTINUOUS DEVELOPMENT OF REFRIGERANTS

As depicted in Fig. 5, four distinct generations can be used to classify the refrigerants' ongoing evolution.

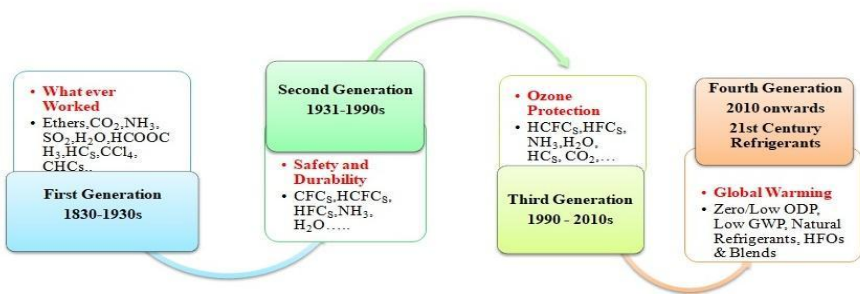

Fig.5. Continuous development of Refrigerants [3, 7, 8].

First generation refrigerants (1830-1930): A variety of refrigerants, including ammonia, carbon dioxide, and others, were used during the first generation between 1830 and 1930 depending on the location and availability. This generation's refrigerants were extremely reactive, poisonous, and combustible.
Second generation refrigerants (1931-1990): The second generation of refrigerants led to the development of CFCs and HCFCs. Reduced toxicity and flammability are the main priorities. The major refrigerants of this generation include NH_3, hydrocarbons (HCs), H_2O, etc. The goal of the Montreal Protocol, which was established in 1987, was to protect the ozone layer from the HCs responsible for ozone depletion.

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Third generation refrigerants (1990-2010): To suit the requirements of refrigeration applications, hydro fluorocarbons (HFCs) and their derivatives were created. In 1994, the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC) were consciously chosen as practical implementation measures to control GHG emissions. By 2030, HCFCs and HFCs are expected to be phased out.

Fourth generation refrigerants (2010 onwards): The low GWP fluorinated propane (propylene) isomers make up the fourth generation of refrigerants. Currently, hydrofluoroolefins, a novel family of fluorocarbon refrigerants, are the most likely replacement (HFOs). They are predicted to replace HFCs in numerous applications despite having a GWP that is too low. Table1 displays the GWP and ODP of various low GWP refrigerants. [3, 7, 8]

TABLE 1. List of Low GWP refrigerants [3, 7, 8].

Refrigerants	ASHARE	GWP (100years)	ODP
Natural Refrigerants	R-744	1	0
	R-717	0	0
	R-718	0	0
Hydrocarbons	R-600	3.3	0
	R1270	1.8	0
	R-170	5.5	0
	R-600a	3	0
Synthetic refrigerants	R-123	79	0.01
	R-134a	1300	0
	R-32	677	0
	R-1234yf	<1	0
	R- 1234ze(E)	<1	0
	R-1132E	1	--

APPLICATIONS OF BOILING HEAT TRANSFER

Due to the efficient removal of heat created in this heat transfer, boiling heat transfer has received considerable attention for a long time. As one of the most important boiling types, it is widely used for a variety of engineering reasons, which are listed in table 2 as follows.

TABLE 2. Engineering purposes of flow boiling [26].

Sr.No.	Engineering Purposes
a)	Heat Exchangers such as compact, plate etc.
b)	Heating Pipes like pulsating, wick and Wickless etc.
c)	Magneto and Electro hydrodynamics.
d)	Tubes like Helically coiled, Micro tubes and channels.
e)	Steam boilers and jet impingement purposes.
f)	Heavy duty diesel engine water jacket
g)	Nano refrigerants and their Purposes.
h)	Tube bundles.
i)	Applications of microgravity.
j)	Tubes of solar Collectors.
k)	Metal Forming Operations.
l)	Nuclear reactor, water purification, Refineries of oil and petrol, paper manufacturing, juice extraction of sugar cane etc.

EXPERIMENTAL OVERVIEW

Over the past few decades, researchers have put a lot of effort into studying low GWP refrigerants as shown in Table 3. The results of experimental work using the working fluids R-600a and R-410A for four distinct copper tubes in horizontal orientation made with flame spraying, taking into account 10°C Saturation temperature, 5 to 50 heat fluxes (kW.m^{-2}), and achieving

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boiling heat transfer across has increased across by 1.1 to 2 times by Dewangan et al. [9]. Lin and Mark [10] conducted a review study on the pool boiling of low GWP fluids such as hydrofluoroolefins (HFOs), hydrocarbons (HCs), carbon dioxide (CO_2), and ammonia (NH_3) on improved surfaces such as structure surfaces, porous surfaces, and others. Kedzierski and Lin [11] a study of pool boiling on the surface of a re-entrant cavity using the refrigerants R-151A, R-1234yz(E), and R-1233d(E) on structured surfaces was undertaken, and the results revealed an improvement in heat flux and prediction model. Kumar and Chuan [12] R-1234ze (E) and R-134a were used as the working fluids in experimental work using GEWA-B5H and smooth tubes, POE oil, and it was stated that the improvements in HTC for these two gases ranged from 2.9 to 8.8 and 2.8 to 6.6, respectively.

Wen et al. [13] research was done experimentally to examine working fluids like R1234ze(E), R-1233zd(E), and R-134a in a nucleate pool boiling outside of two re-entrant cavity tubes with 6°C saturation temperature and heat fluxes from 10 to 80 ($kW.m^{-2}$). The results showed that boiling heat transfer forecasts reduced reliance on the surface structures. Byun et al. [14] It was demonstrated how low global warming potential refrigerants R-1234ze(E) and R-1233zd(E) were employed in an experimental study of a plain tube and two other tubes with saturation temperatures of 4.4 °C and 26.7°C, heat fluxes from 10 to 50 ($kW.m^{-2}$), and it was found that both refrigerants' heat transfer coefficients increased.Ubara et al. [15] thermal analysis of working fluid R-1233zd(E) with declining film evaporation and pool boiling on spray coated tube led researchers to the conclusion that coated tubes transport heat 2.1 to 4.8 times faster than smooth tubes at 20°C saturation temperature and heat fluxes between 10 and 85. (kW.m-2). Welzl et. al. [16] conducted an experiment using working fluids R-245a and R-1233zd (E) to study the nucleate pool boiling in an organic Rankine cycle in a geothermal application. Longo et al. [17] used R1234yf and R1234ze (E) as working fluid substitutes for R-134a, with saturation temperatures of 10°C, 15°C, and 20°C, and heat fluxes of 15°C – 30°C, in an experimental evaluation of flow boiling (kW.m-2). Yang et al. [18] in order to draw the conclusion that fluid characteristics, flow circumstances, and flow patterns affect pressure drop and flow boiling heat transfer performance, an experiment was conducted using HFO-1234yf as the working fluid in a circular tube with an inner diameter of 4 mm and a length of 600 mm at saturation temperature of 14°C.

Anwar et al. [19] by using the working fluid, R-1234yf, with saturation temperatures of 27°C and 32 °C and heat fluxes ranging from 05 to 130, the experimental work was carried out to make the prediction that boiling heat transfer depends on operating pressure, applied heat flux, mass flux, and vapour as well ($kW.m^{-2}$).Jige et al. [20] heat transfer coefficients of the combination rely on mass flux as well as vapour quality and mass fraction, and the effect of heat flux was minimal on heat transfer, according to flow boiling experiments with mixtures of R-1234yf and R-32 in a horizontal multiport tube with a rectangular micro channel.Zhao et al., [21] the average heat transfer coefficient is totally dependent on the drying quality, according to research that looked at the flow boiling of a number of low GWP refrigerants, including R-245fa, R-1233zd(E), R-1224yd(Z), and HFE347pc, at saturation temperatures of 37°C, 41°C, 34°C, and 70°C, respectively. Yang et al. [22] in a smooth horizontal tube with an inner diameter of 6 mm and a heat flux ranging from 10.6 to 74.8 $kW.m^{-2}$, experimental data were compared with nine correlations using blends of R-1234ze (E) and R-600a in various compositions ($kW.m^{-2}$).Lillo et al. [23] it was discovered through experimental research in a horizontal stainless tube with an inner diameter of 6 mm of flow boiling, working fluids of R-1233zd (E), saturation temperatures of 24.2°C and 65.2°C, and heat fluxes of 2.4 to 40.9 ($kW.m^{-2}$), that the trends in the bottom-of-the-tube heat transfer coefficient are not reliant on vapour quality as heat flux increases. Righetti et al.[24] researchers looked at R-1233zd(E) in a flow boiling experiment in a microfin tube with an inner diameter at the fin tip of 4.2 mm at a mean saturation temperature of 65.2°C and a heat flux of 15 to 90($kW.m^{-2}$) and came to the conclusion that R-1233zd(E) might replace R-245fa.

Every experiment depends on working fluids, thus we must take into account all of the pertinent factors that are associated to them in order to conduct the experiment in a controlled and safe manner. Table 4 enumerated the key influences on the pool and flow boiling of pure fluids and binary/multi component combinations.

FACTORS INFLUENCING BOILING HEAT TRANSFER COEFFICIENT AND PRESSURE DROP

Effect of heat transfer mechanism on boiling transfer coefficient

In technical applications like heat exchangers, heat pumps, and the cooling of electronic devices, boiling is one of the most efficient ways to transport heat. The two main methods of flow boiling heat transmission are known as nucleate boiling and convective boiling, respectively. The relationship between them must therefore be established in order to analyse the flow boiling heat transfer. Five distinct flow patterns for convective boiling were discovered in Fig.4: dispersed plug, slug, churn, wavy, and (smooth) annular flow.

Lee et al. [28] carried out an experimental investigation on the heat transfer from boiling water in a channel with low mass flow. According to the findings, the effect of convective boiling heat transfer was minimal, and the mass flow only marginally boosted the heat transfer coefficient. The pressure drop and boiling heat transfer in horizontal microchannels of R290 were investigated by Choi et al. [29].

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TABLE 3. Summary of studies related to boiling heat transfer of Low GWP Refrigerants.

Researchers	Refrigerants	Tube orientation and dimensions	Saturation Temperature (°C)	Heat Flux (kW.m-2)	Observations
Dewangan et al. [9]	R-600a and R-410A	Horizontal tube, diameter= 25.4mm, length = 116mm	10°C	5 - 50	1.1-2 times increased in boiling heat transfer
Lingnan and Kedzierski [10]	HFOs, HCs, CO_2 and NH_3	Enhanced surfaces like structured surfaces, porous surface and others	--	--	Pool boiling of low GWP refrigerants on enhanced surfaces
Kedzierski and Lin [11]	R-151A,R-1234yz(E) and R-1233d(E)	Flattened, horizontal Turbo-ESP surface	4.6°C	10 - 100	Improved in heat flux and prediction model improved
Kumar and Wang [12]	R-1234ze(E) and R-134a	Horizontal arrange Tube (GEWA-B5H tube)	-6°C 0°C 10°C	10 - 90	Enhancement in HTC 2.9-8.8 for R-1234ze(E) 2.8-6.6 for R-134a
Wen-Tao et al. [13]	R-1234ze (E), R-1233zd (E) and R-134a	Reentrant tube Cavity	10°C	10 - 80	Pool boiling heat transfer coefficients of R1233zd(E) is more than 40 % lower than R134a
Byun et al. [14]	R-1234ze(E) and R-1233zd (E)	Plain tube and Enhanced Tube	4.4°C 26.7°C	10 - 50	Wilson Plot method used to derive tube side heat transfer coefficient and compare the results
Tsutomu et al. [15]	R-1233zd (E)	Horizontal tube diameter =19.05 mm length =50 mm	20°C	10 - 85	Coated tube exhibits 2.1 to 4.8 times higher heat transfer than smooth tubes.
Matthias et al. [16]	R-245fa R-1233zd (E)	Plain tube diameter = 32 mm length = 822 mm	100°C	--	Geothermal applications
Longo et al. [17]	R-1234yf and R-1234ze (E)	Copper tube Inner diameter =4 mm, length=800 mm	10°C 15°C 20°C	15 - 30	R-1234yf and R-1234ze (E) will work as substitute to R-134a
Yuh et al. [18]	R-1234yf and R-134a	Circular tube Inner diameter =4 mm length=600 mm	14°C	10 - 60	Pressure drop and flow boiling heat transfer performance depend on fluid properties, flow conditions and flow patterns
Zahid et al. [19]	R-1234yf	Vertical Stainless Steel tube Inner diameter = 1.60 mm length= 245 mm	27°C 32°C	05 -130	Boiling heat transfer depends on applied heat flux, operating pressure, mass flux and vapor quality.
Daisuke et al. [20]	zeotropic binary mixture R1234yf/R32	horizontal multiport tube with rectangular minichannel	average of dew- and bubble-point temperatures of 15°C	05 - 20	Heat transfer coefficients of the mixtures depend on mass flux, vapor quality, mass fraction and, effect of heat flux on heat transfer was minute.
Zhao et al. [21]	R-245fa, R-1233zd(E), R-1224yd(Z) and HFE347pc	Vertical upward flow tube Inner diameter = 4 mm	37°C 41°C 34°C 70°C	06 - 20	Averaged HTC totally depends on the dryout quality.
Qiang et al. [22]	Blends of R1234ze(E)/R600a	Smooth horizontal tube Inner diameter= 6 mm	--	10.6 - 74.8	Experimental data compared nine correlations
Lillo et al. [23]	R-1233zd(E)	Single horizontal stainless tube Inner diameter= 6 mm	24.2 -65.2°C	2.4 - 40.9	With increasing heat flux trends of heat transfer coefficient at the bottom not dependent on vapor quality
Giulia et al. [24]	R-1233zd(E)	Microfin tube Inner diameter at fin tip = 4.2 mm	mean saturation temperature 65.2°C	15 -90	R1233zd(E) as a substitute to R245fa

Table 4. Effects of fluid nature on pool and flow boiling [27].

Pool Boiling	Pure Fluids	bulk fluid temperature, heat surface material/conditions, heater surface orientation, fluid type, heat flux, Pressure, gravity.
	Mixtures	bulk fluid temperature, heat surface material/conditions, heater surface orientation, fluid type, heat flux, Pressure, gravity, fluid composition, mass transfer resistance, marangoni effect, heat from dilution and dissolution
Flow Boiling	Pure Fluids	Pressure, gravity, fluid composition, mass transfer resistance, marangoni effect, heat from dilution and dissolution, mass flux, vapour quality, fuel inlet condition.
	Mixtures	fluid type, heat flux, Pressure, gravity, fluid composition, mass transfer resistance, marangoni effect, heat from dilution and dissolution, mass flux, vapour quality, fuel inlet condition, heater/channel configuration, channel orientation

They discovered that, in cases of low mass flow, the relationship between mass flow and the heat transfer coefficient was not clear-cut. The heat transfer coefficient did, however, rise in the medium and high mass flow range as a function of mass flow and saturation temperature.Copetti et al. [30] Predicted effects of heat flux tended to diminish as vapour quality rose. When there was a large heat flux, the mass flow was almost completely independent of the heat transfer coefficient, which decreased. The cause was that high heat flux in nucleates boiling, which was less impacted by mass flow, dominated the boiling heat transfer. Since the vapour quality mostly impacts the heat transfer mechanism in the channel, it is crucial to ascertain the vapour quality of the operating state before examining the impact of the heat transfer mechanism on the heat transfer coefficient.

Effect of heat flux on boiling heat transfer coefficient

For the boiling heat transfer of pure fluids, the heat flux mostly impacts the nucleate boiling heat transfer. More vaporised cores can easily form on the tube surface due to the increased heat flux and higher degree of superheating. As a result of the large improvement in nucleate boiling, the rates of bubbles forming and separating from the wall also rise. Increased heat flux may result in more active nucleation spots in the channel, which would raise the heat transfer coefficient. Bortolin et al. [31]. Nevertheless, as vapour quality rises, convection boiling improves and nucleate boiling declines, which reduces the effect of heat flux on the heat transfer coefficient. The vapour quality thus influences the difference in heat transfer coefficients between various heat fluxes at the same mass flow and saturation pressure. Consequently, with constant mass flow and saturation pressure, the vapour quality influences the differences in heat transfer coefficients between various heat fluxes. [32].

Effect of mass flow on boiling heat transfer coefficient

The working fluid's mass flow has both favourable and unfavourable effects on the two-phase heat transfer coefficient when the vapour quality is reduced.Jige and Inoue [33] The dominance of nucleate boiling was acknowledged as the reason why the mass flow had minimal impact on the heat transfer coefficient in low vapour quality locations. In the high vapour quality zones, however, the heat transfer coefficient rose with the mass flow. This occurrence occurred as a result of improved forced convection and an increase in vapour quality due to mass flow during the initial drying process.. De Oliveira et al.[34] By analysing the boiling heat transfer characteristic of R1270 in a horizontal tube, it was hypothesised that the local heat transfer coefficient increased with the mass flow. Mass flow had a more noticeable impact on the heat transfer coefficient the greater the vapour quality. The study above leads to the conclusion that, under most circumstances, the boiling heat transfer coefficient increased with the mass flow. It may be seen from the analysis above that under most circumstances, the boiling heat transfer coefficient increased with the mass flow.

Effect of saturation temperature on boiling heat transfer coefficient

According to Mastrullo et al. [35] experimental findings, as shown in Fig. 6, the performance of the heat flux was essentially constant as the saturation temperature rose. According to researches, the law of heat transfer coefficient changing with the saturation temperature was not certain, as shown in Table 5. This regularity was not only affected by vapor quality but also by fluid flow conditions and channel size. Therefore, it is of importance to consider the multi-factors influence of saturation temperature on the heat transfer coefficient when studying the influence of saturation temperature on the heat transfer coefficient.

FACTORS INFLUENCING OF PRESSURE DROP

In the study of boiling heat transfer, the pressure drop is one of the key characteristic variables. Without establishing the regularity of the pressure drop change and calculating method, equipment cannot be constructed properly or operated safely. Most of the time, two-phase friction pressure drop, accelerating pressure drop, and gravity made up the pressure decrease when there was flow boiling [42].

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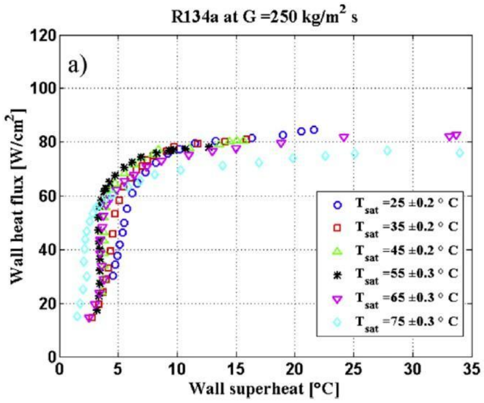

Fig. 6. Boiling curves for 25°C to 75°C and 250kgm-²s-¹ [35].

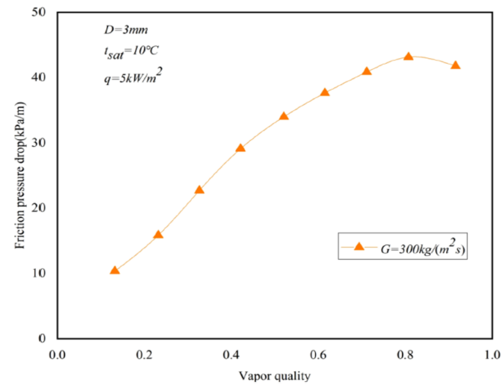

Fig. 7. Friction pressure drop with the vapor quality [45].

Table 5. Heat transfer coefficient changing with the saturation temperature.

Refrigerants	Boundary conditions	Saturation temperature (T_{sat})	Trend
R290 [36]	q = 15 Kw/m² G = 150 kg/m²s D_{in}= 3.0 mm	0°C, 5°C, 10°C	The heat transfer coefficient of R290 increases with an increase in saturation temperature (0–10°C).
R290 [32]	q = 0–200 Kw/ m² G = 200 - 300 kg/m² s D_{in} = 1.7 mm	23°C, 33°C, 43°C	The heat transfer coefficient of R290 increases with an increase in saturation temperature (23–43°C).
R290 [37]	q = 13 Kw/ m² G = 180 kg/ m² s D_{out} = 4 mm	280 K, 282 K, 284 K, 286 K	The heat transfer coefficient of R290 increases with an increase in saturation temperature (280K–286 K).
R245fa [38]	q = 8,12,14 Kw/ m² G = 80,120 kg/m² s D_{in} = 29 mm	55°C, 65°C, 75°C	The heat transfer coefficient of R245fa increases with an increase in saturation temperature (55–75°C).
R134a, R1234yf, R1234ze [35]	Wall superheat=0–35 °C G = 250 kg/ m² s D_{in} = 1.33 mm	25°C, 35°C, 45°C, 55°C, 65°C, 75°C	The effect of saturation temperature (25–75°C) on the heat transfer coefficient can be neglected.
R455a, R452b [39]	q = 15.5-25.5 Kw/m² G = 200-300 kg/m²s D_{in} = 8 mm	11°C, 18.5°C, 31°C	The effect of saturation temperature (11–31°C) on the heat transfer coefficient can be neglected
R134a, R1234ze(E) [40]	q= 5Kw/m2 G = 150 kg/m2s	5°C, 10°C, 15°C	The heat transfer coefficient decreases a little when the saturation temperature
R290 [41]	G = 200-400 kg/m2s D_{in} = 1.7 mm,1.224 mm	23°C, 33°C, 43°C	The effect of saturation temperature (23 °C–43 °C) on the heat transfer coefficient can be negligible

Friction pressure drop, which was brought on by energy lost in the water flow due to friction and eddy currents, was the source of the overall pressure drop [43, 44]. As a result, no adequate correlation could account for all contributing factors, and some of them were difficult to represent in the empirical relationship.

Effect of vapor quality on pressure drop

Nie et al. [45] investigated the pressure drop caused by R134a's boiling heat transfer in a 3 mm tube. The two-phase flow velocity and pressure drop in the microchannel were also raised due to the improvement in vapour quality. Compared to areas with good vapour quality, areas with low vapour quality had a greater pressure drop. The pressure decrease also displayed a gradual declining pattern after reaching a particular high, as depicted in Fig. 7. This event occurred as a result of the pressure decrease progressively stabilising when the flow pattern was annular flow. The flow pattern switched from annular to spray as the vapour quality got even better. The pressure loss was minimised at this point due to the vapour phase's dominance in the two phases, the flow's stability, and the lessened disturbance.

Effect of heat flux on pressure drop

The channel's bubble density will rise as the heat flux rises, and the fluid disturbance will have an impact on the pressure decrease. According to Gao et al. [46], the frictional pressure drop was hardly impacted by the heat flux. It showed that fluid movement, not the nucleate boiling of the wall, was what primarily caused the frictional pressure drop. When examining the flow pressure decrease of the pure fluid and mixture, Tang et al. [44] and Yu et al. [47] both came to the same conclusion.

Effect of mass flow on pressure drop

By modifying the vapour speed and turbulence intensity, the mass flow primarily modifies the pressure drop in the channel. As a result, the channel's shear force is altered. According to Liang et al. [48], as the mass flow grew, the test tube's on-way resistance also did so. This, they argued, increased the pressure drop since it increased the on-way resistance. The boiling intensity and vapour formation were found to be more significant with a smaller mass flow at the same heat flux, which increased the contribution of the accelerated pressure drop to the total pressure drop, according to the authors' analysis. [49,50]

CONCLUSION

A significant change in the environment resulted from the usage of CFC, HCFC, and some HFC refrigerants, particularly because of the increase in greenhouse gas concentration over the earth's surface caused by greenhouse gas emissions. International Protocols and Bodies now demonstrate a movement in attention towards environmentally benign refrigerants like HFOs, which have naturally low GWP and ODP values. R1234yf, R1234ze(E), R1233zd(E), and R1243zf are possible refrigerants that could be employed in the near future to replace the working fluids currently used in HVAC&R systems with improved surfaces. The extent of the practical usage of these fluids in enhanced boiling is still being determined with low GWP refrigerants, despite the fact that many experiments have been published with the most favourable effects. Furthermore, this study highlighted a number of variables influencing heat transfer coefficients and pressure drop in boiling heat transfer of low GWP refrigerants, which is undoubtedly helpful.

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